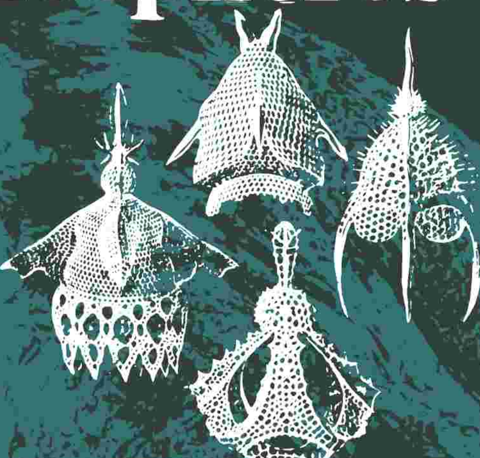
Traces of Bygone Biospheres

A. V. Lapo



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А. В. Лапо

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Contents

To the English-speaking Reader

At present our knowledge about the phenomena and processes occurring in the surrounding world has vastly expanded. At the same time it is only now that humanity has begun to understand both the scope of its activities and its dependence on the state of the biosphere. Understandably, the universal interconnection and interdependence of natural phenomena has become the focus of attention of modern natural science, and a synthesis of achievements in particular fields has become the dominant trend in the development of science as a whole.

This trend towards synthesis has found its most dramatic manifestation in the interpenetration of sciences concerned with animate and inanimate nature. A teaching of the biosphere has developed – a science which stands in its own right and cannot be reduced either to geography or biology, but makes use of their advances and results, and, in turn, influences the development of geology. The founder of this science was the brilliant Russian scientist Vladimir Ivanovich Vernadsky (1863-1945).

This book will describe the biosphere and the role of life in geological processes; reading it, you will learn about the scientists who dealt with these problems and, above all about V. I. Vernadsky himself. His name is bound up with the problems treated in this book, just as the name of Albert Einstein is bound up with the theory of relativity. The highest moral qualities of Vernadsky and Einstein also bring them together. And, evidently, it is not by chance that the greatest scientific discoveries of the twentieth century were made by such irreproachable personalities as Vernadsky and Einstein. "To all who knew him, even slightly, he will remain an ideal of a man of high purpose and purity of character and a scientist who never lost his interest in the search for knowledge" * – this is what one of Vernadsky's contemporaries wrote about him.

Vernadsky's name was famous already during his lifetime. In 1889, when quite a young man, he was elected a corresponding member of the British Association for the Advancement of Science. Later, the National Academies of France, Czechoslovakia and Yugoslavia, the Geological Societies of France and Belgium, the Biochemical Society of India, and the American Mineralogical Society elected Vernadsky their foreign member.

Vladimir Ivanovich Vernadsky.

Every year since 1959, to commemorate Vernadsky's birthday, Vernadsky Readings have been conducted at the Institute named after him in Moscow. In the papers read there N. V. Belov, D. S. Korzhinsky, A. B. Ronov, V. S. Sobolev, A. P. Vinogradov and other prominent Soviet scientists, as well as their foreign colleagues T. F. W. Barth, B. R. Doe, R. M. Garrels, A. E. Ringwood, J. Wyard paid their homage to Vernadsky.

Among contemporary scientists writing in English there are two men – G. E. Hutchinson and H. A. Lowenstam – who can be said to have contributed most to the development of the ideas considered in this book. G. E. Hutchinson is an active

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* T. M. Stadnichenko, "Memorial of Vladimir Ivanovich Vernadsky", *American Mineralogist*, 1947, v. 32, 3-4, p. 194.

propagandist of Vernadsky's ideas in the United States, a well-known biogeochemist, limnologist and ecologist, a winner of the Franklin medal, the highest award from the Franklin Institute in Philadelphia (which was also conferred upon Thomas Edison, Niels Bohr, Max Planck, Albert Einstein, Enrico Fermi, Theodosius Dobzhansky). G. E. Hutchinson began to be interested in problems of biogeochemistry by the early forties, under the influence of his friendship with V. I. Vernadsky's son Georgi Vladimirovich. Hutchinson has deserved his high repute by works in the biochemistry of atmospheric gases, aluminium, phosphorus, by the discovery of the "plankton paradox", by his monographs on ecology and limnology, and by the programmatic work "Biosphere", which has been translated into Russian.

Much credit for investigations into the role of life in geological processes is also due to H. A. Lowenstam, an outstanding scientist who was forced to leave his native Germany in the days of fascism and is now working in the United States. H. A. Lowenstam is well known mainly for his contributions to the study of biomineralisation and biosedimentation phenomena, as well as to the investigation of fossil reefs.

For the present edition the text of the book has been revised and amplified; in this much is due to the valuable comments received from my fellow-countrymen and colleagues I. N. Drozdova (Leningrad), M. A. Golubets (Lvov), D. P. Grigoryev (Leningrad), A. N. Ivanov (Yaroslavl), and P. M. Rafes (Moscow), as well as from S. Czarniecki and K. Görlich of Poland and J. Obrhel of Czechoslovakia. To all these persons I would like to express by sincere gratitude.

Since in the text of this book references are often made to sources published in the Russian language with which English-speaking readers may not be conversant, the book is supplemented with a list of suggestions for further reading in some European languages.

In conclusion I only venture to express the hope that they who open this book will not be disappointed after having read it to the end.

The author

Strange Fate

"Father could understand everything."

N. V. Toll-Vernadskaya

Foreword

"When he was elected an honorary member of scientific institutions, it was an honour both to Vernadsky himself and in no smaller measure to the institutions that elected him. These institutions took pride in avowing: "Academician Vernadsky has consented to be our honorary member"...

"More than half a century has passed since the time when his scientific creativity was in its prime, a very long period indeed, but during this period there was no scientist to approach him...

"It is very difficult to become a new Vernadsky, but young scientists ought not to lose heart. Way is open wide to them... If we pose a question whether anyone of them will be a second Vernadsky, it is difficult to give a positive answer. Certainly, anything comes about in nature, and one should not lose hope.

"What matters most is that each can improve the quality of his work, can attain new, necessary results if he follows the example laid down by Vernadsky, studies the principles of his work, and applies the specific features of this work."

This is what an outstanding geologist of our time, Lenin prize winner academician Dmitri Vasilievich Nalivkin*, said at the centenary of Vernadsky in 1963.

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* D. V. Nalivkin, "In memory of the world's greatest geochemist". In: "Materials for the Scientific Session of the All-Union Geographical Society, Dedicated to the 100th Anniversary of V. I. Vernadsky's Birthday", Leningrad, 1963, pp. 3-5 (in Russian).

This book is about the teaching of Vladimir Ivanovich Vernadsky about the biosphere, and the aim with which this book was written is that each would be able, as D. V. Nalivkin put it, "to improve the quality of his work".

Vladimir Ivanovich Vernadsky presents an astounding figure in the natural science of the twentieth century. It seemed as if he had no awareness that science was partitioned into fields (and in modern natural science their number is over a thousand).

Vernadsky was a naturalist in the broad sense of this word, possibly, the last one in the history of science. Though he was neither a biologist nor a geographer by education, biologists rank him with Darwin and Pavlov, and geographers consider him to be one of the originators of modern geography. Vernadsky's works are not merely fundamental in some particular field: Vernadsky founded new sciences. There are at least three such sciences: radiogeology, biogeochemistry, and the teaching of the biosphere (recently it was suggested that the latter science should be called biospherology*).

Although biogeochemistry and the teaching of the biosphere are new branches of science, they actively influence long-standing areas of natural science. Recently the article "Vital Forms of Plants Relating to the Teaching of the Biosphere" was published in *Botanical Journal,* and G. G. Vinberg, a well-known Soviet biologist, President of the All-Union Hydrobiological Society, Corresponding Member of the USSR Academy of Sciences, at one of scientific conferences read his paper "Vernadsky's Ideas in Modern Limnology". Limnology is a scientific study of lakes and V. I. Vernadsky was never specially concerned with it.

A strange fate: Vernadsky's ideas contribute to the development of those allied areas, in which he did not work. Evidently, the thing is that Vernadsky not only laid foundations of sciences and formulated fruitful ideas. Albert Einstein once said: "Science is an attempt to bring the chaotic diversity of our sensory experience in correspondence with a certain unified system of thinking". Vernadsky has created such a system. This system of thinking, or, if you like, a global conception, is based on the determining role of life in geological processes. It was created by Vernadsky for the geologic past, but – a strange

* G. V. Gegamian, "About the Biospherology of V. I. Vernadsky", *Journal of General Biology,* 1980, v. 41, 4, pp. 581-595 (in Russian).

fate!–it became actual, even topical for us, who live in the end of the second millennium.

"A strange fate", wrote Vernadsky*, then at the age of twenty five, to his wife, "Most of all I was attracted, on the one hand, by the problems of the historical life of mankind, and, on the other hand, by the philosophical aspect of mathematical sciences. And I did not go in for either of these fields. I did not go in for history, because I wanted first to receive training in natural history and then to pass over to history; nor did I go in for mathematics, since I did not and do not believe in my mathematical abilities..."

For all that, he had decided upon the path to follow quite early. On the occasion of the seventeenth anniversary of his birth Volodya Vernadsky asked his father to present him with an English edition of one of Darwin's books (by that time he already could read in several languages). The father presented him with something else–evidently, being of the opinion that it was too early for his son to read such serious books–and Volodya was so upset that his father had to concede. This book with the inscription "To my beloved son" is now kept in V. I. Vernadsky's Study in Moscow (now a museum).

In his young years Vernadsky had already formulated questions about which he cogitated all his life. The manuscript of the report which he read at a conference of the Student Scientific and Literary Society of Petersburg University in December of 1884 has survived, and there we find the following words: "But what is life? And matter–which is in perpetual continuous and lawful motion, where endless destruction and creation occurs, where there is no rest–is it dead? Can it be that only the hardly noticeable film on an infinitely small dot in the universe–on the Earth–possesses radical, specific properties, and that death is reigning all over beyond it?... For the time being one can only bring up these questions. Their solution is sooner or later given by science."

The "Vernadskian phenomenon" was moulded by the encyclopaedic character of his interests. His closest friends were people of various professions. Those who knew Vernadsky well could not help wondering at his conduct in conversations: he was not only a fine listener, but could easily "get his companion to talk", as one would say to-day. And those were

* *From Vernadsky's Correspondence*, *Priroda*, 1948, 9, p. 76 (in Russian).

not idle conversations. With D.S. Rozhdestvensky Vernadsky talked about nuclear physics; with N.Ya. Marr, about the Japhetic theory; with D.D. Pletnev, about the theoretical fundamentals of cardiology; with N.I. Vavilov, about the coloration of plants and about the varieties of wheat.

In his eightieth year, in answer to the question in a questionnaire: "What do you regard as most characteristic and most valuable in the way you organise your labour as a scientist: plan, accuracy, system, or something else?" Vernadsky wrote, "I think that, most probably, it is system and the striving for understanding the world around me. In addition, I attach extreme importance to matters of ethics*."

If we open Vernadsky's "Biogeochemical Essays", a collection of his papers published in 1940, we shall see the following dedication above the author's preface: "I dedicate these 'Biogeochemical Essays' to my wife Natalia Yegorovna, née Staritskaya, with whom we have been together for more than fifty years, to my helpmate in work, never failing in her belief that to live is to love people and to search freely for truth". Is there any need in saying that such an understanding of the import of life was the guiding ethical principle for Vernadsky himself?

Vernadsky would not have been Vernadsky, were it not for his ability to organise his work to the maximum possible extent. Many of his contemporaries noted his ability to take advantage of (as he used to say) the smallest "bits of time". Vernadsky attached great importance to this and passed on the skill of time saving to his son Georgi and daughter Nina.

And one more characteristic detail: in answer to another question from the questionnaire we have already mentioned, Vernadsky wrote: "I have a reading knowledge of all Slavonic, Romance and Germanic languages."**

A strange fate! "We consult him now no less frequently, perhaps, even more frequently than during his lifetime; particularly in the course of our scientific work, where his ideas and appreciations always attend us"–thus one of Vernadsky's contemporaries wrote about him. His works are striking not only because of his profound knowledge of the subject, but also because of the wealth of factual material and (now we

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* *Priroda*, 1967, 9, p. 97 (in Russian).

** *Ibid.*, p. 96.

know-why!) excursions into history. Some of Vernadsky's works are such that, one would think, only a whole body of authors could have the power to write them. But they were written by one man, rather advanced in years: all the main Vernadsky's works about the biosphere were written by him when he was already over sixty. Not always did it come easily to him.

"If you observe persons engaged in scientific work, you notice how often they are irritated because of the course taken by, and the essence of, their work, or how often they cannot make themselves work, because all their will has been used in petty, strenuous work, and they have to summon up their strength again..." - this is a quotation from another letter Vernadsky wrote to his wife in the same year of 1889*.

These qualities of V. I. Vernadsky - the encyclopaedic character of his interests and his outstanding capacity for work - provide, I think, a clue to the understanding of the "Vernadskian phenomenon". And, as Academician Nalivkin says, though one is not to become a second Vernadsky, it is necessary that one should learn from his example.

The first thing to strike anyone is the integrity of Vernadsky's world outlook. I cannot refrain from citing one more of his letters, written in 1892**:

"I generally do not understand the division of love into some kind of "sensual", or animal, and some kind of lofty, or ideal type. It seems to me that, in general, the conception about the sensual, animal, entertained by us is something really comical. Only one thing matters here: how high in general is the personality of each of the two who are in love and how far they are equal. We see absolutely the same thing everywhere: in friendship, in common conversation, in the way of spending time together, etc. The baseness of nature or low culture will put the same stamp of vulgarity anywhere. I think, the time has come for us to stop regarding the "body" as something despicable and to get rid of the narrow christian (or monkish) division into the spirit and the body. Real spiritual life, real high-principled side of life consists just in using the best sides of both the body and the spirit".

The expression of his lucid eyes was that of a philosopher and a child; his gait was fast, his figure was well-proportioned, a little stooped only in his old age. Vernadsky did not like to

* *From Vernadsky's Correspondence*, *Priroda*, 1948, 9, p. 76.

** *Russian Literature*, 1979, 3, pp. 198-199.

be photographed, and only a few of his photographs are left. For some reason, descriptions of his appearance in the memoirs of his contemporaries are also few. The best description was given by D.V. Nalivkin*. It refers to 1914.

"...A narrow, chiselled face, a high prominent forehead of a scientist, dark hair streaked with grey, running in cascades above it caused wonder and surprise. But even these features were merely a background for the eyes of unparalleled clarity, lucidity and profundity. It seemed that the entire cast, the entire soul of this extraordinary man was gleaming in them."

Vernadsky died in 1945, in the eighty-second year of his life.

Vernadsky is not easy to read: his mode of thinking was in abstract philosophical categories. His works are rich in factual material and tabulated numerical data, but there are few illustrative charts, effective images and colourful comparisons. Sometimes this caused misunderstanding. But in respect of Vernadsky even the historical perspective becomes reversed: it will suffice to compare the evaluation of his creative legacy, given in different years. The fiftieth anniversary of the publication of Vernadsky's monograph about the biosphere was marked by holding special conferences; yet in 1927 it had been appraised by its reviewer in the following manner:

"Geologists calmly listened to Academician Vernadsky before, and they now listen taciturnly to yet another of his antihistorical communications. The rather interesting book of Vernadsky requires, however, a critical approach. The style of exposition is somewhat heavy. The book loses also because of the main, most important ideas being inadequately underscored and concentrated. Nevertheless, the interest which the book presents must motivate its study notwithstanding."

Indeed, geologists "calmly listened" to academician Vernadsky. Vernadsky's works about the role of life in geological processes were rarely cited in the thirties, and in the obituary no mention at all was made that he had created the teaching of the biosphere. At that time only the Biogeochemical Laboratory (BIOGEL) organised by Vernadsky was concerned with problems of biogeochemistry (now this laboratory has grown into the Institute of Geochemistry and Analytical Chemistry, bearing Vernadsky's name).

The grandeur of Vernadsky's ideas was recognised only after

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* D.V. Nalivkin, "Preparation of expeditions to Central Asia", *Essays of History of Geological Knowledge*, Issue 11, 1963, p. 30 (in Russian).

his death. Academician Alexander Evgenievich Fersman*, one of the most convinced disciples of Vernadsky, called by his friends "ball lightning" for his tremendous energy (and for his figure), wrote in 1945 about the creative legacy of Vernadsky.

"For decades, for whole centuries will these brilliant ideas be extended and studied, will new pages, providing a source for new strivings, be opened... It is not yet time for going deep into his vast archives and numerous records of his biography; it will take many years of work for his disciples and historians of natural science to reveal the main trends in his scientific creativity, to unriddle the complicated compositions of his text, still not clear to us. This task lies with the generations to come..."

Vernadsky was already worshipped, but not yet understood.

Now the time of understanding has come. Vernadsky's books which were not published during his lifetime are now in print: two volumes of "Reflections of a Naturalist" (1975, 1977), "Living Matter" (1978), a third issue of "Problems of Biogeochemistry" (1980), two volumes of Vernadsky's correspondence with B.L. Lichkov (1979, 1980)... Written 30 or 50 years ago, these materials in a strange manner turn out to be new in their ideas, the depth with which the scientific material is treated and the breadth with which it is generalised.

In modern natural science Vernadsky remains the leader.

A fate to be envied...

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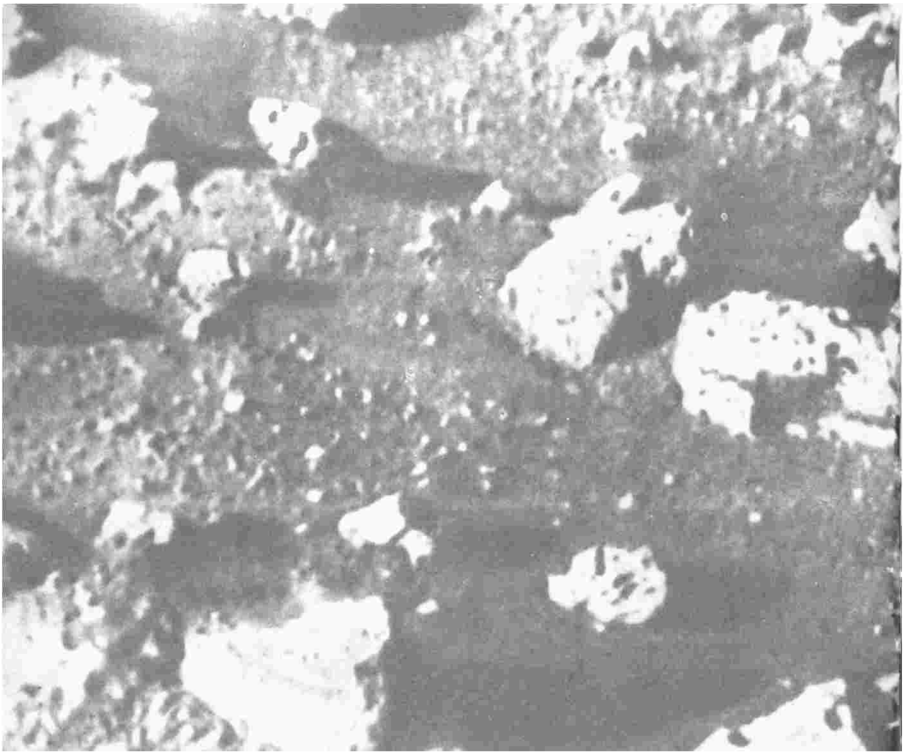
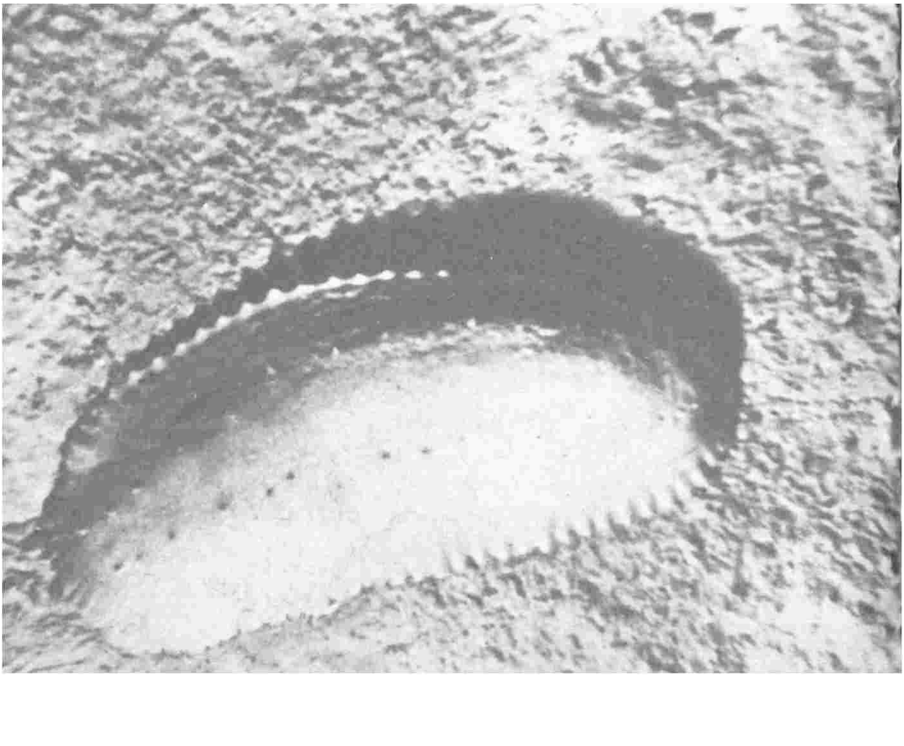
* A.E. Fersman, "Vladimir Ivanovich Vernadsky", *Bull. of MSN*, Geol. section, 1946, v. 21, 1, pp. 53-54.





1 BIOSPHERE

"Ages and millennia had passed before human thought could note the traits of a single consistent mechanism in the seemingly chaotic picture of nature."

V. I. Vernadsky, 1926

In 1926 in Leningrad a book was issued in 2 thousand copies, with nothing showy in its design. But this book was to become one of the greatest events in the history of natural science of the twentieth century. It came from the pen of V. I. Vernadsky and its title was "The Biosphere". It was in this very thin book which contained only one hundred and fifty pages that the biosphere of the Earth was for the first time shown to be an integral dynamic system controlled by life. Three years later the book was reissued in Paris in French.*

More than half a century has passed since that time; extensive evidence has appeared, both indicative of the determining role of life in geological processes, and concerning the deposits which date back to the biospheres of bygone epochs.

* W. Vernadsky, *La biosphère*, Alcan, Paris, 1929, 232 p.

◀ Martian surface. Our Earth would nave been the same, but for life on it.

Holothurian, a characteristic representative of abyssal fauna. The Atlantic Ocean at a depth of 2120 m.

It is this compass of problems that we shall consider in our book. But, as V. I. Lenin said, "...anybody who tackles partial problems without having previously settled general problems will inevitably and at every step "come up against" those general problems without himself realising it."*

Bearing this in mind, we devote the first chapter of the book to the teaching of the biosphere.

This term appeared in the scientific literature in 1875 in a monograph devoted to the geological structure of the Alps.

Edward Suess
(1831-1914).

The author of the monograph was Edward Suess (1831-1914), a Gold Medal winner of the Russian Geographical Society, an eminent Austrian geologist, "a generaliser of geological facts", as Academician V. A. Obruchev used to call him. E. Suess wrote, "One thing seems to be foreign on this large celestial body consisting of spheres, namely – organic life... On the surface of continents it is possible to single out a self-contained biosphere..."**

Thus, inconspicuously for the contemporaries, the word "biosphere" had come into use. Suess coined it concurrently with two other similar terms: "hydrosphere" and "lithosphere", by analogy with the term "atmosphere" already current in the literature. Having coined a new term for which such brilliant future was in store, and actually introducing a new concept into science, E. Suess gave no definition of it. In their euphonious Latin biologists call such terms *nomen nudum*, which means "naked name". The term "biosphere" began to be used occasionally in the literature, every author understanding it in his own way. Since 1911 the term "biosphere" has been used by Vladimir Ivanovich Vernadsky.

Vernadsky was one of the brilliant pleiad of disciples of Vasili Vasilievich Dokuchaev (1846-1903), who is to be credited mainly

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* V. I. Lenin, *Collected Works*, vol. 12, p. 489, Foreign Languages Publishing House, Moscow, 1962.

** E. Suess, *Die Enstehung der Alpen*, Wien, 1875, S. 159.

for having been the first among naturalists to understand the danger of fractionating the science about nature into a plurality of particular disciplines. In his work "Concerning the Teaching of the Zones of Nature" (1898) Dokuchaev wrote that natural science had made great advances in the study of such natural objects as living organisms, minerals, rocks, and so forth. But at that time investigations concentrated on individual objects "rather than on their relationships, the genetic, everlasting and always regular connection which exists between forces, bodies and phenomena, between the inanimate and living nature... Meanwhile, these relationships, these regular interactions constitute the essence of cognition of nature, the core of real nature philosophy – the best and highest charm of natural science."*

Dokuchaev had focussed his attention on the soil, i.e. a natural body where occurs the interaction of all the three "natural kingdoms" singled out at that time: minerals, plants, and animals. Vernadsky had singled out the soil as an autonomous – the fourth – natural kingdom and showed that the properties of soil are determined by the interaction of biogenic and abiogenic factors.

Vernadsky caught up and brilliantly developed the ideas of his teacher. If Dokuchaev's works on soils may be likened to a spark, then the works of Vernadsky in the biosphere, no doubt, were the flame which flared up from that spark. And though the term "biosphere" was introduced into the literature not by Dokuchaev but by Suess, it is just Dokuchaev who is regarded as the harbinger of the contemporary teaching of the biosphere. It is not without reason that already in our days in "Fundamentals of Ecology" by the American scientist E. Odum Dokuchaev was called the "pioneer of ecology"**.

In simple terms, the biosphere is our environment, the "nature" in which we live. In his various works Vernadsky gave several definitions of the biosphere, always emphasising its two distinctive features. The first feature: "the biosphere is the envelope of life, i.e., the area of existence of living matter"***;

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* V. V. Dokuchaev, *Works*, v. 6, Moscow, Publishing House of USSR Academy of Sciences, 1951, p. 399.

** E. P. Odum, *Fundamentals of Ecology*, III ed., W. B. Saunders Co., Philadelphia, 1971.

*** V. I. Vernadsky, *Works*, v. 1, p. 178 (in Russian). (Further on references to this edition will be abbreviated as *Works*.)

the second feature: "the biosphere can be regarded as the area of the Earth's crust occupied by transformers which convert cosmic radiations into effective terrestrial energy: electric, chemical, mechanical, thermal, etc."*

V. V. Dokuchaev regarded the biotic and abiotic factors as being partners that enjoyed equal rights in the formation of soil. Vernadsky, having passed over to the global level, showed that the leading factor which transforms the face of the Earth is life. Its specific feature resides not only in that it accelerates chemical reactions: some reactions outside of organisms at normal temperatures and pressures do not proceed at all. Thus, fats and carbohydrates are oxidised in an organism at a temperature of about 37°C, whereas outside it they can be oxidised only when heated to 450-500°C. Under industrial conditions synthesis of ammonia from molecular nitrogen is carried out at a temperature of 500°C and under a pressure of 300-350 atmospheres. Microorganisms carry out this reaction at normal temperature and under normal pressure. This means that in living organisms some specific catalysts must develop, which accelerate the course of chemical processes.

Such protein catalysts actually developed by the protoplasma have been found in living organisms and received the name "enzymes". Extremely small quantities of these enzymes are sufficient for the chemical processes to proceed in living organisms. In the whole world a dozen kilograms of nitrogenase can hardly be collected; nitrogenase is a wonderful enzyme which is employed by organisms for the synthesis of nitrogenous compounds from atmospheric nitrogen. Academician I. P. Pavlov called enzymes "instigators of life". In recent years the leading role of enzymes in life processes has become all the more apparent. For instance, there is an opinion that "life is nothing else but strictly ordered interaction of enzymatic processes" (Wilstetter, 1929), and in Professor Yermolaev's recently published manual of physical geography** "the biosphere is understood as being that part of the geographical envelope of the Earth, within the boundaries of which the physico-geographical conditions ensure normal work of

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* W. Vernadsky, *La biosphère*, 1929, Alcan. Paris, p. 12.

** M. M. Yermolaev, *Introduction to Physical Geography*, Leningrad, Leningrad State University Press, 1975, p. 229 (in Russian).

enzymes". First attempts have been made to reveal the role of enzymes in geological processes as well.*

The biosphere of the Earth, as we understand it to-day, is a global open system having its own "inputs" and its own "outputs". Its "input" is the flux of solar energy incoming from space; its "output" comprises those substances formed in the process of vital activity of organisms, which for some reasons have escaped from the biological cycle (sometimes for many millions of years). Figuratively speaking, this is an output to "geology".

At present the biosphere of the Earth is considered to be a cybernetic system possessing the properties of self-regulation. Fifty years ago such terms did not exist, and Vernadsky spoke in this sense about the "orderliness of the biosphere" (and in earlier works, about its "mechanism").

Vernadsky saw one of the most characteristic manifestations of the orderliness of the biosphere in the presence of an ozone shield which is located above the biosphere and absorbs ultraviolet radiation deleterious to life (for us this is a most dramatic manifestation of self-regulation of the Earth's biosphere as the cybernetic system). The composition of the gaseous envelope of our planet is fully regulated by life.

Another example of self-regulation is the World ocean. Every year rivers introduce 1.5 million tons of calcium carbonate into the ocean, but the salt composition of oceanic water remains substantially unchanged. Why? Organisms use these carbonates for building their skeletons, and after their death these carbonates go down to the oceanic floor. Thus, through the creation of "calcium covers" of our planet the composition of oceanic waters is stabilised. This mechanism has been working in the biosphere for many millions of years.

Consequently, self-regulation of the Earth's biosphere is ensured by living organisms. This allows one to regard the biosphere as a *centralized* cybernetic system. This name is used to denote systems in which one element, or one sub-system, plays a dominant role in the functioning of the system as a whole. This element is called the *leading* part of the system, or its *centre***. Living organisms in the biosphere play the role of such a centre.

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* G. I. Bushinski, "Inhibitors and Stimulators in Lithogenesis", *Lithology and Miner. Resources*, 1967, 4, pp. 495-497.

** A. D. Hall, R. E. Fagen, "Definition of System", *General Systems*, 1956, v. 1, pp. 18-28.

According to the necessary diversity law of Wiener-Shannon-Ashby, which is considered to be the basic law of cybernetics, a cybernetic system only then possesses stability for blocking external and internal disturbances, when it has sufficient *internal diversity.*

The Earth as a planet is characterised by considerable diversity of *natural conditions.* This is determined by its spherical shape, by its revolution around the Sun and rotation about its own axis, which, in turn, conditions latitudinal and seasonal changes in the intensity of the solar energy input; considerable diversity of natural conditions is also created by the dissected relief of the Earth. The range of the absolute data of the Earth's surface is over 19 km: from +8848 m (Mount Chomolungma, Everest) to −11,022 m (Mariana Depression in the Pacific Ocean). But the main diversity of the Earth's biosphere is created by living organisms.

A most interesting (so far underestimated) generalisation about the creation of the nonuniformity of the medium by organisms was made in the beginning of this century by the Russian microbiologist, Professor Mikhail Andreevich Yegunov (1864-1937): "Any medium populated by living organisms is a bio-anisotropic medium. Bio-anisotropy is a general phenomenon; there is no bio-isotropy. This follows from the fact that between the medium and every organism a continuous metabolism takes place, and therefore at every given moment different points of the medium differ from each other in their physico-chemical composition. Diffusion can never completely level out these differences as long as the cause that brings them about exists"*.

It is believed that about two million species of living organisms are represented in the present-state biosphere (and there was about a billion of them during the entire period of its existence), each of the species, in turn, including millions and billions of individuals dispersely distributed in the space. Recently it has been calculated that on the territory near the Angara river within an area of 0.23 square kilometres there live 535 (!) species of invertebrates, each of these species, naturally, interacting with the environment in its own way. It is the activity of living organisms that creates the extraordinary diversity of the "nature" around us, the extraordinary diversity

* M.A. Yegunov, "Bio-anisotropic basins". In: "*Yearbook of Geology and Mineralogy of Russia*", 1900-1901, v. 4, p. 42 (in Russian).

of the biosphere. Perhaps, until recently we could not appreciate this diversity: we had simply nothing to compare our biosphere with. Only now, after we have seen on the screens of our television sets and on pages of illustrated editions the landscapes of other planets, deprived of life, only now we can fully appreciate the "internal diversity" of the biosphere. It provides a definite guarantee for the preservation of life on our planet.

Now it is difficult for us to imagine the real scale of those geological catastrophes which occurred in the history of the Earth. Most dreadful of the earthquakes which occurred within the memory of mankind were accompanied by faults with an amplitude of 4 to 6 m. Tectonic phenomena of such dimensions are considered to be a national disaster: let us recall the dreadful Peruvian earthquake of 1970, which took about 100 thousand lives. In geological deposit faults are known which have an amplitude of several kilometres. No doubt, the subsidence did not come about all at once, but it went to such a depth – several kilometres!

The most terrible form of volcanic activity is lava flows. Eruptions of such type were rather rare occasions within the memory of mankind. The largest of them took place in the beginning of this century on the sparcely populated territory in Alaska. The height of the cliff formed there by solidified lava reaches 100 m. In the 1883 eruption of the Krakatao volcano (in the Sunda Straits, Indonesia) the fallout of volcanic ash formed a 2 to 60 m layer on the island.

How numerous were they – geological catastrophes – in the history of the biosphere? Nevertheless, as Vernadsky emphasised time and again, azoic deposits (that is, deposits deprived of life) have nowhere been found. This is confirmed also by contemporary science: all the evidence accumulated by geology shows the development of the Earth's biosphere to be continuous throughout the geologic history. The internal diversity of the biosphere has ensured its stability even to most significant catastrophic shocks.

Professor O.P. Fisunenko, a paleobotanist of Voroshilovgrad, has calculated that the number of genera of higher plants was: in the Silurian, 1; in the Devonian, 36; within the interval from the Carboniferous to the Triassic, 150 to 200; from the Jurassic to the Neogene, 250 to 330. These figures are pertinent only to a small interval of the geologic history, but even they demonstrate a definite tendency towards an increase in the internal diversity of the biosphere in the case of higher plants.

It may be supposed that this tendency has been steadily strengthening the "noise immunity" of the biosphere.

Thus, the Earth's biosphere is a self-regulated cybernetic system with an ever-increasing noise immunity, possessing the properties of a homeostat. Such a conception about the biosphere developed from Vernadsky's ideas.

A characteristic feature of the biosphere is the indissoluble connection and all-penetrating interaction of living and nonliving (or, as Vernadsky preferred to call it, 'stagnant') substance.

Charles Lyell
(1797-1875).

Charles Lyell* in his "Principles of Geology", evidently, was the first to introduce a special concept for the interaction of the organic factors (community of living organisms) and inorganic factors (climate, soil, relief, etc.) of the environment. Lyell called it 'station'. Later the British ecologist A. Tansley**, discussing the interaction of living and nonliving substance, introduced the concept of ecosystem now widely employed in the world literature. According to the definition given by D. V. Panfilov, "an ecosystem is a complex of interconnected organisms of different species and of the abiotic medium being changed by them, which is capable of self-regulation and complete self-renewal of the biota". Ecosystems may be of any size. The biosphere of the Earth is a global-scale ecosystem.

In the Soviet scientific literature the term "biogeocoenosis" is also used sometimes. This term was suggested by Academician V. N. Sukachev and compared by him in a special paper with other terms***. Biogeocoenosis is now understood to be an area of the biosphere, through which not a single essential biocoenotic, microclimatic, hydrological, soil, geomorphological, or geochemical boundary does pass.

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* Ch. Lyell, *Principles of Geology*, v. II, London, 1832; 2nd ed., 1833.

** A. G. Tansley, "The use and abuse of vegetational concepts and terms", *Ecology*, 1935, v. 16, pp. 284-307.

*** V. N. Sukachev, "The relationship of the concepts biogeocoenosis, ecosystem and facies", *Soil Science*, 1960, 6, pp. 1-10 (in Russian).

In essence, all these concepts are close and differ mainly in details. Since the concept of ecosystem is "nondimensional", we shall throughout adhere mainly to this term.

Ecosystems are in constant interaction with each other, and in their totality they make up a gigantic cycle of substance within the biosphere. The main elements participating in this cycle are hydrogen, oxygen, carbon, nitrogen, calcium, potassium, silicon, phosphorus, sulphur, strontium, barium, zinc, molybdenum, copper, and nickel.

The biotic cycle in the biosphere is not closed. The degree of reproduction of the cycles reaches 90 to 98%.

On the geologic time-scale incomplete closure of the biogeochemical cycles leads to differentiation of the elements and to their accumulation in the atmosphere, hydrosphere, or in the sedimentary envelope of the Earth. These several per cent of substance not involved in biotic cycle, constitute the "output to geology" which we have already mentioned.

But "geology" is found not only at the "output", but also at the "input" of the biotic cycle of the biosphere. Proceeding from a vast corpus of empirical data, the well-known Soviet geochemist, Corresponding Member of the USSR Academy of Sciences, Alexander Borisovich Ronov has come to the conclusion that the biotic cycle is to a considerable extent "open" and that constant supply of carbon dioxide to this cycle from the bowels of the earth is required. A. B. Ronov has formulated the following "geochemical principle of preservation of life": "Life on the Earth and other planets, all other things being equal, is possible only so long as these planets are active and interchange of energy and substance between their inside and surface takes place."*

Only *substances* are involved in the continuous cycle in the biosphere, whereas concerning energy one can speak only about a *directed flux*. Solar energy incoming to the biosphere is partly consumed for the synthesis of organic matter. The biosphere is a "factory producing macromolecules": autotrophic organisms, absorbing solar energy, convert at this factory inorganic matter that consists of small molecules and is poor in energy into organic compounds which consist of large molecules and are rich in energy, thus supplying all the living matter with them. Being transferred from one trophic level to another, energy is

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* A. B. Ronov, "Vulcanism, accumulation of carbonates, life," *Geochemistry*, 1976, 8, p. 1274.

gradually dissipated. After final decomposition of organic residues, energy is partially accumulated in the Earth's crust in the form of alumosilicates, "geochemical storage batteries" as they are called. Speaking about the penetration of the outer envelope of the Earth by solar energy, the Soviet crystallographer academician N. V. Belov, who has formulated the idea about geochemical storage batteries, drew a parallel with a diamond. When light falls on a diamond, part of the light is reflected from the faces of the precious stone, but *not* a smaller part gets inside the diamond and can emerge from it only after having undergone multiple reflections from the inner faces of the diamond. Solar energy accumulated by living matter is subject to similar wanderings (in the geologic time--scale).

To illustrate the differences in the transformations of energy and matter in the biosphere, the Soviet investigators and popularisers of science P. P. Vtorov (1938-1979) and N. N. Drozdov used a graphic example: a water mill. Its wheel is rotating ceaselessly, remaining in the same place, and symbolises the stock of matter in the biosphere. However, in order that the wheel may rotate, a constant inflow of water is required. In an analogous manner, the flux of solar energy incoming from space "rotates" the wheel of life on our planet.

