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Microstructures, deformation mechanisms and seismic properties of a Palaeoproterozoic shear zone: The Mertz shear zone, East-Antarctica

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ABSTRACT

The Mertz shear zone (MSZ) is a lithospheric scale structure that recorded mid-crustal deformation during the 1.7 Ga orogeny. We performed a microstructural and crystallographic preferred orientation (CPO) study of samples from both mylonites and tectonic boudins that constitute relics of the Terre Adélie Craton (TAC). The deformation is highly accommodated in the MSZ by anastomosed shear bands, which become more scattered elsewhere in the TAC. Most of the MSZ amphibolite-facies mylonites display similar CPO, thermal conditions, intensity of deformation and dominant shear strain. Preserved granulite-facies boudins show both coaxial and non-coaxial strains related to the previous 2.45 Ga event. This former deformation is more penetrative and less localized and shows a deformation gradient, later affected by a major phase of recrystallization during retrogression at 2.42 Ga. Both MSZ samples and granulite-facies tectonic boudins present microstructures that reflect a variety of deformation mechanisms associated with the rock creep that induce contrasted CPO of minerals (quartz, feldspar, biotite, amphibole and orthopyroxene). In particular, we highlight the development of an "uncommon" CPO in orthopyroxene from weakly deformed samples characterized by (010)-planes oriented parallel to the foliation plane, [001]-axes parallel to the stretching lineation and clustering of [100]-axes near the Y structural direction.

Lastly, we computed the seismic properties of the amphibolite and granulite facies rocks in the MSZ area in order to evaluate the contribution of the deformed intermediate and lower continental crust to the seismic anisotropy recorded above the MSZ. Our results reveal that (i) the low content of amphibole and biotite in the rock formations of the TAC, and (ii) the interactions between the CPO of the different mineralogical phases, generate a seismically isotropic crust. Thus, the seismic anisotropy recorded by the seismic stations of the TAC, including the MSZ, must be due to mantle rather than crustal structures.

1. Introduction

Lithospheric scale shear zones are described as localization areas where the deformation is localized between adjacent terrains and dominated principally by simple shear. In association with faults in the upper crust, they profoundly influence the formation and the evolution of mountain belts and sedimentary basins (Alsop and Holdsworth, 2004). They are thus key regions that provide us insights into deformation, rheology and dynamics of the lithosphere (Burov, 2011; Vauchez et al., 2012).

Depending on the interplay of different physical parameters such as far-field forces, lithology, pressure and temperature conditions, fluid transfer and strain rate, various deformation mechanisms can be activated. This has a strong influence on the resulting microstructures, such as grain shape and size, and crystallographic preferred orientation associated with dominant slip systems in minerals undergoing dislocation creep deformation (Nicolas and Poirier, 1976; Passchier and Trouw, 1996; Vauchez et al., 2012).

The Mertz shear zone (MSZ) in Antarctica is a lithospheric shear zone that separates the 2.4 Ga old granulite and amphibolite facies terrains to the west from a 0.5 Ga old intrusive complex related to the Ross Orogeny to the east. Available geochronological data (40Ar/39Ar on amphibole and biotite) show that the MSZ was active at 1.7 and 1.5 Ga in amphibolite and greenschist facies conditions, respectively (Di Vincenzo et al., 2007; Duclaux et al., 2008). Older granulite-facies activity at 2.4 Ga was suggested by Kleinschmidt and Talarico (2000) for the MSZ. However, Duclaux et al. (2008) interpreted this Neoarchean age (2.4 Ga) as being related to a regional orogenic tectonothermal event. This Neoarchean Siderian orogenic event is recorded over the entire eastern region of the Terre Adélie Craton (Ménot et al., 2005, 2007; Duclaux et al., 2008). The deformation of the Terre Adélie Craton (TAC) occurred during Neoarchean to Palaeoproterozoic times. This was a critical period in the Earth's evolution (Hamilton, 1998) which included

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the transition from Archean geodynamics, with heat loss mostly associated with massive magmatic transfer from a mantle which was much hotter than at present, to modern style geodynamics related to plate tectonics (Lee et al., 2008; Dhuime et al., 2012). The MSZ constitutes one of the oldest known shear zones preserved from the early period of modern plate tectonics through its 1.7 Ga activation. It could have been contiguous with the Kalinjala or Coorong shear zones (South Australia) before the Southern Ocean opening during the Cretaceous period (Talarico and Kleinschmidt, 2003; Gibson et al., 2013). Despite its very old age (1.7 to 1.5 Ga), MSZ activity was not associated with voluminous magma injection and differs strikingly from younger Neoproterozoic and Cambrian shear zones for example in Madagascar (Grujic and Mancktelow, 1998; Martelat et al., 1999). Other examples of shear zones from Palaeo- to Mesoproterozoic times in Colorado (Anderson and Cullers, 1999; Shaw et al., 2001), from Neoproterozoic times in South-Africa (Kisters et al., 1998), from Pan-African times in North Africa (Boullier and Bertrand, 1981), in West-Africa (Adissin Glodji et al., 2014) and in North-East Brazil (Tommasi et al., 1994; Neves and Vauchez, 1995; Neves et al., 1996, 2000), and more recently during the Cretaceous in New Zealand (Barker et al., 2010), are commonly associated with high magma production and emplacement (see Brown and Solar, 1998 for a synthesis of deformation and linked melt production).

