# 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

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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:

Score 1 = -0.371*Ti-0.067*Zr-0.399*Y+0.836*Sr
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
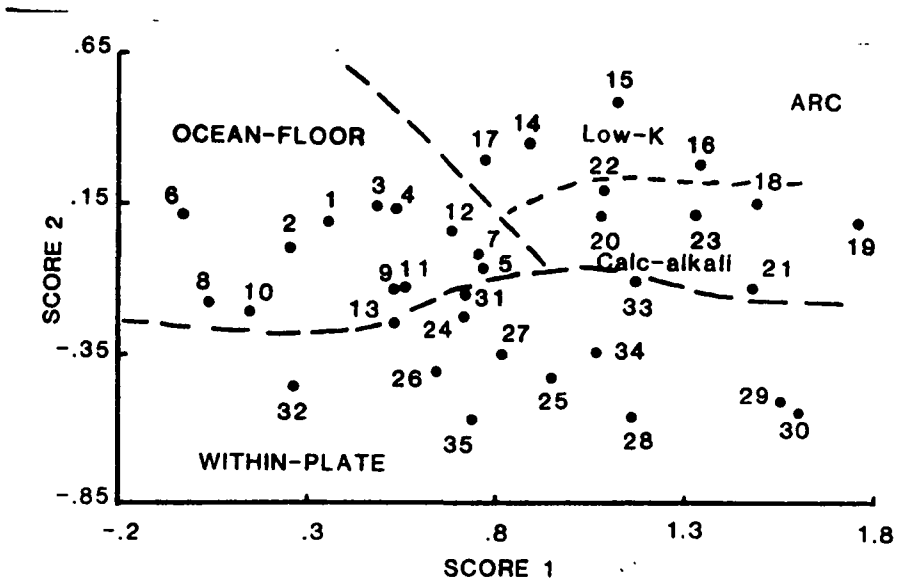isolate the tectono-
magmatic facies.



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.