How fast does this wheel rotate? In Vernadsky's time it was unknown, but now we can already answer this question.

Renovation of the entire living matter of the Earth's biosphere is accomplished on average during 8 years. The matter of land plants (the phytomass of land) is renewed during a period of approximately 14 years. In the ocean the circulation of matter proceeds many times faster: the entire mass of the living matter is renewed in 33 days, whereas the phytomass of the ocean is renewed every day! The process of complete substitution of waters in the hydrosphere takes 2,800 years. In the atmosphere the substitution of oxygen takes several thousand years, and the substitution of carbon dioxide gas, 6.3 years.

These figures show that the geochemical effect of the activity of living matter in the biosphere manifests itself not only during the geologic time (millions and billions of years), but is clearly pronounced even within the historic time (thousands of years and less).

At the same time, some other substances participating in the geochemical cycle have considerably smaller migration rates. Thus, the time required for the photosynthetic decomposition of the water mass of the World Ocean amounts to 5 or 6 million years (above we spoke about the water cycle without the chemical decomposition of water). The duration of the global cycles of carbon, nitrogen, and phosphorus also comes to millions of years.

As early as 1926 Vernadsky had brought forward the question of the boundaries of the biosphere; he returned to it in a special article in 1937.* At that time, however, it was difficult to give a definite answer to it. Now it is not easy to do either.

Nikolai Bronislavovich Vassoyevich, a prominent Soviet geologist, Corresponding Member of the USSR Academy of Sciences, has paid attention to an important feature of the structure of the biosphere, which Vernadsky had emphasised: to the existence of a "life stability field" and a "life existence field" in the biosphere. In the first case (in the "stability field") there exist "conditions which life withstands without ceasing its functions, i.e. such, under which an organism, though suffers, but survives"; in the second case (in the "existence field") there exist "conditions under which an organism can give progeny, i.e. increase the living mass – increase the effective energy of the planet... The limits of the biosphere are conditioned first of all by the life existence field"**. Such an approach to the definition of the boundaries of the biosphere is in complete agreement with the present-day understanding of the biosphere as a global ecosystem (recall the definition given by D. V. Panfilov, cited above).

Now we shall discuss the problem, which physico-chemical conditions determine the boundaries of the biosphere.

First, this is a sufficient quantity of carbon dioxide gas and oxygen. It has been established that in the Himalaya the green vegetation zone is limited to the altitude of 6,200 m where the partial pressure of carbon dioxide gas is one half that at the sea level. But even at a greater height life does not die down completely: certain species of spiders and insects are encountered there. They feed on organic residues brought by the wind.

Second, this is a sufficient quantity of moisture, ensuring normal course of enzymatic processes. Probably, there are no such areas on the Earth's surface, where life would be limited by

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* V. I. Vernadsky, "About the limits of the biosphere", *Izv. AN SSSR*, geol. series, 1937, 1, pp. 3-24 (in Russian).

** V. I. Vernadsky, *Works*, v. 5, pp. 72, 63 (in Russian).

this factor. Even in the driest deserts (for example, in the south of the African continent) darkling beetles are encountered in the thickness of dry sand. These insects do absolutely without atmospheric and soil moisture, getting it only with food. Here, as in the case of high mountains, food is delivered by air and consists of remnants of plants, insects, sometimes, dead birds.

Third, there are favourable thermal conditions which preclude both too high temperatures (causing coagulation of proteins) and too low temperatures (stopping the work of enzymes). Record-holders in survival are procaryotic organisms: bacteria and Cyanophyta (we shall speak about them when their turn comes). Some of their species live on the snow, in small pools of fresh water on the ice floes drifting in the Arctic, in rock formations of the Antarctic; others live in hot springs at temperatures up to 98°C, and in subterranean water, even at 100°C. Isolated from the external world by the 420-metre layer of ice, Procaryota live as prisoners in the coastal waters of the Antarctic. The ice armour which covers them has existed for at least 120 thousand years.

Is there any life in oceans at great depths? Up to the end of the last century scientists excluded such a possibility altogether. First doubts were engendered by the Challenger expedition of 1872-76, during which many bottom-dwelling animals were discovered at depths of 2 to 3 kilometres. Disputes, however, continued; the experiments carried out by the French physiologist Fontaine showed that even bacteria perish in pressure chambers under pressures corresponding to a depth of 6.5 km. Therefore in 1948 the Swedish oceanologist Hans Peterson voiced a suggestion that life in oceans is impossible at depths exceeding 6.5 km. The dispute could be settled only after maximum oceanic depths had been reached. As late as January 23, 1960, at 1:06 p.m. the bathyscaph Trieste with Jacques Piccard and Don Walsh on board touched the bottom of the Mariana Depression (at the point of submersion the depth was 10,919 m).

Flat fish about the size of a man's palm were swimming past the bathyscaph, and a red shrimp was lying on the bottom. The surface of the bottom was covered with a kind of bulges, evidently, created by living organisms. The myth about lifeless chasms of the ocean was finally disproved. Holothurians, or sea cucumbers, proved to be particularly fond of colossal depths. These sea cucumbers are rather ugly multicellular animals, resembling echinoderms and having a "more or less worm-like body" (according to one of contemporary handbooks on zoology).

Thus, both the land surface and the ocean depths correspond to the "life existence field" as Vernadsky understood it and, consequently, pertain to the biosphere. As regards the atmosphere, the only inhabitant there is so-called "aeroplankton": bacteria, yeast fungi, spores of mould fungi, of mosses and lichens, as well as viruses, algae, cysts of protozoans, and so on.* Viable microorganisms have been found at an altitude of up to 77 km. The majority of microorganisms, however, die in a few minutes or even seconds after they get (not on their own accord!) into air. For surviving microorganisms the air medium is not favourable either, and they sink into the state of anabiosis. True, it is assumed that some microorganisms can propagate in low-level storm clouds, but this has not yet been proved. Therefore, the atmosphere on the whole does not essentially satisfy the definition of an ecosystem: neither self-regulation of the system, nor self-renovation of the organisms takes place there. This is exactly the case of a "life stability field" according to Vernadsky: a zone overlaying the biosphere. G. E. Hutchinson** has called it parabiosphere (from the Greek root 'para', at the side of, alongside of).

Where are the confines of the biosphere?

Rendering the definition given by Vernadsky more concrete, one can attribute to the biosphere those zones of the Earth, where aborigenic communities of living organisms exist. Do the lowest atmospheric layers meet this condition? Evidently, yes, since insects and birds dwell there. Among insects there are active predators which live by hunting in the air and come down to earth only from time to time and for passing the night. Many birds, in their turn, are insectivorous and prey on the wing. Thus, the lowest atmospheric layers are the native element for many insects and birds, so that these layers should be attributed to the biosphere, while the upper boundary of the biosphere should be drawn judging from the highest active flights made by flying organisms (the record-breakers among

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* V. V. Vlodavets, *Microflora of Atmospheric Air*. In: "The Role of Microorganisms in the Cycle of Gases in Nature", Nauka Publishers, Moscow, 1979, pp. 50-64 (in Russian).

** G. E. Hutchinson, "The biosphere", *Scient. American*, 1970, v. 223, 3, pp. 44-53.

them being, naturally, birds). Above this boundary parabiosphere is located.

The situation with the lower boundary of the atmosphere is more complicated. Vernadsky supposed* that the entire sedimentary envelope of the Earth was populated by bacteria. The factual data about the occurrence of bacteria in the Earth's crust, available at that time, were insufficient. Only individual observations had been made. So the engineer V. Sheiko in 1901 for the first time found bacteria in the internal waters of the Baku oil fields; a quarter of a century later the American scientist B. Bastin and the Soviet researcher T. L. Ginzburg-Karagicheva published descriptions of the microorganisms found in the subterranean waters of oil fields. In the course of well-drilling operations on the Apsheron Peninsula bacteria were then encountered at a depth of 1,700 m.

However, later investigations did not confirm Vernadsky's idea about the *entire sedimentary envelope* of the Earth being populated with bacterial life. Recent investigations carried out by the microbiologist Kramarenko**, have shown that the distribution of microorganisms in subterranean water, and hence, the lower boundary of the biosphere within continents, are determined by two factors: the temperature of the water and the concentration of mineral salts in them. Live bacteria are revealed in water at a temperature of up to 100°C, though their maximum vital activity is limited to "only" 80°C. The critical concentration of mineral salts is surprising too: 270 g/litre, which means that such water is a mineral solution 10 times more concentrated than oceanic water.

In the course of deep-drilling operations in West Siberia anaerobic microflora, both active and diverse in composition, was found at a depth exceeding 3,000 m. At the same time, if mineralisation of water exceeds the specified limit, bacteria are absent at considerably smaller depths. Such zones, devoid of life (or "azoic" according to Vernadsky) are found in the Angara-Lena Basin already at a depth of about 500 m, and in the Volga-Kama Basin, at a depth of about 1,200 m. As regards the bottom sediments of the World Ocean and inland waters, no relevant data were available until recently. Only a short

* V. I. Vernadsky, "About the limits of the biosphere", *Izv. AN SSSR*, geol. series, 1937, 1, p. 16.

** L. E. Kramarenko, "Microorganisms of subterranean waters and their geochemical significance", *Proceedings of the All-Union Geological Research Institute*, 1975, v. 241, pp. 156-165 (in Russian).

while ago M.V. Ivanov and his colleagues have shown anaerobic microflora to dwell in the Pacific and the Indian Ocean in the bottom sediments at least to a depth of 10 to 12 m. Moreover, in the sediments of the Caspian Sea* it occurs to no less than 114 m below the surface of the sea bed.

The biosphere thus accounts in the ocean for the entire thickness of the oceanic waters and an insignificant bottom film of life, and on continents it comprises a thin superficial layer and a thick underlying layer. All the daylight surface of our planet belongs to the zone of the biosphere. On the Earth's surface only some areas of glacier shields and arid deserts may prove to be azoic. The distribution of living organisms in the biosphere is shown in Fig. 1.

Such are, according to the present-day conceptions, the boundaries of the Earth's biosphere. But the title chosen by Vernadsky for the major book of his life was: "The Chemical Structure of the Earth's Biosphere and of Its Surroundings". Vernadsky had not defined what he implied by the "surroundings" of the biosphere. At present this to a considerable extent is done by Vassoyevich.

Vassoyevich** suggests that one should single out a "megabiosphere" (from the Greek word 'megos', great, mighty), i.e. a multilayer envelope of the Earth, formed as a result of activity of living matter. Its upper boundary is defined by the limit to which the biogenic atmosphere extends; its lower boundary is the envelopes of the Earth, not subject to the influence of life. The megabiosphere includes:

(a) The apobiosphere, i.e. the upper portion of the Earth's atmosphere above the boundary to which life forms in the state of anabiosis extend;

(b) The parabiosphere;

(c) The biosphere;

(d) The metabiosphere, which corresponds to "the area of bygone biospheres" as defined by Vernadsky.

Vernadsky defined "the area of bygone biospheres" as the envelope of the Earth, that had ever been subject to the influence of life. He wrote that the Earth's crust "encompasses

* M.V. Ivanov, S.S. Belyaev, K.S. Laurinavichus, A.Ya. Obraztsova, "Microbiological formation of hydrogen sulphide and methane in contemporary and quaternary deposits of the Caspian Sea", *Geochemistry*, 1980, 3, pp. 416-421.

** N.B. Vassoyevich, "Various interpretations of the concept of the biosphere". In: "*Investigations of Organic Matter of Contemporary and Fossil Sediments*". Nauka Publishers, Moscow, 1976, pp. 381-399.

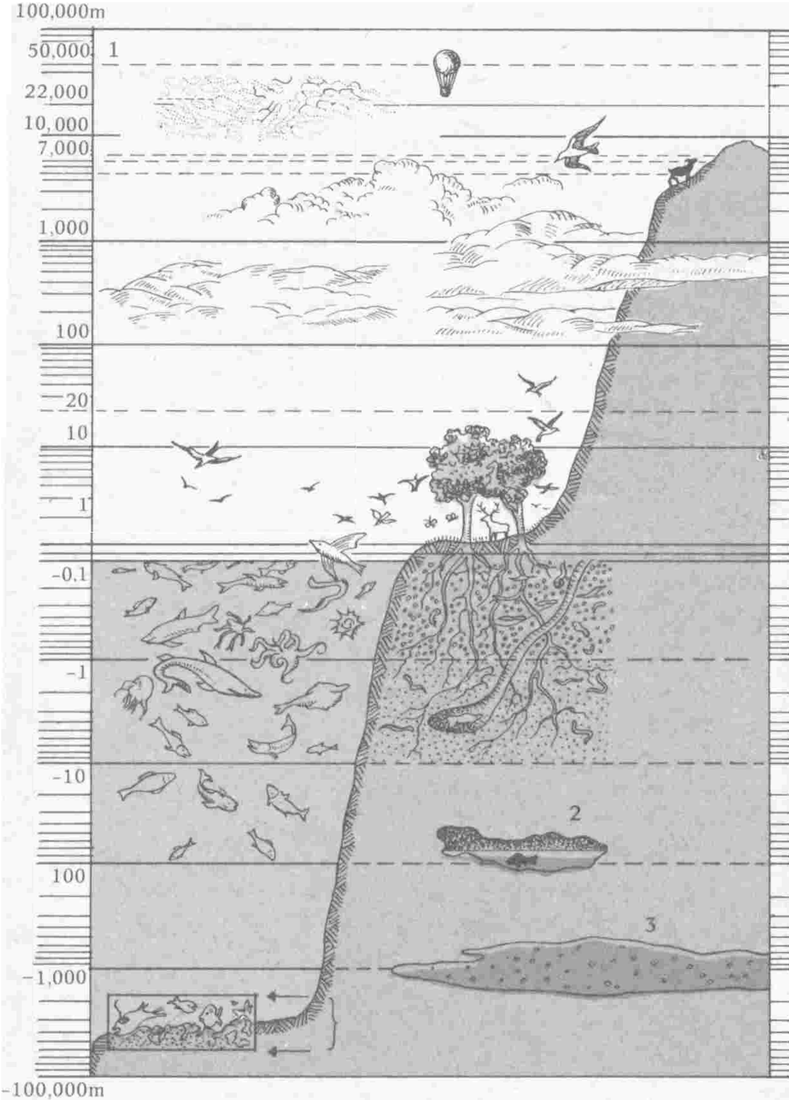

Fig. 1. Distribution of living organisms in the Earth's biosphere (after Kadar, 1965):

1 – ultraviolet radiation; *2* – burrowing organisms; *3* – petroleum bacteria within the range of several dozen kilometres a number of geological envelopes which some time in the past were biospheres on the surface of the Earth. These are the biosphere, the stratisphere, the metamorphic (upper and lower) envelope, the granitic envelope. The origination of them all from the biosphere becomes clear to us only now. These are bygone biospheres".*

Thus, owing to constant inflow of solar energy, intensive work of living matter which is the recipient of this energy, and incomplete closure of the biotic cycle, the biosphere has been continually creating concentric planetary envelopes around itself: the parabiosphere and the apobiosphere (towards its exterior), and the metabiosphere (towards its interior).

A characteristic feature of the biosphere as a dynamic system is its nonequilibrium which is a consequence of the work of living matter and of the inflow of solar energy. As early as 1935 a junior contemporary of Vernadsky, the prominent biologist Erwin Bauer (1890-1942), who spent the last 7 years of his life in the Soviet Union, wrote: "All and only the living systems are never in equilibrium, and due to their free energy they constantly perform work against the equilibrium required by the laws of physics and chemistry under the existing external conditions... We shall denote this principle as "the principle of stable nonequilibrium of living systems"**. Now it is called the principle of Bauer.

This principle is valid for the biosphere as a whole. The gaseous composition of the atmosphere and the salt composition of the ocean are not in equilibrium. Another example is furnished by A. I. Perelman: river water of the taiga and humid tropics contain both oxygen and humic substances in dissolved state. In equilibrium humic substances would have been oxidised by the oxygen present in the system; but such equilibrium never comes, since, though oxidation does proceed, new and new portions of both humic substances and oxygen come into the system.

A distinctive feature of the biosphere resides in its being "watered". "Water without life is not known in the biosphere; negligible in weight, such occurrences of it are rare–

* V. I. Vernadsky, "*The Chemical Structure of the Earth's Biosphere and of Its Surroundings*", Nauka Publishers, Moscow, 1965, p. 35.

** E. S. Bauer, "*Theoretical Biology*", Publishing House of All-Union Institute of Experimental Medicine, Moscow, 1935, pp. 43-44 (in Russian).

temporary-minerals; such are the waters of volcanoes, rich in free sulphuric or hydrochloric acid, perhaps, some brines-and that is all."* At the same time, water is the medium for practically all the chemical processes occurring in the biosphere. This is exactly the reason why chemically pure water in the biosphere is a rarity as great as water devoid of life. Vernadsky liked very much the definition of life as "animated water", which had been given by the French zoologist of the nineteenth century R. Dubois, and he repeatedly cited it in his works. Poetic lines about water also belong to Antoine de Saint-Exupery: "Water, you have neither taste, nor colour or odour, they delight in you, without knowing what you are. One cannot say that you are necessary for life; you are the life itself..."

The content of water in the tissues of living organisms is approximately 5 times greater than in all the rivers of the globe. Recent investigations have shown that half of the water contained in the roots of plants is renewed during several minutes. As a result, the water cycle on land is determined almost exclusively by the transpiration of the plants: they evaporate most of the water which has fallen to land in the form of atmospheric precipitation, while in the ocean the entire volume of the water is filtered through by the Crustacea of the plankton during half a year, the upper layer of the water (0 to 500 m) being filtered in such a manner during 20 days**.

Finally, one more characteristic feature of the biosphere resides in its indissoluble ties with space (to the maximum extent, with the Sun). The connection of solar activity with terrestrial phenomena was noted already in the last century. So, in 1852 Rudolf Wolf, a Swiss astronomer of Bern, calculated the dependence of the Earth's magnetism on the periodicity with which spots are formed on the Sun.

However, geliobiology (the science about the influence of the Sun on biological processes) is usually considered to come into being in 1915, when the report "Periodic Influence of the Sun on the Biosphere of the Earth" was read at the Moscow Archaeological Institute. In this report its author Alexander Leonidovich Tzhijevsky (1897-1964), who later became an eminent scientist, formulated an idea, to the development of

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* V. I. Vernadsky, *Works*, v. 4, Book 2, p. 75 (in Russian).

** V. G. Bogorov, "*Plankton of the World Ocean*", Nauka Publishers, Moscow, 1974, p. 320 (in Russian).

which he then devoted all his life*. The idea may seem even trivial: really, is there anything surprising in that life on the Earth is determined by the Sun? At present a tremendous range of phenomena have been revealed, that are controlled by the "rhythm of the Sun": from the outbreaks of massive proliferation of locusts to the average academic performance of school children. Tzhijevsky was the pioneer, but he did not live to see his ideas recognized...

Now, let us put some things together.

The biosphere is understood as an external envelope of the Earth, pervaded with and formed by life, its development being determined by a constant inflow of energy from space (mainly, solar energy). The biosphere of the Earth is characterized by the presence of liquid water and extensive low-temperature reactions which proceed in the aqueous medium and are to a considerable degree regulated by the action of enzymes. The biosphere produces a gaseous envelope towards its outer edge, and an envelope of sedimentary rocks ("the area of bygone biospheres" or "the metabiosphere") towards the interior of the planet. The cycle of substances in the biosphere is shown diagrammatically in Fig. 2.

Our outline of the biosphere will be incomplete, if we do not, at least briefly, consider the present stage of its development.

Vernadsky called this stage the noosphere (from the Greek root 'noos', mind). This term was borrowed by him from the French mathematician and philosopher E. LeRoy who admitted to formulate the concept of the noosphere together with his friend, the well-known paleontologist and anthropologist P. Teilhard de Chardin (1881-1955). The theory of the noosphere, in its turn, occurred to the French colleagues under the influence of Vernadsky's ideas, whose lectures in geochemistry they had attended at the Sorbonne in 1922-1923. However, the conception of E. LeRoy and P. Teilhard de Chardin was strongly idealistic and even religious in character. (P. Teilhard de Chardin was not only an eminent paleontologist, but also a catholic missionary, though at odds with the ruling doctrine of Catholicism.) Teilhard de Chardin defined the noosphere as "a new canopy", "a thinking stratum", which, having originated towards the end of the Tertiary period, has

* A. L. Tzhijevsky, *Les epidèmies et pertrubations electromagnètiques du milieu extèrieur*, Paris, 1938.

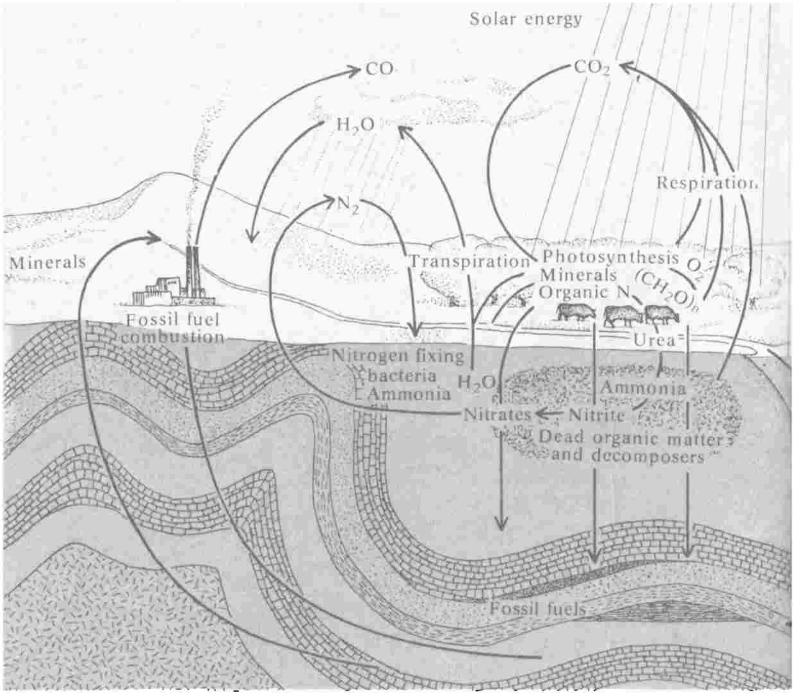


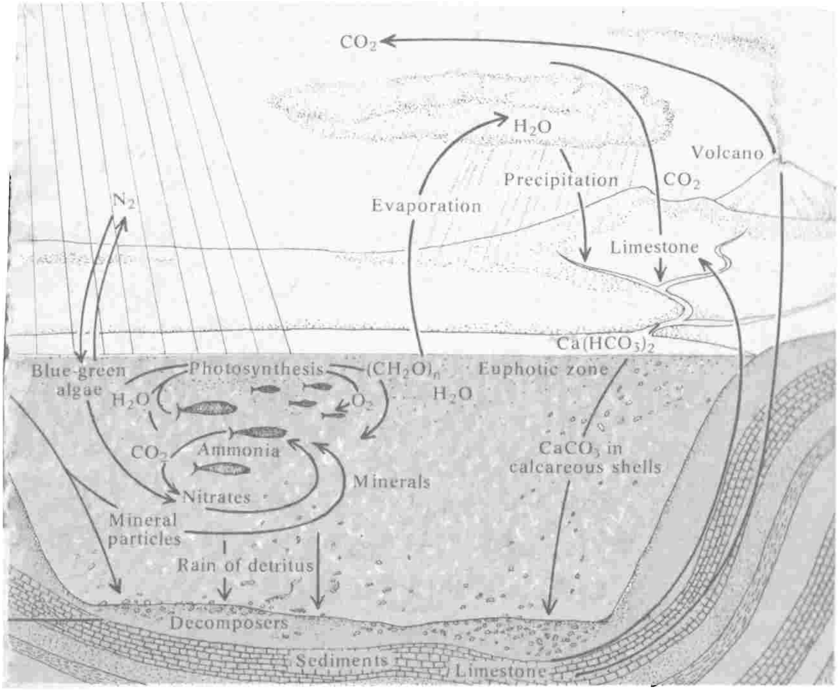
Fig. 2. Cycle of main substances in the biosphere (after Hutchinson, 1972)

since been unfolding over the world of plants and animals – outside of the biosphere and above it*.

Vernadsky's attitude towards the noosphere was altogether different. "I know Marx but little," he confessed to Professor B. L. Lichkov, "but I think that the noosphere will be fully in concordance with his basic conclusions." ** The article of Vernadsky "Some Words About the Noosphere" appeared in the hard time of 1944 and proved to be his last publication to appear during his lifetime. Actually, it was Vernadsky's scientific bequest. In this article conceptions were formulated that

* P. Teilhard de Chardin, *Le phénomène humain*, Paris, 1959, and other editions.

** *Correspondence of V. I. Vernadsky with B. L. Lichkov (1940-1944)*, Nauka Publishers, Moscow, 1980, p. 40.



Vernadsky had come to by degrees, through the logic of his creative work: "Mankind, taken as a whole, is becoming a powerful geological force. And before it, before its thought and labour, there arises the question about the reconstruction of the biosphere in the interests of the freely thinking humanity as a single whole. This new state, which we are approaching imperceptibly, is the noosphere."*

The noosphere is characterized, above all, by the global colonization of the Earth by mankind. Indeed, as Vernadsky emphasized, the history of human society is not only, and even not mainly, the history of wars, changes of dynasties, palace revolutions, etc.; it is, first and foremost, *the history of man's mastering of the planet*. Already after Vernadsky's death mankin began to conquer outer space. A grandiose picture of the futur

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* V. I. Vernadsky, *The Chemical Structure of the Earth's Biosphere and of Its Surroundings*, Nauka Publishers, Moscow, 1965, p. 328.

development of the noosphere was presented by the prominent Soviet astronomer, I. S. Shklovsky in his book "The Universe, Life, Reason" (1962).

In the middle of the last century Charles Lyell compared the abilities of man of that time with the action of terrestrial elements. If all the people living on the Earth, Lyell wrote, attempted to break up the lava which had effused from Icelandic volcanoes in the course of only three years and tried to transfer it to the depths of the ocean, they could work for several millennia and still fail to fulfill the task. The conclusion drawn by Lyell is not very comforting: man is small and miserable in the face of the geological elements.

In the twentieth century the situation has changed. As early as thirty years ago Vernadsky observed that mankind *was becoming* a powerful geological force. Now man *has* indeed *become* that geological force which transforms the face of the planet. Man is growing new varieties of plants, he is breeding new races of farm animals. Selection and domestication are examples of the transition of the biosphere into the noosphere. Man extracts billions of tons of raw materials from the bowels of the Earth and involves these materials into the biotic cycle (in 1970 world's extraction of mineral raw materials per capita reached 20 tons). At present mankind produces 10 times as much energy as is absorbed by living matter.* Man transforms the landscapes which surround him (Fig. 3). It is common practice to distinguish two varieties of cultural landscapes, which exemplify the noosphere: the agrosphere and the technosphere. The first comprises various plantations, fields, gardens, greenhouses, pastures, groves, parks, piscicultural grounds, and so forth. The technosphere is an aggregation of all the items of material culture, as it were, "built into" nature by mankind. These are plants and factories, air fields, stadiums, motorways, architectural structures, and so on. Yet, no matter how grand technology may be, man remains the motive force of the noosphere.

"I am the most alive among the living", writes the poet Arseni Tarkovsky. In Vernadsky's recently published book "Scientific Thought As a Planetary Phenomenon" the following three conclusions about the place of man in the biosphere are formulated:

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* E. V. Girusov, S. S. Lappo, "*Limits of Potentials of the Biosphere*", *Priroda*, 1974, 12, p. 4.

Fig. 3. Changes in the landscapes of the forest zone in the course of development of human society:

A – landscape of 9000-3000 years B.C.; *B* – landscape of 5000-3000 years B.C.; *C* – landscape of 700-1850 years A.D.; *D* – modern landscape

"1. Man, as observed in nature, like all living organisms, like any living matter, is a definite *function of the biosphere*, within its definite space-time.

"2. Man in all his manifestations constitutes a definite regular part of the structure of the biosphere.

"3. *The explosion* of scientific thought in the twentieth century *has been prepared by the entire history of the biosphere* and has its deepest roots in the structure of the latter. The civilisation of "cultured mankind", insofar as it is a form of organization of the new geological force which has formed in the biosphere, *cannot be interrupted or destroyed*, since it is a great natural phenomenon, historically, or, rather, geologically corresponding to the established orderliness of the biosphere"* (italics and quotation marks are Vernadsky's everywhere).

These statements made by Vernadsky were later developed. Thus, the Soviet biologist Stanislav Semenovich Shvarts (1919-1976) showed that the appearance of *Homo sapiens* in the geological history is the consequence of the continuous adaptation of life to diverse abiotic conditions: the more precisely animals react to changes in the external medium, the higher their chances are in the struggle for life. Reason, from the standpoint of an ecologist, is the highest ability to react rationally to changes in external conditions. Furthermore, the origin of mind in man as a biological species has led to the formation of the noosphere. This was vividly sketched by the Soviet writer Boris Agapov: "Naked, hairless, thinskinned, small-mouthed, with unsteady small teeth, with the musculature far weaker than that of his enemies, running and leaping much worse than they, man has created a second nature around him: from the shirt on his body to sputniks in space, and in this second nature, and because of it, he became the most powerful being on the planet."

Vernadsky was convinced that the history of mankind is not something accidental and that it is connected by adamantine ties with the development of the biosphere. This connection (recall that Vernadsky once thought of becoming a historian!) Vernadsky exposed most fully in his most profound work "Thoughts About the Contemporary Significance of the History of Knowledge". Vernadsky wrote: "Throughout the centuries periods recur when within one generation or a few generations,

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* V. I. Vernadsky, "*Reflections of a Naturalist*", Book 2, Nauka Publishers, Moscow, 1977, pp. 32-33.

in one country or in a few countries, certain richly endowed personalities accumulate, whose intellects create the force that alters the biosphere."*

Vernadsky's ideas about the noosphere are still far from being completely embodied. While, on the one hand, extremely productive cultural coenoses of the agrosphere are being created, on the other hand, the impoverishment and extermination of natural ecosystems are taking place. "Thus, the noosphere, so dear to Vernadsky ... is running the risk in reality of turning into the technosphere, or rather, into "the sphere of avidity", governed by the spirit of fortune-hunting, by mediocrities, by the absence of social consciousness, by the ideal of destruction and by the egotistic doctrine of "after me the deluge", said the outstanding Belgian ecologist P. Duvigneaud addressing the XIIth International Botanical Congress.** "He considers that in the present situation agriculture must constitute a single whole with modern technology, reduced to a minimum in biological and ecological processes and producing no deleterious effect on biogeocoenoses. There is no other way.

P. Duvigneaud at the tribune of the XII International Botanical Congress (1975)

The eminent American botanist Frits W. Went, whom I had the good fortune to meet in Leningrad at the same Congress, once calculated that the present-day population on the globe consumes 1000 times as much food and raw materials as the virgin nature of our planet can give. In other words, should people have to return to using only natural resources, only one in every thousand of those now living would survive. The same idea was maintained by G.E. Hutchinson in 1970:

* V.I. Vernadsky, "Thoughts About the Contemporary Significance of the History of Knowledge", *Transactions of Commission for History of Knowledge of the USSR Academy of Sciences*, 1927, Issue I, p. 6.

** P. Duvigneaud, "*Noosphère et l'avenir de la végétation du globe*", XII Int. bot. congr., Proc., Nauka Publishers, Leningrad, 1979, p. 78.

"By the noosphere Vernadsky meant the envelope of mind that was to supervise the biosphere, the envelope of life. Unfortunately the quarter-century since those words were written has shown how mindless most of the changes wrought by man on the biosphere have been. Nonetheless, Vernadsky's transition in this deepest sense is the only alternative to man's cutting his life-time short by millions of years."*

Vernadsky was an optimist. In 1932 he wrote in answer to his opponents: "What we are now living through is not a crisis which disturbs weak souls, but the greatest change in the scientific thought of mankind, which is accomplished only once in millennia; we are experiencing scientific advances, never witnessed by the long generations of our ancestors... Standing at the moment of this change, surveying the future opening up, we should be happy of having been destined to experience this, to participate in the creation of such a future."**

Vernadsky's optimism is not unfounded. It is precisely the teaching of the biosphere and noosphere that allows the elaboration of a complex of ecological measures which enhance the biological productivity of the Earth. As Shvarts said in his report to the session of the USSR Academy of Sciences dedicated to its 250-th anniversary, any prognosis of the development of science for the nearest decades comprises substantial changes in the structure of the biocoenoses of the Earth; the creation of specific biocoenoses capable of self-renovation and self-regulation: anthropogenic landscapes featuring an increased stability and an enhanced capacity to biological purification; the maintenance of the overall balance of the biosphere at a level ensuring the optimal development of human society.

In the world's press nowadays one sometimes encounters three interwoven letters "MAB" in combination with a maximally generalized human figure, the symbol of life in ancient Egypt. This is the emblem of the international programme "Man and Biosphere" adopted at the XVI General Conference of UNESCO in 1970. In 1980 about 100 countries were already participating in the activities envisaged by this programme.

The objective pursued by MAB is the carrying out of long-term investigations of the effect the activities of man have

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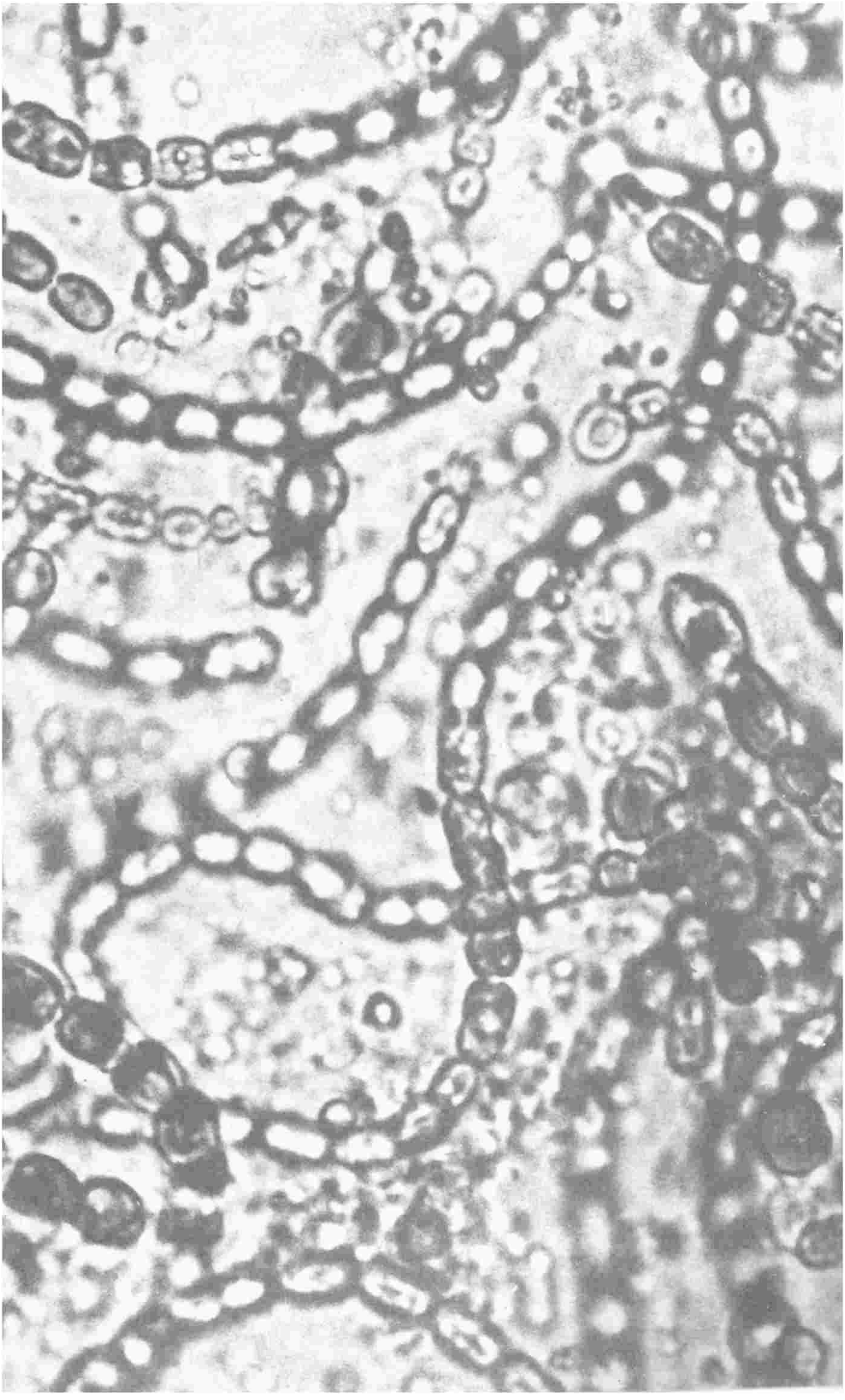
* G. E. Hutchinson, "The biosphere", *Scient. American*, 1970, v. 223, 3, p. 53.

** V. I. Vernadsky, "The problem of time in modern science", *Izv. AN SSSR*, OMEN, 1932, 4, p. 541.

on the natural processes occurring in the biosphere. As the Programme states, "MAB aspires to destroy obsolete barriers between scientists – naturalists, sociologists, decision-makers, and suggests instead an interdisciplinary approach directed towards solving the problems of controlling natural ecosystems and those modified by man."

Vernadsky's teaching of the biosphere is essentially the ideological basis of this international programme.



2 Living Matter

"Biology is the science of the incredible."

Albert Szent-Györgyi

In his book "The Chemical Structure of the Earth's Biosphere and of Its Surroundings" Vernadsky raised the problem of the types of matter of which the biosphere is composed*:

"Its matter (i.e. the matter of the biosphere.–*A. L.*) consists of seven fundamentally dissimilar natural parts that are not accidental geologically.

"First, it consists of an aggregation of living organisms, of *living matter*, scattered in myriads of individuals...

"Second, we deal with matter, created and processed by life... with *biogenic matter*, which is a source of extremely powerful potential energy (coal, bitumens, limestones, petroleum, etc.). The geological activity of living organisms in this matter after its formation is low.

"Third, we have the matter created by processes in which living matter does not participate: *sluggish matter*–solid, liquid, and gaseous...

"A fourth component is *biologically sluggish matter*, which is created simultaneously by living organisms and by sluggish processes and which represents dynamic equilibrium systems of them both. Such are all oceanic and almost all other water of

* V. I. Vernadsky, "The Chemical Structure of the Earth's Biosphere and of Its Surroundings", Nauka Publishers, Moscow, 1965, pp. 58-60.

◀ Filamentous Cyanophyceae Nostoc.

the biosphere, petroleum, soil, weathering crust, etc. Organisms play the leading role in them...

