ISSN 0145-8752, Moscow University Geology Bulletin, 2011, Vol. 66, No. 3, pp. 163–170. © Allerton Press, Inc., 2011.
Original Russian Text © V.S. Savenko, 2011, published in Vestnik Moskovskogo Universiteta. Geologiya, 2011, No. 3, pp. 15–22.

Ecology in Geochemistry

V. S. Savenko

Geography Department, Faculty of the Earth's Hydrology, Moscow State University, Moscow, Russia
e-mail: Alla_Savenko@rambler.ru

Received October 26, 2010

Abstracts—The modern state of the ecological school in geochemistry in the context of the general tendency towards the ecologization of the Earth sciences is considered. The key role of the Russian school of systemic natural sciences [V.V. Dokuchaev, V.I. Vernadskii, B.B. Polynov, V.N. Sukhachev, N.V. Timofeev-Resovskii, and others] in the development of ecological geochemistry, studying the structure and the progress of the system man–biota–abiotic environment at the nuclear–molecular level is noted. The object of study in ecological biochemistry is the ecosphere, which is the system of external geospheres of the Earth (atmosphere, hydrosphere, and the top lithosphere, including the zone of metamorphism) and the "home" for all breathing organisms, including humans.

Keywords: geochemistry, ecology, ecological geochemistry, and ecosphere.

DOI: 10.3103/S0145875211030100

Ecology and Earth sciences. It is accepted to relate the origins of the science of ecology to the publication of *A Universal Morphology of Organisms* by E. Haeckel in 1866. Haeckel named the universal science about the relationship of organisms with the environment as the totality of all biotic and abiotic conditions of an organism's existence that affect its vital activities and evolution. Having emerged as a branch of biology, ecology first primarily studied the influence of environmental factors on organisms. Much less attention was paid to the other side of their interaction with the environment, i.e., changes in the environment caused by breathing organisms; however, it was admitted that this was an inseparable attribute of the interaction.

In 1930s–1940s, ecology witnessed rapid development of the systemic school that studies biological systems at different levels of organization (species, population, biocenosis, biogeocenosis, and ecosystem). Biogeocenoses and ecosystems in general were attributed to them, although their classification as biological systems at the supra-organism level is very conditional, for they include both biotic and abiotic components of an organism's environment. Studying the structure, functioning, and development of the biotic component of biogeocenoses is the domain of biology. When biogeocenoses are considered as a whole or as natural systems of a certain type, research leaves the domain of biology and comes into the jurisdiction of biogeocenology, which is an independent and, as N.V. Timofeev-Resovskii and A.N. Tyuryukanov stressed [1967], nonbiological science that is conceptually related to Dokuchaev's pedology.

For a long time, ecology remained an a purely biological sciences which overall and eventually was aimed at studying the influence of abiotic and biotic environmental factors on the condition, functioning, and development (evolution) of biological systems. Modifications of environments by organisms were considered, as a rule, from the viewpoint of changing living conditions. Ecology was seen as a science that explores relationships of animate nature and abiocoens in terms of reflecting these relationships in the organic world. It was in this—biocentric—form that ecology held its position in the structure of biological knowledge.

In the second half of the 20th century, when it became clear that uncontrolled growth of industrial and agricultural production lead to changes in the environment that are incompatible with the conditions of human biological existence, scientists started to use the word "ecology" in the context of the relationship of humans with the surrounding biotic and abiotic world. Many people began to imply, under ecology, a science (or a complex of sciences) that studies the interactions between society and nature. More moderate authors, trying to avoid the "unfriendly" absorption of biological ecology, suggested that this direction of research be called ecology of man or social ecology (socioecology). For studies in the system humans–environment, a neutral term was proposed: the doctrine of the environment, closely matching the term "environmental science," which is widely accepted in Western literature.

Anthropocentrism, which turned the methodological basis of the "new" ecology, led to the propagation of a purely utilitarian view of ecological problems and reduction of environmental studies to the development of protecting nature and sanitary measures. This was to a large extent facilitated by the prevailing ideology of ecological conformism in the scientific community, according to which all negative consequences of economic activities could be readily eliminated if one had more perfect technologies and necessary fiscal resources. Another cause of the expansion of ecology and its reduction to nature protection was the urge of many scientific figures, based on conjunctures, to join the fashionable ecologic subject area. As a result, ecology began to include any nature protection arrangement, the development of energy and material-saving technologies, optimization of land use, etc.; currently there are over hundred different and independent "ecologies" (including ecology of personality, ecology of culture, and ecology of conscience). The logical justification of the process of uncontrolled propagation of pseudo-ecological disciplines is the thesis that the goal of all ecological studies is the search for ways to ensure normal living conditions [Gorshkov, 1995]. Such a statement, however, is equally applicable to any science, and one cannot but agree with G.A. Zavarzin [2003] who termed the modern ecological boom ecodemagogy.

