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Texture and elastic anisotropy of a mylonitic anorthosite from the Morin Shear Zone (Quebec, Canada)

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ABSTRACT

A sample of anorthosite from the granulite facies Morin Shear Zone (Quebec, Canada) was investigated for crystal preferred orientation and elastic anisotropy. Time-of-flight neutron diffraction data obtained with the HIPPO diffractometer at LANSCE were analyzed with the Rietveld method to obtain orientation distribution functions of the principal phases (plagioclase, clinopyroxene and orthopyroxene). Texture and microstructures are compatible with the plastic deformation of the aggregate under high-T conditions. All mineral phases depict a significant preferred orientation that could be related to the general top-to-the north shearing history of the Morin Shear Zone. Texture patterns suggest that (010)[001] in plagioclase and (110)[001] in clinopyroxene are likely dominant slip systems. Using preferred orientation data P- and S-waves velocities and elastic anisotropy were calculated and compared with previous studies to explore elastic properties of rocks with different pyroxene-plagioclase mixtures. P-wave velocity, S-wave splitting and anisotropy increase with clinopyroxene content. Seismic anisotropy is linked to the texture symmetry which can lead to large deviations between actual anisotropy and that measured along Cartesian *XYZ* sample directions (lineation/foliation reference frame). This is significant for the prediction and interpretation of seismic data, particularly for monoclinic or triclinic texture symmetries.

1. Introduction

It has been proposed that the deformation of continental lithosphere is mainly driven by the mechanical response of the lower crust (e.g. Royden et al., 1997; Ranalli, 1995, 2003; Rutter and Brodie, 1992). Geophysical observations (e.g. Chen and Molnar, 1983; Wong and Chapman, 1990), thermomechanical models (e.g. Beaumont et al., 2001) and extrapolation of experimental flow laws (e.g. Brace and Kohlstedt, 1980; Kohlstedt et al., 1995; Dimanov et al., 2007) point to a model of long-term strength for the lithosphere with a relatively weak lower crust, placed between a stronger upper crust and mantle (Burov and Watts, 2006). Thermal and compositional heterogeneity of the lithosphere result in a variety of rheological behaviors across tectonic plates and alternative models could play a significant role in some geodynamic contexts (e.g. Maggi et al., 2000; Jackson, 2002). Those features evolve with time and one should consider rheological boundaries as dynamic entities in the Earth system (e.g. Bürgmann and Dresen, 2008).

High-strain zones are recognized as essential pieces of that architecture, but the proportion of localized to distributed strain-flow with depth is not well understood (Ellis and Stöckhert, 2004; Bürgmann and Dresen, 2008). The existence of a laminated lower crust, as revealed by seismic surveys, could be interpreted as the result of localized strain, supporting the role of shear zones (e.g. Franke, 1995; Rey, 1995; Cook et al., 1997; Ji et al., 1997). It is clear that interpretations of seismic data, both in structural and lithological terms, has to rely on a quantitative knowledge of the mechanical properties of shear zones.

Most rock-forming minerals are elastically anisotropic. When deformed in a high-strain zone, crystal preferred orientation or texture often develops. Therefore the aggregate of minerals in deformed rocks will show macroscopic anisotropy (e.g. Kocks et al., 2000), and potentially become a highly reflective volume in the lithosphere (e.g. Ji et al., 1997).

The dominant mineral phases in the lower crust are plagioclase and pyroxene (e.g. Tullis, 1990; Ji et al., 2004a,b; Dimanov et al., 2007). Both exhibit strong anisotropy of their physical properties

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as single crystals (e.g. Brown et al., 2006; Jackson et al., 2007; Sang et al., 2011; Kaercher et al., 2014), and a contrasting mechanical behavior, with plagioclase as the weak phase (e.g. Mackwell et al., 1998; Dimanov and Dresen, 2005).

