IJIRR

International Journal of Information Research and Review
Vol. 1, Issue, 3, pp. 062-067, September, 2014

Full Length Research Article

STRUCTURAL EVIDENCE FOR SLIP PARTITIONING AND INCLINED DEXTRAL TRANSPRESSION IN THE HIGH ZAGROS BELT: ALIGOUDARZ AREA, NW IRAN

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ARTICLE INFO

Article History:
Received 22nd June, 2014
Received in revised form 11th July, 2014
Accepted 13th August, 2014
Published online 21st September, 2014

Keywords:
Slip Partitioning,
Transpression,
Zagros Mountain,
Iran

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 (Harland, 1971) 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 (e.g. Sanderson and Marchini, 1984; Teyssier *et al.,* 1995; Dewey *et al.,* 1973; Lin *et al.,* 1998; Jones *et al.,* 2004; Sarkarinejad and Azizi, 2008; Sarkarinejad *et al.,*2008; Sarkarinejad ,2005). 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 (Tikoff and Teyssier, 1994; Fossen and Tikoff, 1998; Sarkarinejad and Azizi, 2008; Sarkarinejad *et al.,*2008). Since different models have been proposed to the transpression zone boundary (Sarkarinejad and Azizi, 2008; Sarkarinejad *et al.,*2008), Sanderson and Marchini (1984) proposed a three dimensional model in which a vertical shear zone has strike-slip motion and the zone narrows in transpression, Fossen and Tikoff (1993) introduced a modification of this model considering a deformation matrix for simultaneous simple-pure shearing and volume change, and its application to transpression–transtension tectonics. Fossen and Tikoff (1993) 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 Teyssier (1994) used the kinematic vorticity number (Truesdell, 1954) to records a nonlinear ratio of the pure shear to simple shear components during deformation. Robin and Cruden (1994) developed a model with no-slip boundaries between deforming zone and the wall rocks and Jones *et al.* (1997) 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 britle-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 (Stocklin,

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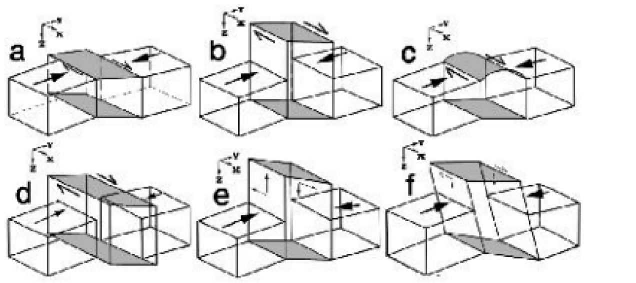

Figure 1. Different transpression models (in X, Y and Z coordinate). The full arrows represent the shortening perpendicular to the transpression zone. The half arrows represent the shear component. (a) Plane strain general shear. (b) Model of Sanderson and Marchini (1984). (c) Model of Robin and Cruden (1994). (d) Model of Jones et al. (1997). (e) Model of Lin et al. (1998). (f) Model of Jones et al. (2004).

1968; Berberian and King, 1981; Alavi, 1994; Alavi, 1996) 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 (Hynes and McQuillan, 1974; Stocklin, 1974). This orogen consists of the Urumieh-Dokhtar Magmatic Arc (UDMA) and the Sanandaj-Sirjan Metamorphic Zone (SSMZ) (Berberian, 1977; Berberian *et al.,* 1982), and the Zagros Fold-Thrust Belt (ZFTB)(Alavi, 1994) (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 (Berberian and King, 1981; Berberian *et al.,* 1982; Alavi, 1994). 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 (Berberian, 1995; Nemati and Yassaghi, 2010).

