The system $\text{Na}_2\text{CO}_3$-$\text{FeCO}_3$ at 6 GPa and its relation to the system $\text{Na}_2\text{CO}_3$-$\text{FeCO}_3$-$\text{MgCO}_3$

ANTON SHATSKYI1,2,*, SERGEY V. RASHCHENKO1,2, ELJI OHTANI1,3, KONSTANTIN D. LITASOV1,2, MIKHAIL V. KHELESTOV1, YURI M. BORZDOV1,2, IGOR N. KUPIRYANOV1,2, IGOR S. SHARYGIN1,2 and YURI N. PALYANOVI1,2

1V.S. Sobolev Institute of Geology and Mineralogy, Russian Academy of Science, Siberian Branch, Koptyug pr. 3, Novosibirsk 630090, Russia
2Novosibirsk State University, Novosibirsk 630090, Russia
3Department of Earth and Planetary Material Science, Tohoku University, Sendai 980-8578, Japan

ABSTRACT

The phase relations in the $\text{Na}_2\text{CO}_3$-$\text{Fe}_0.87\text{Mn}_{0.06}\text{Mg}_{0.07}\text{CO}_3$ system have been studied in Kawai-type multi-anvil experiments using graphite capsules at 6.0 GPa and 900–1400 °C. Subsolidus assemblages comprise the stability fields of $\text{Na}_2\text{CO}_3$ + $\text{Fe}_2\text{CO}_3$ and $\text{Na}_2\text{Fe}_2\text{CO}_3$ + siderite with the transition boundary at $X(\text{Na}_2\text{CO}_3) = 50$ mol%. Intermediate $\text{Na}_2\text{Fe}_2\text{CO}_3$ compound has rhombohedral $R\overline{3}$ eitelite structure with cell parameters $a = 4.9712(16)$, $c = 16.569(4)$ Å, $V = 354.61(22)$. The $\text{Na}_2\text{CO}_3$-$\text{Na}_2\text{Fe}_2\text{CO}_3$ eutectic is established at 1000 °C and 66 mol% $\text{Na}_2\text{CO}_3$, $\text{Na}_2\text{Fe}_2\text{CO}_3$ disappears between 1000 and 1100 °C via incongruent melting to siderite and a liquid containing about 55 mol% $\text{Na}_2\text{CO}_3$. Siderite remains a subliquidus phase at 1400 °C at $X(\text{Na}_2\text{CO}_3) \leq 30$ mol%.

The ternary $\text{Na}_2\text{CO}_3$-$\text{Fe}_2\text{CO}_3$-$\text{MgCO}_3$ system can be built up from the corresponding binary systems: two systems with intermediate $\text{Na}_2(\text{Mg,Fe})(\text{CO}_3)$, phase, which melts congruently at the Mg-rich side and incongruently at the Fe-rich side, and the (Mg,Fe)CO$_3$ system with complete solid solution. The phase relations suggest that the maximum contribution of FeCO$_3$ component into the lower solidus temperatures of Na-bearing carbonated mantle domains could not exceed several tens of degrees Celsius.

Keywords: Natrite, siderite, eitelite, high-pressure experiment, carbonatite, phase relations, mantle, melting

INTRODUCTION

Previous experimental studies demonstrate that siderite forms a complete solid solution with magnesite, which would be stable under upper and lower mantle conditions and may transport carbon in subducting lithospheric plates into the deep mantle (Dasgupta et al. 2004; Santillán and Williams 2004; Lavina et al. 2010; Boulard et al. 2011; Franzolin et al. 2011; Litasov et al. 2013a). The observations of FeCO$_3$ as inclusions in diamond in association with the (Mg,Fe)SiO$_3$ and (Fe,Fe)O assemblage (Stachel et al. 2000) support these experimental observations. Yet, in the presence of alkalis, carbonates could melt at much lower temperatures to form alkali-rich carbonatite melts (Brey et al. 2011; Grassi and Schmidt 2011; Litasov et al. 2013c). Such melts were also found as recrystallized microinclusions in diamonds from kimberlites (Navon 1991; Schrauder and Navon 1994; Zedgenizov et al. 2007; Weiss et al. 2009). Owing to their low density (Genge et al. 1995; Guillet and Sator 2011), enhanced wetting properties (Hunter and McKenzie 1989; Minarik and Watson 1995; Yoshino et al. 2010), and ability to transport silicate components (Shatskiy et al. 2013b), such melts could stem from subducted oceanic lithosphere and percolate upward along grain boundaries (Hammouda and Laporte 2000) or by means of diapirc ascent (Litasov et al. 2013b, 2013c). This could suppress the amount of carbon, which can be potentially transported down to the transition zone and lower mantle (Dasgupta and Hirschmann 2010). It is, therefore, essential to know phase relations in simple alkali-alkaline earth and Fe-bearing carbonate systems under mantle conditions.

Although phase relations in the alkali-earth carbonate systems were studied extensively from upper down to lower mantle conditions, (e.g., Katsura and Ito 1990; Ono et al. 2007; Nagai et al. 2010; Franzolin et al. 2011; Boulard et al. 2012), the studies of the alkali-bearing carbonate systems were limited to Fe-free compositions (Eitel and Skaliks 1929; Cooper et al. 1975; Shatskiy et al. 2013a, 2013c, 2013d). At the same time, an investigation of Fe-bearing carbonate systems, e.g., $\text{Na}_2\text{CO}_3$-$\text{Fe}_2\text{CO}_3$-$\text{MgCO}_3$-CaCO$_3$, has particular importance, given the abundance of Na and Fe in carbonate melt inclusions in diamonds (up to 7–14 wt% Na$_2$O and 11–58 wt% FeO) from the upper (Tomlinson et al. 2006; Kleln-BenDavid et al. 2009; Zedgenizov et al. 2009) and lower mantle (Kaminsky et al. 2009b, 2013) as well as the abundance of Fe-bearing species in hydrothermally altered oceanic crust subducted into the Earth’s mantle (Lecuyer and Ricard 1999). As a part of an investigation of the $\text{Na}_2\text{CO}_3$-$\text{Fe}_2\text{CO}_3$-$\text{MgCO}_3$-CaCO$_3$ system, the corresponding binary systems have to be examined. Since phase relations in the $\text{Na}_2\text{CO}_3$-$\text{MgCO}_3$, $\text{Na}_2\text{CO}_3$-$\text{CaCO}_3$, $\text{Fe}_2\text{CO}_3$-$\text{MgCO}_3$, $\text{MgCO}_3$-$\text{CaCO}_3$, and $\text{CaCO}_3$-$\text{Fe}_2\text{CO}_3$ systems at 6 GPa have been already studied (Buob et al. 2006; Gavryushkin et al. 2014; Shatskiy et al. 2013a, 2013d, 2014), here we present new experimental data on phase relations in the $\text{Na}_2\text{CO}_3$-siderite system at 6 GPa and 900–1700 °C. Using obtained data we discuss a possible topology of the ternary $\text{Na}_2\text{CO}_3$-$\text{Fe}_2\text{CO}_3$-$\text{MgCO}_3$ system and the influence of iron component on melting in the petrologically important system $\text{Na}_2\text{CO}_3$-$\text{CaCO}_3$-$\text{MgCO}_3$. 