But would it be right to restrict the usage of the term "ecology" and use it only in connection with the study of the relationships (interactions) between organisms and the environment? Literally, ecology means the science about the house, and the meaning implied under the notion "house" is crucial. In classical ecology, it corresponds to the totality of breathing organisms and their environment, i.e., the house together with its inhabitants. With the appearance of humans, the quantitative composition of the inhabitants has changed and their relationships were modified radically. However, the possibility of considering such objects as specific ecosystems (natural–anthropogenic) has been fully retained, with all the consequences concerning the extended interpretation of ecology. Since humans with their economic activities entered the domain of ecological studies, it lost its initial, purely biological content and began to turn into a cross-disciplinary scientific school that unites natural and technical sciences and humanities from a certain viewpoint. A new ecological paradigm underpins this unification, according to which human society, the organic world and the abiocoen are functionally coupled components of the integral ecosystem at the planetary scale.

Economic activity is not inherent to the rest of the organic world. It exists in the interdependence with abiotic and biotic processes and, altogether, creates a specific form of the structural–functional organization of the Earth's space. We do not know and, frankly speaking, have not yet strived to learn laws that determine the functioning and development of natural–anthropogenic ecosystems that consist of the abiotic components of the environment, biota, and human society along with the technical and socioindustrial infrastructure created by man. Casting light on these laws is a common scientific, fundamental and, without any doubt, ecological problem.

V.V. Dokuchaev was among the first to accentuate the necessity of full-fledged research on the inseparable triad: man, animate nature, and inanimate nature. In a public lecture delivered in 1898 he said: *"In the latest times ... the doctrine about those proportions and interactions (and to an equal extent about the laws governing their age-long changes) that exist between so-called animate and inanimate nature, on the one hand, and man with the entire variety of manifestations of his physical and spiritual life, on the other hand, ... has started to be increasingly distinguished from the vast domain of biological sciences and separated into a special discipline"* [Dokuchaev, 1961, p. 55]. These words, which were spoken over 100 years ago are of similar topicality today when the crisis concerning the relationships between man and nature has reached its acme and when the creation of the complex doctrine about the interactions among the man, animate nature, and the abiocoen has turned into a vital task of modern civilization. The current process of the ecologization of science undoubtedly leads to the development of a new ecology, an interdisciplinary scientific amalgamation that aims at the complex study of the system man–biota–abiotic environment.

There are many terms for the new ecology: major ecology, ecology with a capital E, mega ecology, global ecology, social ecology, ecology of man, ecolonomy, and geoecology, etc. The latter term seems to be preferable, because geoecology, literally translated, means the science about the house (home) located on the Earth. All natural and anthropogenically changed ecosystems not only occupy a certain part of the planet's space, but create it and in aggregate form a house whose modern inhabitants are living creatures and man. That is why this science studies the patterns of the functioning and evolution of all natural and technogenic organic geosystems at all levels of hierarchic organization. In essence, such a concept of geoecology completely matches the contemporary extended understanding of ecology.

Geoecology is very close to geography, which, according to W. Davis, plays the role of a global ecological discipline; he said in the early 20th century that it studied the relationship between animate and inanimate nature. The influence of economic activities on these two types of nature and the reciprocal impact of the modified environment on man became the subject of geographical studies long ago. Moreover, the very term "geoecology" was first used in 1939 by the German geographer C. Troll as a synonym for landscape ecology [Troll, 1972]. In fact, geography explores the area of mutual penetration and co-existence of the three phase conditions of the Earth's matter (atmosphere, hydrosphere, and lithosphere), in which climatic turnover of this material occurs. This area, including the lower layers of the atmosphere, the World Ocean, and the upper active layer of the earth, is called the landscape sheath and is the functional kernel of the biosphere. Different components of the landscape sheath (the organic world, soils, natural waters, and the atmosphere) are studied by biocenology, pedology, oceanology, hydrology, meteorology, and other special disciplines with geographical trends, where attention is accentuated on the spatial aspect of the structure and functioning of the studied objects.

Geography per se is aimed at elucidating the general structural–functional organization of the landscape sheath and constitutes, in essence, the topology of the multidimensional space of the latter, whose dimensions, besides spatial coordinates and time, are all the physical, chemical, biological, and other parameters that are taken into account. If during interactions among biota, economically active man, and the abiocoen, all system-forming processes were localized within the landscape sheath, geoecology would be really considered an excessive synonym of geography.