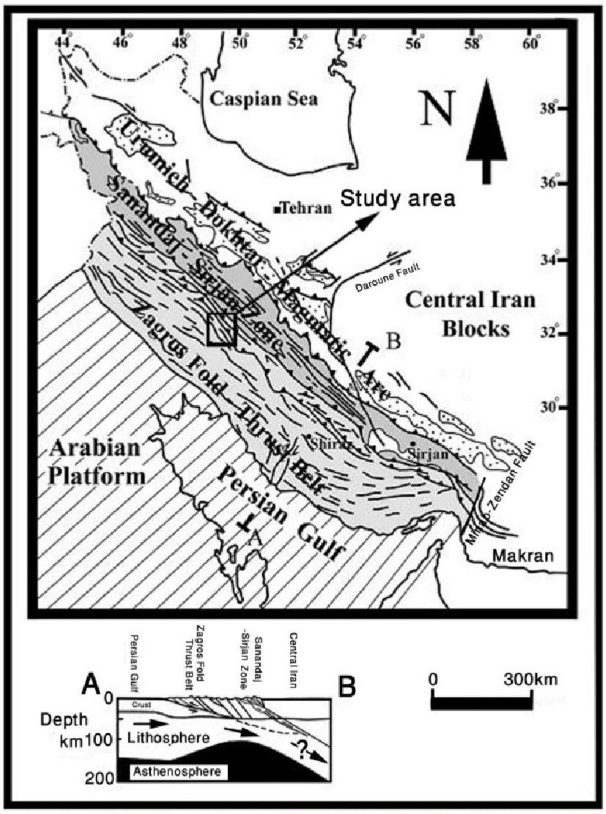

Figure 2. Tectonic map of the Zagros orogenic belt with sub-divisions according to Stocklin (1968), Berberian and King (1981) and Alavi (1994). The Zagros orogenic belt includes the Urumieh-Dokhtar Magmatic Arc, the SanandajeSirjan metamorphic belt and the Zagros Fold-and-thrust belt (Sarkarinejad and Azizi, 2008).

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 (Haynes and McQuillan, 1974; Hessami *et al.,* 2001; Sherkati and Letouzey, 2004; Mohajjel and Rasouli, 2014). The Simply folded belt has a lower topography and is characterized by simple longitudinal folds associated with numerous blind thrust faults (Berberian, 1995; Agard *et al.,* 2005, 2011) (Fig. 3).

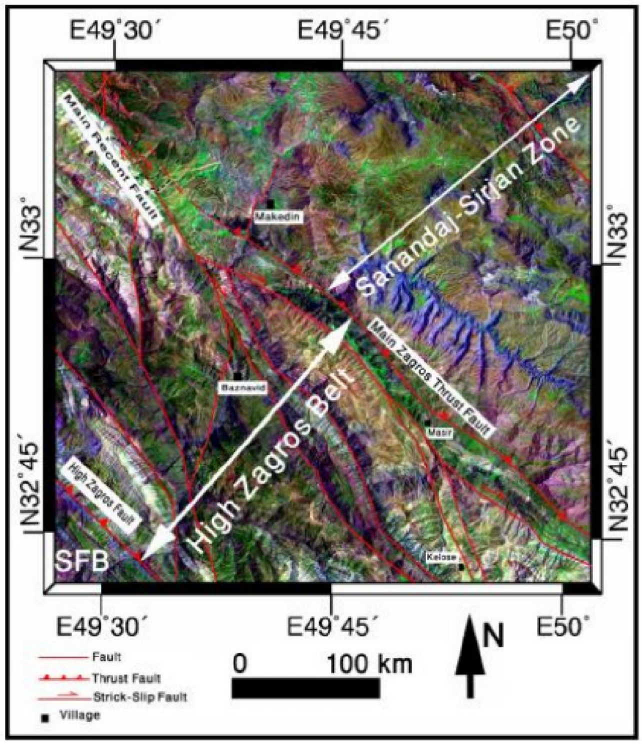

Figure 3. satellite image and major structures along the studied area.

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 (Berberian and King, 1981; Alavi, 1994, 2004; Sarkarinejad and Azizi, 2008; sarkarinejad *et al.,*2008). Based on plate tectonic reconstructions and geological constraints from the suture zone, collision is now thought to have occurred in the Miocene (Mohajjel *et al.,* 2003; Agard *et al.,* 2005; Nemati and Yassaghi, 2010; Mohajjel and Rasouli, 2014). A reconstruction based on a global plate motion model suggests that the collision started around 10 Ma (McQuarrie *et al.,* 2003). Tectono-stratigraphic studies provide evidence for propagation of deformation towards the SW since the Eocene (Alavi, 1994; Hessami *et al.,* 2001; Sherkati and Letouzey, 2004), Middle to Upper Miocene (Khadivi *et al.,* 2012) 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 (Haynes and McQuillan, 1974; Hessami *et al.,* 2001; Sherkati and Letouzey, 2004; Khadivi *et al.,* 2012). 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 Recen Fault

(Berberian, 1995; Talebian and Jackson, 2004; Alipor *et al.* 2012).

