Geochimica et Cosmochimica Acta 1964, Vol. 28, pp. 2013 to 2024. Pergamon Press Ltd. Printed in Northern Ireland

Concentration trends and frequency distribution patterns for elements in igneous rock types

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(*Received* 1 *January* 1964)

Abstract—In samples of any defined igneous rock type some compositions will approach those of associated and earlier-formed rock types and others will approach those of associated and later-formed rock types. Thus in an area showing genetically related granites, adamellite and granodiorite, a large selection of samples properly described as adamellite would be *expected* to show all compositional variations towards granodiorite or granite. The trends of concentration changes of elements plotted against a common measure of evolution within any defined rock type are discussed. Frequency distribution patterns for data for a reasonable number of samples of the rock type are shown to vary from element to element, and the importance of analytical errors is illustrated. The degree and sense of skewness in the frequency distribution diagrams is entirely relative and depends on the method of sample selection as well as on analytical error.

IT is now nearly 10 years since AHRENS first discussed in this journal the lognormal distribution of the elements (1954a) and suggested a fundamental law that (some) elements were lognormally distributed in specific igneous rocks. Criticism of the so-called law was prompt and incisive. AHRENS' statistical approach was questioned by MILLER and GOLDBERG (1955), and AUBREY (1956) was quick to point out that a lognormal distribution cannot apply even approximately to all the major constituents of a rock; many minor elements will follow major elements in failing to obey the law. Further enthusiastic papers by AHRENS (1954b, 1957) were published purporting to vindicate the law but important criticism about the selection of data and the degree of conformity to a lognormal pattern remained unanswered. One of the latest papers by AHRENS (1963) renews many doubts, for in it he attempts to establish his law by considering data for granites of quite different mineralogical (and chemical) composition. He considers that "despite the problems associated with sampling, *specificity of material* (italics by J. R. B.) and analytical error, the results of the statistical study should be meaningful". Granitic rocks from the three geographically distinct areas of Japan, Nigeria and southern Africa are discussed separately but they vary so much within each area that they might as well have been considered together. Thus for K, for example, the histograms in AHRENS' Fig. 2* show a range of at least from 0·8% to more than 4% in the Japanese granites ($SiO_2 > 65\%$), at least from 2·3% to more than 4·4% in the Nigerian Younger Granites and at least from 1·6% to more than 4·6% in the Pre-Cambrian granites of southern Africa. For the Nigerian rocks in particular BUTLER *et al.* (1962) have indicated

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[*] It may be noted that the caption in this Fig. 2 (AHRENS, 1963) is incorrect. The left-hand, centre and right-hand histograms refer, in fact, to rocks from Japan, Nigeria and southern Africa respectively. Six per cent frequency is unaccounted for in the African rocks.

the considerable mineralogical differences by grouping the rocks into (i) Ca-amphibole-granites and granite-porphyries, (ii) Ca-amphibole-granites with biotite, (iii) biotite-granites (Ca-amphibole absent), (iv) riebeckite–biotite-granites and (v) riebeckite-granites (biotite absent). The 80 specimens analysed included in addition to these types one lepidolite–biotite-granite, one microgranite, three rhyolites and one comendite. Ahrens appears to have used results for 78 of the rocks (p. 338, line 2) and these must, therefore, include at least 2 rhyolitic rocks amongst at least 76 granites *sensu lato*. In the histograms showing the frequency distribution of K "distinct negative skewness is recognizable". He goes on to say that "K is unusual in showing such a distribution as most other elements show positive skew (lognormal) distribution".

It must be recognized that the choice or selection of data is largely outside Ahrens' control. The negative skew distribution of K in Nigerian granites could easily be changed into a positive skew distribution by producing new data for K on appropriate samples and a knowledge of the petrology of the rocks and an awareness of some of the likely evolutionary trends would soon help to decide which these appropriate samples were. The degree and sense of skewness of frequency distribution of concentrations of elements in igneous rocks is, I suggest, entirely relative. These differences can be readily explained when it is realized that samples of any rock type must vary in composition if they are genetically related to rocks in the same petrographic province. In the Nigerian Younger Granite province the Ca-amphibole-granites will show all compositional differences implicit in the evolutionary sequence Ca-amphibole-granite → biotite-granite; in calc-alkali provinces granodiorite will show all compositional variations between tonalite and adamellite; in basaltic provinces rocks correctly described as basalt may show all gradations to mugearite, and those correctly described as mugearite may show all compositional variations to basalt or trachyte. Rock types may be specific in the sense used by Ahrens but they are continuously variable between mineralogical or chemical limits as understood by the petrologist.

If the geochemical behaviour of certain elements in an igneous rock type is known it is not difficult to suggest the frequency distribution patterns that would arise from data from an adequately large number of specimens sampled systematically with respect to any chemical measure of progressive change. The data given by Nockolds and Allen (1953, 1954, 1956) for calc-alkali as well as for alkali and tholeiitic igneous rock series are particularly relevant here.

Suppose that Fig. 1(a) represents the true concentration trends of a major element A and a minor element B against a rock compositional trend in an evolutionary series of igneous rocks. The latter (as abscissa) could be represented by per cent SiO_2, Mg/Fe ratio, Larsen index etc. Any change in the parameter could of course, change the slope and curve of the concentration trends of A and B from that shown in Fig. 1(a), but a variety of trend curves will be discussed later and it is a comparison of trends against a common parameter which will prove instructive. The trends are shown between limits on the abscissa corresponding to chemical extremes of the rock type. The frequency distribution curves drawn from data on the concentrations of A or B in a selection of samples will depend entirely on the method of selection of these samples. Therefore let the sampling be systematically uniform