Tectonophysics 587 (2013) 79–88

Contents lists available at SciVerse ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Progressive deformation partitioning and recrystallization of olivine in the lithospheric mantle

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ARTICLE INFO

Article history:
Received 27 February 2012
Received in revised form 12 June 2012
Accepted 4 July 2012
Available online 25 July 2012

Keywords:
Deformation partitioning
Olivine
Serpentinization
Lithospheric mantle
Yakuno ophiolite

ABSTRACT

Intense serpentinization within the Machinoyama ultramafic body, eastern-most part of the Yakuno ophiolite in the Paleozoic Maizuru belt, SW Japan, resulted in the development of block-in-matrix structure in the brittle regime, possibly associated with exhumation along a fault. Various microstructures are heterogeneously distributed throughout peridotite blocks in a serpentinite matrix. The microstructures are classified into four domains according to olivine grain size: coarse (1.0–1.5 mm), medium (0.5–1.0 mm), small (0.2–0.5 mm), and fine-grained (0.01 mm). Even in a single peridotite block, the medium-, small- and fine-grained domains occur at various scales. In particular, the fine-grained domain occurs in thin zones that cut across the other domains. These observations suggest that deformation in the peridotites before the serpentinization was partitioned into anastomosing zones during progressive inhomogeneous non-coaxial shear, resulting in the simultaneous development of a range of microstructures from the coarse-grained domain to the small-grained domain. Olivine crystal-preferred orientations tend to be weaker with decreasing olivine grain size, indicating a change in deformation mechanism from dislocation creep to grain-size-sensitive creep. Moreover, the fine-grained domains contain much more second phase than the small-grained domain even in the same sample, suggesting the role of the second phases on strain localization during dynamic recrystallization of olivine.

1. Introduction

Mylonite is a typical tectonite of the ductile regime and is characterized by a foliation and usually a lineation, indicative of intense ductile deformation (e.g., Bell and Etheridge, 1973; Hobbs et al., 1976; Passchier and Trouw, 2005). Mylonites were first thought to form by brittle milling of the rock (Lapworth, 1885); however, Bell and Etheridge (1973) proposed the mode of origin that is accepted today; i.e., mylonite forms dominantly by ductile flow, with the effects of minor brittle deformation restricted to isolated lenses or grains (Passchier and Trouw, 2005). Mylonite commonly occurs in narrow, planar zones of intense deformation, and the grain size in mylonite is generally finer than that in surrounding rocks, into which the mylonite shows a gradational transition (Bell and Etheridge, 1973).

Strain localization is common in natural rocks such as mylonites, where localized geometries generally show complex structures with varying intensities of ductile deformation at scales ranging from micrometers to meters (e.g., Bell, 1978; Hudleston, 1999; Fletcher, 2005; Nicolas and Porier, 1976; Ramsay, 2003). Deformation partitioning occurs at various scales because of the presence of primary and secondary heterogeneities in the rock (Bell, 1981; Bell et al., 1986). Whereas the effects of deformation partitioning are obvious in the case of localized shearing at the margin of relatively competent rock bodies, the effects and role of deformation partitioning are much less certain in anastomosing shear zones, in which case the initial rock was relatively homogeneous (e.g., Ramsay, 2003; Nicolas and Porier, 1976; Braun et al., 1999; Hudleston, 1999; Fletcher, 2005; Bell and Bruce, 2007). In this paper, we describe deformation partitioning in residual peridotites of the Machinoyama ultramafic body, which are originally relatively homogeneous rocks. We present variable microstructures resulting from various degree of deformation during shearing in the peridotites and discuss how the variable microstructures occur.

2. Geological setting

The Yakuno ophiolite occurs in a narrow ophiolite belt (the Maizuru belt) that crosscuts the Inner Zone of Southwest Japan in an ENE–WSW orientation (Ishiwatari, 1985; Fig. 1a). A complete ophiolite succession, including basaltic volcanics, mafic–ultramafic cumulates, and residual peridotite, is exposed in outcrops between the Oshima Peninsula and Yakuno, although each part of the succession generally occurs in a separate tectonic slice (Ishiwatari, 1978, 1985).

This ophiolite was exposed at the surface by the end of the Permian, as indicated by the occurrence of gabbro and amphibolite boulders in nearby Upper Permian conglomerates and by the Lower Triassic age of an unconformity at the top of the ophiolite (Kano et al., 1961;

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http://dx.doi.org/10.1016/j.tecto.2012.07.008