"Fifth, this is *matter*, which is in the state of *radioactive decay* in the form of a few relatively stable radioactive elements... Here we are dealing with chemical elements having a complicated isotopic composition, which penetrate all the substance of the biosphere and go down to an unknown depth...

"On the other hand, all the matter of the biosphere and, evidently, of the biosphere alone, is permeated by a sixth form of substance: by *scattered atoms*, which are continually created from all kinds of terrestrial matter under the influence of cosmic radiations...

"Finally, the seventh type of terrestrial substance is *matter of cosmic origin...*" (italics are V. I. Vernadsky's everywhere.–*A. L.*).

In Chapter Two we shall consider the types of matter occurring in the biosphere, particular attention being paid to living matter.

Vassoyevich, considering the classification of matter suggested by Vernadsky, noted that from the logical standpoint it is not impeccable, since the distinguished categories of matter partly overlap (for instance, matter of cosmic origin is at the same time sluggish). On the other hand, the dismal experience of mankind since Vernadsky's death has taught us that radioactive isotopes (e. g. strontium-90) accumulate in living organisms and, consequently, can enter into the composition of both living and sluggish matter. As regards "biologically sluggish matter", it cannot be regarded as a specific type of substance, since, according to the definition given by Vernadsky, it consists of two matters: living and sluggish. By its character this is a dynamic system rather than a matter, the fact emphasized by Vernadsky himself (we shall discuss this problem in Chapter IV).

Vernadsky constructed his classification of the types of matter in the biosphere according to several parameters:

(a) according to the character of matter as such (living or sluggish);

(b) according to the character of the initial matter (biogenic matter and sluggish matter are distinguished, life not taking part in the formation of the latter);

(c) according to the feature of radioactivity (matter is distinguished, which is in the state of radioactive decay);

(d) according to the degree of dispersion of the molecular structure (matter is distinguished, which is represented by scattered atoms);

Table 1

TYPES OF MATTER OF THE EARTH'S BIOSPHERE

Gradations according to initial material	Types of matter of terrestrial origin	Types of matter of extraterrestrial origin
Biogenic	Living matter Synonyms: bios, biota	Not known
Abiogenic	Not known	Not known
Biogenic	Biogenic matter: (a) neobiogenic (b) paleobiogenic Synonym: organogenic matter	Not known
Abiogenic	Abiogenic matter of terrestrial origin Synonym: sluggish matter	Abiogenic matter of extraterrestrial origin Synonym: matter of cosmic origin

(e) according to the feature of the terrestrial or extraterrestrial origin (matter of cosmic origin is distinguished).

We shall try to represent the genetic classification of the types of matter of the biosphere in matrix form. As the classification parameters we shall choose the following three main parameters: (a) the character of matter: living or nonliving; (b) gradations according to the initial material: formed from living matter–biogenic and formed from nonliving matter–abiogenic; (c) the feature of its terrestrial or extraterrestrial origin (Table 1). Radioactivity and the degree of dispersion of the molecular structure as classification parameters are omitted.

Matters of terrestrial origin in the biosphere may be both living and nonliving. To living matter, according to Vernadsky, there belong all living organisms of the biosphere. Contemporary living matter is biogenic, since it is formed exclusively by proliferation of the already existing living matter.

Over the ages there has existed a belief in the possibility of the spontaneous origination of living matter from nonliving matter (abiogenesis). In the poem "On the Nature of Things" written by Lucretius Carus (first century BC), which is an encyclopaedia of the ancient natural science, one can read the following lines about putrefying substances:

Though the dull clod, or sapless root as dull,
When the moist shower the putrid strife has roused.
Themselves the vermin race in crowds create:
Changed, then, their nature from arrangements new,
And full empowered perceptive life to rear.

It was only in the end of the last century that Louis Pasteur (1822-1895) proved the groundlessness of such conjectures. The thesis "The living from the living" Vernadsky called "the principle of Redi"*. In 1931 he wrote: "The Redi principle does not deny abiogenesis: it only indicates the limits within which abiogenesis is absent. In the Earth's history such conditions are possible, when there was no biosphere, and physico-chemical conditions or states existed on the Earth's crust, which are now absent and which were sufficient for abiogenesis." These lines date back to over half a century ago, but abiogenic living matter still remains unknown.

Florentine naturalist, physician, and poet Francesco Redi (1626-1697).

Nonliving matter present in the biosphere can be either biogenic or abiogenic. Biogenic matter is created as a byproduct of the vital activity of organisms. Constituents of such biogenic substances are remnants of dead organisms, products of their shedding and fall-off (this mass can be rather considerable: for example, a crayfish during the 20 years of its life sheds 50 carapaces; in woody plants dead organic matter by the end of their life exceeds the weight of living matter by 3 to 4 times – recall resilient carpets of conifer needles around fir-trees or of shed bark around eucalipti). Constituents of biogenic matter are also excrements of animals and products of the exogenous metabolism of living organisms (recent investigations have shown that in aquatic ecosystems 10 to 40% of the primary products of planktonic algae is, evidently, secreted into the medium and may serve as a source of carbon

* W. Vernadsky, *La géochimie*, Alcan, Paris, 1924, pp. 331-334.

and energy for other organisms). The role of the exogenous metabolism products is very important in bacteria. Higher plants also secrete into the environment specific substances which are called bactericides-fungicides-protozoacides. Specific biogenic substances which do not require any particular explanations are such various substances as urinary and bilinary calculi, pearl, galipot (resin), milk, honey, wax, filament sectreted by silkworm, web, and so on.

Biogenic matter falls into two categories:

(a) neobiogenic matter which is formed by living matter extant in the given geological epoch;

(b) paleobiogenic matter formed by living matter of past geological epochs.

A distinctive feature of neobiogenic matter is its extreme instability in the biosphere, mainly because it is energetically processed by living organisms. Only an insignificant part of neobiogenic matter passes over to the fossil state (and thus becomes paleobiogenic matter). However, curious incidents happen sometimes. For example a web was found, which had been woven millions of years ago! It was preserved due to a happy chance: as soon as this small web had been woven by the eight-legged ancestor of our spiders, resin somehow got onto it; the resin solidified, then got into sediments, and after millions of years a piece of amber was found with the web enclosed in it. In the United States in some gem shops one can buy coprolites for 5 dollars apiece. These coprolites are another paleobiogenic substance, namely, fossil excrement of dinosaurs.

The first paleobiogenic substance whose organic origin was proved were enigmatic triangular stones, known since antiquity. They were considered to be "a freak of nature" and called "stone tongues", in Latin – glossopetrae. The island of Malta abounded in them, and every owner of a more or less large collection of rarities in Europe would boast of one or several items of glossopetrae. Only in the 17th century the great Danish naturalist Nicolaus Steno (1638-1686) established that these were fossil teeth of sharks and thus laid down the first principles of paleontology.

Living matter is studied by the sciences of the biotic cycle; meanwhile, biogenic matter, actually, is not specially studied by any of the natural sciences. Therefore, as stated in one of the documents, "the main attention of geologists should be paid to the material products of the vital activity of organisms... This is one of the important specific features in the approach of

Fossil shark tooth (in times of old they were called glossopetrae) in phosphorite of the Paleogene Period. Life-size. Algeria.

geologists to the vital activity of the organism, and which should be always borne in mind*." One cannot but agree with this statement.

Finally, the last type of matter of terrestrial origin is nonliving abiogenic matter; examples of such kind of substances are products of volcanism and gases evolving from the interior of the Earth. According to present-day estimates, about 3 billion tons of abiogenic matter annually enter in the biosphere.

Neither living nor biogenic matter has been scientifically established to be present in the matter of extraterrestrial origin. So far "newcomers" have appeared only in science fiction novels and films. True, in 1961 the British journal "Nature" published a paper by G. Claus and B. Nagy**, in which unusual formations encountered in meteorites were described. The authors called them "organised elements" and defined them as the remains of extraterrestrial microorganisms.

However, according to conclusions drawn by G. P. Vdovykin***, the "organised elements" turned out to be silicates, surrounded by a shell of abiogenic carbonaceous substance.

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* "*Materials for Discussion and Conference on Sedimentary Rocks*", Publishing House of the USSR Academy of Sciences, Moscow, 1951, p. 50.

** G. Claus, B. Nagy, "Microbiological examination of some carbonaceous chondrites", *Nature*, 1961, v. 192, 4803, pp. 594-596.

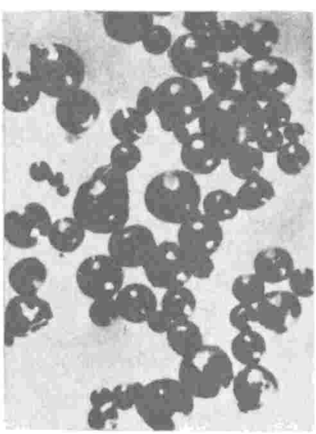
*** G. P. Vdovykin, "Organised elements" in carbonaceous chondrites", *Geochemisty*, 1964, 7, pp. 678-682.

Thus, in spite of extensive searches, no traces of the living and biogenic matter of extraterrestrial origin have yet been found. As regards abiogenic matter of extraterrestrial origin, this is a quite real thing. Certainly, everybody knows about meteorites, though this is a rather rare natural phenomenon. Since the 15th century only several hundred meteorites have been observed falling and collected on the globe.

There have been only 5 cases of a man being hit by a meteorite, i.e. one a century; 1 person was killed. The last case of somebody being hit occurred, it seems, on November 30, 1954. A four-kilogram meteorite fell through the roof and ceiling of a house, rebounded from a radio set, and hit the landlady, who was resting after lunch, in the leg. Thus Mrs. Hodges of Sylacauga, Alabama, USA, entered history.

Meteorites are the best known, but far from the most widespread form of abiogenic matter of extraterrestrial origin. In its composition meteoritic dust is predominant, with the diameter of particles reaching dozens of microns, and also smaller particles whose dimensions approximate molecular ones. The total amount of the abiogenic matter of extraterrestrial origin, arriving annually from space to the biosphere of the Earth, according to estimates given by different authors, varies within a considerable range. Most authors, however, are inclined to estimate the income of cosmic matter at 10^4 to 10^6 tons a year.

Living matter, however, constitutes only an insignificant part of the biosphere. If this matter were distributed over the surface



Abiogenic matter of extraterrestrial origin: cosmic dust isolated from Devonian rocks of the Urals. 30-fold magn.

of our planet, it would cover it with a film as thin as 2 cm. Nevertheless, it is precisely living matter that, in Vernadsky's opinion, plays the leading role in the formation of the Earth's crust. Vernadsky wrote: "If the amount of living matter fails to attract attention in comparison to the sluggish and biologically sluggish masses of the biosphere, *biogenic rocks* (i.e. those created by living matter) constitute a tremendous part of its mass, go far beyond the limits of the biosphere" (italics are Vernadsky's – *A. L.*). This statement, formulated by him half a century ago, as a matter of fact, is substantiated by geological material and realised fully only now.*

We have already used the term "living matter" without giving a comprehensive definition of this concept. Definitions were provided by Vernadsky several times in somewhat different wordings, but the essence of the definition did not change: "Living matter of the biosphere is an aggregation of its living organisms"**. At first sight it may seem that this concept does not introduce anything new (indeed, there are such terms as "life", "organic world"), and therefore there is no need for it. As if anticipating these arguments, Vernadsky emphasized that the word "life" has a lot of meanings and nuances.

We are accustomed to the word "life" going beyond the concept of substance and suggesting the sphere of philosophy, folklore, artistic creativity (it will suffice to recall the titles of novels, collections of poems, magazines, and motion pictures). The concept "living matter" introduced by Vernadsky is unequivocal and requires quantitative characteristics. "I shall refer to the aggregation of organisms reduced to their weight, chemical composition and energy, as living matter", Vernadsky wrote in one of his works. It is noteworthy, that he, so modest in self-appraisal, considered the introduction of numeric value and measure into biology to be his great scientific achievement.

Of course, when introducing the term "living matter", Vernadsky did not consider this matter to be uniform; and further, he did not consider any single compound (or group of compounds) decisive for living matter. In his "Essays of Geochemistry", published several times during his lifetime in

* A. V. Sidorenko, V. A. Tenyakov, Sv. A. Sidorenko, "On the biological nature of Earth sialic crust". In: "*Pre-Cambrian*", Nauka Publishers, Moscow, 1980, pp. 5-11.

** V. I. Vernadsky, "Problems of biogeochemistry", Part 2, *Trans. Connec. Acad. Arts a. Sci.*, 1944, v. 35, pp. 483-517.

Russian, French, German, and Japanese, Vernadsky wrote: "An idea, rather widespread some years ago (published in 1924 – *A. L.*), that life phenomena can be explained by the existence of complex carbonaceous compounds – living proteins – is irrevocably disproved by the body of empirical facts of geochemistry, since neither proteins, nor other carbonaceous compounds, nor protoplasm – their usual mixture – can lead to an understanding of living matter. Living matter is an aggregation of all organisms. Its behaviour is the result of its entire matter as a whole. To say that manifestations of organisms are first of all concentrated in proteins rather than in carbonates, or in free atmospheric oxygen generated by them, is to contradict reality."*

Living matter includes both organic (in the chemical sense) and inorganic or mineral substances. Morphologically, mineral formations of living matter are quite diverse. As examples it is possible to cite mineral inclusions in tissues of higher plants (so-called "phytolites"), droplets of elemental sulphur in the cells of some bacteria, shells of mollusks and brachiopoda, frustules, skeletons of animals, and so forth. In the composition of the living matter of the ocean alone there are about 20 inorganic minerals. Many of them are ephemeral and after the death of organisms they are transformed with time into other, more stable mineral modifications.

Vernadsky considered living matter to be "a form of activated matter", emphasizing that "this energy is the greater, the greater the mass of the living matter". From time to time its energy sharply increases, and colossal accumulations of living matter are formed. Such mass outbreaks of proliferation of "our smaller brethren" are described in scientific literature and in belles-lettres. Thus, Lawrence G. Green in his excellent book "Old Africa's Secrets" describes miles-long herds of South African gazelles (*Antidorcas marsuplalis*) that migrated over Africa in the last century. Once such a herd took 3 days to pass through a village. And gazelles can cover 100 and even more miles a day.

Medieval chronicles describe hordes of mice and rats which from time to time fell upon towns. Invasions of locusts, causing famine and disaster, have been known since days of old. In 125 BC more than 800 thousand people died from starvation in North Africa because of the mass proliferation of locusts. Some

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* W. Vernadsky, *La géochimie*, Alcan, Paris, 1924, pp. 263-264.

years ago the beach of Chudskoye Lake was suddenly covered with a layer of small pleasant-looking bugs that we know from our childhood as "ladybirds". The living red carpet covered not only bushes, stones and sand, but even the water surface. And so it was for about three days. Then the bugs disappeared.

Vernadsky illustrated his ideas about temporary accumulations of living matter using the data of the British naturalist G. Carruthers* who observed the annual flight of locusts over the Red Sea. The flight of this swarm of insects took a whole day. The space occupied by this swarm was 6 thousand km^3, and its weight was $4.4 \cdot 10^7$ tons, the weight of all the copper, lead and zinc man extracted throughout the last century. Unfortunately, swarms of such dimensions are encountered even now. For instance, according to recent observations in Argentina the flight of a swarm of desert locusts lasted 5 days. Swarms of locusts of up to 120 km in length and 20 km in width are described.

"It can cover all the Earth and devour all what is on the earth. When it breaks loose, the sun darkens and stars lose their glitter. It has the head of a lion, the neck of an ox, the breast of a steed, the wings of an eagle, the belly of a scorpion, the hips of a camel, the legs of an ostrich, the tail of a serpent" – this passage from an ancient Arab manuscript seems to have been written specially to illustrate in artistic form Vernadsky's idea about living matter as activated matter.

"What is a swarm of locusts from the biogeochemical point of view?", Vernadsky concludes his arguments, "it is, as it were, disperse of rock, extremely active chemically, and found in motion"**. No researcher before Vernadsky approached living matter from such standpoint. Living organisms were under the jurisdiction of the "biological department", and it occurred to nobody that living matter could be regarded as rock. The reason, evidently, was that this rock was of a specific kind.

Let us consider in brief the specific properties of living matter.

1. Living matter of the biosphere is characterized by tremendous free energy. In the inorganic world only unsolidified lava streams are comparable to living matter in the quantity of free energy. They are, perhaps, even richer in energy, but quite short-lived.

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* G. T. Carruthers, "Locusts in the Red Sea", *Nature*, 1890, v. 41, p. 153.

** V. I. Vernadsky, *Works*, v. 4, Book 1, p. 92.

2. A sharp contrast between the living and nonliving matter of the biosphere is observed in the rates of chemical reactions: in living matter reactions proceed thousands, and sometimes even millions of times faster (in Chapter One we have already explained this by the action of enzymes). Alexander Todd, President of the Royal Society of London, awarded the 1957 Nobel Prize and the 1978 Gold Medal of Lomonosov writes: "One of the specific features of living matter lies in that it carries out chemical reactions with a remarkable accuracy and orderliness and under much less severe conditions than in the production of substances by purely chemical methods." For life processes it is characteristic that to obtain small masses or portions of energy causes much greater energies and masses to be transferred and processed. So, the weight of insects eaten by a tomtit during one day is equal to the weight of the bird itself; some caterpillars consume and process daily 200 times their own weight.

3. A distinctive feature of living matter is that the individual chemical compounds constituting it – proteins, enzymes, etc. – are stable only in living organisms (to a considerable extent this is also characteristic of mineral compounds which are part of living matter). As Friedrich Engels wrote, "death is... the decomposition of an organic body which leaves no trace, except the chemical components of which it was formed"*.

Sometimes one has to "dodge" so as to preserve the external skeleton: thus, mollusks living in acidic waters in which the substance of their lime shell may be easily dissolved, coat it from the outside with chitin. "We know of only one state of mineral substance completely protected against dissolution in water: this is the state of living organic matter", Academician V. R. Williams emphasized.

4. "Arbitrary motion, to a considerable extent self-regulating, is a general feature of any living natural body in the biosphere." ** Vernadsky distinguishes two specific forms of motion of living substance: (a) passive stimulated by their proliferation and inherent to both animal and vegetable organisms; (b) active engendered for the purposeful transference of organisms (characteristic of animals and to a lesser extent, plants).

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* K. Marx and F. Engels, *Works*, v. 20, p. 610.

** V. I. Vernadsky, "Problems of biogeochemistry", Part 2, *Trans. Conn. Acad. Arts a. Sci.*, 1944, v. 35, pp. 502-503.

Living substance tends to fill all available space (within the limits of the globe, and as regards man, he goes even farther). The property of maximum expansion is inherent to living matter in the same manner as it is characteristic of heat to transfer from more heated to less heated bodies, as it is characteristic of a soluble substance to be in a solution, and of a gas, to dissipate in space.

5. Living matter displays considerable greater morphological and chemical diversity than nonliving matter. The difference between a virus and, say, an African elephant, is much greater than between any of the most contrasting representatives of nonliving matter. The chemical composition of living matter is strikingly diverse. More than 2 million organic compounds are known to enter into the composition of living matter. At the same time the number of natural compounds (minerals) of nonliving matter is only about 2 thousand, that is, three orders of magnitude smaller. Moreover, in contrast to nonliving abiogenic matter, living matter is not represented by the liquid or gaseous phase exclusively. Bodies of organisms are built from substances that are in all three phase states. However, despite all the diversity of the composition of living matter, the entire organic world of the Earth is noted for a surprising biochemical unity. The establishment of this unity is one of the most fundamental discoveries of our time. Insofar as this is the subject of biochemistry, we shall not go into particulars, but shall only quote Albert Szent-Györgyi: "Man does not differ so much from the grass growing under his feet".

6. Living matter is represented in the biosphere in the form of dispersed bodies - individual organisms. The "living ocean" of Stanislav Lemm in his novel "Solaris" remains science fiction. The dimensions of individual organisms vary from 20 nm in the case of the smallest viruses to 100 m (the range being over 10^9). The largest organisms in geological history are encountered now: these are whales among the animals and sequoias among the plants. In Vernadsky's opinion, the minimum and maximum dimensions of organisms are determined by the possibilities of their gas exchange with the medium.

7. Being disperse, living matter is never found on earth in a morphologically pure form, i.e. in the form of populations of organisms of one kind: it is always represented by biocoenoses. This would seem to be in contradiction with our everyday experience: we know pure pine tree woods where nothing but pines grow; in films we have seen bird colonies (sometimes

birds of one kind, e.g. sea-gulls), sea lion populations on desert shores of arctic seas... But this monotony proves to be only apparent. As N.V. Timofeyev-Resovsky points out*, "even the most simple biocoenosis of some dry pine forest on sand is a community consisting of approximately a thousand species of living organisms". Pine woods could not exist were it not for the decomposition of the decaying needles, branches and trunks through the agency of saprotrophic organisms and for the return of mineral substances to the biological cycle. Sea-gulls and sea lions could not live were it not for their "canteen" located nearby, i.e. the sea with whose inhabitants they constitute a unified ecosystem.

8. The principle of Redi ("all the living from the living") about which we have already spoken is a distinctive feature of living matter. Living matter exists on the Earth in the form of the continuous alternation of generations. Owing to this, contemporary living matter, being characterised by continuous renovation, proves to be genetically connected with living matter of all the past geological epochs. In contrast to this, nonliving abiogenic matter comes to the biosphere from outer space or comes out in portions from the lower-lying envelopes of the globe. Such separate portions may be formed as a result of similar processes and, thus, be analogous in composition, though in the general case they have no genetic connection with each other.

9. For living matter the presence of an evolutionary process is characteristic. The reproduction of living matter occurs not by way of "stamping", i.e. not by way of the absolute copying of preceding generations, but by way of morphological and biochemical changes which are sometimes slow and sometimes more rapid (in the geological sense!).

Among the species which compose the living matter of the biosphere there exist rarities: living fossils or "persistents" (from the Latin "persisto", to stand firm). This name is given to biological species which have not changed over many millions of years. As an example Vernadsky cites Radiolariae from the protozoan sub-kingdom and Lingula from the brachiopods. These examples may now be miltiplied: the rhynocephalian reptile Tuatara of New Zealand, Xiphosura (representatives of Eurypterida), mollusc Neopylina galatea, and others.

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* N.V. Timofeyev-Resovsky, "Biosphere and man", *Priroda*, 1970, 8, pp. 2-9.

A sensational discovery was made in 1938: a lobefin fish Latimeria of impressive dimensions (a metre and a half in length and 57 kg in weight) was caught. This fish was believed to have become extinct 70 million years ago. (Paleontologists should be credited that the fish as caught corresponded to the reconstructions they made from the fossil skeletal remnants!) The story of the discovery of the mollusc Neopylina galatea is approximately the same, raised in 1952 by the Danish ship "Galatea" from a depth of 3950 m.

The ocean depths, naturally, still hide many secrets from us. But persistents exist in the soil as well. Paleobotanist V. A. Krasilov and entomologist D. A. Krivolutsky in the upper Jurassic coal measures of the Bureya Basin found remnants of loricate mites, many of which proved to be identical with contemporary ones!

10. Academician Boris Borisovich Polynov (1877-1952) emphasized yet another specific feature of living matter: "The quantity of mass of living matter, corresponding to the given moment, cannot give an idea of the enormous amount of it that has carried out its work during the entire time of the existence of organisms"*. Essentially, the mass of the biogenic matter of the metabiosphere is the integral of the mass of the living matter of the Earth with respect to geological time, while the mass of the nonliving abiogenic matter of terrestrial origin is a constant value in the geological history. One gramme of Archean granite at present will remain 1 g of the same substance, while an equal mass of living matter, though remaining 1 g, has existed for milliards of years through changes of generations and all this time it has been carrying out geological work.

Living matter is a specific kind of rock... an ancient and, at the same time, an eternally young rock. A rock which creates itself and destroys itself to originate again in new generations in the innumerable forms constituting it. The Phoenix of ancient legends...

As any subject of scientific investigation, living matter should be classified. Vernadsky wrote: "We distinguish *a uniform living matter–generic, specific*, etc., and a nonuniform living matter such as forest, steppe, biocoenosis in general, consisting of

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* B. B. Polynov, *Selected Works*, Publishing House of the USSR Academy of Sciences, Moscow, 1956, p. 437.

uniform living substances, their regular combinations"* (italics are V. I. Vernadsky's.–*A. L.*). And if nonuniform living matter, as Vernadsky understood it, corresponds to rock, uniform living matter may be regarded as a mineral. Refining this concept, Vernadsky wrote that uniform living matter in its scope corresponds to the biological species or race of living organisms.

There is no necessity to use larger taxons of the organic world, such as genera, families, etc., since they comprise too diverse parts of living matter not interrelated under natural conditions.

Vladimir Sergeevich Sadikov.

For characterising uniform living matter at the level of species Vernadsky suggested the use of three quantitative characteristics: (a) chemical composition; (b) average weight of organisms; (c) average rate with which they populate the entire surface of the globe.

Vernadsky posed the problem of investigating the chemical living matter as early as 1919. To solve this problem, he recruited the biochemist, Professor V. S. Sadikov (1874-1942), his numerous pupils, and also A. P. Vinogradov, who was then a beginner (their joint works on the investigation of living matter were published in 1924)**. The technique for the chemical analysis of living matter was elaborated by V. S. Sadikov.

Investigations into the chemical composition of living matter were carried out extensively at the Biogeochemical Laboratory of the USSR Academy of Sciences (BIOGEL), set up by Vernadsky in 1927 in Leningrad (in 1934 this Laboratory was transferred to Moscow). In Transactions BIOGEL there were published such papers as "Analysis of the Plankton from the Ekaterininsky Pond at Detskoye Selo" by A. P. Vinogradov,

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* V. I. Vernadsky, "Problems of biogeochemistry", Part 2, *Trans. Conn. Acad. Arts a. Sci.*, 1944, v. 35, p. 488.

** W. S. Sadikow, A. P. Winogradow, "Untersuchungen über die Zusammensetzung des lebendigen Substrats", *Biochem. Zeit.*, 1924, Bd. 150, H. 5/6, SS. 372-391.

"The Mineral Composition of the Skeletons of Some Contemporary Echinoderms" by K.F. Terentieva, "Investigation of the Chemical Composition of Red Clover" by T.I. Gorshkova. This trend of research was further developed in the generalizing works of Alexander Pavlovich Vinogradov (1895-1975), later an academician, who took over the post of Director of BIOGEL after Vernadsky's death.

In the late thirties and early forties A. P. Vinogradov published an extensive report "The Elementary Composition of

Young research workers of BIOGEL; the last on the right is A. P. Vinogradov.

Marine Organisms" (which was translated and published in the United States in 1953)*. Investigations of living matter "with measure and weight" are still going on. At present non-uniform rather than uniform living matter is the subject of investigation, mainly, the biomass and productivity of various ecosystems and, on the basis of these data, of the biosphere as a whole.

Vernadsky approached the classification of living matter from geochemical positions. In so doing, Vernadsky proceeded from the classification of organisms according to the method of nutrition, elaborated in the 1880s by the German biologist W. Pfeffer. Vernadsky wrote: "We shall call autotrophic all

* A. P. Vinogradov, *The Elementary Composition of Marine Organisms*, New Haven, 1953, 647 pp.

organisms which take all the chemical elements necessary for their life in the contemporary biosphere from the sluggish matter surrounding them, and do not require ready organic compounds of another organism for the construction of their body"*. This term is formed from the Greek roots "autos", self and "trophē", nourishment.

Pfeffer called organisms which require for their nourishment living matter formed by other organisms heterotrophic (from the Greek "hetero-", other, different), and organisms featuring a mixed type of nourishment, mixotrophic (from the Greek "mixis", act of mingling or mixing). Examples of mixotrophic organisms are insectivorous plants.

At the time of W. Pfeffer only one source of energy was known, employed by green plants: solar energy. Therefore such organisms are called "photoautotrophic" (from the Greek "phōs" (gen. "phōtos"), light). However, in 1890-1892 Sergei Nikolaevich Vinogradsky, a young Russian microbiologist (1856-1953) discovered the phenomenon of chemosynthesis: the ability of certain bacteria to produce living matter by the use of energy obtained by nitrification, i.e. by oxidation of ammonia to nitric acid.

This was an outstanding discovery. It rarely happens that some field of science is so completely and exclusively associated with the name of one man as chemosynthesis is with the name of S.N. Vinogradsky. Later on bacteria were discovered capable of obtaining energy as a result of oxidation of other elements as well: hydrogen, sulphur, and iron. Recently the Soviet microbiologist N.N. Lyalikova succeeded in isolating a novel chemoautotrophic microorganism which exists by virtue of the oxidation of antimony**. Thus, a whole world of chemoautotrophic bacteria has already been discovered, which play an essential role in the circulation of substance in the biosphere, particularly in the creation and annihilation of some types of ore deposits.

As already stated, heterotrophic and mixotrophic organisms cannot synthesize organic substance on their own, but they use it in its ready form. Among the heterotrophs two categories of organisms may be distinguished: organisms feeding on living organic substance prior to its natural dying off (these organisms

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* W.I. Vernadsky, *La biosphère*, Alcan, Paris, 1929, p. 123.

** N.N. Lyalikova, "Stibiobacter senarmontii - a novel microorganism oxidising antimony", *Microbiologiya*, 1974, v. 43, 6, pp. 941-948.

are called biotrophic) and those consuming dead organic remains (such organisms are called saprotrophic, from the Greek "sapros", rotten). In developed ecosystems there exists a complicated food chain (otherwise called trophic chain), and consumers of autotrophs, in their turn, become victims. "The bug ate grass, the bird pecked the bug, the ferret supped the bird"–such are three links in the food chain of biotrophs, as depicted by Nikolai Zabolotsky.

An aggregation of living organisms featuring similar nourishment is called a trophic level. Organisms of any level of the trophic pyramid feed on living matter of the lower-lying level. The lowest-lying trophic level (in other words, the base of the trophic pyramid) is constituted of autotrophic organisms. On average, only about 10% of energy is transferred from one level to another. The rest of the energy is either converted into heat and dissipated, or (most often) is not assimilated at all. The great French physiologist Claude Bernard (1813-1878) wrote: "Life can only exist where there are both synthesis and organic destruction." In the now existing terrestrial ecosystems the weight of the living matter of heterotrophs is hundreds and thousands of times smaller than that of the living matter of autotrophs (in forests, for example, it is 2,000 to 5,000 times smaller). As a result, biotrophs fail to cope with their food resources, and the major part of the living matter products dies off. The dead organic products and products of the metabolism of the biotrophs are consumed by a whole army of various saprotrophs which completely decompose these substances to mineral compounds: carbon dioxide gas, water, nitrogen, and mineral salts.

"When god Anu created the heaven, the heaven created the earth, the earth created rivers, rivers created ditches, ditches created slime and slime created the worm, the worm looked at the sun and cried, and his tears appeared before the face of goddess Ei.

"What do you give me as food and drink?" the worm asked.

"I shall give you as food rotten wood and the fruit of trees."

Such is, according to the Babylonian cuneiform text, the origin of saprotrophs on earth; they not only protect the biosphere from self-poisoning (many of the decomposition products of dead organic substances are extremely toxic) but also, by breaking down organic substances, return carbon and nitrogen to the mineral form, and it is only in this form that these elements can be consumed by autotrophs. It is characteristic that while biotrophs for their normal development need mixed food consisting of various substances (proteins, fats, sugars or starch), saprotrophic bacteria in the presence of a source of nitrogen and ash elements can be satisfied with some single organic substance, for example, protein or sugar. They easily decompose biogenic organic substances of both vegetable and animal origin. Moreover, they can deal with many organic materials created by man: plastics, naphthalene... Polyethylene presents greater difficulties to bacteria, but if the polyethylene is exposed to ultraviolet radiation, bacteria can use it as well.

Recently A. M. Ugolev, Corresponding Member of the USSR Academy of Sciences, formulated the tasks of a new science: trophology. According to his definition, "the subject of trophology is the regularities of assimilation (that is, of the absorption and incorporation of substances necessary for life) at all the levels of organisation of biological systems, from the cell, organ and organismic to the populationary and planetary."* In accordance with the basic conception of trophology, each kind of living organisms of the biosphere uses definite sources of nutrition and, at the same time, it serves as a nutritional object for other kinds of organisms. Living organisms must have a definite phagicity, i.e. be available to another organism as a source of food, and a definite trophicity, i.e. to have nutritional properties and an ability to be assimilated. With such an approach the paradoxical conclusion is drawn that there exists a mutual adaptation of so called trophological partners. Figuratively speaking, the victim must not run away too fast from its predator, and the predator must not devour it too easily. Only in this case will predators feed predominantly on ill, imperfect and ageing members of the population, and the numbers in the population as a source of nutrition will be maintained at a definite level.

The British ecologist D. Owen** considers that in the course of evolution there takes place a mutual adaptation of autotrophs and heterotrophs and that the traditional view concerning the perfection of the means of protection of the "one being eaten" against the "eating one" must be radically revised.

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* A. M. Ugolev, "Trophology - a new interdisciplinary science", *Vestnik AN SSSR*, 1980, 1, p. 50.

** D. F. Owen, "How plants may benefit from the animals that eat them", *Oikos*, 1980, v. 35, 2, pp. 230-235.

Thus, with the use of new approaches, the brilliant insight of Vernadsky is confirmed concerning the universal integration of life within the scope of the biosphere. The concept of interspecific competition, which prevailed in the last century, is being replaced by the conception of the mutual adaptability of species.

We have considered the classification of living matter according to the methods of feeding of the organisms. The well-known Soviet biologist and biogeographer D. V. Panfilov suggested that living matter should be classified into two categories according to quite a different principle. He has distinguished in the biosphere a reproductive living matter and a somatic living matter (in biology cells which perform any function except reproduction are called somatic). The mass of reproductive living matter is insignificant in relation to the somatic one, but it is the reproductive living matter that determines the continuity of the development of life on our planet. The biospheric role of the somatic living matter is to transport the reproductive living matter to all corners of the Earth and thus ensure the "everywhereness" of life.

"Who is who" in the biosphere? Let us try to combine two approaches to living matter: the functional and the biological (systematic) (Table 2).

In the macrosystem of cellular living organisms, suggested by the prominent Soviet biologist Academician Armen Leonovich Takhtadzhian*, two superkingdoms of the organic world are distinguished: procaryotes and eucaryotes, the main difference between them being the absence of the karyon (i.e. of the cell nucleus) in the procaryotes. In the procaryotes there is no differentiation between somatic and reproductive living matter either. The procaryotes include only one kingdom: schizophytes, which is subdivided into the subkingdoms of bacteria and blue-green algae (otherwise termed Cyanophyceae). We shall start our excursion in the organic world of the Earth with bacteria.

The mention of bacteria usually brings about associations with most unpleasant phenomena: fever heat, rigour, swamp fever... However, only 0.1% of all the bacteria on earth causes diseases in man. One of the leading microbiologists of our time, Foreign Member of the USSR Academy of Medical Sciences

* A. L. Takhtadzhian, "Four kingdoms of the organic world", *Priroda*, 1973, 2, pp. 22-32.

Table 2

Macrosystem of Living Organisms and Their Functions in the Biosphere

Macrosystem of living organisms*						
Super-kingdoms	Kingdoms	Subkingdoms	Photoautotrophs	Chemoautotrophs	Biotrophs and mixotrophs	Saprotrophs
Procaryotes	Schizophytes	Bacteria	+	+	+	+
		Cyanophyceae	+	–	–	–
Eucariotes	Plants	Red algae	+	–	–	–
		Real algae	+	–	–	–
		Higher plants	+	–	Extremely rarely (insectivorous plants)	?
	Fungi	Lower fungi	–	–	Rarely	+
		Higher fungi	–	–	Rarely	+
	Animals	Protozoa	–	–	+	Very rarely
		Metazoa	–	–	+	+

* After A. L. Takhtadzhian, with the replacement of the subkingdom of blue-green algae by Cyanophyceae.

André Lvov was fair in remarking that we should not be angry with them, since if it were not for microbes, there would be no life on earth and there would be no... microbiologists. This joke is no exaggeration: bacteria do perform necessary functions in the biosphere. Among all the living on earth the subkingdom of bacteria holds the record as to the diversity of its methods of feeding: it is the only subkingdom which includes examples of all the four types of feeding.

There are about 50 species of photoautotrophic bacteria on earth. In contrast to all other organisms bacteria do not evolve oxygen in photosynthesis. But we can pardon them that! Bacteria are, evidently, the most ancient photosynthesizing organisms on our planet.

Nikolai Ivanovich Andrusov.

The main role of bacteria in the cycle of substances in the biosphere is two-fold: (1) decomposition of dead organic substances and the return of the constituent elements to the biotic cycle; a considerable part of this work is performed by bacteria in the alimentary tracts of metazoans; (2) continuous implication of new portions of ash elements and nitrogen into the biotic cycle. As early as the end of the last century Nikolai Ivanovich Andrusov (1861-1924), later an academician and at that time a supernumerary extraordinary Professor of Mineralogy at Yuriev University, was the first Russian geologist to realize this role of bacteria in the biosphere. "Bacteria, evidently, have existed on the globe for a long time. The tremendous role they play in the cycle of sulphur, nitrogen and carbon makes the life of other organisms inconceivable without them," he wrote.*

The significance of the fixing of nitrogen from the atmosphere in the biosphere can be compared only with autotrophic assimilation of carbon dioxide gas. From the general biological standpoint nitrogen is more valuable than the rarest noble metals, but only bacteria (and Cyanophyceae considered

* N. I. Andrusov, "Bacteriology and geology, their interrelationships", *Sci. Papers of the Imperial Yuriev University*, 1897, 1, p. 19.

below) are capable of fixing atmospheric nitrogen in their bodies and thus of implicating it into the biogeochemical cycle.

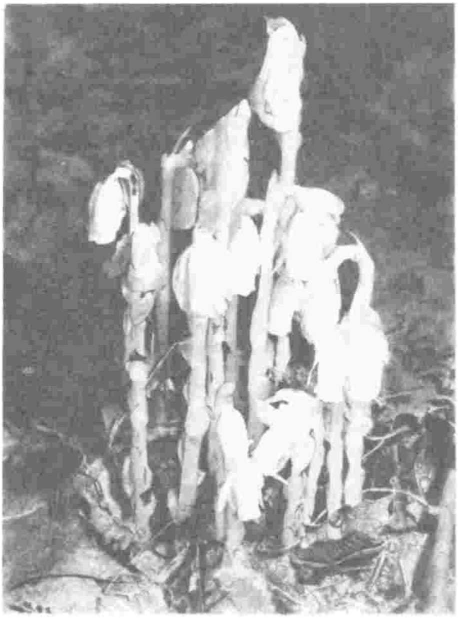
The functions of bacteria in the biosphere are so diverse that in principle ecosystems may exist, in which living matter is represented exclusively by bacteria, part of which belongs to autotrophs and another part, to biotrophs and saprotrophs. No other organisms (except for Cyanophyceae) are capable of such an autonomous existence in the biosphere.

Bacteria are ubiquitous in the biosphere. The Dutch microbiologist Martin V. Beijerinck (1851-1931) formulated the following postulate which is now named after him: "Bacteria develop everywhere where there are the conditions for their existence" (naturally, they develop not by way of spontaneous generation: the principle of Redi is operative here as well). Recently viable bacteria were even found on the Moon, where they had been brought from the Earth by some previous spaceship.

