Structural Evidence for Slip Partitioning and Inclined Dextral Transpression in the High Zagros Belt: Aligoudarz Area, NW Iran

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ABSTRACT

The High Zagros belt is a portion of the external zone of the Zagros orogenic belt. Structures of the High Zagros belt in the Aligoudarz area (NW Iran) are consistent with dextral transpressional deformation, which is related to the oblique collision between the African–Arabian continent and the Iranian microcontinent. The High Zagros belt in this area consists of NW-striking, dextral strike-slip fault (Main Recent Fault) that are linked with imbricate fans and oblique-slip thrusts. Quantitative kinematic structural analyses suggest localized shear zones deformed with a significant pure shear component. Spatial shear zones indicators are well developed in the Aligoudarz area and indicate shear zone parallel stretching and shear zone perpendicular shortening. The occurrence of a horizontal stretching component parallel to the deformation zone boundary allows a kinematic model of combined transpression and lateral extrusion for this part of the Zagros orogeny.

INTRODUCTION

The term transpression [16] have been adopted to describe oblique relative motion between lithospheric plate and this deformation is the simultaneous occurrence of strike-slip shearing and shear zone normal shortening and has been considered as an important style of the deformation in the regions of oblique convergence [13, 20, 22, 31, 32, 33, 34, 42]. Areas of transpression record structures such as mineral lineations, folds, foliations and secondary shear zones with spatial orientations that may vary along strike and dip of the transpression zone [14, 33, 34, 43].

Since different models have been proposed to the transpression zone boundary [32, 34], Sanderson and Marchini [31] proposed a three dimensional model in which a vertical shear zone has strike-slip motion and the zone narrows in transpression, Fossen and Tikoff [15] introduced a modification of this model considering a deformation matrix for simultaneous simple-pure shearing and volume change, and its application to transpression–transstension tectonics. Fossen and Tikoff [15] expanded their model by expressing the flow kinematic quantities, such as kinematic vorticity number, in terms of finite strain parameters assuming a steady-state deformation history. Tikoff and Teyssey [43] used the kinematic vorticity number [44] to records a nonlinear ratio of the pure shear to simple shear components during deformation. Robin and Cruden [30] developed a model with no-slip boundaries between deforming zone and the wall rocks and Jones et al. [19] introduced an additional component of extension in the horizontal direction that allows for unconfined extrusion of the deformation zone (Fig. 1).

The present study uses new data and information about the structures in the NW Iran, part of the High Zagros in Aligoudarz area and we aim to present geometrical and kinematic evidence for transpression deformation in High Zagros. We introduce for the first time brittle-ductile shear zone in High Zagros belt.

Tectonic setting:

The Zagros orogen is a linear collisional orogen and located in the middle of the Alps-Himalaya orogenic system [3, 9, 38] extends for more than 1500 km with a NW–SE trend from the East Anatolian fault in eastern Turkey to the Minabe-Zendan fault system in southern Iran [17, 37]. This orogen consists of the Urumieh-Dokhtar Magmatic Arc (UDMA) and the Sanandaj-Sirjan Metamorphic Zone (SSMZ) [8, 10, 34], and the...
Zagros Fold-Thrust Belt (ZFTB) [3] (Fig. 2). This belt results from the closure of the Neo-Tethyan Ocean due to northeast-dipping subduction of oceanic crust below the Iranian microcontinent [3, 8, 9]. The ZFTB can be divided into two structural domains as an imbricate thrust belt or the High Zagros Belt (HZB) and the Simply Folded Belt (SFB) that are separated by the High Zagros Fault [11, 29].

Fig. 1: Different transpression models (in X, Y and Z coordinate). The full arrows represent the shortening perpendicular to the transpression zone. The half arrows represent the shear component. (a) Plane strain general shear. (b) Model of Sanderson and Marchini [31]. (c) Model of Robin and Cruden [30]. (d) Model of Jones et al. [19]. (e) Model of Lin et al. [22]. (f) Model of Jones et al. [20].

