Enstatite-forsterite-water equilibria at elevated temperatures and pressures

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ABSTRACT

The compositions of aqueous fluids in equilibrium with enstatite + forsterite were investigated at temperatures from 900 to 1200 °C and pressures from 1.0 to 2.0 GPa. Experiments, performed in a piston-cylinder apparatus, involved the location of phase boundaries between the stability fields of enstatite and enstatite + forsterite, and enstatite + forsterite and forsterite. The intersection of these two phase-boundaries near the H₂O apex was used to define the fluid composition. The results indicated a systematic increase in the concentration of silica in the fluid phase with increasing temperature. The experiments indicated that the concentration of dissolved MgO was below 0.3 mol% and not resolvable using our techniques. This finding was corroborated by microprobe analyses of quench precipitates from the fluid phase, which gave on average 0.2 mol% MgO. Because of the low MgO concentrations, the mean values of the intercepts with SiO₂-H₂O binary of the fitted lines representing, respectively, the phase boundaries between the enstatite and enstatite + forsterite and between the enstatite + forsterite and forsterite stability fields were taken to represent the concentrations of dissolved silica at the various temperatures and pressures of the present study. The concentrations increased from 0.6 mol% at 900 °C to 3.9 mol% at 1200 °C at 1.0 GPa. The pressure effect from 1.0 to 2.0 GPa at 1000 °C appeared to be minor and not resolvable using our techniques. At 1.0 GPa, the base 10 logarithm of the molal concentration of dissolved silica in equilibrium with enstatite + forsterite was obtained combining data from the present study with those from Nakamura and Kushiro (1978) and Manning and Boettcher (1994):

\[
\log m_{\text{SiO}_2(aq)}^{\text{En-Fe}} = 6.869 - 1.335 \times 10^4 / T(\text{K}) + 5.544 \times 10^6 / T(\text{K})^2.
\]

Comparison with studies of the solubility of quartz (Manning 1994) indicated that thermodynamic properties of aqueous silica derived from silica-saturated systems may not be applicable to calculations in silica-deficient systems at high pressure.

INTRODUCTION

Aqueous fluids are involved in the mass-transport and metasomatic processes occurring in many geological terrains such as subduction zones, spreading centers, arc magmatism, and ore deposits. To have a better and quantitative understanding of these processes, compositions of aqueous fluids coexisting with minerals must be known, which can be done both experimentally and theoretically. In terms of experiments, three distinct techniques can be applied. The first is the determination of the weight loss of mineral grains after experiment (e.g., Anderson and Burnham 1965; Manning 1994); the second is the extraction and analysis of fluids or precipitates (e.g., Schneider and Eggler 1986; Walther and Orville 1983; Hemley et al. 1977; Manning and Boettcher 1994); and the third is the determination of intersection of phase boundaries by identification of mineral coexistence after experiment (e.g., Nakamura and Kushiro 1974, Ryabchikov et al. 1982). In terms of theory thermodynamic calculations are performed routinely for mineral-fluid equilibria (e.g., Johnson et al. 1992).

Among minerals considered, quartz has received the most attention (e.g., Kennedy 1950; Weill and Fyfe 1964; Anderson and Burnham 1965; Walther and Orville 1983; Manning 1994). These studies have reported fluid compositions in silica-saturated systems over a wide range of temperatures and pressures. As for silica-deficient systems, Hemley et al. (1977) determined silica concentrations in equilibrium with forsterite + enstatite and other mineral assemblages at 0.1 GPa. Walther and Helgeson (1977), using thermodynamic properties of aqueous silica derived from quartz solubility studies, successfully predicted silica concentrations in equilibrium with mineral assemblages in the system Al₂O₃-SiO₂-H₂O and MgO-SiO₂-H₂O at 0.1 GPa and temperatures from 25 to 600 °C. At higher pressures, Nakamura and Kushiro (1974), Ryabchikov et al. (1982), and Manning and Boettcher (1994) determined the silica concentration in equilibrium with enstatite + forsterite from 1.0 to 3.0 GPa and temperatures from 700 to 1310 °C.

To fully understand the mass-transport and metasomatic processes occurring in silica-deficient systems, systematic investigations of the compositions of aqueous fluids in equilibrium with the mineral pair enstatite + forsterite were undertaken in the present study at pressures from 1.0 to 2.0 GPa and temperatures from 900 to 1200 °C. Fluid compositions were determined by locating the intersection of phase boundaries. Data

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