Cyanophyceae constitute the second subkingdom of procaryotes. In their viability they can compete only with bacteria (Cyanophyceae are found even in atomic reactors). In 1883 all living substance on Krakatao Island was destroyed by an eruption, but already three years later Cyanophyceae were growing on volcanic ash and tuff. Cyanophyceae were the first to return to the ill-famed Bikini atoll after the American atomic weapons tests; finally, Cyanophyceae became the first settlers on the barren rocks of the Island of Surtsey which came into being in 1963 as a result of the eruption of a submarine volcano to the south of Iceland. Cyanophyceae are encountered everywhere: on land and in the ocean, in hot springs and on the snow. They thrive in the Antarctic, in polluted water bodies or in arid deserts. The olive-coloured slimy film that covers the beach stones washed by waves is home for colonies of Cyanophyceae. Small green "leaves" or balls which overcrowd artificial water reservoirs at the time of their "bloom" are Cyanophyceae as well. Their lavish development in water bodies contaminated with nitrogenous compounds brought there from fields is a serious contemporary problem*.

Cyanophyceae are quite diverse in their morphological features. Monocellular, colonial and filamentous representatives can be encountered among them. One of the species of ancient

* G. E. Hutchinson, "Eutrophication", *Amer. Scientist*, 1973, v. 61, 3, pp. 269-276.



Indian pipe – a plant which does not trouble itself with photosynthesis.

Cyanophyceae is named after Vernadsky: Oscillatorites wernadškii Schep. About a hundred species of Cyanophyceae are capable of fixing atmospheric nitrogen. They do not need soil nitrogen. This property allows them to inhabit such places where there is no soil: barren rocks, snow, the bark of trees.

In his famous "Systema naturae" ('The System of Nature') (1758) Carolus Linnaeus wrote: "Who would believe that such beings as fish can be present in water if we did not see them with our own eyes." These words are no less applicable to Cyanophyceae.

What is the biospheric role of Cyanophyceae? Evidently, it consists in preparing the previously barren substrate for population by nonuniform living matter. Cyanophyceae are pioneers of this nonuniform living matter. Thus, according to the observations of W. O. Towson, in the highlands of the Pamirs and of the Caucasus, Cyanophyceae, together with nitrifying bacteria, form black-coloured sinters on stones. If one scrapes such a sinter from the rock, one can see small insects – Collembola which process the remains of bacteria and Cyanophyceae. This triad creates soils on formerly barren rocks.

It turns out that procaryotes, the most primitive organisms on earth, having no proper karyon, are in the vanguard of the conquest of living space and by their activity prepare the soil, both in the direct and the figurative sense, for more developed ecosystems. They, the procaryotes, can live without us... And we, can we do without them?

Thus, procaryotes display a remarkable ability to exist without oxygen in the atmosphere and without nitrogen in the soil. The representatives of another superkingdom of living organisms – eucaryotes – do not possess such wonderful properties.

Eucaryotes are quite diverse morphologically: from microscopic fungi to man! Three kingdoms are distinguished among them: plants, fungi and animals. Each kingdom performs its definite function in the biosphere.

All plants, with rare exceptions, are autotrophs, only photoautotrophs being encountered among them. Photosynthesis takes place due to the presence of a specific magnesium-containing pigment, chlorophyll, in the cells of the plants. The plant kingdom is subdivided into three subkingdoms: red algae, proper algae and higher plants.

Red algae (most of them) are marine plants which live in the tidal zone attached to rocks. Red algae are quite diverse in their structure. In the majority of cases these are rather large multicellular organisms reaching about a metre in length. In addition to chlorophyll red algae contain one more pigment, contributing to photosynthesis, namely, phycoerythrin. The specific properties of phycoerythrin allow red algae to carry out photosynthesis under conditions of diminished illumination and, hence, at greater depth. Due to this red algae live at depths down to 180 m, while other aquatic plants which possess only chlorophyll are not encountered at depths exceeding 100 m.

True algae (which should not be confused with aquatic flowering plants!) constitute another vast subkingdom of plants. Its representatives are rather diverse in both their structure and size (from unicellular Euglenophytae to fifty-metre giants – Macrocystis and Pelagophycus). The role of algae in the biosphere is clear: being autotrophs, algae perform the function of a green screen on the 70.8% of our planet covered with water. Proceeding from these considerations scientists in Vernadsky's time believed algae to play the fundamental role of producing oxygen in the biosphere. At present it is established not to be the case: algae give only 1/4 of the entire annual production of autotrophs and, hence, 1/4 of the total oxygen input into the atmosphere.

The atmosphere of our planet is formed mostly by higher plants which constitute the last subkingdom of the kingdom of plants under consideration. Higher plants, naturally, belong to autotrophs, but – it is a small flock that has not a black sheep! – there are originals among them, which resort to other types of feeding. Thus, there are even predator-biophages among them. By using animal food, which these plants procure by way of real hunting, they compensate for the chronic deficiency of soil nitrogen. Such are sundew, bladderwort and some other insectivorous exotic plants: Nepenthes (a liane of equatorial forests), Sarracenia and Darlingtonia (growing in the New World). There are many plant-predators in Africa. For instance, near Cape Town Roridula shrubs grow, which capture and devour small animals up to frogs. The fertile imaginations of the first African travellers even created a man-eating tree. It goes without saying that such a tree is the result of an idle flight of imagination: plants cannot hold animals larger than frogs and small fish with their trapping tools (it happens that even such prey is sometimes stolen by dexterous spiders, especially in the tropics). All in all, there are about 450 species of predatory plants in the biosphere. This is less than 0.2% of the total number of 250,000 plants extant.

Insectivorous plants and some parasitic plants (European misletoe, dodder) are partial biotrophs: they are mixotrophs. Saprotrophs, which are extremely rarely encountered among higher plants, for example, Hypopitus and Indian pipe, belong to the same category. These deadly pale small plants not troubling themselves with photosynthesis are sometimes encountered in forests. They were considered to exist only on the nutrient substances of the decomposing forest litter, but they have now been shown to be partial parasites, and, evidently, there are no real saprotrophs among higher plants*.

However, sundew, European misletoe, Hypopitus are those exceptions which confirm the general rule that higher plants are photoautotrophs. In addition, higher plants feature predominantly passive form of motion of living matter. Reproductive and somatic substance is differentiated in them, and the possibilities of independent motion of the somatic

* T. A. Rabotnov, "Once again about constortia", *Bull. of MSN*, Biol. div., 1978, v. 83, 2, pp. 88-95.

substance are quite limited: it is hardly probable that one can go very far using only stems and rootstocks (a tuft of grass in a pot in my window seems not to have grown a centimetre in three years). True, one species of plant does hobble, however clumsily, on its tree feet*, but this species is the fruit of science fiction rather than botanical reality. As to the propagating of the reproductive substance by themselves, higher plants are altogether incapable of such a thing.

And fungi were fungi.
They're like nobody else on earth.

So laconically has the Japanese poet Jun Takami characterised the second kingdom of eucaryotes. The latter have long been attributed to the kingdom of plants, but – the poet is right! – fungi are "not like" plants.

All fungi are incapable of synthesizing organic substance by themselves. In the absolute majority of cases fungi are saprotrophs, though biotrophs are sometimes also encountered. These are predatory fungi which capture into their trapping nets small soil inhabitants. But this is a specific case, and while the biospheric function of plants is to create organic substance, the biospheric function of fungi is to decompose the died-off organic matter and thus prepare it for reutilisation by living matter. At present it is quite unlikely that anybody will agree with the French botanist S. Veillard who lived in the beginning of the eighteenth century and exclaimed in a fit of temper: "Fungi are a cursed tribe, an invention of the devil, devised by him to disturb the harmony of the rest of nature created by God." The "divine harmony" of the biosphere would not exist without the "cursed tribe" of the fungi.

We have discussed the functions of two kingdoms of eucaryotes, namely, of plants and fungi, in the biosphere. At first sight everything is clear: plants play a constructive, creative role in the biosphere, and fungi play a destructive role: they close the biological cycle, prepare nutrition for autotrophs. But then what is the purpose of animals in the biosphere? What is the purpose you and I serve here?

The heavy body of a cow,
Positioned on four extremities,

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* J. Wyndham, *The Day of the Triffids*, London, 1951 and other editions.

Crowned with a temple-like head
And two horns (like the moon in its first quarter),
Will also be not understandable,
Will also be incomprehensible
If we forget about its meaning
*On the map of the living of the whole world.**

Let us try to make out the meaning of animals "on the map of the living of the whole world". Let us start with protozoans.

To this subkingdom there belong unicellular animal organisms (sometimes they form colonies). They live mostly in an aqueous medium: in landlocked bodies of water, from rain pools to the ocean, in the moisture contained in soils, and parasitic forms live in the bodies of other living organisms.

Most protozoans are biotrophs: they feed on bacteria, unicellular algae and other small organisms, including protozoans as well; saprotrophs and parasites are also encountered among them.

Protozoans constitute a necessary link in the biogeochemical cycle of matter in the biosphere, though, maybe, this link is not so noticeable as that constituted by photoautotrophs. The main function of protozoans consists in redistributing living matter in biologically sluggish systems containing a sufficient quantity of water. For the functioning of the biosphere as a whole the ability of some marine protozoans to concentrate certain elements in their external skeleton, a feature which is not so clearly manifest in other eucaryotes, is also of great importance.

Metazoans constitute a second, much more numerous subkingdom of animals. It comprises about 1.3 million species, this being greater than the number of representatives of all other subkingdoms taken together. 7/8 of the species of all the metazoans live on land. G.E. Hutchinson**, having set himself to answer the question of why there are so many kinds of animals, came to the conclusion that the extremely high diversity of land fauna is associated with the diversity of land plants. The ample vegetarian diet of the biosphere is almost entirely consumed by numerous connoisseurs of vegetable food. Predators are considerably less numerous in the biosphere. As

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* N. Zabolotsky, *Verses and Poems*, Sovetsky Pisatel' Publishers, Moscow-Leningrad, 1965, p. 235.

** G.E. Hutchinson, "Homage to Santa Rosalia or why there are so many kinds of animals", *Amer. Naturalist*, 1959, v. 93, 870, pp. 145-159.

to the number of species, the first place among the metazoans is held by insects, molluscs, second and vertebrates, third.

Metazoans possess an active form of motion of living substance. As is rightly noted in an old trustworthy document, "an animal by its nature is a nomadic being". Only rare sedatory forms which attach themselves to some substrate do not feature an active form of motion. The freedom of movement of the metazoans determines their main biospheric function. "In the majority of landscapes and biocoenoses animals perform an indispensable function," write Yu. A. Isakov and D. V. Panfilov, "by transforming vegetable organic matter into the dispersed state and disseminating it with sufficient uniformity from the living and perished plants to the places of growth and development of subsequent generations of vegetable organisms. This is, if one may say so, the "cosmic role" of animals"*. However strange this may seem, predators also play an essential role in it. Attacking the flocks of ungulate animals, they drive them from place to place and thus preclude excessive spoiling of pastures.

In addition to plants which extract nutrient substances from soil, metazoans are the only representatives of the living matter of the biosphere, which transfer matter in the course of the geochemical cycle in a direction contrary to the flow. Should they suddenly disappear from the biosphere, life would become possible only in the direct proximity of water bodies. And while insects transfer substance over dozens of metres from the plant that has created organic matter, vertebrates transport it over distances measured by kilometres, and seasonal migrations of migratory birds and some fish effect global transfer of substances in the biosphere.

Metazoans are the only animals in the biosphere. They transport "foreign" reproductive living matter: spores, pollen and seeds of higher plants, and thus contribute to their settling in the biosphere.

Being biotrophs, metazoans consume part of the production of autotrophs and due to it they perform a regulatory and stabilising function in ecosystems. Thus, by destroying part of the products, they protect ecosystems against overproduction of nondecomposed dead organic matter which hinders renewal of

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* Yu. A. Isakov, D. V. Panfilov, "Main aspects of medium-forming activity of animals". In: "*Medium-forming Activity of Animals*", Moscow State University Press, Moscow, 1970, p. 4.

vegetation. In marine ecosystems metazoans, by eating out the plankton, also perform the function of a regulator of the mass of the autotrophs (they additionally affect them with the metabolic products excreted into the water). As R.I. Zlotin puts it, losses in the production of the autotrophs is the "price" the vegetation "pays" to herbivorous animals for the acquisition of homeostatic reactions by the ecosystem.

In the biosphere not affected by man vegetation in principle cannot be overgrazed by herbivorous animals: the population of the herbivorous animals will fall before the extent of the "grazing" becomes catastrophic for the vegetation. On average, within an area of the terrestrial portion of the biosphere there live about 10 mass species of vertebrates with a total consumption of about 1% of the primary production* (in other words, of the annual growth of the vegetation).

By absorbing particular elements and excreting the products of metabolism, the metazoans actively affect their habitat. In this respect most active are filtre-feeding organisms (in aquatic ecosystems) and detritophagous animals (in soils and bottom sediments of water bodies).

Finally, some of the metazoans are saprotrophs (worms, some insects and arachnids, carrion-feeding birds and mammals). Observations have shown the decomposition of dead organic matter to proceed without the participation of animals two to five times slower than usual.

Are there photoautotrophs among animals? Yes, there are, though they carry out photosynthesis not quite independently. These are the worms Convoluta roscofferensis living on the Channel Islands of Jersey and Guernsey near the British Isles. Having hatched from the egg, these worms swallow microscopic algae which, remaining alive, penetrate through the walls of their intestine into the body cavity. Owing to the great number of algae absorbed, the worms acquire a bright green colour. The algae inside the worms, as is their custom, are busy with photosynthesis and supply their hosts with food. As a result, the buccal orifice and the alimentary tract become unnecessary for these worms and atrophy. Thus, among animals there are those that feed as plants, while among the plants there are such that feed up in the way animals do. But, naturally, these are the rarest exceptions.

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* F.B. Golley, "Impact of small mammals on primary production." In: "*Ecological Energetics of Homeotherms*" (ed. J.A. Gessaman), US University Press, 1973.

Thus, metazoans in the biosphere are its transportation means, control panel, conditioner, and sanitation means. Evidently, it is not accidental that the number of their species is one million and three hundred thousand...

Do you remember the butterfly from Ray Bradbury's novel "A Sound of Thunder", that very butterfly that changed the course of history? The famous American science-fiction writer did not exaggerate its importance. The biosphere is a finely balanced system, and there is nothing superfluous and insignificant in it. Both, "an exquisite thing, a small thing that could upset balances", created in the imagination of Ray Bradbury and "the heavy body of a cow" from Zabolotsky's poem find their place "on the map of the living of the whole world".

I should like to conclude the chapter about the living matter of the biosphere with the words of Vernadsky: "Living matter has always, throughout geological time, been and remains to be an indissoluble regular constituent of the biosphere, a source of energy entrained by it from solar radiations, the matter which is in the active state, which has the main influence on the course and direction of the geochemical processes of the chemical elements in the entire earth's crust."*

In the next chapter we shall consider the work performed by living matter in the biosphere.

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* V.I. Vernadsky, *Works*, v. 1, p. 217.

3 Most Powerful Geological Force

"It is impossible to understand the history of sedimentary rocks without taking into account the powerful influence of organisms on the migration of substances in the earth's crust and on the formation of sediments."

L. S. Berg, 1944

The work of living matter in the biosphere is quite diverse; for a better understanding of the result of this work, some geological concepts should be defined first.

Geologists subdivide the process of formation of sedimentary rocks into four stages. The first of these, the stage of hypergenesis, is, as it were, preparatory: during this period initial products are formed, which are later transformed into sedimentary rocks. During the second stage, the stage of sedimentogenesis, there takes place the transfer of matter and the formation of friable noncemented sediments: sands, clays, coquina, silts, peat, etc. The third stage is called diagenesis. During this period friable, often loose sediments are transformed into dense strongly cemented rocks: sandstones, argillites, limestones, fossil coals. Finally, at the fourth stage, which is called katagenesis, there take place further densification and transformation of the sedimentary rocks. As we shall see later,

Product of biogenic migration of the 2nd kind: a termite nest over 6 m high. North Australia.

living matter plays the most important, even decisive role in the stages of hypergenesis, sedimentogenesis and diagenesis.

According to Vernadsky, the work of living matter in the biosphere may be manifested in two main forms: (a)chemical (biochemical) – the first kind of geological activity; (b)mechanical – the second kind of such activity.

The geological activity of the first kind – construction of the body of organisms and digestion of food – is, naturally, more important. The functional definition of life, given by Friedrich Engels, has become classical: "Life is the mode of existence of protein bodies, the essential element of which consists in *continual metabolic interchange with the natural environment outside them,* life ending with the ending of this metabolic interchange" * (italics are Engels'.– *A. L.*).

Charles Darwin (1809-1882).

In actual fact, continual metabolic interchange between the living organism and the environment outside it conditions the manifestations of the majority of functions of living matter in the biosphere. According to the calculations of a biologist, during the lifetime of a man 75 tons of water, 17 tons of carbohydrates, 2.5 tons of proteins, and 1.3 tons of fats pass through his body. Meanwhile, in terms of the geochemical effect of his physiological activity man is far from being the most important kind of living matter in the biosphere. The geochemical effect of the physiological activity of organisms is in inverse proportion to their sizes, and the activity of

* K. Marx and F. Engels, *Works*, v. 20, p. 616.

procaryotes – bacteria and Cyanophyceae – proves to be the most significant.

The quantity of substance passed through the organism is also of great importance. In this respect the maximum geochemical effect on land is by soil-eaters and in the oceans, by mud-eaters and filtre-feeding organisms. Charles Darwin* calculated that the layer of excrement excreted by earthworms on the fertile soils of England was about 5 mm a year! Hence, earthworms pass the entire 1 m thick soil stratum through their intestines during 200 years. In ocean polychaetes, representatives of the same phylum of annelid worms, close relatives of the earthworms, compete with the latter in their "throughput capacity"; others in the competition are crustaceans. It is sufficient to have 40 polychaetes per square metre for the surface layer of bottom sediments, with a thickness of 20 to 30 cm, to pass annually through their intestines (in this case the substrate is substantially enriched with calcium, iron, magnesium, potassium and phosphorus, compared with the initial muds). This is far from being the limit. The Dutch scientist G. S. Cadèe** compiled a cumulative table illustrating the depth of reworking of bottom sediments by bentos animals. From this table it follows that on the Californian coast living organisms annually rework up to 1.5 m of sediments!

Coprolites are known in geological deposits starting from the Ordovician, but it is beyond doubt that most of them are not taken into account in geological descriptions. This is because of the inadequate study of the problem and because of the absence of diagnostic features for the determination of coprolites.

At the same time, in the bottom sediments of modern water bodies fecal lumps of invertebrates are quite widespread and often constitute the main component of the sediment. In the South Atlantic, for example, oozes are almost completely composed of the feces of planktonic crustaceans, and along the shores of the North Sea the bottom sediments formed by the feces of mussels are up to 8 m thick.

Biogenic migration of the atoms of the second kind, i.e. mechanical, is definitely manifest in land ecosystems with a well developed soil cover which allows animals to make deep

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* Ch. Darwin, *The Formation of Vegetable Mould Through the Action of Worms*, Murray, London, 1881, 326 pp. and other editions.

** G. S. Cadèe, "Sediment reworking by *Arenicola marina* on tidal flats in the Dutch Wadden Sea", *Netherl. J. Sea Research*, 1976, v. 10, 4, pp. 440-460.

shelters. Owing to the mounds made by burrowing animals primary unweathered minerals get into the upper layers of the soil and, upon decomposition, are involved in the biotic cycle. The outstanding Soviet zoologist A. N. Formosov* (1899-1973) was one of the first to point this out. And the American geologist M. Chaffrey noted that termites and ants may become good assistants of geologists: it will be necessary only to investigate the dump wastes around their "mines", which sometimes reach 70 metres!

The concepts of a "burrow" and of a "nest" are usually associated in our mind with rodents and birds. Meanwhile, biogenic migration of the atoms of the second kind is widespread not only on land, but also in marine ecosystems, and its role in the latter may prove to be even more considerable. Organisms make shelters for themselves on the sea bottom as well, and not only in the soft, but also in rocky ground. Oligochaete and polychaete burrow as deep as 40 cm and more. Bivalve mollusks usually bury themselves to a small depth, but some of them, namely, Solemydae and Mya, dig burrows, such that even a marmot would envy: they reach a depth of several metres. Alas, in the tidal zone and in the sand washed through by waves neither a burrow can be dug, nor a nest can be built. The only alternative is to bore rocky formations. And such boring jobs are indeed performed. They are tackled by algae and sponges, by bacteria and mollusks, by polychaete, sea urchins and small crustaceans** - ***...

Borers appeared in the remote geologic past. Formations bored by them are found even in Pre-Cambrian deposits; they are continuing their destructive work even now. The boring activity of pholads (mollusks of the family Pholadidae) sometimes brings about catastrophic results. When recently in the region of Sochi an ill-thought out project caused the share to be denuded of pebbles, the shore started retreating at a rate of 4 m a year. The main perpetrators of the destruction were pholads: they had occupied every metre of the rocky shore

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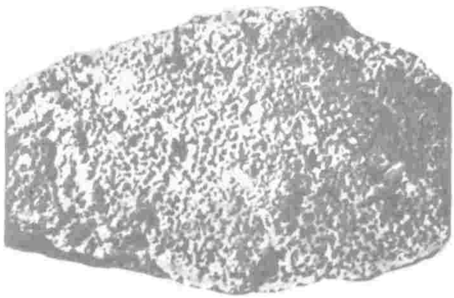
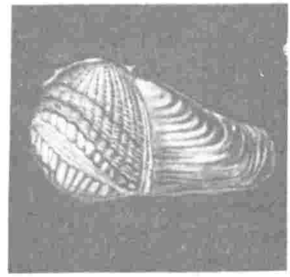
* A. N. Formosov, "Mammalia in the steppe biocenose", *Ecology*, 1928, v. 9, 4, pp. 449-460.

** J. E. Warme, "Boring as trace fossils, and the processes of marine bioerosion". In: "*The Study of Trace Fossils*" (ed. R. W. Frey), Springer, Berlin a.o., 1975, pp. 181-227.

*** R. G. Bromley, "Borings as trace fossils and *Entobia cretacia Portlock*, as an example". In: "*Trace Fossils*" (ed. T. P. Crimes, J. C. Harper). Seel House Press, Liverpool, 1970, pp. 49-90.



Traces of boring of Devonian limestone by the sea worm Trypanites. Slightly magnified.



Pholad or "sea borer" - an active borer of sea coasts.

composed of clay shales and all set to bore underwater burrows. Fortunately, a way was found to live with the pholads: the shore was reinforced with the aid of transverse partitions, the space between the partitions being filled with pebbles. As a result, the borers were destroyed: the pebbles moving under the impact of the waves crushed and ground them. In Western Europe a not less dangerous activity is carried out by the woolly-handed crab, which was casually brought from China: it has got into many rivers and, when building its burrows, it undermines the banks and destroys dams.

Movement of living matter as such can be regarded as biogenic migration of the second kind. Seasonal migrations of birds, movements of animals in search of food, mass migrations of animals are forms of such movement. Naturally, all these diverse forms of motion of living matter cause transportation of nonbiogenic substance as well.

As we have seen, Vernadsky classified the processes carried out in the biosphere by living matter according to the character of the processes themselves. N. A. Andrusov, Vladimir Ivanovich's contemporary, approached this problem in a somewhat different manner. In his work which we have already referred to he wrote: "The chemical activity of the organism in general, having a geological importance, can be reduced to two categories: first, to the formation of preservable secretions on the external surface or inside; second, to the formation of liquid and gaseous secretions, capable of entering into various chemical reactions with the surrounding inorganic world". As a matter of fact, the

Table 3

CHARACTER AND LOCALIZATION OF PROCESSES CARRIED OUT BY LIVING MATTER

Kind of geological activity	Process occurs: / Character of process	within the organism	outside of the organism
I	Chemical (biochemical)	Digestion of food, construction of body of organism	Secretion of metabolic products and excreta into external environment; extracellular digestion
II	Mechanical	Passing of inorganic components of food through alimentary tract of soil- and mud-eaters	(a) Movement of living matter as such (as a consequence, transportation of biogenic substance); (b) transfer of nonliving matter by organisms in the course of activity

same idea on the basis of present-day data was developed by the microbiologist T. V. Aristovskaya. She has pointed out that migration of the atoms of chemical elements can be both a direct and an indirect result of the vital activity of organisms (first of all, of bacteria). In Table 3 the classification approaches of Vernadsky (horizontal rows) are combined with those of Andrusov–Aristovskaya (vertical columns). For an understanding of the work performed by living matter in the biosphere, three basic statements, which Vladimir Ivanovich called "biogeochemical principles", are of great importance.

In the formulation of V. I. Vernadsky* these principles are as follows:

Principle I: "Biogenic migration of the atoms of chemical elements in the biosphere always tends to its maximum manifestation".

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* V. I. Vernadsky, *The Chemical Structure of the Earth's Biosphere and of Its Surroundings*, Nauka Publishers, Moscow, 1965, pp. 283, 286; *Biogeochemical Essays*, AN SSSR Press, Moscow-Leningrad, 1940, p. 185.

Principle II: "The evolution of species in the course of geological time, leading to the creation of life forms that are stable in the biosphere, proceeds in a direction which increases the biogenic migration of the atoms of the biosphere" (or, in another wording: "In the evolution of species those organisms survive, which by their life increase the biogenic geochemical energy").

Principle III: "During the entire geological time, since the Cryptozoic *, the population of the planet had to be the maximum possible for the entire living matter then existing".

For Vernadsky Biogeochemical Principle I is closely associated with the capability of living matter for unlimited proliferation under optimal conditions. "The whirl of atoms", which is life, according to the definition given by Georges Cuvier, tends to unlimited expansion. The consequence of this is the maximum manifestation of the biogenic migration of atoms in the biosphere.

Biogeochemical Principle II, eventually, touches upon the cardinal problem of modern biological theory: the question about the purposeful character of the evolution of organisms. Vernadsky entertained the idea that in the course of evolution advantages are obtained by those organisms which have acquired an ability to assimilate new forms of energy or "learned" to utilise the chemical energy stored in other organisms. Thus, in the course of biological evolution the "efficiency" of the biosphere as a whole increases. This has been recently demonstrated in purely mathematical terms by V.V. Alexeyev who, proceeding from calculations, came to the following conclusion: "Evolution must develop in the direction of an increase in the matter exchange rate in the system." And further: "It becomes clear why enzymes were formed, whose role resides in drastically increasing the rates of reactions that are extremely slow under usual conditions".

Biochemical Principle II of Vernadsky is confirmed by the most diverse empirical material. Thus, in 1956 the soil scientist V.A. Kovda **, now Corresponding Member of the USSR Academy of Sciences, reported the results of chemical investigation of more than 1,300 samples of ash of modern

* The Cryptozoic period is the term suggested by the American geologist Ch. Schuhert (1858-1942) for "the era of latent life" (i.e. the pre-Cambrian period).

** V.A. Kovda, "Mineral composition of plants and soil formation", *Soil Science*, 1956, 1, pp. 6-38.

higher plants. On the basis of this extensive factual material the author came to the conclusion that (with a few exceptions) the ash content of plants increases from representatives of ancient taxons towards younger ones. This regularity is one of the particular manifestations of Biogeochemical Principle II. Generally, however, its manifestations in the biosphere are quite diverse and rather unexpected. Let us consider another example from botany.

The Soviet botanist A. P. Khokhryakov *, recently established the evolution of higher plants to have a specific tenor, residing in an intensification of changes of the organs in the course of the individual development of the organism. Thus, in the opinion of A. P. Khokhryakov, in lepidodendrons (arborescent club mosses) only a part of the leaves was subject to the change. In more evolutionarily advanced plants, pteridophytes, only the leaves are subject to shedding as well, but in this case a greater part of the leaves is changed per unit of time with respect to the mass of the entire body than in the case of lepidodendrons. In most primitive gymnospermous plants, cycads, only the leaves undergo changes, with the exception of their bases. In conifers the branches and bark are changed periodically. Finally, on the example of flowering plants the transition from perennial forms (trees and shrubs) to annual forms (herbs) can be seen most definitely. The same transition is observed also in other taxons of higher plants: among ancient horsetails and club mosses arborescent forms were predominant, while present-day horsetails and club mosses are herbs; in the geological past there were many arborescent forms among ferns, while now arborescent ferns are dying out. Such intensification of the changes, naturally, brings about an enhancement of the biogenic migration of atoms in the biosphere. Principle II is "at work" here as well ... True, conifers for some reason do not want to become herbs, while mosses, on the contrary, have never been trees.

A. P. Khokhryakov, being a botanist, considered only plants; Professor Alexander Ilyich Perelman, a prominent Soviet geochemist, has given a more extensive treatment of the problem of the purposeful character of evolution **. He has

* A. P. Khokhryakov, *Regularities of the Evolution of Plants*, Nauka Publishers, Novosibirsk, 1975, p. 204.

** A. I. Perelman, *Geochemistry of the Biosphere*, Nauka Publishers, Moscow, 1973, p. 168.

calculated that in terms of the ratio of the logarithms of annual production to the "instantaneous biomass" of living matter (coefficient "K") contemporary ecosystems make up the following series:

1. Taiga landscapes (0.54-0.55);
2. Landscapes of humid deciduous forests:
   (a) of the moderate belt (0.59-0.62);
   (b) of the subtropical belt (0.66);
   (c) of the tropical belt (0.68);
3. Herbal landscapes (0.83-0.95).

It may be supposed that this is an "evolutionary series" of landscapes and that now disappeared landscapes had a value of "K" smaller than 0.5.

Finally, Biogeochemical Principle III is also associated with the "omnipresence" or "pressure" of life. This factor ensures the endless capture by living matter of any territory suitable for the normal functioning of living organisms.

Some decades ago many paleontologists believed that the expansion of life over the globe proceeded very slowly.

It was thought, for example, that land plants in the Carboniferous and even in the Permian period had been spread mainly on marshy coastal plains, and that drought-resistant vegetation formed only in the Cenozoic period. These conceptions were recently shown to be erroneous by a detailed analysis carried out by the Soviet paleobotanist S. V. Meien. In his opinion, the presence of a developed vegetative cover on continents is proved not only by numerous findings of plants in Paleozoic continental deposits. Facies analysis has shown that the sedimentation conditions which existed at that time principally did not differ from those existing to-day. Meanwhile, if land vegetation did not exist, the character of the drain from the continents would be quite different than that observed now.

Did the progressive expansion of life take place at all in the course of geological history? Vernadsky considered that there was not sufficient factual material to give an unequivocal answer to this question. He wrote: "Life penetrates everywhere where it did not exist before, but we cannot assert that these were areas of the planet actually always free from life, never occupied in other geological times. It appears possible that these areas free from life were formed in the nearest geological epochs, and we observe merely the mastering by new forms of life of those areas from which the old living matter had disappeared for some reason or other. This may be so for cave life, for example. But an assumption may also be made that here we see a real expansion of the area of life as well, there having been a long-term evolution of the organisms adapting to new conditions. It seems to me that otherwise it is difficult to explain with confidence the adaptation of deep-dwelling organisms living at a depth exceeding 6 km, though it cannot be regarded as proved."* It cannot be regarded as proved even now.

What are the functions of living matter in the biosphere? According to Vernadsky** there are nine such functions: (a)gas function; (b)oxygen function; (c)oxidation function; (d)calcium function; (e)reduction function; (f)concentration function; (g)function of destruction of organic compounds; (h)function of reducing decomposition; (i)function of metabolism and respiration of organisms.

In a modern manual "Principles of Sedimentology"*** the following biological processes having geological significance are distinguished: (1)metabolism of organisms, leading to the formation of skeletons from calcium carbonate; (2)subsequent destruction of these skeletons by predators and other destroyers, which leads to the formation of various forms of skeletal detritus; (3)precipitation of lime mud by the organisms; (4)its pelletisation by organisms; (5)burrowing activity of the organisms and mixing of the sediments by them; (6)activity of microorganisms effecting various chemical reactions contributing to the formation of minerals.

Summarizing all the available information concerning the activity of living matter, we can single out 5 main functions of living matter in the biosphere (Table 4).

The energetic function manifests itself in the assimilation of energy, mainly of solar energy. "Only life with its morphological sophistication could capture the sun's rays on earth for millions of years, as we see it with coal," said Academician V.L. Komarov at the I Congress of Soviet botanists in 1921. Indeed, only due to the "green shield" of the biosphere, to photoautotrophs, is solar energy not merely reflected from the

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* V.I. Vernadsky, *The Chemical Structure of the Earth's Biosphere and of Its Surroundings*, Nauka Publishers, Moscow, 1965, p. 284.

** W. Vernadsky, "Sur les conditions de l'apparition de la vie sur la Terre", *Rev. gén. sci.*, 1932, t. 43, 17-18, pp. 503-514.

*** G.M. Friedman, J.E. Sanders, *Principles of Sedimentology*, Wiley, N.Y., 1978, p. 120.

Table 4

MAIN FUNCTIONS OF LIVING MATTER IN THE BIOSPHERE

	Function	Brief characteristics of process
1	Energetic	Absorption of solar energy in photosynthesis and of chemical energy through decomposition of energy-saturated substances; transfer of energy via the food chain of heterogeneous living matter
2	Concentration	Selective accumulation in the course of vital activity of definite kinds of substance: (a) employed for building of the organism body; (b) removed from it during metabolism
3	Destructive	(1) Mineralization of neobiogenic organic matter; (2) Decomposition of nonliving inorganic matter; (3) Implications of the formed matter in biotic cycle
4	Medium-forming	Transformation of the physicochemical parameters of the medium (mainly due to neobiogenic matter)
5	Transportation	Transfer of matter against the force of gravity and in a horizontal direction

surface of the planet, heating only its superficial layer, but penetrates deep into the earth's crust and is a source of energy for practically all exogenous processes (we have already spoken about this in Chapter One). This aspect of the activity of living matter was formulated most concretely by G. V. Gegamian: "The energy balance of the planet (i. e. of the Earth – *A. L.*) as of a cosmic system depends on living matter."*

The supply of geological processes with energy through the activity of living matter is most clearly manifest at the stage of diagenesis.

Interesting work on this problem was carried out in the period from the twenties to the thirties by Professor Perfiliev.

Ingenious experiments proving the biogenic nature of diagenetic processes were carried out by M. M. Yermolayev**,

* G. V. Gegamian, "On the Biospherology of V. I. Vernadsky", *Journal of General Biology*, 1980, v. 41, 4, p. 588.

** M. M. Yermolayev, "On the lithogenesis of plastic clayey marine sediments", *Izv. AN SSSR*, geol. series, 1948, 1, pp. 121-138.

the author of the above-cited manual of physical geography, now Professor of Kaliningrad University.

A sample of ground taken from the sea bottom was placed in an undisturbed state into a glass tube. Two zones were clearly observable in the sample: an upper oxidized zone and a lower reduced zone. Then the tube was sealed off at its upper end and turned upside down. The lower layer of the ground was thus found at the top. The tube was filled with water, and the water was changed every day during a period of 17 months. The result was a complete "reversal" of the ground sample: the oxidized horizon lying at the bottom became reduced, and the formerly reduced horizon became oxidized. Yermolayev explained this phenomenon by migration of the anaerobic and aerobic bacterial complexes.

To make sure that the character of the redox process was biogenic, a second series of experiments was carried out. A sample of strongly reduced ground from the Laptev Sea was divided into two parts. One of these parts was kept in its initial state under a layer of water in a vessel; the other part was placed into another vessel, and the microflora in it was destroyed by means of an antiseptic. After definite intervals of time the ratio of trivalent iron to bivalent iron was measured in both vessels as a characteristic of the intensity of redox processes. In eight days this ratio in both vessels increased 1.5 times. During the subsequent 40 days the measured characteristic in the vessel with the antiseptic remained unchanged, while in the control vessel it increased by as much as 8 times! This was a direct proof of the oxidation being effected by the microflora (in the vessel with the destroyed microflora the oxidation during the first eight days of the experiment proceeded under the action of enzymes).

In the course of diagenesis microorganisms carry out hundreds of various reactions. Some of the microorganisms in bottom sediments are chemoautotrophs and exist at the expense of energy-saturated inorganic compounds. In the main, however, the microflora of bottom sediments work on biogenic fuel, namely, on detritus coming from the upper levels of the water mass.

The essence of the energetic function of living matter in the biosphere can be formulated in the words of Vladimir Ivanovich: "Within a limited defined area, clearly separated from other parts of the planet, within a specific Earth envelope constituted by the biosphere characterised by irreversible processes, life will increase over time, rather than diminish, the free energy of this envelope." *

The second main function performed by living matter in the biosphere is that of concentration. The substance being concentrated is either employed for the building of the soft body and the skeleton of the organisms, or excreted into the environment.

The concentration of matter occurs in two ways. The most widespread case is the concentration of elements in ionic form from true solutions. Most marine invertebrates build their skeletons in this way. The second case is sedimentation of substance from colloidal solutions by filtering organisms.

Yakov Vladimirovich Samoilov.

The problem of the concentration of elements by living matter from true solutions was intensively elaborated by the outstanding Russian mineralogist, Vernadsky's disciple and companion-in-arms, Professor Yakov Vladimirovich Samoilov (1870-1925). Unlike his great teacher, Samoilov approached this problem mineralogically rather than geochemically. There was rather little factual material at the beginning of the century, and sometimes one had to be guided by intuition. Samoilov's intuition did not fail him. In 1910 in an article concerning barite deposits Samoilov wrote: "We think it appropriate to pose the question... of the possibility of there being some organisms containing barium in their shell, and, consequently, about the possibility of concentrations of this element occurring by virtue of the vital activity of the known organisms...." **

At that time there were no data about the finding of barium in the composition of marine organisms. But in the same year of 1910 the book "Investigation of Lower Organisms" by A. Shchepotiev was published, in which barite crystals found in

* V. I. Vernadsky, "On some fundamental problems of biogeochemistry", *Transactions BIOGEL* 1939, Issue 5, p. 12.

** Ya. V. Samoilov, *Bioliths*. Sci. chem.-techn. Publishing House, Leningrad, 1929, p. 33.

plankters, namely, in rhizopods, were described! The supposition made by Ya. V. Samoilov was dramatically confirmed.

Now it is established that the ability of concentrating elements from rather dilute solutions is a characteristic feature of living matter. It is known that in the contemporary biosphere organisms extract masses of calcium carbonates, magnesium carbonates and strontium carbonates, silica, phosphates, iodine, fluorine, and other components from undersaturated solutions. Bacteria prove to be most energetic agents in this respect. The well-known microbiologist W. E. Krumbein* showed that in the products of the vital activity of definite species of microorganisms, as compared with the environment, the content of manganese is 1,200,000 times higher, the content of iron is 650,000 times higher, that of vanadium is 420,000 times higher, of silver, 240,000 times higher, etc. But even bacteria do not create minerals "from nothing". This specific feature of living matter was formulated by the Soviet geologist A. V. Khabakov by the following aphorism: "Bacteria are not autocratic creators of mineral deposits, but their natural concentration specialists."