The High Zagros belt is a NW-SE trending zone of high topography 10-65 km wide, along the southern border of the Sanandaj-Sirjan zone. It is bordered by the Main Zagros thrust fault to the north and High Zagros fault to the south containing numerous steeply NE-dipping thrust faults and tectonic slices with Paleozoic sedimentary rocks thrust over Cenozoic rocks [8, 17, 18, 26, 36]. The Simply folded belt has a lower topography and is characterized by simple longitudinal folds associated with numerous blind thrust faults [1, 2, 11] (Fig. 3).

Fig. 2: Tectonic map of the Zagros orogenic belt with sub-divisions according to Stocklin [38], Berberian and King [9] and Alavi [3]. The Zagros orogenic belt includes the Urumieh-Dokhtar Magmatic Arc, the Sanandaj-Sirjan metamorphic belt and the Zagros Fold and thrust belt [34].

The timing of collision and location of the suture in Zagros are controversial. Collision has been considered to by some authors to have initiated with obduction of ophiolites and deep-marine sedimentary rocks in the Late Cretaceous [3, 5, 9, 33, 34]. Based on plate tectonic reconstructions and geological constraints from the suture zone, collision is now thought to have occurred in the Miocene [1, 26, 27, 29]. A reconstruction based on a global plate motion model suggests that the collision started around 10 Ma [24]. Tectono-Stratigraphic studies provide evidence for propagation of deformation towards the SW since the Eocene [3, 18, 36], Middle to Upper Miocene [21] and the main regional folding in the Zagros fold-and-thrust belt is believed to have taken place from the late Miocene and during the Pliocene [17, 18, 21, 36]. Seismic activity in the simply folded belt is relatively higher than in the High Zagros belt and earthquake focal mechanisms indicate that oblique convergence has been partitioned into reverse slip along NW-SE blind thrusts and dextral strike-slip displacement along the Main Recent Fault [6, 11, 41].
Basic information (Geologic maps, Satellite data) collected and use Arc Gis9.3 and Global Mapper applications for georeferencing these maps and satellite data. The different layers (like faults, geologic units, roads, villages, springs and drainages) were extracted.

In field studies we identified main structures and analyzes geometric, kinematic and dynamic of those structures. For this purpose, all the required information was measured and accurately recorded; also oriented sampling was conducted of outcrops and transferred to the laboratory for study. The measurement orientations were plotted with respect to the mesoscopic structures framework on equal-area, Lower hemisphere stereographic projections and contoured using SpheriState and Stereo softwares to geometric and structural analyzes of thrust and nappes.

The contact surface of metamorphic rocks in Sanandaj–Sirjan Zone and Radiolarite Zone and Zagros Zone were studied and was analyzed geometric of structures in this outcrop. The relationship between deformation and structures were identified and estimated available conditions on deformation (ductile, brittle or ductile–brittle) and we obtained better understanding of deformation stages in mesoscopic structures (sometimes in microscopic). After analyzing all the collected data, deformation pattern in this area and stages of deformation process were presented.

RESULTS AND DISCUSSION

The Aligoudarz structures are part of the Zagros Thrust System of the hinterland zone of the Zagros orogenic Belt. The Zagros Thrust System in this area consists of four sheets of NW-striking (N30-W to N45-W), NE-dipping dextral strike-slip duplex structures (Main Recent Fault) (Fig. 4) that are linked with imbricate fans and oblique slip thrusts. The Zagros Thrust System was previously considered to be a “Crush Zone” [45], or the “Main Zagros Thrust Zone” [8, 9, 17, 34, 39], or the “Main Zagros Reverse” or the “Suture Zone” [11]. 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” [3]. 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 [12, 23, 34].

Given the presence of dextral shear sense indicators such as S-C fabrics (Fig. 5), brittle-ductile deformation and Overturned folds patterns (Fig. 6), we interpret the Zagros Thrust System in the Aligoudarz area to be overprinted by a dextral transpressional shear zone. The combination of strike–slip and oblique-slip deformation along the Sanandaj–Sanandaj metamorphic Zone and High Zagros belt plus a strong component of pure shear deformation is consistent with a transpressional flow regime [31, 34, 43]. Dextral transpressional shearing predominantly localized within the metamorphic rocks in the hanging wall of the Main Zagros Thrust [34].

