

THE ROLE OF CARBON DIOXIDE IN THE GENERATION AND EMPLACEMENT OF KIMBERLITE MAGMAS: NEW EXPERIMENTAL DATA ON CO₂ SOLUBILITY

Dreibus¹, G., Brey¹, G., Girnits², A.

1. Max-Planck-Institut für Chemie, Abt. Kosmochemie, Postfach 3060, 55020 Mainz, Germany

2. Institute for Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry, Staromonetny 35, Moscow 109017, Russia

The abundance of primary calcite in kimberlites and the explosive mode of eruption suggest an important role of CO₂ in kimberlitic magmatism. Brey et al. (1991) have shown that CO₂ solubility in a melt similar to the average group 1A kimberlite increases from 5 wt% at 20 kbar to 11 wt% at 40 kbar. They also predicted that at pressure above 45 kbar it increases sharply and could be as high as 20-30 wt% at 50-60 kbar. Here we present new experimental results on CO₂ solubility in such melts at 45-55 kbar. We used four starting mixtures which were similar to the material studied by Brey et al. (1991) except for lower Na₂O and some variations in CaO and MgO contents (Table 1).

Table 1. Compositions of starting materials used for the CO₂ solubility experiments (in wt%, recalculated to a 100 wt% volatile-free basis).

Mix.#	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅
Kmg1	35.2	1.87	3.33	9.77	39.0	8.52	0.19	0.95	0.95
Kmg2	33.6	1.78	3.18	9.32	41.8	8.13	0.18	0.91	0.91
Kca1	36.0	1.91	3.41	10.0	35.1	11.2	0.20	0.98	0.98
Kca2	35.2	1.87	3.33	9.77	34.2	13.3	0.19	0.95	0.95
K*	36.4	1.93	3.45	10.1	35.4	8.81	0.81	1.0	1.0

K* - starting material from Brey et al. (1991)

The starting mixtures were prepared from oxides and carbonates (CaCO₃ and MgCO₃), bulk CO₂ content equaled to approximately 30 wt%. The experiments were carried out on a belt apparatus in sealed platinum capsules, 4 mm i.d., 5 mm high. The kimberlitic material was in direct contact with the platinum container, however very short exposures at run temperature (15 min) kept iron loss low (<15%, Brey et al., 1991). Oxygen fugacity was not buffered, but graphite was never found in run products, indicating oxygen fugacities above CCO buffer. At such conditions CO₂ is the dominating fluid component. The majority of experiments were conducted above the liquidus of the studied kimberlites and only quench carbonates and silicates were observed in the run products. In some cases equilibrium orthopyroxene crystals were found in amounts of no more than a few percents. All charges

contained gas bubbles especially numerous in the upper portion of the capsules. Bulk carbon was determined in the quench products by an infrared analyzer after oxidation in an induction furnace. Two or three pieces from different parts of each charge were picked and analyzed separately. The results showed the homogeneity of the run products, the difference between CO₂ concentrations obtained for various parts of a single sample was always below 1 wt%. The average CO₂ contents are shown in Table 2.

Table 2. Run conditions and average CO₂ concentrations.

Mix#	P, kbar	T °C	CO ₂ , wt%
Kmg1	55	1700	21.2
Kmg1	47	1650	20.2
Kmg2	55	1700	22.9
Kmg2	45	1640	20.2
Kca1	55	1700	20.6
Kca1	47	1650	15.6
Kca2	55	1710	21.2
Kca2	47	1650	20.0
Kca2	50	1650	17.3

The CO₂ solubility appeared to increase moderately with increasing pressure and fraction of divalent cations (Ca, Mg and Fe) in the melt. Comparison with lower pressure results of Brey et al. (1991) confirms the predicted sharp increase of CO₂ solubility in kimberlitic melt at 40 - 45 kbar.

The saturation of kimberlite with CO₂ affects significantly its near-liquidus phase relations (Girnis et al., submitted). At 55 kbar garnet and magnesite crystallize together with orthopyroxene already at 1670°C, which is very close to liquidus (Table 2). At lower CO₂ contents much higher pressures are required to stabilize garnet on the liquidus of such low-alumina melts. Ringwood et al. (1992) reported garnet crystallization in the 1A kimberlite at more than 100 kbar under fluid-undersaturated conditions with bulk CO₂ concentration of 5 wt%.

Proceeding from the phase equilibrium and solubility results we suggest that the initial melts of group 1A kimberlites were equilibrated with carbonated garnet harzburgite at the base of the continental lithosphere where the melts became CO₂ saturated. The sharp decrease of CO₂ solubility at approximately 45 kbar resulted in vigorous degassing at this level. The separation of 10 wt% of CO₂ fluid, as pressure decreased from 50 to 40 kbar, reduced the bulk density of kimberlite magma by approximately 4-5%.

Together with the decrease of magma viscosity this might trigger rapid magma ascent towards the Earth's surface. At pressures between 45 and 40 kbar a substantial portion of CO₂ escapes from the kimberlitic melt, whereas further ascent to depths corresponding to approximately 10 kbar does not result in significant degassing. The exsolved carbon dioxide may separate during its way through the lithosphere from the kimberlitic magma which reaches the upper levels of the Earth's crust containing only moderate amounts of volatiles as observed in kimberlites. The formation of kimberlite diatremes is related to the second episode of extensive degassing at pressures below 10 kbar when CO₂ solubility falls rapidly again with decreasing pressure.

Brey G.P., Kogarko L.N., Ryabchikov I.D. N. Jb. Miner. Mh., 1991, 159-168.

Ringwood A.E., Kesson S.E., Hibberson W., Ware N. Earth Planet. Sci. Lett., 1992, 113, 521-538.