

Composition of carbonatite melts and conjugate silicate liquids

Oxide	1	2	3	4	5	6	7	8	9	10
SiO ₂	2.94	6.56	4.50	1.60	6.43	9.33	44.46	32.38	42.12	32.51
TiO ₂	0.45	1.66			0.94	0.81	0.73		2.28	1.70
Al ₂ O ₃	1.95	1.09	0.40	0.36	0.80	0.91	14.68	8.62	14.79	7.76
FeO _{tot}	4.61	10.66	2.30		4.18	4.12	5.41		7.92	6.65
MgO	14.19	3.68	0.92		1.00	10.93	0.65		0.91	10.49
MnO		0.25			0.23				0.18	
CaO	21.29	34.50	31.59	55.46	37.16	29.19	11.13	42.92	12.77	16.14
Na ₂ O	4.99	5.74	16.35	0.28	7.27	3.56	11.07	6.22	8.91	6.60
K ₂ O	0.35	2.41	5.17		1.73	2.34	5.73		3.53	3.34
P ₂ O ₅	0.48	5.92	1.21		0.56	2.19	0.23		0.12	1.41
CO ₂		28.17								
Total	51.49	100.00	62.44	57.70	60.30	63.37	94.09	90.14	93.53	86.60

- (1) Carbonatite melt produced in equilibrium with a peridotite source (column 3 of Table 1 in ref. 1). (Total includes Cr₂O₃ = 0.22.)
- (2) Carbonatite parent magma of Twyman and Gittins⁶.
- (3) Immiscible carbonatite melt FH24 of Freestone and Hamilton⁴, $P = 7.6$ kbar, $T = 1,100$ °C.
- (4) Immiscible carbonatite melt KH11 of Kjarsgaard and Hamilton⁵, $P = 5.0$ kbar, $T = 1,250$ °C.
- (5) Immiscible carbonatite melt BK208 of Kjarsgaard and Hamilton (unpublished), $P = 5.0$ kbar, $T = 1,000$ °C.
- (6) Immiscible carbonatite melt BK193 of Kjarsgaard and Hamilton (unpublished), $P = 6.0$ kbar, $T = 1,200$ °C.
- (7) Conjugate silicate liquid to (3).
- (8) Conjugate silicate liquid to (4).
- (9) Conjugate silicate liquid to (5).
- (10) Conjugate silicate liquid to (6).

components. The distribution of elements between immiscible liquids is strongly affected by pressure, temperature and the bulk composition of the system¹, with compositional effects being particularly important (see Fig. 6 of ref. 4). Kjarsgaard and Hamilton⁵ used compositions containing only five components (SiO₂-Al₂O₃-CaO-Na₂O-CO₂), so the immiscible carbonatite liquids produced could not contain FeO, MgO, P₂O₅ and the like. Gittins was correct to point out that these melts were poor in Si O₂ and Al₂O₃ (see column 4 of the table), but again this could be the result of pressure, temperature and composition. Our more recent (unpublished) results show that the addition of TiO₂, MgO, FeO, F and P₂O₅ ensures that these components occur in the immiscible carbonate melt, and also that the addition of these components affects the partitioning of Al₂O₃ and SiO₂ between immiscible melts such that the carbonate liquids contain noticeably higher contents of these two elements.

The table shows that we have produced, by immiscibility, carbonate liquids whose compositions compare favourably with those considered to be "realistic carbonatite parent magmas" by Gittins (compare columns 5 and 6 with columns 1 and 2). Furthermore, the conjugate alkali silicate liquids produced in these experiments (compare columns 9 and 10) have compositions that are suitable as parent magmas for the attendant alkali silicate rocks found in carbonatite complexes.

Gittins² suggests that the next step in testing the primary-melt model of ref. 1 is to examine rare-earth element concentrations. Hamilton *et al.*⁷ have made this test for an immiscible silicate/carbonate system, using lavas from Oldoinyo Lengai as

starting materials. Rare-earth element concentrations for the Oldoinyo Lengai phonolite and natrocarbonatite⁸ are used in ref. 7 to calculate a set of natural rock partition coefficients, and these compare very well with those derived from the experiments at 3 kbar and 1,050 °C.

