DEPARTMENT OF
MINERALS AND ENERGY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

1972/137

STATISTICAL STUDY OF THE GEOCHEMISTRY OF META-IGNEOUS ROCKS OF THE EASTERN CREEK VOLCANICS AND SOLDIERS CAP FORMATION, MOUNT ISA - CLONCURRY AREA, QUEENSLAND.

by

S. Henley

1972/137

STATISTICAL STUDY OF THE GEOCHEMISTRY OF META-IGNEOUS ROCKS OF THE EASTERN CREEK VOLCANICS AND SOLDIERS CAP FORMATION, MOUNT ISA - CLONCURRY AREA, QUEENSLAND.

by

S. Henley

SUMMARY

This Record constitutes a chapter on statistical analysis to be incorporated in a Bulletin on the Proterozoic basic metavolcanic successions, Mount Isa - Cloncurry area.

Multivariate statistical methods are applied to data for 23 elements on 62 samples of meta-basalt, metadolerite and amphibolite to determine relationships among variables and among samples, and in an attempt to distinguish between the rocks of the two formations (Eastern Creek Volcanics and Soldiers Cap Formation) on the basis of their geochemistry.

Factor analysis indicates the various types of alteration, but is not an ideal methods for investigating chemical relationships in these suites of rocks; nonlinear mapping (Q-mode and R-mode) clarifies the relationships among the variables and illustrates the chief differences between the behaviour of elements in the two groups of rocks.

STATISTICAL STUDIES

Analyses of 20 elements[1] and % H_2O and CO_2 on 27 samples from the Eastern Creek Volcanics (E.C.V.) and 35 samples from the Soldiers Cap Formation (S.C.F.) volcanics were subjected to R-mode factor analysis in an attempt to determine (a) what are the associations among the elements and (b) how many factors control the chemical variations observed.

Lacking clear results from the factor analysis, a 'non-linear mapping' (Sammon, 1969) was then performed to find the inter-relationships among the samples, and a modification of Sammon's method was employed to clarify the relationships among the variables.

1. FACTOR ANALYSIS

Principal components analysis (to extract the maximum variance components of the data as orthogonal vectors) followed by Varimax rotation to orthogonal simple structure, gave a factor matrix which was then rotated by the Promax method to oblique simple structure. By following this procedure, one hopes to partition the variables into a small number of factors, which may be mutually correlated, such that each variable appears dominantly in as few factors as possible; variables with similar geochemical behaviour will appear in the same factors, with the same sign, those with strong antipathetic relationships will appear in the same factors, but with opposite signs, and those which are uncorrelated will appear in different factors.

(i) Eastern Creek Volcanics: Four factors account for 74% of the variance; factor loadings on the variables and correlations between factors are listed in Table 2. A number of points may be extracted from this table: Mg, Cr, and Ni have high negative loadings, as do Ca and Al, while high positive loadings are found on Ti, Fe, Na, P, and Zn, in factor 1; this apparently represents an inverse relationship between a characteristically 'early' group on one hand and a group of typically 'late' elements on the other.

In the second factor, Cr, Ni, and Zn correlate positively with H_2O and CO_2, and negatively with Si, K, and Cu, suggesting perhaps some hydrothermal process in which the samples with higher water and carbonate contents tend to be enriched in Cr, Ni, and Zn and depleted in Cu, K, and Si.

The third factor, with Mn and V opposing P and S, suggests an oxidation process; deposition of Mn oxides accompanying depletion of sulphides and phosphates. Factor 4, with Si, Rb, Sr, Zr, Ba, and CO_2 opposing Fe and Al, may represent replacement of the feldspars, pyroxenes and amphiboles by quartz, carbonates, and biotite (which frequently contains much Rb and Zr).

---

[1] Variables studied were Si, Ti, Al, Fe^3, Fe^2, Mn, Mg, Ca, Na, K, P, H_2O, CO_2, S, 3V, Cr, Ni, Cu, Zn, Rb, Sr, Zr, Ba. Values used for Fe were obtained by application of the transformation suggested by Irvine and Baragar (1971): $\%Fe_2O_3 = \%TiO_2 + 1.5$ except when there is insufficient iron, when all iron is quoted as Fe_2O_3.

