DISTRIBUTION OF MINOR ELEMENTS IN ROCKS

RESEARCH on the geochemistry of the rarer elements was given a real impetus in the 1930's by the investigations of the late V. M. Goldschmidt and his co-workers. Progress at that time was due, in the main, to the introduction and application of sensitive methods of instrumental analysis. Except for the period of the war years, interest and investigation on the geochemistry of the rare elements has continued to grow, and the recent discussion at Oxford arranged by Section C (Geology) of the British Association reflected in several respects the progress which has been made during the past few years. The programme of speakers and discussion was arranged so as to cover the distribution of minor elements in a broad way, starting with aspects of cosmochemistry and followed by consideration of minor element behaviour of igneous rock series, sedimentary rocks and finally metamorphic rocks. In his introductory remarks, the chairman, Prof. L. R. Wager (University of Oxford), pointed out that once geochemical patterns of minor element behaviour were firmly established for known conditions—as, for example, in fractionated rock sequences—they could no doubt be used in solving more complex geological problems of rock genesis where processes are less clear.

Dr. L. H. Ahrens (University of Oxford) directed attention to the general qualitative similarity of composition of various materials composing the observable universe. He pointed out, however, that it is only the earth and the meteorites which can be sampled directly and are capable, therefore, of precise quantitative investigation: this opens up the possibility of testing exact quantitative equivalence of composition. Evidence of such equivalence would be of geochemical, geophysical, petrological and nuclear-physical significance. Tests could be carried out by examining pairs or larger groups of elements, provided they show a high degree of geochemical coherence: zirconium–hafnium; niobium–tantalum; some rare earths and potassium–rubidium were cited as possibilities. Adequate data are available only for the pair of alkali metals, and their association in the commonest rocks and meteorites were discussed in detail. Earlier investigations of Ahrens, Pinson and Kearns[1] indicated that the ratio potassium/rubidium remains uniform throughout the principal types of rock and is very similar or possibly equal to that in chondrites, the commonest meteorites. Their observations were restricted mainly to North American rocks, and evidence from other sources was therefore desirable. Some seventy new determinations, mainly on igneous rocks from South Africa, have since been made and all observations are represented in Fig. 1. The close association of potassium and rubidium in rocks and meteorites is evident, and calculation shows that the ratios of potassium to rubidium for rocks and chondrites are equal to within about 5 per cent. Dr. Ahrens pointed out that as neither element is a participant of either metal or sulphide phases, it can be concluded similarly that the ratio of potassium to rubidium for the earth is equal to that for meteorites ± 5 per cent. This is the first, and so far only, example of its kind and has been taken as evidence in support of a common origin for the earth and meteorites. This information does not, however, appear to be of use with regard to the problem of two possible origins of the meteorites—either from a shattered planet or from a collision of asteroids. It is desirable that similar research be carried out on other possible pairs or groups of elements. Sir Edward Bailey commented on the analogy between the ratio of potassium to rubidium and the ratios of various isotopes of different elements in the earth and meteorites which observation has shown to remain uniform. Prof. Wager and Dr. M. H. Hey commented on the fact that Dr. Ahrens's data apparently show that different parts of the earth may be characterized by slight but significant differences in their potassium–rubidium ratio and that this is perhaps the first and only reliable indication of any fundamental regional differences.

