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Kinematics of Transpressional Deformation Zones in the Urmia Fault Zone, Northwest Iran

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Abstract

Metamorphic and various intrusive rocks in the Urmia area are located in a transpressed active continental margin. These complexes in the Zagros orogen were deformed during an oblique convergence scenario between the Arabian and Sanandaj–Sirjan blocks in NW Iran. The Urmia area contains both NW-SE striking dextral strike-slip and SW verging NE dipping ductile reverse shear fabrics. Ductile shear fabrics are overprinted by subsequent younger thrust and strike-slip fault systems. Abundant syn-tectonic granitoides have been intruded into the Urmia area during convergent. Shear deformation fabrics are well identified in both deformed intrusive and metamorphic rocks. The geometry and kinematics of shear fabrics indicate a deformation partitioning in both ductile and brittle conditions during a progressive transpression tectonic regime.

Keywords: *Urmia fault zone, structural analysis, deformation partitioning, transpression tectonic.*

1. Introduction

The Urmia Fault Zone (UFZ) is located in the North Sanandaj-Sirjan zone of northwest Iran (Fig. 1). The Tethyan orogenic collage formed from the collision of dispersed fragments of Gondwana with Eurasia [1]. Within this context, three major tectonic elements with NW-SE trends are recognized in Iran because of the collision of the Afro-Arabian continent and Iranian microcontinent. They include the Urumieh-Dokhtar magmatic arc (UDMA), the Sanandaj-Sirjan metamorphic zone and Zagros-Folded-Thrust Belt [1].

2. Methodology

This study introduces the geometry and kinematic characteristics of deformed rocks in the Urmia area and covers the fabrics in UFZ in order to identify the structure, shear fabrics, and shear sense indicators of the zone. We believe that this fabric study of the UFZ is necessary to obtain a tectonic model of the Neo-Tethys closure in NW Iran.

3. Regional geological background

The UFZ were studied by Hagipour and Aghanabati [3] during geological mapping and stratigraphic investigations. The basement rocks in NW Iran are characterized by Upper Precambrian metamorphic rocks derived from northern Gondwanaland, which includes amphibolite, metagabbros, and slightly metamorphosed shale [3 and 4].

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Metamorphic rocks in the UFZ are mylonitized Zaigun and Lalun formation, mylonitized Barut formation, and phyllonite and chlorite schist rocks (Fig. 2).

4. Discussion

Structural analyses of the UFZ indicate that they consist of NW-SE oriented various metamorphic rocks. They contain a NW-SE trending, moderate to steeply dipping mylonitic foliation to the NE. Stretching lineation plunge shallowly to moderately towards the NE. Thrust faults are oriented the same as mylonitic foliation. Ductile fabrics are superimposed by brittle structures. Orientations of the structures indicate that the main stress trend is NE-SW. About 15 km to the northeast of the area shows strike-slip faults and NE-striking reverse faults that are offset by a series of normal fault sets. The reverse faults dip at 42° to 51° to the SE and show dip-slip striae. The strike-slip faults are arranged into two sets: one striking N-SE with left-lateral motion and the other striking N-S with right lateral strike-slip motions. A normal fault, parallel to the axis (NW-SE) is visible on the back-limb of the Meskin anticline. This is a high angle fault dipping toward the south (Fig. 4).

4-1. Structure

4-1-1. Foliations

The ‘‘main foliation’’ of the mica-schist is recognized as a continuous schistosity that is characterized by planar fabric elements of layer silicates or flattened/stretched grains that have a preferred orientation and are distributed throughout the rocks [5]. Measurements of the ‘‘main foliation’’ show a mean strike of N43°W to N32°W.

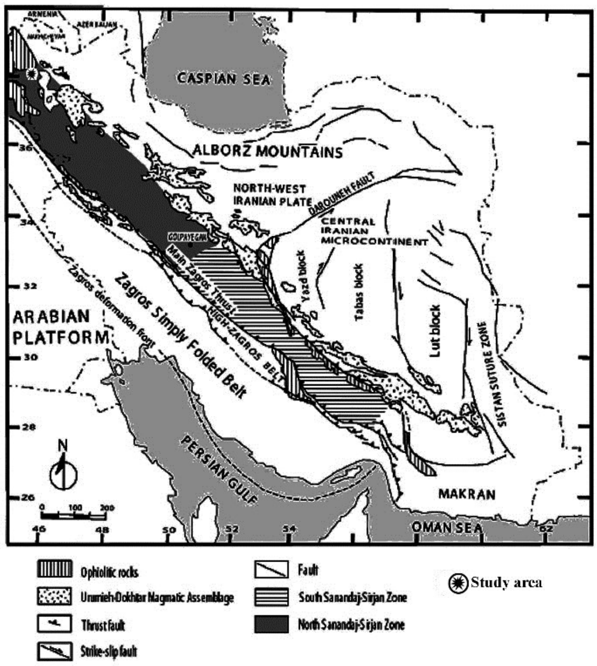

Fig 1. Major structural zones of Iran [2]. Inset shows location of Urmia quadrangle.

