Effect of water on carbonate-silicate liquid immiscibility in the system KAlSi₃O₈-CaMgSi₂O₆-NaAlSi₂O₆-CaMg(CO₃)₂ at 6 GPa: Implications for diamond-forming melts

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ABSTRACT

To clarify the effect of water on carbonate-silicate liquid immiscibility in the diamond stability field, we performed experiments in the system KAlSi₃O₈-CaMgSi₂O₆-NaAlSi₂O₆-CaMg(CO₃)₂ under nominally dry and hydrous conditions by adding 1.5 wt% H₂O at a pressure of 6 GPa and temperatures of 1000 to 1500 °C. Both systems start to melt at 1050–1100 °C. Under anhydrous condition the melting occurs via the following reaction: 6KAlSi₃O₈ (K-feldspar) + 6CaMg(CO₃)₂ (dolomite) = 2(Ca₉Mg₆)(Al₁Si₁₂O₃₆) (garnet) + Al₂SiO₅ (kyanite) + 11SiO₂ (coesite) + 3 K₂Ca₉Mg₆(CO₃)₂ (carbonatitic melt) + 3CO₂ (fluid and/or liquid), where n ~ 0.3–0.4. The carbonatitic melt has the following composition 38(K₀.₆Na₀.₄)₂CaMg(CO₃)₂O₆, 62Ca₉Mg₆(CO₃)₂O₈. A second immiscible silicic melt containing (in wt%, volatile free) SiO₂ = 68.8, Al₂O₃ = 12.6, CaO = 3.7, MgO = 2.4, Na₂O = 1.0, and K₂O = 11.3 appears at 1250 °C. Both melts remain stable up to 1500 °C and coexist with the clinopyroxene ± garnet ± coesite residue. In the presence of water stored away in phengite, the melting begins with silicic melt, which contains (in wt%, volatile free) SiO₂ = 61.4, Al₂O₃ = 13.5, CaO = 4.7, MgO = 3.0, Na₂O = 2.2, and K₂O = 13.3, and coexists with phengite, dolomite, clinopyroxene, and coesite. The phengite + dolomite assemblage remains to 1100 °C and disappears at 1200 °C producing two immiscible melts carbonatic with approximate composition, 19(K₀.₈Na₀.₁₂)₂CaMg(CO₃)₂O₆, 81Ca₉Mg₆(CO₃)₂O₈, and silicic containing (in wt%, volatile free) SiO₂ = 63.3, Al₂O₃ = 15.6, CaO = 4.5, MgO = 3.0, Na₂O = 2.0, K₂O = 11.6. The present results imply that partial melting of continental material subducted to a depth of 200 km can yield simultaneous formation of two immiscible melts, K-dolomitic and K-alumino-silicate. Under dry conditions, carbonatic melt appears earlier (at a lower temperature). Given the low density and high mobility of this melt, it must rapidly percolate upward, leaving a refractory eclogite-like residue and leaving no chance for the formation of a second alumino-silicate melt. However, under hydrous conditions silicate melt appears earlier than carbonatic melt, leaving a phengite- and dolomite-bearing residue, which finally yields the formation of two immiscible silicic and carbonatic melts. The compositions of these melts fall in the compositional range of carbonatic and silicic high-density fluids (HDFs) in diamonds worldwide. Thus, we suggest that the presence of water is a necessary requirement for the formation of immiscible HDFs inclusions in diamonds, and this suggestion is strongly supported by natural data from HDFs.

Keywords: Carbonate-silicate liquid immiscibility, K-feldspar, phengite, carbonated pelites, high-density fluids, diamond formation, high-pressure experiment, Earth’s upper mantle; New Advances in Subduction Zone Magma Genesis

INTRODUCTION

Compositions of inclusions in diamonds from kimberlites worldwide indicate that highly potassic carbonatic and silicic melts/fluids, so-called high-density fluids (HDFs), have existed at the base of the continental lithosphere during the most of the Earth’s history (Smith et al. 2012; Shirey et al. 2013). HDFs are believed to be responsible for mantle metasomatism and the formation of the lithospheric diamonds (Navon et al. 1988). Unlike peridotite- or eclogite-derived melts (Yaxley and Brey 2004; Dasgupta and Hirschmann 2007; Brey et al. 2008), HDFs are characterized by abnormally high concentrations of alkalis, especially potassium (Bulanova et al. 1988; Navon et al. 1988; Novgorodov et al. 1990; Schrauder and Navon 1994).

It was recently found that potassic aluminosilicate and potassic-dolomitic melts, similar to silicic and carbonatic HDFs in diamonds, are immiscible and can be formed by partial melting of carbonated pelites at 6 GPa (Shatskiy et al. 2019). However, the anhydrous pelite melting begins from