

SOURCE MANTLE, RESIDUUM AND PARTIAL MELT COMPOSITIONS DEDUCED FROM THE KIMBERLITE RECORD

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After consideration of phase equilibria and petrographic characters (O'Hara 1973a,b) compositions have been selected as representing best available estimates of undepleted source rock and depleted residuum in the upper mantle sampled by kimberlite diatremes from data presented or cited by Berg (1973), O'Hara et al (1973). Compositions based on the data of Berg (1973) are systematically slightly richer in MgO than those based on data of O'Hara et al (1973).

I One method of interpreting these results, and its conclusions are discussed by O'Hara et al (1973) involving use of a best fit to observed rock types.

II An alternative approach is to select chemical analyses of garnet-lherzolite and either garnet-harzburgite or harzburgite, and to calculate the composition of the liquid which must be extracted from garnet-harzburgite in any particular amount in order to obtain the observed residuum. The spread of 'average' analyses creates large uncertainties in this calculation. An 'acceptable' fit is shown in table 1A and in fig 1 in relation to the maximum possible spread consistent with both sets of average compositions. Low silica and extremely high MgO and FeO characterise all such solutions, pointing to ultrabasic liquids as the only plausible extracts. Knowing the Fe/Mg ratio of the residue and applying the empirical Fe/Mg distribution coefficient derived by Roeder and Emslie (1971), it is possible to choose within the linear range of table 1A those compositions yielding the best fit. This criterion suggests that a composition with close to 32% MgO constituting a 12-20% partial melt will provide an internally consistent model.

Table 1A Compositions of plausible liquid extracts (primary magmas) to cause observed variation in ultrabasic nodules from kimberlite.

	(a)	(b)	(c)	(d)	(e)
SiO ₂	45	44	42.5	41.5	40.5
Al ₂ O ₃	3	4.5	6	7	8
FeO	8.5	10	11.5	13.5	15
MgO	38	34	30	26	22
CaO	2.6	3.8	4.7	6	7
Na ₂ O	.4	.8	1.2	1.6	2

Table 1B Approximate percentage of source garnet-lherzolite converted to liquid in each case using average garnet-lherzolite of Berg 1973 (1) or O'Hara et al (2).

(1)	21	14	10	8	7
(2)	37.5	23	17	13	11

A liquid intermediate in composition between columns (b) and (c) satisfies the equilibrium Mg:Fe distribution coefficient (see fig 1).

III Alternatively the same calculations can be made using individual selected analyses of garnet-peridotite and garnet-harzburgite or harzburgite from the published data tables. The subjective element and the consequences of sampling errors tend to become dominant, even though this technique offers the possibility of choosing individual rocks free from alteration or contamination.

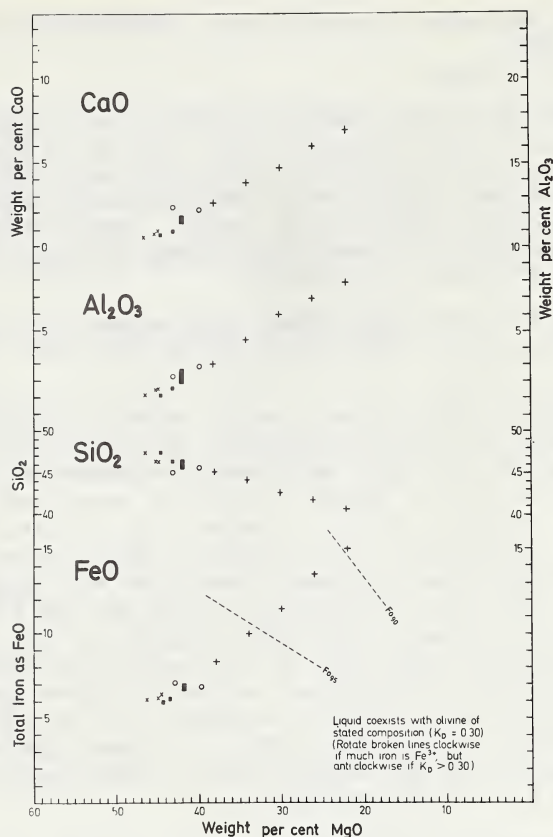


Fig 1 Oxide plot v. MgO (volatile free) showing average harzburgite, garnet lherzolite from Berg (1973; X-symbols) and O'Hara *et al* (1973 fig 1, filled boxes). Two open circles represent two relatively fertile garnet-lherzolites (Berg 1973) which nevertheless are very much less fertile than 1032 (MF) of O'Hara *et al* (1973 fig 1). Large + symbols indicate tabulated selected liquid compositions (table 1).

Methods I, II, III described above lead to identification of the composition and amount of primary magma which was actually produced during the partial melting events which most profoundly affected the upper mantle sampled by kimberlite. Significantly, the pressure required to stabilize the required phase equilibria is high and the deduced liquid product very scarce at the earth's surface, particularly in recent geological times.

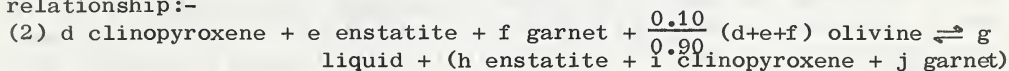
The next method attempts to calculate the liquid composition which will be produced by partial melting of garnet-lherzolite under some known or assumed form of the phase equilibria, starting from the composition of the coexisting minerals.