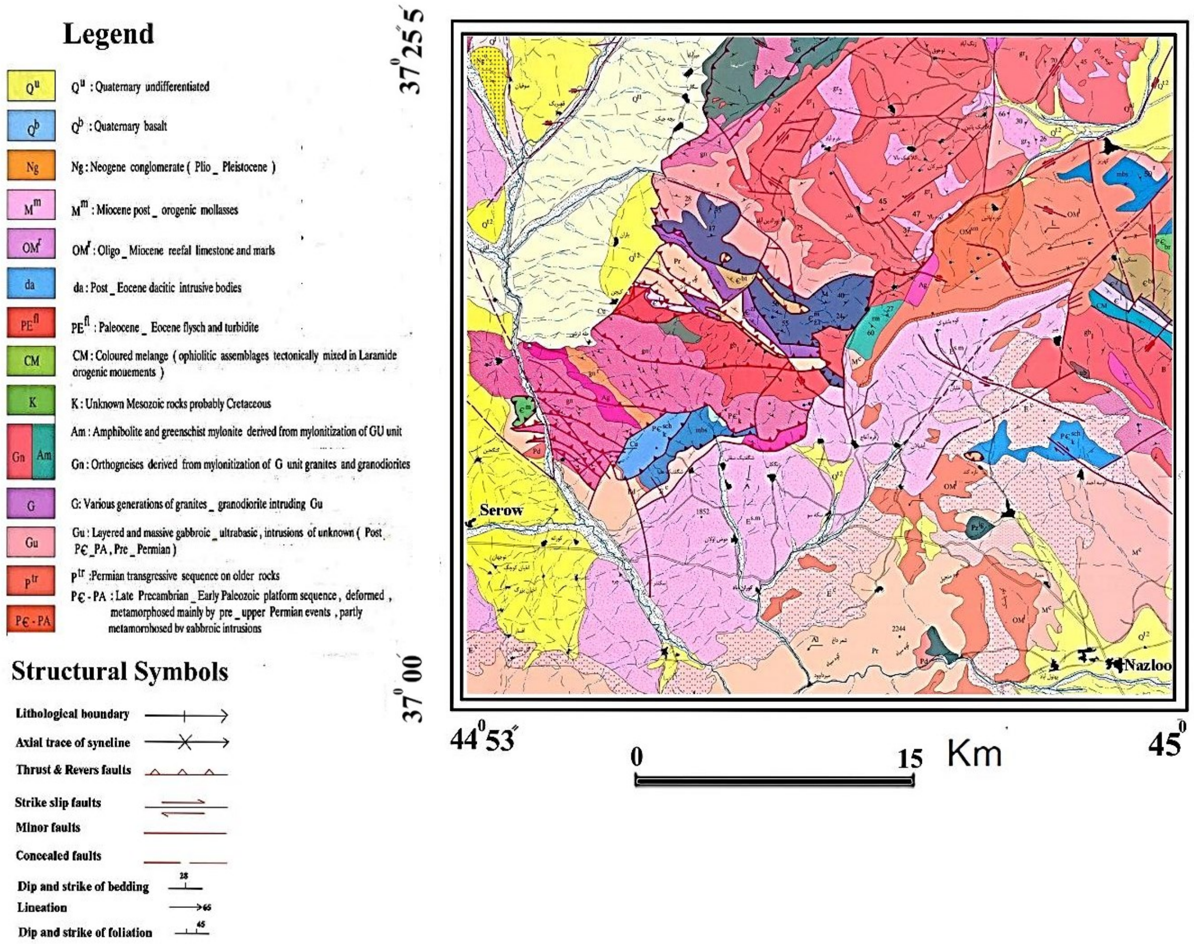

Fig 2. Simplified geological map of the Urmia area modified after the geological map of Survey of Iran in 1:100,000 scale, and modified after [3].

The strong main foliation (S1) was formed during the first deformation phase (D1). This foliation is overprinted by the second foliation (S2), which is defined by compositional layering and preferred orientation of platy minerals. The S2 foliation usually forms crenulation cleavages that consist of symmetrical and asymmetrical microfolds. The orientation of S2 varies from N52°E to N58°E and S1 and S2 are oriented at an angle of 45° to 59° on the microscopic scale. Typically, S2 has a relatively constant NE-SW orientation that changes only modestly from one location to another (Fig. 3 and 4).

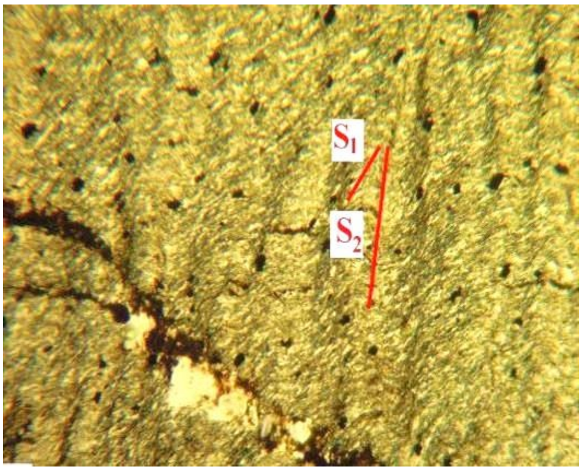

Fig 3. Crenulation cleavage (S2 subvertical) overprinting a slaty cleavage (S1). Development of the crenulation cleavage was accompanied by solution effects. Gareh Aghaj, Urmia. Width of view 5 mm. PPL