Exploring the crystallographic preferred orientation of deformed pyroxene-plagioclase aggregates could lead to a better understanding of the mechanical and seismic properties of lower crust shear zones. Previous work has focused on texture development of plagioclase aggregates, both naturally and experimentally deformed (e.g. Ji and Mainpraice, 1988; Ji et al., 1997; Rybacki and Dresen, 2000; Xie et al., 2003; Feinberg et al., 2006; Gómez Barreiro et al., 2007; Homburg et al., 2010). By comparison, relatively little is known about texture in metabasites (e.g. Mehl and Hirth, 2008; Kanagawa et al., 2008; Gómez Barreiro et al., 2010; Gómez Barreiro and Martínez Catalán, 2012). Moreover, our knowledge of deformation mechanisms of plagioclase and pyroxene are incomplete (e.g. Dornbusch et al., 1994; Bascou et al., 2002; Gómez Barreiro et al., 2007).

In previous studies mylonites from an anorthositic shear zone in Canada (Morin Shear Zone) have been analyzed. Only the texture of plagioclase was investigated in some detail (e.g. Ji et al., 1994, 1997; Zhao, 1997; Xie et al., 2003). Since then texture analysis evolved from the limited and time consuming U-stage procedures and pole figure goniometry to electron backscatter diffraction (EBSD), synchrotron X-ray diffraction and neutron diffraction. Here we are revisiting this natural laboratory to apply time-of-flight (TOF) neutron diffraction and advanced data analysis to quantify the texture of not only plagioclase but also pyroxene (e.g. Gómez Barreiro and Martínez Catalán, 2012). Based on preferred orientation patterns we then model elastic properties of anorthosite mylonite and finally extend the results to explore elastic anisotropy of rocks with different plagioclase-pyroxene contents to discuss the compositional effect on the physical properties of mafic mylonites (Lloyd et al., 2011).

2. Geological context

The Morin Terrane is part of the Allochthonous Monocyclic Belt, in the SE of the Grenville Province, Canada (Rivers et al., 1989). The Morin Terrane is composed of a Mid-Proterozoic anorthosite suite, surrounded by charnokites, granulites and metasediments (Doig, 1991). For a discussion of the tectonic setting and tectonothermal evolution of the Morin Terrane see Martignole and Friedman (1998), Wodicka et al. (2000) and McLelland et al. (2010).

The Morin anorthosite suite is bounded on the east, by the 5 km-wide Morin Shear Zone (Zhao et al., 1997), which contains a variety of igneous and metasedimentary lithologies. The mylonitic fabrics are defined by quartz ribbons, and flattened aggregates of plagioclase and pyroxene, with a penetrative subhorizontal N0-160E lineation and a west-dipping foliation (Zhao et al., 1997; Ji et al., 1997). Deformation conditions reached granulite facies (630–750 °C/550–750 MPa; Indares and Martignole, 1990). Kinematic criteria at different scales indicate a top-to-the north sense of shear (e.g. Zhao et al., 1997).

3. Sample description

A sample was collected 10 km NW the town of Rawdon (Quebec, Canada) in a mylonitic–ultramylonitic band of meta-igneous rocks. The composition is between a leuconorite and anorthosite, with about 90% plagioclase, 7% clinopyroxene and 3% orthopyroxene. The lineation is defined by elongated pyroxene aggregates and some

