Genetic relation of the Zagros thrust and Sanandaj-Sirjan zone

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Abstract: The Zagros thrust (crush zone) and the Sanandaj-Sirjan zone separate the Zagros Fold belt from Central Iran. The Zagros passive continental margin setting of the Jurassic–Middle Cretaceous was followed in the Upper Cretaceous by arc collision linked to the closing of the Neo-Tethys and the collision of the Arabian and Iranian plates. The northwest–southeast trending Sanandaj–Sirjan Zone consists of several elongate sub-zones and much of the orogenic activity in the Sanandaj–Sirjan Zone is now related to closing of Tethys. Therefore the Zagros thrust and the Sanandaj-Sirjan zone provide a unique opportunity within the Alpine system to evaluate the interplay between a young Tertiary collision, volcanism, metamorphism and earlier subduction/obduction processes. This article detects genetic relation of The Zagros Thrusting System and properties of the Sanandaj-Sirjan zone. Investigations show two area have related evolutionary history from cretaceous to recent.

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Key word: Zagros thrust, Sanandaj-sirjan zone, Collision, Crush zone**.**

1.Introduction

The Zagros folded belt passes northeastward without a sharp boundary into a narrow zone of thrusting bounded on the NE by the main zagros Thrust line. In this zone older Meosozoic rocks and the Paleozoic platform cover were thrust southwestward in several schuppen-like slices on the younger Mesozoic and Tertiary rocks of the folded belt. The thrust zone represent the deepest part of the Zagros Basin in Mesozoic and early Tertiary time. The High Zagros are bounded on the NE by two faults, the reverse Main Zagros Fault (MZF) and the dextral Main Recent Fault (MRF), which together approximate the Zagros (Neotethys) suture zone between the Arabian and Eurasian plates ([Berberian, 1995], [Bosold et al., 2005] and [Authemayou et al., 2006]). To the SW, the high-angle reverse-dextral High Zagros Fault (Fakhari, 1996b) defines the boundary between the High Zagros and Simply Folded Zone (Mohajjel et al 2003).

The Sanandaj –Sirjan Zone was first recognized as a separate linear structural element by stocklin (1968). the zone lies between the main Zagros Thrust in the SW and the Urumiyeh-Bazman volcanic belt in the NE. It joins the Taurus orogenic belt in Turkey. The ranges occupy a NW –trending belt in which the Zagros structural grain is overprinted on the typical Central Iran structural framework(Fig. 1).

Characteristic features include the consistent Zagros trend of the zone as a whole, the nearly complete lack of Tertiary volcanics and the poor development of Tertiary formations in general. Part of the zone is characterized by Paleozoic volcanism and Hercynian and or Early Kimmerian metamorphism (Mohajjel et al 2003).

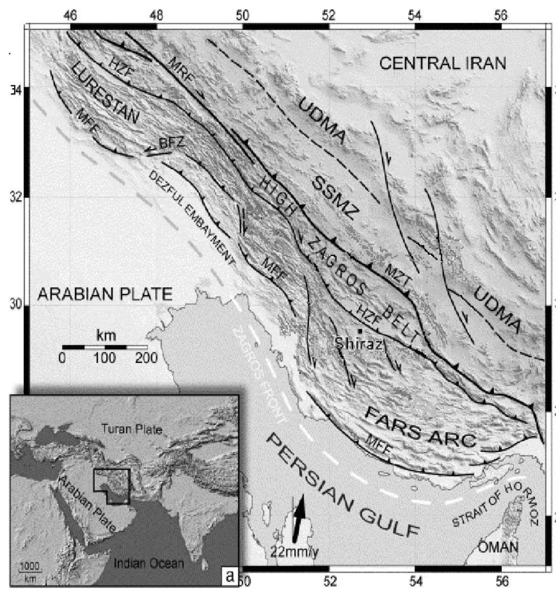

Fig.1. Index map of the studied area within the Zagros fold-and-thrust belt, Sanandaj-Sirjan zone and situation of the different structural domains in SW-Iran. UDMA, Urumieh–Dokhtar Magmatic Arc; SSMZ, Sanandaj–Sirjan Metamorphic Zone; MZT, Main Zagros Thrust; MRF, Main Recent Fault; HZF, High Zagros Fault; ZSFB, Zagros Simple Fold Belt; MFF, Mountain Front Fault; BFZ, Balarud Fault Zone. Black arrow indicates GPS convergence vector from Vernant et al. (2004). Inset (a): location map in the Middle East.