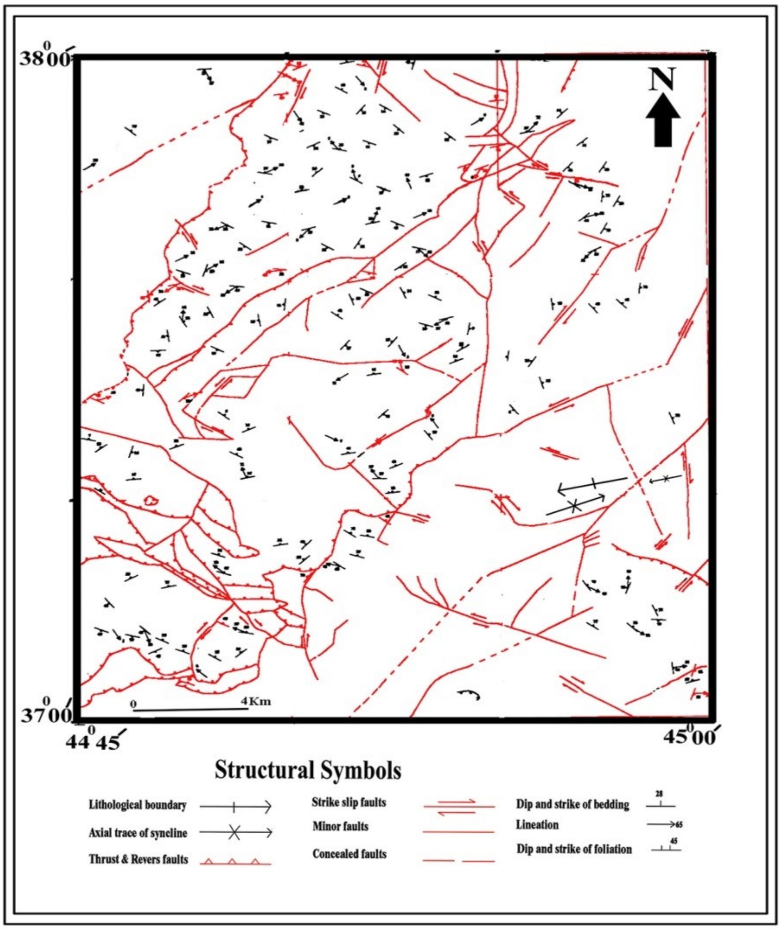

Fig 4. Structural sketch map across the Urmia fault zone

4-1-2. Stretching lineation

Various types of stretching lineations formed in the UFZ area during ductile deformation, including a stretching lineation in the mylonite defined by the long axes of ellipsoidal quartz grains and long narrow quartz ribbons, mesoscopic fold hinge lines (Fig. 5). The mean plunge and trend of the stretching lineation of elongated quartz grains is N42°W to N67°W and the main trend of the stretching lineation is N67°E to N42°E throughout the area (Fig. 4).

Fig 5. Stretching lineation in the UFZ area

4-1-3. Slickefibres

Lineations developed in the fractured rock such as striations on slickensides, and fibrous crystal growths on the NW-SE trending were observed at the Serow area (Fig. 6). These slickenfibres used to determine displacement direction, but only to indicate the last-stage movement direction or local displacement, since they may not represent a movement history of such long lived and mobile zones.

4-1-4. Asymmetrical folds

At the outcrop of the study area, which is located at the northwest exit road of Qushchi toward the Qulonji village, a minor structure of a Z-shaped drag fold was studied. A stratum of a horizontal quartz vein was deformed by frictional drag into folds (Fig. 7) that are convex in the direction of the relative slip. The convex of the folding was used to determine the direction and sense of slip. At the drag fold's outcrop it was observed that strata on the hanging wall of the thrust-slip and reverse-slip faults were dragged into an anticline, whereas strata on the footwall were dragged into a syncline. Tight asymmetrical drag folds were observed down plunge and were characterized as Z-shaped. The high clockwise rotation that constructed the asymmetric, Z-shaped drag fold reflects a right-handed shear, specifically a dextral displacement of top-to-the northeast trending. The latter displacement that appears on the Z-shaped drag fold may be associated with a NE-SW folding event or otherwise with the maximum compressional axis of NE-SW trending that occurs today, while the maximum extensional axis occurs on NW-SE trending with normal faulting and scarps. Under a vertical compressional component (σ_2) the Z-shaped fold was compressed, since the two convex folds occur in a tighter – compacted – version of a Z-shaped drag fold, while brittle faulting produced a small offset of the Z-drag fold.

4-1-5- Tension gashes

In the study area tension gashes were formed primary under the shortening or stretching shear zone. The veins were formed as infilled extension fractures oblique to the shear zone boundaries, and with continued deformation they became folded and rotated to sigmoidal shapes. Secondary, they were folded by a vertical compression axis. The observed curved veins were formed under a high compression of a secondary event (folding), to construct folded tension gashes and distorted shear sense indicators, confusing the kinematics analysis as they illustrate an opposite direction of shear sense (Fig. 8). According to [6], long, thin veins such as these have become folded by buckling as they rotated during shearing, undergoing a shear of the reverse sense to the overall shear zone, resulting in minor folds of the vein with apparently the wrong asymmetry for the major zone of the shear. These sorts of structures are relatively common in greenschist-facies shear zones. The synchronous and cyclical operation of brittle-solution transfer/crystal-plastic deformational mechanism is particularly clear in this case.

