

Superimposing magma chamber and melting regime processes: how easy is it to (mis)interpret the liquid products?

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Choice of partial melting model. Less-than-perfect fractional melting processes (O'Hara 1993) yield liquid products which quite closely simulate products of equilibrium partial melting (EPM); a useful first approximation is that the partial melting event supplies a liquid which is an EPM product of the true source region composition.

Choice of magma chamber process. Less-than-perfect fractional crystallisation processes (O'Hara 1993, O'Hara and Mathews 1981) in magma chambers yield liquid products which quite closely simulate those of equilibrium partial crystallisation (EPC) of the *gross input to the magma chamber*, including any materials assimilated from the roof and walls; a useful first approximation is that the partial crystallisation event supplies a liquid which is an EPC product (the equations are identical to EPM) of the average magma chamber input composition.

Simplifying assumptions. In this formulation the space problem is ignored and contamination by assimilation of country rock or previously erupted lavas assumed to be non-existent. It is further assumed that the distribution coefficient, d , for each element remains constant throughout both processes and is the same in each process.

A simple two-stage model. The simplest two-stage model of a 'real' system in which erupted

liquids have trace element concentrations which have been controlled both by variations in the partial melting process and by modification of liquid compositions within a magma chamber assumes that an EPM product of the true source region, with mass fraction f_1 of melt formed, is the average input composition into a magma chamber where events simulate the effects of EPC crystallisation with mass fraction f_2 of the input material emerging as lava. Then the concentration of an ideal trace element in the erupted lava, C_L , is related to that in the extracted partial melt, C_E , and that in the original source material (mantle), C_O , by $C_L/C_O = (C_L/C_E) \times (C_E/C_O) = 1/\{f_1-d(1-f_1)\} \cdot \{f_2-d(1-f_2)\}$ which in turn decomposes into $C_L/C_O = 1/\{[f_1f_2 + d(1-f_1f_2)] - d(1-d)(1-f_1)(1-f_2)\}$.

Properties of this simple relationship. This has the form of an EPM or EPC equation with the product, f_1f_2 , substituted for the single mass fraction of melt but with an additional 'discrepancy' term to be subtracted in the denominator. This term causes a maximum *increase* in the value of C_L/C_O when $d = 0.5$, very large and rapidly growing *decreases* in the value of C_L/C_O when $d \gg 1$, and has negligible effect on C_L/C_O when d is close to 1 or close to zero - i.e. the *highly incompatible trace elements will be uniquely insensitive to the fact that a two stage model is involved* and will be readily interpreted as though their liquid had been produced by EPM of whatever was the gross input to the magma chamber, using the product of the two mass fractions of melt really involved!

The reciprocal concentration relationship. The direct relationships for C_E/C_O , C_L/C_E are hyperbolic; the relationships for reciprocal relative concentration are linear, of the form $C_O/C_E = (1-d)f_1 + f_1$; $C_E/C_L = (1-d)f_2 + f_2$ while that for $C_O/C_L = (1-f_1f_2)d + f_1f_2 - d(1-d)(1-f_1)(1-f_2)$ which departs from linear as shown in Fig.1. The maximum shortfall from a fit to the straight line $C_O/C_L = (1-f_1f_2)d + f_1f_2$ at $d = 0.5$ when $f_1 = 0.1$, $f_2 = 0.7$ (10% melt, 30% later fractionation) is ~ 0.067 or 14% of the value on the ideal straight

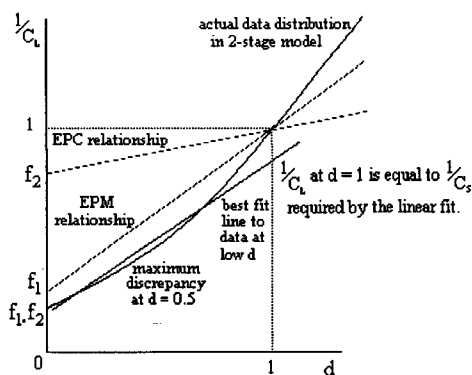


FIG. 1.

