LETTERS

Equation of state of Al-bearing stishovite to 40 GPa at 300 K

SHIGEAKI ONO,1,* TAKUMA SUTO,2 KEI HIROSE,2 YASUHIRO KUWAYAMA,2 TETSUYA KOMABAYASHI,2 AND TAKUMI KIKEGAWA3

1Institute for Frontier Research on Earth Evolution, Japan Marine Science & Technology Center, 2-15 Natsushima-cho, Yokosuka-shi, Kanagawa 237-0061, Japan
2Department of Earth and Planetary Sciences, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro, Tokyo 152-8551, Japan
3High Energy Acceleration Research Organization, Tsukuba 305-0801, Japan

ABSTRACT

The compression behavior of Al-bearing stishovite was investigated by powder X-ray diffraction up to 40 GPa with the BL13A beamline at the Photon Factory (KEK, Japan). A reliable equation of state for stishovite was obtained using a diamond anvil cell coupled with a yttrium-aluminum-garnet (YAG) laser-heating. A sample containing 2.1 wt% Al2O3 was heated using a YAG laser at each pressure increment to relax deviatoric stress. X-ray diffraction measurements were carried out at 300 K using the angle-dispersive technique. A least squares refinement of the data yielded equation of state parameters where the bulk modulus $K_0 = 282 (\pm 2)$ GPa when the first pressure derivative of the bulk modulus $K_0'$ was fixed at 4. The effect of Al is to decrease slightly the bulk modulus of stishovite and increase the density of the subducted oceanic crust. The enhanced compressibility of Al-bearing stishovite certainly has geophysical and geochemical implications for the fate of the subducted slab, as this mineral is the main constituent of subducted mid-oceanic ridge basalt (MORB) in the Earth’s mantle.

INTRODUCTION

Stishovite is thought to represent about 10 and 20% of the volume of the subducted mid-oceanic ridge basalt (MORB) in the Earth’s upper and lower mantle, respectively (Irifune et al. 1986; Ono et al. 2001). The chemical composition of stishovite is not pure SiO2 because a small amount of Al2O3 can be dissolved into it (Pawley et al. 1993), and the Al2O3 content in stishovite increases with increasing temperature (Ono 1999). Pawley et al. (1993) and Smyth et al. (1995) reported the synthesis of stishovite in the presence of Al2O3 and H2O with up to 2.0 wt% Al2O3 and 500 ppm OH–, and also gave the crystal chemistry of Al substitution in H-bearing stishovite. Natural stishovite in the subducted MORB seems to contain a few weight percents of Al2O3 as estimated by previous high-pressure experiments (Irifune et al. 1986; Kesson et al. 1994; Ono and Yasuda 1996; Hirose et al. 1999; Ono et al. 2001). However, the thermoelastic properties of Al-bearing stishovite are uncertain, and it is not known, because of the limited experimental data, whether Al-bearing stishovite is in its stable phase throughout the entire range of conditions in the lower mantle.

The stability and thermoelastic properties of pure SiO2 stishovite have been reported in many previous studies. The low-pressure stability limit of stishovite is about 10 GPa (Akaogi et al. 1995; Zhang et al. 1996). However, experimental reports related to the high-pressure stability limit have been controversial. Nagel and O’Keeffe (1971) first suggested the possibility of a pressure-induced stishovite-CaCl2-type structure phase transition, based on crystal chemical arguments. In many high-pressure experimental studies, the CaCl2-type structure phase was observed and its phase boundary determined (e.g., Andrault et al. 1998; Ono et al. 2002a). Recently, however, Dubrovinsky et al. (2001) reported on the phase boundary between stishovite and α-PbO2-type structure phase.

Several studies have addressed the equation of state of pure SiO2 stishovite, and general agreement has been reached (e.g., Weidner et al. 1982; Ross et al. 1990; Liu et al. 1999). The bulk modulus $K_0$ is close to 300 GPa when its first pressure derivative $K_0'$ is fixed at 4, and using a higher-order equation of state, the recent compression curves are well fitted by $K_0 = 291$ GPa and $K_0' = 4.3$ (Andrault et al. 1998).

We have directly investigated the stability and pressure-volume equation of state (EOS) of Al-bearing stishovite over pressures from 1 bar to ~40 GPa, equivalent to lower mantle conditions. In this paper, we compare the bulk modulus of Al-bearing stishovite with that of the pure stishovite reported by previous studies.

EXPERIMENTAL PROCEDURE

A polycrystalline specimen of Al-bearing stishovite was synthesized in a 1000-ton multi-anvil apparatus (SEDI-1000) (Takahashi et al. 1993) at the Magma Factory, Tokyo Institute of Technology. The initial material was prepared by mixing SiO2 and Al(OH)3. Prior to mixing, reagent grade SiO2 and Al(OH)3 powders were heated at 100 °C for 24 hours. The mixture was ground in an agate mortar, and was loaded into a platinum capsule that was sealed by welding. The Al-bearing stishovite used in this study was synthesized under a pressure...