CAN TRACE ELEMENT DISTRIBUTIONS RECLAIM TECTONOMAGMATIC FACIES OF BASALTS IN GREENSTONE ASSEMBLAGES?

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During the past two decades many words have been written both for and against the hypothesis that the tectonic setting of a suite of igneous rocks is retained by the chemical variability within the suite. For example, Pearce and Cann (1) argued that diagrams can be constructed from modern/recent basalt subcompositions within the system Ti-Zr-Y-Nb-Sr such that tectonomagmatic settings can be reclaimed. If one accepts their general conclusion, it is tempting to inquire as to how far this hypothesis can be extended into other petrological realms. If chemical variations of metabasalts retain information relating to their genesis (tectonic setting), for example, this would be most helpful in reconstructing the history of basalts from greenstone belts.

Pearce and Cann (1) type diagrams are prepared by selecting a training set for which the tectonic settings of all of the analyses are known and obtaining a projection in which overlap of the fields of the known groups is minimized. IF, the training set is representative of a larger target population of interest, the projection may allow assignment of an "unknown" (an analysis not part of the training set) to one of the recognized groups. As the ratios of the variables are retained when percentages are formed, the search for such fields presumes that there are limits on the ratios of the three variables which identify a particular tectonomagmatic setting. The selection of three components and projection onto the plane of the ternary, however, does ignore potentially useful information and one could argue that a dimension-reducing procedure such as principal components analysis might lead to a more satisfactory and potentially useful display form.

However, a successful analysis of date with any multivariate procedure requires more than an understanding of the procedure itself. Additionally, the form of the data should be such that statistical procedures can be rationally interpreted. The subcomposition Ti-Zr-Y-Sr, for example, is part of a set of percentages and therefore subject to all of the concerns previously expressed by Chayes (2), Butler (3) and others concerning difficulties in interpreting both statistical measures of relationship (such as the correlation coefficient) and empathetic analysis of "patterns and trends" expressed in some compositional sub-space.

Simply stated, a set of composition percentages contains a mix of information from at least two sources:

(1) physical/chemical relations among the variables

(2) a change in the structure of the data as a result of a transformation such as percentage formation.

Statistical procedures typically allow one to recognize a behavior pattern that departs from a hypothesized expected behavior. The difficulty in interpreting percentages arises as a result of the mix of information noted above. For example, given a statistically significant correlation between Zr and Ti, can one automatically assume that contribution from the mechanical process of forming percentages is negligible? Is it possible, in fact, that the mechanical process is the only one operative for a given measured relationship? Can the investigator separate these two effects in a given situation and assess their influence?

Until recently (Aitchison, 4,5) these questions received a great deal of discussion and warning (Chayes, 2 and Butler, 3) but no defined solution. Aitchison (4,5) presents a set of procedures that ultimately are designed to allow an invstigator to make use of information contained within a set of percentages and these procedures are adequately described in the literature. A training set of average Ti-Zr-Y-Sr analyses of 35 modern basalts (including 24 from Pearce and Cann (1) and 11 drawn from the current literature) with known tectonic settings was drawn from the literature Space is insufficient to tabulate these raw data and details will be published elsewhere; copies of the raw data, however, are available from the author).

Aitchison's tests for basis independence (4) and complete subcompositional independence (5) both reject their respective null hypotheses (6). Thus, the investigator is assured that the mechanical contribution is not dominant and that a physical-chemical interpretation is warrented. Each analysis was normalized to its geometric mean and eigenvalues and associated eigenvectors extracted from the variance-covariance matrix of the resulting log-row-centered data using principal components analytical procedures. The first two eigenvalues account for some 92% of the total variance and a plot of the first two principal component scores is given in Figure 1. The boundaries are empirical and constructed so as to isolate the known tectonomagmatic groups. The distribution of scores successfully delineates (1) the Within Plate Basalts, (2) the Ocean Floor Basalts, and (3) the Arc Basalts. The principal component scores are computed as follows:

$$\text{Score 1} = -0.371*Ti-0.067*Zr-0.399*Y+0.836*Sr$$

$$\text{Score 2} = -0.338*Ti-0.560*Zr+0.740*Y+0.158*Sr$$

where the individual variables are expressed in log-row-centered form. In keeping with Pearce and Cann's suggestions (1), Ti is defined as TiO_2 times 100 and Y is defined as 3Y. As one is dealing with a logarithmic function, multiplication by a constant changes the scale of the resulting projection but not the spatial relationships. Ten sets of analyses from the literature were cast into the space defined in Figure 1. In general, the tectonomagmatic settings predicted from Figure 1 are in excellent agreement with interpretations by the respective authors. Of prime concern in this case, however, is the effect of metamorphism on such subcompositions. Many authors (1) have noted that Sr is easily mobilized during low to intermediate grade metamorphism whereas Ti, Zr and Y remain relatively constant. Three of the 35 analyses are plotted in Figure 2 with additions and subtractions of 10% and 30% total Sr. These sets of points define sets of straight lines which are subparallel to the X-axis. Note that the "trend" of these lines is such that it

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may be possible to differentiate between Within Plate and Plate Margin Basalts (Ocean Floor plus Arc) if the above model for Sr mobilization holds.

