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Fabric superposition in upper mantle peridotite, Red Hills, New Zealand

Caroline E. Webber[a,*], Timothy Little[b], Julie Newman[c], Basil Tikoff[a]

[a] Department of Geology and Geophysics, University of Wisconsin-Madison, 1215 West Dayton Street, Madison, WI 53706, USA
[b] School of Earth Sciences, Victoria University of Wellington, Wellington, New Zealand
[c] Department of Geology and Geophysics, Texas A&M University, College Station, TX 77843, USA

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ABSTRACT

At least four generations of superposed fabrics that formed at upper mantle conditions are recorded by field relations, mineral compositions, and olivine lattice preferred orientation in the Red Hills, an ultramafic massif in South Island, New Zealand. The oldest fabric is found in the Central Domain and contains north-dipping compositional bands of harzburgite, dunite, and minor lherzolite. Expressions of second-generation fabrics that cross-cut Central Domain fabric are cm-scale, south-dipping shear zones; and a >50 m-thick zone of south-dipping shear, the South-dipping Domain. A third, younger, superposed fabric occurs in a ≥1 km-thick package on the west side of the field area, called the West Domain. The West Domain is composed of harzburgite and lherzolite, and is characterized by steeply west-dipping foliation and by isoclinal folds of older compositional banding. The youngest fabric, the East Domain, is preserved in a ∼50 m-thick zone on the east side of the field area. The East Domain is composed of lherzolite and contains cm-scale compositional bands that define a microstructually distinct, shallowly east-dipping foliation. The West and East Domains are interpreted to have formed by transposition of Central Domain fabric. Fabric transposition is generally expressed by an abrupt overprinting or truncation, rather than by a progressive deflection of foliations. This study demonstrates that multiple overprinting fabrics exist in the upper mantle, similar to the fabric superposition commonly observed in mid- to lower-crustal rocks.

1. Introduction

The upper mantle is volumetrically a major component of the lithosphere, therefore understanding deformation in the upper mantle is critical to understanding large-scale, plate tectonic processes. The dominant source of information on mantle deformation comes from experimental deformation of olivine in laboratory settings (e.g., Kohlstedt and Goetze, 1974; Hanson and Spetzler, 1994; Wendt et al., 1998; Holtzman et al., 2003). Extrapolation from experimental to tectonic scales requires an assumption of deformational homogeneity; however, this may not be valid in naturally deformed rocks, depending on the scale of interest (Paterson, 2001). Shear wave splitting data in active tectonic settings is another source of insight on deformation in the lithospheric mantle (e.g., Savage, 2002 and references therein), but the technique requires averaging of physical properties over large regions. The direct measurement of mantle fabrics in exposed ultramafic bodies is one method to assess fabric homogeneity and to correlate between these different spatial scales of observation.

A variety of field studies in outcrops of the lithospheric mantle have investigated fabrics at the intermediate (100 m to km) scale. Well-known areas include Oman (e.g., Michibayashi and Mainprice, 2004), the Pyrenees (e.g., Vissers et al., 1997), Newfoundland (e.g., Suhr, 1992), and the western Mediterranean (e.g., Van der Wal and Vissers, 1993; Dijkstra et al., 2004). Commonly, mantle deformation fabrics are interpreted as forming at a spreading center. For example, Suhr (1992) reported multiple overprinting fabrics in the Bay of Islands Ophiolite, and interpreted the fabrics as forming at a spreading center. Other examples of mantle shear zones are interpreted in the context of uplift and emplacement of an ultramafic massif. Well-known examples of this type of deformation come from Alpine peridotites, specifically, the Pyrenees (e.g., Vissers et al., 1997) and Greece (e.g., Dijkstra et al., 2004).

Our study of the Red Hills massif, South Island, New Zealand focuses on a polyphase history of deformation that took place in upper mantle rocks at inferred upper mantle pressure and temperature conditions. Detailed geologic mapping in Red Hills reveals that fabric transposition occurred on at least two scales, and we identify at least three superposed zones of localized deformation. A Central Domain of lithologically heterogeneous and

* Corresponding author. Present address: ExxonMobil Production Company, 396 West Greens Road, CORP-WGR-408, Houston, TX 77067, USA. Tel.: +1 608 469 4413; fax: +1 713 431 1570.
E-mail address: carolinewebber581@hotmail.com (C.E. Webber).

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compositionally banded ultramafic rock is overprinted by distinctive fabrics in its center and on its western and southeastern flanks. This type of fabric superposition is commonly observed in mid- to lower-crustal rocks, but is rarely reported for the lithospheric mantle. This study focuses on the field documentation of these patterns and considers the implications of compositional and structural heterogeneity for upper mantle deformation.

2. Tectonic setting and geologic history

2.1. Geologic setting of the Dun Mountain Ophiolite Belt

The Red Hills ultramafic massif (~100 km^2) is located in the northern portion of South Island, New Zealand (Fig. 1A). The Red Hills massif is part of the Dun Mountain Ophiolite Belt (DMOB), a package of ultramafic rocks and associated sediments that is discontinuously exposed for >1100 km. The DMOB is divided into two segments dextrally offset by ~460 km on the Alpine Fault. The DMOB is up to ~8 km wide (Davis et al., 1980) and gravity surveys indicate that the ultramafic part of this body is <4 km thick (Malahoff, 1965).

