CORRELATIONS AMONG MINERALOGICAL AND SPECIFIC GRAVITY DATA FROM A GRANODIORITE PLUTON[1]

J. ALLAN CAIN

Geology Department, Western Reserve University, Cleveland, Ohio

In the current efforts to quantify geologic data, standard statistical techniques are being applied to geologic information to provide a better understanding of geologic processes. This paper describes the results of linear correlation analysis between each pair of the following variates: quartz percentage, feldspar percentage, feldspar ratio (K feldspar/plagioclase), color index (percentage mafic minerals), and specific gravity.

The unit selected for study is a 40 square-mile pluton in the Precambrian granitic and metamorphic complex of northeastern Wisconsin. The regional geologic setting of this mass (the Newingham Granodiorite) was described by Cain (1961) and summarized by Cain (1963).

RESULTS

A specimen was collected from each of 53 outcrops closest to the intersections of a square mile grid laid in random orientation over the outcrop map. Within each outcrop, the specimen was taken from that part of the exposure nearest the grid intersection. For each sample, modal data were derived from thin sections stained for potash feldspar (Chayes, 1952), using a minimum of 1,400 point-counts per section. Specific gravity determinations were made on specimens weighing from 200 to 300 g to ensure adequate representation of the rock. Details of methodology were given by Cain (1961).

Table 1 shows the data derived from this study. Such raw data are difficult to assess, thus linear correlation coefficients were determined (via IBM 650) for each of the ten pairs of variates. As an aid in interpreting these coefficients, the empirical results of a mineralogical comparison between granite and gabbro are also given for the same pairs of variates (table 2). The variations and relative proportions of minerals in igneous rocks were presented by Pirsson and Knopf (1925: 144) in a diagram which has been reproduced, with little modification, in several standard texts. Thus, it is well known that, in general, plagioclase percentage, color index, and specific gravity decrease in value from gabbro through granite. These three variates would therefore be expected to show positive correlation with each other. Similarly, potash feldspar percentage and quartz percentage increase from gabbro through granite and should be positively correlated. Clearly, each variate that increases in value will show negative correlation with each variate that decreases. Thus, it is possible to predict the behavior of a given pair of variates based solely on this empirical study (table 2). It will be noted, however, that the empirical study yields information only on the type of correlation to be expected (i.e., positive or negative), not the numerical value of the correlation coefficient.

It should be pointed out that correlation analysis does not illustrate changes in the geographical distribution of variates. However, trend surface analysis (Grant, 1957; Krumbein, 1959) is a convenient method for studying such regional variability and was applied to the data in table 1 by Cain (1962).

It also must be emphasized that the causes of observed associations are not given by correlation analysis. For example, one can say that a positive correlation exists betweeen color index and specific gravity because mafic minerals are

[1]Contribution number 5, Department of Geology, Western Reserve University.

TABLE 1

Modal and specific gravity data from a granodiorite pluton in northeastern Wisconsin

Specific gravity	Color index	Feldspar ratio	Quartz %	Feldspar %
2.70	19.54	0.010	24.25	56.20
2.71	20.68	0.053	31.12	48.19
2.69	17.67	0.026	30.94	51.39
2.69	14.00	0.028	30.05	55.95
2.67	10.59	0.009	26.63	62.78
2.71	17.23	0.025	26.31	56.45
2.66	10.67	0.010	35.42	53.91
2.71	15.27	0.136	26.64	58.09
2.71	14.05	0.316	24.95	60.99
2.74	14.03	0.015	31.41	54.56
2.71	23.47	0.162	28.64	54.69
2.72	13.77	0.260	28.99	57.25
2.70	15.82	0.242	23.38	60.79
2.69	12.52	0.125	29.01	58.47
2.69	14.86	0.217	25.15	59.99
2.72	13.55	0.004	32.93	53.51
2.70	12.20	0.059	31.96	55.84
2.70	6.41	0.128	31.44	62.15
2.69	16.59	0.071	28.34	55.07
2.71	18.25	0.000	29.36	52.39
2.69	13.13	0.080	32.66	54.20
2.72	15.68	0.065	25.80	58.52
2.70	14.01	0.052	25.01	60.97
2.71	15.92	0.126	25.49	58.58
2.70	13.77	0.116	29.58	56.64
2.70	11.89	0.092	26.78	61.32
2.68	15.70	0.164	22.52	62.78
2.69	9.10	0.002	32.34	58.56
2.68	13.05	0.183	25.58	61.36
2.70	14.78	0.171	27.99	57.23
2.73	14.73	0.059	32.59	52.67
2.68	8.05	0.005	30.35	61.60
2.70	10.86	0.012	24.81	64.32
2.70	14.67	0.007	32.24	53.09
2.70	10.98	0.011	29.13	59.89
2.69	9.69	0.226	29.89	60.42
2.67	8.41	0.084	35.52	56.07
2.72	12.95	0.117	30.36	56.68
2.70	14.33	0.156	23.80	61.87
2.71	14.43	0.239	23.98	61.58
2.74	10.81	0.094	26.66	62.53
2.70	10.12	0.011	27.17	62.72
2.72	15.45	0.221	28.72	55.83
2.68	9.53	0.108	36.49	53.98
2.70	13.74	0.009	33.25	53.01
2.71	13.33	0.018	32.62	54.05
2.69	10.48	0.266	26.63	62.89
2.68	10.97	0.153	30.51	58.51
2.71	11.07	0.095	33.22	55.71
2.71	12.48	0.109	34.00	53.52
2.71	12.28	0.185	32.66	54.85
2.69	13.71	0.030	31.53	54.76
2.67	6.42	0.211	34.69	58.89