However, the bottom of the landscape sheath, which limits geographers' penetration into the depth of the Earth, both on earth and in ocean, runs in the lithosphere at the depth of several dozens, or at best, hundreds, of meters. Deeper, the exclusive jurisdiction of geology is located, which studies processes no less important for the existence of life on Earth than those passing within the landscape sheath. In the first order, this concerns the regeneration of the "nutrients" needed by autotrophs (CO_2, CH_4, H_2O, and other volatile components) that return to the biosphere as a result of the metamorphism of sedimentary rocks at high values of temperature and pressure. In the absence of this process, at the modern level of the primary production of organic substances, the Earth's ecosystems would consume all inorganic carbon that is available to autotrophic organisms in only 140000 years [Savenko, 2004]; this would mean that life would cease to exist on our planet. Of no less importance for life on the Earth are geotectonic processes, due to which the convective circulation of the lithogenic material in the Earth crust occurs, continents move, and other phenomena take place, triggered by forces beyond the limits of the landscape sheath. Therefore, geoecology is neither a synonym, nor a partial division of geography, geology, or biology. Geoecology is an interdisciplinary scientific school that studies the global geosystem man–biota–abiocoen environment, which can be called the ecosphere.

The ecological school in geochemistry. Geochemistry studies natural objects and phenomena at the atomic–molecular level and reveals the laws and history of the migration of chemical atoms in the Earth's space. Modern analytical methods allow for a sufficiently precise definition of the amount of any chemical element in any object that permits sampling. The geochemical language is very simple, since the geochemical "alphabet" embraces only about 90 "letters," viz., chemical elements; geochemical description of various natural objects and phenomena is of significant universality as the contemporary geochemistry is underpinned by the fundamental laws of physics and chemistry. By virtue of these circumstances, the geochemical approach allows one to consider, on one quantitative basis, diverse natural and anthropogenic processes, which is invaluable when complex ecological problems that affect human society, animate nature, and inanimate nature in their integrity are to be resolved.

The formation of scientific disciplines occurs in the case when the surveyed object (phenomenon) possesses a certain total set of properties that substantially distinguish it from all other objects (phenomena). In this sense, geochemistry is not an exclusion. However, in chemical terms, all geochemical processes pass in strict accordance with chemical laws. We are unaware of any fact that would indicate that the interaction of atomic shells under natural conditions occurred otherwise than under the same conditions in chemical laboratories or in technological processes. Nevertheless, the very existence of geochemistry indicates that the geochemical processes are peculiar. The chemical and chemico–technological processes occur under conditions created by man. The situation in geochemistry is quite different as the conditions are set forth by the evolutionarily developed form of the structural–functional organization of natural systems, or, in other words, in the form of the spatial and temporal coupling of elements of the systems and elementary processes, the elements are bound with each other. The geochemical processes occur under conditions defined by the systemic organization of nature and this is what crucially distinguishes them from chemical ones, and distinguishes geochemistry from chemistry.

The origins of ecological–geochemical ideas can be found as far back as at first stages of the germination of scientific chemistry. At the turn of the 18th and 19th centuries, the chemist A.L. Lavoisier and biologist J.B. Lamarck independently described a biotic circulation of substances in nature and stressed its role as a determinant in the formation of the substance composition and structure of the Earth surface. Lamarck noted that, despite their trifling mass compared to that of inanimate matter, the breathing organisms, acting continuously over a long time, change the environment no less significantly than abiogenic processes. A century later, the prominent microbiologist S.N. Vinogradskii voiced similar ideas about biogenic migration as the global biotic turnover of matter, in which the entire organic world of our planet participates, in his speech "On the role of microbes in the general circulation of life" delivered in 1896 at a meeting of the members of the Emperor's Institute of experimental medicine. He said: "All animate matter rises before us as an aggregate, as one giant organism, borrowing its elements from the reservoir of inorganic nature, purposefully governing all processes of its progressive and regressive metamorphosis, and, finally, giving all that was borrowed back to dead nature" [Vinogradskii, 1996, p. 1120].

In the most general form, the ecological paradigm in geochemistry was realized by V.I. Vernadskii in his doctrine of the Biosphere, according to which all living organisms and their environment were considered as an integral unity, with the interdependence of the migration of the atoms of chemical elements. In the small book *Biosphere* published in 1926, he formulated several fundamental statements that were directly related to ecology.