(ii) Volcanics of the Soldiers Cap Formation: It takes 6 factors to account for 80.8% of the variance; the Promax factor loadings and correlations are listed in Table 3.

These factors are less easily interpreted than those for the Eastern Creek Volcanics. Factor 1 contains positive loadings on P, Zr, and Si, and negative on Mg, Cr, Ni, presenting a contrast between typically late and typically early elements.

The second factor, with iron-related elements opposing Si, Al, H_2O, and Sr, appears to reflect an antipathetic relationship between salic minerals and opaque minerals. Factor 3, with loadings only on K, Cu, Ni, and CO_2, repeats even more clearly the pattern shown by factor 2 for the E.C.V. rocks - potassium and copper, though chemically quite different, behave coherently, in both the E.C.V. and S.C.F., during alteration processes.

Factor 4, with positive loadings on Ca, CO_2, and Sr and negative loadings on Si and Na, represents carbonatisation of the feldspars, while Factor 5 contains only one significant loading on Mn.

Factor 6 contains very high positive loadings on Zn, Rb, and Ba, correlated with S and P, and evidently represents some process of hydrothermal alteration: the lack of any correlation between factors 3 and 6 demonstrates that there are at least two distinct types of hydrothermal alteration, with copper typical of one and zinc of the other.

2. NONLINEAR MAPPING

Interpretation of the results of factor analysis is difficult and frequently unconvincing, and thus it is desirable to try an alternative approach. Nonlinear mapping, hitherto used in information retrieval and pattern recognition, was recently applied to a problem in the geochemistry of stream sediments (Howarth, 1972) and appeared to be of great potential value in clarifying relationships in multivariate geological data. The method was devised by Sammon (1969) and has been extended by Henley (1972) to study relationships among variables.

Given a triangular distance matrix or correlation matrix derived from multi-dimensional data, the nonlinear mapping method generates a matrix as close to it as possible, from a two-dimensional array. Plotting the valuesof this array then gives a plane diagram showing an optimum degree of structure of the data.

(i) Distance matrix:

The entire data matrix of 58 samples and 23 variables was subjected to nonlinear mapping, and the resultant two-dimensional array was plotted (Fig. 1). There are a number of striking features of this plot:

(a) the majority of analyses of both E.C.V. and S.C.F. volcanics lie on a single straight line - they belong to the same suite of rocks,

(b) the fields of E.C.V. and S.C.F. rocks are almost coincident,

(c) following from (b), most analyses of each group lie within the field of overlap,

(d) by examining the analyses of a few of the rocks on the linear trend, it is found that the trend represents variation mainly in Si and Ca contents; the S.C.F. rocks to the right are generally more Ca rich, and the E.C.V. rocks to the left more Si rich (perhaps representing simply variation in the content of calcic plagioclase),

(e) the rocks which lie off the trend are characterized by some sort of alteration, deuteric, hydrothermal, or otherwise.

(ii) Correlation matrix:

The data (as used in the previous section) were subjected to R-mode nonlinear mapping, and the results are presented in Figs. 2, and 3. These are optimal two-dimensional representations of the relationships among the variables in (a) the Soldiers Cap Formation and (b) the Eastern Creek Volcanics, and give a much clearer picture than was obtained from factor analysis.

(a) Soldiers Cap Formation (Fig. 2). There are a number of distinct associations of elements to be seen in this diagram. The very close correlation of Ti and Fe^3 is, of course, artificially produced by the use of the Irvine & Baragar (1971) transformation.

Fe^2, Mn, and V form a coherent group in the diagram, as do Mg, Cr, and Ni, closely correlated with Ca, Al, Sr, and H_2O. Zn, Rb, and Ba are very closely grouped, far from K (and indeed from any other elements). Si and CO_2 lie close together, and K, Cu, and Na display a somewhat less definite association.

These element associations may be assigned tentative interpretations in terms of the mineralogy of the rocks. The large Mg, Ca group may be related to the content of Mg-rich amphibole, chlorite, etc., and Ca-rich plagioclase; the negative correlation between this group and the Fe, Mn, V, and Na, K groups suggests a broad early magmatic/late magmatic variation.

