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Evidence for non-coaxiality of ferrimagnetic and paramagnetic fabrics, developed during magma flow and cooling in a thick mafic dyke

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ABSTRACT

A detailed analysis of fabrics of the chilled margin of a thick dolerite dyke (Foum Zguid dyke, Southern Morocco) was performed in order to better understand the development of sub-fabrics during dyke emplacement and cooling. AMS data were complemented with measurements of paramagnetic and ferrimagnetic fabrics (measured with high field torque magnetometer), neutron texture and microstructural analyses. The ferrimagnetic and AMS fabrics are similar, indicating that the ferrimagnetic minerals dominate the AMS signal. The paramagnetic fabric is different from the previous ones. Based on the crystallization timing of the different mineralogical phases, the paramagnetic fabric appears related to the upward flow, while the ferrimagnetic fabric rather reflects the late-stage of dyke emplacement and cooling stresses.

1. Introduction

The high sensitivity and rapid measurements made anisotropy of magnetic susceptibility (AMS) one of the most applied and powerful tools to assess the petrofabric, even for low anisotropy rocks (see, Borradaile and Henry, 1997; Borradaile and Jackson, 2010; Hrouda, 1982; Tarling and Hrouda, 1993). Despite these advantages, it was soon recognized that AMS interpretation is not always straightforward. The superposition of magnetic fabrics, related to magnetic carriers with normal and inverse fabric, or with distinct preferred orientations and/or shapes, is one factor that can result in a whole-rock AMS fabric that does not reflect the true preferred orientation of minerals (Borradaile and Henry, 1997; Chadima et al., 2009; Fanjat et al., 2012; Ferré, 2002; Hirt and Almqvist, 2012; Lamali et al., 2013; Potter and Stephenson, 1988; Rochette, 1988; Rochette et al., 1999; Silva et al., 2008; Tarling and Hrouda, 1993).

To decompose composite magnetic fabrics complementary experimental methods (e.g., anisotropy of magnetic remanence and high-field torque magnetometry) and analytical and computational solutions have been developed to separate sub-fabrics (e.g., Banerjee and Stacey, 1967; Callot and Guichet, 2003; Ferré et al., 2004; Jelinek, 1996; Kratinová et al., 2006, 2010; Henry, 1983, 1997; Henry and Daly, 1983; Hrouda and Jelinek, 1990; Martín-Hernandez and Garcia-Hernandez, 2010; Martín-Hernandez and Hirt, 2001, 2004; McCabe et al., 1985; Moreira et al., 1999; Roperch and Taylor, 1986; Schmidt et al., 2007; Stephenson, 1980; Stephenson et al., 1986).

More recently, rock magnetic fabrics studies start to be complemented by quantitative microstructural and crystallographic preferred orientation analyses in order to better understand the rheological behaviour of rocks (e.g., Bascou et al., 2005; Boiron et al., 2013; Cifelli et al., 2009; Machek et al., 2014–this volume; Závada et al., 2007).

The aim of this paper is a better understanding of intrusive processes. This requires recognition of how a dyke's petrofabric records different strain regimes, due to the evolution of stress fields and thermal gradients during magma emplacement and cooling. Different rock minerals crystallize at different times and likely under variable stress fields. Recognizing petrofabrics of individual minerals that are related to different episodes of mineral crystallization during magma emplacement is therefore a key approach. To this aim, we employ a combination of microstructural and textural approaches (neutron diffraction—ND, and image analyses to obtain crystallographic preferred orientation—CPO) with analyses of magnetic fabrics in low and high fields (AMS for

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whole-rock, anisotropy of ferrimagnetic susceptibility—AFMS and anisotropy of paramagnetic susceptibility APMS).

The thick Foum Zguid doleritic dyke—FZD (e.g., Leblanc, 1974) in southern Morocco was selected for this case study (Fig. 1). The dyke emplacement at great depth was associated with a forceful magma injection that affected their sedimentary host-rocks both mechanically and thermodynamically: folding and flattening of the host sedimentary layers, mineralogical and textural transformations due to Fe-metasomatism and thermally induced recrystallizations (Silva et al., 2010). Previous FZD studies (Silva et al., 2004, 2006a,b, 2010) were based on detailed low-field AMS, partial anisotropy of anhysteretic remanence (pAARM), paleomagnetism and rock magnetism. The comparison between AMS and pAARM fabrics has often revealed the composite character of the AMS fabric, related to superimposition of normal and inverse fabrics. The presence of an inverse fabric is common in the inner domains of the dyke due to single-domain particles that result from lamella exsolution processes of pristine Ti–iron oxides. Near the margins, where Ti-iron oxides are euhedral grains without exsolution textures, AMS and pAARM fabrics are coaxial with a normal fabric. The magnetic foliation mostly strikes parallel to the vertical dyke plane, but with dip variations along cross-sections within the dyke: dip towards the inner part in the chilled margin and towards the outside in inner domains. Magma flow interpreted from the imbrication between magnetic foliation and dyke plane (Geoffroy et al., 2002) should be downward at the chilled margins and upward in the inner domain. However, downward flow would contradict the observed upward deflection of bedding in the host sedimentary rocks (cf. Silva et al., 2010). A similar contradictory AMS pattern between the margin and the central part has been also observed in the great dolerite Messejana–Plasencia dyke (Silva et al., 2008).