The first statement ascertained the existence of a unified mechanism on the Earth, via which different geological (planetary) processes, including the phenomena of life, interact in a certain manner and are organized in space and time, forming a dynamic structure, whose element is the Biosphere, viz., the part of the Earth's space where living creatures exist. The notion of life was related to the functioning of the Biosphere as an integral system, not to separate organisms, or their totality. V.I. Vernadskii pointed out that "Phenomena of life must be considered as parts of the biosphere mechanism and those functions that are executed by the living substance in this complex, but quite orderly mechanism, the biosphere, in the most basic and deepest way affect the character and structure of living creatures" [Vernadskii, 1960, pp. 48–49]. This statement formulates the main goal of the systemic–ecological approach to Earth sciences, being the clarification of the means (mechanisms) of coupling physical, chemical, and biological processes, which lead to the formation of a certain structural and functional organization of the space of life.

The second statement stressed the organizing role in the Biosphere of cosmic energy, specifically, of solar radiation. The fact that solar radiation is the energetic basis of life of the Earth was known long before V.I. Vernadskii. The novelty was the statement that the energy of the cosmos forms a special dynamic structure of substance flows on the Earth surface, which are tied in a certain way and form the shape of the biosphere. V.I. Vernadskii wrote: "The substance of the biosphere, due to these (cosmic radiations—author's comment) is imbued with energy; it becomes active, collects and distributes in the biosphere the energy obtained in the form of radiation, turns it eventually into energy in the Earth's environment that is free and able to produce work. ... The appearance of the Earth is changed by them and is sculpted by them to a significant extent. It is not only the reflection of our planet, manifestation of its substance and its energy, but it simultaneously is a creature of the external forces of the cosmos. Due to this, the history of the biosphere sharply differs from the history of other parts of the planet and its significance in the planetary mechanism is absolutely exclusive" [Vernadskii, 1960, pp. 10–11].

The third fundamental provision recognized the leading role of biota in creating the biosphere: "There is no chemical force on the Earth's surface that acts more constantly and, therefore, is more powerful in terms of its final effects than living organisms taken as a whole. The more we study chemical phenomena of the biosphere, the more we are convinced that there are no cases where they are independent of life. ... And furthermore, it becomes clear that the cessation of life would be inevitably related to the cessation of chemical changes except for the entire Earth crust but, anyway, its surface, the appearance of the Earth, the Biosphere" [Vernadskii, 1960, p. 21].

Of special importance for the modern stage of development of the ecological school in geochemistry are Vernadskii's considerations regarding human economic activities as a novel form of biogeochemical processes. In "Geochemical Sketches," V.I. Vernadskii gave the following characteristic of the geochemical activities of humans: "Man introduced in the planet's structure a new form of living substance action on the exchange of atoms of the living substance with stagnant matter. Previously, organisms influenced the history of only those atoms that were needed for their growth, reproduction, feeding, and breathing. Man expanded that circle, influencing elements necessary for technology and the creation of civilized forms of life. ... With the further development of civilization, the impact of these processes must increase, migration of atoms on the biogenic basis will increasingly expand, and the numbers of thus captured atoms will grow. It is obvious that this is not an accidental fact; it was predetermined by the entire paleontological evolution. This is as natural a fact as the rest" [Vernadskii, 1954, pp. 222–223].

This exceptionally important empirical generalization by V.I. Vernadskii gives grounds to consider that the resolution of modern ecological problems cannot be sought in the mere decrease of intensive economic activities to the level that would not essentially distort the natural organization of biosphere processes, because this would be a regression contravening the process of evolution on Earth. At the same time, this summation points at the possibility of "reconciliation" of humans with the biosphere. Economic activities, which are consciously developed and governed, should be brought in line with those principles of organization of biosphere processes, which have emerged as a result of the long joint evolution of the biotic and abiotic components and ensured the sustained development of the biosphere for billions of years.

V.I. Vernadskii indicated that all geochemical manifestations of life on Earth are associated with the processes of reproduction and metabolism [Vernadskii, 1954, 1960]. Man is a living creature as well, and all physiological processes found in animals are also inherent to him. But human metabolism is not limited only by physiological processes: "technogenic" metabolism is related to man, that is: economic activities, which are expressed in a special type of energy and mass exchange with the biotic and abiotic environment and are carried out with the use of tools that are not parts of the human body. This distinguished humans from all other forms of life on Earth. But in the geochemical respect the physiological metabolism and economic activities, differing in form, eventually come to one and the same end: the migration of chemical elements.

With the appearance of humans and the increase in economic activities, a substantial change of the structural and functional organization of geochemical processes that were historically developed during many millions of years occurred in the biosphere. The latter gradually transited into a new state, the Noosphere, whose determinants are to an equal extent the human society and the rest of animate and inanimate nature. In the Noosphere, the laws of the biospheric migration of chemical elements must change radically. All biogeochemical laws, of course, retain their action, but here new laws of technogenic migration are added, the elaboration of which is undoubtedly an independent geochemical problem.