The close Si, CO_2 correlation suggests that variation in Si content may be related to silicification/carbonatization processes. The Rb, Zn, Ba correlation is difficult to explain, but may tentatively be attributed to biotite, into which all three elements are commonly concentrated.

(b) Eeastern Creek Volcanics (Fig. 3). Associations between elements generally appear less close than in the S.C.F. rocks, suggestive of a tendency to metasomatic redistribution. There is still good coherence among Mg, Ni, and Cr, and Ca and Al display good correlation, though the Mg and Ca groups are now distinct. The Fe, Mn, V group of the S.C.F. rocks has disintegrated, Fe and Mn now being widely separated, and V being closer to K, H_2O, and the Rb, Ba group.

Cu and S are very closely correlated, indicating the probable presence of a copper-bearing sulphide phase; CO_2 and H_2O lie close together; and Rb and Ba correlate strongly with Sr and Zr: the interpretation of this cluster of elements as due to their concentration in biotite is supported by the presence of Zr, which occurs very commonly in zircon inclusions in biotite.

CONCLUSIONS

Statistical study has shown that the Eastern Creek Volcanics and the Soldiers Cap Formation volcanics are broadly similar and lie on the same variation trend. The different types of alteration are indicated in the factor analyses, in which the chemical effects of silicification/carbonatization and biotitization are all evident. At least one factor in each rock group can be interpreted as due simply to variation between early and late magmatic compositions.

Q-mode nonlinear mapping has shown that the E.C.V. and S.C.F. rocks are essentially similar in chemistry, but the the S.C.F. volcanics exhibit a wider range of compositions and tend to have higher calcium contents. Most rocks of both groups fall within a field of overlap and lie on a single line of variation.

Some of the conclusions may be compared with the findings of Smith & Walker (1971), on greenstones in the Mount Isa mine area. Smith & Walker suggested that by the action of hydrothermal and retrograde metamorphism, iron-rich chlorites were altered to magnesium- and silicon-rich chlorites, and there was a simultaneous loss of copper. At the same time, plagioclase was converted to calcite. As a combined effect of these processes depletion of Ba, Ca, Cu, K, Na, Si, Sr, Co, Fe, Mn, Ni, and Ti took place. Redeposition of some of these elements occurred in secondary calcite/quartz veins which contain some chalcopyrite and other sulphides.

R-mode nonlinear mapping clarifies the relationships among the variables and illustrates the chief differences between the two groups of rocks in terms of element behaviour.

In both E.C.V. and S.C.F. rocks, there is a statistical correlation among Mg, Cr, and Ni, and between Ca and Al. There is also some correlation between Fe^2 and Mn, and a close association of Rb and Ba together with other elements that are commonly concentrated in biotite, apart from K.

The differences in element behaviour are exemplified by the correlations among Fe^2, Mn, and V: in the S.C.F., the three elements are strongly correlated, whereas in the E.C.V., the correlations are very weak. Cu also behaves in markedly different ways in the two rock groups: in the S.C.F., Cu correlates with K, Na, Si, and CO_2, but in the E.C.V. Cu correlates very strongly with S.

In the present study, there is no indication of such drastic alteration of rock compositions by metamorphism and hydrothermal action; in both rock groups, the original magmatic variations may still be recognized, though in the E.C.V. there is some obvious redistribution of elements, with Zr and Sr both concentrating in biotite[1] (Zr as inclusions of zircon), and the correlations among, for example, Fe, Mn, and V, becoming weaker.

---

[1] This interpretation is uncertain owing to the rarity of biotite in the rocks: an alternative interpretation might invoke intergranular phases or trace element enrichment of existing minerals (e.g. feldspars, amphiboles, etc.).

It has been shown in this study that factor analysis is not an ideal statistical method for examing chemical relationships in these suites of rocks, and nonlinear mapping appears to be a more appropriate technique: the small amount of distortion necessarily involved in forced projection into a plane is more than compensated for by the relative ease of interpretation.

REFERENCES

GLIKSON, A.Y., DERRICK, G.M., and HENLEY, S., in preparation - Proterozoic basic metavolcanic successions, Mount Isa - Cloncurry area. Bur. Min. Res. Aust. Bull.