The northwest–southeast trending Sanandaj–Sirjan Zone consists of several elongate sub-zones. From southwest to the northeast these sub-zones are (1) radiolarite sub-zone, (2) Bisotun sub-zone, (3) ophiolite sub-zone, (4) marginal sub-zone, and (5) complexly deformed sub-zone(Fig. 2) (Mohajjel et al 2003).

All five sub-zones and Cainozoic rocks in the southwestern Sanandaj–Sirjan Zone form part of a complicated imbricate thrust system with out-of-sequence thrusts locally juxtaposing younger over older units (Mohajjel et al 2003).

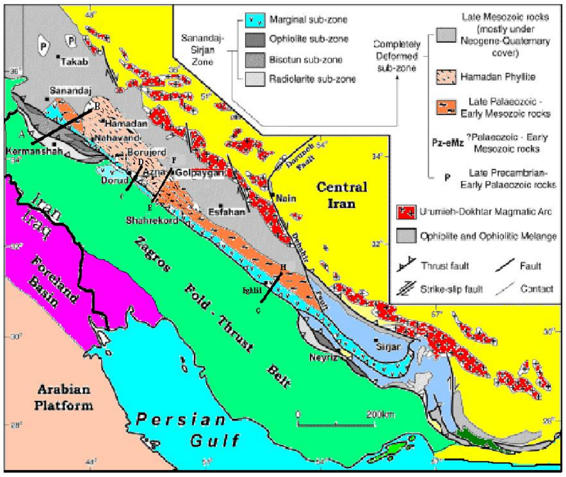

Fig.2. Simplified tectonic map of The Zagros thrust and The Sanandaj–Sirjan Zone. Showing Cross sections (Mohajjel et al 2003). Cross sections have studied by Mohajjel et al (2003), Sarkaninejad and Azizi (2006) and Alavi (1994).

2.Structural relation of the Zagros thrust (Crush zone) and the Sanandaj-Sirjan zone

The Zagros Thrust System was studied by any people. It was considered to be a “Crush Zone” (Wells, 1969), or the “Main Zagros Thrust Zone” ([Takin, 1972], [Hynes and McQuillan, 1974] or the “Main Zagros Reverse” or the “Suture Zone” (Berberian, 1995). The so-called “Main Zagros Thrust” which is traditionally considered as the boundary between the Sanandaj–Sirjan Zone and the Zagros Simply Folded Belt is by no means a single “high-angle reverse fault”, nor is it a narrow zone of “crush rocks” (Alavi, 1994). The thrust system is an array of kinematically, geometrically and mechanically related faults that developed in a sequence during regional deformation and are associated with deformation above a basal detachment ([Boyer and Elliot, 1982] and [McClay, 1992]). Therefore it is more reasonable to classify and name it as the Zagros Thrust System rather than the “Main Zagros Thrust Zone” or “high-angle reverse fault” or “Crush Zone” (Sarkaninejad and Azizi, 2006). It System with various components of dextral strike-slip, imbricate fans, oblique slip thrusts, shear zones and brittle listric faults contains elements that are consistent with inclined transgression, including components of strike-slip and dip-slip (Jones et al., 2004). According to Sarkaninejad and Azizi (2006) the Zagros Thrust System formed during triclinic dextral transgression in an inclined, obliquely convergent thrust wedge.

In the Kermanshah region an earlier thrust event occurred in the Maastrichtian–Palaeocene. This is indicated by ophiolite and radiolarite-derived clasts in conglomerates of the Maastrichtian–Palaeocene Amiran Formation in the adjoining Zagros Fold-Thrust Belt (Braud, 1987) and by an angularly unconformably overlying Eocene–Miocene rock succession (10 km east of Harsin, Braud and Shahidi).

