Quantitative kinematic flow and strain analyses of the drag folds associated to the Sananadaj- Sirjan HP-LT metamorphic belt, southwestern Iran

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Abstract

Presence of the asymmetric and drag folds are characteristics of many ductile shear zones. The origin of these folds is variable, as their development may pre-date, synchronous, or post-date of the shearing events. Folds and other meso- and micro- structures in shear zone are often asymmetric. However the finite geometry, symmetry and degree of asymmetry and their orientations related to shear zones are influenced by many variables other than shear sense. In consequences, folds often have complex link with kinematic, as evidence in shear zones. The final geometry, of folds and their rheology and initial orientation of folded surfaces depends on the vorticity within the shear zone. The Seh-Ghalatun area in southwestern Iran is part of the Sanandaj- Sirjan HP-LT metamorphic belt within the Zagros Orogenic belt. This area gives an opportunity to study asymmetrical and drag folds and estimate kinematic vorticity number. Drag folds are mainly found in the folded quartzite and quartzo-feldspathic layers. The outcrop-scale drag folds were used to estimate kinematic vorticity number (W_k), initial fault angle (α_0) and estimate finite strain (R_s). Fault orientation (α), drag fold angle (β) and the ratio of the thickness of deflected layers at the fault (L) and further away (T) were also measured and than was compared with α, β angles and L/T. using these parameters, in the Seh-Ghalatun area, the estimated mean kinematic vorticity number is $W_m = 0.78 \pm 0.06$ and mean finite strain value is $R_s = 2.32 \pm 0.13$. The kinematic vorticity number and finite strain values were obtained from population of antithetic and synthetic faults related to the drag folds. The estimated finite deformation (W_m) value indicate relative contribution of 38% pure shear and 62% simple shear components for the formation of drag folds.

Key word: *Drag fold; Kinematic vorticity number; Finite strain; Zagros orogenic belt*

Introduction

Drag fold refers to deflection of curved markers adjacent to a fault [1]. The slip along a fault will cause heterogeneous deformation in the vicinity of the fault. Drag folds are found in foliated rocks. Some authors have described a range of drag fold structures and they proposed a number of classification schemes by four categories based on combination of two parameters to identify as follow : fault movement is either antithetic or synthetic with respect to the sense of shear [2] and drag folds are normal or reverse with respect to the slip along the fault, which normal drag refers to markers that are convex in the direction of slip and reverse drag to markers that are concave in the direction of slip[3]. Normal drag folds probably are the most commonly recognized phenomena [4]. Reverse drag has been suggested form at result of local decrease in displacement in the fault- normal direction. Drag markers line may change along a fault from reverse at its center to normal at fault termination [5]. Numerical modeling [2] has shown that the drag of central marker is only function of the angle, Q, the acute angle measured from the fault to the undeformed central marker. At the low angles(φ<30°) faults develop a normal drag and if the markers meet the fault at higher angles (φ>30°) reverse drag will develop (Fig.1).

Geological setting

The Seh- Ghalatun area is located in Neyriz area, southwest Iran, and it is part of the Sanandaj-Sirjan HP-LT Metamorphic belt, within the Zagros orogenic belt. The Zagros orogenic belt is a linear collisional orogen and is part of the Alpine-Himalayian orogenic belt. This belt extends for about 2000 km in NW-SE direction from the East Anatolian fault of eastern Turkey to the Oman line in Southern Iran [6, 7]. Sanandaj-Sirjan zone with NW-SE trending is about 150-200 km wide, more than 1550 km along and has structural trend, which are parallel to the rest of the Zagros orogenic elements[8]. Metamorphic rocks with different metamorphism grade are basis for the distinguishing HP- LT and LP- HT metamorphic belts in Sanandaj- Sirjan zone [9]. The study area is part of HP-LT metamorphic belt and consist of mainly metamorphosed mafic and ultramafic rocks such as amphibolite, eclogite, bluschist, kainite schist, quartzo-feldspathic gniess and quartzite[10,11]. New study on ^{40}Ar / ^{39}Ar step-heating of amphibole from the amphibolites gives a weighted mean age of 91.23 ± 0.89 Ma. This Turonian- Cenomanian age indicates Neyriz ophiolite subdoction following the convergence of Afro-Arabian continent with the Iranian microcontinent and closure of Tethyan Ocean and exhumation of high- grade metamorphic rocks along thrusts and shear zones which reveals the HP-LT conditions of metamorphism[12]