Perhaps a combination of detailed knowledge of the geology of a particular greenstone assemblage plus judicious use of diagrams analogous to Figure 1 will enable the investigator to see through effects which heretofore may have masked petrogenetically significant information.

References: (1) Pearce, J.A. & Cann, J.R. (1973), Earth planet. Sci. Lett., 19, 290. (2) Chayes, F., (1971) Ratio Correlation, Univ. Chicago Press, Chicago, Ill. (3) Butler, J.C. (1979) Amer. Mineral., 64, 1115. (4) Aitchison, J. (1981) Math. Geol., 13, 175. (5) Aitchison, J. (1984) Math. Geol., 16, 617. (6) Woronow, A. & Butler, J.C., (1986) Comp. and Geos., in press.

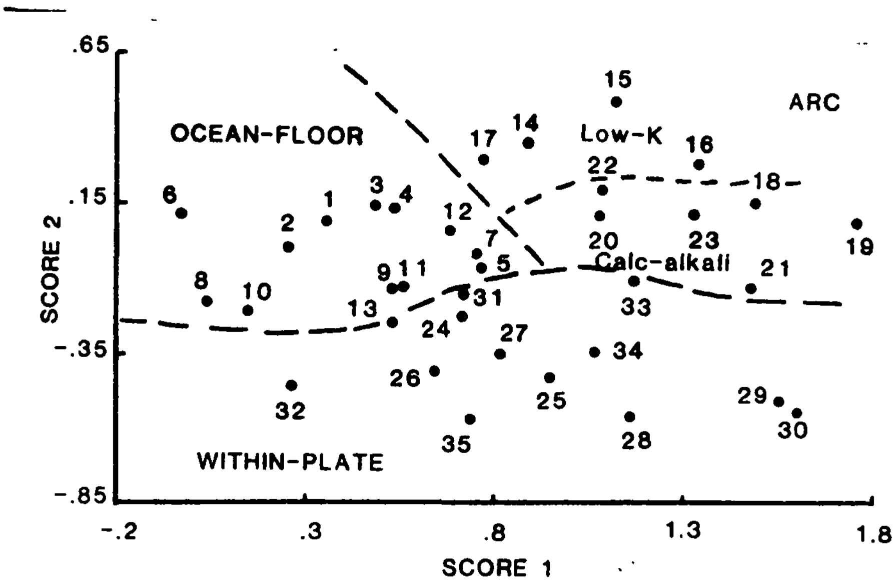

FIGURE 1. A plot of the first two principal components for the training set of 35 basalt analyses. Numbers refer to specific analyses which are available as a separate from the author. Boundary curves are empirical and drawn to isolate the tectono-magmatic facies.

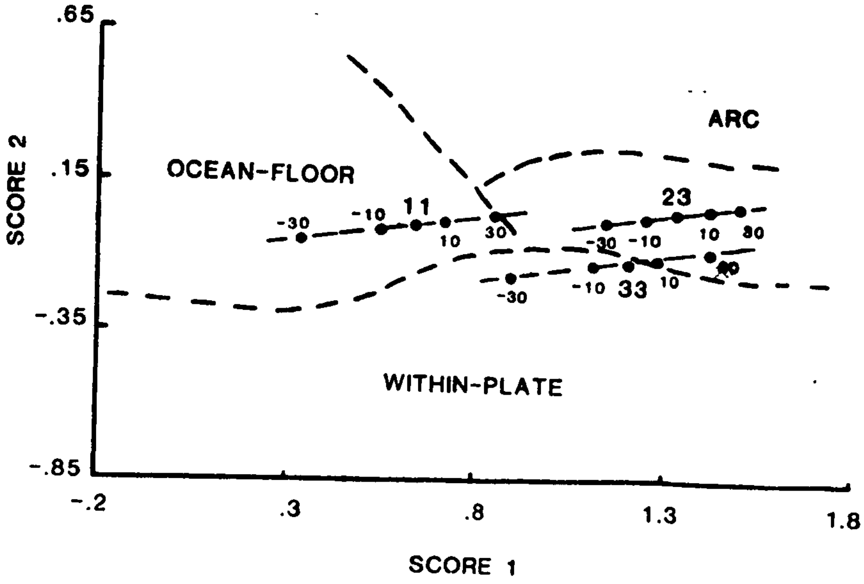

FIGURE 2. Additions and subtractions of 10% and 30% Sr for three of the basalt analyses in the space defined by the first two principal components. Note that the trends are parallel to each other and sub-parallel to the boundary between the Within Plate and Plate Margin facies.