HENLEY, S., 1972 - Plane representation of multivariate data structure. Bur. Miner. Resour. Aust. Rec. 1972/123.

HOWARTH, R.J., 1972 - Author's replay to discussion on Empirical discriminant classification of regional stream-sediment geochemistry in Devon and east Cornwall. Trans. Instn. Min. Metall., 81, B116-9.

IRVINE & BARAGAR (1971) - A Guide to the chemical classification of the common volcanic rocks. Can. J. Earth Sci. 8 p. 523-548.

SAMMON, J.W., 1969 - A nonlinear mapping for data structure analysis. IEEE Trans. on Computers, C-18, p. 401-409.

SMITH, S.E., and WALKER, K.R., 1971 - Primary element dispersions associated with mineralization at Mount Isa, Queensland. Bur. Miner. Resour. Aust. Bull. 131.

TABLE 1. ROCK SAMPLES INCLUDED IN THE STATISTICAL ANALYSIS

Eastern Creek Volcanics	Soldiers Cap Formation
70201001	69200026
70201003	69200028
70201005	69200030
70201007	69200031A
70201008	69200032A
70201009	69200035A
70201010	69200039
70201011	69200043A
70201012	69200043B
70201014	69200045
70201019	69200047
70201020	69200052
70201021	69200058B
70201024	69200066
70201025	69200072
70201027	69200073A
70201032	69200086
70201035	69200090
70201036	69200091
70201037	69200092
70201038	69200096
70201048	69200098
70201059	69200102
70201067	69200107
70201069	69200305
70201072	69200307
70201075	69200308
	69200309
	69200310
	69200311
	69200312

TABLE 2. PROMAX FACTOR PATTERN MATRIX AND FACTOR CORRELATION MATRIX FOR THE EASTERN CREEK VOLCANICS

ELEMENT	FACTOR			
	I	II	III	IV
Si	.009	.648	.145	.653
Ti	.728	-.339	-.202	.200
Al	-.787	-.131	.163	-.469
Fe(3)	.809	-.162	-.214	.177
Fe(2)	.693	-.125	-.051	-.638
Mn	.191	.216	-.814	-.312
Mg	-.954	-.251	-.235	-.086
Ca	-.550	.371	-.094	-.242
Na	.499	-.352	.183	-.215
K	.159	.648	.188	.328
P	.700	-.228	.507	-.263
H (H_2O)	.022	-.806	.077	.391
C (CO_2)	.271	-.537	.139	.520
S	.154	.240	.504	-.070
V	.024	.059	-.817	.333
Cr	-.889	-.522	.042	.136
Ni	-.965	-.466	-.010	.002
Cu	.106	.445	-.095	-.088
Zn	.589	-.400	-.241	-.170
Rb	.027	.061	.008	.972
Sr	-.093	-.131	-.058	.944
Zr	.101	-.131	-.062	.936
Ba	.057	-.031	-.087	.960
Factor				
I		-.269	-.052	.096
II			.039	-.053
III				-.002

TABLE 3. PROMAX FACTOR PATTERN MATRIX AND FACTOR CORRELATION MATRIX FOR THE SOLDIERS CAP FORMATION VOLCANICS

ELEMENT	FACTOR					
	I	II	III	IV	V	VI
S	.433	-.678	-.102	-.498	.005	.006
T	.223	.763	.064	-.088	-.160	.114
Al	-.128	-.547	-.131	-.329	.205	-.055
Fe(3)	.267	.677	.121	.043	-.271	.137
Fe(2)	-.073	.978	-.034	.065	-.174	-.064
Mn	-.075	.425	-.237	.127	-.911	-.102
Mg	-.976	.110	.061	-.103	-.037	.085
Ca	.091	-.138	-.394	.799	.118	-.028
Na	.227	-.111	-.010	-.925	.204	-.122
K	-.259	-.218	.804	-.197	-.153	.098
P	.520	.051	.117	-.105	-.315	.425
H (H_2O)	-.135	-.540	.143	.377	-.109	.095
C (CO_2)	.389	-.028	.559	.528	.350	-.021
S	.034	.107	.276	-.006	.203	.636
V	-.088	.901	-.178	-.098	-.079	-.280
Cr	-.597	-.227	.114	.299	-.164	-.073
Ni	-.751	-.304	.420	.035	-.150	-.178
Cu	-.037	.174	.946	-.026	.420	-.072
Zn	-.002	-.033	-.114	.046	.023	.996
Rb	.011	-.041	-.110	.040	.096	.998
Sr	.340	-.511	-.252	.526	-.156	-.210
Zr	.579	.011	.367	-.183	-.212	-.447
Ba	-.081	-.165	.037	.021	-.100	.972
Factor						
I		.218	.193	-.208	-.113	.112
II			.025	-.171	-.073	.244
III				-.039	-.277	.039
IV					.287	-.132
V						-.158

