Chromian spinel during melting experiments of dry peridotite (KLB-1) at 1.0–2.5 GPa

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ABSTRACT

The stability and chemistry of chromian spinel were determined for dry mantle (spinel lherzolite) melting at pressures between 1.0 and 2.5 GPa and temperatures between 1250 and 1500 °C. To find the most suitable sample container, we tested three different possibilities at 1.5 GPa: a Pt capsule, a Re/Pt capsule, and a graphite/Pt capsule. The oxygen fugacity of the run products with Pt, Re/Pt, and graphite/Pt are FMQ + 4 to 5, −2 to 0, and < −10, respectively. We conclude that the Re/Pt capsule is most suitable for melting experiments of dry peridotite at high temperatures and the oxygen fugacity similar to that of the terrestrial upper mantle, which has been estimated to be near FMQ. Using Re/Pt capsules, batch-melting experiments of a dry spinel lherzolite from Kilborne Hole (KLB-1) were performed. Our experimental results and natural mantle peridotites are significantly different in terms of the stability field and the Cr/(Cr + Al) atomic ratio (= Cr′) of chromian spinel. Spinel, which is common in natural mantle peridotite regardless of their bulk chemistry, disappeared at a much lower degree of melting in our experiments. The upper limit of the Cr′ of spinel just before its disappearance decreases rapidly from 0.45 to 0.13 with increasing pressure, whereas natural peridotites have a wide range of Cr′ from 0.1 to 0.8. Our dry experiments, compared with previous hydrous experiments, indicate that the upper limit of Cr′ increases with increasing H2O content. These findings suggest that the petrological variation of natural mantle peridotite cannot be formed by simple batch melting but may be the result of more complex melting.

INTRODUCTION

Although it is present only in small quantities, chromian spinel is a very important phase during melting processes in the shallow mantle. The compositional variation of spinel as a function of bulk peridotite chemistry has been well documented in many studies on the basis of field observations (e.g., Dick 1977; Dick and Bullen 1984; Arai 1987, 1990; Takahashi N. 1992; Ozawa 1997). The most important feature of spinel is the wide range of Cr/(Cr + Al) atomic ratio (= Cr′), which rises from 0.05 to 0.6, sometimes reaching 0.8, as the Mg/(Mg + Fe) atomic ratio (= Mg′) of coexisting olivine is increased. In natural peridotites, the modal proportion of clinopyroxene gradually decreases and finally disappears with an increase in the Cr′ of spinel. The systematic increase in Cr′ of spinel is considered to have resulted from partial melting and melt-extraction processes because the partial melting preferentially exhausts clinopyroxene relative to coexisting minerals. Chromian spinel exists in minor amounts throughout the peridotite lithologies: lherzolite, harzburgite, and dunite. Therefore, chromian spinel is considered to be one of the best indicators of degree of partial melting for natural mantle peridotites. The purpose of our study was to determine the chemistry of chromian spinel by melting experiments of KLB-1 (a dry spinel lherzolite from Kilborne Hole) at the conditions of the Earth’s uppermost mantle and to evaluate the observations on natural peridotites.

Constraining the chemistry of chromian spinel in high-pressure melting experiments involves at least two experimental difficulties. The first problem is the difficulty in maintaining the proper oxygen fugacity. The composition and stability field of chromian spinel are very sensitive to oxygen fugacity (Roeder and Reynolds 1991). The oxygen fugacity of the upper mantle has been estimated to be about that of the Fayalite-Magnetite-Quartz buffer (= FMQ) (e.g., Mattioli and Wood 1986). Therefore, we have to keep the oxygen fugacity of the run products close to the FMQ buffer during experiments. The containers used by previous workers, however, cannot maintain this redox state, as will be shown later.

The second problem is Fe loss. It is well known that the proportion of Fe transferred from the sample charge to a metal container can be considerable in high-temperature experiments, such as melting of dry peridotite at mantle conditions (e.g., Jaques and Green 1980). Partial melts particularly enhance the Fe loss because of their rapid diffusion of elements. To prevent this effect, many materials have been used. A Pt capsule is refractory enough to conduct the high-temperature experiments, but the amount of Fe lost from silicate melts becomes very significant at high temperatures (e.g., Jaques and Green 1980). Au-Pd, Ag-Pd alloys, Au, and Fe-saturated Pt are less reactive with Fe (e.g., Sisson and Grove 1993; Kawamoto and Hirose 1994; Hirose and Kawamoto 1995; Gaetani and Grove 1998 and references therein), but the melting points of these materials are too low to allow their use in the melting of refractory dry peridotites. At present, a graphite sleeve is generally used as the inner capsule, which is encased in a sealed Pt tube to eliminate Fe-loss in high-temperature experiments (e.g., Kogiso et al. 1998; Takahashi et al. 1998; Walter 1998).

In this paper, we have tested Pt and graphite/Pt capsules as well as a Re/Pt capsule (Re foil as an inner capsule in a sealed Pt tube; Takahashi et al. 1993) and show that Re/Pt makes the