generally heavy, but this is only possible from subject-matter knowledge. Similarly, the explanations of "expected" mineralogical correlations are based on petrologic theory, as illustrated in Bowen's reaction series, whereby systematic and predictable changes in mineralogy are the result of physicochemical factors. Whether these controls are imposed in a crystallizing magma or in the solid state during granitization is a question outside the scope of this paper.

DISCUSSION

A study of table 2 reveals that, although many variates do exhibit the predicted correlation, several pairs of variates show a correlation sign which differs from that expected: quartz per cent/feldspar per cent, and feldspar ratio/quartz per cent are negatively correlated although each variate increases in amount from gabbro through granite and would be thus expected to show positive correlation. Similarly, color index/feldspar ratio, and specific gravity/feldspar ratio show very low positive correlation although negative correlation is to be anticipated.

The anomalous behavior of quartz per cent/feldspar per cent can be readily explained if the nature of the data is considered. By the methods of modal analysis, quartz per cent, feldspar per cent, and color index sum to 100 per cent.

TABLE 2

Comparison of correlations mathematically derived and empirically observed (cf. the sequence gabbro through granite)

Pairs of variates	Linear correlation coefficients (53 specimens)	Empirical observations (sign only)
Feldspar ratio/feldspar %	+0.37	+
Color index/quartz %	−0.37	−
Quartz %/feldspar %	−0.64	+
Feldspar ratio/quartz %	−0.36	+
Color index/feldspar %	−0.45	−
Color index/feldspar ratio	+0.006	−
Specific gravity/quartz %	−0.15	−
Specific gravity/feldspar %	−0.18	−
Specific gravity/color index	+0.38	+
Specific gravity/feldspar ratio	+0.04	−

If A, B, and C = 100 per cent and the value of A alone is increased (or decreased), then B and C must show a percentage decrease (or increase). This will result in positive correlation between B and C caused solely by variation of A. It will also cause negative correlation between A and B, and A and C. It is important to note that such observed correlations are imposed on the data by inherent mathematical relationships and do not reflect, necessarily, meaningful geologic associations.

Clearly, the three major variates (quartz, feldspar, and color index) are not independent as long as they are expressed as percentages. It is understood that Chayes, Griffiths, Krumbein, and Whitten, *inter alios*, are working on solutions to this problem. In the present study, quartz and feldspar are the dominant constituents (table 1), hence the explanation of their observed negative correlation becomes apparent (see Chayes, 1960).

The behavior of feldspar ratio, which is anomalous in its association with three of the four other variates, is less easily understood. This is particularly so since Whitten (1961) gives correlation coefficients for feldspar ratio/quartz per cent, and color index/feldspar ratio which do agree with empirical observations. The recognition of potash feldspar in this study is dependent almost entirely on the effectiveness of the staining technique. Clearly, imperfections in staining could result in fluctuations of feldspar ratio data, and consequently influence their correlation with other variates. This source of possible error was recognized before the collection of data, however, and any thin sections showing little or uneven staining were treated a second time. It is therefore considered that experimental error alone could not account for the observed correlations of feldspar ratio data.