A major Late Cretaceous deformation has affected the region and produced northwest to west–northwest trending folds, faults and foliations/cleavages (see above). This deformation is recognized in the Dorud-Azna region and is mappable throughout the Hamadan Phyllite where northwest-trending synclinoria and anticlinoria forming a southwest-vergent fold belt are delineated by the Cretaceous outliers (Mohajjel et al 2003). Map-scale folds in Cretaceous rocks are tight to isoclinal typically with vergence to the southwest and this is also the major deformation in the underlying Hamadan Phyllite. The deformation is clearly of Late Cretaceous age as it affects Early Cretaceous (Mohajjel et al 2003) and is post-dated by abundant massive Palaeocene granite intrusions (Fig. 8; Valizadeh and Cantagrel, 1975).

In order to relate and compare the above deformations to the tectonics of the SSZ, a brief account is given here of structures encountered at the rear (to the NE) of the main SSZ thrusts. In general, the deformation style is significantly different, as underlined by the much smoother folds involving Cretaceous Orbitolina limestones where they are preserved (Mohajjel et al 2003).

The sub-Cretaceous angular unconformity provides evidence for regional uplift and tilting of the Hamadan Phyllite in the late Jurassic–early Cretaceous interval and was accompanied by intrusion of limited Late Jurassic and Early Cretaceous granites (Valizadeh and Mohajjel). This unconformity is also recognized in the marginal sub-zone to the southwest. Deformation that predates the Cretaceous unconformity has been observed in several areas (e.g. Hamadan, Berberian and Alavi-Tehrani, 1977 identified northwest-trending folds and axial planar schistosity). Early metamorphism is also indicated by the presence of low-grade metamorphic clasts in Early Cretaceous conglomerates of the marginal sub-zone. Early deformation and metamorphism in the Dorud-Azna region may be related to this event although more data is required to confirm this (Fig. 3) (Mohajjel et al 2003).

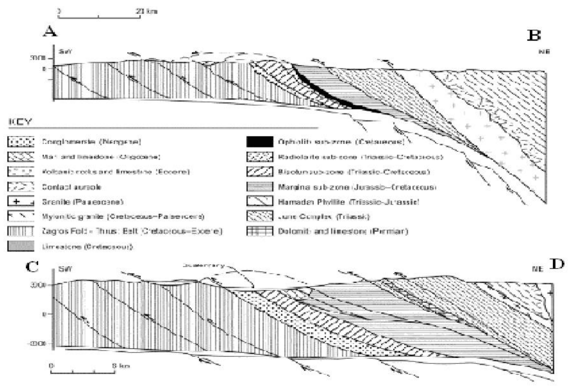

Fig 3. Cross-sections. For locations see Fig. 2. Horizontal scale=vertical scale (Mohajjel et al 2003).

The Golpaygan region is significant as the Cretaceous unconformity is exposed with the underlying Hamadan Phyllite. Alavi (1994) has missed the significance of this unconformity and instead inferred thin-skinned thrusting in this sub-zone and proposed that Cretaceous limestones were thrust over the Late Triassic–Jurassic Hamadan Phyllite(Fig.4).

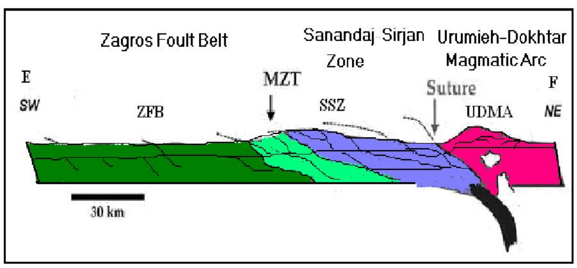

Fig 4. Cross section of The Zagros Thrust and The Sanandaj-Sirjan in Golpayegan area. See fig.2 (Alavi, 1994).

According to Sarkaninejad an Azizi (2006) the Heneshk shear zones in the Eghlid area, are part of the NW-striking, NE-dipping dextral strike-slip Zagros Thrust System of the Zagros orogenic belt. In this portion of the orogenic belt, plastic deformation dominates, and penetrative strain developed. The Zagros Thrust System in this area consists of eight sheets of NW-striking, NE-dipping dextral strike-slip duplex structures that are linked with imbricate fans and oblique slip thrusts (Fig. 5, (Sarkaninejad and Azizi, 2006).