Folding Structure

Mesoscopic-scale outcrops in the Seh-Ghalatun area show asymmetric folds, drag folds, superposed folds and sheath folds which have been used to estimate quantitative finite strain, kinematic vorticity number and sense of shear. Axial plane of the asymmetrical folds give an orientation of N30°W,40°NE to N45°W,39°NE. Clockwise rotation of the asymmetrical fold hinges indicates dextral sense of shear. The superposed folding patterns in this area indicate type 2 and type3 interference patterns. The discrete faults with the drag folds are mainly found in the refolded quartzite and amphibolite layers. Within these layers, discrete faults with the drag folds only occur in profiles that run roughly parallel to shear zone boundary. The drag folds form at cm-scale, steeply plunging faults, best seen on gently dipping outcrop surfaces. Almost all drag folds are reverse drag. Faults with the least offset relative to their length are almost perpendicular to the banding in the quartzite (Fig. 3).

Methodology

Kinematic vorticity number (W_k) is a dimensionless measure of rotation of particles relative to strain and it characterized the amount of shortening proportional to displacement. W_k was originally defined as an instantaneous rotation relative to the instantaneous stretching at a point[13]. Estimating W_k and finite strain that the rocks experienced by using parameters of the drag fold structures that can be measured in the field and from the pictures. the angle (a) between the fault and the far-field foliation, the drag angle (b) between the foliation and the fault measured at the fault, preferably in the middle of the fault, and finally the ratio between the thickness of a marker layer at the fault, measured parallel to the fault (L) at the fault, and perpendicular to the layer (T) away from the fault[14].The plane of observation should be perpendicular to both fault and foliation. The obtained data were processed with the flanking-fold software. The result show an initial fault angle (83°) and the angle between flow apophyses (38°) , which gives mean kinematic vorticity number (W_k) about $W_m = 0.78 \pm 0.06$ .The estimated finite strain from the fault structures is $R_s = 2.32 \pm 0.13$

Conclusion

Drag folds of the Seh-Ghalatoun within the Sanandaj-Sirjan Meatamorphic belt were used to estimate kinematic vorticity ($W_m = 0.78 \pm 0.06$), initial fault angle (83°) and finite strain first fault nucleation ($R_s = 2.32 \pm 0.13$). Mean kinematic vorticity number (corresponding $W_m = W_k$) indicates 38 % pure shear and 62% simple shear for the formation of drag folds. This result has show good correlation with other results that gained of different methods. Also drag folds show dextral sense of shear that experienced in this area.

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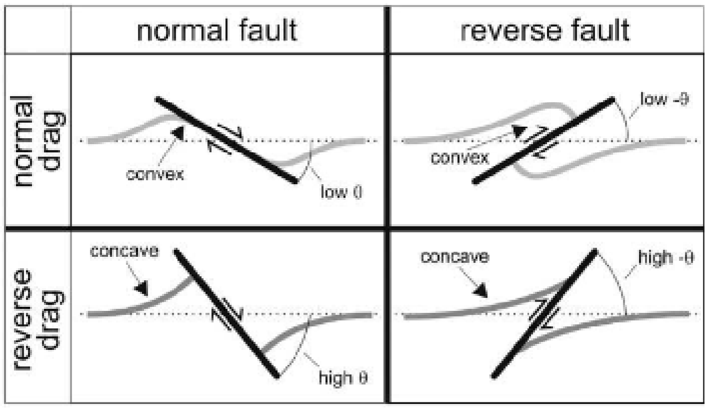

Fig. 1-. Fault drag of a central marker along normal and reverse faults [5].