MATERIALS AND METHODS

Basic information (Geologic maps, Satellite data) collected and use Arc Gis9.3 and Global Mapper applications for georefrencing these maps and satellite data. The different layers (like faults, geologic units, roods, 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)

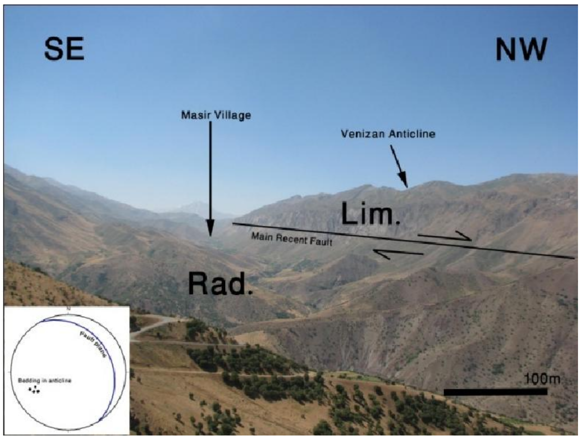

Figure 4. View of the Main Recent Fault scarp and Veniz ananticline, (Rad.)Radiolarit, (Lim.) Limestone. Lower hemisphere stereogram shows Fault plane and bedding in anticline.

(Fig. 4) that are linked with imbricate fans and oblique slip thrusts. The Zagros Thrust System was previously considered to be a ''Crush Zone'' (Wells, 1969), or the ''Main Zagros Thrust Zone'' (Takin, 1972; Hynes and Mc Quillan, 1974; Berberian and King, 1981; Berberian *et al.,* 1982; Sarkarinejad and Azizi, 2008), 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).

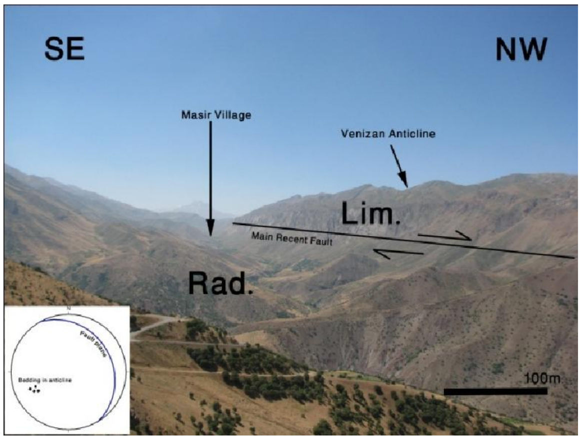

Figure 5. Close up view of the S-C fabric in Main Recent fault zone top-to-the-NE sense of movement. Lower hemisphere stereogram shows S-C planes and movement direction.

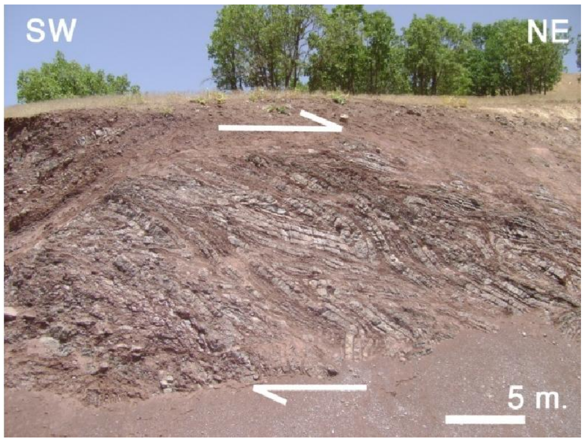

Figure 6. Photograph of Overturned Folds from the Main Recent fault zones.

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; McClay, 1992; Sarkarinejad and Azizi, 2008). Given the presence of dextral shear sense indicators such as S-C fabrics (Fig. 5), brittle-ductile deformaion 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 (Sanderson and Marchini, 1984; Tikoff and Teyssier, 1994; Sarkarinejad and Azizi, 2008). Dextral transpressional shearing predominantly localized within the metamorphic rocks in the hanging wall of the Main Zagros Thrust (Sarkarinejad and Azizi, 2008). 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 subparallel 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.