Any debate on carbonatite magma genesis should include proper consideration of the viability of the immiscibility hypothesis. This process, in conjunction with fractionation, can convincingly account for both the major- and trace-element contents of carbonatites as well as the associated alkali silicate rocks.

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GITTINGS REPLIES—The proponents of liquid immiscibility as the explanation for carbonatite magmas consider the experimental demonstration that various carbonate and silicate liquids are immiscible up to at least 8 kbar pressure to be proof that the carbonate and silicate liquids separated from a common parent magma, whereas I maintain that one must demonstrate not only the existence of liquid immiscibility but also a derivative relationship. In my view this requires the formation of a single quenchable liquid from the two immiscible liquids. Such a liquid might be the hypothetical CO₂-rich nephelinite (or phonolite) that is invoked by Le Bas⁹. If it exists in nature it should be possible to make it in the laboratory.

Until this is done we can only examine the natural rocks for evidence of a CO₂-rich nephelinite that has fractionated to a stage just short of single-liquid instability,

and ascertain what sort of rock it is. We find no such rock — only simple olivine nephelinites and nephelinites.

The postulated parental magma of ref. 6 is not completely correct (for example, the P₂O₅ content is too high) but it is a useful beginning. Some of Kjarsgaard and Hamilton's immiscible carbonate liquids are similar but they and the K_D values of the table are relevant to the problem only if carbonatite magma separates immiscibly from a silicate parent (which is not yet proved) and if the contents of rare earths and other elements such as Nb, P, Sr, Ba, F and Cl are sufficiently high in the parent silicate magma for partitioning to produce the characteristic carbonatite element concentrations. In saying that the next step in testing the primary melt model of ref. 1 would be to examine the rare-earth element concentrations, I was simply making the point in my News and Views article² that unless the liquid of ref. 1 contains the necessary major- and trace-element concentrations it is not a viable parental carbonatite magma. The fact that Hamilton *et al.* have successfully partitioned rare earths into a carbonate liquid at the expense of an immiscible silicate liquid is interesting, but irrelevant to evaluating ref. 1.

I might also point out that if the experiments in ref. 7 used only CO₂ as a transporting fluid they are of limited value because the mobility of CO₂ is restricted to a depth corresponding to 27 kbar, the pressure at which silicate carbonation reactions fix CO₂. Something capable of transporting elements at greater depths is required, and our (unpublished) work suggests that fluorine plays a major part in this and in just about every other aspect of carbonate liquid systems.

Carbonate/silicate liquid immiscibility exists. But is it merely a physical property of silicate and carbonate magmas or does it control their genesis? Do these magmas separate as conjugate liquids from a single mantle-derived parent, or are they each the result of separate mantle-melting events? Is immiscibility a relatively late-stage, upper-crustal process of minor petrological significance, or the principal process by which carbonatite magma is generated?

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1. Wallace, M.E. & Green, D.H. *Nature* **335**, 343 (1988).
2. Gittins, J. *Nature* **335**, 295–296 (1988).
3. Streckheisen, A. *Nues. Jb. Miner. Abh.* **134**(1), 1 (1978).
4. Freestone, I.C. & Hamilton, D.L. *Contr. Miner. Petrol.* **73**, 105–117 (1980).
5. Kjarsgaard, B.A. & Hamilton, D.L. *Miner. Mag.* **52**, 43 (1988).
6. Twyman, J.D. & Gittins, J. in *Alkaline Igneous Rocks* (eds Fitton, J.G. & Upton, B.J.G.) 85–94 (Geol. Soc. spec. Pub. **30**, 1987).
7. Hamilton, D.L. *et al.* in *Carbonatites: Genesis and Evolution* (ed. Bell, K.) (Unwin & Hyman, London, in the press).
8. Gerasimovskiy, V.I. *et al. Geokhimiya* **5**, 515–530 (1972).
9. Le Bas, M.J. in *Alkaline Igneous Rocks* (eds Fitton, J.G. & Upton, B.J.G.) 85–94 (Geol. Soc. spec. Pub. **30**, 1987).