4-2. Microstructure

4-2-1. S-C structures

S-C structures [7]are found in mesoscopic scales in granite mylonite in the north and northwest of the UFZ. It is also observed in metabasites and schists in different areas including Belirkhu, Chaharshanbeh Mountain, Bahleh, Bachechik, and Noraaldin. They indicate dextral shear displacement in NW-SE trending strike-slip shear zones. This fabric is seen as a conjugate set of two foliations that possibly were synchronously formed during a single progressive non-coaxial deformation event. The C planes are parallel to the bulk shear plane, while the S planes are assumed to be parallel to the XY plane of finite strain within the low strain domains between two consecutive high strain domains (C planes). Hence, the obliquity of the S planes relative to the C planes directly reflects the orientation of the finite strain ellipsoid, making S-C fabrics a reliable shear sense indicator [8 and 9] in the UFZ (Fig. 9).

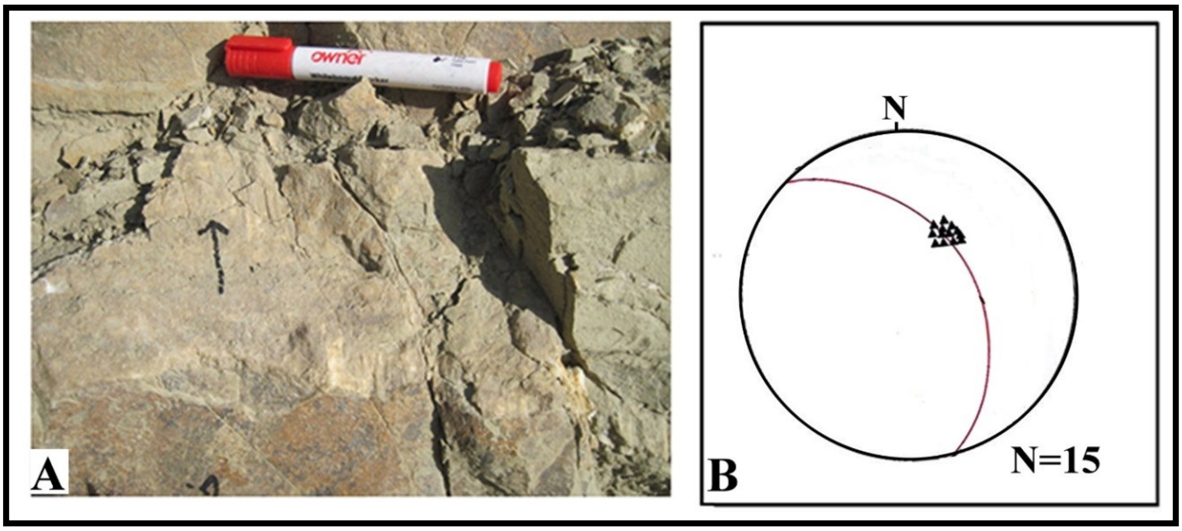

Fig 6. (A) Outcrop of green schist at the Serow area that hosts slickensides of NW-SE trending. (B) Slickensides measured on the plane Serow fault.

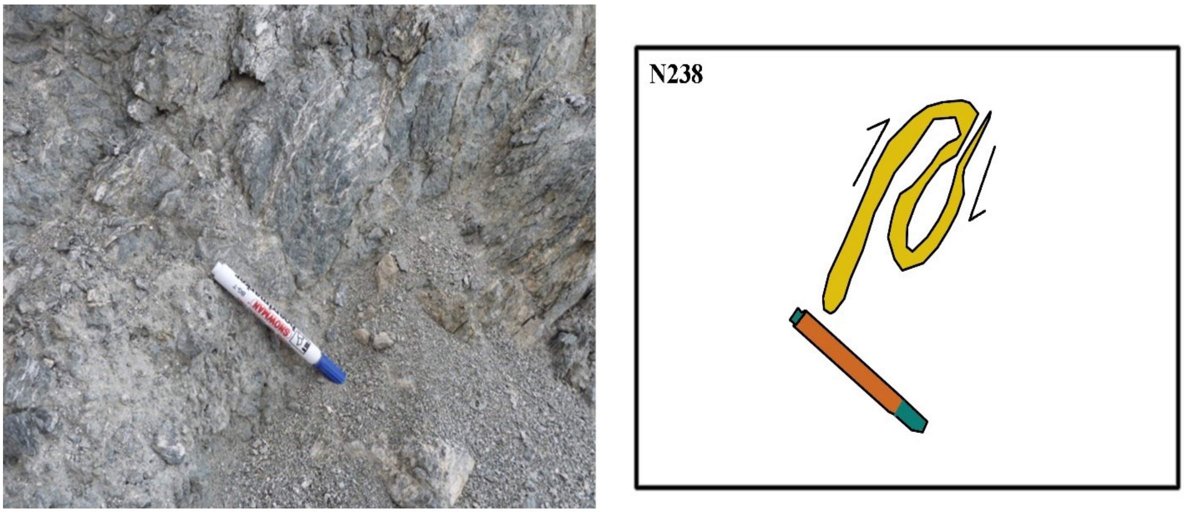

Fig 7. The Z-shaped drag fold form resulting from clockwise internal rotation and progressive deformation, Qulonji area.