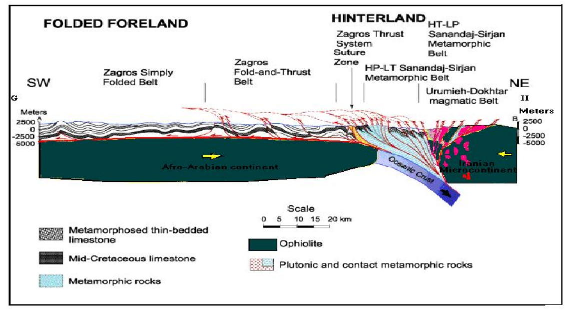

Fig. 5. Large-scale regional cross section of the Zagros inclined transpression from southwest to northeast (Sarkaninejad and Azizi,2006).

In the South of Neyriz the Campanian-Maastrichtian Tarbur Formation angularly unconformably overlies the radiolarite and ophiolite and indicates thrusting of Turonian–Campanian age. The Neyriz ophiolite complex is part of the "Croissant Ophiolitique" (Ricou and Ricou, 1976) that stretches between Oman and the Mediterranean (Gansser; Stocklin; Stocklin; Coleman; Moores; Moores and Stoneley). The Neyriz ophiolite complex, represents an imbricate stack of NW-striking, NE-dipping thrust sheets of ophiolitic and related sedimentary, igneous and locally-metamorphosed rocks, exposed immediately to the southwest of the "Main Thrust" of the Zagros fold-and-thrust belt(Fig. 6).

Thrust sheets containing mantle and oceanic crustal sequences occur in the middle of the stack and constitute what has called the ophiolite component of the Neyriz ophiolite complex which includes peridotite, gabbro, diorite, plagiogranite and mafic and acidic volcanic differentiates (Ghasemi and Talbot 2006).

The Sanandaj–Sirjan HP-LT metamorphic belt and Zagros Thrust System exhibit three distinct deformation phases. The first phase of deformation (D1) led to the formation of the main foliation (S1) (Mohajjel et al 2003). This NW–SE foliation is parallel to the Zagros Thrust System. The S1 foliation may have formed at the peak of metamorphism, whereas later events (S2) are characterized by deformation of this foliation to produce weaker and less penetrative foliation under lower grade or drier metamorphic conditions (Passchier and Trouw, 2005). The third phase of deformation (D3) developed by shear along the shear zones and thrusts and gave rise to the S/C shear band cleavages (S3) (Mohajjel et al 2003).

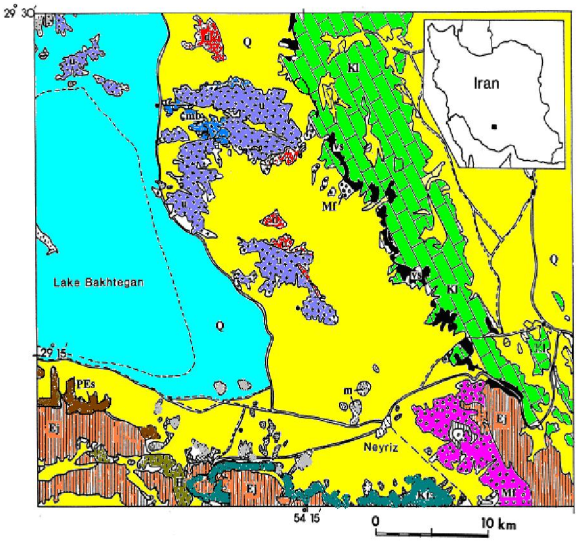

Fig. 6. Geologic map of the Neyriz area showing the distribution of the Hassanabad Unit (vs) along the Main Thrust and the Crush Zone of the Zagros fold belt, at the northeastern edge of the ophiolite belt. The inset map of Iran shows the location of the map area. The Sanandaj–Sirjan metamorphic-igneous belt lies to the northeast of unit “vs” and includes the crystalline rocks under unit “Kl”. Q (Quaternary); Mf (Eocene–Miocene conglomerate and sandstone); Ej (Eocene Alveolina limestone, Jahrum Fm.); PEs (Paleocene–Eocene gypsiferous marl, limestone, sandstone, conglomerate, Sachun Fm.); Kt (Campanian–Maestrichtian, Tarrbur Fm.); vs (Late Cretaceous, Hassanabad Unit); Kl (Cretaceous orbitolina limestone); m (Mesozoic mélange); d (Late Cretaceous ocean floor basalt); u (Late Cretaceous ultramafics); mb (marble); H (Infracambrian Hormuz salt diapir). Modified from Valeh and Alavi Tehrani (1985) and Sabzehi et al. (1993).

