Biotite dehydration, partial melting, and fluid composition: Experiments in the system KAlO$_2$-FeO-MgO-SiO$_2$-H$_2$O-CO$_2$

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ABSTRACT

Biotite solid-solutions are a significant H$_2$O reservoir in the lithosphere, and the assemblage Bt+Op$_x$+Kfs+Qtz is commonly used to estimate $a_{H_2O}$ in high-grade metamorphic and magmatic rocks. Here we report experimental constraints on subsolidus mineral equilibria involving biotite and orthopyroxene in the system KAlO$_2$-MgO-FeO-SiO$_2$-H$_2$O-CO$_2$. Our experiments address the question of stability of biotite of a given $X_a$ in the assemblage Bt+Qtz±Sa, or the stability of the assemblage Op$_x$+Sa±Qtz. Clemens (1993) and Clemens et al. (1997) concluded that CO$_2$ has no effect other than to lower $a_{H_2O}$ and thereby raise the solidus $T$. Our data at $X_{H_2O}^0 < 1$ extend these conclusions to encompass Fe-bearing systems more similar to natural rocks. From a comparison of experimental data and calculated isopleths of biotite composition in the divariant assemblage Bt+Op$_x$+Kfs+Qtz+fluid, it appears that phlogopite-annite solid-solutions must be significantly non-ideal (at $T < 800$ °C) or that enstatite-ferrosilite solid-solutions must have negative values for their Margules-type parameters. Ignoring these factors would result in any calculated $a_{H_2O}$ values being too low. Although various models allow us to estimate $X_{H_2O}^0$ in H$_2$O-CO$_2$ fluids, we are still unable to use biotite equilibria to estimate $a_{H_2O}$ accurately during high-grade metamorphism and magma crystallization. We also consider qualitatively the effects Fe-Mg biotite solid-solution on partial melting equilibria in fluid-poor (rock-dominated) systems in which hydration-dehydration reactions control the fluid composition.

INTRODUCTION

Trioctahedral micas are common in magmatic and metamorphic rocks, and are significant H$_2$O reservoirs in the Earth’s crust and upper mantle. In recent years, investigators have expended considerable energy on the determination of phase relations and crystal chemistry of these minerals. Reliable, internally consistent thermodynamic data for micas are needed for modeling dehydration and partial melting equilibria. There have been detailed studies of isomorphous substitutions in biotite involving components such as Al, Ti, and F (e.g., Circone and Navrotsky 1992; Patiño Douce 1993). Phlogopite [K(Mg,Al)Si$_3$O$_9$(OH)$_2$]-annite [K(Fe,Al)Si$_3$O$_9$(OH)$_2$] solid-solutions are commonly treated as ideal, an assumption based mainly on the distribution of Fe and Mg between biotite and other ferromagnesian silicates (e.g., Mueller 1972). The present work focuses on equilibria in the system KAlO$_2$-MgO-FeO-SiO$_2$-H$_2$O-CO$_2$, as models for dehydration and partial melting reactions involving biotite (e.g., Grant 1985). The following phases may participate in these equilibria: quartz (Qtz); biotite (Bt); phlogopite-annite (Phl-Ann); high sanidine (Sa); orthopyroxene (Op$_x$), enstatite-ferrosilite (En-Fs); silicate melt (M); and supercritical fluid (Fl), H$_2$O-CO$_2$.

Our new data allow us to examine further the validity of the hypothesis of a special role for CO$_2$ in partial melting reactions involving Fe-Mg biotites (e.g., Hansen et al. 1984; Grant 1985; Peterson and Newton 1989b, 1990). This hypothesis is founded upon the experimental data of Wendlandt (1981) and Peterson and Newton (1990). According to these authors, melting of the assemblage Pht+Fe-Mg biotite solid-solution on partial melting equilibria in fluid-poor (rock-dominated) systems in which hydration-dehydration reactions control the fluid composition.

EXPERIMENTAL DETAILS

Starting materials

The starting charges consisted of mixtures of synthetic minerals. The compositions of the charges are given in Table 1. Biotites of the phlogopite-annite series, with $X_a$ [Fe/(Fe + Mg)] = 0.3 and 0.5, and high sanidine were synthesized hydrothermally from gels. Biotites with other compositions and orthopyroxenes were synthesized from K,CO$_3$, Al(OH)$_3$, MgC$_2$O$_4$-2H$_2$O, FeC$_2$O$_4$-2H$_2$O, and X-