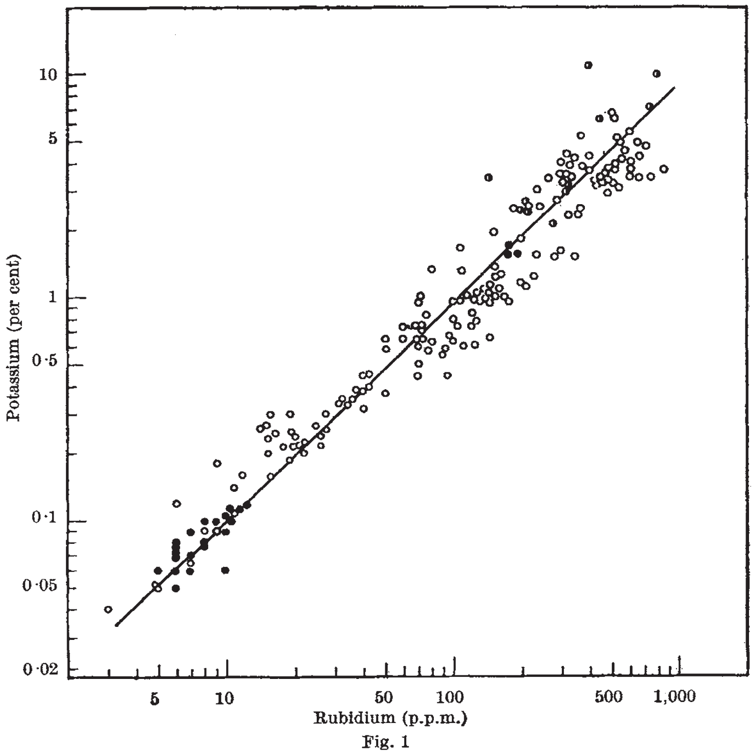

Fig. 1

Dr. S. R. Nockolds (University of Cambridge) described some of the results of recent research at Cambridge. The principal objects of these investigations were to examine the behaviour of trace elements with respect to the major constituent elements in some well-described igneous rock series of calc–alkali, alkali and tholeiitic character: to determine how their behaviour varied from series to series and from group to group and to see what light, if any, they might throw on the origin of the three main branches of igneous rock evolution. Particular attention was given to the calc–alkali and alkali groups, which were represented as follows: (calc–alkali) southern California batholith, the Scottish Caledonian and lavas of Lassen Peak, Crater Lake, Lesser Antilles, the Medicine Lake Highlands and Sierra Nevada; (alkali) Scottish Tertiary, Hawaiian alkali rocks, Polynesian alkali series, and the latite series of Sierra Nevada.

Discussion was confined to lithium, chromium, nickel, cobalt, iron and vanadium, some data on which have already been published[2,3]. For the purpose of demonstrating behaviour, the concentration of each element is related (as ordinate) to the function $[(\frac{1}{3}Si + K) - (Ca + Mg)]$, as suggested by Larsen. The characteristic behaviour of chromium and nickel—a regular and sometimes sharp decrease of concentration with increase in acidity, followed by some levelling—is clearly evident in nearly all examples of a series from each of the three groups. Iron and vanadium behave in much the same way in series of calc–alkali rocks; the concentrations of both decrease regularly with acidity. A similar behaviour is sometimes shown by iron in the alkali rocks, although the amount often remains fairly uniform over a considerable range of low $[(\frac{1}{3}Si + K) - (Ca + Mg)]$ values. Vanadium, on the other hand, invariably increases with increase in the magnitude of the function, passes through a maximum and then decreases regularly with increase in the magnitude of the function. As anticipated, lithium invariably increases with decrease of $[(\frac{1}{3}Si + K) - (Ca + Mg)]$ in all series from each group. Cobalt often follows magnesium, particularly in the calc–alkali rocks, and sometimes iron. Behaviour patterns in the calc–alkali series are often similar to rock series classed as belonging to the tholeiitic group. Dr. Nockolds finally directed attention to recent investigations on hybrid rocks, and it was shown that, unlike the igneous rocks of a series, variation of concentration is linear in respect to the function $[(\frac{1}{3}Si + K) - (Ca + Mg)]$. During discussion of a point raised by Dr. W. Campbell-Smith, Dr. Nockolds stated that the data on the rock series are evidence in support of crystal fractionation.

In a discussion on the distribution of elements in sedimentary rocks, Dr. J. R. Butler (Rothamsted Experimental Station) referred first to the transportation of elements to the oceans, either as ions (simple or complex), as constituents of or associated with colloids, or as constituents of detrital material. The ionic potential (the ratio of ionic charge to ionic radius) of Cartledge as used by Goldschmidt can be used as a starting-point for classifying elements according to their tendency to occur in aqueous solutions as cations or anions, or to be precipitated as hydrolysates. Lead, however, can be transported as a complex ion, and in a discussion which followed it was pointed out that several of the poorly shielded cations (as defined by Ahrens[4])—Au^+, Hg^{2+}, Cu^{2+} and Pt^{2+}, for example—are likely to be transported as stable complexes depending, of course, on pH, composition of the waters and other factors. In a reducing environment, such agencies as hydrogen sulphide may bring about precipitation of a sparingly soluble sulphide (Ag_2S or Cu_2S, for example) provided the solubility product can be exceeded and provided a complex can be broken; the complex AuS^- is particularly stable in this respect.

