

Geochemistry and Biochemistry.

By Prof. A. P. Vinogradov.

(Biogeochemical Laboratory of the Academy of Sciences, U.S.S.R.)

I.

UNTIL quite recently, it was generally believed that organisms—plants and animals—consisted of a very limited number of chemical elements.

This view has, now, to be abandoned, since 60 chemical elements have been discovered in one or the other of the organisms; it is, perhaps, easier to name those chemical elements which have not been found in organisms or about which indications are unreliable. The chemical elements not yet discovered in organisms may be referred to five groups: (1) the radioactive elements Pa, Ac, Po and the numerous radioactive isotopes*; (2) the rare-earth metals—Tl, Eu, Gd, Tb, Dy, Ho, Er, Tm, Y and Lu; (3) the inert gases He, Ne, Kr, X; (4) the elements of the platinum group: Ru, Rh, Pd, Os, Ir, Pt §; and (5) of all the other chemical elements: Te†, Zr†, In, Ta, Hf, Ma, Re, 85† and 87†.

This list shows with sufficient conclusiveness the present position. For the majority of the chemical elements named, there are yet no simple and sufficiently sensitive and accurate methods of determination. It may be conjectured that these elements may be found in organisms only in negligibly small amounts.

Nevertheless, the constant finding of one or the other chemical element, often in small amounts (in thousandth, millionth and lesser parts of a per cent.; they may, therefore, be called microelements), in the tissues of organisms, was not a convincing indication for biochemists, of the important physiological part of those "traces" of microelements. Scores of years were required after I, Cu, Mn, B and many other microelements were found in organisms,

to recognise their important rôle in physiology.

The exceptional interest of the question of the physiological rôle, in particular, of microelements present in the tissues of organisms, arose recently among biochemists (physiological function of Cu, F, B, etc.) and especially among agrochemists (importance of B, Cu, I, etc. for plants).

As in the past, the many-sided researches in this direction, which are conducted by various specialists, physiologists, biochemists, chemists, agrochemists, mineralogists, etc., are being carried out along different paths, and pursue quite different objects. Owing to this there has occurred a certain break. The unique common phenomenon—the process of shifting matter, the *biogene migration* of atoms in the complex *indissoluble system*—soil—soil solution—plants—animals,—was lost sight of by these investigators.

II.

Not less persistently, is the view held that the *chemical elementary composition of organisms* does not represent any differences as to species, genus, etc.; that it is not constant and is subject to considerable variations. In other words, we cannot definitely consider it proved, that the chemical elementary composition of organisms is a specific character. It must be noted, however, that from this point of view, the subject has not been systematically investigated.

The study of the chemical elementary composition of living organisms has been, in a way, the special interest of the physiologist, biochemist, agrochemist and mineralogist. The importance of the problem is only being recognised at present. And, nevertheless, many scores of thousands of analyses of various organisms made during a period of more than a century, by agronomists, biologists and mineralogists, on closer examination, contain direct proof of special features, and of a certain constancy in the chemical elementary composition of species.

For instance, the differences in the contents of phosphorus and nitrogen in plants and animals are very well known. Among organisms are known to us numerous species,

* Besides MsTh, see works from our Laboratory—V. Vernadsky, B. Brunowsky and Kunaseva, *Compt. Rend. d. Sci. Acad. Paris*, 1933, T. 197, 1556.

§ It is of interest to note that Ge was discovered in organisms recently by V. M. Goldschmidt within the ranges indicated in the curve. Into the maximum enters Ru, one of the elements of the platinum group, which forms soluble compounds more easily than others. In the smallest amounts is probably found Th.

† Indications not checked, but their occurrence in organisms is known.

which concentrate definite chemical elements in considerable amounts. We are familiar with the division of plants into the calcareous and siliceous ones. Among the latter are, for instance, the grasses, sedges, horsetails, and diatoms. We know perfectly well the typical iron-organism (also that of manganese, sulphur, etc.); the halophytic flora (Na and Cl), numerous hydrophytes, which collect considerable amounts of aluminium ‡ (marine and fresh water algæ, many aqueous phanerogamous plants—monocotyledons, bacteria, etc.), and the like.