3. Evolutionary relation of the Zagros thrust (crush zone) and the sanandaj-sirjan zone

The tectonic regime between the Arabian margin and the Sanandaj–Sirjan zone changed from passive to convergent (Ricou, 1996; Sengör and Natalin, 1996 and Guiraud and Bellion, 1996). A north-dipping subduction zone under the Sanandaj–Sirjan plate is marked on the Cenomanian–Middle Campanian map. During the Late Cretaceous, obduction occurred on the northeastern margins of the Arabian plate. This obduction was caused by the convergence of the Sanandaj–Sirjan with the Arabian plate (Ricou, 1996; Guiraud and Bellion, 1996).

The Sanandaj–Sirjan plate began to thrust over the Arabian Platform, forming the Zagros Mountains (Dercourt et al., 1993). The main cause of thrusting in the Zagros Mountains, according to Sengör and Natalin (1996), was the counterclockwise rotation of the Arabian plate.

Perhaps prior to the Paleocene, the Lesser Caucasus and Sanandaj–Sirjan and Makran plates were sutured to the Transcaucasus–Talysh system (Fig.7). The closure of the Mesozoic Great Caucasus–South Caspian Basin began at this time. The author (see Golonka, 2000a; Golonka, 2000b and Golonka et al., 2000) attributes this closure to the influence of large plates—Arabian and Lut plates—as well as the development of a subduction zone along the northern margin of the basin.

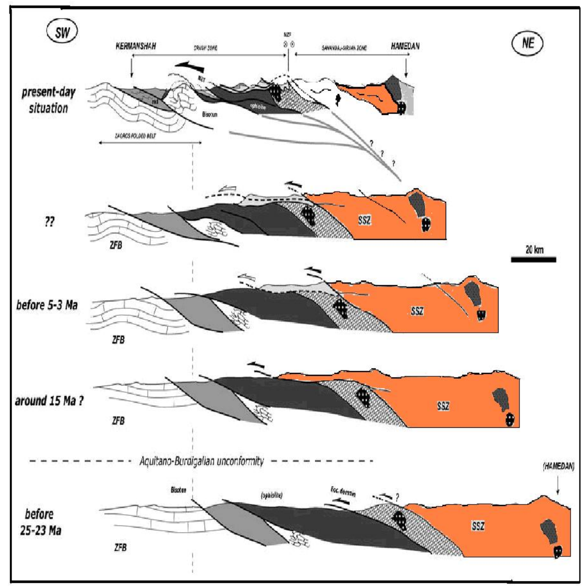

Fig. 7 Progression of convergence with time in the northwest of the Crush zone and the sanandaj-Sirjan Zone. Changes through time SW of the ophiolite unit are only indicative since our study focused on structures located beyond, to the NE; in particular, neither the amount and the timing of shortening in the Zagros Fold belt, which probably started during the latest stages of this evolution, nor the respective amount of shortening of the Bisotun units associated with collision or obduction are known with precision. The amount of shortening in the Crush zone deduced from this reconstruction (about 50–70 km during the last 20–15 Ma) should therefore be considered as a minimum estimate (Agard et al,2005).

According to Searle (1996), beginning in the Eocene, the Arabian plate slowly converged with Eurasia closing the remnants of the Pindos Ocean along the Sanandaj–Sirjan margin (Zagros suture).

The Sanandaj–Sirjan plate began to thrust over the Arabian Platform, forming the Zagros Mountains (Dercourt et al., 1993). The main cause of thrusting in the Zagros Mountains, according to Sengör and Natalin (1996), was the counterclockwise

rotation of the Arabian plate during Oligocene–Middle Miocene.