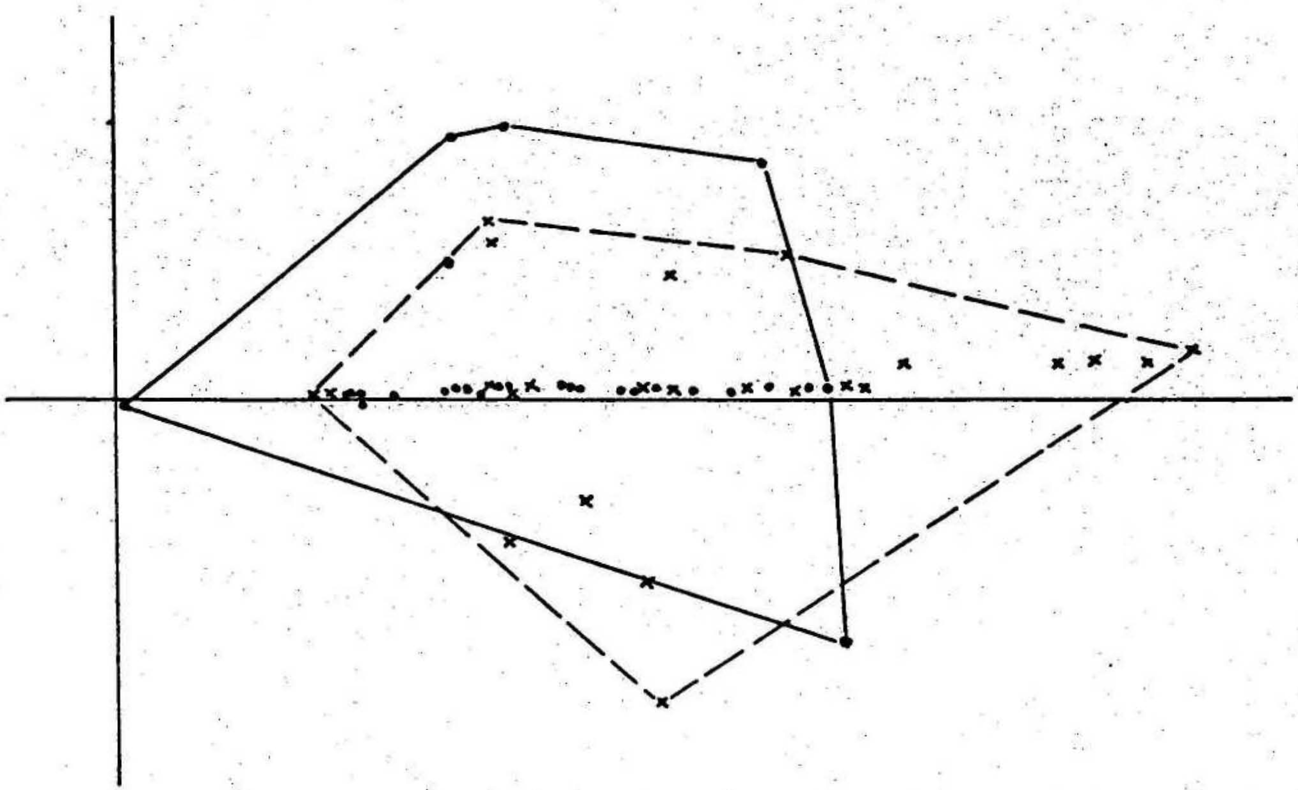

FIGURE 1. Q-mode Nonlinear Mapping for the Eastern Creek Volcanics and Soldiers Cap Formation.