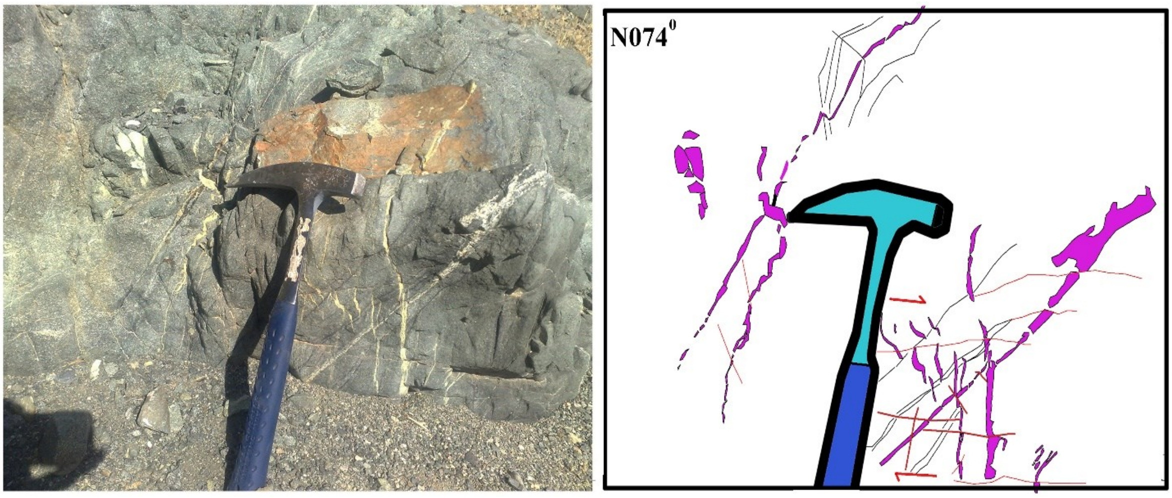

Fig 8. Tension gashes in the en-echelon arrangement. The geometry of the conjugate vein arrays, tension gashes that reveal a dextral shear sense.

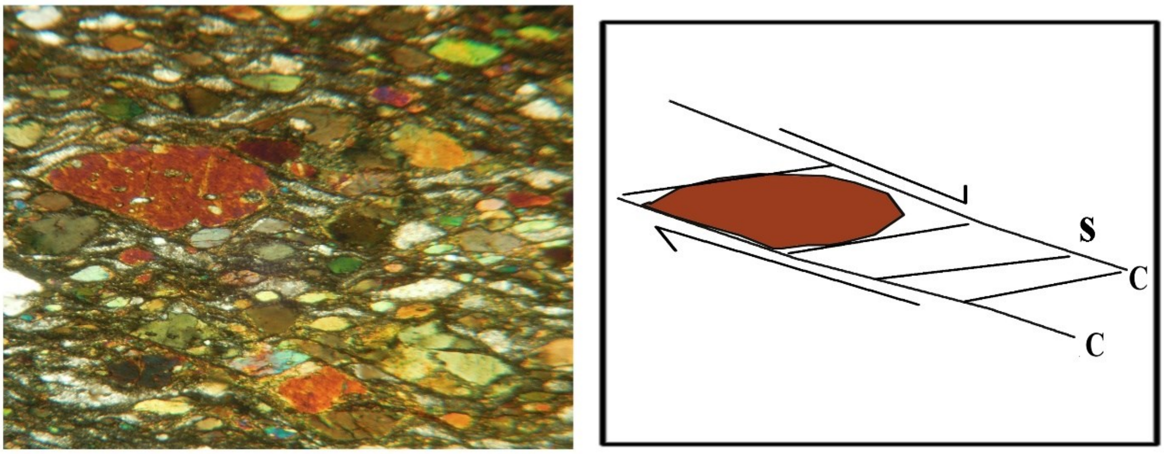

Fig 9. The S-C structure of microscopic scale observed on the XZ plane of the finite strain. The section is parallel to the aggregate lineation and normal to the foliation. The overall shear sense is dextral. Width of view 10 mm. CPL PPL.

4-2-2. Mantled Porphyroclast

Mantled porphyroclasts consist of a central single crystal and a fine-grained mantle of the same mineral. The δ-type and complex mantled clasts mainly occur in high strain mylonites, while σ-type mantled clasts occur also at a lower strain [10]. In the northwest of the Qushchi village, porphyroclasts of relic brittle deformed feldspar crystals show the brittle deformation kinematics, as the quartz deforms around them. The sheared feldspar clast is small, rounded, implying the high deformation intensity. The nature and attitude of this crystal illustrate important kinematic indices. This porphyroclast can be termed as a δ–type porphyroclast. It occurs with a slightly elongate clast and in extended considerable distance of tails (horizontal lines) that cross an inferred central reference plane. These tails are thin, and present tight embayments that exist between the tail and porphyroclast. The kinematics analysis of the δ-type porphyroclast indicates a dextral shear sense (Fig. 10) of NE-SW trending.