In relation to many chemical elements it might be possible to indicate typical organisms—concentrators. It is possible to easily discover the peculiarity of the chemical elementary composition of definite species of living organisms by comparing the composition of different plants for which numerous determinations have been made, especially for the composition of their seeds. In the Biogeochemical Laboratory of the Academy of Sciences of USSR investigations were made on the chemical elementary composition of 13 species of *Acridiidae*, collected from various localities during a period of three to four years. These data have shown a complete stability of the composition of *Acridiidae*, its resemblance to proximate species and very great distinctions from the chemical composition of other insects. Sometimes, in animals, the definite occurrence of only one chemical element acquires a specific character. For instance, investigation of 20 species of ants has shown us, that the species of the family *Camponotinae* contain Mn of an order $N. 10^{-2}$ per cent. but species of the family *Myrmicinae* of an order $N. 10^{-3}$ per cent., while the more primitive family *Ponerinae*, as it seems, contains still less Mn. Another instance: ascidians are rich in vanadium. They are typically vanadium-organisms. Nevertheless, as we have shown, not all the species of ascidians concentrate vanadium. Species from the families *Ascididae*, *Cionidae*, *Botryllidae* and some others concentrate vanadium, whereas the majority of species from the families *Tethyidae*, *Molgulidae*, *Synoicidae*—do not contain any marked amounts of vanadium. Similarly, among the families and genera of living organisms rich in vanadium, manganese, iodine, copper, etc., are

distinguished species exceptionally rich in one or the other chemical element. The number of such instances may be multiplied. We have quoted them in our work on the chemical elementary composition of marine organisms.

Fluctuations observed for the chemical elementary composition of organisms may be accounted for as being due to age, season, sex and ecological factors. The individual fluctuations of the chemical elementary compositions recall similar fluctuations of the morphological characters in organisms.

Thus, there certainly exist typical differences in the composition of definite species, genera and other taxonomic units.

The chemical elementary composition of organisms is a species character.

III.

The chemical elementary composition of organisms or the finding of one or of another element in the tissue of these organisms has been studied by biochemists, as a rule, outside its natural environment—the biosphere.

Between the environment and the organisms there occurs, uninterruptedly the exchange of matter—the environment and the organisms are closely connected by the common history of the atoms of the chemical elements. *Living matter* (totality of all organisms) during more than one million years has shown enormous geochemical activity, by concentrating various chemical elements, by playing a considerable rôle in sedimentary rock formation. In the chemical composition of each organism we encounter the expression of a definite geochemical part played by the given species of living organisms. From a geochemical point of view, some *geochemical functions* are inherent to all organisms—in some the calcareous geochemical function predominates, in others the siliceous or phosphate one, and so on; and, finally, several such functions may take place together. The chemical elementary composition of organisms and therefore the range of participation of the organisms in the biogenic migration of the chemical elements in the biosphere cannot be left without attention when studying the geochemical laws of the distribution, combination and migration of atoms within the earth's crust. For the first time, the *biogeochemical* ideas indicated were stated with exceptional vividness by Prof. V. I. Vernadsky. From that moment the question of the chemical elementary

‡ Contemporary *Lycopodiacea* are rich in Al. Probably the fossil *Leptodendron*, which are closely related to the latter, were also rich in Al. Their coal is rich in Al.

composition of organisms acquired a full scientific value. And the closer we approach it, the more obvious becomes the fact that the general geochemical laws, governing the distribution and combination of the chemical elements in the earth's crust govern also all living matter.

IV.

We have got accustomed to the biogene migration of atoms between organisms and environment, which is occurring in the biosphere during scores of thousands of years. We do not notice this close, indissoluble, unchanging (within historical time) connection between them. It becomes manifest as soon as a disturbance occurs.

We often come across such biogeochemical phenomena.