By now, several ecological schools have developed in geochemistry, which to a significant extent overlap in terms of the problems they solve, but draw attention to different aspects of the relationship between humans, animate nature, and the abiocoen. Regretfully, a consistent interpretation of the subject of study does not exist for some of these, which produces significant uncertainty concerning their relations.

Biogeochemistry. V.I. Vernadskii [1980] called the science that studies the impact of life on the history of the planet's chemical elements, including the chemical composition of organisms and migration of atoms that occur at their direct or indirect participation, biogeochemistry. Stemming from the fact that life as a chemical and geochemical process is realized as the exchange of substances among organisms and their habitat, any forms of direct and indirect chemical interaction of organisms with the abiocoen should be attributed to biogeochemical processes. In this case, upon indirect interaction, the space studied by biogeochemistry may be significantly larger than the biosphere, i.e., larger than the part of the terrestrial space inhabited by breathing organisms. Biogenic migration of chemical elements, which is related to the activities of the living creatures, takes place both in organisms and outside them; therefore, biogeochemistry must study both the biota and abiotic environment. This is the most widespread understanding of biogeochemistry as a science that investigates the biogenic migration of chemical elements in the biosphere.

The concept of biogeochemical cycles, which represent the fullest expression of biogenic migration and generally the means for life to exist on Earth, underlies biogeochemistry. V.I.Vernadskii [1980] outlined three main lines of biogeochemical studies: (1) biological, or biogeochemical cognition of living phenomena; (2) geological, or biogeochemical cognition of the medium of life; and (3) applied, or the study of the biogeochemical role of humans. Subsequently, these started to be considered autonomous directions of research. The biogeochemical functions of humans are, as a rule, excluded from the subject matter of biogeochemistry per se and pertain to the jurisdiction of a separate science, whose content and name are widely discussed.

Geochemical ecology. This school is often considered as a section of biogeochemistry, which studies the impact of geochemical environmental factors on living creatures, but it may be classified as factorial ecology and belong to biological sciences. In the opinion of V.V. Kovalskii [1974], the subject matter of geochemical ecology is the interactions of organisms and their communities with the geochemical environment and with each other; the main objective is the study of the adaptive processes of the organisms, populations, and other communities to the environmental conditions. Thus, during the investigation of the organism–environment, system certain priorities can be traced: geochemical ecology pays more attention to the action of the geochemical environment on organisms, while biogeochemistry, in contrast, is more interested in the impact of organisms on the migration of chemical elements in the environment.

One important and practically valuable division of geochemical ecology is the doctrine about biogeochemical provinces [Vinogradov, 1963], which connects the physiological, morphological, and hereditary changes of organisms with the spatial geochemical heterogeneity of the biosphere (geochemical abnormalities).

Processes that occur at the suborganism level (physiological, biochemical, and genetic) are not considered by geochemical ecologists as such, but are viewed in their relation to the environment and their regulation by it. Similarly, trophic relations of different groups of organisms are considered not only as flows of chemical elements in the biotic substance turnover but also from the viewpoint of their spreading and the forms of their presence in the abiocoen.

Anthropochemistry can be also viewed as a division of geochemical ecology; its goals include the study of the role of the environment in the life of humans and human civilizations [Aleksandrovskaya and Aleksandrovskii, 2004].

Geochemistry of landscapes, chemical geography, and geochemical biocenology. Landscape geochemistry, which is closely tied with Dokuchaev's pedology and Vernadskii's doctrine of the biosphere, was formed within geography to introduce the geochemical aspect in landscape studies. Its founder, B.B. Polynov [1952], viewed landscapes from the viewpoint of the structural and functional organization of flows of chemical elements, where the biotic and climatic circulations of substances played the role of system-forming processes. This approach was implemented by the Russian school of landscape geochemists [M.A. Glazovskaya, A.I. Perelman, N.S. Kasimov, V.V. Dobrovolskii, etc.], limnologists [S.I. Kuznetsov and D. Hutchinson], and oceanologists [A.P. Lisitsyn and M.E. Vinogradov]. Outside Russia, it has been described in detail by J. Fortesque

[1985] under the title of the "geochemistry of the environment." As well, landscape geochemistry studies landscapes transformed in the course of economic activities.

A.A. Grigoryev [1936] called the school that was intended to study chemical aspects of the physico–geographical process chemical geography. Since this process, from the geochemical viewpoint, represents the circulation of substances in the landscape sheath, chemical geography does not leave the jurisdiction of landscape geochemistry and Grigoryev's proposal was not supported by the scientific community.