The DMOB is part of the Dun Mountain-Maitai Terrane, which also includes mafic rocks of the Lee River Group, sedimentary rocks of the Maitai Group, and the Patuki and Croisilles Mélanges (Fig. 1B) (Davis et al., 1980; Johnston, 1986; Kimborough et al., 1992). Ultramafic rocks of the DMOB are separated by faults from the remainder of the mafic and sedimentary rocks in the Dun Mountain-Maitai Terrane. The Brook Street Terrane, which is composed of volcanics and volcaniclastics, is locally in fault contact with the western margin of the Dun Mountain-Maitai Terrane (Johnston, 1986). The eastern margin of the Dun Mountain-Maitai Terrane is in fault contact with accreted sedimentary rocks of the Pelorus Group and the Marlborough Schist (Johnston, 1986).

The DMOB is interpreted to have formed 280 ± 5 Ma, based on U/Pb ages obtained from plagiogranite dikes located in the DMOB (Kimborough et al., 1992). The age of emplacement of the Dun Mountain-Maitai Terrane is unknown, but previous workers suggest a late Permian emplacement, prior to folding and metamorphism associated with the Jurassic – Early Cretaceous Rangitata Orogeny (Johnston, 1982; Davis et al., 1980). Offset of the ultramafic body along the Alpine Fault has occurred since ~25 Ma (Sutherland, 1995; Cooper et al., 1987).

2.2. Origin of the Dun Mountain Ophiolite Belt

The tectonic setting for the formation of the DMOB is unknown. Prior to recognition of ophiolites as obducted oceanic crust, Challis (1965) and Walcott (1965) suggested an intrusive origin. Based on major and minor element chemistry of the ultramafic rocks, Davis et al. (1980) proposed that the DMOB was formed at a mid-ocean ridge. Coombs et al. (1976) suggested that the Dun Mountain ultramafics formed at a spreading center adjacent to an island arc (i.e. the Brook Street Terrane). Based on major and trace element chemistry of basaltic dikes in the Red Hills massif and associated Lee River Group, Sano et al. (1997) suggested that the Red Hills was generated at a spreading center in a back-arc basin. On the basis of similar types of data, Sivell and McCulloch (2000) also argued that the Dun Mountain Ophiolite formed in a supra-subduction zone environment (but probably in a forearc to proto-island arc setting).

2.3. Previous work in the Red Hills ultramafic massif

The Red Hills are mostly unserpentinized, and provide significant horizontal exposure (~100 km^2) and vertical relief (>700 m). Walcott (1965) conducted the first structural study of the Red Hills massif, and mapped (1:50,000) a region of ~260 km^2 including the Red Hills and adjacent areas. Walcott (1965, 1969) divided the

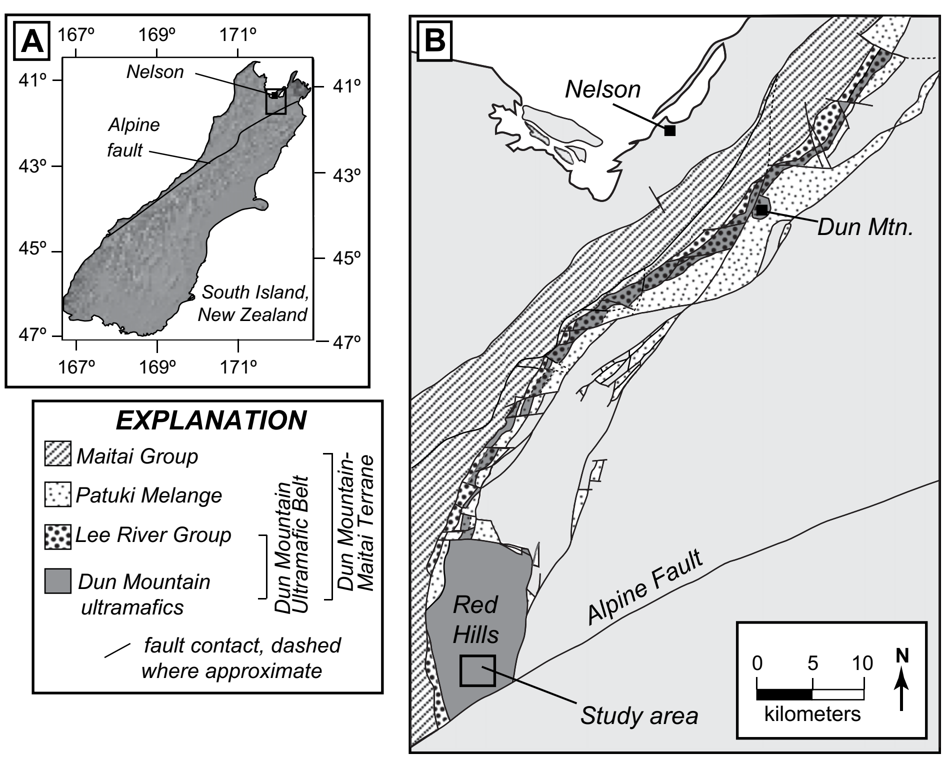

Fig. 1. Location of Red Hills study area. (A) Digital elevation model (digital data available free from www.geographix.co.nz) of South Island, New Zealand illustrating location of Alpine Fault. Box denotes area of image in part B. (B) Map of the northern segment of the Dun Mountain Ophiolite Belt. Note location of Red Hills ultramafic massif and the study area.