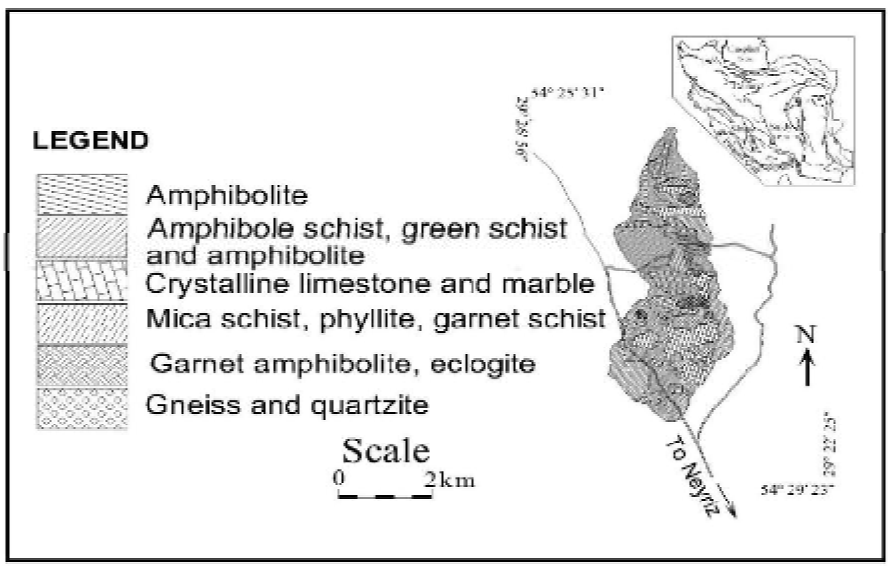

Fig2- Geological map of Seh-Ghalatun area

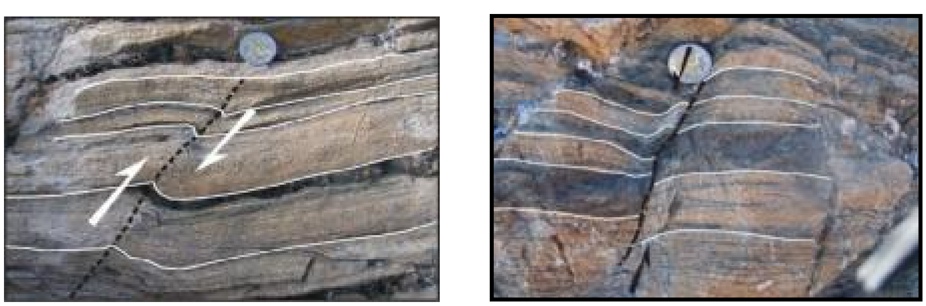

Fig3- Photographs of drag fold structure in the Seh-Ghalatun area, (A) normal darg reverse fault. (B) normal drag and normal fault.

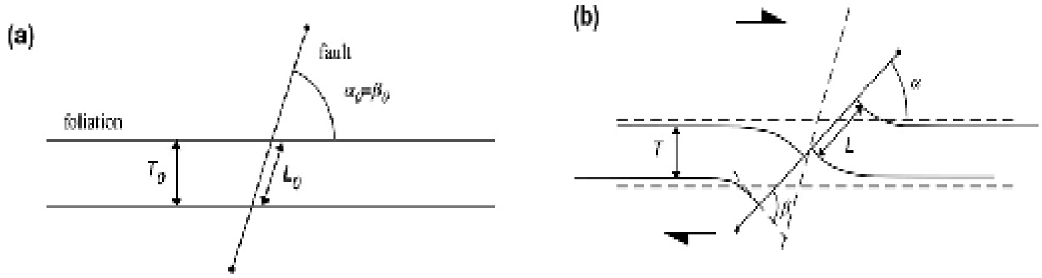

Fig4. Sketch showing a fault and drag fold in the undeformed (a); and deformed (b) stage with all the parameters that are required the analysis [14].

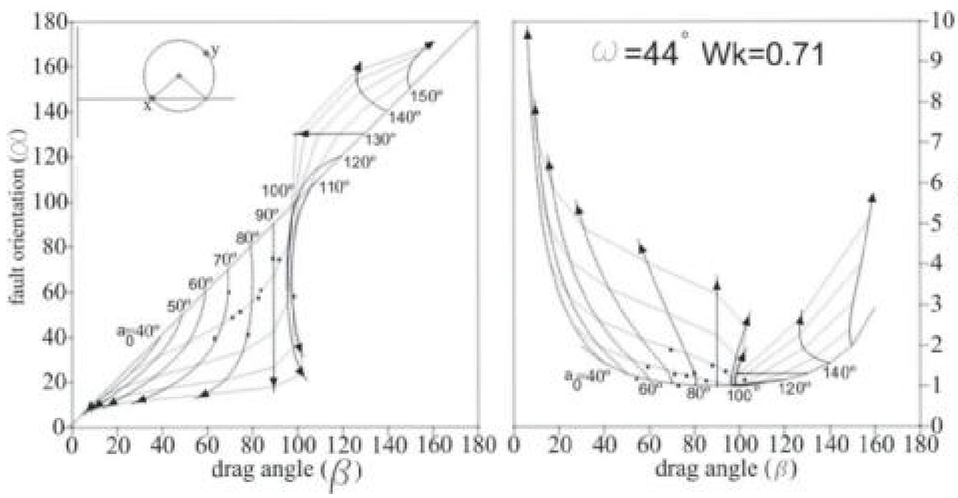

Fig5- Curves of the L/T as a function of b for different vorticities and starting orientations of the fault for one of the stations in the study area.