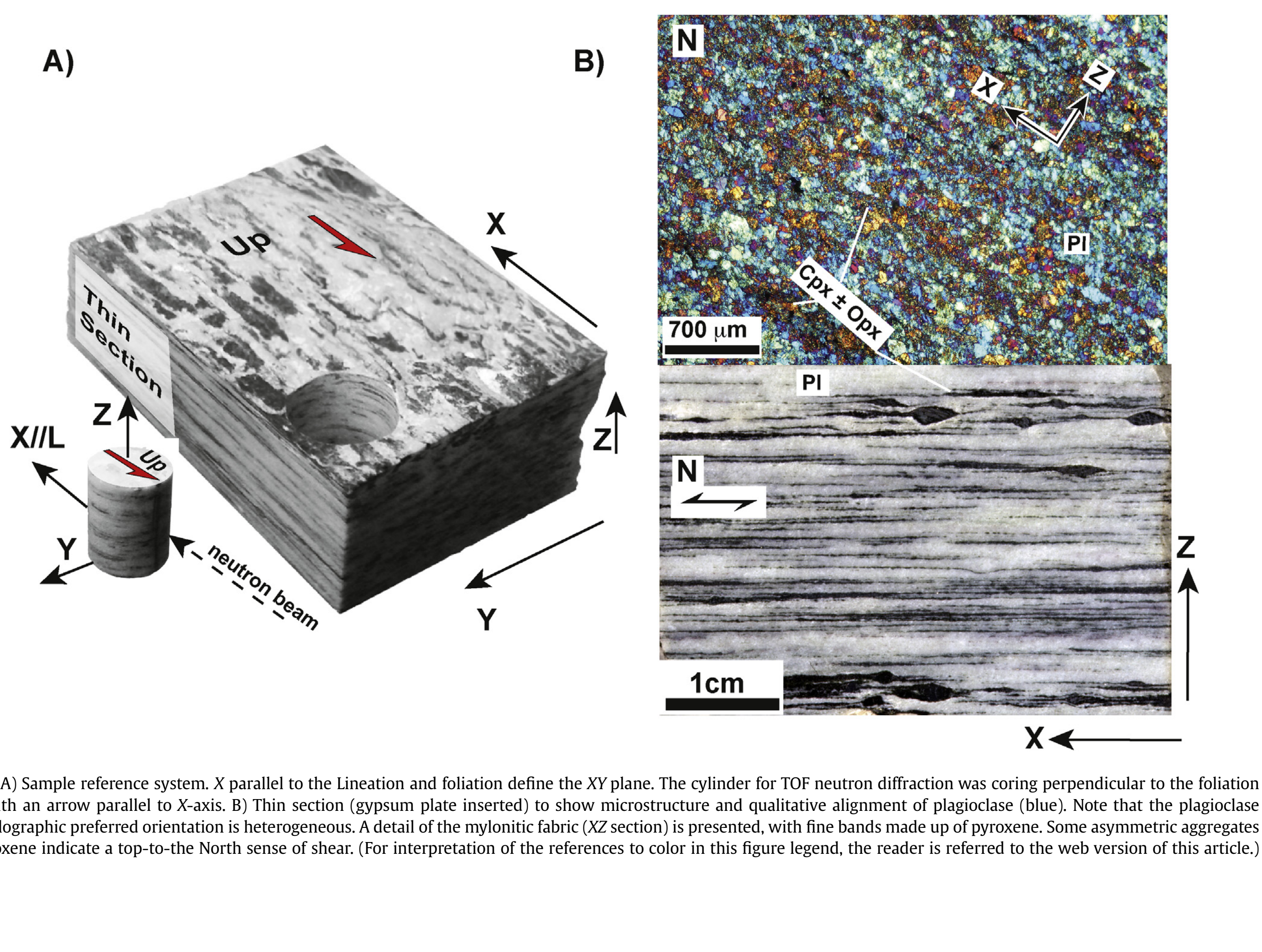

Fig. 1. A) Sample reference system. *X* parallel to the Lineation and foliation define the *XY* plane. The cylinder for TOF neutron diffraction was coring perpendicular to the foliation and with an arrow parallel to *X*-axis. B) Thin section (gypsum plate inserted) to show microstructure and qualitative alignment of plagioclase (blue). Note that the plagioclase crystallographic preferred orientation is heterogeneous. A detail of the mylonitic fabric (*XZ* section) is presented, with fine bands made up of pyroxene. Some asymmetric aggregates of pyroxene indicate a top-to-the North sense of shear. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)