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Crystallographic preferred orientations and microstructure of a Variscan marble mylonite in the Ossa-Morena Zone (SW Iberia)

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Abstract

The mylonitic marbles of the Cherneca shear zone, a Variscan sinistral strike-slip structure developed in the Ossa-Morena Zone (SW Iberia) related to the emplacement of the Santa Olalla Igneous Complex, were studied in detail. Different mylonites (from protomylonites to ultramylonites) were analyzed by Electron Back-Scattering Diffraction (EBSD) in order to determine the crystallographic preferred orientation (CPO) of calcite. The CPOs show very good agreement with experimental torsion work giving suitable interpretations of the operative slip systems and strain quantifications, thus the obtained natural CPOs validate the experimental approaches. A wide range of observed textures and microstructures are mainly controlled by the amount of shear strain, the presence of secondary phases, and the development of antithetic subsidiary shears. The effect of secondary phases and the nucleation of antithetic shear bands on texture development are discussed.

Keywords: Crystallographic preferred orientation; Texture; Microstructure; Mylonite; Shear bands; Variscan Orogeny

1. Introduction

The more suitable rocks for accumulating large amounts of ductile strain at the low temperature dominant conditions in the upper crust are carbonate rocks. Considering their abundance elsewhere, these rocks play a fundamental role during orogenesis. Thus, advancing the knowledge of the formation and evolution of plastic flow in carbonate shear zones is a main objective for the understanding of orogenic processes (Pfiffner, 1982; Van der Pluijm, 1991).

Calcite textures and microstructures in deformed marbles provide information regarding kinematics, deformation mechanisms, stress quantification, characteristics of the strain, and physical parameters during deformation (e.g. temperature). The type of texture (crystallographic preferred orientation, CPO) developed during ductile deformation of calcite is controlled by two factors: active crystallographic slip systems at a given temperature, and the amount of strain. The geological significance of calcite CPOs is shown by experiments carried out on natural marbles (Griggs et al., 1960; Handin et al., 1960; Schmid et al., 1977, 1980; Rutter, 1974, 1995; Rutter et al., 1994; Casey et al., 1998; Pieri et al., 2001a,b; Barnhoorn et al., 2004, 2005), synthetic calcite aggregates (Walker et al., 1990; Barnhoorn et al., 2005), and on simulations performed by numerical modelling (Wenk et al., 1987, 1997, 1998; Wenk and Christie, 1991; Lebensohn et al., 1998; Pieri et al., 2001b). Numerical and experimental results have proven helpful when compared to natural samples.

Deformation experiments on calcite single-crystals (Turner et al., 1954; Griggs et al., 1960; Turner and Heard, 1965; Borg and Handin, 1967; Paterson and Turner, 1970; Weiss and Turner, 1972; Braillon and Serughetti, 1976; Turner and Orozco, 1976; Spiers and Wenk, 1980; De Bresser and Spiers, 1990, 1993) were used to define the crystallographic slip and twin systems active at different temperature, stress and strain rate conditions, and critical activation shear stresses (reviews can be found in Paterson, 1979, and De Bresser and Spiers, 1997). Plastic deformation of calcite occurs in low

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and high temperature regimes. At low temperature deformation is characterized by twining on e{-1018}<40-41>, slip on r{10-14}<-2021> (r<sd>) and on f{-1012}<2-201> (f<sd>). At high temperature deformation is controlled by slip on r{10-14}<-2021> (r<sd>), f{-1012}<10-11>, c{0001}<-12-10> (c<a>), and r{10-14}<-12-10> (r<a>). Both strain regimes are described in De Bresser and Spiers (1997). The r<a> slip system was postulated later by Pieri et al. (2001a) and Barnhoorn et al. (2004) after large torsion experiments in marbles (although no direct observations on single-crystal deformation have been obtained yet). The results from Barnhoorn et al. (2004) on experimental deformation of Carrara marble are very relevant for analyzing natural ultramylonite samples because, for the first time, steady state conditions were reached during the largest shear strains obtained by torsion. Numerical modelling (Wenk et al., 1987, 1997, 1998) was successfully used to reproduce different CPOs depending on the slips systems considered to be active, with a good agreement with laboratory experiments (Lebensohn et al., 1998; Pieri et al., 2001b).

In this paper, we present a systematic study of the microstructures and CPOs of the Cherneca shear zone, a Variscan sinistral structure developed in the Ossa-Morena Zone (SW Iberia). This structure has a special relevance considering that it is the source of the magmas of the Santa Olalla Igneous Complex (Romeo et al., 2006b) and of the recently discovered magmatic mineralized pipes of the Aguablanca Ni–Cu–PGE ore deposit (Lunar et al., 1997; Ortega et al., 1999, 2004; Tornos et al., 2001; Piña et al., 2006).