One more ecological–geochemical school that is connected to landscape geochemistry, is biogeocenology, which studies energy and mass exchange, or biotic turnover, in biogeocenoses, or the simplest systems that have emerged at the boundary of the animate and inanimate worlds [Sukachev, 1967; Timofeev-Resovskii and Tyuryukanov, 1967; and Bazilevich, 1979].

Geochemistry of the environment. This title, as a rule, unites all directions of ecological–geochemical studies. In Russia, this is largely applied work on the study of pollution and geochemical monitoring of the human environment, viz., the atmosphere, surficial and underground waters, soils, ground series, plant, and animal worlds [Beus et al., 1976; Saet et al., 1990].

Geochemistry of technogenesis. A.E. Fersman named the totality of processes carried out by man technogenesis. In agreement with this, the tasks of geochemistry of technogenesis are related to studying different geochemical aspects of industrial and agricultural activities [Suturin, 1990[1]; Tauson, 1990]. A.E. Fersman considered economic activities as a specific means of the struggle for survival, intrinsic only to people, and he was first to attempt to tie the quantitative characteristics of technogenic flows of substances with the geochemical properties of elements (occurrence, ability to be concentrated in deposits, etc.). A.E. Fersman believed that one of the crucial tasks of the geochemistry of technogenesis was the search for laws connecting geochemistry with the economy per se, i.e., the extension of the geochemical approach to all sides of the economic activities, including the processes of production and consumption. Studies in this direction have not yet become the subject of planned research and their coverage is still sparse [e.g., Glazovskii, 1982]. With certain reservations, attempts to create the economic theory on the basis of the general theory of energy and mass exchange can be classified similarly (Alexeev, 1995).

Ecological geochemistry. The understanding of the goals and objectives of ecological geochemistry greatly varies by author. From one viewpoint, its subject matter is the history of the atoms of chemical elements in the biosphere [Alexeenko, 2000] or the behavior of chemical elements under conditions of interaction of living and inert matter [Gavrilenko, 1994], which virtually coincides with the traditional interpretation of biogeochemistry. In agreement with another point of view, ecological geochemistry is aimed at the study of the geochemical aspects of economic activities of humans [Suturin, 1990; Tauson, 1990; Barabanov, 1994; and Yanin, 1999]. In the latter case, it proves to be a synonym of the geochemistry of technogenesis.

According to the classical definition of ecology as the science that explores the relationships of living organisms with the environment, all the above-mentioned schools in geochemistry are, of course, ecological disciplines. Attributing the geochemical aspects of economic activities to ecology does not run counter to this statement, as humans are one of many species that have the ability to labor, i.e., the specific form of energy and mass exchange with the environment that distinguishes man from the rest of animate nature, in the course of evolution.

Studying economic activities from geochemical positions is, by virtue of its undoubted specificity, quite an independent scientific school, which seems to fit the name "geochemistry of technogenesis," since this term precisely reflects the main difference of humans from other organisms. At the same time, the term "ecological geochemistry" best fits the understanding of ecology, which is formed today on the basis of a broad interpretation, in which abiogenic, biogenic, and technogenic processes are considered in their total interdependence and interconditionality.

The above ecological–geochemical "disciplines" relate to the study, at the atomic–molecular level, of various aspects of the structure and functioning of the global, planetary system man–biota–abiocoen environment. Therefore, they are divisions of the scientific school that is formed at the joining of geochemistry and ecology (in the broad understanding of the latter) and which best fits the name "ecological geochemistry." V.I. Vernadskii [1954] considered the subject matter of geochemistry to be the history of atoms on our planet, i.e., their motion in space and time, accompanied by the formation and destruction of chemical compounds, as well as the synthesis and decay of the very atoms. Ecology, in its broader sense, studies the structure and functioning of different hierarchic ranks of ecosystems on our planet, including those that contain man with the additional attributes of economic activities. It is evident that the intersection of interests of geochemistry and ecology occurs in the field of studying ecosystems at the molecular level where the internal structure, external bonds, and development of ecosystems are considered in terms of the structural and functional organization of the entire sum of system-forming abiotic, biotic, and anthropogenic geochemical processes. Proceeding from this, the subject matter of ecological geochemistry can be considered as the history of atoms in the Earth's ecosphere,

[1] For the scientific direction studying the geochemistry of human activity, A.N. Suturin used not a very apporopriate name "geochemistry of anthropogenesis," as anthropogenesis may be understood as a process of parentage and biological evolution of man.

the global, planetary sheath representing the aggregate of all ecosystems at different hierarchic levels, whose components are human society and living and inanimate nature. Ecological geochemistry, understood in this way, appears to be significantly broader than both biogeochemistry, which investigates the biogenic migration of chemical elements in the biosphere, and all other ecological–geochemical schools that study different geochemical aspects of the economic activities of humans.

