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Mylonitic deformation of gabbro in the lower crust: A case study from the Pankenushi gabbro in the Hidaka metamorphic belt of central Hokkaido, Japan

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ABSTRACT

The mylonitization of the Pankenushi gabbro in the Hidaka metamorphic belt of central Hokkaido, Japan, occurred along its western margin at ≈600 MPa and 660–700 °C through dynamic recrystallization of plagioclase and a retrograde reaction from granulite facies to amphibolite facies (orthopyroxene + clinopyroxene + plagioclase + H_2O = hornblende + quartz). The reaction produced a fine-grained (≤100 μm) polymineralic aggregate composed of orthopyroxene, clinopyroxene, quartz, hornblende, biotite and ilmenite, into which strain is localized. The dynamic recrystallization of plagioclase occurred by grain boundary migration, and produced a monomineralic aggregate of grains whose crystallographic orientations are mostly unrelated to those of porphyroclasts. The monomineralic plagioclase aggregates and the fine-grained polymineralic aggregates are interlayered and define the mylonitic foliation, while the latter is also mixed into the former by grain boundary sliding to form a rather homogeneous polymineralic matrix in ultramylonites. However in both mylonite and ultramylonite, plagioclase aggregates form a stress-supporting framework, and therefore controlled the rock rheology. Crystal plastic deformation of pyroxenes and plagioclase with dominant (100)[001] and $(001)1/2\langle 1\bar{1}0\rangle$ slip systems, respectively, produced distinct shape- and crystallographic-preferred orientations of pyroxene porphyroclasts and dynamically recrystallized plagioclase grains in both mylonite and ultramylonite. Euhedral to subhedral growth of hornblende in pyroxene porphyroclast tails during the reaction and its subsequent rigid rotation in the fine-grained polymineralic aggregate or matrix produced clear shape- and crystallographic-preferred orientations of hornblende grains in both mylonite and ultramylonite. In contrast, the dominant grain boundary sliding of pyroxene and quartz grains in the fine-grained polymineralic aggregate of the mylonite resulted in their very weak shape- and crystallographic-preferred orientations. In the fine-grained polymineralic matrix of the ultramylonite, however, pyroxene and quartz grains became scattered and isolated in the plagioclase aggregate so that they were crystal-plastically deformed leading to stronger shape- and crystallographic-preferred orientations than those seen in the mylonite.

1. Introduction

Since gabbro is thought to be a common rock type found in the continental lower crust, its mylonitic deformation under elevated pressure–temperature conditions is important not only structurally in terms of deformation and strain localization processes in the lower crust, but also rheologically in terms of the strength and mechanical behavior of the lower crust (e.g. Rutter and Brodie, 1992). Previous studies of gabbroic mylonites formed at lower crustal conditions revealed crystal plastic deformation and dynamic recrystallization of plagioclase (e.g. Jensen and Starkey, 1985; Olsen and Kohlstedt, 1985; Olesen, 1987; Ji and Mainprice, 1990; Dornbusch et al., 1994; Kruse and Stünitz, 1999; Kruse et al., 2001; Baratoux et al., 2005), crystal plastic deformation of pyroxenes (e.g. Dornbusch et al., 1994; Kenkmann, 2000), and nucleation and growth of amphibole (e.g. Kruse and Stünitz, 1999; Kenkmann and Dresen, 2002; Baratoux et al., 2005). Other studies emphasized the role of syntectonic breakdown reactions of pyroxenes or garnet (e.g. Beach, 1980; Brodie, 1995; Stünitz, 1998; Kruse and Stünitz, 1999; Kenkmann, 2000). However, the dynamic recrystallization, dominant slip systems and crystallographic-preferred orientations of plagioclase are still not well understood even though plagioclase is the most abundant mineral found in the crust (e.g. Tullis, 2002). In addition, the deformation behavior of other constituent minerals such as pyroxenes and amphibole in gabbroic mylonites is still poorly understood (e.g. Dornbusch et al., 1994; Kenkmann and Dresen, 2002).

