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Grain-scale plastic deformation of chromite from podiform chromitite of the Naga-Manipur ophiolite belt, India: Implication to mantle dynamics

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ABSTRACT

The mantle peridotites of the Naga-Manipur ophiolite belt, India host concordant podiform chromitite bodies that preserve various magmatic and deformation structures. Magmatic structures preserve evidence of a gradual transition from nodular to massive varieties. Nodular types are least affected by deformation. Deformation structures, restricted mainly in massive types include intracrystalline features of brittle as well as crystal plastic processes within chromite. Brittle deformation is preserved as grain fracturing and intense microbrecciation along narrow zones forming protocataclasite. Crystal plastic deformation has generated chromite subgrains and new grains in response to recovery and recrystallization processes. Subgrains are polygonal in shape and the boundaries between them are commonly straight forming a mosaic with most meeting at triple junctions. Subgrains are commonly internally zoned and the mosaics formed by them correlate well with the compositional maps. Subgrains show high Al at their cores and high Fe at their boundaries in response to differential, diffusive chemical re-equilibration. We discuss how this compositional resetting related to deformation is significant in various geologic studies related to tectonic setting and thermobarometric evolution of an area. Deformation mechanisms are likely to have started with crystal plastic processes and later switched over to the brittle regime. The preservation of all grain-scale deformation structures in the chromitite bodies of the Naga-Manipur ophiolite belt is suggestive of mantle dynamics, vertical accretion and horizontal movement in particular.

1. Introduction

Chromite is a significant mineral phase in considering the chromium reservoir of the bulk earth, the mantle in particular. It is an essential mineral in peridotites and chromitites of the upper mantle (e.g., Shi et al., 2012) and also in some ophiolites and other supra-subduction zone complexes (e.g., Hebert et al., 2012; Pasava et al., 2011; Peng et al., 2012; Ram Mohan et al., 2013). Grain-scale microscopic observations especially the behaviour and geometry of grain boundaries and other internal structures, which generally provide information on deformation mechanisms, are difficult to undertake on chromite because it is isotropic and predominantly opaque in transmitted light microscopy. Cataclasis has long been regarded as the only deformational behaviour in chromite (Doukhan et al., 1979; Ramdohr, 1969); however, the rheological conditions to address this failure in high-temperature mantle environment were constrained much later by numerical experiments (Holtzman, 2000). Studies on pole-figures of deformed ophiolitic chromites obtained utilising X-ray goniometer also could not reveal any subgrains in the respective samples (Christiansen, 1985). As a result, dislocation creep was not thought to be a dominant mechanism; instead, diffusional creep which normally does not result in a crystallographic fabric was considered as the principal mechanism in the deformation of chromites (Ozawa, 1989). However, back scatter electron (BSE) images, obtained using scanning electron microscope (SEM) (Christiansen, 1986) as well as electron probe micro analyser (EPMA) (Ghosh et al., 2013) identified the substructures in ophiolitic chromites, and this suggests that dislocation processes are active in this mineral deforming at high-temperature during mantle flow. Recent observations from BSE images on chromite deformed at eclogite facies conditions (near to crust–mantle boundary) demonstrate that both dislocation and diffusion creep can operate at varying temperature conditions (Ghosh and Konar, 2011, 2012).

Podiform chromitite bodies are usually irregular, discontinuous concentrations of chromite commonly hosted within discordant or semi-concordant dunite of the shallow mantle sequence of the oceanic lithosphere. It is generally accepted that these bodies actually represent channels of focused melt flow (Arai and Abe, 1995; Arai and Yurimoto, 1994; Zhou et al., 1994, 1996). Favourable tectonic settings for podiform chromitite bodies include island arcs, back-arc basins, and fast spreading ridges (Arai, 1997; Johnston, 1936; Leblanc and Nicolas, 1992; Robinson et al., 1997; Thayer, 1964). In ophiolites they are significantly important because they can record subduction initiation in an arc setting (Rollinson and Adetunji, 2013). These bodies are characterised by distinctive magmatic and deformation structures. They form in channels

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of high melt flow beneath the ridge axis and deform in the outward flow of peridotite (Cassard et al., 1981; Ceuleneer and Nicolas, 1985). Magmatic structures dominantly nodular, orbicular and massive are interpreted to result from fast flowing magmatic systems. In contrast, deformation structures characterised by pull-apart, foliated and mylonitic banded fabrics are thought to have resulted from strong high-temperature (>1000–1200 °C) plastic flow (Ceuleneer and Nicolas, 1985; Huang et al., 2004; Leblanc and Ceuleneer, 1992; Li et al., 2002).