Metazoans act in a simpler way: they do not spend energy for concentrating the elements they need from the environment, but consume them from the living matter of autotrophs. "It is as if a two-stage accumulation is effected here," writes Ya. V. Samoilov. "A chemical element, rather finely dispersed in the environment is absorbed by the plant and, at least in a small quantity, becomes accumulated in it; then in the body of the animal consuming appropriate food there takes place apparent accumulation of the definite chemical element."** Owing to this the concentration of many elements (sodium, calcium, phosphorus, nitrogen, fluorine, chlorine, zinc, and others) in living matter of heterotrophs is higher than in the living matter of autotrophs.

Protein metabolism in animals results in many nitrogen-containing substances being excreted into the environment; the content of phosphorus in such excretion products is also enhanced. Some other elements, passing along the food chain from one level to another, may be concentrated in the excretion products of animals and thus become

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* W. E. Krumbein, "Geomikrobiologische Prozesse bei der Anreicherung nutzbarer Minerale und sedimentärer Lagerstätten", *Erdöl und Kohle, Ergas, Petrochemie*, 1978, Jg. 31, H. 3, SS. 147-151.

** Ya. V. Samoilov, *Op. cit.*, p. 101.

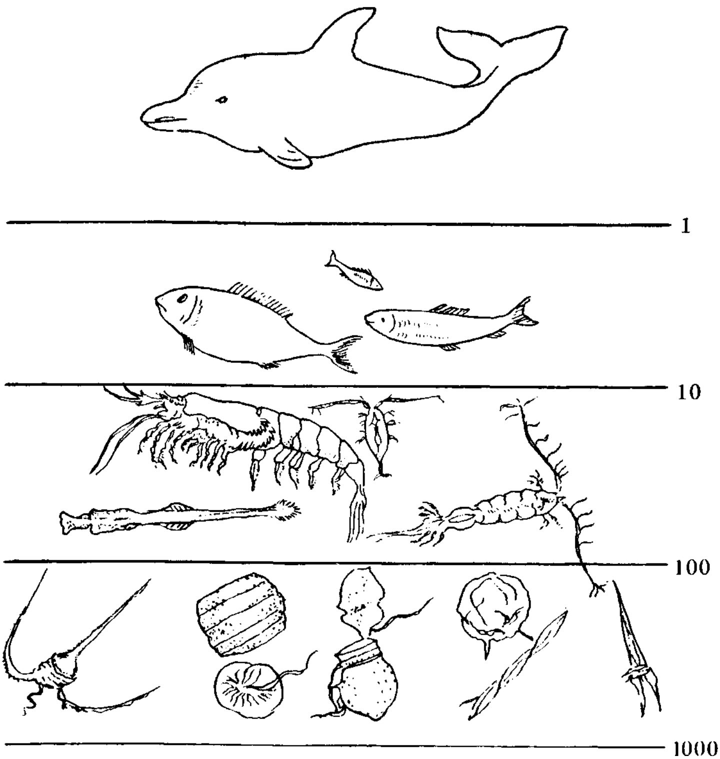

Fig. 4. Ecological pyramid of marine ecosystems (figures illustrate losses of energy with a transition from the lower to the higher-lying trophic levels)

accumulated in neobiogenic matter. An example of such an element is uranium: its content in the guano on the ocean coast of Peru is 10 thousand times higher than in the sea water (Fig. 5).

In contrast to animals, higher plants prefer building the bearing mechanism of their body from organic compounds, mainly from lignin. Plants feature a significant percentage of mineral substances in a dispersed state: the average ash content in contemporary plants ranges from 1.5 to 5%.

Vernadsky classified living organisms into four groups according to the concentration of chemical elements in them.

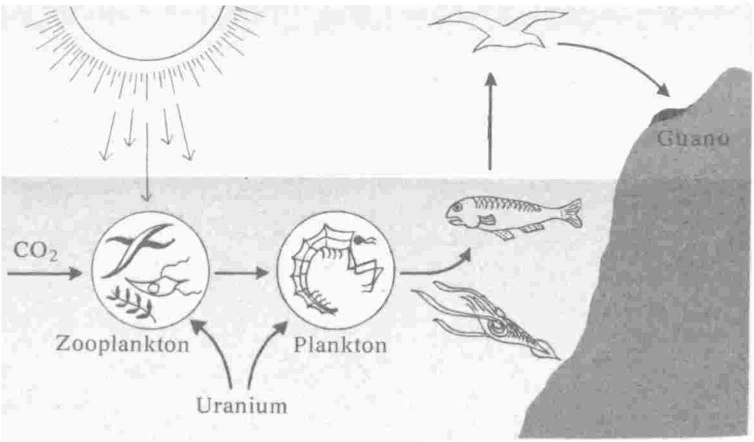

Fig. 5. Diagram of food chain in the ocean, illustrating the possibility of uranium concentration in guano deposits (after Polikarpov, 1976)

The first group – "organisms of some element" – included organisms concentrating a given element in the quantity of 10% and higher. There exist, for instance, siliceous organisms (diatoms, radiolarians, silisponges), calcium organisms (bacteria, algae, protozoans, mollusks, brachiopods, echinoderms, bryozoans and corals), iron organisms (iron bacteria), and so on.

The second group – "organisms rich in some element" – included organisms containing a given element in quantities of about 1% and higher (up to 10%). The content of these elements in the first two groups must be higher than the clarke* of the given element. The third group is constituted by "usual organisms", the fourth group, by "organisms low in a given element".

The prominent Norwegian scientist, one of the founders of geochemistry, Professor Victor Moritz Goldschmidt (1888-1947) treated this problem in a somewhat different fashion. In his geochemical classification of chemical elements Goldschmidt singled out a specific group of biophilic elements, in which he included carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, chlorine, and iodine. Along the same lines, Academician B. B. Polynov in 1948 suggested that a group of

* Clarke of the lithosphere – a unit of the average abundance of an element in the Earth's crust (named after the American geochemist F. W. Clarke).

elements-organogens should be singled out and subdivided into: (a)absolute organogens without which the existence of organisms is utterly impossible (hydrogen, carbon, oxygen, nitrogen, phosphorus, sulphur, potassium, magnesium) and (b)special organogens, necessary for many organisms but not obligatory for all. Eight years later V. A. Kovda in the already cited article added the other six elements to the absolute organogens: iodine, boron, calcium, iron, copper, and cobalt. Further on the number of organogens grew steadily, and it has now been established that if one takes into account those elements which are contained in small quantities, all the elements of Mendeleyev's Table enter into the composition of living matter. Some elements are concentrated by very few organisms, but their content in these organisms can be rather significant. Thus, radiolarians (a subclass of the protozoan class), as a rule, build their skeleton from amorphous silicon. But one of the families, Acantharia, prefer using a less common element, strontium, for the purpose. A still rare element in the marine medium, vanadium, is found in the blood of representatives of most primitive chordates: ascidians, whose content of vanadium pentoxide reaches 15%. For obtaining vanadium ascidians are at present even cultivated in the coastal waters of Japan: the ascidians are sessile forms and one need not catch them. In New Zealand a shrub has been found recently, in whose dried leaves up to 1% of nickel is contained. Actually, these leaves are not a poor nickel ore: even poorer ores are mined nowadays. Yet, until quite recently nobody would even have thought of including nickel in group of organogens.

Academician A. P. Vinogradov distinguished two types of concentrations of chemical elements by living matter.

I. Mass increase of the content of a given element in a definite medium. For example, there is much sulphur and iron in living matter in volcanic regions; the flora of zinc, copper and other ore deposits is enriched with corresponding metals; the content of boron, copper, iron, manganese, barium and rubidium in calcareous tests is determined by the salinity of water.

II. Specific concentration of this or that element by organisms irrespective of the medium (examples of such specific concentrations have already been given above).

Recently research fellows of the Far Eastern Research Centre of the USSR Academy of Sciences, G. N. Sayenko, M. D. Kobryakova, V. F. Makienko and I. G. Dobromyslova disclosed a principally new phenomenon: organisms concentrate not one particular element from the medium, but a whole group of elements, usually consisting of 4 to 7 elements.

For the biosphere as a whole it is customary to speak about the *biophilicity* of elements: the ratio of their average content in living matter to the clarke of a given element in the lithosphere. Carbon is characterised by maximum biophilicity; nitrogen and hydrogen are less biophilic.

The concentration of chemical elements by living matter can manifest itself in two principally different forms: as morphologically shaped mineral formations and organo-mineral compounds.

Mineral formations that became part of the body of living organisms are the product of secretion by special glands. As early as in the thirties A. P. Vinogradov recognised four main series of the mineral composition of the skeletons of living organisms: (a) carbonate; (b) phosphate; (c) sulphate; (d) formed by hydrates, hydroxides and silicates. In recent decades a considerable contribution to the investigation of this problem was made by Heinz A. Lowenstam, an outstanding scientist who was forced to leave his native Germany in the days of fascism and is now working in the United States. He is well known for his contribution to the study of the biomineralisation phenomenon, to the investigation of fossil reefs, and to the study of the paleotemperatures of ancient basins using oxygen isotopic analysis data. Professor Lowenstam showed that living matter in the course of vital activity, processes to form crystals of the usual shapes described in crystallography. Geologists, however, when they find crystals of some mineral in sedimentary mass, consider them to have been formed abiogenically.

In living matter crystals may be encountered singly (as in the above-mentioned case with barite in rhizopods). But more often these crystals in the form of aggregates make up the external or internal skeleton of living organisms. Everybody well knows what an internal skeleton is; an external skeleton is a housing with the aid of which an organism protects itself from the external medium. Examples of such external skeletons are calcareous tests of mollusks, corneous carapaces and plastrons of turtles, crabs and some ancient fish. The external skeleton is particularly popular with protozoans, especially plankters. Not only animals from the subkingdom of protozoans, but many algae are also keen on it. The shape of the carapace can be rather diverse, and as to its material, many years of experience (amounting to hundreds of millions of years) have proved amorphous silica (preferred by most primitive organisms, such as unicellular algae, protozoans and sponges) and calcium carbonate to be most suitable for the purpose. Some organisms, however, prefer sulphates and the animals most advanced evolutionally, phosphates.

Higher plants have no skeleton, and their mineral component is represented by so-called "phytoliths"-secretion products in the form of crystals or rounded inclusions. These phytoliths consist of inorganic matter (silica) or of organomineral matter (calcium oxalate). Some multicellular algae, in contrast to higher plants and similarly to animals, prefer "props" from calcium carbonate.

H. A. Lowenstam* compiled a table illustrating the distribution of minerals in the composition of nonuniform living matter (Table 5).. It turned out that low-organised organisms secrete only one mineral, though different species, orders and classes can secrete different minerals. In animals with a more complicated organisation the skeleton may be composed of two minerals, and sometimes a third mineral may also be represented in their body. Thus, the shells of mollusks from the family Patellacea are composed of aragonite and calcite, and their masticatory apparatus (radula) is encrusted with crystals of goethite (iron hydroxide). Unlike man, mollusks do not get a set of iron teeth made by the dentist: they have it from the cradle, made by nature.

Chordate mollusks form the greatest number of minerals (as can be clearly seen from the Table), while some algae (diatoms, green algae and brown algae) synthesize only one mineral each.

Most mineral formations which enter into the composition of living matter are poorly soluble in sea water, and therefore, after the organisms die away, these formations accumulate in sediments (certainly, there are exceptions to this rule). The concentration of the elements in the organomineral compounds is of secondary importance for the sedimentation, since after the death of organisms such compounds rapidly decompose, and metals from the neobiogenic substance rapidly return to the biotic cycle.

Living matter, performing the concentration function in the biosphere, may play a significant role at the stage of

* H. A. Lowenstam, "Impact of life on chemical and physical processes". In: "*The Sea, v. 5, Marine Chemistry*" (ed. M. N. Hill). Wiley, N. Y., 1974, pp. 715-796.

	Minerals	Bacteria	Algae: Diatoms	Algae: Green	Algae: Red	Algae: Brown	Algae: Yellow-green (coccolithophorids)
Carbonates	Calcite	?			+		+
	Aragonite	+		+	+	+	
	Calcite and aragonite						
	Vaterite						?
	Calcite, monohydrate						
	Amorphous calcium carbonate						
Phosphates	Dahllite						
	Francolite						
	Amorphous hydrogel of calcium phosphate						
	Amorphous hydrogel of iron phosphate						
Silica	Opal		+				
Iron oxides and hydroxides	Magnetite						
	Goethite						
	Lepidocrocite						
	Amorphous iron hydroxides						
Sulphates	Celestine						
	Barite						
	Gypsum						
Halides	Fluorite						

(AFTER H.A. LOWENSTAM, 1974)

Protozoa	Sponges	Coelenterata	Bryozoa	Brachiopoda	Sipunculoidea	Annelida	Mollusks	Anthropoda	Echinoderms	Chordata
+	+	+	+	+		+	+	+	+	+
+	+	+	+		+	+	+	+		+
		+	+		+	+	+	+		+
										+
							+			+
		+				+	+	+		+
						+	+	?		+
				+			+			+
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sedimentogenesis. At present geologists have come to the conclusion that biofiltration is the main mechanism of the sedimentation of finely dispersed terrigenous material in pelagic zones.* Organisms, after having used nutrient elements, excrete the filtered substance in the form of fecal lumps. These lumps gradually decompose and therefore it is not always easy to recognise the role of living matter in the precipitation of colloidal particles.

The process of biofiltration accelerates the precipitation of colloidal particles by thousands of times. Many organisms are filtre-feeding ones, including crustaceans and worms. In shallow water the role of mussels is particularly important. These mollusks due to active filtration accumulate dozens of centimetres of ooze a year and bury themselves in the sediments. As early as 1948 the hydrobiologist K. A. Voskresensky drew a noteworthy conclusion: "The fact of the implication into benthic circulation of a water layer of considerable thickness in combination with active removal from it of suspended matter by the populated bottom requires a reconsideration of sedimentary differentiation processes. Stokes' law and its modifications which take into account only the regularities of mechanics, physics and chemistry are inadequate in the dynamic field where the biomasses of filtre-feeding organisms manifest themselves. In the region of the populated bottom relatively simple laws are cancelled out by higher biohydrological ones."** American scientists came to the same conclusion after having investigated the bottom fauna of the Florida Strait.***

By now the concentration function of living matter has been studied in sufficient detail. In Vernadsky's time the problem was mainly one of the degree of concentration of particular elements by various types of homogeneous living matter; at present information is available concerning their concentration by the heterogeneous living matter of various ecosystems.

E. A. Boichenko, D. Sci. (Biol.), Vernadsky's pupil and continuer

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* A. P. Lisitsin, "Terrigenous sedimentation, climatic zonation, and interaction of terrigenous and biogenous material in the ocean". *Lithol. a. Miner. Resour.*, 1977, v. 12, 6, pp. 617-632.

** K. A. Voskresensky, "The belt of biofiltration organisms as a biohydrological system of the sea", *Trans. State Oceanogr. Institute*, 1948, Issue 6 (18), p. 99.

*** R. N. Ginsburg, H. A. Lowenstam, "The influence of marine bottom communities on the depositional environment of sediment", *J. Geol.*, 1958, v. 66, 3, pp. 310-318.

Table 6

COMPARATIVE DATA ON PROVED RESERVES OF SOME CHEMICAL ELEMENTS AND ON THEIR ANNUAL ACCUMULATION BY LIVING MATTER (AFTER BOICHENKO *ET AL.*, 1968)

Element	Annual concentration in photosynthesis, t	World reserves of raw materials, t	Element	Annual concentration in photosynthesis, t	World reserves of raw materials, t
Carbon	10^{11}	10^{12}	Cobalt	10^5	10^6
Phosphorus	10^9	10^{10}	Nickel	10^6	10^7
Chromium	10^5	10^8	Copper	10^7	10^8
Manganese	10^7	10^8	Zinc	10^7	10^7
Iron	10^8	10^{11}	Molybdenum	10^5	10^6

of his cause, and her co-authors* have succeeded in estimating the order of the concentration function of plants for the biosphere as a whole and in comparing these data with the world reserves of particular raw materials (the figures are as for 1968) (Table 6). As can be seen from these figures, the vegetational cover of our planet annually concentrates mineral matter in amounts comparable to most of the elements with their reserves in the lithosphere, accumulated there during millions of years of geological history. I believe this to be the best illustration of the statement made by Vernadsky in 1935: "In the rapidity of concentration of solid substance from its scattered state, biogeochemical energy is probably the greatest force – in the sense of geological time – existing on our planet."**

The third main function of living matter in the biosphere, the destructive one, manifests itself at the stage of hypergenesis in the destruction of nonliving matter and its implication in the biotic cycle. This function is realised in the form of three continually occurring processes (see Table 4).

In the preceding chapters we have already discussed the multiple utilisation of the elements involved in the biotic cycle by living matter. The problem, however, lies in that living matter cannot employ the elements required in whatever form they may be: the organic constituent of neobiogenic matter must be decomposed into simple inorganic compounds, such as

* E. A. Boichenko, G. N. Saenko, T. M. Udelnova. "Variation in metal rations during the evolution of plants in the biosphere". In: *Recent Contribution to Geochemistry and Analytical Chemistry*", Wiley, N.Y., 1975, pp. 507-512.

** V. I. Vernadsky, *Works*, vol. 1, p. 535.

carbon dioxide gas, water, hydrogen sulphide, methane, ammonia, etc. As we know, a whole army of saprotrophs is busy with decomposing the dead organics.

Another aspect of the problem is the decomposition of nonliving organic matter by the living one. Decomposition of minerals under the action of microorganisms was established as early as the beginning of the twentieth century.* - ** It has now been shown that in the processes of decomposition of minerals various microflora take part, including algae, fungi, bacteria, and other organisms. As we have already mentioned at the beginning of this chapter, in marine ecosystems an important role is played by boring organisms. The first investigation on boring algae was published in 1902 by our fellow-countryman, later an academician, Georgi Adamovich Nadson (1867-1940). He showed that boring algae mostly inhabit carbonate rocks and play a considerable role in returning to the biological cycle not only calcium, but also other vitally important elements: magnesium and phosphorus.***

Georgi Adamovich Nadson.

Nadson's works did not generate interest among biologists or geologists at the beginning of this century. More than that: when I ordered the "Botanicheskiye Zapiski" ('Botanical Notes') of 1902 containing Nadson's paper at a library, the journal proved to have its pages uncut: nobody had bothered to read it in the course of three quarters of a century! Now Nadson's works have been republished, and, as German scientists have put it, "the characteristics of microorganisms as geological agents, given by Nadson, now begin to shine with a new light"****.

* J. Stoklasa, "Biochemische Kreislauf des Phosphat-ions in Boden", *Zbl. Bakteriol., Parasitenk., Infekt. und Hyg.*, Abt. 2, 1911, Bd. 29, H. 4.

** K. Bassalik, "Über Silikatzersetzung dürch Bodenbakterien", *Z. Gärungsphysiol.*, 1912, Bd. 2; 1913, Bd. 3.

*** G. A. Nadson, "Les algues perforantes, leur distribution et leur role dans la nature", *CR Acad. Sci.* (Paris), 1927, t. 184, pp. 1015-1017.

**** W. Schwartz, A. Müller, "Geomikrobiologie, Entwicklung und Stand eines neues Forschungsgebietes", *Erdöl u. Kohle*, 1953, Jg. 6, H. 9, SS. 523-527.

It has now been shown that the role of biogenic particulation of carbonates, carried out by other organisms, is also significant. Recently it was established that coral reefs (composed of calcium carbonate) are intensively grazed by some fish (e.g. by parrot fish) and sea urchins. These animals pass the bitten-off pieces of calcium carbonate through their alimentary tract and then excrete it as carbonate mud. It has been calculated* that in the region of the Virgin Islands sea urchins deposit several kilograms of finely particulated carbonates per square metre of the bottom in such a manner! Proceeding from this type of evidence, the Soviet lithologist I. V. Khvorova came to the conclusion that many ancient organogenic-detrital carbonate rocks also originated not because of the mechanical effect of waves on the sediment, but due to the crushing of shells by predatory and mud-eating animals.

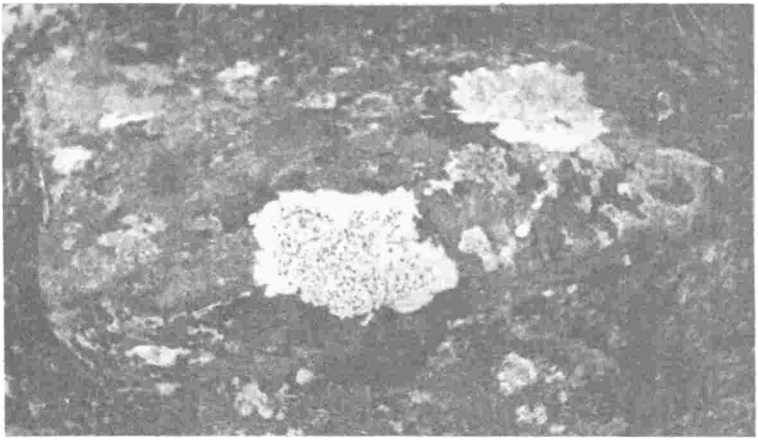
While carbonates are particulated by organisms largely owing to the mechanical activity of the organisms** (II kind of geological activity of living matter), in the decomposition of alumosilicates the I kind of such activity–chemical–is observed (we shall discuss the decomposition of alumina in Chapter Five). In general the chemical decomposition of various minerals under the action of living matter occurs in the biosphere on a tremendous scale.

As early as the beginning of the twentieth century the following experiment was carried out. Fourteen species of bacteria contained in the intestines of earthworms were sown on particulated rock-forming minerals. It turned out that the majority of the minerals had undergone biogenic decomposition, the degree of such decomposition depending on the kind of the bacteria and on the composition of the minerals. Alkali elements were the first to pass into solution; next were alkali-earth elements, as well as iron, silica and alumina. Mould fungus under laboratory conditions in a week liberates from basalt 3% of the silicon, 11% of the aluminium, 59% of the magnesium, and 64% of the iron contained in it.

The pioneers of life on the rocks–Cyanophyceae, bacteria, fungi and lichens–wage a real chemical war with rocks, using a rich arsenal of original weapons against them, including

* J.C. Ogden, "Carbonate-sediment production by parrot fish and sea urchins on Caribbean reefs". In: "*Reefs a. Relat. Carbon. Ecol. a. Sedimentology*", Tulsa, 1977, pp. 281-283.

** G.E. Farrow, J. Clokie, "Molluscian grazing of sublittoral algae-bored shells and the production of carbonate mud in the Firth of Clyde, Scotland", *Trans. Roy. Soc. Edin.*, 1979, v. 70, 5-9, pp. 139-148.



Lichen on rocky ground. Chukotka.

solutions of both inorganic acids – carbonic, nitric, sulphuric (up to 10% solution capable of burning-through paper!) and organic acids. Some higher plants also possess chemical weapon: for example, the roots of fir trees growing on soils poor in nutrients, secrete strong acids which decompose minerals of the abiogenic matter.

It can now be considered established that in the biosphere there takes place biogenic chemical decomposition of kaolin, serpentine, nepheline, muscovite, biotite, albite, apatite, and many other minerals.

By decomposing minerals of one or another kind, organisms selectively extract calcium, potassium, sodium, phosphorus, silicon, as well as many microelements from them (thus involving these elements in the biological cycle). For instance, elephant grass in the African savannas annually extracts from one hectare of soil 250 kg of silica and 80 kg of alkalies and alkali earths; jungles extract from the same area as much as 9 tons of silica! The process of involving the chemical elements in the biological cycle occurs everywhere in the biosphere. Bacteria act even in such toxic circumstances (from man's point of view) as the oxidation zone of sulphide deposits of copper, antimony, molybdenum, which is of great ore-forming importance. Bacteria even oxidise gold, the metal which we call eternal. One microbiologist remarked with sadness that the marble monument to Louis Pasteur in Paris is being destroyed by bacteria, whose activity he was so eager to prove.

Mankind has learned to put the destructive activity of microorganisms to advantage: in some industrially advanced countries leaching of useful components from ores is carried out with the participation of bacteria.* At present copper, uranium, zinc and even arsenic are already extracted from ores by bacterial methods. In the United States about 10% of the overall extracted copper is "delivered to the surface" by bacteria. Bacterial leaching of lead, nickel, cobalt, molybdenum, cadmium, and titanium is quite feasible. As compared to conventional methods of metallurgy, bacterial leaching is noted for a far more complete extraction of metals. Therefore the new method is especially effective in processing poor ores which were earlier not profitable enough to develop. Waste dumps and dressing plant tailings can also be reprocessed.

The destructive function of living matter is an important aspect of its activity in the biosphere. The biosphere is not only "a factory producing macromolecules" but also a huge mill. As in a Japanese fairy tale, this mill cannot stop, but goes on milling incessantly. It has been milling for so many milliards of years already, and it is not salt but rocks that it has been milling! The mill of life works most energetically on land, and in the near-shore concentrations of life of marine ecosystems.

The fourth basic function of living matter is the medium-forming one; it resides in the transformation of the physico-chemical parameters of the medium as a result of processes of vital activity. While the influence of the external medium on organisms has been within the scope of traditional topics of biology since the time of its origination, the feedback – the action of the organisms on the medium (of life on "non-life") – began to appear in outline only with the discovery of photosynthesis. Vernadsky, drawing upon the investigations carried out by F. Houssay, J. S. Haldane, F. Henderson and A. Lotka, made a basic conclusion that "the organism deals with the medium to which it is not only adapted, but which is adapted to it"**. An important event was also the conclusion drawn by M. A. Yegunov that in the course of their vital activity organisms create the nonhomogeneity of their habitat (bioanisotropy, which has already been mentioned in Chapter

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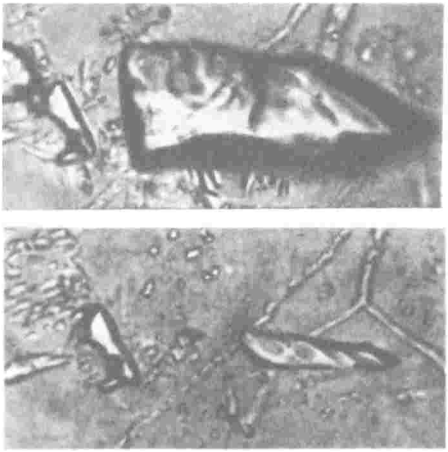
* D. G. Lundgren, M. Silver, "Ore leaching by bacteria", *Ann. Rev. Microbiol.*, 1980, v. 34, pp. 263-283.

** V. I. Vernadsky, "Problems of biogeochemistry", *Transactions BIOGEL*, 1980, Issue 16, p. 22.



Decomposition of nepheline by microorganisms: (a) initial particles; (b) the same particles after having been decomposed for 4 days by the microscopic fungus Penicillium.

One). Much new data have been obtained in recent decades by geochemists.* - **

The most evident manifestation of the influence of living matter on the environment is mechanical action or the II kind of geological activity of living matter. Metazoans strongly change the properties of soil by making their burrows in it (for instance, owing to the loosening of the soil carried out by earthworms, the volume of air in it increases by a factor of 2.5). The roots of higher plants (particularly of woody ones) also change the mechanical properties of soil: they consolidate the soil and protect it against erosion. Thus, erosion of the 20-cm surface layer of soil in prairies takes 29 thousand years, and in woods, 174 thousand years. Forest vegetation is capable of retaining soil even on slopes with a gradient of 20 to 40°. Filamentous Cyanophyceae act in a similar manner: they create a kind of a net which protects soil against erosion. In the mountain soils of Tajikistan there are sometimes more than 100 m of filamentous Cyanophyceae in 1 g of soil! In fact, this is felt rather than soil: no heavy shower can wash it away.

The mechanical activity of living matter has, no doubt, great influence on the environment, yet, as to its scale, it cannot be

* L. G. M. Baas Becking, I. R. Kaplan, D. Moore, "Limits of the natural environment in terms of pH and oxidation-reduction potentials", *J. Geol.*, 1960, v. 68, pp. 243-284.

** W. E. Krumbein, "Sedimentmikrobiologie und ihre geologischen Aspekte", *Geol. Rundschau*, 1971, Bd. 60, Hf. 2, SS. 438-472.

compared with the influence on the environment of the neobiogenic matter formed by living organisms (the I kind of geological activity, proceeding outside of organisms). For a better understanding of this influence, we shall briefly consider those main parameters which characterized the physico-chemical conditions of the environment. There are two such parameters: the hydrogen index and the redox potential.

The hydrogen index (it is denoted as pH) characterizes the content of hydrogen ions in a medium and is numerically equal to the negative common logarithm of the H^+ ion concentration in a given medium, expressed in gram-ions per litre. pH values vary within a range of 0 to 14. For distilled water pH is 7. Natural water with pH from 6.95 to 7.3 is considered to be neutral, with pH lower than this value, acidic, and with pH exceeding the above value, alkaline.

The redox potential of a medium (Eh) serves as a measure of its oxidation-reduction capacity. This potential is measured in volts or in millivolts. If the redox potential values are positive, the medium is oxidative; if they are negative, the medium is reducing. In recent marine bottom sediments, for example, Eh varies from +600 to −350 mV.

The influence of photoautotrophs on the environment is represented in a general form in Fig. 6. Photosynthesis in the biosphere proceeds by the following reaction (simplified):

$$6CO_2 + 6H_2O + 674\,\text{cal} \xrightarrow[\text{chlorophyll}]{\text{sunlight}} C_6H_{12}O_6 + 6O_2\uparrow$$

In the course of their vital activity photoautotrophs continually produce oxygen. Owing to this reaction there is an oxidative situation in the surface portion of the biosphere and the content of carbon dioxide gas in the atmosphere is maintained at a low level owing to its intensive absorption by photoautotrophs.

In photosynthesis, however, not only oxygen is evolved, which is a strong oxidant, but organic substances also originate, which are strong reducing agents. The neobiogenic matter which is formed after the dying away of living matter, having reached the bottom of water bodies, in boggy soils decomposes and a sharply reducing medium is created under conditions of oxygen deficiency. Various types of fermentation result in the formation of gases with various compositions (see Fig. 6). The composition of the gases is determined also by the specific relation of the saprotrophs and by the structure of initial

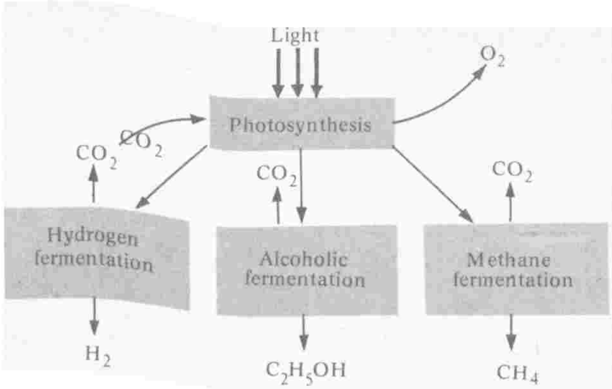


Fig. 6. Diagram of photosynthesis of living matter and microbiological decomposition of neobiogenic organic matter (after Krasnovsky, 1977)

products. Thus, in the case of the decomposition of organic substances under anaerobic conditions hydrogen, ammonia, organic acids, and anions SO_4^{2-}, PO_4^{3-}, NO_3^- are formed.

Products of decomposition of steppe herbs form neutral and weakly alkaline reaction solutions; some wormwoods and saxaul litter-fall give an alkaline reaction (pH 8-8.5), and the mass of died-off conifer needles, heather, lichens, and sphagnum gives an acidic reaction (pH 3.5-4.5).

Here it is appropriate to recall the words of B. B. Polynov: "Above all I consider that the statement, so frequently encountered, to the effect that this or that phenomenon, say, the formation of sediment, depends on pH values rather than on organisms, is wrong. I consider that the very counterposing of the pH to organisms is wrong. Suppose that somebody was impressed by a tall tree and decided to find out why the tree had grown to such a height. In answer to his question he is informed that the height of a tree depends on the number of metres along the length of its trunk. I believe that an explanation with reference to pH does not differ at all from the explanation suggested above, since pH is also a measure, the same as a yardstick or a metre, and it cannot be the first cause; moreover, pH as such is quite often in direct dependence on the amount of CO_2 emanated by the organisms."* This

* B. B. Polynov, *Selected Works*, AN SSSR Publ. House, Moscow, 1956, pp. 466-467.

comment by B.B. Polynov is confirmed by factual material for all natural media.

The atmosphere is a component of the biosphere, common to all living beings. Biogenic formation of oxygen and nitrogen, the two basic gases of the atmosphere, was shown by V.I. Vernadsky himself. Nowadays the question of the biogenic origin of other atmospheric gases is being cleared up. Investigations made by G.E. Hutchinson have contributed much to the solution of this problem*. According to calculations made by geochemists, 50% of all atmospheric hydrogen is formed as a result of the activity of living matter. The formation of carbon monoxide as a result of biogenic processes has also been proved. In particular, in oceanic waters (especially in algae accumulation zones) the content of carbon monoxide exceeds by hundreds of times that in equilibrium in the atmosphere. Land plants, on the contrary, absorb carbon monoxide. Thus, one beech tree during one hour can process 2.35 kg of this gas, which is so deadly dangerous to man.

As a matter of fact, the decisive influence of green plants on the composition of the atmosphere has long been known; the role of bacteria in these processes, on the contrary, only began to be elucidated recently. It turned out that bacteria are responsible for the formulation of the composition of soil air**, and terrestrial atmosphere is in equilibrium to it. Bacteria are responsible also for the formation of gases of the Earth's metabiosphere and, in particular, of industrial accumulations of combustible gases.

Living matter exerts decisive influence on the composition of the natural waters of the Earth–also mainly by giving off neobiogenic matter into the environment. Thus the acidic reaction of waters is most often associated with the dissolution of biogenic substances–carbon dioxide gas and humic acids–in them. The process of photosynthesis in the surface portions of water bodies causes a reduction in the partial pressure of carbon dioxide gas and an increase of pH. In the algae bloom of fresh-water bodies, caused by Protococcaceae and Cyanophyceae, the pH of water rises to 9-10 and higher. The

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* G.E. Hutchinson, "The biochemistry of terrestrial atmosphere", In: "*The Solar System*" (ed. G.P. Kuiper), v. 2, Univ. Chicago Press, Chicago, 1954, pp. 371-433.

** E.N. Mishustin, G.A. Zavarzin, "Ecology of microorganisms and biospheric preserves", In: "Biospheric Preserves", Gidrometeoizdat Publishers, Leningrad, 1977, pp. 100-108.

decomposition processes of neobiogenic organics occur throughout the depth of water, and everywhere the living population of the ocean breathes, leading to opposite results: the partial pressure of carbon dioxide gas in the water increases and the water pH decreases (rotting algae may bring down the pH of sea water down to 6.4).

In the bottom sediments of water bodies physico-chemical conditions of the medium are determined mainly by the presence of organic substance: in the presence of organic substance the conditions are reducing, in its absence they are oxidative. Reducing conditions are created when this is stagnation in the decomposition of the died-away organics by sulphate-reducing bacteria with the formation of hydrogen sulphide. This process occurs everywhere, provided there are accumulations of organic neobiogenic substance, humidity and sulphate-ion (SO_4^{2-}). If hydrogen sulphate is not removed from the medium, self-poisoning of the medium takes place (zones of the Black Sea and the Cariaco Depression, contaminated with hydrogen sulphide, should be recalled here). The medium-forming action of living matter is particularly evident in this case: the above-the-bottom layer of sulphate-reducing bacteria, with a thickness of up to 5 cm, poisons the sea with hydrogen sulphide to a depth of over one kilometre, limiting the habitat of zooplankton and large sea animals to the upper 200 or 300 metres only.

Of all the representatives of the Earth's organic world microorganisms are the most important in their medium-forming influence. Many of them are capable of actively changing the environment in accordance with their vital requirements. For example, in an excessively acidic medium such microorganisms secrete neutral products instead of acidic ones, and in an alkaline medium they intensively produce acids. In the opinion of I. L. Rabotnova, the evolution of microorganisms has proceeded by way of developing an ability of changing the medium, while the perfection of more highly organised organisms resided in that they isolated their internal sphere from the environment.

An important role in the biosphere is played by sulphate-reducing bacteria and thiobacteria: sulphate-reducing bacteria convert sulphate-ion into hydrogen; thiobacteria realize a reverse reaction, i. e. they oxidize hydrogen sulphide to sulphuric acid. It is hardly necessary to prove the medium-forming role of these reactions.

Almost dramatic situation was created by thiobacteria during the Kiev metro project. Before the commencement of tunneling work they dragged out a miserable existence in Paleogene sands. The ingress of oxygen to the depths was hindered, and the bacteria suffered from oxygen deficiency. During tunneling compressed air was pumped to the faces and the bacteria livened up. The hydrogen index (pH) of the medium reached values of less than 1 (to put it otherwise, subterranean water turned into a strong solution of sulphuric acid). In a month or two robust bolts of reinforced concrete structures were half destroyed. The situation became critical, and subway engineers could only shake their heads: nothing like it had ever happened before. Microbiologists came to the rescue: they found those guilty and suggested that the method of tunneling should be changed. The subway engineers had to give up pumping compressed air into the tunnel.

The case of the Kiev subway is not the only example of microbiologists coming to the aid of construction engineers. It is known how much trouble is caused by quicksands in construction engineering. The soil scientist V. V. Radina* has proved their bacteriogenic origin. In the investigation of the soils in the Nizhne-Obskaya hydroelectric power plant project she has established that soil acquires a plastic state (becomes plasticized as construction engineers say) mainly because of slimy substances (and, as became apparent later, gases and surface active substances) produced by bacteria. The degree of soil liquefaction depends on the availability of food for bacteria (such as potassium, phosphorus, died-away organics). Evidently, biological control of quicksands is not far off.

In aqueous ecosystems the medium-forming role of living matter is, perhaps, manifested even more definitely and many-sidedly. "The heterogeneous living matter of the ocean, the life of the sea, taken as a whole, may be regarded as a special mechanism which completely changes the chemistry of the sea," wrote Vernadsky.** Indeed, organisms that absorb carbonates and silica (Fig. 7) from sea water not only change its mineral composition, but also change the acidity of the medium by increasing the relative content of alkalies. Rookeries also exert

* V. V. Radina, "The role of microorganisms in the formation of the properties of soils and of their stressed state", *Gidrotekhnicheskoje stroitel'stvo*, 1973, 9, pp. 22-24 (in Russian).

** W. Vernadsky, *La géochimie*, Alcan, Paris, 1924, p. 295.

a considerable influence on the aqueous medium. Near the rocks where they are located the foreshore of about 50 m wide is intensively enriched with the faeces of birds. During the nesting period the content of phosphates and nitrates in sea water may increase by a factor of over 100, and the area of sea locations enriched with these elements sometimes exceeds 200 km^2. In case of poorly populated cliffed shores many inshore water areas stretching for dozens of kilometres are under the influence of colonial sea birds.