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This paper describes the grain-scale processes during mylonitization of the Pankenushi gabbro in the Hidaka metamorphic belt of central Hokkaido, Japan, which occurred at ≈600 MPa and 660–700 °C. Microstructural observations and a large amount of shape- and crystallographic-orientation data for the constituent minerals in two representative samples provide important new information concerning the deformation behavior of plagioclase and other constituent minerals in gabbro under lower crustal conditions.

2. Geological setting

The Hidaka metamorphic belt of south–central Hokkaido, Japan (Fig. 1a) lies within a zone of collision between the Kuril arc and the Northeast Japan arc since the early Tertiary (e.g. Komatsu et al., 1983; Kimura, 1986). The Hidaka metamorphic Main Zone (e.g. Fig. 1b) represents a partial section through the ancient Kuril arc crust, the upper 23 km of which is exposed at the surface along the Hidaka Main Thrust (HMT; Fig. 1b) (Komatsu et al., 1983). The Main Zone consists of felsic and mafic metamorphic rocks, and plutonic rocks such as gabbro, diorite and tonalite (Komatsu et al., 1983; Osanai et al., 1991). The metamorphic grade gradually decreases eastwards from granulite through amphibolite to greenschist facies (Osanai et al., 1991). The footwall of the Hidaka Main Thrust is either the Hidaka metamorphic Western Zone or the Idon'nappu belt (e.g. Fig. 1b). The Western Zone is narrow (≤4 km), and consists mainly of greenschist, amphibolite and metagabbro, which collectively are interpreted to form a meta-ophiolitic assemblage (Miyashita, 1983). The Western Zone lies in thrust contact with the Idon'nappu belt along the Western Boundary Thrust (WBT; Fig. 1b). The Idon'nappu belt is composed of an accretionary mélange of Cretaceous to Paleocene age (Kiyokawa, 1992; Ueda et al., 1993).

The Pankenushi gabbro in the northern part of the Hidaka metamorphic Main Zone (Fig. 1a) is mylonitized along its western margin by dextral shearing (Toyoshima et al., 1994; Toyoshima, 1998). It is considered to have been intruded concurrently with anatexis of the Main Zone rocks (Maeda and Kagami, 1996) which has been dated at approximately 55 Ma (Owada et al., 1991) and corresponds to a metamorphic peak in the Main Zone (Komatsu et al., 1994). The exhumation of the Main Zone rocks along the Hidaka Main Thrust is estimated to have occurred approximately at 17 Ma (Arita et al., 1993). Hence the mylonitization of the Pankenushi gabbro occurred sometime between 55 Ma and 17 Ma.

In the Pankenushi river area, the western margin of the Pankenushi gabbro together with felsic granulite in contact with the gabbro are mylonitized in a 200–300 m wide zone (Fig. 1b), where a N- to NNW-trending, subvertical mylonitic foliation and a subhorizontal mylonitic lineation are developed (Fig. 1c). We collected two representative mylonite samples along the Pankenushi trail for detail analyses in this study (Fig. 1b): a gabbro mylonite sample (GbM) and a gabbro ultramylonite sample (GbUM). In addition, we collected a sample of garnet–biotite gneiss (GBGn; Fig. 1b) to constrain pressure–temperature conditions from immediately adjacent metamorphic rocks.