x = Soldiers Cap Formation

. = Eastern Creek Volcanics

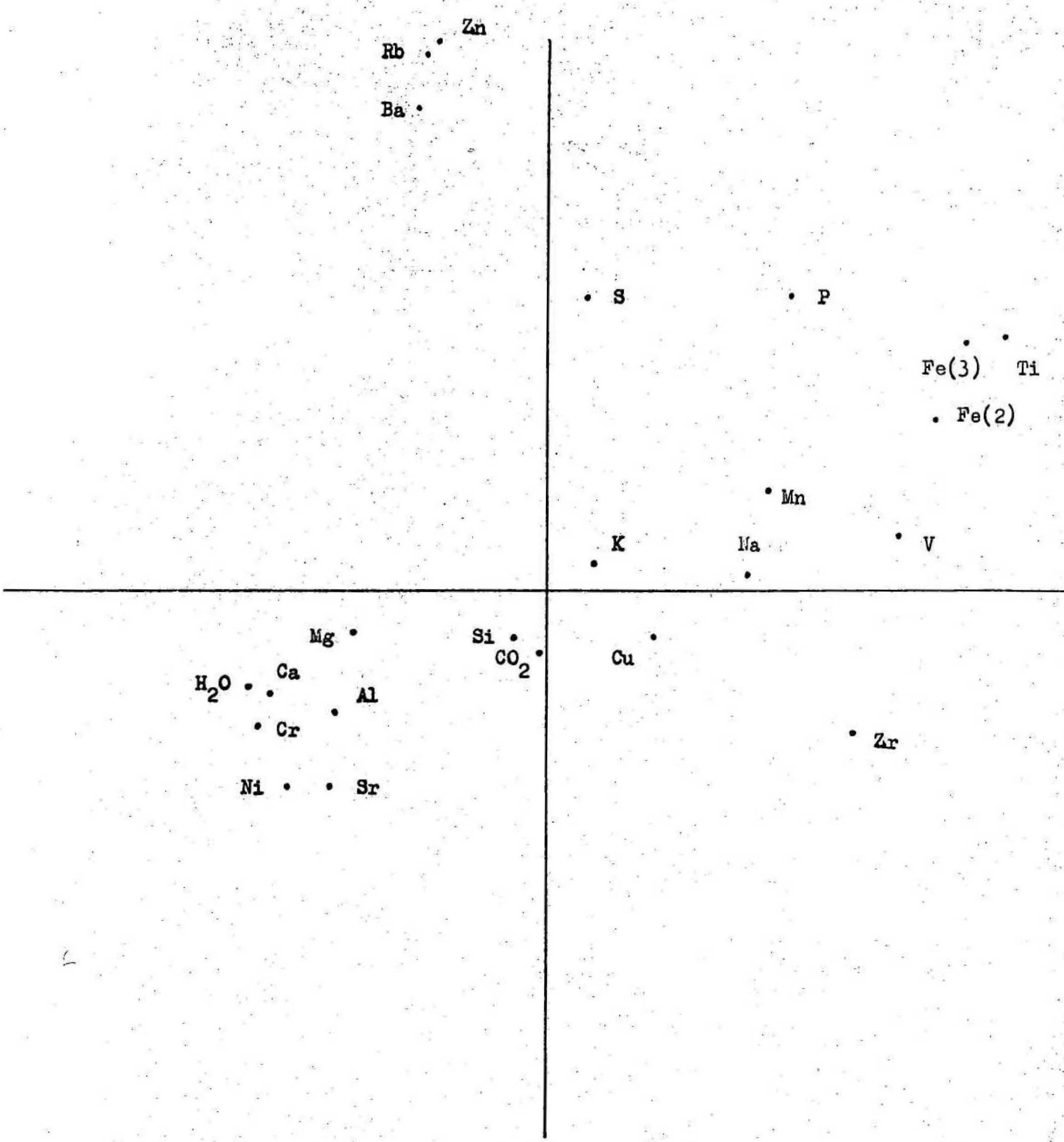

FIGURE 2. R-mode Nonlinear Mapping for the Soldiers Cap Formation meta-volcanics.