The present study indicates that two different fault styles exist in the Aligoudarz area. Both oblique reverse and oblique normal faulting has occurred along the Main Recent Fault. The oblique reverse Main Recent fault dipping to the SW opposite to the dip direction of the early thrust faults occur in the area and cut these thrusts.
(Fig. 7). This is the earliest displacement event along the Main Recent fault zone as shown by the associated hanging wall anticline along the SW side of the fault (Fig. 4). Other SW-dipping sub parallel oblique reverse faults occur on the SW the satellite images (Fig. 3). The SW-dipping oblique reverse fault planes are cut and therefore postdated by the oblique dextral normal fault planes along the Main Recent fault zone (see Figs. 8 and 9). This evidence confirms that the reverse displacement was older than oblique dextral normal displacement.

Fig. 4: View of the Main Recent Fault scarp and Venizan anticline, (Rad.) Radiolarit, (Lim.) Limestone. Lower hemisphere stereogram shows Fault plane and bedding in anticline.

Fig. 5: Close up view of the S-C fabric in Main Recent fault zone top-to-the-NE sense of movement. Lower hemisphere stereogram shows S-C planes and movement direction.

Figure 6: Photograph of overturned Folds from the Main Recent fault zones.

**Slip Partitioning And Transpression:**

The Zagros collision zone has been affected by dextral transpression. Transpression structures have been traced by field observations in different parts of the collision zone [1, 7, 27, 34, 35]. Result of brittle deformation in Fars area of the Zagros [28] reconstructed paths of relative Arabia-Eurasia motion involved a change in average values from N030 (56-33 Ma) to N025 (33-19 Ma), N009 (19-10 Ma), and N005 (last 10 Ma). Despite uncertainties in kinematics reconstructions, these results strongly support the hypothesis of a
significant anticlockwise change in the paths of Arabia with respect to Eurasia since the early Oligocene. Meanwhile, transpression in Zagros collision event produced by oblique collision of the Arabia with SW Iran and in contrast with NE-SW shortening in the Zagros orogen, the sutured area, with respect to the rest of the belt, has been affected by a strong orogen-parallel shear component. Shear movements in the High Zagros produced deformation partitioning and shortening across the High Zagros [7].

![Fig. 7: View of the Main Recent Fault scarps, Venizan area. Lower hemisphere stereogram shows Fault plane and slickenline.](image1)

Transpression in the Zagros collision zone is observed to the SE of the Aligoudarz area. Deformation partitioning in the Venizan carbonates has been documented [26] and further SE, right-lateral transpressional flower structures have been presented in south of Aligoudarz area [6] in High Zagros. The same positive flower structures also documented in High Zagros more further SE [7]. We propose that deformation partitioning produced during dextral transpression in the south of Aligoudarz region of the Zagros post dating the NE-SW shortening in the Zagros due to collision event. The oblique reverse Main Recent fault containing dextral displacement is the first evidence for transpression in the structures of the Aligoudarz area (see Figs.8 and 9).

![Fig. 8: Close up view of the brittle-ductile shear zone in Main Recent fault zone.](image2)

![Fig. 9: Photograph of brittle-ductile Deformation in Main Recent fault zones. Lower hemisphere stereogram shows fracture planes.](image3)
Conclusion:
The Aligoudarz area is 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 (Fig. 8), and penetrative strain developed. The Zagros Thrust System in this area consists of dextral strike-slip duplex structures that are linked with imbricate fans and oblique slip thrusts (Main Recent Fault). Quantitative data on structures and deformation in the High Zagros belt in Aligoudarz area of southwest Iran demonstrate structural and kinematic characteristics of dextral transpressive deformation along the Main Recent Fault and “Main Zagros Thrust Zone”. The presence of dextral shear sense indicators suggests that the Zagros Thrust System formed during triclinic dextral transpression in an inclined, obliquely convergent thrust wedge. In this simple shear and pure shear dominated transpression, about 40% strike-slip partitioning is required to accommodate the finite strain and re-orientation of instantaneous strain axes.

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