Ecological geochemistry studies the ecosphere, viz., the system of external geospheres of the Earth (atmosphere, hydrosphere, and upper lithosphere up to the metamorphic sheath inclusive), being the "house" for humans and other living creatures. Although vast spaces of the ecosphere are deprived of life, there are compelling reasons to consider it as the "home" for all living things, since all its parts are functionally interrelated and form a holistic system. Any house has not only a living space, but also walls, roof, foundation, and different communications, otherwise it would not be a house. The ecosphere is wider than the biosphere, which, to put it picturesquely, is the "living space" where living organisms exist. The biosphere, viz., the area of direct life of organisms, is a part of the ecosphere, and life as a geological phenomenon far outreaches its limits.

The specificity of the methods of ecological geochemistry is related to studying ecosystems at the atomic–molecular level. Another important peculiarity of its methods is that it uses the systemic-evolutionary approach, based on the postulate of the systemic construction of the surrounding world. The current state of any natural, technogenic or natural–technogenic ecosystem is defined by the character of internal structural and functional organization of its constituents and processes of their interaction, by the participation of this system in the structural and functional arrangement of systems at a higher hierarchic level, and by the preceding history of its development. The systemic–evolutionary approach implies resolving three major questions: (1) the belonging of the surveyed object (phenomenon) to a certain type of system; (2) the definition of its position in the internal and external structural and functional organization of the given system; and (3) setting the genetic connection with other objects (phenomena) related to this system and its external medium.

We note here two essential aspects related to the use of the systemic–evolutionary approach in ecological geochemistry and geochemistry in general. One of them touches the peculiarities of the manifestation of the fundamental laws of chemistry in natural systems, and another pertains to specific features of the evolution of the latter.

The systemic–evolutionary approach is based on admitting the potential diversity of trajectories of ecosystem development. The evolution of living matter is a combination of occasional and targeted processes. The appearance of new species is related to the accidental mutation of genes, but not every mutation achieves the level of species formation. Most mutations are suppressed by mechanisms of biospheric homeostasis; only some, holding the pressure of other forms of life, are realized in the biosphere and become a factor in its evolutionary development. Being probabilistic in its basics, biological evolution has directionality due to the restraints posed by the current state of the biosphere, which, in turn, is causally tied to the preceding history of development. By virtue of the great potential of species diversity, all possible variants of development cannot be realized, even in a very long period of time. This means that the evolution of the organic world may be considered to be the result of the simultaneous expression of two processes that have different relationships with time: mutations, which per se do not have temporal orientation, and natural selection, which ensures the temporal vector of evolutionary development.

Two important consequences pertaining to the study of life as a planetary phenomenon follow from the principle of the potential diversity of biological evolution: (1) the current state of the biota is not unambiguously predefined by its preceding state and it does not preset its further states; and (2) any state of the biota, that was realized in the past or exists currently, cannot be considered a priori to be the most optimal state of all its possible conditions. These issues indicate the necessity of considering ecological–geochemical problems in the historical aspect in all cases, without any exceptions.

REFERENCES

1. Aleksandrovskaya, E.I. and Aleksandrovskii, A.L., *Istoriko-geograficheskaya antropokhimiya – novoe napravlenie v naukakh o cheloveke i geosfere*, *Izv. Akad. Nauk, Ser. Geogr.*, 2004, no. 4, pp. 19–26.
2. Alekseenko, V.A., *Ekologicheskaya geokhimiya* (Ecologic Geochemistry), Moscow: Logos, 2000.
3. Alekseev, V.V., Energeticheskii bazis ekonomiki, *Vestn. Mosk. Un-ta*, Ser. 5. 1995, no. 2. pp. 10–16.
4. Barabanov, V.F., *Vvedenie v ekologicheskuyu geokhimiyu* (Introduction in Ecological Geochemistry), St. Petersburg: S.-Pb. Gos. Univ., 1994.
5. Bazilevich, N.I., *Biogeokhimiya Zemli i funktsional'nye modeli obmennykh protsessov prirodnykh ekosistem*, in *Tr. biogeokhim. laboratorii. T. 16* (Works of Biogeochemical Laboratory), Moscow: Nauka, 1979, pp. 56–73.
6. Beus, A.A., Grabovskaya, L.I., and Tikhonova, N.V., *Geokhimiya okruzhayushchei sredy* (Geochemistry of the Environment), Moscow: Nedra, 1976.
7. Dokuchaev, V.V., *K voprosu o sootnosheniyakh mezhdu zhivoi i mertvoi prirodoi*, in *Soch. T. 8* (Collection of works), Moscow: Akad. Nauk SSSR, 1961, pp. 55–57.
8. Fortesque, J., *Geokhimiya okruzhayushchei sredy* (Geochemistry of the Environment), Moscow: Progress, 1985.