Knowledge of the deep structures' continuity (potentially down to the mantle) allows a better understanding of the deformation distribution across the lithosphere and therefore its rheology. However, the lack of mantle-derived melt injection during the activation of the MSZ does not provide an argument for a possible continuity of the deformation down to the mantle. Structural studies show that amphibolite and retrogressed granulite are both affected by the 1.7 Ga deformation (Pelletier et al., 2002; Ménot et al., 2005; Gapais et al., 2008), but no lower crust or mantle xenoliths were found. These observations only argue that the MSZ penetrates at least down to the intermediate crust. Because of the lack of geological evidence, other tools have to be used to image the deep structure of the shear zone.

A geophysical approach can provide alternative information. SKS-wave anisotropy is an efficient tool for mapping mantle structure deformation (Silver, 1996), as SKS samples an entire vertical section through both asthenosphere and lithosphere. For the Terre Adélie and George V Land region, no clear continuation of the MSZ into the lithospheric mantle was observed from the SKS-wave anisotropy study of Lamarque et al. (2015) despite a strong variation in crustal thicknesses on both sides of the MSZ highlighted by the airborne gravity study of Jordan et al. (2013) and receiver function analysis of Lamarque et al. (2015). In order to fully interpret the seismic recordings for the MSZ, it is therefore necessary to determine the crustal contribution of the SKS-wave anisotropy measurements.

The present study focuses, firstly on the description of deformation processes based on analysis of micrometric to millimetric scale structures. It was performed by both optical analysis and electron backscatter diffraction (EBSD) crystallographic preferred orientation (CPO) measurements in samples from the strongly deformed domains of the MSZ (mylonites) and from the less affected areas outside the shear zone where numerous tectonic boudins are preserved. Subsequently, CPO measurements and modal compositions allow us to calculate the contribution of the crust, in particular the one due to the MSZ ductile deformation. Results are compared to the SKS-wave anisotropy measurements of the TAC performed by Lamarque et al. (2015).

2. Geological settings

The Mertz shear zone (MSZ) is a major structure clearly visible at the Correll Nunatak (67°35′S, 144°16′E; Stillwell, 1918; Di Vincenzo et al., 2007; Ménot et al., 2007), Fig. 1. The MSZ activation occurred during the 1.7 Ga tectono-metamorphic event (Di Vincenzo et al., 2007; Duclaux et al., 2008), synchronously with the structuration of the Dumont d'Urville and Cape Hunter sedimentary basins, the activation of the Zélée shear zone (141°E) and the development of a network of anastomosed narrow shear zones that have affected the Neoarchean basement, which is still visible at Stillwell Island for example.

The MSZ marks the boundary between the Neoarchean to Palaeoproterozoic TAC and a metasedimentary complex intruded by a 0.5 Ga-old granitic suite related to the Ross Orogeny (Fanning et al., 2002; Di Vincenzo et al., 2007).

At Correll Nunatak, the mylonitic foliation is decimetre-thick subvertical and oriented N340° to N–S. The mineral lineation is found to be gently dipping and most of shear markers clearly indicate a dextral shear sense (Kleinschmidt and Talarico, 2000; Talarico and Kleinschmidt, 2003; this study). From mineral assemblage observations, the MSZ might represent a mid-crustal strike-slip fault that could have accommodated large horizontal displacements during successive shearing events at 1.7 and 1.5 Ga in amphibolite and greenschist facies conditions, respectively (Di Vincenzo et al., 2007; Duclaux et al., 2008). However, the last activation of the MSZ at 1.5 Ga was discussed by Ménot et al. (2005), who suggested that a younger age (maybe post-Ordovician) cannot be formally ruled out because Palaeozoic rocks are found to be juxtaposed east of the MSZ.

Within the MSZ, some tectonic boudins preserve such Neoarchean penetrative structures of the TAC. They are predominantly composed of felsic to mafic orthogneiss and granite intruding metasedimentary country rocks. This 2.55–2.44 Ga old continental crustal segment (Oliver and Fanning, 2002; Duclaux et al., 2008) exposes two distinct tectonic units (Port Martin and East Commonwealth Bay) that were metamorphosed under amphibolite and granulite facies conditions respectively, and represent intermediate to deep crustal sections (Ménot et al., 2005), Fig. 1.

More detailed geological settings are presented in the Supplementary materials (Appendix 1) with a structural description of the studied outcrops.

3. Microstructures

3.1. Methods

We studied 20 samples located at Correll Nunatak in the amphibolite facies unit and at Aurora Peak, Murchison Mount, Cape Gray and Stillwell Island in the granulite domain (Fig. 1). We grouped the samples according to their deformation microstructures (strongly, moderately and weakly deformed samples) then, we selected one or two representative samples from each group.

Crystallographic orientations were measured by electron backscatter diffraction (EBSD) technique using a scanning electron microscope JEOL JSM 5600 at the University of Montpellier and a JEOL JSM 6500F at the Ecole des Mines at Saint-Etienne. Polished thin sections were made parallel to the lineation and perpendicular to the foliation (XY plane). Electron backscatter diffraction patterns (EBSPs) were acquired at an accelerating voltage of 17 kV and a working distance of about 25 mm. They were manually or automatically (step size of 10 μm) acquired and indexed using the Channel 5 software from HKL Technology, Denmark. For analysis, 5–7 Kikuchi bands were matched with expected EBSPs. The accuracy of the crystallographic orientation of each measurement is typically lesser than 1°.

Crystallographic orientations are displayed using pole figures, with equal area lower hemisphere projections, where the sample lineation is represented by X, the foliation plane is represented by (XY) and the direction normal to the foliation plane by Z. The fabric strength is quantified by using the dimensionless J-index (Bunge, 1982), which is equal to 1 for a random distribution and tends toward infinity for a single crystal orientation.

In some samples, foliation plane and lineation direction were not easy to identify. In order to replace EBSD measurements in the structural frame (X, Y, Z), we used magnetic foliation and lineation identification