A new chemical etching technique for peridotites using molten anhydrous borax

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ABSTRACT

A new chemical etching technique has been devised for synthetic Fe-free peridotites composed of forsterite (Fo), enstatite (En), and diopside (Di). Among the etchants were acids, molten carbonates, and borates, but it was found that only molten anhydrous borax (Na₂B₄O₇) dissolved all phases equally. Molten anhydrous borax was found to be a successful etchant in equally enhancing all the grain (i.e., Fo-Fo, En-En, and Di-Di) and interphase (i.e., Fo-En, Fo-Di, and En-Di) boundaries. From the back-scattered electron images of the etched surface, maps of grain- and interphase-boundaries can be obtained semi-automatically for microstructural analysis by using image processing software. An Fe-bearing wehrlite was also etched successfully by molten anhydrous borax, thus showing the usefulness of this technique for enhancing the grain- and interphase-boundaries in many natural peridotites.

Keywords: Etching, peridotite, anhydrous borax, grain boundary, interphase boundary

INTRODUCTION

Rheological properties of rocks depend significantly on their microstructure. The effective viscosity and seismic anisotropy of the Earth’s interior, for example, are functions of grain size and crystallographically preferred orientation of minerals (e.g., Karato et al. 1986; Zhang and Karato 1995). In many experimental studies concerning deformation (e.g., Karato et al. 1986) and grain growth (e.g., Tullis and Yund 1982), enhancing of grain boundaries is essential for analyzing rock microstructures properly. Chemical etching is a frequently used method for enhancing grain boundaries and defect structures. Many chemical-etching techniques have been reported for enhancing defect structures of single crystals (e.g., Wegner and Christie 1976, 1985 for olivine and pyroxenes) and grain boundaries of monomineralic rocks (e.g., Cooper and Kohlstedt 1984 for dunite).

However, etching of polymineralic rocks requires some additional improvements because of the different solubility of the minerals to etchants (e.g., Petzow 1997). Herwegh (2000) used acidic liquids as etchants on a carbonate mylonite composed of calcite, dolomite, and other minerals. He succeeded in enhancing the grain boundaries of calcite only because dolomite and other minerals are less soluble than calcite. Thermal etching, which is the annealing of polished samples at ~0.7·T_m for several tens of minutes (where T_m is the melting point of the sample materials), can be used for polycrystalline ceramics composed of two phases (e.g., French et al. 1990 for Al₂O₃-ZrO₂ mixture). It has been reported that thermal etching is also effective in some biminarmonic silicate rocks. For example, Xiao et al. (2002) performed thermal etching on anorthite-quartz aggregates. High-temperature, long-duration heat treatment, however, can cause grain boundary migration of samples and spoil the original microstructure. In material science, molten salts are sometimes used for etching of ceramics (e.g., Petzow 1997). In comparison with thermal etching, etching by molten salts requires lower temperature (200–1000 °C, depending on T_m of the salts) and much shorter etching duration (several tens of seconds). For example, thermal etching of polycrystalline alumina requires annealing for 20 min at 1400 °C, whereas etching by NaHSO₄ (Petzow 1997) requires much shorter duration (1 min) and lower temperature (300 °C). Hence it is obvious that grain-boundary migration will not occur during etching by molten salts. Molten salts might be applicable to etching on bi- and poly-mineralic rocks, because some of them (e.g., Li₂B₄O₇) can dissolve various silicate minerals (e.g., Norrish and Hutton 1969). However, their application to etching on polycrystalline silicates and natural rocks has not yet been reported.

In this study, chemical etching by several acids and molten salts are tested for synthetic peridotites. A new chemical-etching technique using molten anhydrous borax (Na₂B₄O₇) is found to successfully etch and enhance various types of grain- and inter-phase-boundaries of a peridotite composed of forsterite, enstatite, and diopside. Peridotite was chosen because of its importance to mantle petrology and geochemistry. The etched surface facilitates the analysis of the back-scattered electron (BSE) images, useful for analyzing rock microstructures.

EXPERIMENTAL PROCEDURE

Sample preparation

Dunite, orthopyroxenite, clinopyroxenite, harzburgite, wehrlite, and websterite were synthesized for etching tests under various conditions. The starting materials for these rocks were prepared from Fe-free gel powder of different compositions. Details of the sol-gel method are based on Hamilton and Henderson (1968) and Kawamura (1994). The starting materials for the wehrlite were also prepared by fine grinding of natural single crystals of San Carlos olivine (Fo₀₀), and diopside from Nepal (Di₀₀).

All the samples were synthesized at 1200 °C and 1.2 GPa for 160 h. The high-pressure sintering experiments were conducted in a Boyd-England type 3/4-piston-cylinder apparatus at Tohoku University. About 10 mg of the starting materials was packed into Pt-lined, four-hole Ni capsules (length = 3 mm, hole diameter = 1.8 mm), and 1.0–1.5 wt% distilled water was added with a microsyringe for promoting grain growth. Addition of water would not lead to formation of a melt phase under the conditions prevalent during the experiment, because the solidus temperatures in the Fe-free Fo-En-Di system at 2 GPa under water-saturated condi-

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