2. Sampling and methods

A total of 38 igneous samples were selected from the sampling station FZ7 (e.g., Silva et al., 2010). These samples were quasi-continuously collected along two dyke cross-sections from the NW margin of the dyke: i) cross-section A1, between the NW margin and 20 m from it, and ii) cross-section A2 is spaced 10 m from A1, and limited to the first meter of the contact with host sedimentary rocks. The aim of this sampling strategy is to better evaluate the evolution of the fabrics along those profiles located near the margins.

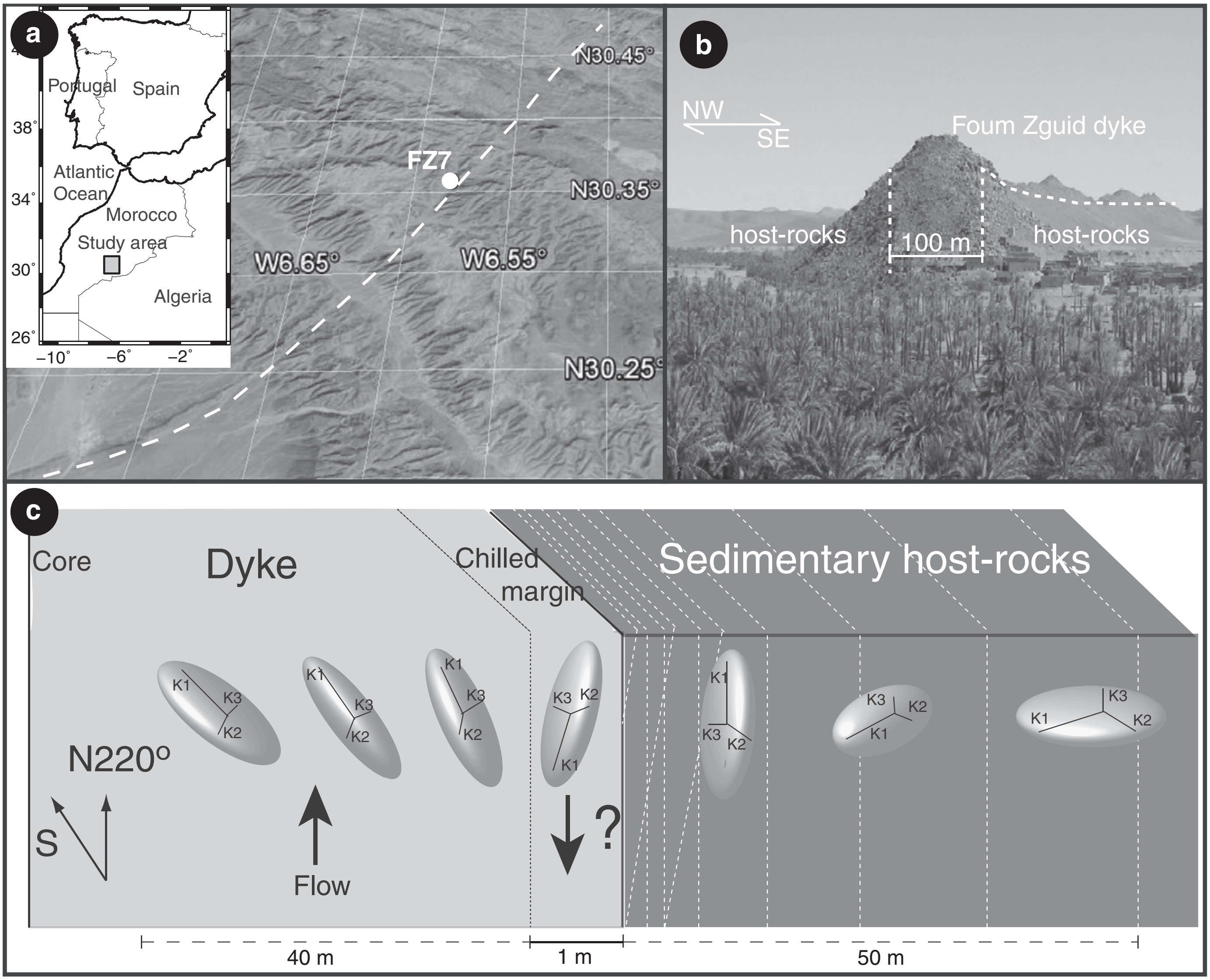

Fig. 1. (a) Satellite images (available from Google) with geographical location of the study station (white circle). White dashed line represents the main igneous body; (b) photo of the Foum Zguid dyke (topographic high) with indication of its thickness and contacts with sedimentary host rocks (white dashed line); (c) nonscaled sketch of the AMS ellipsoids patterns observed for dyke and sedimentary host rocks along the distance to the contact (adapted from Silva et al., 2010); white dashed lines at the sedimentary host rocks exemplify the planar discontinuities observed during field work.