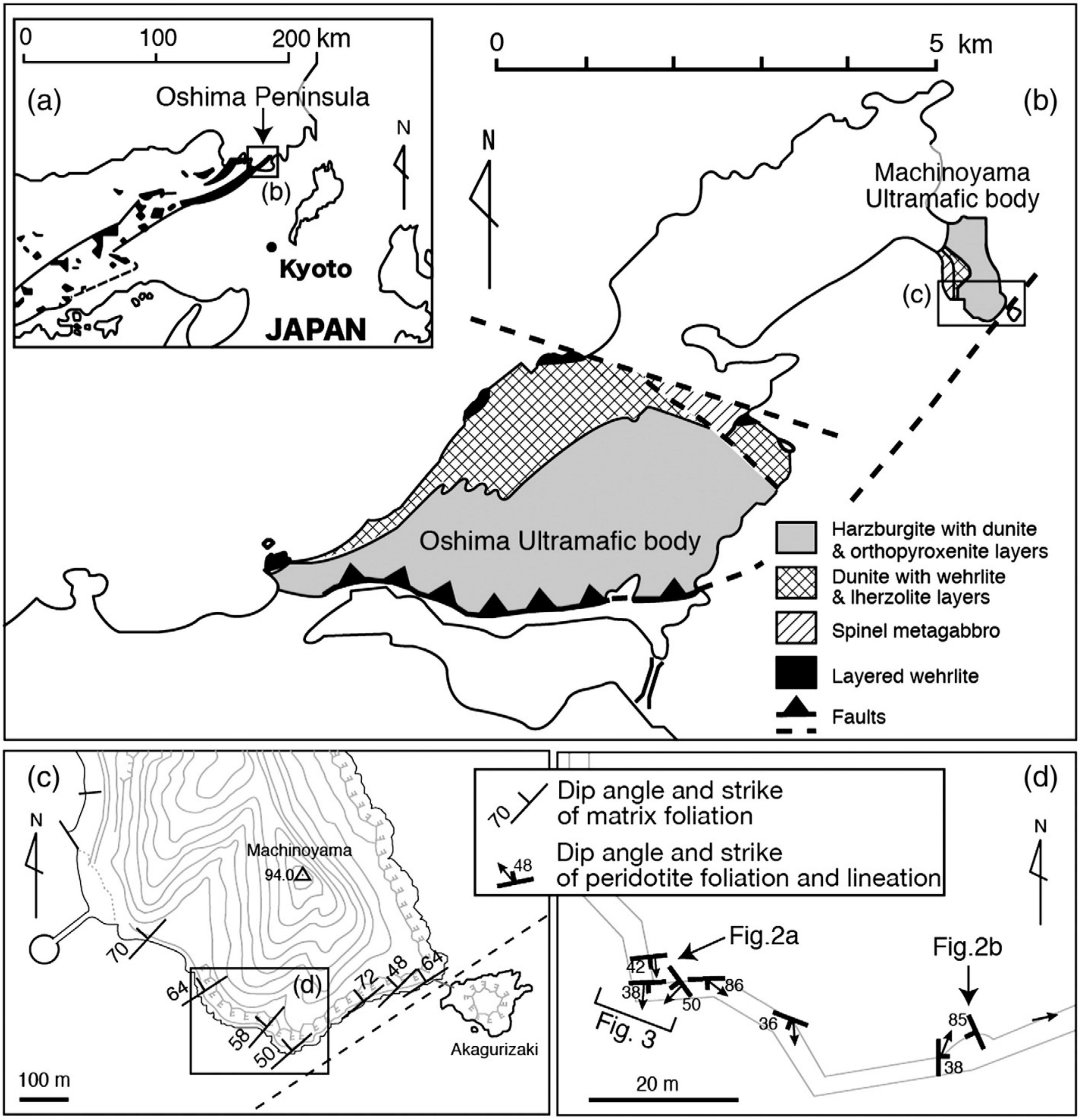

Fig. 1. (a) Index map of the Kinki district, Japan (black areas are the Yakuno ophiolite in the Maizuru belt). (b) Simplified geological map of the eastern-most part of the Yakuno ophiolite on Oshima Peninsula, showing the locations of the Oshima and Machinoyama ultramafic bodies. The study area is located at the southern margin of the Machinoyama ultramafic body, where it is bound by a fault. (c) Enlarged map of the southern part of the Machinoyama ultramafic body, showing the orientation of the foliation in the serpentinite matrix. (d) Map of the area indicated by the rectangle in (c), showing the orientation of foliation and lineation in peridotite blocks.

Ishiwatari, 1985). The present configuration of the ophiolite belt was probably established in the Jurassic, when the Yakuno ophiolite and its Permo–Triassic sedimentary cover were thrust southward onto Carboniferous–Jurassic continental-margin sediments of the Tanba belt (Hara, 1982; Ishiwatari, 1985).

The residual peridotite is exposed in two discrete ultramafic bodies (the Oshima and Machinoyama bodies) on Oshima Peninsula (Fig. 1a–b). The Machinoyama ultramafic body represents the eastern-most part of the Yakuno ophiolite on the peninsula, and it is the lower, ultramafic part of the ophiolite. The body is small, measuring 1.2 km N–S and 0.7 km E–W. The fault that separates the Maizuru belt from the Ultra-Tanba belt is located between the Machinoyama body and Akagurizaki Island (Fig. 1b–c; Ishiwatari and Hayasaka, 1992).

Outcrops on the southeastern margin of the Machinoyama body show block-in-matrix structure towards the fault boundary with the Ultra-Tanba belt (Figs. 2a–b and 3a). The blocks consist of serpentinites and serpentinized peridotites, and are fragmented, with the spaces between blocks being filled by scaly serpentinites (Figs. 2a–b and 3a). Komori and Michibayashi (2011) showed that the blocks decrease in