The *deficiency* or *excess*, as compared with the usual presence in the environment, for instance in soils, of some definite chemical elements, owing to the peculiarity of the geochemical history of the given locality, calls forth, over tremendous areas, a change of the qualitative and quantitative morphological composition of the soil cover and of the animal world connected with it. It is well known, for instance, that the deficiency of Ca, P, (for instance, in soils originating from granite) calls forth a disturbance in the composition of the flora. Thus, for instance, the grasses of the Savannas and steppes experience phosphate hunger, etc., and in their turn the steppe animals, cattle from the pastures, become sick because of deficiency of phosphorus (and lime) (inflammation of the bones, "brittle bones"). Those phenomena are observed also on cultivable soils throughout the whole world. The deficiency of Fe (and Mn) in the soil leads to sickness of both plants and animals. Perfectly well known is the spread of endemic goitre among men, cattle, birds, fishes, etc., in localities with a deficiency of iodine in the soil, drinking water, etc. At present, in many countries (Holland, Germany and others) are known soils demanding Cu for the successful growth of crops. The absence of Cu in the feed, appears to cause in cattle a special sickness (licking disease). Many soils, as it has now become evident, demand for the normal growth of some crops—leguminous plants, flax and the like—a definite amount of boron. On the contrary a certain excess of one or another chemical element in the soil, leads to similar *geochemical provinces* occupied by peculiar

biogeochemical endemics. We know of Se, As, and other "poisonings" of some soils. The excess of F in soils, soil waters, in drinking water in many countries—U. S., Algiers, Tunis, and others—causes an endemic disease of man, the so-called "mottled enamel", and so on. Much in this direction we still do not know. Similar biogeochemical endemics connected with the presence in the soils of Zn, Al, serpentine and others have a lesser range. All this leads to the formation of peculiar variations in some definite plants from these soils. It seems to us that the existence of regions (soils) with an unusual content of some chemical elements, forming geochemical provinces or separate "spots", should prove a kind of hindrance for the spreading of definite species of organisms.

Therefore, such geochemical provinces have the property of a selecting and transforming factor for organisms. In the process of their life and evolution, plants and animals in their turn (in a geological sense) lived on a definite substratum which formed only one of the stages.

Thus, it seems to us, that in each *species of organisms are concealed the chemical characters of their origin*.

The study of the chemical elementary composition of organisms from a geochemical point of view helped us to arrive at some general conclusions. The average chemical composition of living matter may be graphically expressed in the form of a curve (see Fig. 1). Comparison with similar curves for the distribution (frequency) of *atoms* in the soils, earth's crust, living matter, etc. shows that at their basis lies one general law of quantitative distribution of atoms. However, they differ in details. Each of the paragenetic spheres (living matter—biosphere) is characterised by its peculiarities. We see from the curve for the distribution of chemical elements in the living matter that: (1) the number of atoms of chemical element in the living matter is in inverse proportion to its atomic number (atomic weight). In other words, the chemical elementary composition of the living matter, as a whole, is definitely related to the number of charges on the nuclei (protons). (2) The curve shows a regular periodicity (6 and 8) with definite maxima and minima, representing certain regular deviations from the hypothetical inclined curve (which may be traced from H to U). Periodicity for the number of atoms in living matter is