Recently, however, it was established that living matter changes not only the chemical, but also the physical parameters of the medium, its thermal, electrical and mechanical characteristics. For instance, there is an opinion that Indian summers are caused by the activity of living matter, or, to be more exact, by the autumn peak in the activity of saprotrophs. The situation is rather simple: as soon as much decomposing organic matter accumulates during this period much heat is liberated in its decomposition. It turns out that Indian summers are caused by fungi...

Recently an interesting manifestation of the medium-forming activity of living matter was found first in the Black and then in the White Sea. It received the name "bioelectric effect". This effect resides in that living substance (phytoplankton) creates an electric field with a negative charge, and accumulations of neobiogenic matter (died-away plankton) create positive fields.*

In recent years the diverse medium-forming activity of living matter has been revealed to an ever increasing extent and in the most various manifestations. One of the most general conclusions has been formulated recently by Yu. V. Davydov, Yu. P. Kazansky and V. N. Kataeva: "The vegetable world actively influences the change of the gas composition in the atmosphere and, accordingly, the ionic composition of oceanic water, while animals exert almost no influence on the atmosphere, but do change the cationic composition of sea water."

Evidently, much remains still unknown of the regularities of the influence of living matter on the medium, and what is known requires comprehensive thinking over and generalisation. That is why we discussed the problem of the medium-forming role of living matter in such detail and with the use of diverse

* R. M. Demenitskaya, A. M. Gorodnitsky, "Measurement of electric fields in the ocean", *Transactions of the Institute of Geology of the Arctic*, 1979, v. 181, 88 p.

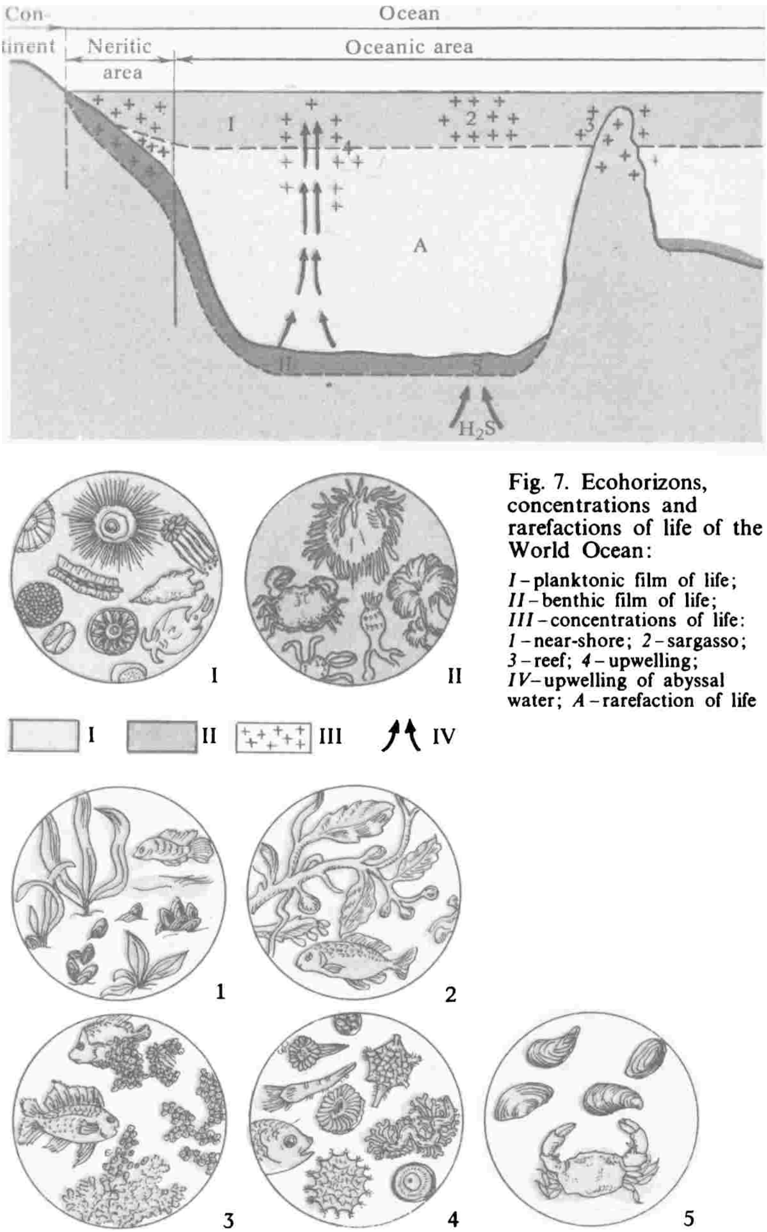
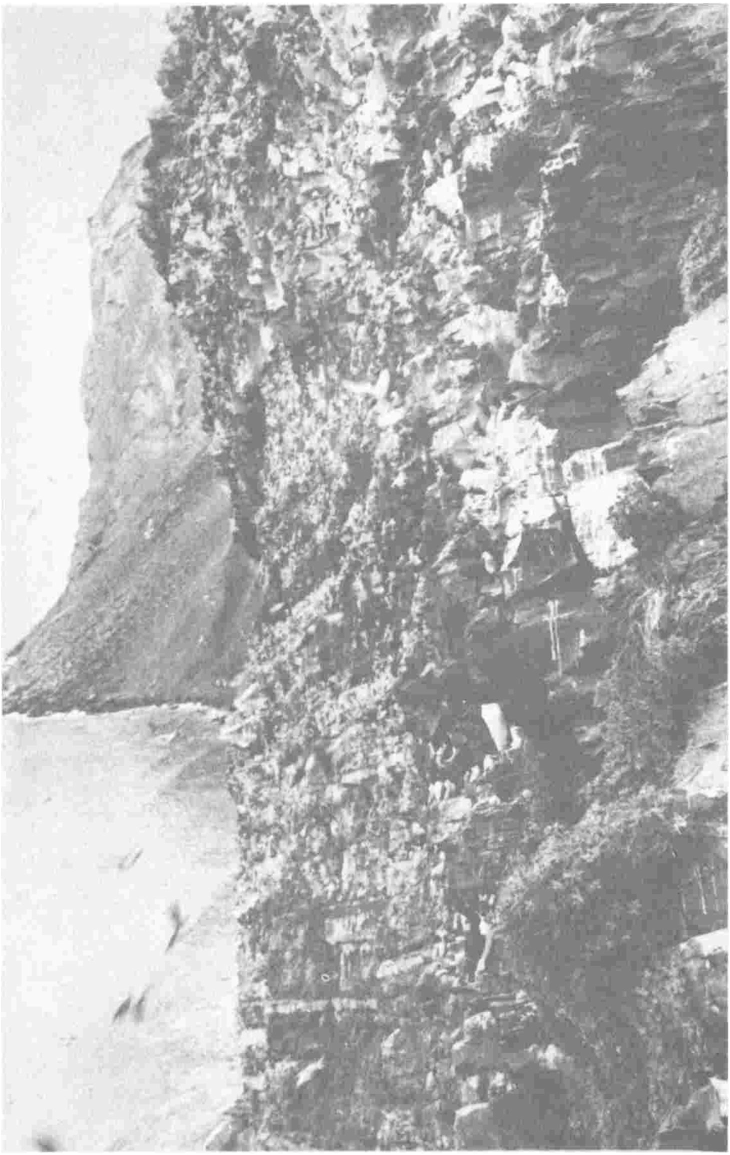


Fig. 7. Ecohorizons, concentrations and rarefactions of life of the World Ocean:

I – planktonic film of life; *II* – benthic film of life; *III* – concentrations of life: *1* – near-shore; *2* – sargasso; *3* – reef; *4* – upwelling; *IV* – upwelling of abyssal water; *A* – rarefaction of life



Rockery on the coast of the Bering Sea in Chukotka.

facts. The creation of a general theory of the medium-forming role of life is a thing of the future.

Finally, the fifth main function of living matter in the biosphere is that of transportation. Even in Newton's time it was known that the transport of flows of matter on our planet is determined by the gravitational force of the Earth. Nonliving matter by itself moves on the Earth only downwards. Rivers, glaciers, avalanches, taluses move only in this direction.

Living matter is the only factor (in addition to surface tension) which conditions the reverse movement of matter: upwards, from the ocean to the continents. "Feeding of terrestrial organisms with marine food proceeds on such a scale," Vernadsky wrote, "that maybe it compensates for – at any rate it returns to the land – a commensurable portion of those masses of chemical elements which rivers take from the land to the sea in solution. Since the Mesozoic era this role has been played mainly by birds"*. The same role is played by shoals of sea fish going up the rivers for spawning, and a considerable portion of matter is brought out of fresh-water bodies to land by countless hordes of winged insects. As regards horizontal shifts, here only tornados and hurricanes may compete with accumulations of homogeneous living matter in the mass of the substance transferred and in the distances over which it is transported. There are no other competitors.

These are the five main functions of living matter in the biosphere. Vernadsky wrote: "Living matter embraces and reconstructs all the chemical processes of the biosphere... Living matter is the greatest geological force, growing with time"** (from this statement we borrowed the heading for this chapter). To give the memory of the great founder of the teaching about the biosphere his due Professor A. I. Perelman suggested that the following generalization should be called "Vernadsky's Law":

"The migration of chemical elements in the biosphere is realized either with the direct participation of living matter (biogenic migration) or it proceeds in a medium the geochemical specific features of which (O_2, CO_2, H_2S, etc.) are conditioned by living matter, both that part inhabiting the given system at present, and the part that has been acting on the Earth throughout geological history."***

* V. I. Vernadsky, *Works*, v. 4, Book 2, p. 93.

** V. I. Vernadsky, *The Chemical Structure of the Earth's Biosphere and of Its Surroundings*, Nauka Publishers, Moscow, 1965, p. 127.

*** A. I. Perelman, *Geochemistry*, Vysshaya Shkola Publishers, Moscow, 1979, p. 215.

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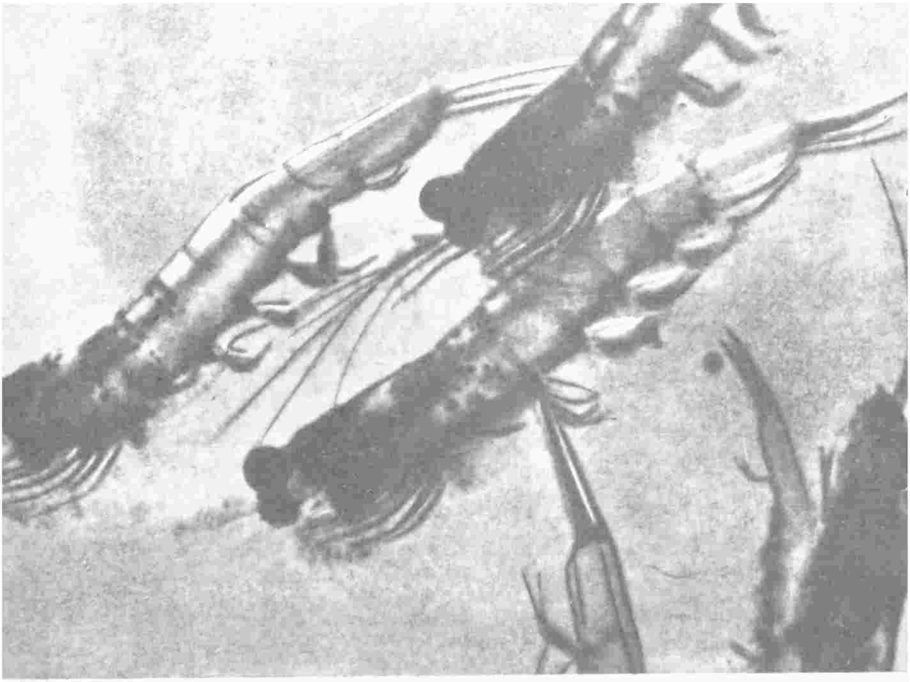

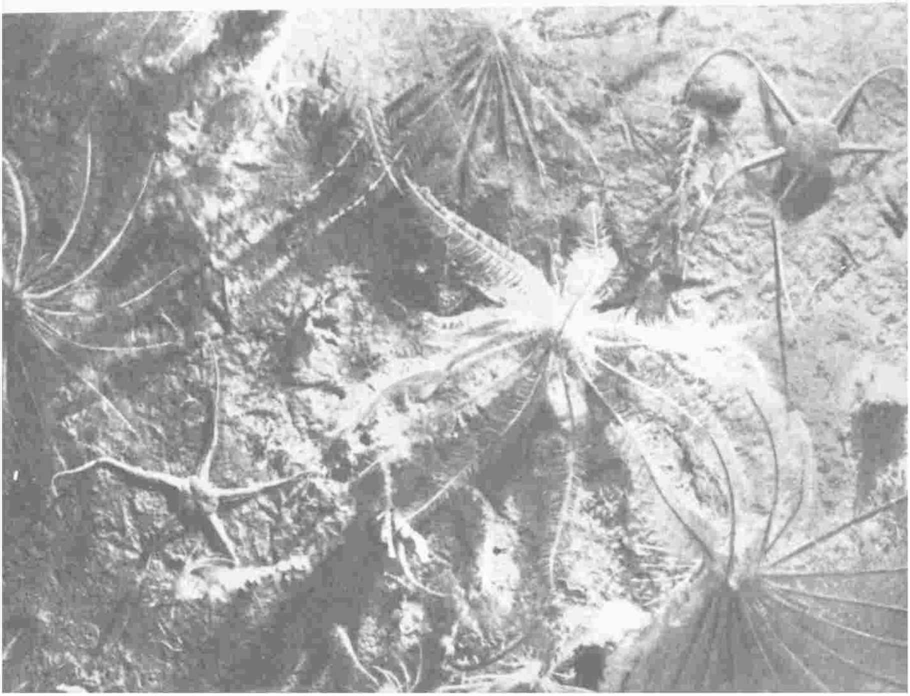

4 Three Factors: Bio-, Eco- and Tapho-

"The final quantity and quality of natural products depend not only on the formation conditions but to a considerable extent also on the conservation conditions."

Iohannes Walther, 1895

Formation of paleobiogenic matter in the Earth's crust is controlled by the following three factors:

First – the productivity of living matter which serves as starting material in the formation of biogenic matter: biological factor (bio-factor);

Second – the conditions favourable for concentration of neobiogenic matter: ecological factor (eco-factor);

Third – the situation ensuring the transition of biogenic substance into the fossil state: taphonomic factor (tapho-factor).

In this chapter we shall consider how the above factors work in the contemporary biosphere.

It has been established that the distribution of living matter in the biosphere is extremely non-uniform. Its quantities in

◀ Krill – routine diet of whales. Tens of times natural size.

Benthic film of life of the antarctic shelf at a depth of 91 m. Numerous starfish are seen.

Table 7

QUANTITY OF LIVING MATTER (FOR DRY WEIGHT OF ORGANIC MATTER, 10^9 T) IN VARIOUS ECOSYSTEMS OF THE EARTH'S BIOSPHERE (AFTER BAZILEVICH, WITH ADDITIONS)

Character of living matter	Groups of ecosystems	Marine ecosystems	Land ecosystems	Ecosystems of inland water bodies	Biosphere as a whole
Autotrophs		0.17	2402.50	0.04	2402.71
Heterotrophs		3.30	23.0	0.78[1]	27.08
Total		3.47	2425.50	0.82	2429.79

[1] N.I. Bazilevich gives no data. We have tentatively assumed that the ratio of autotrophs and heterotrophs in ecosystems of inland water bodies is the same as in marine ecosystems.

various ecosystems of the Earth according to the data of N.I. Bazilevich* is shown in Table 7.

To characterize the distribution of living matter in the biosphere Vernadsky introduced the concepts of areas of maximum concentration of life, "which occupy, perpetually varying, the same locations in the earth's envelopes corresponding to the biosphere"**. Vernadsky has characterized two forms of life concentrations: viable films which can be traced over tremendous areas (for instance, planktonic viable film that covers the entire upper part of the depth of the ocean water), and concentrations of life, featuring a more local occurrence (for instance, concentrations of standing water bodies). The degree of life concentrations is usually measured by a few metres or dozens of metres; it is much less frequent for the degree of life concentrations to be found in one or two hundreds of metres, i.e. in relation to the biosphere as a whole it is measured in negligible magnitudes. The rest of the biosphere is a zone of rarefaction of living matter.

Developing this idea of Vernadsky, A.I. Perelman*** noted that the entire biosphere is distinctly subdivided along the vertical into two zones: an upper zone within which photosynthesis occurs, and a lower zone where photosynthetic

* N.I. Bazilevich, "Biogeochemistry of the Earth and functional models of metabolic processes in natural ecosystems", *Trans. BIOGEL*, 1979, v. 17, pp. 55-73.

** W. Vernadsky, *La biosphere*, Alcan, Paris, 1929, p. 198.

*** A.I. Perelman, *Geochemistry of landscape*, Vysshaya Shkola Publishers, Moscow, 1975, p. 34.

reactions cannot proceed. He suggested that the upper zone should be called "phytosphere" and the lower zone, "redusphere". In his criticism of these denominations N. B. Vassoyevich* suggests that the respective denominations for the two zones should be "photobiosphere" and "melabiosphere" (from the Greek root 'μελαζ', dark). However, the term "melabiosphere" is not quite appropriate either, since it differs only in one letter from other terms introduced by N. B. Vassoyevich: "metabiosphere" and "megabiosphere".

In the formation of terms in scientific literature the Greek root 'μελαζ' is transliterated more often as "melan" than "mela"; there exist such terms as "melanium", "melanite", "melanines", "melanoresinite". Therefore the lower zone of the biosphere should preferably be called "melanobiosphere" rather than "melabiosphere" as suggested by N. B. Vassoyevich. We shall use the term "melanobiosphere", accordingly.

The boundary between the photobiosphere and the melanobiosphere almost coincides with the day surface: light penetrates into soil to a depth of several millimetres. In an aqueous medium the position of the boundary is determined by the transparency of water. The thickness of the photosynthesis zone varies from several centimetres in torrential rivers carrying significant quantities of mud to the first hundred of metres down (to 180 m at most) in parts of the ocean, remote from land. Thus, the thickness of the photobiosphere varies from several centimetres to the first hundred of metres (on land – upwards from the day surface and in the ocean – downwards from the surface of sea: the photosynthesis zone).

The thickness of the melanobiosphere is 1 to 2 orders of magnitude greater: in oceans this is the entire mass of water lying below the zone of the photobiosphere; on continents this is the layer of the biosphere, extending from the day surface to the lower boundary of propagation of active bacterial life.

The photobiosphere and the melanobiosphere may be subdivided along the vertical into smaller zones (or horizons). Thus, the Soviet researcher Yu. P. Byallovich introduced the concept of biogeocoenotic horizon, and gave the following definition of it:

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* N. B. Vassoyevich, "Various Interpretations of the Concept of the Biosphere". In: "*Investigations of the Organic Matter of Recent and Fossil Sediments*", Nauka Publishers, Moscow, 1976, pp. 381-399.

"The biogeocoenotic horizon is a vertically isolated and structural part of the biogeocoenosis that is further indivisible vertically. From top to bottom the biogeocoenotic horizon is uniform in its biogeocoenotic components, in their interconnections, in the transformations of matter and energy occurring in it, and in the same ways it differs from the neighbouring biogeocoenotic horizons, serving as a roof and as a bed for it.* Biogeocoenotic horizons for the sake of brevity are called biogeohorizons. In ecosystems of all ranks it is possible to trace not only these elementary, further indivisible biogeohorizons, but also strata of higher ranks, which may be called ecohorizons. The photobiosphere and the melanobiosphere are ecohorizons of the highest–global–rank. The films of life distinguished by V.I. Vernadsky may be regarded as a particular case of ecohorizons.

According to the landscape principle, all ecosystems of the Earth's biosphere may be classified into three main groups: marine ecosystems, ecosystems of land, and ecosystems of inland water bodies.

Let us consider the distribution of living matter and the manner of biogenic substance accumulation in these main types of ecosystems of the biosphere.

"Biogenic salts in the depths and the presence of light at the surface", such was the aphoristic form of expressing the main problem of marine ecosystems, offered by Yu.Yu. Marti. The World Ocean comprises the open water (oceanologists call it pelagic zone) and the bottom (benthic zone). The pelagic zone within the limits of the photobiosphere in oceanology is termed euphotic zone; the lower part of the pelagic zone is termed aphotic zone. In essence, these are three self-contained ecohorizons of the ocean (looking downwards): an euphotic zone, an aphotic zone, and a benthic zone, each of them being characterised by its specific living matter and environmental conditions. In some half-closed basins with hindered circulation of water (such as the Black Sea) there is found another specific weakly populated ecohorizon: a zone contaminated with hydrogen sulphide, where only several species of anaerobic bacteria vegetate.

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* Yu. P. Byallovich, "Biogeocoenotic horizons", *Trans. MSN*, 1960, v. 3, pp. 44-45.

V. I. Vernadsky* distinguished in the ocean two viable films (planktonic and benthic) and three types of life concentrations (littoral, sargasso, and reef). Both viable films are confined to the interfaces: planktonic to the gaseous/liquid and benthic to the liquid/solid one (Fig. 7).

The planktonic film of life according to V. I. Vernadsky basically corresponds to the euphotic zone of the ocean. In the composition of living matter it drastically differs from land ecosystems: organisms passively suspended in water and incapable of withstanding currents dominate here (these organisms are called plankton). A community of autotrophic planktonic organisms is called phytoplankton, and that of heterotrophic organisms, zooplankton. In the contemporary biosphere phytoplankton is represented by algae (mainly single-celled) and by photosynthesizing bacteria, single-celled diatoms, accounting for 70% of the entire annual production of phytoplankton. The composition of zooplankton is more varied. Its most significant group is constituted by small Crustaceans (Copepoda and Euphasicea); accumulations of these Crustaceans are called "krill". This krill is the basic diet of whales. As to the biospheres of the geological past, the composition of their planktonic film of life is considered in detail in an excellent paper by H. Tappan and A. R. Loeblich**.

The population density in the planktonic film is such that nine tenths of the living organisms, be they plants or animals, are devoured before the term of their natural death: Copepoda devour diatoms and, in their turn, are devoured by larger Crustaceans, etc. The number of living organisms in the planktonic film rapidly decreases with depth (Fig. 8). According to the data obtained by an expedition in the thirties, the content of living organisms in 1 litre of sea water proved to be as follows: in the surface layer, 10,147 individuals; at the depth of 50 m, 9,443; at the depth of 100 m, 2,749. The thickness of the planktonic film as a peculiar concentration of life was estimated by Vernadsky to be 50 to 60 m.

The euphotic zone is the kitchen-garden of the ocean. It is in this zone that all the autotrophic living matter is synthesized. It

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* W. J. Vernadsky, "Ozeanographie und Geochemie", *Mineralog. u. Petrograph. Mitteil.*, 1933, Bd. 44, H. 2/3, SS. 168-192.

** H. Tappan, A. R. Loeblich, Jr., "Geobiological implications of fossil phytoplankton evolution and time-space distribution", *Geol. Soc. Am., Spec. Paper*, 1970, No. 127, pp. 247-340.

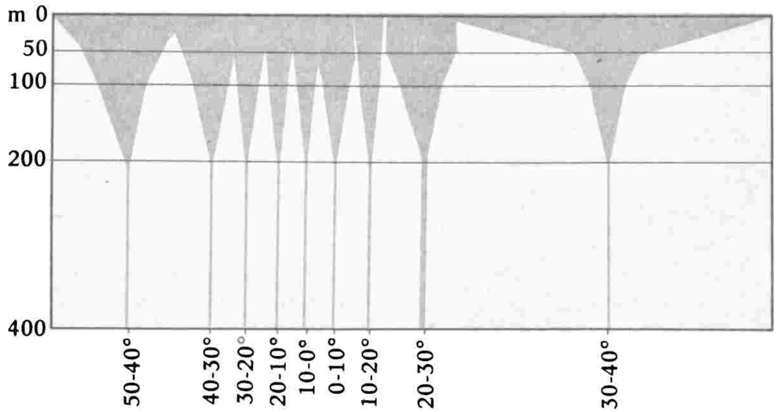

Fig. 8. Distribution of plankton biomass along the depth depending on geographic latitude (after Lohmann)

nourishes all the ocean (not an easy thing to do!), and the energy accumulated by it is sufficient for all the geochemical processes occurring in the ocean. The geological role of the plankton is tremendous: it supplies raw materials for future rocks. The planktonic film of life produces enormous amounts of neobiogenic matter which, however, cannot accumulate in it, but descends by gravity into the mass of water until it reaches the bottom.

Under the planktonic film a thick aqueous aphotic zone of "life rarefaction" (after Vernadsky) is located. The thickness of the aphotic zone is 40 times that of the euphotic one (the average depth of the ocean is 3,800 m). The density of living matter in the aphotic zone is several orders of magnitude lower than in the euphotic zone. This is a region of eternal gloom, and there is no autotrophic living matter of its own in the aphotic zone. Heterotrophic organisms feed on detritus, i.e. on non-living organic matter, or else they are predators. The finer the detritus, the slower it passes through the aphotic zone of the ocean; thus, organic remains 2 mm in diameter reach a depth of 5 km in 3 days; those 0.2 mm in diameter, in 2 years and 4 months; particles 20 microns in diameter, in 233 years. In such a slow descent they are repeatedly used by detritus feeders: there is no alternative; and the nutritional value of the detritus steadily diminishes.

The aphotic zone is thus transient. Biogenic matter is not accumulated there in solid state either, though in dissolved state the content of mineral feeding elements there is higher than in the euphotic zone.

The benthic film of life, after Vernadsky, corresponds to the concept of benthic zone as understood by oceanographers. 157 thousand out of the 160 thousand species of sea animals live there. The concentration of living matter in the benthic film within the shelf, as we shall see later, may be quite considerable. In Vernadsky's time the benthic film had been studied only within the shelf, and owing to this he unintentionally made a mistake by extrapolating the shelf data to the benthic film as a whole, regarding it as a receptacle of life even richer than the planktonic film*. It has now been established, however, that in the deepest regions of the ocean the biomass of benthos does not reach even 1 g per m^2 of the bottom.

An interesting experiment was carried out recently by scientists of Columbia University (USA) in the East-equatorial region of the Pacific**. A camera arranged there at a depth of 4,873 m automatically photographed the ocean floor every 4 hours over 202 days. During this period only 35 animals crawled or walked within the field of view of the camera. In other words, an animal passed there only once in six days!

There is a close correlation dependence between the distribution of the biomasses of the planktonic and benthic films of life, and, as a rule, to areas with a high biomass of the plankton there correspond areas with an increased content of living matter in the benthic zone. In honour of the well-known Soviet oceanologist who discovered this dependence, it is called "the L. A. Zenkevich correspondence principle".

While formation of the planktonic (surface) film is conditioned by the penetration of sunlight into the upper layers of the ocean, the accumulation of life in the benthic film of life is determined by the presence of... a bottom or floor. Naturally, the bottom or floor as such cannot feed, but retains all that could not have been eaten earlier (and leftovers are said to be the sweetest). Moreover, solid substrate offers a hiding place (and there are not so many hiding places in the ocean).

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* W. J. Vernadsky, "Ozeanographie und Geochemie", *Mineralog. u. Petrograph. Mitteil.*, 1933, *Bd.* 44, *H.* 2/3, *SS.* 168-192.

** A. Z. Paul, E. M. Thorndike, L. G. Sullivan, B. C. Heezen, R. D. Gerard, "Observation on the deep-sea floor from 202 days of time-lapse photography", *Nature*, 1978, v. 272, No. 5656, pp. 812-814.

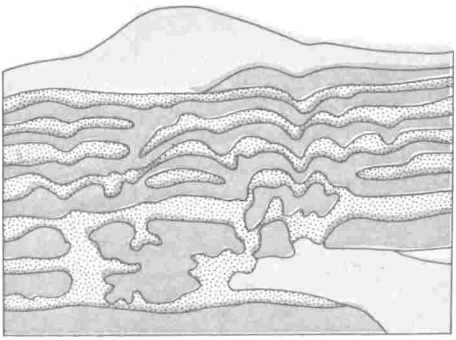

Fig. 9. Disturbances in the bedding of bottom sediments, caused by lugworm. Sediments of different composition are shown by hatching (after Alekseev and Naidin, 1973)

All that lives in the benthic zone (except predators) feeds on detritus. Mud-eaters indiscriminately devour soil and assimilate the detritus contained in it. The most active mud-eaters in the benthic film are worms, holothurians, sea urchins, and starfish. In addition to them, some other representatives of the benthos bury themselves in the bottom sediments (and thus change their texture): Cephalopoda (e.g. cuttlefish) and bivalved mollusks, Ophiuroidea, Malacostraca (Isopoda, Amphipoda, crabs) and even some fish (plaice). As a result of their activity the surface layer of bottom sediments is continually "shovelled up" to quite a considerable depth*.

The Soviet scientists A.S. Alekseev and D.P. Naidin** recently showed how diverse the effects of the burrowing benthic fauna can be (Fig. 9). Under the action of organisms textures are often formed which resemble shrinkage, cracks, traces of small erosions and roiling. Sometimes such textures "manifest themselves" only in the process of diagenesis. The main action produced by organisms on the sediment is mechanical intermixing which increases its homogeneity. But there are animals which act in an opposite sense: they sort out sediments*** and make, for example, sand "still more sandy".

Most diagenetic reactions are carried out by bacteria. The "biological reactor" of the diagenesis of bottom sediments works on detritus. Owing to biogenic decomposition the detritus slowly

* K.K. Turekian, J.K. Cochran, D.J. De Master, "Bioturbation in deep-sea deposits", *Oceanus*, 1978, v. 21, No. 1, pp. 34-41.

** A.S. Alekseev, D.P. Naidin, "Disturbances of sedimentary bedding by littoral invertebrates", *Lithol. a. Miner. Resour.*, 1973, v. 4, pp. 435-444.

*** J.D. Howard, "The sedimentological significance of trace fossils", In: "*The Study of Trace Fossils*" (ed. R.W. Frey), Berlin a.o., Springer, 1975, pp. 131-146.

disappears from the muds, whereas soil solutions are markedly enriched with the decomposition products, first of all with carbon dioxide gas, hydrogen sulphide, hydrogen, and ammonia; the soil solution pH drops, free oxygen disappears from the mud solution, and the formerly oxidising medium becomes reducing, this being accompanied by an Eh drop to a negative value.

The role of the benthic zone, i.e. of the benthic film of life, in the biosphere is no less important than that of the planktonic film. If the planktonic film is the kitchen-garden of the ocean, the benthic zone is a storehouse of its finished products. All what has escaped from the biotic cycle due to specific conditions in the benthic zone, after having been created by the living matter of the ocean, is immured there for ages. The planktonic film of life supplies raw materials for sediments, while the benthic film is the main oceanic ecohorizon where their accumulation takes place. The main, but not the only one, as has been shown by recent investigations.

Juvenali Petrovich Zaitsev*, Corresponding Member of the Academy of Sciences of the Ukrainian SSR, discovered an interesting phenomenon: "an anti-rain of cadavers". It turned out that not only the bodies of large organisms float up after their death (as earlier believed), but those of various small marine living beings as well. They finally sink, but, passing through the surface layer, they have time for substantially enriching it with dissolved organic matter.

Another source of nonliving organic matter in the near-surface layer is organic matter absorbed by gas bubbles rising from the sea depths. The incoming of nonliving organic matter with the gas bubbles in the near-surface layer exceeds the formation of living matter in the process of photosynthesis by as much as 10 times. As a result, a lot of organic matter is accumulated at the surface of the sea, mainly, in colloidal form. During storms this matter is churned into a snow-white foam; that very foam, out of which, according to ancient mythology and to the well-known picture by Sandro Botticelli, Venus, the goddess of love and beauty, was born...

The population of the near-surface layer of the water mass is quite distinctive. The five-centimetre layer of water intercepts 40% of solar radiation, mainly, the ultraviolet region of the

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* Ju. P. Zaitsev, "Life of sea surface", Naukova Dumka Publishers, Kiev, 1974, p. 112.

spectrum being absorbed. Paradoxically enough, photosynthesis is suppressed there. The base of the trophic pyramid is constituted of saprotrophic microorganisms which process nonliving organic matter, since it is in excess there. The number of bacteria in the near-surface layer is hundreds and thousands of times greater than in the lower horizons of the water mass. The second step of the trophic pyramid is constituted of the minutest heterotrophs: protozoans, larvae of all kinds of mollusks, worms, crustaceans, fish, and other animals. There is quite a lot of young fish and germs of organisms – fish eggs – in the near-surface layer, all keeping to the very surface of the water. Finally, subsequent steps of the trophic pyramid are constituted by larger invertebrates, fish, and sea birds.

Zaitsev called the near-surface layer of the ocean "the incubator of the pelagic zone". Future generations of sea inhabitants are concentrated there. At the same time, it is just the surface of the sea that is most subject to contamination with petroleum and petroleum products; as a result, innumerable quantities of tender young fish perish. As Zaitsev put it, "the region of maximum negative effect on the living coincides with the region of greatest population sensitivity". The tomorrow of the ocean is in danger...

In addition to life films, there exist concentrations and rarefactions of life in the ocean. Deserts on land have been known to mankind long since; in the ocean they were discovered rather recently. Thus, a vast water desert was found in the Pacific Ocean in the region of the Hawaiian Islands. The concentration of living matter there comes to $3 \cdot 10^{-6}\%$. In other words, in order to collect a one-litre jar of marine organisms, we would have to filter neither more nor less, but 30 million litres of oceanic water.

V. I. Vernadsky classified the concentrations of life in the ocean into three types: (a) littoral; (b) sargasso; (c) reef (see Fig. 7).

Littoral concentrations correspond to neritic regions of the ocean. As a matter of fact, they originate there, where both films of life, the planktonic and the benthic, meet and combine those good things of life which they carry: sunlight and solid substrate; moreover, the littoral concentrations of life are characterized by an abundant inflow of mineral and organic substances from the continent and have still another good thing: intensive stirring of the water mass (this enables repeated use of ash elements). As a result of the combination of all these

A mussel bank.

positive factors, in littoral concentrations the biomass of plankton is hundreds of times, and that of the benthic fauna, many thousands of times, greater than in bathypelagic regions. The degree of processing of sedimentary material proves to be correspondingly high. In the littoral concentrations of life it is such that excrements of marine organisms often turn out to be the main component of the sediments.

A distinctive feature of the littoral concentrations of life is the predominance of metazoans rather than protozoans. In this case a comparative monotony of life is characteristic: from one to 12 species of organisms may here constitute up to 95% of biocoenoses. An example of such one-type accumulations are mussel banks. In all seas, except tropical ones, mussels make up a thick littoral border. Their biomass sometimes reaches dozens of kilograms per square metre of the bottom.

High concentration of organisms with skeletons of calcium carbonate leads to the appearance of coquina accumulations.

As has been shown by A. A. Aksenov for the Azov Sea, the formation of large coquina accumulations takes place in the case of a high productivity of benthos, shallow sea or shallow regions of the sea, predominance of coquina in the composition of detrital deposits, etc.

An illustration of other aspects of the activity of littoral concentrations of life is furnished by the above-mentioned investigation of mussel banks in the White Sea, carried out by K. A. Voskresensky in the forties, directly stimulated by Vernadsky's ideas. Voskresensky carried out an uncommon work, if not the only one of its kind then at any rate one of the few at that time, and therefore particularly valuable. By laboratory experiments and field observations he proved that the activity of mussel banks controls the colloidal composition of coastal water, sedimentation within the limits of flat coast and – even more difficult to take in at once – no less than the circulation of water within the littoral zone!

All these three functions (in the preceding chapter they were discussed as the concentration, medium-formation and transportation functions) are performed through filtering of inshore water by mussels. Biogenic circulation is set up due to the fact that water, free from colloidal particles, becomes lighter and ascends (Fig. 10). Later on it was also established that many organisms from the littoral concentration of life secrete mucous substances into the bottom sediments. Bivalved mollusks, crustaceans, echinoderms, Hemichorda are among such organisms. These mucous substances, as well as byssuses of mollusks (sticky, easily solidifying filaments with the aid of which mollusks attach themselves to a substrate), homes of polychaetes, and other formations add to the mechanical strength of bottom sediments. As a result of this conditions are created for the preservation of sediment grains in an apparently foreign hydrodynamic medium.

Life concentration of another type is represented by sargasso concentrations; these are sea areas, overcrowded with multicellular algae not attached to the sea bottom: Sargassum or Phyllophora. This type of concentration is characterized by

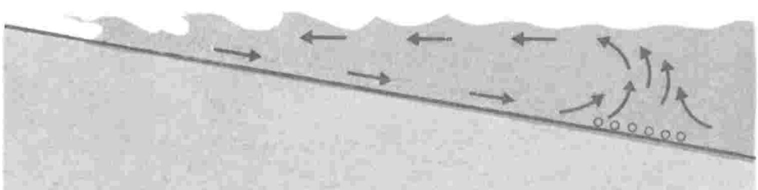

Fig. 10. Scheme of biogenic circulation of water in near-shore concentration of life (after Voskresensky, 1948)

Brown alga Sargassum natans.

a very high biomass and an extremely low productivity of living matter.

Christopher Columbus first described this wonder of nature: "grass" floating in the open sea where the depth reaches 4 to 6 km. "At dawn we came across so much grass that the sea seemed to be covered with it as with ice. The grass was coming from the west", was the entry Columbus made in his diary on September 21, 1492. The following day he wrote: "For part of the day there was no grass, then it became quite dense."

The brown alga Sargassum owes its name to the Portuguese word 'sargaço', a kind of grapes. These algae are yellowish-brown plants with strongly sectioned "leaves"; their characteristic feature is the presence of spherical air sacs or bladders which resemble vine. A tangled mass of the algae and animals there is the sargasso concentration of life, distinguished by Vernadsky.

A classical example of the concentration of life of this kind is the ecosystem of the Sargasso Sea located south-east of North America. Its biomass amounts to 4-11 million tons, i.e. to about 1% of the entire biomass of the living matter of the autotrophs of the World Ocean. The low annual productivity of the sea can be explained by its specific hydrological conditions: its boundaries are defined by an elliptical stream, and vertical intermixing of the water is weak.

Another similar "concentration of life" was found in the north-western part of the Black Sea by one of the founders of Russian hydrobiology, Academician Sergei Alekseevich Zernov (1871-1945). There, in an area of about 11,000 km^2 in shallow water a concentration of the red alga of genus Phyllophora, not attached to the bottom, is located. The biomass of this concentration of life (5.5 million tons) is not inferior to that found in the Sargasso Sea. Now in "Zernov's Phyllophora field" (so called in honour of its discoverer) the gathering of Phyllophora is organised for the production of agaroid. Agaroid finds application in various branches of the economy.

Reef concentration of life is the third and last type of the concentrations of life known in Vernadsky's time (we shall consider it in the next chapter); in our days two more characteristic concentrations were established: upwelling and abyssal rift ones.