The significance of cation hydration was emphasized by considering the alkali metals. Degree of hydration is determined mainly by size. It was pointed out that available evidence for the pair Cs^+ and K^+ (radii 1·67 and 1·33 respectively) indicates that the ratio of cæsium to potassium is greater in shale than in igneous rocks; further fully quantitative investigations are, however, required to verify this. Dr. Butler suggested that a critical examination of the cæsium to potassium ratio might prove to be helpful in the problem of the origin of glauconite. The importance of illite as a constituent of argillaceous sediments was stressed. Unlike other clay minerals, illite can provide inter-sheet structure sites of potassium for camouflage of rubidium and cæsium.

Gallium, chromium, cobalt, copper, zinc, tin, lead, zirconium and the alkali earths were discussed in addition to the alkali metals. When contrasting the abundance of gallium in igneous rocks (15 p.p.m.) with the value of 50 p.p.m. for shale, Dr. Butler pointed out that although interesting conclusions can be derived on the basis of these figures, the latter come from different sources, and as different analytical procedures have been used they are not strictly comparable. The danger of comparing data from different sources was strongly endorsed by those participating in the discussion. Available data should be used with extreme caution and there is a great need for improving the quality of future determinations.

Prof. F. J. Turner (University of California) emphasized the fact that whereas considerable data are now available on igneous rocks in particular, and sedimentary rocks to a lesser extent, quantitative data on the metamorphic rocks are conspicuously lacking. This has led to much speculation on patterns of behaviour and their possible geological significance in the metamorphic terranes. Thus, for example, Sahama[5] has observed in a reconnaissance investigation that the boron concentration in serpentine is much higher than that in parent peridotite; this suggests the action of sea water as a cause for boron enrichment, as it contains appreciable boron. Prof. Turner concluded that provided large samples are examined, departure from ideal iso-chemical metamorphism is rarely profound in the case of the common elements. It was felt, however, that concentrations of the trace elements are more likely to show large variations. He referred to the earlier reconnaissance work of Sahama[5] and Shaw[6], which indicated iso-chemical metamorphism with respect to several of the minor elements. He then considered from a theoretical point of view the possible patterns of behaviour which may be found when data become available, and dealt briefly with the only two exhaustive investigations known to him, neither of which has yet been published. The first of these is an investigation by A. E. Engel and Celeste Engel (California Institute of Technology) on progressively metamorphosed rocks of the Grenville Series in the Adirondacks, which indicates trends different from the earlier work; for not only do elements such as strontium, lead, manganese and chromium appear to be added to some beds and removed from others, even when there is no indication of general metasomatism or magmatic influence, but also isotope composition varies. The second detailed work is that of Pitcher and Sinha (Imperial College of Science and Technology, London), who have analysed several series of bulk samples taken across a pelitic hornfels formation in a contact aureole in Donegal. In profiles of 1,500 ft. in length taken normal to the contact, the mean composition of all samples was found to remain the same. The formation had remained a closed system and there appeared to be no metasomatism; metamorphic differentiation had, however, occurred along each profile and compositional gradients had been set up.

A general impression left by the discussion on the distribution of minor elements was that most investigations nowadays involve far more analyses than heretofore; this is a healthy development. There is no doubt that a vast amount of fresh and exciting information remains to be unearthed, but real progress will only be achieved by combining quality with quantity.

[1] Ahrens, L. H., Pinson, W. H., and Kearns, M. M., *Geochim. Cosmochim. Acta*, **2**, 229 (1952).

[2] Nockolds, S. R., and Allen, R., *Geochim. Cosmochim. Acta*, **4**, 105 (1953).

[3] Nockolds, S. R., and Allen, R., *Geochim. Cosmochim. Acta*, **5**, 245 (1954).

[4] Ahrens L. H., *Nature* [**174**, 644 (1954)].

[5] Sahama, Th. G., *Bull. Comm. géol. Finlande*, **136**, 15 (1945).

[6] Shaw, D. M., *Geochim. Cosmochim. Acta*, **2**, 185 (1952).

