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Geochemical Ecology and Problems of Health

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Geochemical ecology and problems of health

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The state of health or disease is determined by the nature of the organism, the properties of the biosphere, the heterogeneity of its natural geochemical composition and changes brought about by technology (technogenic changes). For a systematic study of the conditions of health and endemic diseases we have suggested a system of biogeochemical regionalizing of the biosphere with the aid of biospheric taxa: regions of the biosphere, subregions of the biosphere, biogeochemical provinces. The main criteria of the regionalizing are biogenous cycles of chemical elements (links of the biogeochemical food chain from soil-forming rocks to man). An important criterion of the biogeochemical regionalizing is threshold concentrations of chemical elements. The organism regulates its metabolism within the ranges of chemical element concentration between the upper and the lower thresholds (necessity range). When chemical elements are present in concentrations above the upper threshold and below the lower threshold, dysfunctions and endemic diseases are observed. Hence, the biogeochemical food chain allows us to establish critical links responsible for the state of health or endemic disease. Principles of optimizing the conditions of the environment and life have been worked out. The creation by us in the U.S.S.R. of biogeochemical maps relating conditions of the environment to biological reactions of organisms has proved a useful method of studying the ecological structure of the biosphere.

It is necessary to consider the state of health and disease as being not only determined by the nature of the organism, but also by the properties of the biosphere, especially by its chemical heterogeneity being characterized in some subregions of the biosphere by a substantial heightening or lowering of the concentration of elements and the disturbance of correlations between them (Kovalsky 1960, 1974, 1975). Such changes in the environment may be natural, but may also be determined by technogenic pollution. As a scheme of investigating the ways of chemical element migration may serve their biogenic cycle, the biogeochemical food chain of chemical elements (figure 1) which shows the links and primary connection between organisms and their geochemical environment (chemical elements of soil-forming rocks, soils, muds, water, atmospheric air, microorganisms, plants, forages, food products, diets, animals and man). Such biogenic cycles of chemical elements of subregions of the biosphere and biogeochemical provinces include a whole number of small cycles, and connect the separate links of the biogeochemical food chain with one another (figure 2), for example: soil–microorganisms; soils–plant root systems; muds and waters of continental basins–aquatic and muddy organisms (bacteria, fungi, algae, flowering plants, animal organisms); organisms–atmospheric air; pasture plants–forages–diets–animal organisms; food products–diets–man. The quantitative and qualitative characteristic of the biogeochemical food chain links of chemical elements (natural and technogenic) and of the biomass of microorganisms, plants and animal organisms allows us to introduce the phenomena under investigation into the range of biospheric processes and into the biospheric cycle of chemical elements.

Each link of the biogeochemical food chain may be considered in relation to the others, in an attempt to understand causal relations. The establishment of causal relations between the phenomena in the biosphere is necessary to develop a model theoretical programme linking geochemical and biological mechanisms and the artificial production of biological effects (e.g. the morphological variation in plants under extreme conditions of the natural or technogenic environment, of metabolic disturbances, of endemic diseases of plants and animal organisms, and the molecular mechanisms of these ecological phenomena).

The chemical heterogeneity of the biosphere may best be measured by determining the chemical variability of the biogeochemical food chain (routes of biogenic migration of chemical