The sub-Cretaceous angular unconformity provides evidence for regional uplift and tilting of the Hamadan Phyllite in the late Jurassic–early Cretaceous interval and was accompanied by intrusion of limited Late Jurassic and Early Cretaceous granites (Valizadeh and Mohajjel). This unconformity is also recognized in the marginal sub-zone to the southwest. Deformation that predates the Cretaceous unconformity has been observed in several areas (e.g. Hamadan, Berberian and Alavi-Tehrani, 1977 identified northwest-trending folds and axial planar schistosity). Early metamorphism is also indicated by the presence of low-grade metamorphic clasts in Early Cretaceous conglomerates of the marginal sub-zone. Early deformation and metamorphism in the Dorud-Azna region may be related to this event although more data is required to confirm this(Mohajjel et al 2003).

4.Discussion

Rifting of the northeastern margin of Arabia to form the southern arm of the Tethyan Ocean has occurred in two events (Fig. 9(a) and (b)). Firstly, the southern arm of Tethys was forming by sea-floor spreading in the Late Permian as shown by the geology of Oman where pelagic sediments of this age occur in the Hawasina nappes (Bechennec et al., 1990.

In Iran evidence for the first of these events is documented in the Esfahan to Sirjan part of the Sanandaj–Sirjan Zone (Saidi et al., 1997). Subsidence analysis of the Carboniferous to Cretaceous succession of the northeastern Sanandaj–Sirjan Zone near Eghlid indicates rifting in the Early Permian followed by a Late Triassic event that Saidi et al. (1997) related to subduction along the northeastern margin of Tethys. A major mid Permian marine transgression (Berberian and King, 1981) occurred throughout Iran similar to that in the Arabian Peninsula and these have been related to opening of the southern arm of Tethys (Mohajjel et al 2003).

Continental platform conditions persisted in Iran into the Mesozoic outside the Sanandaj–Sirjan Zone with deposition of shallow marine to continental strata. Within the northeastern part of the Sanandaj–Sirjan Zone, Triassic continental and shallow-marine sedimentary successions were interrupted by widespread basaltic magmatic activity (June Complex). The Late Triassic to Jurassic Hamadan Phyllite formed from deep-marine sedimentation and is probably related to thermal subsidence after the magmatic event. This sequence is synchronous with the second extensional event in the southern arm of Tethys. The deposition of volcanic sandstones interbedded in the Triassic succession in the Eglid region (Saidi et al., 1997) are thought to be derived from volcanism associated with the second rift event rather than reflecting subduction of Tethys to the southwest of Central Iran (Mohajjel et al 2003).

The age of this rifting event is similar to that in the northeastern Sanandaj–Sirjan Zone and related to the second extensional event along the passive margins of the south arm of Tethys (Mohajjel et al 2003). The northeastern margin of the Afro-Arabian continent in Iran remained a passive margin until the Late Cretaceous collision event which is consistent with the Permian to Jurassic extensional faulting along the Mediterranean margin of Africa and Early Cretaceous intracontinental rifting of the African plate (Guiraud and Bosworth, 1997).