9. Gavrilenko, V.V., *Nekotorye aktual'nye problemy ekologicheskoi mineralogii i geokhimii*, *Zap. Vseross. Mineral. O-va*, 1994.
10. Glazovskii, N.F., *Tekhnogennye potoki veshchestv v biosfere*, in *Dobycha poleznykh iskopaemykh i geokhimiya prirodnykh ekosistem* (Production of Minerals and Geochemistry of Natural Ecosystems), Moscow: Nauka, 1982, pp. 7–28.
11. Gorshkov, V.G., *Fizicheskie i biologicheskie osnovy ustoichivosti zhizni* (Physical and Biological Foundations of the Sustained Life), Moscow: Izd. VINITI, 1995.
12. Grigor'ev, A.A., *O khimicheskoi geografii*, in *Akademiku V.I. Vernadskomu k pyatidesyatiletiyu nauchnoi i pedagogicheskoi deyatel'nosti. T. 2* (For Academician V.I. Vernadskii on the Occasion of the 50th Anniversary of Scientific and Pedagogical Activities), Leningrad: Akad. Nauk SSSR, 1936, pp. 1231–1236.
13. Koval'skii, V.V., *Geokhimicheskaya ekologiya* (Geochemical Ecology), Moscow: Nauka, 1974.
14. Polynov, B.B., *Geokhimicheskie landshafty*, in *Geograficheskie raboty* (Geographic Works), Moscow, 1952, pp. 381–393.
15. Saet, Yu.E., Revich, B.A., Yanin, E.P., et al., *Geokhimiya okruzhayushchei sredy* (Geochemistry of the Environment), Moscow: Nedra, 1990.
16. Savenko, V.S., *Chto takoe zhizn'? Geokhimicheskii podkhod k probleme* (What is life? A Geochemical Approach to the Problem), Moscow: GEOS, 2004.
17. Sukachev, V.N., *Biogeotsenologiya i ee sovremennye zadachi*, *Zh. Obshch. Biol.*, 1967, vol. 28, no. 5, pp. 501–508.
18. Suturin, A.N., *Geokhimicheskie cherty antropogennykh protsessov*, in *Geokhimiya tekhnogennykh protsessov* (Geochemistry of Technogenic Processes), Moscow: Nauka, 1990, pp. 60–74.
19. Tauson, L.V., *Sovremennye problemy geokhimii tekhnogeneza*, in *Geokhimiya tekhnogennykh protsessov* (Geochemistry of Technogenic Processes), Moscow: Nauka, 1990, pp. 3–13.
20. Timofeev-Resovskii, N.V. and Tyuryukanov, A.N., Biogeotsenologiya i pochvovedenie, *Byul. MOIP. Otd. Biol*, 1967, vol. 72, no. 2, pp. 106–117.
21. Troll', K., L*andshaftnaya ekologiya (geoekologiya) i biogeotsenologiya. Terminologicheskoe issledovanie*, *Izv. Akad. Nauk SSSR, Ser. Geogr.*, 1972, no. 3, pp. 114–120.
22. Vernadskii, V.I., *Ocherki geokhimii*, in *Izbrannye sochineniya. T. 1* (Selected Works), Moscow: Akad. Nauk SSSR, 1954, pp. 5–392.
23. Vernadskii, V.I., Biosfera, in *Izbrannye sochineniya. T. 5* (Selected Works), Moscow: Akad. Nauk SSSR, 1960, pp. 5–102.
24. Vernadskii, V.I., *Problemy biogeokhimii. 1. Znachenie biogeokhimii dlya poznaniya biosfery*, in *Tr. biogeokhim. laboratorii. T. 17* (Works of the Biogeochemical Laboratory), Moscow: Nauka, 1980, pp. 10–54.
25. Vinogradov, A.P., *Biogeokhimicheskie provintsii i ikh rol' v organicheskoi evolyutsii*, *Geokhimiya*, 1963, no. 3, pp. 199–212.
26. Vinogradskii, S.N., *Rol' mikrobov v krugovorote zhizni*, *Vestn. Ross. Akad. Nauk*, 1996, no. 12, pp. 1116–1120.
27. Yanin, E.P., *Vvedenie v ekologicheskuyu geokhimiyu* (Introduction in Ecological Geochemistry), Moscow, 1999.
28. Zavarzin, G.A., *Lektsii po prirodovedcheskoi mikrobiologii* (Lectures on Natural Historical Microbiology), Moscow: Nauka, 2003.