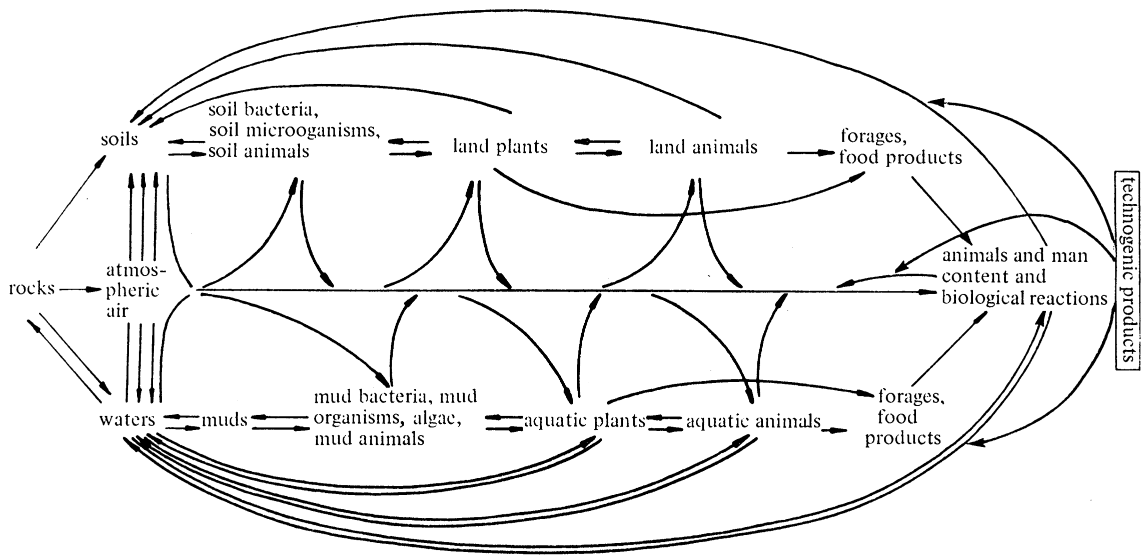

Figure 1. Biogeochemical food chain. Paths of biogenic migration of chemical elements in the biosphere and their biogenic cycles.

elements) and of its individual components (Kovalsky 1974). The biogeochemical food chain or the biogenic cycle of element migration in the biosphere is not a constant system. It is a labile system showing the adaptative variations of living organisms during the change of the chemical composition of soil-forming rocks, soils, ecological properties of the soil microflora, the vegetative cover, and animals. Under various geochemical conditions of the environment the biogeochemical food chain of macro- and microelements may apparently, owing to quantitative and qualitative changes, be used for the chemical characterization of subregions of the biosphere and of biogeochemical provinces. The chemical variability of the biogeochemical food chain may reach substantial dimensions (Kovalsky 1965) but it must to a definite degree be limited with respect to the content of chemical elements in microorganisms, in plants and especially in animals (homeostasis). During the evolutionary process in all organisms mechanisms have been developed which regulate the supply and the level of chemical elements in the body. Variations in the content of chemical elements in the body are, however, sometimes substantial, the ranges of which characterize the action of regulatory mechanisms which arose during