While in sargasso concentrations the productivity of living matter is limited by weak intermixing of the water, in upwelling regions (Fig. 11), where water enriched with phosphorus and nitrogen rises from a deeper to a shallower depth, the productivity is tremendous. The most powerful producing system of the World Ocean is located in the zone of the Peruvian upwelling. Its area, occupying only 0.02% of the total water area of the Ocean, yields up to 15-20% of the world catch of fish.

Abyssal rift concentrations (not to be confused with reef ones!)-perhaps, the most unusual ones-were discovered in 1977 by American scientists* in the Pacific between the coast of Equador and the Galapagos Islands at a depth of 2,400 m. The press christened it "the Galapagos phenomenon." It is a phenomenon indeed: these concentrations of life are unique in that they are located in the melanobiosphere, and the food chain in them is based on an energy the source of which is not the Sun, but the internal heat of the Earth. There is a rift here: the zone of a gaping fault in the earth's crust, and "geysers", from which hydrogen sulphide is liberated, are gushing on the ocean floor. This abyssal hydrogen sulphide in a miraculous manner does not kill all the living (as in the Black Sea), but it is consumed by chemoautotrophs: by thiobacteria. Their number reaches several milliards in every litre of water. Thiobacteria

* R.D. Ballard, J.B. Corliss, "Oases of life in the cold abyss", *Nat. Geogr.*, 1977, v. 152, 4, pp. 440-453.

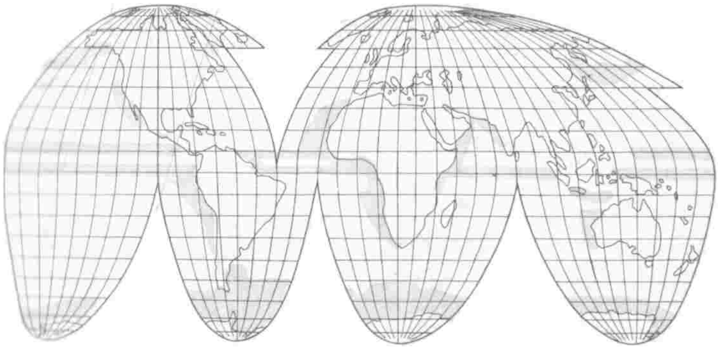

Fig. 11. Upwelling concentrations of life in the World Ocean (after Lafond, 1966)

make up the base of the food pyramid of rift concentrations of life. The fauna there is quite unusual and investigations of it have just been begun. In particular there were described previously unknown tubular worms up to 3 m in length, dandelion-shaped colonial medusae, etc. The density of the benthos here is several orders of magnitude higher than usual in the abyssal zone of the ocean: kilograms rather than fractions of a gram per square metre.

The abundance of rift concentrations of life is still difficult to estimate. Small areas discovered by the Americans may turn out to be first evidence of the existence of previously unknown concentrations of life fed by the plutonic energy of the Earth.

Such are contemporary data on the concentrations of life in the ocean.

As early as 1923 Vernadsky formulated the problem which could not be solved at that time: to study quantitatively the abundance of living matter in the ocean*. Now this problem has been successfully solved: maps have been drawn showing the distribution of the primary productivity and of the biomass of living matter on the territory of the World Ocean. The primary productivity of the ocean turned out to be unexpectedly low: in the major portion of the water area it does not reach even 0.5 g/m^2 a day, this corresponding to the productivity of a semidesert! A second surprise is the paradoxical ratio of the

* A. P. Lisitsyn, "Biogenic sedimentation in the oceans and zonation", *Lithol. a Miner. Resour.*, 1977, v. 12, 1, pp. 1-17.

biomasses of the living matter of autotrophs and heterotrophs: the biomass of the living matter of heterotrophs proved to be dozens of times greater. An explanation of this strange phenomenon may be found in the colossal production and rapid change of phytoplankton generations.

In the early sixties, on the basis of the generalization of a large corpus of empirical data, a map of the bottom sediments of the World Ocean was compiled at the Institute of Oceanology of the USSR Academy of Sciences. It was established that accumulation of neobiogenic matter in oceanic sediments is controlled by three types of zonation: climatic, vertical, and circumcontinental, climatic zonality being of greatest importance. In different climatic zones organisms assimilate different components from sea water: in cold parts of moderate zones mainly silica is mobilised; in arid parts, only carbonates; and in equatorial and humid parts, carbonates and silica.

Vertical zonation of accumulation of neobiogenic matter is determined by the so-called "level of carbonate compensation"-the critical depth, below which, because of the high pressure and low temperature of sea water, there occurs dissolution of the carbonate skeletons of calcium organisms. This phenomenon, discovered in the seventies of the last century by the well-known British oceanologist J. *Murray* (1841-1914), conditions the absence of carbonate sediments at depths exceeding 3.0 to 5.5 km. It has now been established that the position of the carbonate compensation level in the oceans changed in the course of geological history. Its maximum depth is characteristic for the present time, while in the Mesozoic era it was 1.0 to 1.5 m higher than now.

Circumcontinental zonation (from the Latin word 'circum', around) manifests itself in that the composition of sediments changes as one moves away from continents towards the oceanic area of the ocean. The density of life in this direction decreases, and it would seem we have a right to expect a decrease in the content of neobiogenic matter in the sediments as well. However, this is not the case: as one leaves the continents, the content of biogenic matter in the sediments increases. Why? The explanation is simple: it is not the absolute quantity of biogenic matter that decreases, but its percentage in the sediments because of its strong dilution with a terrigenous admixture coming from the continent. On the periphery of the ocean 92% of terrigenous material is deposited!

Being more abundant, terrigenous sedimentation "outdoes" the biogenic one; in central parts of the ocean, remote from the land, the situation changes. Having generalized considerable factual material, the Soviet oceanologist, Corresponding Member of the USSR Academy of Sciences, Alexander Petrovich Lisitsyn comes to the following conclusion: "The biogenic process in the pelagic zone of the ocean on the whole is scores of times more powerful than the terrigenous one, and the processes of preparation, transportation, and deposition of sedimentary material by the bios are dominant here."*

Such are some of the regularities in the distribution of living matter in the ecosystems of the contemporary World Ocean and in the accumulation of neobiogenic matter in them. The ecosystems of land considerably differ from the marine ones, though there are certain common features as well. As in the ocean, there are two films of life on land, the upper film being located in the photobiosphere and the lower film, in the melanobiosphere. And it is there that the similarity ends.

The upper film of life on land is terrestrial; it exists as we already know, upwards from the surface of soil to the upper boundary of the biosphere.

These are the landscapes we are accustomed to, and there is no need to describe them. Located below is a soil film of life; this is a specific world, where the concentration of life is higher than in the terrestrial film. Thus, in one gramme of forest soil there are, on average, 400 million bacteria, 2 million microscopic fungi, 100 thousand microscopic algae, and 10 thousand protozoans.

In contrast to the ocean, on land both films of life are in direct contact: they are not separated one from the other on the vertical by several kilometres of space sparsely populated with life. Here there are no problems limiting the productivity of the ocean ("biogenic salts at the depth"), and autotrophic organisms procure the elements they need from soil. After death their remains – neobiogenic organic matter – also enter the soil.

Further down below the thin layer of soil (its thickness amounts to several decimetres and seldom reaches 1-1.5 metres) an area of life rarefaction is located. This is a world almost

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* A. P. Lisitsyn, "Terrigenous sedimentation, climatic zonation, and interaction of terrigenous and biogenous material in the ocean", *Lithol. a. Miner. Resour.*, 1977, v. 12, 6, pp. 617-632.

untouched by investigations. With the rare exception of caves, here everywhere – from the lower boundary of soil to the lower limit of the biosphere – only bacterial, i.e. microscopic life is possible. The subterranean prisoners have selected moisture for their habitat: they live in subterranean water and in its contact with rocks. Proceeding from the studies of microorganisms dwelling in subterranean water, the Soviet microbiologist L. E. Kramarenko has distinguished "zones of hydrogeochemical zonation of the Earth's crust"* (Table 8). In essence, these zones are definite ecohorizons of the subsoil part of the melanobiosphere in its continental portion.

Taking this circumstance into account, it is possible to distinguish on land (Fig. 12) the following five ecohorizons of the biosphere (going downwards): (1) land film of life; (2) soil film of life; (3) aerobic subterranean ecohorizon corresponding to the aerobic zone after L. E. Kramarenko; (4) aerobic-anaerobic subterranean ecohorizon (the mixed zone after L. E. Kramarenko); (5) anaerobic subterranean ecohorizon (the anaerobic zone after L. E. Kramarenko).

Living matter is distributed nonuniformly not only in the vertical section of the biosphere, but also laterally. Vernadsky distinguished on land: (a) coastal and (b) flood-plain concentrations of life. Taking into account present-day data on the determination of the biomass of various ecosystems, it is possible to distinguish a third type of concentration of this kind: tropical and subtropical forests of humid areas.

According to Vernadsky, coastal concentrations of life include inshore territories of continents and islands. The concentration of life there is determined mainly by the process of terrigenous decomposition of land.

The second, flood-plain type of concentration of life on continents Vernadsky characterized in his "Essays on Geochemistry" as "accumulation of life in the basins of great rivers", including not only fertile river valleys but their deltas as well. According to present-day data, these ecosystems are characterized by the highest productivity on land: though their area is negligible (less than 1%), they produce 10% of living matter. An increase in production by more than an order of magnitude against the average standard of land ecosystems is

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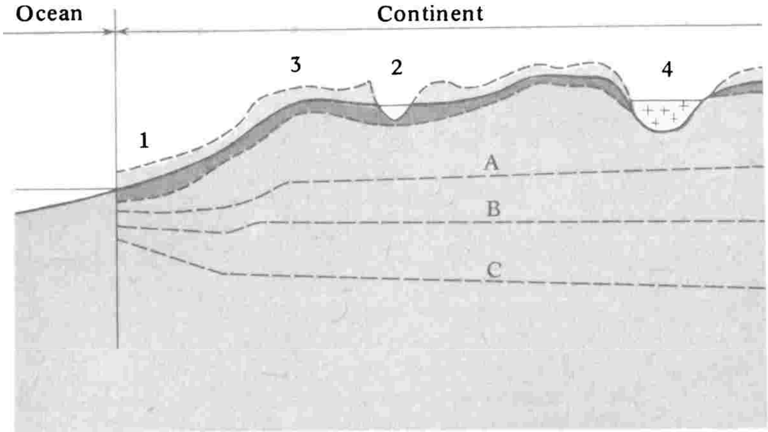
* L. E. Kramarenko, "Microorganisms of subterranean water and their geochemical importance", *Transactions of the All-Union Geological Institute*, 1975, v. 241, pp. 156-165.

Table 8

SCHEME OF HYDROBIOCHEMICAL ZONATION OF SUBTERRANEAN PART OF THE BIOSPHERE OF LAND (AFTER L. E. KRAMARENKO (1975))

Zones	Eh	Microorganisms (examples)	K *	Neobiogenic matter - products of vital activity of bacteria
Aerobic	+ 800 to + 100 mV	Thiobacteria, nitrifying, methaneoxidising, hydrogen-oxidising bacteria	Up to ∞	SO_4^{2-}, NO_3^-, NO_2^-, CO_2, oxide forms of metals
Mixed	+ 100 to + 200 mV	Thiobacteria, nitrifying, hydrogen-oxidizing, denitrifying, sulphate-reducing, methane-producing, hydrogen-producing bacteria	About 1	SO_4^{2-}, NO_3^-, NO_2^-, CO_2, oxide forms of metals; H_2S, N_2, H_2, CH_4, reduced forms of metals
Anaerobic	− 200 to − 400 mV and lower	Sulphate-reducing, denitrifying, methane-producing, hydrogen-producing bacteria	Down to 0	H_2S, N_2, H_2, CH_4, reduced forms of metals

* K is the aerobic/anaerobic bacteria occurrence percentage ratio.



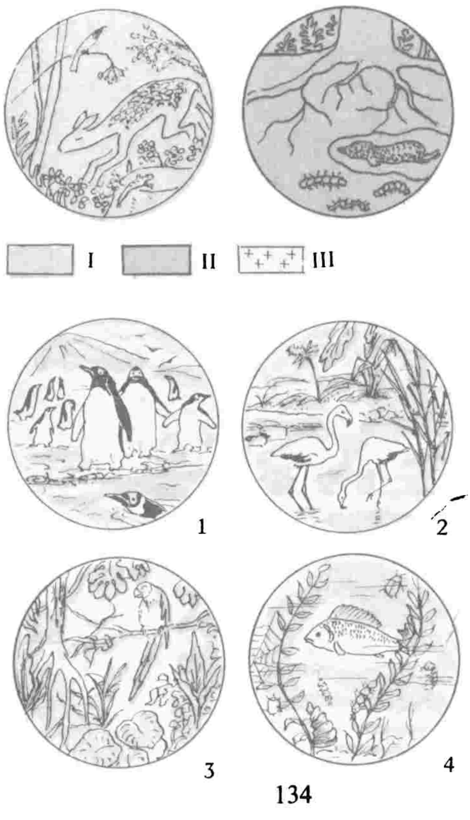


Fig. 12. Ecohorizons, concentrations and rarefactions of life on the continent:

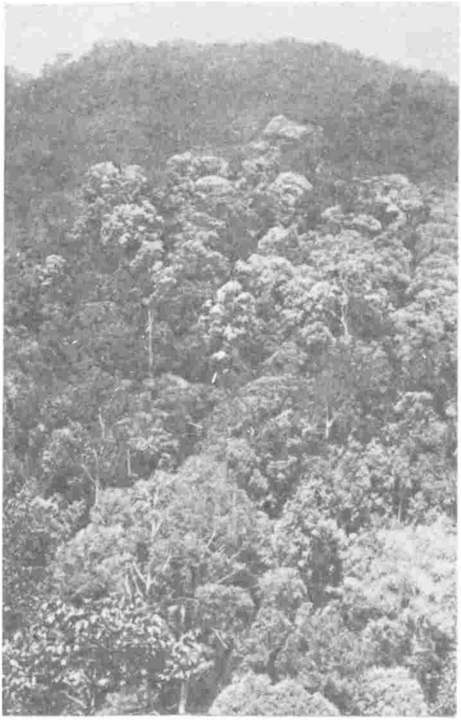
I – terrestrial film of life;
II – soil film of life;
III – concentrations of life:
1 – shore; *2* – flood-plain;
3 – tropical and subtropical forests of humid areas;
4 – concentrations of stagnânt water bodies;
A-C – rarefactions of life:
A – aerobic subterranean ecohorizon;
B – aerobic-anaerobic ecohorizon; *C* – anaerobic subterranean ecohorizon

explained by an abundant supply of flood plains and particularly of deltas with mineral nutrition elements. As examples of flood-plain concentrations of life Vernadsky cited the Amazon, the Orinoco, the Zambezi, the Ob, and the Irtish. Contemporary estimates of the biomass necessitate amendments to be made to Vernadsky's conceptions: ecosystems possess a more considerable phytomass only within the limits of the subtropical and tropical belt. Therefore the valleys of our great rivers the Ob and the Irtish cannot be cited as examples of concentrations of living matter.

Finally, tropical and subtropical forests of humid areas are the third type of concentrations of living matter on continents. Their phytomass reaches a record level 650 t/ha (in the taiga of the Soviet Union the respective figures are 200 to 250 t/ha). D. V. Panfilov says that tropical forests resemble a gigantic green cascade frozen in its downfall. Not only the flora, but also the fauna of tropical forests is abundant and diverse. Mammals, birds, reptiles, amphibians, and especially insects are represented by a large number of species. Insects, mainly thermites, very rapidly destroy the died off parts of plants (the fallen leaves, branches, fallen or still standing trunks of dead trees). Thick branches of trees are almost completely destroyed by insects after a period of 3 to 5 years; dry leaves and small branches lying on the ground disappear within a few months. As a result, in humid tropical forests possessing a colossal biomass, neobiogenic organic matter practically does not accumulate.

Figure 13 shows how great differences in the productivity of the ecosystems of the Earth can be. Both the total quantity of living matter and its annual production are distributed over the area of the continents in an extremely nonuniform manner: for example, the reserves of biomass in the richest and in the poorest belts on land differ almost by a factor of 100. The distribution of the absolute masses of living matter and of annual production is determined here by global climatic factors: by temperature, by the quantity of precipitation, and by the fertility of soils.

A distinctive feature of the living matter of land is its composition: higher plants are characterized by absolute predominance in the biomass and productivity. The remaining eight subkingdoms of the organic world are found in a drastically subordinate position. But among higher plants there are "leaders" as well; these are woody plants. The biomass of forests makes up 84% of the total biomass of the



Tropical forest. Malaysia.

living matter of land (productivity, however, is more modest: about 40%).

In absolute quantity of biomass land is rather inferior to the ocean, but accumulation of biogenic matter on continents, as a rule, does not take place. In this connection Vernadsky wrote: "Here we have a rather perfect dynamic equilibrium which results in the tremendous geochemical work of the living matter of land leaving, after scores of millions of years of its existence, negligible traces in the solids constituting the earth's crust."*

I think that this phenomenon can be explained by inorganic biogenic matter almost not being formed on land: higher plants prefer their carcass to be built from lignine rather than from calcium carbonate or silica, as in the case of marine organisms.

* W. Vernadsky, *La biosphère*, Alcan, Paris, 1929, p. 192.

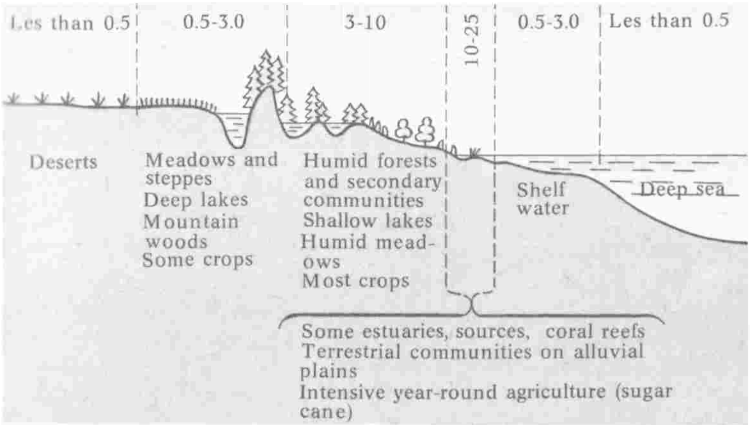


Fig. 13. Productivity of various ecosystems of the Earth's biosphere (in grams of dry matter per m^2 per day) (after Villy and Detier, 1971)

As a result, after the plants die away, their remains are completely decomposed under normal conditions.

Finally, the last type of ecosystems of the Earth are continental water bodies. The main mass of the surface water of land is concentrated in pools, lakes and swamps, rather than in rivers. On continents Vernadsky singled out a characteristic type of concentration of life: "concentrations of stagnant water bodies". The main water bodies here are lakes.

In the concentrations of shallow stagnant water bodies synthesis of the living matter of autotrophs occurs in the entire mass of the water. The activity of mud-eating animals in the bottom sediments of lakes is quite considerable. Most active mud-eaters in lakes are worms and larvae of dipterans (in particular, mosquito larvae, so familiar to aquarists). Under favourable conditions worms build up several millimetres of excrement a year.

Concentrations of stagnant water bodies are of great importance in sedimentation. Thus, in the littoral part of many lakes coquina is often accumulated, but this is not the only product of accumulation in lakes. The Soviet limnologist, Professor Leonid Leonidovich Rossolimo (1894-1977) suggested that the following types of lakes should be distinguished by the character of sediments: (a) lakes which are accumulators of drift; (b) lakes which are concentrators of dissolved mineral substances; (c) lakes which are accumulators of organic matter.

In lakes which are concentrators of dissolved mineral substances the accumulation of matter can proceed under the influence of abiogenic processes (evaporation) and of biogenic processes (concentration of elements by living organisms). Detailing his classification, Rossolimo distinguishes iron-accumulating, calcium-accumulating, and silicon-accumulating lakes. As regards lakes which are accumulators of organic matter, shallow lakes (having a depth of 2 to 10 m), not vast in area, either small-drainage or no-drainage ones, protected from the wind, and located in the forest zone of moderate climates are most typical.

We have discussed the distribution of living matter and the potentiality of sedimentation in various ecosystems of the Earth's biosphere. But was it always thus? Did films and concentrations of life exist in the geological past as well, and were they the same as now? Is the extrapolation of the situation observed today to the geological past justifiable?

Vernadsky wrote: "There can be no doubt that beginning with the most ancient Paleozoic era we have an indication to the existence in nature of the same concentrations and rarefactions of living matter as those observed today. It is easy to check that already in the Cambrian there were the same types of marine biocoenoses as we have now... In all geological periods the same picture is observed, though the morphological composition of these concentrations and rarefactions changes sharply."* Vernadsky's standpoint is confirmed by the data obtained in modern science. In the opinion of Academician Alexander Vasilievich Sidorenko, the sedimentogenesis of the pre-Cambrian and of the Phanerozoic eras is similar in essence as a single whole, found at different stages of continuous evolutionary development. Evidently, since the appearance of the ozone shield on the Earth the distribution of living matter in the biosphere and the conditions of sedimentation in it, even if there were changes in them, did not change principally, and such changes were mainly fluctuational in character. This does not exclude the possibility that during definite periods some other, now nonexisting facies could also exist on the Earth.

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* V. I. Vernadsky, *Living matter*, Nauka Publishers, Moscow, 1978, pp. 299-300.

At present the first attempts are being made to delineate the concentrations of life of bygone epochs, proceeding from the studies of sedimentary rocks: for example, to outline zones of upwellings.*

All the sedimentary rocks of the Earth (in the past 3.4 milliard years of its development) have formed in the biosphere. I believe that this thesis in the most concise form renders the geological aspect of Vernadsky's teaching. Living matter takes an active part in the formation of sedimentary rocks, and all sedimentary rocks comprise a certain (even if at times very small) amount of paleobiogenic matter. The ratio of the abiogenic and paleobiogenic matter in rocks may vary: from fossil coals, whose low-ash varieties are composed almost completely of paleobiogenic organic matter, and limestones consisting of paleobiogenic inorganic matter, to sandstones, in which there may be quite little paleobiogenic material. Paleobiogenic matter in sedimentary rocks is rather diverse: vegetable detritus, various remains of organisms, (miospores, large-size fragments of plants, microscopic remains of plankton, spicules of sponges, teeth of sharks, shells, bones of vertebrates, etc.), amber, coprolites, and such microbiogenic minerals as sulphides, carbonates, hydroxides of iron, and so on.

Thus, we have considered the conditions of the accumulation of biogenic matter in the contemporary biosphere. On the basis of this material we now return to the question of the three factors of formation of paleobiogenic matter in sedimentary rocks: the biological, ecological, and taphonomic factors.

In a general form the connection between biological productivity and the quantity of neobiogenic matter accumulating in an ecosystem is not questionable. In its turn, the biological productivity of ecosystems depends on a number of factors: climate (mainly on the ambient temperature and on the amount of precipitates), availability of mineral nutrition elements, intensity of solar radiation, and degree of mineralization of natural water.

The influence of temperature on the quantity of living matter is different: in ecosystems of the ocean there is no direct relationship, while on continents such a direct relationship does exist. In terrestrial ecosystems the average yearly temperature

* F. T. Banner, "*Pithonella ovalis* from the Early Cenomanian of England", *Micropaleontology*, 1972, v. 18, 3, pp. 278-284.

determines not only the quantity of the biomass, but also the type of the predominant vegetation. Thus, forest grows only in those regions, where at least for four months mean monthly temperatures exceed + 10°C. In addition to this, in middle latitudes usually a few species of plants prevail (coniferous forests or stipa steppes in the Soviet Union furnish a good example), while the fauna is extremely diverse. In tropical forest the opposite is observed: a tremendous diversity of plants and relatively few, though specialized animal species, participating in the life of the former.

Aridity of the climate influences to the same degree both terrestrial and oceanic ecosystems: "the saturation with life" of the ecosystems of the humid belt is considerably higher. Introduction of abiogenic matter from the internal strata of the earth's crust is also beneficial to biological productivity. We have already mentioned specific rift concentrations of life. Generally high productivity of phytoplankton is observed in the region of the Pacific volcanic belt everywhere; for the vegetation in areas of recent volcanicity gigantism is characteristic. The introduction of endogenic matter probably not only increases the productivity of matter in the biosphere, but also contributes to the formation of species. Anyway, Vernadsky's comrade-in-arms, Professor Boris Leonidovich Lichkov (1888-1966) thought so. In the geological history of the Earth there have been observed global short-term upsurges in the productivity of living matter, observed from the increase in the role of biogenic matter in the composition of sedimentary deposits. The reasons for such upsurges are still unknown.

Is it always that an increase in biological productivity – the bio-factor – causes an increase in the quantity of biogenic matter in the sediments? In some cases such a relationship is quite marked: for example, in the ocean, at depths above the level of carbonate compensation, the intensity of accumulation of carbonate oozes is in direct dependence on the productivity of phytoplankton. In lakes the situation is quite the reverse: it is established that lakes with a low level of biological productivity produce muds with a high content of neobiogenic organic matter. Evidently, in addition to the "bio", there exist some other factors which control the accumulation of biogenic matter in sediments.

Scientists faced the action of these factors for the first time in the middle of the last century, when "a telegraphic rope" (the word "cable" did not yet come into use then) was laid across the Atlantic. This was the beginning of purposeful investigation of the oceans, the nascence of a new science: oceanology. Sediments from oceanic depths were studied for the first time. Their composition proved to be unexpected.

"Why have no fish bones, teeth, scales, shells, starfish, corals, or other parts of animals, not liable to rapid decay, been found?" wrote a scientific reviewer of that time. The correct explanation was found: "When these inhabitants of the near surface water die, their corpses become the spoils for animals with a lower organization, which, in their turn, in the same way, reduce to primitive organisms... long before the remains of animals dwelling on the surface of the sea reach the bottom and become assimilated with its mass, they, maybe, pass through various instances and finish this wandering in microscopic animals that inhabit the deepest parts of the sea."

Let us try to imagine for a moment that living matter existing on the Earth is exclusively autotrophic. Then the accumulation of nonbiogenic matter would be controlled only by its productivity (it is another matter that life would have exhausted itself after several hundred or thousand years). But in reality heterotrophic living matter exists on the Earth as well. In the presently existing ecosystems the consumption of autotrophic living matter does not exceed, as we have already mentioned, several per cent. Living matter reutilises mainly neobiogenic rather than living matter. In most cases saprotrophs with the potent assistance of abiogenic factors honorably accomplish their difficult task of decomposing neobiogenic matter into simple components suitable for re-use by living matter: carbon dioxide gas, water, hydrogen sulphide, ammonia, and so on.

Sometimes, however, complete decomposition of neobiogenic matter does not take place. The activity of saprotrophs may be suppressed by the aridity of climate (in a desert), or by excessive humidity (in a swamp), by low temperatures (in tundra), or, else, by the toxicity of the medium. In the water of sphagnum bogs, for example, there are phenols which render it sterile. It was not for nothing that in the Middle Ages sailors, when setting out on long voyages, provided themselves with just such water. This water also renders invaluable services to archaeologists: it conserves for ages such wooden relics as piles, pavement plankings, boats, oars, small articles.

The completeness of neobiogenic matter decomposition is also materially dependent on the length of destruction processes.

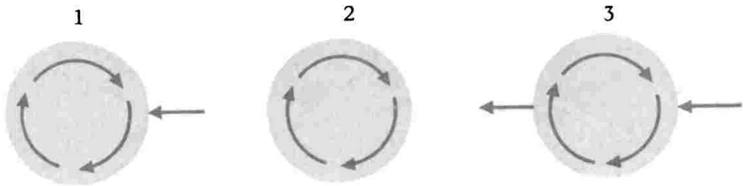

Fig. 14. Types of ecosystems after D. V. Panfilov (1976):
1 – transit type; *2* – autonomous; *3* – accumulative; the flow of nutrient substances is indicated by arrows

Thus, in lakes and in shallow parts of the ocean, where the planktonic film is separated from the benthic film only by a few metres of water mass, the quantity of detritus decomposed during the precipitation will be, naturally, much smaller than in bathypelagic basins. Accordingly, in shallow basins a greater amount of neobiogenic matter escapes from the biological cycle. It has been calculated that only 2.7% of all neobiogenic organic matter is accumulated in the bathypelagic part of the ocean, 26.3% is accumulated on shelves and on the continental slope, while 71% is accumulated on swampy part of land and in shallow continental basins.

The Soviet scientist Dmitri Victorovich Panfilov, whose works have already been more than once cited in this book, speaking at the XXIII International Geographic Congress in Moscow (1976) suggested that three main types of ecosystems should be distinguished*: transit, autonomous, and accumulative. Transit ecosystems are characterized by constant supply and evacuation of mineral nutrition elements used by plants; autonomous ecosystems, by weak supply and evacuation; and accumulative ecosystems, by considerable supply and weak evacuation of matter (Fig. 14). As examples of accumulative systems D. V. Panfilov cited oceanic abyssal zones, mangroves, swamps, and the like. Nothing other than neobiogenic matter accumulates there: organic (in mangroves and swamps) or inorganic (in oceanic abyssal zones).

It has recently been suggested that the factor ensuring the concentration of neobiogenic matter in ecosystems should be

* D. V. Panfilov, "Natural-history classification of natural ecosystems". In: *International Geography-76*, Section 4. Moscow, 1976, pp. 91-96.

called the eco-factor*. The well-known Soviet microbiologist Vladimir Ottonovich Tauson (1894-1946) was the first to emphasize the importance of this factor in the accumulation of caustobioliths.

The eco-factor is also responsible for conditions which preclude the supply of considerable amounts of terrigenous material to the ecosystem, material which dilutes neobiogenic matter: levelled-out relief of the surrounding territory and weak oscillatory motions of the earth's crust. Those areas of the

Vladimir Ottonovich Tauson.

Johannes Walther

biosphere, in which formation of biogenic or chemogenic sediments takes place, not disturbed by the supply of terrigenous material, are called concentration basins. To such basins, according to the ideas held by Academician D. V. Nalivkin**, there belong those, in which phosphate, manganese, ferruginous, and other sediments are accumulated; peat moors are also concentration basins. (It should be noted that some people still thinking in the old-fashioned way consider that for the accumulation of peat downwarping of the

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* A. V. Lapo, "Living matter of the biosphere and formation of sedimentary rocks and ores", *Izv. AN SSSR, geolog. series*, 1977, 11, pp. 121-130.

** D. V. Nalivkin, "An important reserve of mineral resources", *Priroda*, 1959, 2, pp. 14-15.

peat moor bed is required. This supposition is based entirely on a misunderstanding: on feckless extrapolation of the laws of mechanics to a biological object, namely, to the peat accumulation ecosystem.)

All the above arguments are pertinent to sedimentogenesis – to the stage of the accumulation of sediments, proceeding in the biosphere. On the geological time scale conservation of neobiogenic matter in ecosystems is an altogether temporary phenomenon, something like leaving one's luggage in an automatic left-luggage locker. Normally life takes back its luggage (that is to say, neobiogenic matter). Some extraordinary circumstances are required for the lock in the check-room to remain unopened and the luggage immured in it. Under the conditions of the biosphere such an extraordinary circumstance is allowed by the process of burial. Only when isolated from the processes of active decomposition does neobiogenic matter get a chance to be preserved over millions of years of geological history. Only by having ceased to be a sediment and having become a rock.

Johannes Walther (1860-1937), the German scientist and classic of geology, whose words we cited in the epigraph to this chapter, laconically formulated the following thesis: "We call deposits all the forming accumulations of matter: only those which have remained preserved become rocks."

The transition of biogenic matter into the fossil state, its transformation from neobiogenic to the paleobiogenic matter, proceeding at the stage of diagenesis, may be called the tapho-factor of formation of sedimentary rocks (from the Greek 'taphos', tomb).

A most general case of burial of neobiogenic matter on land is subsidence of the basin of its accumulation. But there can be sudden burials too. Within the memory of mankind catastrophic burials of whole cities have taken place. A well-known case is that of Pompeii which was buried under a layer of volcanic ash as thick as 4 metres. Another, not so commonly known example: on May 31, 1970 the city of Yungay in the mountains of Peru was flooded with a ten-metre (!) layer of mud in the space of a few seconds.

Sudden burials of a similar kind occurred in the geological past as well. For example, findings of "fossil forests", i.e. accumulations of mineralized trunks of trees, buried at the site of their growth, are not so rare. If the tree had not rotted before it was covered by sediments means that the process of its burial was very rapid. In oceans burial of low-stability biogenic matter may also occur as a result of very intensive sedimentation and, hence, isolation of subsequent portions of the sediment from the aggressive action of sea water and from the activity of the benthic fauna.

The general situation on land is not favourable for biogenic sedimentation. Ivan Antonovich Yefremov (1907-1972), both a paleontologist and a writer, creator of the teaching about the regularities of the burial of organic remains in the earth's crust (taphonomy), suggested that situations favouring the burial of biogenic matter should be called ultrafacies*. Yefremov notes that from a continent there remains a hiatus in the geological chronicle, surrounded by a belt of ultrafacies.

In this respect the ocean, or, to be more precise, its benthic film of life, is a complete antithesis to the continent. It has already been mentioned that the benthic film of life is of extreme importance in the formation of sedimentary rocks, since there exist conditions for preservation of biogenic matter for a long geological time. "As the remains of life and roiled parts of sluggish matter gradually fall, the lower layers of marine mud become lifeless, and chemical bodies formed by life have no time to pass over into gaseous products or for entering into new living matter. The living layer of mud never exceeds a few metres, though it grows continually from the surface. It always dies down from below."** It is there that the final chords of the grand symphony of life sound, and neobiogenic matter, departing from the biosphere, is transformed in the course of geological time into paleobiogenic matter.

The quantity of biogenic matter that passes into the fossil state is negligible in relation to the annual production of living matter. In the case of carbon, for example, it amounts to 0.05% for the biosphere as a whole, and to 0.4% for the World Ocean (0.7% for the underwater outskirts and 0.1% for the oceanic region). Such negligible fractions of matter, escaping from the biological cycle owing to passing over into the fossil state, are the constituents of the biogenic matter of the metabiosphere.

V. I. Vernadsky represented the formation of sedimentary rocks diagrammatically*** as shown in Fig. 15. From this diagram it

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* I. A. Yefremov, "Taphonomy and geological chronicle", *Trans. of Paleontol. Inst. of the USSR Acad. Sci.*, 1950, v. 24, pp. 1-178.

** W. Vernadsky, *La biosphère*, Alcan, Paris, 1929, pp. 177-178.

*** W. Vernadsky, "Sur l'analyse des sols au point de vue géochimique", *Acte IV conf. int. pedol.*, t. II, Rome, 1926, p. 573.

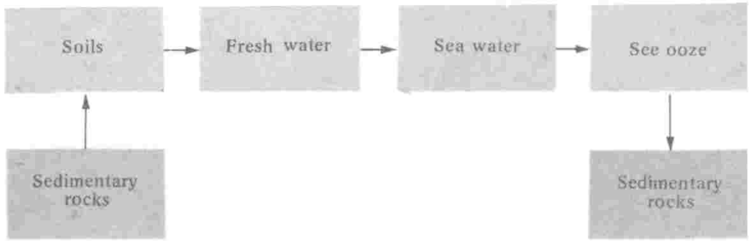

Fig. 15. Principal diagram of formation of sedimentary rocks (after Vernadsky, 1926)

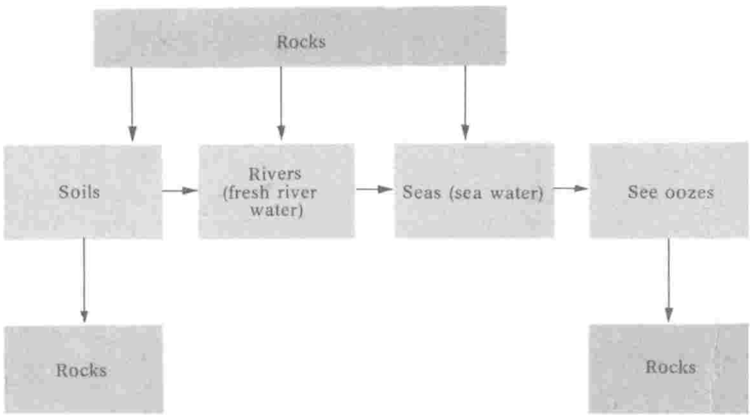

Fig. 16. Principal diagram of formation of sedimentary rocks (after Lichkov, 1946)

follows that in the twenties and thirties Vernadsky thought of the formation of sedimentary rocks as being an exclusively underwater process. In the forties, however, L. S. Berg and B. L. Lichkov* (Fig. 16) substantiated an opinion that sedimentary rocks can also be formed on the surface of continents, in the course of soil formation processes. Vernadsky supported this idea: at any rate it was he who presented B. L. Lichkov's paper treating this topic to the "*Izvestiya AN SSSR*" and mentioned B. L. Lichkov's work with sympathy in

* B. L. Lichkov, "Changes in the relief and evolution of the soil and mud formations of land and sea in the Earth's history (theory of sedimentation)", *Izv. of the Tajik Branch of the USSR Acad. Sci.*, 1946, 11, pp. 3-28.

his book "The Chemical Structure of the Biosphere and Its Surroundings" (1965, p. 128). The accumul.tion of sediments and their diagenetic transformations occur in dynamic systems of a specific kind, which Vernadsky called biologically sluggish natural bodies.

This concept was introduced by Vernadsky* in 1938 to distinguish in the biosphere not only living and sluggish bodies, but also systems in which their interaction is realized. As examples of biologically sluggish natural bodies V. I. Vernadsky cited soils, forests, crust of weathering, oozes, surface water, oceans as a whole. "Organized biologically sluggish bodies account for a considerable portion of the biosphere in terms of its weight and volume," writes Vernadsky. "Their remains, after the death of the organisms of which they are composed, make up biogenic rocks which take up a tremendous part of the stratisphere."** Whether sedimentary rocks are formed as a result of diagenetic transformation of the bottom sediments of water bodies or of soils, in both cases their formation proceeds in biologically sluggish natural bodies (or, after A. I. Perelman***, in biologically sluggish systems). What is the role played there by living matter and what processes occur in the biologically sluggish systems? Let us consider Fig. 17. A distinctive feature of biologically sluggish systems is the presence of living matter in them.

If living organisms composing the system die, it can no longer be considered to be biologically sluggish. In all biologically sluggish systems the content of living matter (in relation to the total mass) is small, but it is just this living matter that plays the leading role in their functioning.

Since there is living matter in the system, there must necessarily also be products of its vital activity, and died away organic matter, i.e. neobiogenic matter. In biologically sluggish systems abiogenic matter must necessarily be present as well (it may be additionally incorporated there as a terrigenous admixture, as products of volcanism or as extraterrestrial material: terrestrial and extraterrestrial matter are combined in

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* V. I. Vernadsky, "Problems of biogeochemistry", pt. 2. *Trans. Conn. Acad. Arts a. Sci.*, 1944, v. 35, pp. 483-517.

** V. I. Vernadsky, *The Chemical Structure of the Biosphere and Its Surroundings*, Nauka Publishers, Moscow, 1965, p. 128.