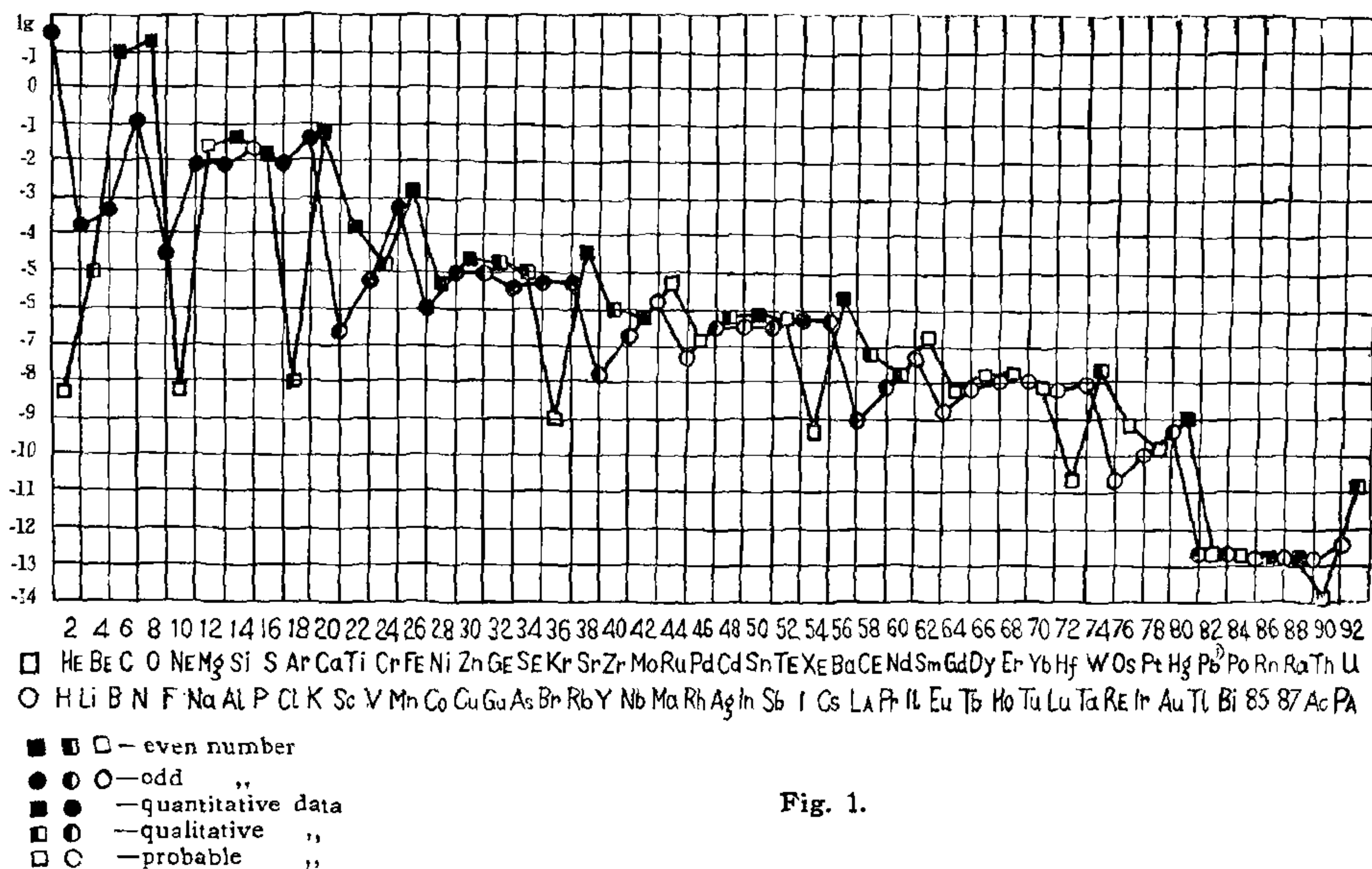
Chemical Elementary Composition of Living Matter (in per cent atoms).

Fig. 1.

accurately observed within the ranges of the first 50-60 elements, for which experimental data exist. The curve can be extended further; few data exist for the remaining chemical elements—Au, Hg, Ra, Th, etc. (3) The chemical elements which occur in maximal quantities play the chief part in the composition of organisms. In relation to those elements numerous organisms—concentrators,—are known. They are especially varied and numerous among the representatives of ancient groups of organisms (*Tallophyta*, *Protozoa*, etc.). The elements, occurring in minimal quantities, are not concentrated by organisms. From a geochemical point of view those elements—inert gases, Hf, Zr, Th, Rb, Se, partially Ti, and others—are characterised by a nearly complete absence in them of the capacity to form soluble compounds (in soil, etc.)* in natural conditions.

Thus the range of deviation from the straight inclined line (appearance of maximum and minimum) for different elements depends on the chemical properties

of atoms (outer electrons of atoms). Therefore, those maxima and minima occurring in definite species find places on the curve and although they may vary in the position, they nevertheless do not disturb the general periodicity of the curve.

In the future a more detailed study of the distribution of the chemical elements in the organisms from a geochemical point of view shall allow biologists, physiologists, agronomists, geochemists, etc., to tackle important problems of natural science using a common scientific language.

REFERENCES.

1. V. I. Vernadsky, *La biosphère*, 1930, Paris.
2. *Idem*, *Geochemistry*, 4th Edition, 1935, Moscow. Extensive literature quoted (in Russian). *Idem* in German—*Geochemie in ausgewählten Kapiteln*, 3rd Edition, Leipzig, 1930.
3. A. P. Vinogradov, *Transact. of the Biogeochemistry Laboratory*, 1935, **3**, Leningrad-Moscow.
4. *Idem*, Vol. IV (in the press).
5. Works of the Laboratory are printed in *Transact. of the Biogeochemistry Laboratory* and in the *Conf. read. de l'Academy d. Sc. USSR.*, 1926-1935.