Plastic deformation of chromite by dislocation creep mechanism has been speculated from mantle chromitite pods (Holtzman, 2000). In this study we document various grain-scale deformation structures in chromite from podiform chromitite bodies of the Naga-Manipur ophiolite belt, India. This study describes the intracrystalline deformation that generated subgrains and new grains in response to recovery/recrystallization processes as a result of mantle dynamics related to its vertical accretion or horizontal flow, induced by temperature gradients. We emphasize the importance of this study in understanding the grain-scale compositional re-equilibration of deformed minerals which may have major implications in establishing the geotectonic environment as well as in geothermobarometric studies. This work shows how a detailed microstructural work is a prerequisite before finding the right places for carrying out chemical analyses of chromites to use the analytical data for several purposes as mentioned before.

2. Brief geological overview

The Naga-Manipur ophiolite (NMO) belt forms a part of the Tethyan ophiolite belt and is generally interpreted as representing the eastern suture of the Indian Plate (Acharyya, 2007; Gansser, 1980; Mitchell, 1981) (Fig. 1). The NMO belt was accreted just prior to the mid-Eocene as a result of the collision of the Indian plate with the Burma plate and is best preserved as a narrow belt along the eastern margin of the NNE–SSW trending Indo-Burma Range (IBR), northeast India. The ophiolitic rocks occur mainly as rootless subhorizontal bodies overlying Eocene–Oligocene flyschoid sediments and are represented by dismembered ultramafic (and rarely mafic) rocks closely associated with subordinate volcanics and oceanic pelagic sediments. The mafic crustal units, gabbroic rocks in particular are poorly developed in the NMO belt. Lherzolite (with ~10 modal% of clinopyroxene, recalculated in serpentine-free basis), transitional to harzburgite is the most dominant among the mantle peridotites. Podiform chromitites in the NMO belt occur mainly as concordant bodies of variable dimensions up to

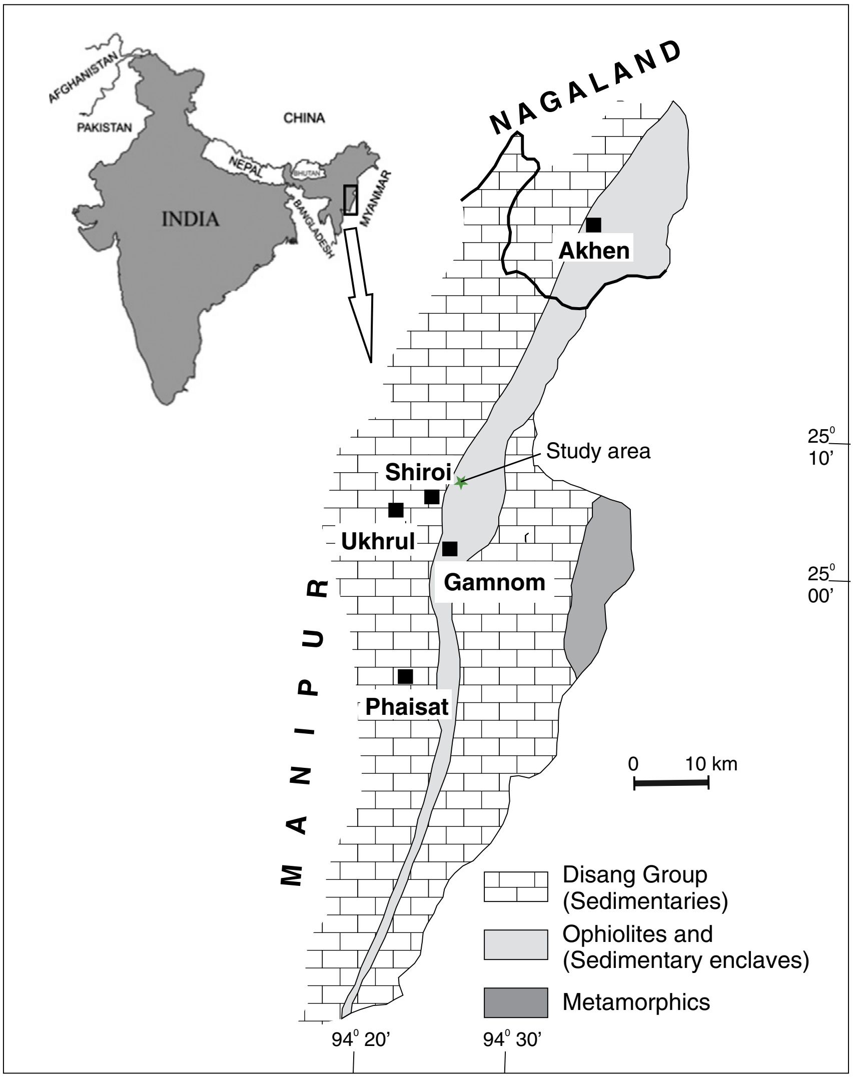

Fig. 1. Generalised geological map of the NMO belt. The green asterisk around the village Shiroi indicates the study area (N25°08′57″:E94°28′20″).