IV In partial melting of garnet-lherzolite, the change is expressed by the relationship (derived from O'Hara and Yoder, 1967):-

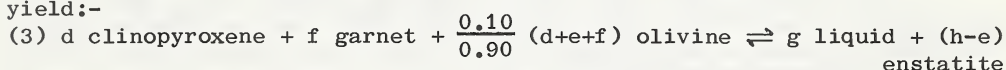
$$(1) \ a \text{ clinopyroxene}_{ss} + b \text{ garnet}_{ss} + (1-a-b) \text{ olivine} = c \text{ liquid} + (1-c) \text{ enstatite}_{ss}$$

quantities a,b,c (weight fractions) are not precisely known, and vary with pressure. Moreover, the compositions of the clinopyroxenes

undergoes major changes in the content of potential garnet and enstatite with both P,T. Nevertheless, this relationship offers the possibility of obtaining an approximate linear solution for the compositions of the liquids which might be produced in partial melting of a particular garnet peridotite. Data from O'Hara and Yoder (1967) and Davis and Schairer (1965) indicate that the quantity $(1-a-b)$ is of the order of 0.10 at 30-40 kb. The liquid composition produced when all garnet and clinopyroxene have been consumed in partial melting may then be obtained from the relationship:-



where clinopyroxene, enstatite, etc. are the analysed compositions of these minerals in the low temperature subsolidus assemblage of the garnet peridotite, and d, e,j are absolute weight fractions in the peridotite, d and f being known from the mode. For the purpose of this approximate calculation, the quantities i, j, representing solid solution components in the enstatite are assumed to be small, and the extra enstatite dissolved in the clinopyroxene at the solidus (e) may be transferred, to yield:-



and this has been solved for the trial cases where $0.10 (d+e+f)/0.90=0.10 (d+f)$ and $0.20 (d+f)$ respectively, and $(h+e)$ ranges from +0.20 to -0.20. The amounts, (g of equation III) and compositions of the calculated 'liquids' are presented, these analyses and percentages representing linear ranges within a possible primary magma might be. The nature of the calculation is displayed diagrammatically in fig 2.

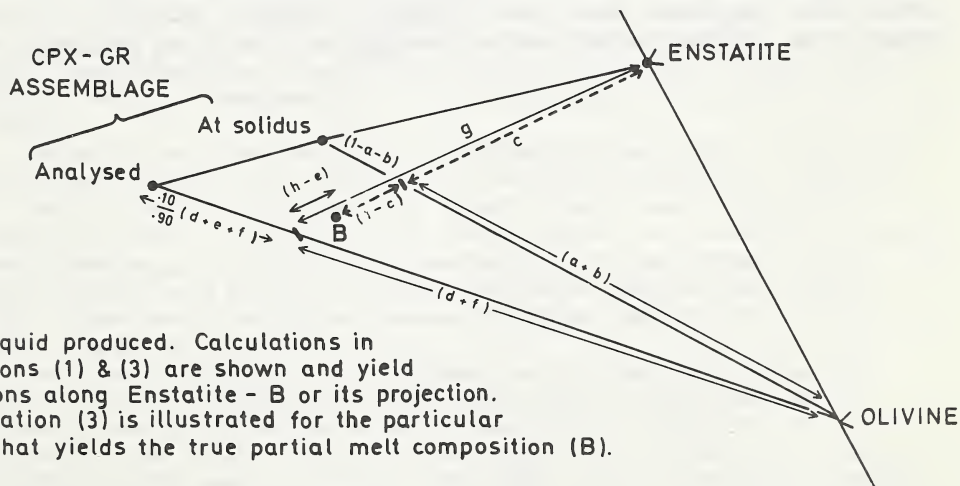


Fig 2

The obvious fallacy in this first trial calculation is that it assumes that all end-member components in each mineral solid solution contribute equally to the liquid product. This is not true, conspicuously so in the case of the Na and Ca clinopyroxene components, the Cr and Al pyroxene

and garnet components, the Fe and Mg components of all minerals, and the Ni component of olivine. The liquids, therefore, should have higher values of Na_2O , Al_2O_3 and FeO than calculated from (3) and lower values of MgO, NiO.

A correction procedure has been adopted for FeO and MgO, based upon the Roeder and Emslie (1970) relationship and an indicated $\text{Mg}/(\text{Mg}+\text{Fe}) = 0.95$ in the residual minerals (from petrography of residual harzburgites). While retaining the same total number ($N_{\text{FeO}+\text{MgO}}$) of molecules of FeO and MgO in the compositions, the number to be calculated as FeO (N'_{FeO}) has been increased, and that to be calculated as MgO (N'_{MgO}) decreased, until
$$\frac{5}{95} \frac{N'_{\text{MgO}}}{N'_{\text{FeO}}} = 0.3.$$

The weights of FeO, MgO corresponding to N'_{FeO} , N'_{MgO} have then been calculated, reinserted in the original compositions and the totals rescaled to 100%. The results represent an approximate linear series of solutions which should include the composition of the primary magma which might be formed by partial melting of natural garnet lherzolite at 30-40 kb pressure (90-120 km depth).

References

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