4-2-3. V pull-apart microstructures

The feldspar porphyroclasts in the mylonite show varieties of micro-shear zones or micro-faults that caused displacement of the porphyroclast fragments. Micro-faults make an angle of 29° with the C-type shear band cleavages. Two types of microfaults have been recognized: bookshelf structures [11 and 12] and pull-apart structures [13 and 14]. The bookshelf structures in the porphyroclasts show sets of parallel synthetic slips that are parallel to the regional dextral sense of shear. The fragments of feldspar porphyroclast is separated during rotation and they form ‘‘V’’ pull-apart microstructures (Fig. 11). Two types of ‘‘V’’ pull-apart geometry are recognized. Centrally located fractures produced parallel geometry (type I) pull-aparts and off-centered fracture geometry (type II; [14]). The ‘‘V’’ pull-apart is filled with finegrained muscovite that displays a strong preferred orientation.

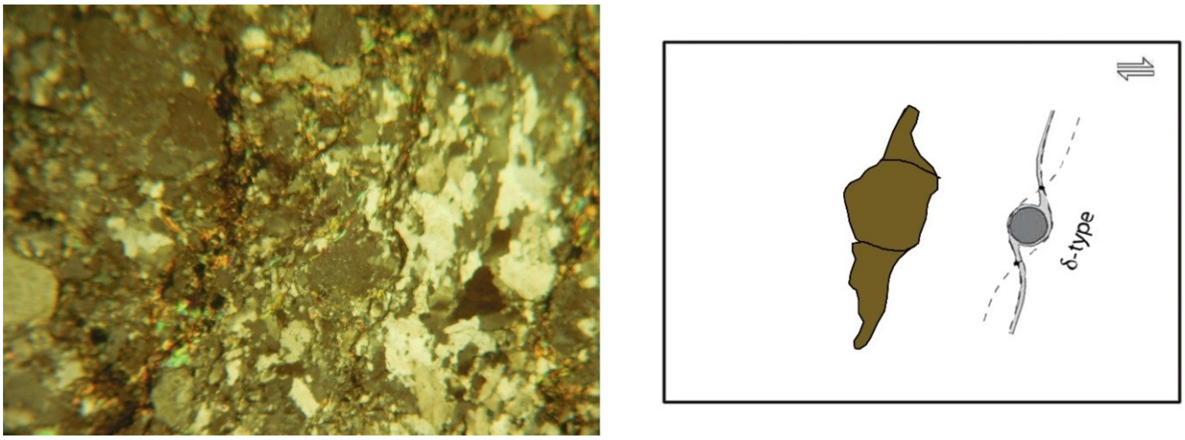

Fig 10. A δ-type porphyroclast in the Qushchi area. Shear sense is dextral. Width of view 4 mm, PPL.

4-2-4. Mineral Fish

In the study area, fish-shaped structures develop in a number of different minerals in mylonitic rocks. Apart from the minerals discussed, fish-shapes were also observed in mica and amphibole minerals showing fish-shapes have different crystal structures and a wide range of physical properties. All fish structures have this in common: they were formed as porphyroclasts embedded in a matrix that underwent non-coaxial flow. Mineral fish are rather abundant in the UFZ. Where the mineral fish touch the shear planes that bound them, the shear strain is maximum and where equidistant from a pair of C-planes the shear strain is minimum. Mica fish, with a lenticular-shape form, occurs close to the forenamed outcrops of the Nazloo area showing in agreement the dextral shear sense (Fig. 12a). It appears to be a lenticular shape with curved sides, ending in sharp tips. The sides of this fish are straight and parallel to foliation. The orientation of the microfault planes of the fish is parallel to the shortest side, continuing parallel or at a small angle to the long axes of the fish. The microfaults separate the fish in smaller parts, implying the rapid deformation. The fragmentation of the fish infers that deformation took place at the transitional zone brittle-ductile. Amphibole fish, with parallelogram-shape form, are observed close to the forenamed outcrops of the Qushchi area, showing in agreement the dextral shear sense (Figs. 12b). The shape of group 2 fish is thought to have evolved from group 1 by drag along zones of concentrated shear, localized along the upper and lower contacts [15].

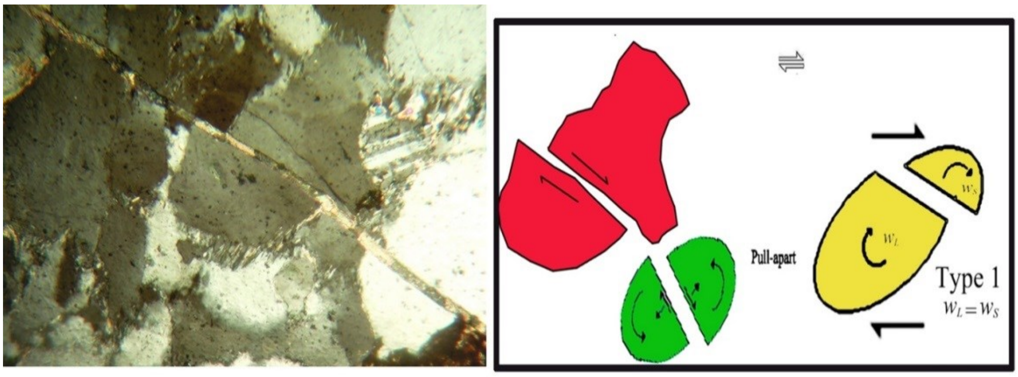

Fig 11. Feldspar porphyroclasts transected by micro-faults and feldspar fragments that are separated and rotated forming pull-apart structures. The overall shear sense is dextral. The section is parallel to the stretching lineation and normal to the foliation. Nazloo, Urmia. Width of view 4 mm. PPL.