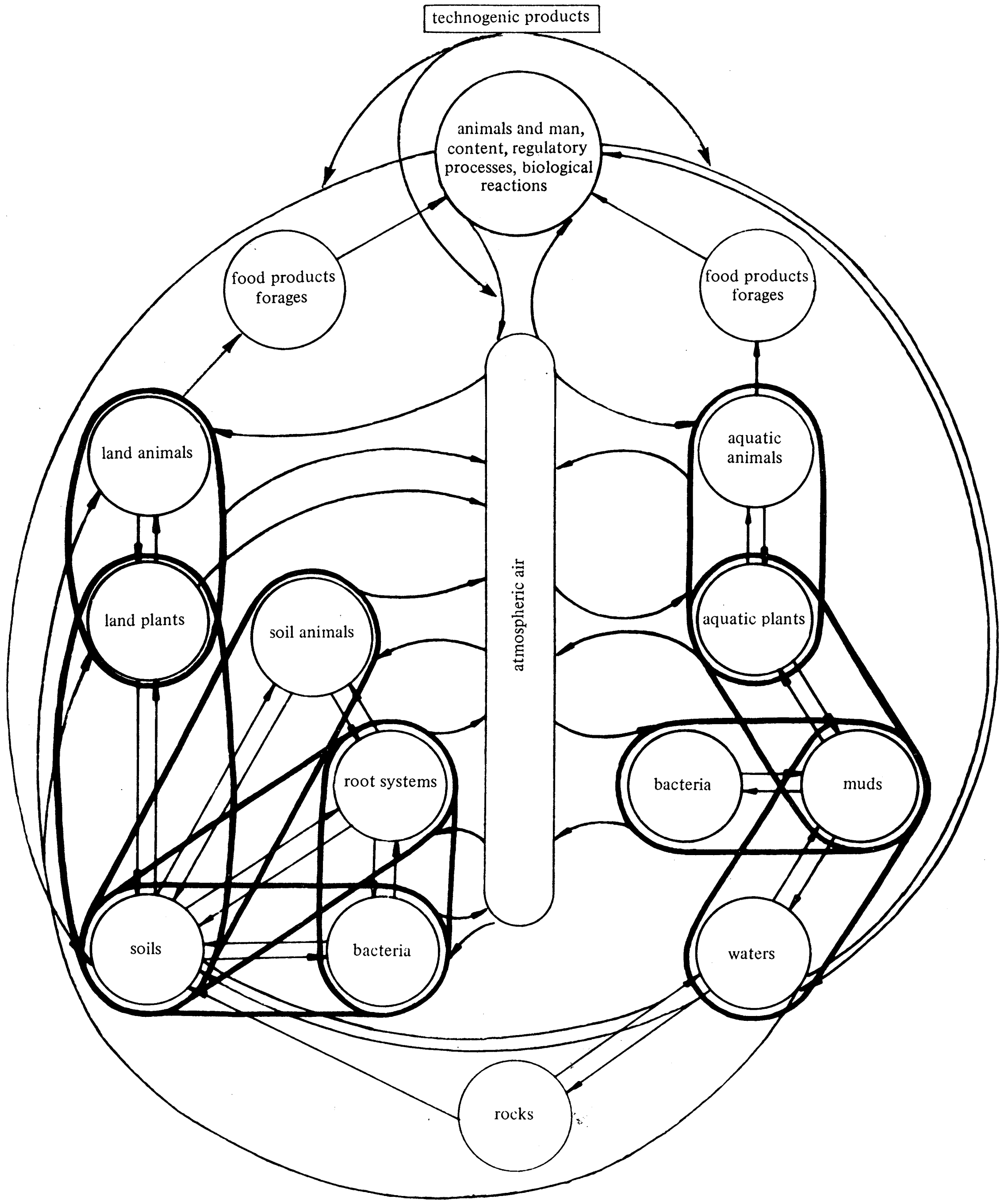

FIGURE 2. Biogenic cycles of chemical elements in the subregions of the biosphere and biogeochemical provinces.

evolution (Kovalsky 1965). At specific low or high concentrations of chemical elements in organisms, the regulating systems cannot cope with the regulation of metabolic processes. Limiting upper and lower concentrations of chemical elements in soils, waters, air, forages, food products, diets, liquids and tissues of organisms, in the ranges within which the organism is able to regulate the processes of metabolism, are called threshold concentrations of chemical elements (Kovalsky 1974, 1976). Below the lower threshold concentrations and above the upper

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ones a failure of regulatory processes and of a number of subsequent biological reactions of the organism is observed, the manifestations of which depend on the biological nature of the organism, the strength of action of the geochemical environmental conditions (biochemical changes of metabolism, dysfunctions, morphological variations, and endemic diseases). All of these biological reactions are available for study at a molecular level. Notions about threshold concentrations of chemical elements give a more precise definition of the structure of the biosphere, as they allow one, with a definite probability, to base an assumption about the restriction of specific kinds of organisms to definite geochemical conditions, and to search for endemic diseases in cases when the concentrations of some elements in the environment are lower or higher than the threshold concentrations; detailed investigations of the chemical variability within populations of the organisms are necessary as only a proportion of them will not have adapted to extremes in the geochemical environment.

