

KIMBERLITES, FLUIDS, AND DIAMONDS: ACTIVITY RELATIONS IN THE SYSTEM Mg-Ca-Al-K-C-O-H

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Textural and chemical features of kimberlite and diamond genesis focus on magmatic conditions (Wylie, 1980; Eggler, 1974). However, the existence of a significant aqueous fluid component in the mantle has been recognised (Ryabchikov and Boettcher, 1980; Schneider and Eggler, 1986; Taylor and Green, 1988; Clement et al., 1991). H₂O-rich fluid inclusions in diamonds are the most spectacular physical evidence, and suggest that at least some diamond growth in the presence of an H₂O-bearing aqueous phase, as opposed to crystallization strictly from a magma (Navon et al., 1989; Turner et al., 1990; Schrauder and Navon, 1993, 1994). One means of representing the equilibrium relationship between a fluid and its constituent minerals is through activity diagrams, in a manner similar to that for hydrothermal systems (Johnson and Norton, 1985). In this context the serpentinization of kimberlite can be modeled in terms of activity relations between the fluid and the dominant minerals present.

We initiate this approach by looking at the fluid responsible for the serpentinization of kimberlite. It is believed that the kimberlite is a crystalline mush at the time of emplacement and that fluids play a role in the eruption and serpentinization of the kimberlite (Clement, 1982). During serpentinization, olivine is altered to serpentine, calcite, and/or phlogopite. Groundmass minerals such as diopside and monticellite also experience alteration. Serpentinization is best developed in the diatreme facies of the kimberlite, at approximately 3 km depth. From this relation a pressure of 1 kb is chosen and is treated as constant during serpentinization. Primary minerals are nearly end-member phases, activity for a given aqueous component is designated by square brackets [], H₂O activity is set at unity. Chrysotile, lizardite, and antigorite are known alteration products of kimberlite, whereas talc is rare (Mitchell, 1986). Chrysotile was chosen for this study, and by plotting the logK_{reaction} for chrysotile-forsterite and forsterite-talc at 1 kb, it was established that chrysotile is first appears as a stable phase at ~420°C. Activity diagrams have been constructed near the phase stability condition for chrysotile, at 500°C and at 400°C.

Activity boundaries are obtained by combining the hydrolysis reactions for minerals of interest, as in the example for forsterite-chrysotile:



The reactions are balanced on SiO₂ as quartz is never observed as an alteration phase in kimberlite:



$$\text{at } 400^\circ\text{C, } 1 \text{ kb:} \quad \log K_{\text{eq}} = \log \left[\frac{\text{Mg}^{+2}}{[\text{H}^+]^2} \right] = 5.5$$

The minerals forsterite, talc, monticellite, diopside, and chrysotile are plotted against $\log[\text{Mg}^{+2}]/[\text{H}^{+}]^2$ and $\log[\text{Ca}^{+2}]/[\text{H}^{+}]^2$ activities. The fluid is in equilibrium with the primary mineralogy olivine in a matrix of diopside and/or monticellite. Calcite is also a primary mineral, and a calcite saturation surface is projected into activity space to establish the $\log[\text{CO}_2\text{g}]$. Magnesite is seldom observed in kimberlite, and the magnesite saturation surface lies well above the chosen assemblage.

The onset of serpentinization is restricted to a maximum depth of 3 km as chrysotile is not stable at pressures higher than 1 kb. Serpentinization is an emplacement phenomenon; the occurrence of serpentine (i.e. chrysotile) as a primary magmatic phase is unlikely. Modeling supports the observation that olivines are often completely altered to serpentine whereas monticellite and diopside are relatively fresh. Serpentinization can take place by changing T at constant P and does not require the introduction of fluids from external sources. If this fluid is sufficiently enriched in CO_2 , it may be capable of forming microdiamonds prior to or during emplacement of the kimberlitic magma (Levinson and Pattison, 1995). Additional modeling of fluids in equilibrium with reduced carbon phases is underway.

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