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Quartz *c*-axis evidence for deformation characteristics in the Sanandaj–Sirjan metamorphic belt, Iran

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ABSTRACT

Quartz *c*-axis fabric, finite strain, and kinematic vorticity analyses were carried out in well-exposed quartz mylonites to investigate the heterogeneous nature of ductile deformation within the Eghlid deformed area in the High Pressure–Low Temperature (HP–LT) Sanandaj–Sirjan metamorphic belt (Zagros Mountains, Iran). This belt belongs to a sequence of tectonometamorphic complexes with low- to high-grade metamorphic rocks affected by a polyphase deformation history. Asymmetric quartz *c*-axis fabrics (type I) confirm a localized top-to-the-southeast sense of shear. Quantitative finite strain analysis in the *XZ*, *XY* and *YZ* principal planes of the finite strain ellipsoid demonstrate that the strain ratio increases towards the thrust planes of the Zagros Thrust System. Kinematic vorticity analysis of deformed quartz grains showed sequential variation in the kinematic vorticity number from ~0.5 to ~0.8 between the thrust sheets. Such vorticity numbers show that both simple and pure shear components contribute to the deformation. Our results show that simple shear dominated deformation near the thrust faults, and pure shear dominated deformation far from them. Quartz *c*-axis opening angles suggest deformation temperatures range between 450° ± 50 °C and 600° ± 50 °C, which yield greenschist to amphibolite facies conditions during ductile deformation.

1. Introduction

In many deformed rocks, the lattice orientation of crystals is not randomly distributed, but arranged in a systematic way. Such rocks have a lattice preferred orientation (LPO) for a specific mineral. In the case of crystals with a planar or elongate shape in a particular crystallographic direction, such as micas and amphiboles, an LPO is easy to recognize as a foliation or lineation (Passchier and Trouw, 2005). However, for minerals such as quartz and calcite this is more difficult. In minerals with equate grain shapes, dislocation creep is the most important mechanism for development of a LPO (Passchier and Trouw, 2005). The slip system or deformation twinning that is active in a crystal depends on the critical resolved shear stress (CRSS) and indirectly reveals the metamorphic and deformation conditions. Usually, more than one slip system can operate in a mineral and the CRSS of each slip system changes with temperature and activity of certain chemical elements. Comparison of natural LPO patterns with known temperature, strain geometry and vorticity of the progressive deformation can help to determine the influence of these parameters on LPO development.

The analysis of lattice preferred orientation patterns is of considerable interest for investigating the kinematics and geometry of flow in natural shear zones (Bouchez and Pecher, 1981). Microstructural studies of quartz are of great significance especially in understanding the flow mechanisms and deformation patterns in these zones. Fabric development in quartz is governed by the dominant slip systems (basal $\langle a \rangle$ slip, rhomb $\langle a \rangle$ slip and prism $\langle a \rangle$ slip) and the strain path (Bhattacharya and Webber, 2004; Passchier and Trouw, 2005). This paper shows the results of fabric data, finite strain, and kinematic vorticity from a natural shear zone within the High Pressure–Low Temperature (HP–LT) Sanandaj–Sirjan metamorphic belt. This systematic study shows the sequential development of quartz fabrics between two thrust fault sheets in the Zagros Thrust System.

2. Regional geological background

The Zagros Orogenic Belt is part of the Alpine–Himalayan Mountain Range and extends for about 2000 km in a NW–SE direction from the East Anatolian Fault of Eastern Turkey to the Oman Line in southern Iran (Alavi, 1994). The Zagros Belt is the result of the closure of the Neo-Tethys by oceanic crust consumption at a NE-dipping subduction zone below the Iranian microcontinent, and subsequent Late Cretaceous continental collision between the Afro-Arabian continent and Iranian microcontinent (Stocklin, 1968; Dewey et al., 1973; Berberian and King, 1981; Alavi, 1994; Blanc et al., 2003; Sarkarinejad et al., 2008). Convergence between the Afro-Arabian continent and the Iranian microcontinent

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accounts for thrusting and large-scale strike slip faulting associated with crustal shortening. Postcollisional crustal shortening is still active (Jackson and McKenzie, 1984; Allen et al., 2004) with a N–S oriented convergence rate of approximately 20 ± 2 $mmyr^{-1}$ (Vernant et al., 2004).

From northeast to southwest the Zagros consists of three NW–SE trending parallel zones (Alavi, 1994) (Fig. 1): (1) The Urumieh–Dokhtar Magmatic Assemblage (UDMA). (2) The Sanandaj–Sirjan Metamorphic Belt (SSMB). (3) The Zagros Fold and Thrust Belt (ZFTB). The SSMB is 150–200 km wide and more than 1500 km long from northwest (Sanandaj) to southeast (Sirjan). The borders of the SSMB are parallel to the main NW–SE regional structures. Widespread thrusting in the Sanandaj–Sirjan Zone is related to the subduction and collision from Cretaceous to Tertiary times (Alavi, 1994). In addition to thrust faults, ductile structures, including tight-isoclinal folds and associated foliations and lineations abound in the metamorphic Late Palaeozoic and Mesozoic formations, and plutonic rocks outcrop in the central part of the SSMB (Sarkarinejad et al., 2010a, 2010b). The study area within the SSMB was located in the region of Eghlid, 130 km north of Shiraz in southwest Iran (Fig. 2). The study area has been sandwiched between two major thrusts due to the Zagros Thrust System and shows the geometry of a transpressional shear zone (Sarkarinejad et al., 2010a, 2010b). The most abundant rocks are deformed metamorphic rocks such as micaschists, greenschists and quartzites.