ANIMAL POPULATIONS AND FORESTRY

AT the recent meeting in Oxford, Sections D (Zoology) and K* (Forestry) of the British Association held a combined symposium under the chairmanship of Prof. L. W. Grensted to discuss animal populations with reference to British forestry. Mr. G. H. Thompson, of the Department of Forestry, University of Oxford, opening the symposium with a general introduction, reviewed briefly some of the more important forms of injury caused by animals at different stages in the life of a forest. Insects, rabbits, squirrels, mice and voles often severely damage seed and young trees. In older forests the chief pests are insects, particularly those feeding on foliage. Conifers have a smaller capacity for regenerating lost foliage than broad-leaved trees, yet in Great Britain defoliating insects have so far killed comparatively few conifers. The British fauna includes species, such as the nun moth and pine noctuid, that are important pests of conifers on the Continent of Europe, but which in Britain have so far remained uncommon: the reason for their scarcity is unknown. The pine looper (*Bupalus piniarius* L.), although usually a common moth, first reached epidemic numbers in 1953 at Cannock Chase, completely defoliating 120 acres of Scots pine and severely attacking a much larger area. A similar attack in 1954 would almost certainly produce heavy tree mortality. Non-lethal degrees of defoliation presumably reduce growth increment, but no data exist.

Trees weakened by drought or defoliation, or unthrifty owing to unsuitable site conditions or old age, are susceptible to attack by insects such as wood-wasps and certain bark-beetles which cannot successfully oviposit in healthy vigorous trees. At Cannock Chase the defoliated pine are entered by a bark-beetle (*Myelophilus piniperda* L.), the tunnels of which in the cambium girdle and kill trees that might recover if protected from further loss of foliage. It is often hard to decide whether an insect species feeds exclusively on weakened trees, because of the difficulty of defining health.

Apart from safeguarding future vigour by choosing tree species suited to the sites to be planted, the forester may attempt to prevent or reduce animal injury by sylvicultural, biological or by chemical means. His choice of methods should be based on ecological knowledge, and in particular of those factors limiting population numbers. In fact, little is known of the population dynamics of even the more important forest pests. The science is new, and population studies are very time-consuming; the collection of data for even a dozen species of insect and three species of mammal is a formidable task. Climate, predators and parasites, and food supply are probably the chief factors influencing animal numbers. Past freedom from epidemics of coniferous defoliators may have been due to the absence of large blocks of forest of an appropriate age-class.

The application of insecticides may be justifiable to save a tree crop otherwise doomed; but, apart from the expense and impermanence of treatment, the biological implications are not fully understood, and the pest may ultimately benefit by destruction of its associated parasites and predators, or resistance to the insecticide may be developed. Forest practice should aim at keeping the injurious animal fauna below the level at which economic damage occurs by biological and sylvicultural methods; and to achieve this objective detailed knowledge is required of the factors affecting animal numbers.

Mr. F. A. Courtier, of the British Forestry Commission, described studies recently initiated to determine a satisfactory method of estimating grey squirrel populations in order that the efficacy of control measures may be assessed. A native of North America, the grey squirrel was first observed in Great Britain in 1828 and has since spread to almost every county. It is most injurious in forests, particularly to broad-leaved trees, girdling and killing stems at ground-level and also destroying leading shoots. Barking usually occurs in late spring or early summer when sap-flow is most active. There are two main breeding periods—December–January and May–June. The restricted breeding periods and relatively long time—ten weeks—spent by the young in the drey offer excellent opportunities for control.

Visual counts of adults have not given comparable results under varied woodland conditions. The relationship between the number of the breeding and the sheltering type of drey and the size of the squirrel population is being studied in mature oak woodland.

Courtier referred to estimates of population by the capture–recapture method being undertaken by Monica Shorten in an isolated wood that offers seasonal variation in food; this produces a more settled squirrel population. After intensive trapping, marking and release, the area is cleared of dreys and as many squirrels as possible are killed. Records of marked squirrels shot also provide information concerning their movements.

The squirrel population on a small area in Alice Holt forest is being studied for a period of years. Permanent trapping sites have been established. After pre-baiting for five days, trapping is conducted for four consecutive days; this procedure is repeated at intervals of six weeks. Trapped squirrels are marked and released after recording sex, weight, breeding condition, injuries and moult-stage. The squirrels show little fear of the traps and appear not