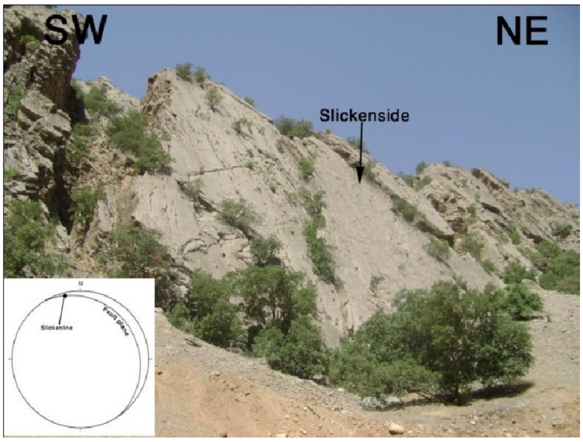

Figure 7. View of the Main Recent Fault scarps, Venizan area. Lower hemisphere stereogram shows Fault plane and slickenline.

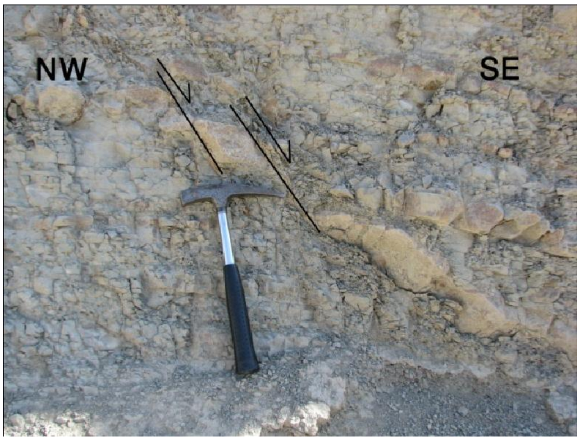

Figure 8. Close up view of the brittle-ductile shear zone in Main Recent fault zone.

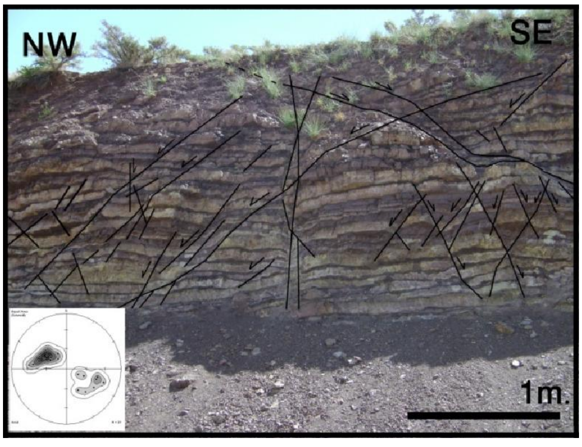

Figure 9. Photograph of brittle-ductile Deformaion in Main Recent fault zones. Lower hemisphere stereogram shows fracture planes.

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 (Mohajjel *et al.,* 2003; Agard *et al.,* 2005; Authemayou *et al.,* 2006; Sarkarinejad and Azizi, 2008; Sarkarinejad *et al.,* 2010). Result of brittle deformation in Fars area of the Zagros (Navabpour *et al.,* 2007) reconstructed paths of relative Arabiae 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 (Authemayou *et al.,* 2006).

Transpression in the Zagros collision zone is observed to the SE of the Aligoudarz area. Deformation partitioning in the Venizan carbonates has been documented (Mohajell *et al.,* 2014) and further SE, right-lateral transpressional flower structures have been presented in south of Aligoudarz area (Alipour *et al.,* 2012) in High Zagros. The same positive flower structures also documented in High Zagros more further SE (Authemayou *et al.,* 2006). 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).

Conclusion

The Aligoudarz 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 (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.

Acknowledgements

The authors are grateful to Professor K. Sarkarinejad and E. Darvishi for useful reviews and suggestions. H. Qanbari is warmly thanked for the handling of the manuscript and many detailed corrections. We are indebted to M. Sadeghi and D. Mohamadi for fruitful discussions. I also would like to thank to Professor A. Nadimi, Esfahan University, Esfahan, Iran, Professor M. Mohajjel, Tarbiat Modares University, Tehran, Iran and Ms. Nikoonejad at college of engineering of Fars science and research branch, Islamic Azad University for their valuable suggestions constructive comments that led to significant improvements of this manuscript, Davood Boniadi, S. Akbari and A. Mohebali are sincerely acknowledged for their assistant in the field and laboratory. This paper forms part of the PhD thesis of the first author. A. Azizi takes this opportunity to thank the Azad University of Aligoudarz branch for continuous support over these years.

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