Miller and Kahn (1962: 185) point out that the use of ratio data in correlation analysis can result in apparent negative correlations which are merely indications of spurious correlation. For this to occur, there must be no correlation between the two components of the ratio (in this case, K feldspar and plagioclase). However, there is a recognized negative correlation between K feldspar and plagioclase (Pirsson and Knopf, 1925: 144) and since feldspar ratio in this study is positively correlated with three variates but shows negative correlation with only one, it is considered that the results are not due solely to the use of ratio data.

From a study of the petrography of the granodiorite, it was noted that microcline is present in veinlets and discontinuous rims to plagioclase crystals (Cain, 1961). Therefore, a probable explanation of the feldspar ratio values would be that potash feldspar represents a late stage addition to the rock unit, and thus its behavior (and hence that of feldspar ratio) would not conform to the patterns dictated by "normal" magmatic crystallization.

SUMMARY

Since the petrographic evidence alone would have indicated the probable late-stage addition of potash feldspar, quantitative analysis of the data may seem to have achieved little. It is important to note, however, that the converse is also true in that the anomalous behavior of feldspar ratio values is apparent from a study of correlation coefficients without a petrographic textural study.

The low values of the correlation coefficients may be due to several factors, including (a) a non-linear relationship between some or all of the variates; (b) the variates being grouped into categories which are too general (i.e., color index includes biotite, hornblende, and accessories); and (c) the mineral composition of plutonic rocks not following an entirely systematic and predictable sequence.

In any case, the correspondence between observed and expected correlations is good (except for the effects of data of constant sum), and linear correlation analysis is seen to be a simple statistical method which can be used to geologic advantage. Thus, if these data had been obtained from rocks so fine-grained that no textural information could be obtained and spectrochemical methods were required for mineral determinations, one could predict an anomalous genesis for potash feldspar based solely on observed correlation coefficients. Naturally, such a prediction would involve the assumption that the nature of mineralogical variations in plutonic rocks is similar to that in fine-grained lavas or dikes. Although discussion of this premise cannot be covered in this paper, it is possible that comparison of correlation coefficients and other measures of association and variability from plutonic and volcanic rocks may provide additional information on the origin of granitic rocks (Chayes, 1950, Whitten, 1960).

ACKNOWLEDGMENTS

I am grateful to the Research Corporation for financial support of an investigation which yielded these and other data, and to Drs. J. C. Griffiths, W. C. Krumbein, and E. H. T. Whitten for their discussions of statistical techniques.

REFERENCES CITED

Cain, J. A. 1961. Geology of the Pembine area, Marinette County, Wisconsin. Wisconsin Geol. and Nat. History Survey, open-file report. 105 p.

———. 1962. Petrology of a Precambrian pluton near Pembine, Wisconsin (abstract). Inst. on Lake Superior Geol., Houghton, Michigan. Bull. 8: 5.

———. 1963. Some problems of the Precambrian geology of N.E. Wisconsin: A review. Ohio J. Sci. 63: 7–14.

Chayes, F. 1950. On a distinction between late magmatic and post-magmatic replacement reactions. Am. J. Sci. 248: 22–36.

———. 1952. Notes on the staining of potash feldspars with sodium cobaltinitrite. Am. Mineral. 37: 337–340.

———. 1960. On correlation between variables of constant sum. J. Geophys. Res. 64: 4185–4193.

Grant, F. 1957. A problem in the analysis of geophysical data. Geophysics 22: 309–344.

Krumbein, W. C. 1959. Trend surface analysis on contour-type maps with irregular control-point spacing. J. Geophys. Res. 64: 823–834.

Miller, R. L. and **J. S. Kahn.** 1962. Statistical analysis in the geological sciences. John Wiley and Sons, New York. 483 p.

Pirsson, L. V. and **A. Knopf.** 1925. Rocks and rock minerals. Second edition revised. John Wiley and Sons, New York. 426 p.

Whitten, E. H. T. 1960. Quantitative evidence of palimpsestic ghost-stratigraphy from modal analysis of a granitic complex; 21st Intl. Geol. Cong., Norden, Rept. Pt. 14: 182–193.

———. 1961. Quantitative areal modal analysis of granitic complexes. Geol. Soc. Am. Bull. 72: 1331–1360.