Our investigations have shown that in one and the same population of animals, certain individuals possess different threshold susceptibility to one and the same geochemical factor of the environment, for example, to small amounts of Cu in the environment and in the diet of sheep, to low Co or I content or to the raised content of Sr, Se or Mo. Owing to the physiological and chemical heterogeneity of individuals in the population, the functions of the regulating systems of the organism may only in a certain number of individuals be disturbed to such a degree that dysfunction and endemic diseases arise. For example, in Cu deficiency and the changed ratio of Cu, Mo and SO_4^{2-}, endemic ataxia is found in animals, which is characterized by a decrease in activity of oxidizing enzymes of the central nervous system, by dysfunction of motor nerve centres, disturbance of motion coordination of animals, a state of convulsions and paralysis; in Co deficiency the synthesis of vitamin B_{12} by the microflora of the alimentary tract is diminished and the animal's requirement cannot be satisfied, leading to the appearance of endemic hypovitaminosis and avitaminosis of B_{12}; in Sr excess the normal function of the cartilage and bone phosphatase, of the epiphysian cartilage and of the bone-forming process is disturbed, which causes the development of Urov endemic disease of man and animals; when the Mo content of man's diet is increased, the quantity or activity of xanthine oxidase increases, causing a disturbance of purine metabolism and the appearance of a disease similar to gout (molybdenum gout). A great number of such biogeochemical endemic diseases are known. When Cu or Co is deficient in the diet, it is possible, by increasing Cu and Co levels in the diet, to lessen the number of animals affected by deficiencies of these elements and thus diminish or eliminate endemic diseases. At Sr excess the threshold susceptibility to this element is lowered by increasing the amount of Ca in the diet, which to a significant degree may prevent the development of Urov disease. At a high Mo content it is possible, by balancing the Mo and Cu ratios in the diet to lower the effect of Mo on xanthine oxidase, to decrease the concentration and activity of xanthine oxidase in the animal and to prevent the appearance of molybdenum gout symptoms. Phenomena of such a kind may be considered as methods of optimization, as controls of the biochemical adaptation of organisms to low or high concentrations of some microelements in the environment and in the diet. These factors are of importance for medicine, animal husbandry and veterinary services and must necessarily be studied with a view to the development of a widespread prevention of biogeochemical endemic diseases. Here we come across the most important problem of our time: the role of the natural and the technogenic geochemical environments in health preservation and the increase of diseases in animals and man.

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Thus, the quantitative and qualitative chemical characteristics of the components of the biosphere lead us to the understanding of important questions of its ecological structure. The fundamental significance of this direction makes biogeochemistry one of the leading sciences of our time.

Geochemical ecology, having been studied under various conditions of the environment, has served as a basis for the development of the system of biogeochemical regionalizing. Biogeochemical regionalizing is a new and necessary method of studying the structure of the biosphere based on the recognition of the unity of life and of the natural geochemical environment in the biosphere and the determination of the interaction of geochemical factors of the environment and organisms which is realized in successive links of the biogeochemical food chain and which depends on natural concentrations of chemical elements and the threshold susceptibility of organisms (Kovalsky 1976, 1977).

When the system of the biogeochemical regionalizing of the biosphere is constructed, taxonomic units of the biosphere as a whole are of course necessarily characterized by biospheric parameters – the biogeochemical food chain, threshold concentrations and biological reactions of the organisms: regions of the biosphere, subregions of the biosphere and biogeochemical provinces (Kovalsky 1976, 1977).

The regions of the biosphere, taxa of first order of the global ecosystem of the biosphere, have geographical signs of soil-climatic zones or their combinations, but with an obligatory characteristic of the biogeochemical food chain of chemical elements (cycle of biogenic migration of elements as a biospheric sign) and of prevailing biological reactions of organisms to geochemical properties of the environment (alteration of the chemical composition of organisms and of metabolism, threshold susceptibility, reaction in the form of morphological variability, sometimes deformity, endemic diseases, etc.). In the U.S.S.R. the following regions of the biosphere are discerned: the taiga–wood non-chernozemic; the wood–steppe, the steppe chernozemic (including grey wooded soils) arid steppe, semi-desert, desert region; mountain regions of the biosphere which still require special biogeochemical differentiation. Joining of some soil zones is justified by the presence of common links of the biogeochemical food chain including forages and food products, diets and biological reactions of animals (Kovalsky 1976, 1977).

Each region of the biosphere is characterized by a biogeochemical mosaic and may, according to the principle of geographical continuity, be divided into subregions of the biosphere, i.e. second-order taxa of the biosphere. Subregions of the biosphere are distinguished: (1) those in which there are combined characteristics of the region according to element concentrations which may reach threshold values, to ratios of chemical elements and the possible display of specific biological reactions; and (2) subregions of the biosphere the signs of which may not correspond to the characteristics of the region (they are formed above ore deposits during dispersion of the ore metals, in drainless regions and in regions of volcanism, as well as during technogenic pollution of the biosphere).