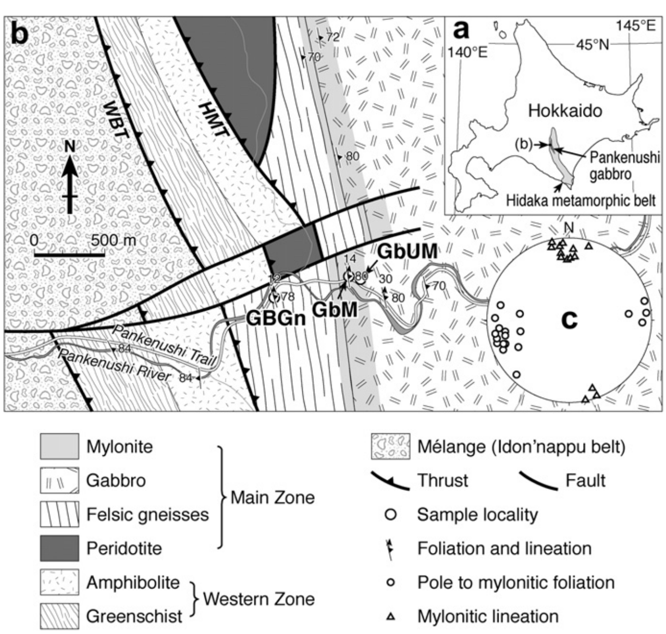

Fig. 1. (a) Index map showing locations of the Hidaka metamorphic belt, the Pankenushi gabbro and the study area (b). (b) Geologic map of the study area, where three sample localities (GbM, GbUM and GBGn) are shown. *HMT*, Hidaka Main Thrust; *WBT*, Western Boundary Thrust. (c) Equal-area, lower-hemisphere projections of mylonitic foliation (19 data) and lineation (14 data) measured at several localities.

3. Microstructures

Microstructures in the gabbro mylonite samples were observed by means of optical and back-scattered electron (BSE) microscopy, viewing thin sections cut perpendicular to the mylonitic foliation and parallel to the mylonitic lineation.

3.1. Gabbro mylonite sample (GbM)

This sample contains porphyroclasts of orthopyroxene, clinopyroxene and plagioclase set in a matrix of either fine-grained (≤150 μm) monomineralic plagioclase grains or a fine-grained (≤100 μm) polymineralic aggregate (Fig. 2a). These two matrix types alternate in layers to define the mylonitic foliation, while elongate pyroxene porphyroclasts primarily delineate the mylonitic lineation (Fig. 2a; cf. Toyoshima, 1998).

Pyroxene porphyroclasts commonly contain lamellae or inclusions of ilmenite and exsolution lamellae (Fig. 2a,d). They exhibit undulose extinction and bending, but subgrain boundaries and bulging grain boundaries are not observed. Asymmetric tails of orthopyroxene, clinopyroxene, quartz, hornblende, biotite and ilmenite grains indicate a dextral sense of shear (Fig. 2a,c,d). Lobate quartz grains are commonly distributed around pyroxene porphyroclasts along their foliation-subparallel boundaries, while euhedral to subhedral hornblende and biotite grains are common in porphyroclast tails (Fig. 2c–e). Pyroxene porphyroclast rims are locally isolated or almost isolated by the presence of quartz, hornblende and biotite grains (Fig. 2c,d).

Plagioclase porphyroclasts exhibit undulose extinction and deformation twinning, and are surrounded by finer, monomineralic-aggregate plagioclase grains (Fig. 2b). The latter are polygonal in shape, and commonly have subgrain boundaries and bulging grain boundaries (Fig. 2f), while they rarely exhibit deformation twins.

The fine-grained polymineralic aggregate comprises orthopyroxene, clinopyroxene, quartz, hornblende, biotite and ilmenite (Fig. 2a,g). They are derived from pyroxene porphyroclast tails, and those derived from orthopyroxene porphyroclast tails are rich in orthopyroxene (e.g. Fig. 2g), while those derived from clinopyroxene porphyroclast tails are rich in clinopyroxene.

3.2. Gabbro ultramylonite sample (GbUM)

This sample contains a few pyroxene porphyroclasts set in a fine-grained polymineralic matrix of plagioclase, orthopyroxene, clinopyroxene, quartz, hornblende, biotite and ilmenite (Fig. 3a,b). Orthopyroxene porphyroclasts are markedly elongate, whereas clinopyroxene porphyroclasts are less elongate (e.g. Fig. 3a). Plagioclase porphyroclasts are absent. In the fine-grained