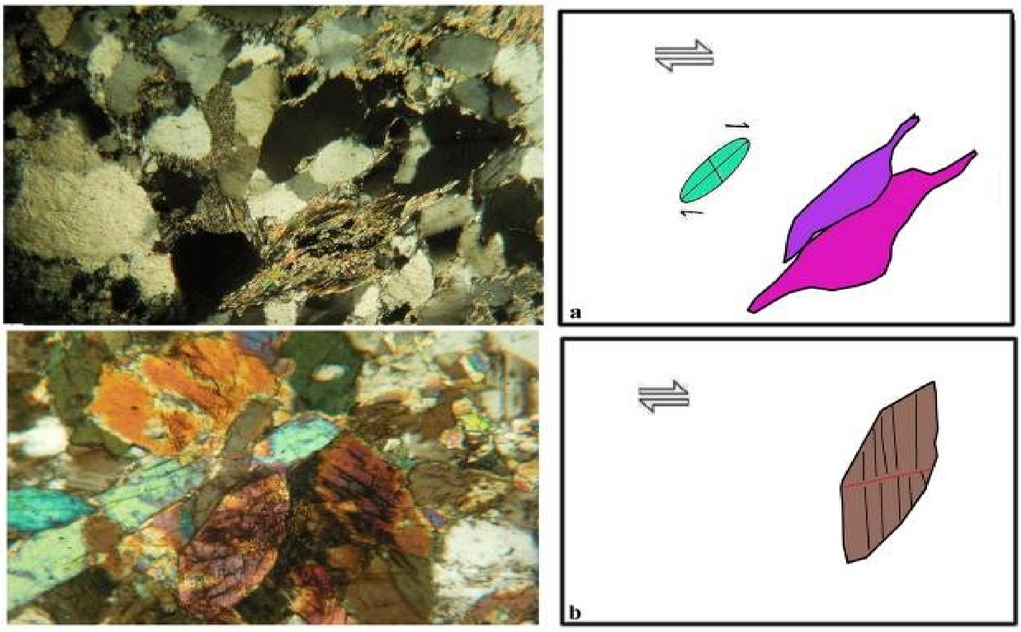

Fig 12. Mineral fish are rather abundant in the UFZ; a) Mica fish in the Nazloo village, lenticular fish with internal discontinuity in the right tip of the fish, b) Amphibole fish in the Qushchi area. Shear sense in all photographs is dextral. Width of view a 4 mm, b 10 mm. a, b: PPL.

4-2-5. Millipede microstructure

These structures are an effect of foliation deflection adjacent to a rigid porphyroblast. Structures similar to deflection folds and millipede structures can be reproduced experimentally in homogeneous, non-partitioned flow around rigid objects. Passchier and Trouw [10] claimed that deformation in rocks is generally partitioned into lenses ('pods') with little deformation or predominantly coaxial shortening, surrounded by an anastomosing network of shear zones (Fig. 13). They envisaged that porphyroblasts with millipede structures grow syntectonically in these pods until they impinge on the surrounding shear zones where they stop growing or dissolve.