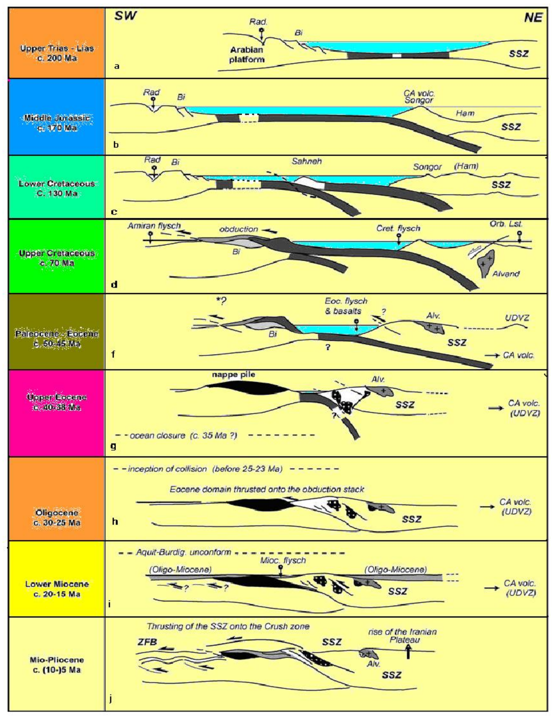

Fig.9. Tentative geodynamic evolution of the northwest of the Crush zone and the sanandaj-Sirjan Zone. *Alv*. Alvand intrusion; *Bi* Bisotun unit; *CAvolc*. calc–alkalinevolcanism; *Cret*. Cretaceous; *Ham* Hamedan; *Orb. Lst*. Orbitolina limestone; *Rad* radiolarian through; *SSZ* Sanandaj–Sirjan zone; *UDVZ* Urumieh–Dokhtar volcanic zone; *ZFB* Zagros Fold belt.(Mouthereau et al. *2005*).

The northeastern margin of Tethys in the Sanandaj–Sirjan Zone changed from a passive margin to an active margin with the subduction of Tethyan sea floor (Fig. 9(d)). In the reconstructions of the Tethysides by Sengör and Natal'in (1996) subduction is shown along the southern margin of the

Podataksasi Zone from the Middle Jurassic to the early Miocene. Igneous activity is consistent with initiation of subduction in the Late Jurassic Cretaceous deformation in the marginal and complexly deformed sub-zones best displays evidence for this subduction (Agard at al. 2005).

In the Zagros, ophiolite obduction may have resulted from an island arc collision with the Arabian passive margin. Irregularities in the shape of the continental margin are related to ophiolite generation at re-entrants in passive margins (Pinet and Tremblay, 1995) and this may explain the discontinuous nature of the ophiolite sub-zone that is only found in the Kermanshah and Neyriz regions. The ophiolite generation and obduction event in the Oman-Iran region is much longer than the relatively short-lived Santonian compressional event recorded in the African plate (Guiraud and Bosworth, 1997).

Opening of the Red Sea and the Gulf of Aden resulted in the rotation of Arabia with respect to Africa (Nubia and Somalia) since 30 Ma (Bonatti; Hempton and Guiraud). This plate movement has been responsible for oblique convergence between the Arabian plate and Central Iran and final closure of Tethys. Convergence has produced deformation (southwest-vergent thrusting, out-of-sequence thrusting) mainly along the former Cretaceous obduction zone in the Sanandaj–Sirjan Zone and deformation in the Zagros Fold-Thrust Belt (Fig.9f); Berberian, 1995). Timing is well constrained by late Miocene and Recent synorogenic siliciclastics that consist mostly of conglomerate in the Zagros Fold-Thrust Belt and along the southwestern border of the Sanandaj–Sirjan Zone (Alavi, 1994).

5.Conclossion

Across the Zagros domain, several major tectonic events are shown to have taken place at the end of the Cretaceous, during the late Eocene and from the Mid-Miocene onwards (ca. <20–15 Ma), respectively. In northern Zagros (Kermanshah–Hamedan area), final resorption of the oceanic domain must have taken place slightly after 35 Ma, and collision must have started before ca. 25–23 Ma (Agard at al. 2005).

The Crush Zone, which includes cataclastically-deformed rocks of both the southwestern edge of the Sanandaj–Sirjan block and the northeastern part of the ophiolite complex, formed as a result of the Miocene contractional tectonics. The Miocene contractional deformation led to renewed thrusting and slicing in the ophiolite complex and the cataclastic intercalation of the volcaniclastic–volcanic rocks with the Cretaceous limestone at the southeastern edge of the Sanandaj–Sirjan. The thrusting of the SSZ over the Crush zone after the start of collision: at least 50–70 km of convergence was accommodated by intracontinental shortening and subduction. The shortening rate across the Crush zone since the Mid-Miocene (20–15 Ma) is estimated at a minimum 3–4 mm/year. Progress of the deformation across the Main Zagros thrust also strongly suggests that the suture zone is effectively located between the Crush zone and the SSZ, contrary to earlier claims (Agard at al. 2005).

Comparing reconstructions of plate kinematics and, the total Eurasia–Arabia convergence reaches about 450 km since 19 Ma (early Miocene), whereas the shortening across the entire Zagros fold belt is thought to be in the range of 50–80 km during the same period(Agard at al. 2005 and Mohajjel et al 2003).

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