

THE GRAPHICAL ANALYSIS OF MIXING RELATIONSHIPS - RATIO:RATIO PLOTS; J.C. Butler, Geosciences, University of Houston, Houston, TX 77004

The role of mixing in igneous petrology has been debated for nearly 100 years and continues to be of interest due to the increasing number of accurate and precise bulk rock analyses. Langmuir et al. (1) showed that the mixing equation of Vollmer (2) is applicable to the analysis of binary mixtures as portrayed in three different forms of plots: (1) oxide-oxide; (2) oxide-ratio; and (3) ratio-ratio. Mixtures of intermediate composition were formed by blending magma 1 and xenolith from Wilcox (3). Mixing produces perfect linear relationships between all pairs of measured components; thus, oxide-oxide plots of mixtures should exhibit a linear pattern.

When ratio-ratio plots are prepared (Figure 1), mixtures of intermediate composition will plot as a hyperbole with curvature controlled by the relative amounts of the denominator components (2). Failure of such plots to exhibit a hyperbolic pattern are taken as an indication that mixing is not a viable mechanism. All of the intermediate points on the hyperbolic curve must have ratios of their denominators that are proportionately intermediate to the two mixing end members. As a measure of the consistency of the denominator ratios Langmuir et al. (2) suggest preparation of a companion plot in which one of the original ratios is plotted against the ratio of the denominators of the two ratios so that the two ratios have a common denominator. If all of the samples are consistent with a mixing model the companion plot will exhibit a linear pattern (2). One of the two possible companion plots for Figure 1 is presented in Figure 2. It should be noted that the samples align in the proper sequence within the mixing range.

It is well known (4) that the formation of ratios with a common denominator from uncorrelated parts will induce a positive correlation among the ratios. The greater the difference between the coefficient of variation of the denominator variables and those of the numerator variables, the greater the induced positive correlation between the ratios. Can this induced (or spurious) correlation be strong enough to mimic a mixing model for a data set in which the components are uncorrelated? One hundred values for each of the 7 variables in the reference data set were simulated to have means and standard deviations equal to those of the reference set but with zero correlations. The companion plot analogous to that in Figure 2 for the simulated set is given in Figure 3. The strong positive correlation (+0.98) by itself certainly appears to confirm an origin by mixing of two end members. However, in this case the strength of the relationship is a measure of the size of the coefficient of variation of the denominator (0.45) relative to those of the numerators (0.06 and 0.07). A ratio-ratio plot analogous to Figure 1 for the simulated data set is given in Figure 4. A comparison of Figures 1 and 4 would surely dismiss an origin by mixing hypothesis. Langmuir et al. (2) argue that companion plots (see Figures 2 and 3) should be called upon to confirm mixing. Failure to construct oxide-oxide plots (such as in Figures 1 and 4), however, might lead the investigator to falsely assume conformity to a mixing model as portrayed in Figure 3.

Langmuir et al. (1) illustrate a number of potentially useful extensions to the analysis of mixtures that can be applied once the role of mixing has been verified. Verification, however, requires familiarity with

the effects of ratio formation as most mixing models are constructed so that a linear pattern confirms the model. Formation of ratios with common denominators may either enhance or detract from a true mixing situation and, although probably of infrequent occurrence, could be solely responsible for the linear pattern.

## REFERENCES

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 (2) Langmuir, C.H., Vocke, R.D., Hanson, G.N. (1978), *Earth Planetary Science Letters*, 37, 380-392. (3) Wilcox, R.E. (1976), *Evolution of Igneous Rocks*, Princeton University Press, 205-224. (4) Butler, J.C. (1976), *Amer. Geophysical Union*, in press.