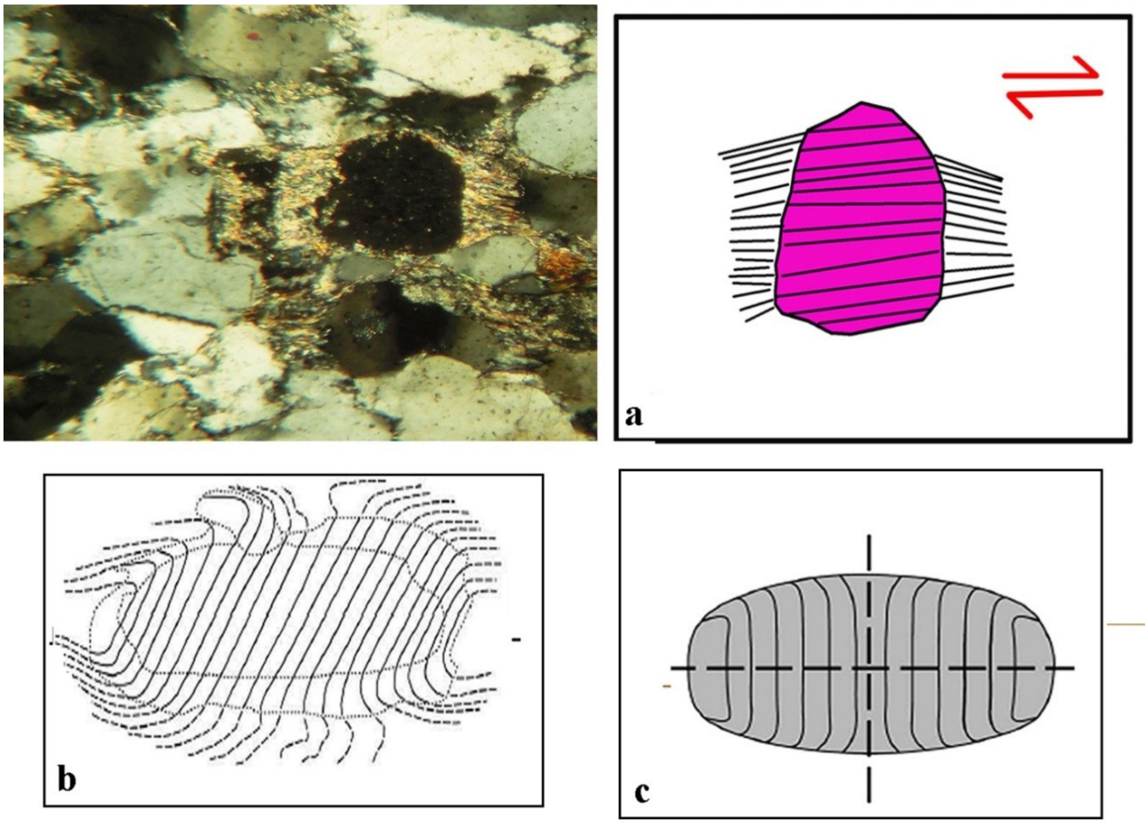

Fig 13. a) Photomicrograph mosaic of millipede microstructure developed in adjacent feldspar porphyroblasts; b) Line drawing of the millipede microstructure [16]; c) Idealized millipede microstructure with characteristic orthogonal symmetry planes with respect to curvature of the internal foliation [16].

5. Conclusion

Structural analysis in the Urmia Fault Zone (UFZ) indicate that they consist of NW-SE oriented various metamorphic rocks. They contain NW-SE trending moderate to steeply dipping mylonitic foliation to the NE. Stretching lineation plunge shallowly to moderately towards the NE. Thrust faults are oriented similar to mylonitic foliation and ductile fabrics are superimposed by brittle structures.

Shear sense indicators such as S-C fabrics, shear bands, shear folds, book-shelf structures, fishes and mantled porphyroclasts indicate that the UFZ deformed via the dextral transpression tectonic regime. The Urmia area contains both NW-SE striking dextral strike-slip and SW verging NE dipping ductile reverse shear fabrics. Ductile shear fabrics are overprinted by subsequent younger thrust and strike-slip fault systems. Abundant syn-tectonic granitoides were intruded into the Urmia area during convergent. Shear deformation fabrics have been well identified in both deformed intrusive and metamorphic rocks. The geometry and kinematics of shear fabrics indicate a deformation partitioning in both ductile and brittle conditions during a progressive transpression tectonic regime (Fig. 14). The UFZ deformed during an oblique convergence scenario between the Arabian and Sanandaj–Sirjan blocks in NW Iran.

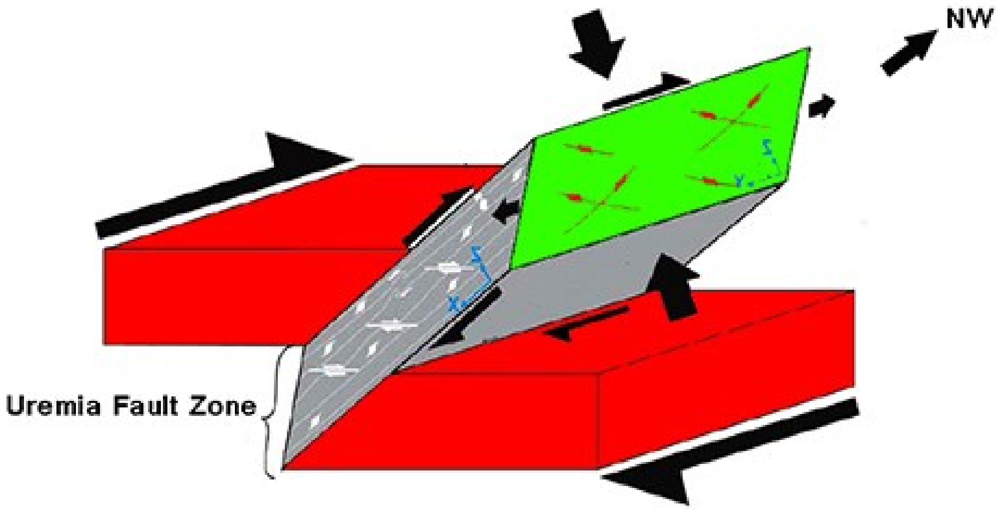

Fig 14. Three-dimensional model proposed for the triclinic strain of the UFZ. The overall dextral kinematics reflects conditions observed at UFZ. The footwall and hanging wall are shown in white and the shear zone is in red. In XZ sections, parallel to the mineral stretching lineation, we observe. The obliquity is resolved in a strike-slip and a dip-slip component. In addition, in YZ sections perpendicular to the regional thrust transport direction, we observe both sinistral and dextral kinematics on similar types of structures to those described within the XZ sections. The coexisting opposing senses of shear in the YZ sections occur on all scales and are documented by many types of kinematic indicators. The geometry and kinematics of shear fabrics indicate a deformation partitioning in both ductile and brittle conditions during a progressive transpression tectonic regime. The UFZ deformed during an oblique convergence scenario between the Arabian and Sanandaj-Sirjan blocks in NW Iran.

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