"Observed" data set created with $c_s=1, f_1=0.01, f_2=2$. Three minima were found and the curves corresponding to each are labelled with the respective putative values of c_s . The data set is dominated by relative concentrations for highly incompatible elements, and the best fit ($C_s=4.06$) satisfies these, but fits the compatible elements poorly. Fits with lower values of C_s (2.12, 1.25) yield a better fit for the more compatible elements but require proportionally much smaller putative values of f to yield the required relative concentrations of the highly incompatible elements.

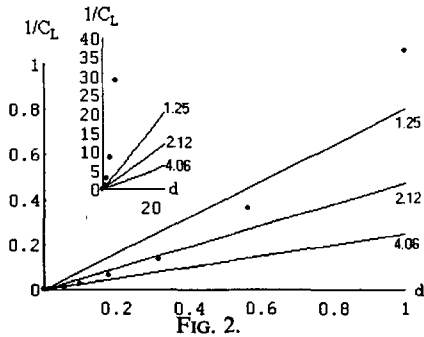


FIG. 2.

This data set gave an extremely unstable fit with at least three minima being found:-

- $C_s=4.06, \phi=0.008$, Sum of squares of differences = 7063
- $C_s=2.12, \phi=0.004$, Sum of squares of differences = 43272
- $C_s=1.25, \phi=0.002$, Sum of squares of differences = 115407

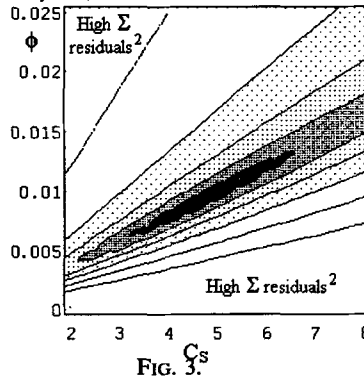


FIG. 3.

line - a discrepancy not necessarily much greater than the combined uncertainties from sampling and analytical errors and uncertainties about the values of distribution coefficients to be used.

Fitting two-stage products with a one-stage model. Hypothetical data sets have been synthesised for a number of sets of values for f_1 and f_2 , each with in-built random errors of up to 10% - an extreme case is plotted in Fig. 2 together with lines for three least squares best fits of these data to the arbitrary single stage melting relationship $C_s/C_L=(1-f)d + f$ where C_s , the initial concentration levels in the source, and f , the apparent mass fraction of melting, are allowed to be independent variables. Fig. 3 contours the values of the sum of squares of residuals as a function of variations in C_s and f used in achieving this fit. The result is, however, sensitive to the range of d -values from which data are chosen for fitting; exclusion of data for compatible elements biases the result towards higher C_s and lower f . An

alternative view of the problem is provided in fig. 4 where actual results for two stage models are shown normalised to the EPM/EPC surface for various values of C_s . Good fit in one part of the range of d is achieved only at the expense of poor fit elsewhere; concentrating on the incompatible elements, there is a some pressure to choose a source region with a value of C_s which approaches 2 times the true source value.

The scope for misinterpretation. Data sets for products of superimposed EPM-EPC liquids, especially the data for incompatible elements alone, can readily be interpreted as products of a single stage EPM event even when the equivalent of more than 30% crystallisation has taken place in the magma chamber (although there will be a tendency to nominate an 'enriched' source, possibly with mysterious depletion of the most incompatible relative to less incompatible elements). This 30% is sufficient to explain the widespread low-pressure cotectic character of so many erupted basic magmas. The ability to explain the trace element data without recourse to a magma chamber event is *not evidence that such events have not taken place*. Aspects of the trace element data provide a 'window' through into source region characteristics *only if there have been no damaging effects in the magma chamber* (e.g. roof assimilation, Soret diffusion between layers in a double diffusive stack).

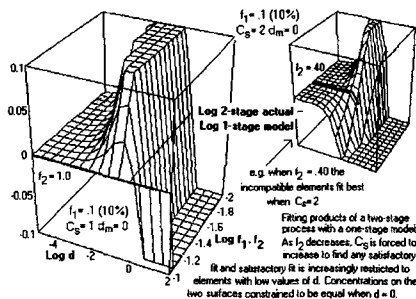


FIG. 4.

References

O'Hara, M.J. (1993) In Prichard, H.M. *et al.* (eds) *Magmatic Processes and Plate Tectonics*. Geol. Soc. London Spec. Publ. 76, 39-59.