Samples were chosen to represent a wide range of total strain within the Cherneca marble shear zone. Samples comprise: (1) ultramylonites completely dominated by dynamically recrystallized grains; (2) mylonites characterized by core-mantle textures with oblique porphyroclasts indicating low amount of shear; and (3) oblique subsidiary antithetic shears developed cross-cutting a zone of protomylonites. We also analyzed textures of the marble out of the shear zone to compare them with textures within shear zone. CPOs were obtained from individual crystallographic orientations of grains measured by Electron Back-Scattering Diffraction (EBSD) (Prior et al., 1999; Leiss et al., 2000).

The obtained CPOs were compared with experimental and numerical modelling studies, which show good agreement. Our results and comparison with experimental and numerical examples provided: (1) the sense of shear for each sample (from patterns with monoclinic symmetry with respect to the shear plane) being coherent with mesoscopic indicators; (2) the slip systems active during deformation, giving a qualitative estimate of temperature in agreement with the proximity of the magmatic intrusions; and (3) a qualitative estimate of the amount of shear accommodated in each sample.

2. Geological setting

The Cherneca shear zone is located on the southern limb of the Olivenza-Monesterio antiform (Fig. 1), a major, WNW–ESE trending Variscan structure, occupying a central position

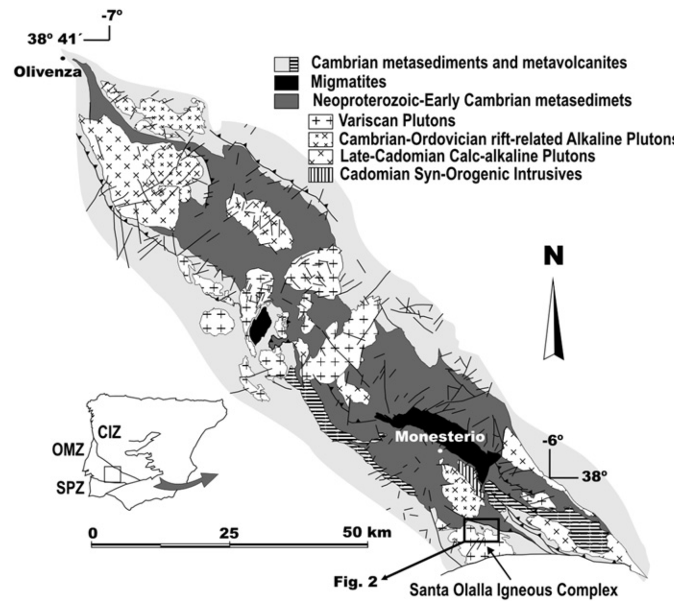

Fig. 1. Geological map of the plutonic rocks in the Olivenza-Monesterio antiform showing the location of the Santa Olalla Igneous Complex and Fig. 2 that corresponds to the Cherneca shear zone. Inset: Southern divisions of the Iberian Massif (CIZ, Central Iberian Zone; OMZ, Ossa-Morena Zone; SPZ, South Portuguese Zone).

within the Ossa-Morena Zone (OMZ). The OMZ forms one of the SW divisions of the Iberian Massif, the westernmost outcrop of the Variscan orogen in Europe (Ribeiro et al., 1990). The OMZ has been interpreted as a poly-orogenic terrane accreted to the Central Iberian Zone during the Cadomian orogeny (620–530 Ma), the suture of which is exposed along the Badajoz-Córdoba shear zone (Quesada, 1990, 1991, 1997; Eguíluz et al., 2000). A rifting event culminating in formation of a new oceanic tract (Rheic Ocean) is recorded in the OMZ during Cambro-Ordovician times (Liñán and Quesada, 1990; Sánchez-García et al., 2003; Expósito et al., 2003). A passive margin stage followed until the onset of the Variscan orogeny in mid Devonian times. In this part of the orogen, Variscan tectonics started with oblique subduction of the Rheic Ocean beneath the southern margin of the OMZ, where accretion/eventual obduction of oceanic fragments formed the Pulo do Lobo accretionary prism and Beja-Acebuches Ophiolite (Munhá et al., 1986; Silva, 1989; Quesada, 1991; Quesada et al., 1994a). At the same time, an arc was growing on the hanging-wall, i.e. on the Ossa-Morena plate (Santos et al., 1987). Subduction of the oceanic crust led to oblique (sinistral) collision against the South Portuguese Zone, which diachronously propagated southeastwards from Late Devonian to Late Viséan (Ribeiro et al., 1990 Quesada, 1991). Subsequent orogenesis consisted of sinistral continental subduction of the outer margin of the South Portuguese Zone under the OMZ until its waning in Early Permian times.

During the whole orogenic process from the Middle Devonian to the Early Permian, the OMZ acted as the upper plate being subjected to a transpressional sinistral tectonic regime. The pre-existing Cadomian suture was reactivated under a sinistral strike-slip regime (Badajoz-Córdoba shear zone). This