3. Quartz LPO patterns

Quartz *c*-axis were measured for seven oriented samples of quartz-rich mylonites from a NE–SW transect in the study area (Fig. 2). The aim of these measurements was to estimate the finite strain from the quartz porphyroclasts, and the vorticity numbers between the thrust faults bounding the shear zone. *c*-axis orientation of 200 or more quartz grains from each sample were measured on *XZ* sections (cut parallel to the lineation and perpendicular to the foliation). In this reference frame, the foliation is assumed to represent the *XY*-plane of the finite strain ellipsoid, and in this plane, the lineation represents the direction of the maximum finite elongation. All analyzed samples are strongly foliated and form quartz ribbons. The quartz grains in the quartz ribbons show evidence of extensive dynamic recrystallization associated with grain boundary migration and subgrain rotation (Fig. 3).

The *c*-axis measurements were carried out for each sample (Fig. 4a). Fabric skeletons were prepared by connecting the crests and ridges of each fabric diagram (Fig. 4b) (Lister and Williams, 1979; Lister and Hobbs, 1980). All diagrams record a well-preserved shape and lattice fabrics form asymmetric crossed girdls indicating non-coaxial shearing consistent with the dextral sense of shear of the SSMB (Law, 1990). The top-to-the-SE sense of shear is confirmed by quartz *c*-axis microtextures (Fig. 4a and b). The obliquity of the central girdle segment with respect to the foliation

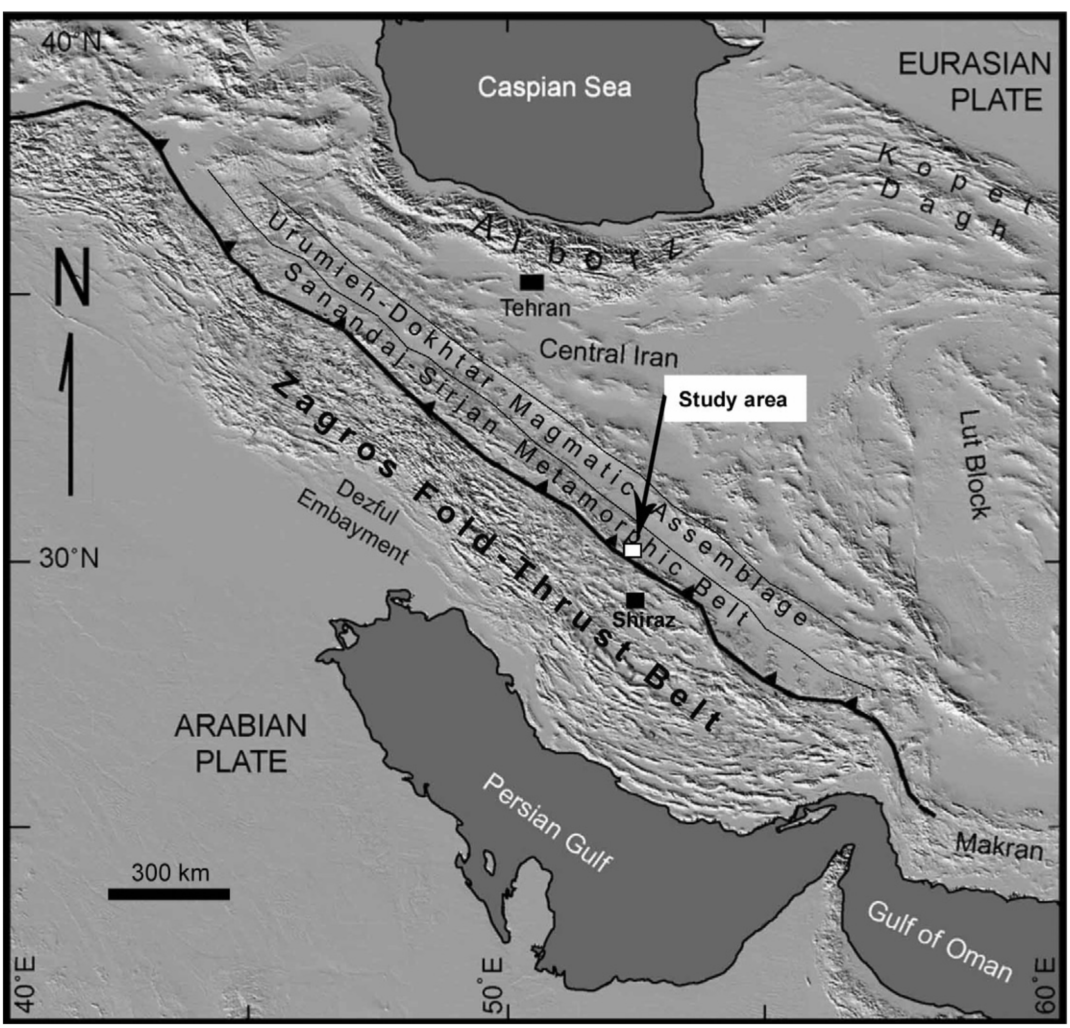

Fig. 1. The Sanandaj–Sirjan shear zone and the Zagros belt from northeast to southwest in western Iran.