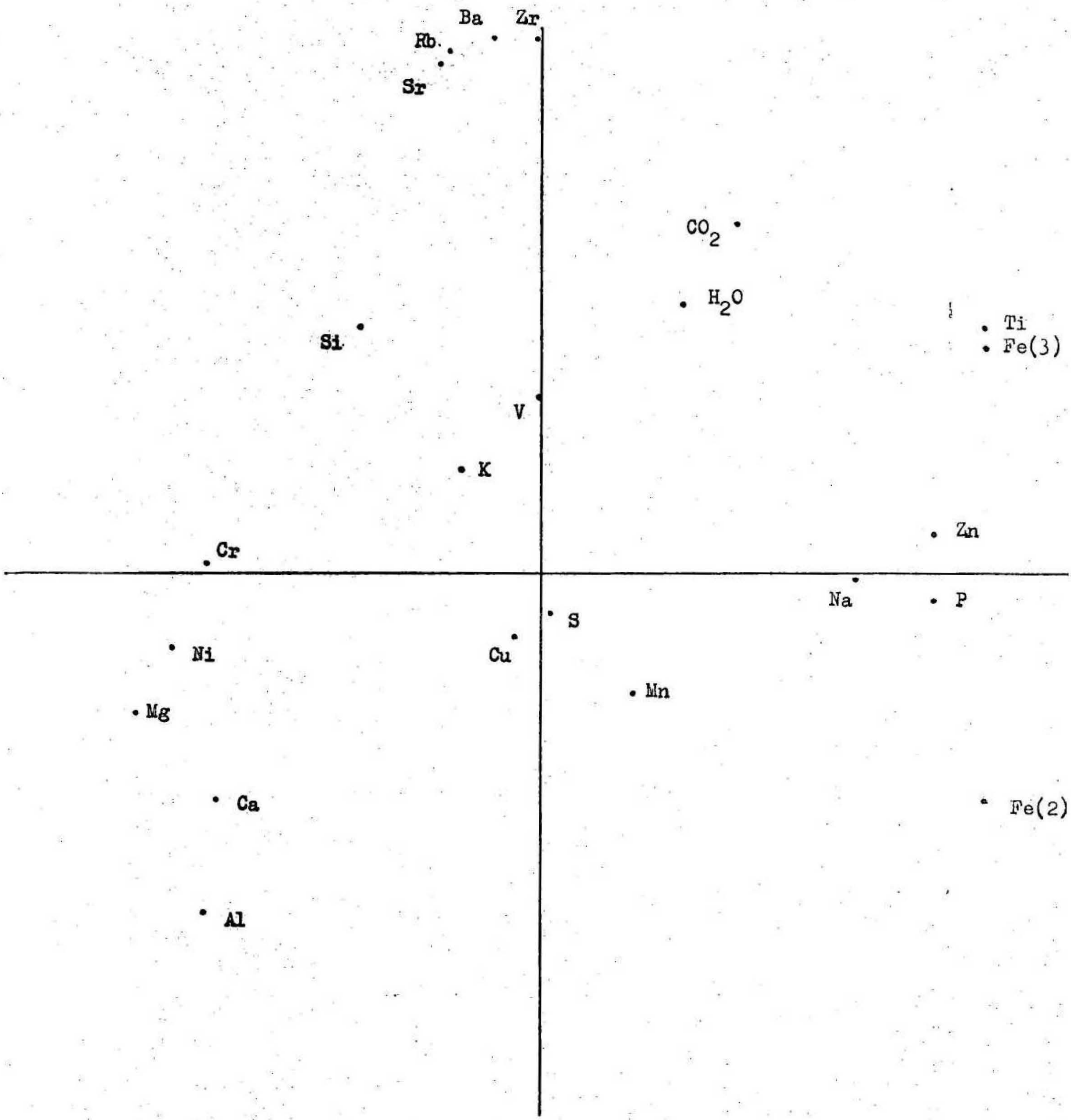

FIGURE 3. R-mode Nonlinear Mapping for the Eastern Creek Volcanics meta-volcanics.