Subregions of the biosphere do not possess biogeochemical uniformity; under extreme conditions of the subregions of the biosphere, biological reactions caused by deficiency or excess of certain natural or technogenic elements may be pronounced. Some of the subregions of the biosphere, where the concentration of chemical elements is constantly outside the threshold values, are characterized by constant biogeochemical endemic reactions; some are potentially dangerous with respect to the possibility of endemic disease appearance; some are only characterized by a rare appearance of separate biological reactions. Hence, in the composition of the subregions of the biosphere, territories are revealed with constant characteristic reactions of organisms, frequently in the form of endemic diseases. These territories may vary in size and have been called biogeochemical provinces (Vinogradov 1938) (taxa of third order) – but we introduce the concept of biogeochemical provinces into the system of biogeochemical regionalizing instead of describing them as separate isolated territories (Kovalsky 1974, 1976). The system of biogeochemical regionalizing of the biosphere as a geographical continuum must cover the continents of the Earth.

Questions of the biogeochemical regionalizing of the biosphere are one of the most important tasks of natural science. Upon the system of biogeochemical regionalizing of the biosphere may be based the study of the ecological structure of the biosphere. The notion about taxa of the biosphere allows one to revise and more precisely define the classification and characteristic of geochemical landscapes. It is the immediate task of biogeochemistry.

As a necessity, the biogeochemical regionalizing uses as a method the biogeochemical mapping (Kovalsky 1974) based upon the quantitative characteristics of the links of the biogeochemical food chain and upon data of geochemical ecology (Kovalsky 1974, 1976). Biogeochemical mapping is the result of the complex work of various specialists (e.g. biogeochemists, geochemists, geographers, pedologists, hydrochemists, hydrobiologists, microbiologists, zoologists, geobotanists, zootechnicians, agrochemists, medical and veterinary physicians, biochemists and anthropologists) and requires careful coordination of their efforts during obtaining and discussing information. Maps based on biogeochemical regionalizing may give ecological information about possible metabolic variability in plants and animals, and about its dependence on geochemical conditions in the environment (Kovalsky 1968). It follows from the above that biogeochemical regionalizing and mapping are important ways of studying the biosphere, and of revealing its biogeochemical and ecological structure. As biogeochemical mapping is based on the quantitative characteristics of the biogeochemical food chain, the system of regionalizing involves data on the content of natural and pollutant chemical elements in soils, plants, and forages, as well as on biological reactions of plants, animals and man to their excess or deficiency in the environment. Information offered by maps of the biogeochemical regionalizing allows the use of these maps for a number of applied problems, including those of farming (productivity of livestock and crops), veterinary and medical hygiene (prevention of endemic diseases, improvement of fertilizability of animals), medicine (prophylactic and remedial use of microelements), fish breeding (increasing the productivity of fish breeding ponds by restructuring the biogenic cycle of some elements, for example, in the non-chernozemic zone – the Co cycle), pharmacognosy (increase of the synthesis of alkaloids, flavonoids and other biologically active substances in drug plants by using microelements as fertilizers as a basis of ecological investigations under various geochemical conditions). Biogeochemistry in its present state is able to discover more and more new ways of applying its theoretical notions to the development of practical problems of significance for the national economy (Kovalsky 1974).

In the evolution of the Earth and human society, all technogenic influences upon the environment and life must be considered as natural inevitable stages of the development of the biosphere (global technogenic alterations of the biosphere by the wide use of mineral and microelemental fertilization, the increase of motor transport, aerial communications, development of mining and other kinds of industry). In the biosphere, together with the evolution of society,

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technology and science, the technosphere has arisen which is intruding itself more and more into the biosphere in which the settled relative equilibrium of ecosystems is progressively disturbed under the intensifying influence of technogenic factors. The development of the technosphere induces a new function of the biosphere: organization of planned regulations of the structure and function of ecosystems, the development of the so-called noosphere (Vernadsky 1944) – the shell of the Earth with supremacy of reason, when with the aid of scientific prognosis and calculation, ecosystems of optimum productivity and controllable equilibrium are created, being regulated by man and his technology which make the biosphere correspond in the best way to the evolution of the biological, social, mental, moral and aesthetic life of man.

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