*** A. I. Perelman, *Biologically sluggish systems*, Nauka Publishers, Moscow, 1977, p. 160.

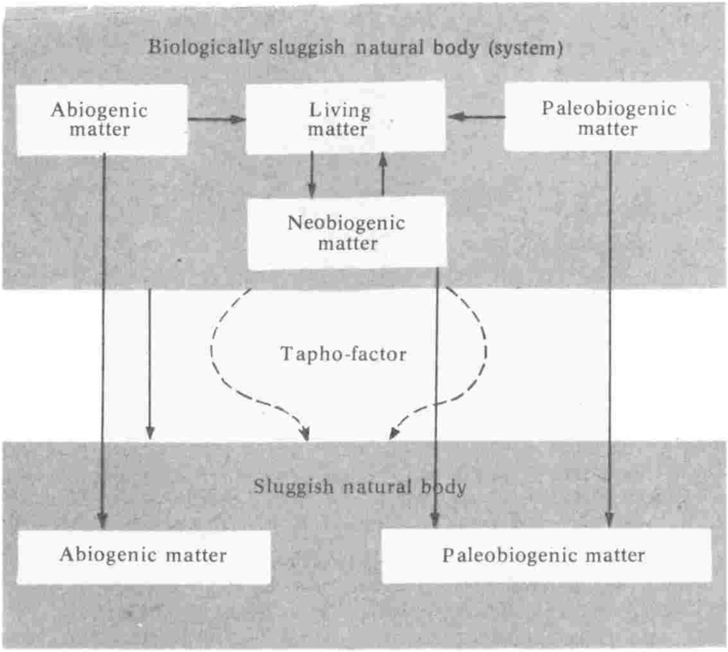


Fig. 17. Diagram of formation of sedimentary rocks in biologically sluggish systems with subsequent burial

this diagram). Paleobiogenic matter may also (though not necessarily) be present: limestones, phosphorites, and so forth.

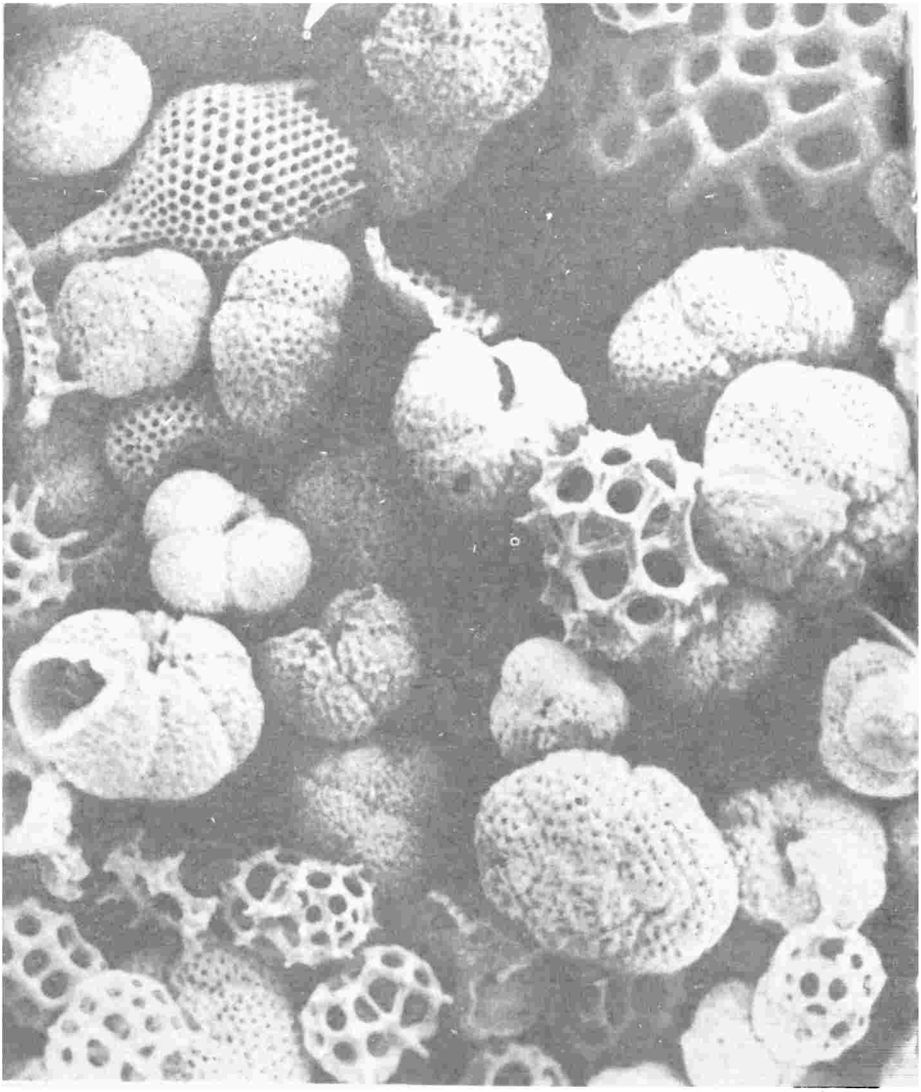
In the course of processes of vital activity living matter continually consumes and involves new portions of abiogenic matter into the biological cycle (it should be remembered that this is one of the basic functions of living matter in the biosphere). Mostly abiogenic matter of terrestrial origin is assimilated, but evidently, a part of abiogenic matter of extraterrestrial origin is also used.

As well as abiogenic matter living matter consumes biogenic matter. Living matter utilizes paleobiogenic matter too (thus, shells of borers require biogenic limestones for their making). Higher plants assimilate phosphorus-containing minerals, and some species of bacteria, organic matter of coals and petroleums; thiobacteria oxidise biogenic sulphides created by their predecessors, i.e. by sulphate-reducing bacteria, etc.

Thus, just as forty rivers flow into Baikal and only one river flows out of it, so living matter involves into its cycle all types of nonliving matter and produces only one type: neobiogenic matter.

Biologically sluggish systems create sedimentary rocks. After burial life in them comes to a standstill, the biologically sluggish natural body is converted into the sluggish one. As a result, from the four types of matter, comprising biologically sluggish systems, two types of nonliving matter of sluggish systems are formed: abiogenic and biogenic.

The sedimentary envelopes of the Earth, in the most simplified form, are stratigraphically superposed traces of the bygone biospheres of our planet. Taken together, they make up the metabiosphere of the Earth: a many-kilometre envelope, whose character is to a considerable extent determined by the activity of four thin films of life: the planktonic, benthic, land, and soil ones.



Abyssal oceanic ooze consisting of remains of foraminifers and radiolarians.

5 Metabiosphere

"The unity of the Earth's stratisphere resulting from the development of the bygone biospheres of the planet has become apparent."

B. S. SOKOLOV, 1975

At the end of Sredny Prospect in Leningrad the area between the 19th and 20th Lines is occupied by a magnificent edifice clad in grey stone. It is called the Palace of Geology. Once the Geological Committee, practically the sole geological establishment of pre-revolutionary Russia, was located there; now three leading establishments of the Ministry of Geology of the USSR are accommodated in this building: the All-Union Geological Institute, the All-Union Geological Library, and the Central Museum of Geological Prospecting named after Academician F. N. Chernyshev. A grand hall and a wide staircase going up to the top. In the hall there are creations of nature and not of human hands: a block of coal from the Donets Coal Field, petrified trunks of extinct trees, a masterpiece of the Mesozoic Era: an ammonite. Traces of bygone biospheres...

In January 1959, in the Palace of Geology the V Session of the All-Union Paleontological Society was opened. It seemed as if there was nothing special about it: such sessions are held every year, but the topic of that session was unusual: "The importance of the biosphere in geological processes."

This representative forum – more than 500 scientists participated in it – was the first scientific conference at which the role of living matter in the formation of the earth's crust was considered from so many aspects and so comprehensively. Its initiator, the well-known Soviet paleontologist and later Lenin prize winner, Boris Pavlovich Markovsky (1895-1966), delivered a programmatic report "Life as a Geological Factor."* Numerous more special communications were devoted to problems of the biogenic origin of carbonate rocks, combustible minerals, iron and manganese ores, phosphorites, bauxites...

The V Session of the All-Union Paleontological Society summarized the results of the investigations carried out during those decades that had passed since the publication of the first works of Vernadsky about the geological role of life. But the importance of this session lay not only in this: at the same time it opened up a new stage in the development of Soviet lithology.

Vernadsky's ideas have by rights won general recognition. The brilliant pleiad of scientists who meritoriously develop these ideas includes many contemporaries and younger contemporaries of Vernadsky.

Owing to the efforts of these investigators outstanding advances have been made in studying the role of life in the formation of sedimentary rocks. The last chapter of our narrative is devoted to this question. The present is said to be the clue to the cognition of the past. We shall use this clue to gain a better understanding of the way in which sedimentary rocks were formed in the geological past.

According to present-day classifications, sedimentary rocks are subdivided into the following groups: (1) detrital; (2) argillaceous; (3) allite; (4) ferruginous; (5) manganese; (6) phosphate; (7) carbonate; (8) siliceous; (9) salts; (10) caustobioliths.** Among the sedimentary rocks carbonate and siliceous rocks, as well as caustobioliths, are characterized by the highest concentrations of paleobiogenic matter.

Different authors estimate the content of carbonate rocks in the sedimentary layer of the Earth's crust to be within the range of 10 to 18 per cent. Vernadsky attributed particular importance to the role of life in the formation of carbonate rocks and even distinguished, as already been mentioned,

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* "*The Importance of the Biosphere in Geological Processes. Problems of Interconnection of Paleontology and Tectonics*", Moscow, Gostoptekhizdat Publ. 1962, p. 248.

** N. V. Logvinenko, *Petrography of sedimentary rocks*, Vysshaya Shkola Publishers, Moscow, 1974, p. 700.

a specific "calcium function" of the living matter of the biosphere. The mechanism of formation of calcium carbonate by living organisms has been considered recently by the well-known West German scientist E. Degens*, and the role of algae and bacteria in this process, by W. E. Krumbein**.

Not so long ago the ratio of the chemogenic and biogenic sedimentation of carbonates in marine ecosystems was a subject of heated argument. Some lithologists held that the role of chemogenic carbonate accumulation was essential in marine water bodies of the Black Sea type, featuring restricted communication with the World Ocean. However, recent investigations of the Black Sea have proved that the character of carbonate accumulation there was biogenic. On the Bahama Bank too, carbonate sedimentation has long been considered chemogenic; but detailed investigation showed finely dispersed carbonate material to be composed of the remains of microscopic algae, bacteria, and fragments of shells.***

In contemporary living matter of marine ecosystems carbonates play a notable role (see Table 5). The distribution of carbonates on the ocean floor at great depths is limited by the level of carbonate compensation.

Lisitsyn**** classifies neobiogenic carbonate sediments of marine ecosystems into two subtypes: planktogenic and benthogenic. Both life films of the ocean thus create their own types of carbonate sediments.

The planktogenic subtype, in its turn, is subdivided into three classes: foraminiferal, coccolithic, and pteropodal. At least half of the area of recent carbonate accumulation of the open sea is composed of foraminiferal oozes.

Foraminifers belong to the subkingdom of protozoans. Their contemporary representatives are microscopic beings. Among extinct forms there existed rather large organisms. These include nummulites, giants among one-celled animals, which reached 10

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* E. T. Degens, "Why do organisms calcify?", *Chem. Geol.*, 1979, v. 25, 3, pp. 257-269.

** W. E. Krumbein, "Calcification of bacteria and algae". In: "*Biogeochemical Cycling of Mineral-Forming Elements*" (ed. P. A. Trudinger, D. J. Swaine). Amsterdam a. o. Elsevier, 1979, pp. 47-68.

*** R. D. Stieglitz, "Scanning electron microscopy of fine fraction of recent carbonate sediments from Bimini, Bahamas", *J. Sediment. Petrol.*, 1972, v. 42, 1, pp. 211-226.

**** A. P. Lisitsyn, *Oceanic Sedimentation Processes*, Nauka Publishers, Moscow, 1978, p. 392.

to 16 cm. Their Latin name means "stone coins". Indeed, nummulites resemble petrified small coins. An Azerbaijanian legend recounts that this is the money of a rich man who refused to give alms to a pauper. Nummulites were first classed with organic remains only in the eighteenth century, whereas nummulitic limestones had been used much earlier: the Egyptian pyramids are built of them.

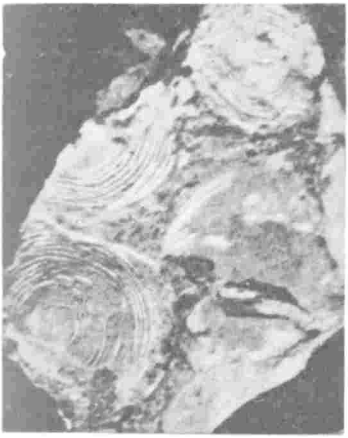
Other foraminifers are less effective but rather diverse. There are about a thousand species now existing, and only 30 of them are planktonic; the rest are inhabitants of the benthic film of life. The body of foraminifers is rather diverse in shape: it can be spherical, tubular, dendritic... The body is covered from the outside with a thin calcareous test having tiny openings running through it. Recent foraminiferal oozes are composed of the tests of these organisms (mostly, of their fragments). Foraminifers appeared in the Cambrian period and acquired an important role in calcareous sedimentation since the Carboniferous era.

Recent coccolithic oozes are considerably less abundant than the foraminiferal ones. They are composed not of the remains of animals, but of the remains of microscopic golden-brown algae Coccolithophorida (a good example of how biogenic matter is formed in the photobiosphere and accumulated in the melanobiosphere, in the benthic film of life). The skeletons of coccolithophoridae consist of calcareous plates which, in their turn, consist of crystals of calcium carbonate. After their death coccolithophoridae disintegrate into a fine carbonate powder.

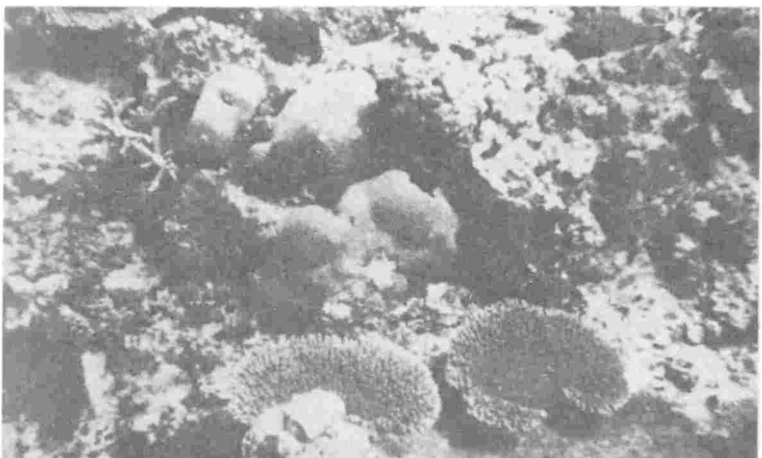
Finally, pteropodal oozes are least abundant among recent carbonate planktogenic sediments. The initial material for their formation was furnished by the remains of tests of small (0.3 to 10 mm) gastropod mollusks: pteropods.

Such are the main types of recent carbonate planktogenic oozes. It has been calculated that they cover about 128 mln km^2 of the floor of the World Ocean, or about 36% of its area. Their average thickness is about 400 m, and accumulation rate, about 1 cm in 1000 years. There are sufficient grounds to believe that for the biospheres of the geological past the order of the planktogenic carbonate accumulation figures was not smaller. It has been calculated that coccoliths alone under stable favourable living conditions over the Cretaceous period, for example, could have produced a 7-km thick layer of ooze.

The second subtype of recent biogenic carbonate sediments is formed by the benthic film of life. These sediments are called benthogenic, and Lisitsyn subdivides them into several classes.



Nummulitic limestone from the Pyramid of Cheops. 1.5-fold magnification.



Part of the underwater portion of the Great Barrier Reef. Australia.

The first class – shell, or molluskan, deposits – are encountered mainly on shelves and on summits of sea-mounts. Among shelves areas most favourable for the accumulation of coquina are those adjacent to the coast with a flat relief and without a developed river drainage. These include the colossal coquina fields at the eastern and northern edges of the Caspian Sea, in the north-west corner of the Black Sea, on Bahama Cay, off the coast of Florida. Such is, finally, the Sea of Azov which is even called "molluskan". In the near-shore zone coquina undergoes intensive crushing, and the described sediments are often represented by shell sands. In the past geological epochs shell deposits were also composed of molluskan remains, though during certain periods brachiopods also acquired great importance.

Another class of benthogenic carbonate deposits is coral-algal. It is formed in reef concentrations of life.

The reef concentrations are one of the most highly productive ecosystems of the biosphere. Reefs grow at a rate of 10 and sometimes up to 25 cm/year. The total area of all the reefs of the world is 600 thousand km^2.

The Great Barrier Reef alone, stretching along the east coast of Australia, exceeds in volume all the buildings made by man. Reefs consist of calcium carbonate. Nowadays this will surprise nobody, but just try to imagine the impression this news produced on a planter of the last century, who lived on a coral island and had been importing lime from England for years! This story was told by a traveller of that time.

Corals are the best known contemporary reef-builders. Therefore all reefs are sometimes called coral reefs, though it is not quite correct. In addition to corals, reefs are created by the activity of various living beings: green and red algae, mollusks, echinoderms, and other organisms, the palm being borne by green algae of the genus Halimeda and by red algae Zithotamnion. The tissues of corals themselves are literally packed with photosynthesizing symbiotic algae zooxanthellae, similar to the case of "photosynthesizing" worms mentioned in Chapter Two. Cyanophyceal also play an important role in the creation of autotrophic living matter of coral reefs.

The high productivity of the ecosystem of coral reefs can to a considerable extent be explained by the porosity of the reef structure itself: reef-forming organisms can "pass through" tremendous volumes of water, filtering off nutritious materials. The discovery of this most interesting phenomenon must be put to the credit of the Soviet biologist Yuri Ivanovich Sorokin. In view of biofiltration of tremendous masses of water, a low concentration of biogenic elements is no limitation to the development of coral reefs. This ecosystem successfully solves the eternal problem of oceanic life: "biogenic salts in the depth."

Yu. I. Sorokin* believes that the concentration of dissolved organic matter in the ocean is controlled on the global scale by the filtering activity of coral reefs. According to his estimations, the entire mass of ocean water is filtered through the reefs over a period of 40 thousand years. The range of recent reefs is limited to water with an average annual temperature of at least 18°C. Reef builders are hard to please in some other respects too: the sea water must have a definite salinity (from 2.7 to 4.0‰), it must not be turbid, and it must contain much oxygen. Finally, corals need light, and therefore they live at a depth of not over 40 to 50 m. The thickness of coral reefs sometimes reaches 1200 to 1400 m. How could it happen that the remains of organisms in shallow water turned out to be at such a depth?

Charles Darwin was the first to give a correct answer to this question. In his classic work "The Structure and Distribution of Coral Reefs"** he showed that the formation of coral reefs proceeds in the course of continuous subsidence of the sea floor. Corals (and other organisms) compensate for this subsidence by their growth, and the depth of the sea remains approximately the same. This circumstance enables one to use reefs for reconstructing the tectonic conditions of the geological past.

Fossil reefs are noted for their wide-spread occurrence. In the opinion of Academician D. V. Nalivkin, in the Cenozoic and Mesozoic periods reef limestones accounted for most of the mass of all limestones. If you happen to be in Leningrad, you can see reef limestones not only at the Museum of Geological Prospecting: they were also used for decorating the underground hall of the subway station "Ploshchad' Vosstaniya". Looking carefully at these limestones, one can discern organic remains in them: derelicts of sea lilies (the name may be misleading, since sea lilies are not plants, but animals, crinoids, which are becoming extinct). Complexes of reef-builders have undergone considerable changes over geological history. D. V. Osadchaya and E. V. Krasnov*** distinguish several stages in the development of reef-building complexes (Fig. 18).

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* Yu. I. Sorokin, "Ecosystems of coral reefs", *Bull. AN SSSR*, 1978, 11, pp. 29-35.

** Ch. Darwin, *The Structure and Distribution of Coral Reefs*, Smith, Elder a. Co., London, 1874, 278 pp. and other editions.

*** D. V. Osadchaya, E. V. Krasnov, "Evolution of reef-building organisms", *Trans. of the Institute of Geology and Geophysics*, Siberian Division of the USSR Academy of Sciences, 1977, Issue 302, pp. 113-125.

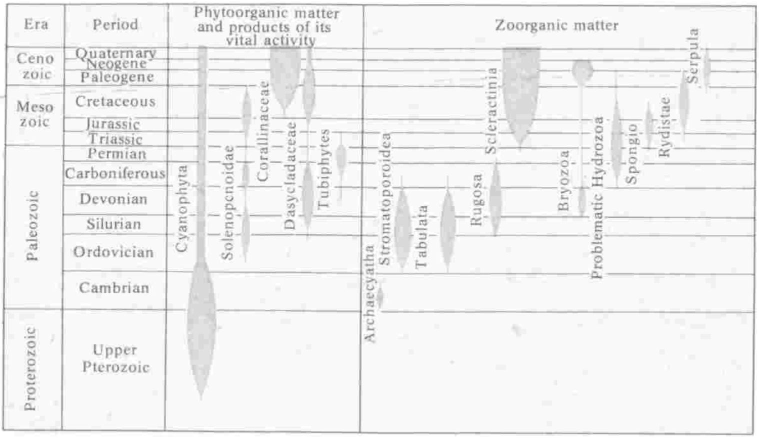

Fig. 18. Diagram of evolution of main builders of organogenic structures (after Osadchaya and Krasnov, 1977)

In addition to shell and coral-algal, there exist three more classes of recent benthogenic carbonate sediments which are not so wide-spread: (a) foraminiferal (as you remember, foraminifers can be not only planktonic, but benthic as well); (b) bryozoan; (c) sediments composed of the remains of echinoderms, ostracods, serpulids, and barnacles. All these types of carbonate sediments are predominant on the shelf, on the upper part of the oceanic slope, and on underwater uplifts.

Thus, recent benthogenic carbonate sediments of marine ecosystems are formed by two concentrations of life: littoral concentration and reef concentration. In the remaining water area of the ocean calcareous sediments are formed by the planktonic film of life. In the geological past the scheme of carbonate accumulation was, evidently, the same (see Fig. 22), though the species of carbonate-depositing organisms and the position of the carbonate compensation level were different.

Modern carbonate accumulation proceeds not only in marine ecosystems, but also in lakes, though the character of the processes occurring there is substantially different. In the opinion of Sergei Ivanovich Kuznetsov, prominent Soviet microbiologist, Corresponding Member of the USSR Academy of Sciences, the precipitation of carbonates in lakes takes place both under the effect of processes of evaporation of oversaturated solutions (as observed, for instance, in Lake

Algal reef of carboniferous age on the Amga river in Yakutia.

Sevan) and owing to the geochemical activity of bacteria. In lakes bacteria function not as direct concentrators of calcium carbonate: they merely create conditions favourable for its precipitation (the medium-forming function of living matter is thus manifest). The resulting microcrystalline calcite in combination with debris of charophytes, crustaceans and thin-valved mollusks gives so-called "lacustrine chalk" or "lacustrine marl". In the near-shore part of the lakes coquina is aggraded in some places.

Thus, in the contemporary biosphere there takes place the accumulation of carbonate sediments which then undergo further transformations. Neobiogenic carbonate sediments are characterized by the presence of minerals unstable under biospheric conditions (Academician V. F. Chukhrov called such minerals "geological ephemerae"): aragonite, vaterite, calcite monohydrate, which are then transformed into calcite. Formerly loose sediments undergo cementation, conditioned to a considerable extent by the activity of sulphate-reducing bacteria*, and sometimes, dolomitization of these sediments takes place. Neobiogenic matter is thus converted into paleobiogenic matter, i. e. into sedimentary carbonate rocks.

* J. C. Deelman, "Two mechanisms of microbial carbonate precipitation", *Naturwissenschaften*, 1975, Bd. 62, No. 10, SS. 484-485.

According to their mineral composition carbonate rocks are classified into calcite rocks (in which the mineral calcite with the formula $CaCO_3$ is predominant), dolomite rocks (in which dolomite of the formula $CaMg(CO_3)_2$ prevails), and rocks having a mixed composition.

Calcite rocks include mainly diverse limestones and one more rock with which we are most directly concerned between the ages of seven to seventeen: writing chalk. As investigations on carbonate rocks become more and more fundamental and the data on them more extensive, an ever greater portion of these rocks proves to be biogenic. This was noticed already by one of the founders of Soviet lithology, Professor Mikhail Sergeevich Shvetsov (1885-1975). He wrote: "It has become a thing of the quite recent but already almost legendary past, that even a prominent geologist, having glanced in the field at a dolomite bed, would pin a label of sandstone on it in his publications, which would stick for decades, or, examining limestones consisting of algae, would declare them to be of a specific, tectonic 'conchoidal' texture." These words date back to the early thirties, but the process of "biolithization" of limestones (and of rocks in general) goes on even now.

Lucien Cayeux.

The origin of many limestones from the skeletal remains of organisms was recognized by Nicolaus Steno. The first microscopic investigations of limestones were carried out in the 1870s by the well-known British naturalist Henry Clifton Sorby (1826-1908), President of three Scientific Societies of Great Britain: Microscopic, Mineralogical, and Geological.

No small contribution to the "biolithization" of limestones was made by the excellent "Atlases of Rock-forming Organisms" published in the thirties by the French scientist Lucien Cayeux (1864-1944) and by our compatriot, disciple of Ya. V. Samoilov, Vladimir Petrovich Maslov (1891-1968). By now foraminiferal, pelecidopodal, brachiopodal, bryozoan, crinoidal, and many other types of limestones have been distinguished, composed of various skeletal remains of organisms (Fig. 19). Pre-Cambrian limestones of various regions, which earlier were all lumped

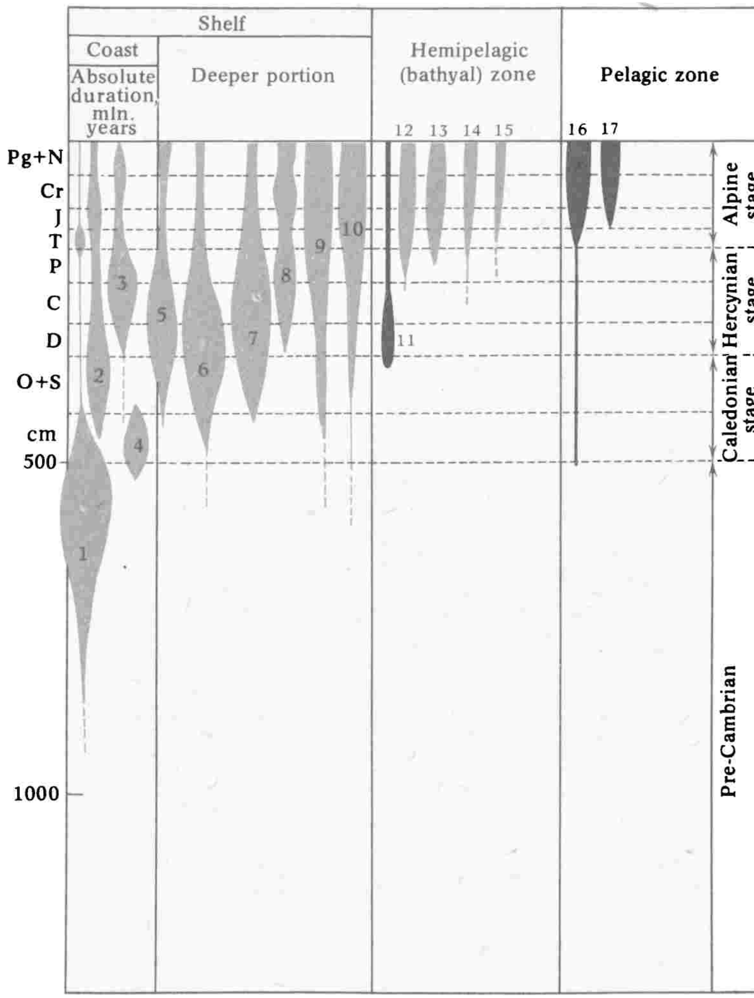

Fig. 19. Evolution of biogenic carbonate accumulation (after Strakhov, 1949):

1 – calcareous algae; *2* – corals; *3* – benthic foraminifers; *4* – archaeocyatheans; *5* – bryozoans; *6* – brachiopods; *7* – crinoids; *8* – sea urchins; *9* – pelecypods; *10* – gastropods; *11* – pteropods; *12* – abyssal brachiopods; *13* – crinoids; *14* – abyssal bivalved mollusks; *15* – abyssal sea urchins; *16* – coccolithophorids; *17* – foraminifers. Slant hatching – benthos; black – plankton together under the classification of chemogenic, are now gradually re-attributed to the rank of biogenic*.

Biogenic limestones can be composed not only of the skeletal remains of organisms and calcified thallomes of algae: coprolite limestones are also related to them; coprolite limestones are rocks the starting material for which are excrements of mud-eaters that processed lime mud. Limestones of this type are aggregates of fine lumps–coprolites (discernible only under the microscope) in combination with microgranular calcite. They have been known at least since the Ordovician and often make up whole strata as thick as 0.5 to 3, and sometimes even up to 6 m (Moscow Syneclise, Kuznetsk Basin, South-West of England). Detrital limestones are also biogenic. Both the constructive and destructive roles of life are dramatically manifest in them: comminution and re-deposition of the calcareous substrate as a result of the activity of living organisms (this was mentioned in Chapter Three).**

Formerly limestones were considered to be abyssal formations, though this conclusion was purely speculative. Detailed ecological analysis has shown many biogenic limestones to be extremely shallow-water marine or fresh-water deposits. Thus, M.S. Shvetsov (1922) in the Lower Carboniferous limestones of the Near-Moscow Basin found stigmariae: rhizomes of arborescent lycopods, provided with thin root appendages. Vegetable remains of such kind could not be transported; one could only suppose that the basin had been extremely shallow and that it was periodically infested with arborescent lycopsids (their carbonified remains make up the coal beds of the Near-Moscow Basin). The evolution of carbonate accumulation conditions in geological history was considered by J.L. Wilson in his circumstantial monograph***.

Writing chalk is a peculiar calcite rock. A zone of deposits containing writing chalk extends throughout the whole of Europe: from England to the banks of the Emba. Great Britain is supposed to owe its ancient name "Albion" (from the Latin 'albus', white) to the chalk cliffs of Dover.

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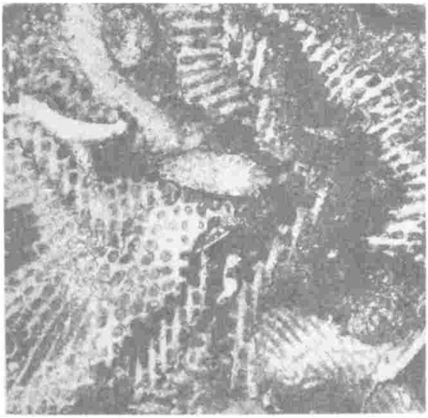
* J. Schneider, "Biological and inorganic factors in the destruction of limestone coasts", *Contr. Sedimentology*, 1976, 6, p. 112.

** S. Golubic, R.D. Perkins, K.J. Lukas, "Boring microorganisms and microborings in carbonate substrates". In: *The Study of Trace Fossils* (ed. R.W. Frey), Berlin a.o., Springer, 1975, pp. 229-259.

*** J.L. Wilson, *Carbonate Facies in Geological History*, Berlin a.o., Springer, 1975.



Bryozoan limestone of Carboniferous age. 7-fold magnification. The Kuznetsk Coal Fields.

Early investigations into the nature of chalk were carried out in the last century by the famous German naturalist Christian Gottfried Ehrenberg (1795-1876). He supposed that chalk originated from foraminifers and particles of abiogenic origin. It has now been established that chalk is a fossil analogue of coccolithic ooze. 90 to 98 per cent of its fine dispersed portion is composed of coccoliths. There are from 10^{10} to 10^{11} coccoliths in one cubic centimetre of chalk! In addition to coccoliths, exoskeletons of sea urchins, rostra of belemnites, and shells of mollusks are encountered in chalk.

For a long time it was not clear why chalk features no lamination. This problem was solved with the aid of a method of impregnating chalk with lubricating oil*, elaborated by the Soviet lithologist G. I. Bushinsky (1903-1980). With such treatment traces of mud-eaters filled with their excrements become apparent. It becomes clearly seen that coccolithic ooze, from which chalk formed, had been intensively processed by mud-eaters and repeatedly passed by them through their alimentary tract. This circumstance conditions the absence of lamination in writing chalk. The bioturbation of mud-eaters in the English Chalk rocks has recently been considered by W. J. Kennedy**.

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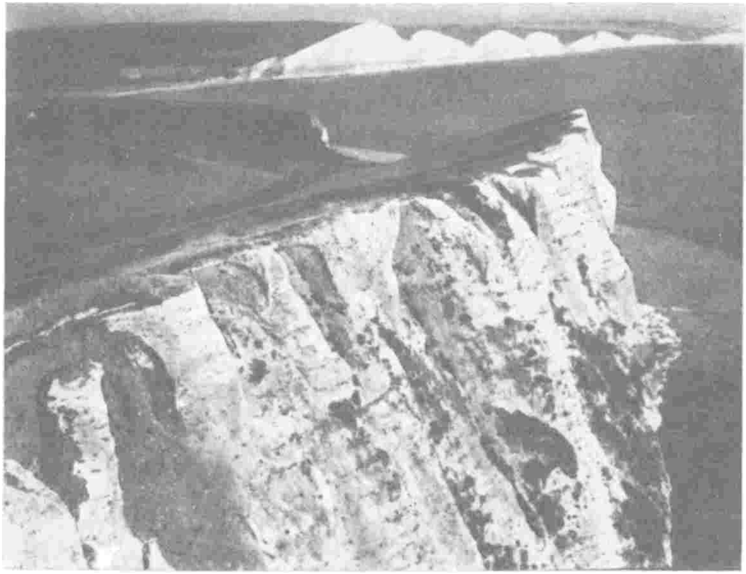
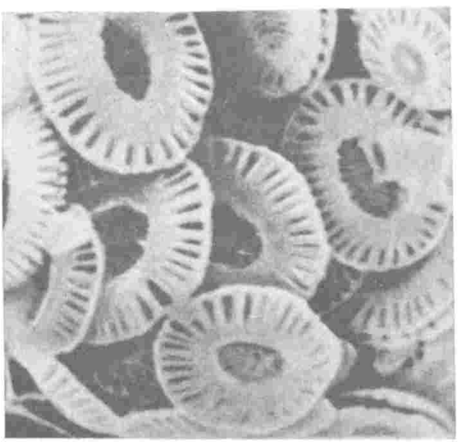
* G. I. Bushinsky, S. I. Shumenko, *Writing chalk and its origin, Lithology and Useful Minerals*, 1979, 2, pp. 37-54.

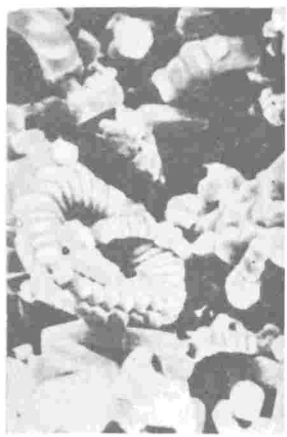
** *W. J. Kennedy*, "Trace fossils in the Chalk environment". In: "*Trace Fossils*" (ed. T. P. Crimes, J. C. Harper), Liverpool, Seel House Press, 1970, pp. 263-282.



Chalk cliffs on the south coast of Great Britain between Eastbourne and Seaford. In the background – Beachy Head.



Recent coccolith ooze of the Black Sea. Scanning electron micrograph. 8,000-fold magnification.



Writing chalk composed of remains of coccoliths. Scanning electron micrograph. 4,300-fold magnification.

Writing chalk is characteristic only for Upper Cretaceous deposits, this being associated with the thriving of coccolithophorids in the seas of that time and with conditions favourable fór the accumulation of calcareous sediments. There was much dispute about the depth of chalk formation: different authors estimated in to be in the range of 200-300 to 1100-1300 m. As a matter of fact, the depth of accumulation of coccolithic oozes in the Cretaceous period could be different. This is easy to understand: coccoliths were produced by the planktonic film of life, and the depth of the sea where oozes accumulated was not critical.

Dolomites are a specific type of carbonate rocks. They are named after their discoverer, the French mineralogist, D. Dolomieu (1750-1801).

In appearance dolomite rocks are very much like limestone, but, in contrast to it, they do not foam when acted upon with cold dilute hydrochloric acid. Well preserved remains of organisms are rarely encountered in these rocks. This, evidently, is an indication of an enhanced salinity of the basin in which they had deposited. Dolomite rocks are encountered mainly in pre-Cambrian and Paleozoic deposits; they are considerably less common in the Mesozoic and, particularly, in the Cenozoic.

As soon as it comes to dolomites, a dolorous note can be detected in geological papers and manuals. "The problem of the formation of dolomite rocks is known to be one of the most difficult in theoretical lithology," writes Academician N.M. Strakhov. "Not many rocks are known, about which so many contradictory opinions have been voiced and suggestions put forward on the question of their origin, and whose origin, nevertheless, still remains as dubious and obscure as that of dolomites," testifies Professor M.S. Shvetsov.

The complexity of the problem lies in that dolomite cannot be found in the composition of contemporary living matter (see Table 5). True, quite recently it has been found in an urolith of a Dalmatian dog*. Recent dolomite sediments could not be found for a long time. It was only in the thirties and forties that such sediments were found in the sediments of salt lakes and lagoons in the Soviet Union (Balkhash), on the south coast of the Persian Gulf, on the Bahama shoals, in southern Florida,

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* C.E. Mansfield, "An Urolith of Biogenic Dolomite - Another Clue in the Dolomite Mystery", *Geochim. cosmochim. Acta*, 1980, v. 44, 6, pp. 829-839.

and in Australia (Coorong Lagoon)* It was established that in the recent geological epoch dolomite accumulates in aqueous ecosystems characterized by high salinity, a high pH of the water, and abundant vegetation.

As has been shown by the founder of theoretical lithology and geochemistry of sedimentary rocks in the Soviet Union, Academician Nikolai Mikhailovich Strakhov (1900-1978), dolomite formation in this case is conditioned by the medium-forming activity of autotrophic living substance: in the course of the photosynthesis process plants extract from water the carbon dioxide dissolved in it; this leads to an increase of the pH and contributes to the precipitation of dolomite. American scientists came to the same conclusion, proceeding from the study of pre-Cambrian dolomites of California**. The connection between an enhanced content of organic matter and dolomite formation can be well traced on fossil material: dolomite rocks often emit the smell of hydrogen sulphide, and if the rock consists of alternating calcite and dolomite intercalations, then dolomite is concentrated in the dark intercalations, and calcite, in the light ones.

Thus, in many cases there exists a marked positive correlation between the content of biogenic organic matter and dolomite in the rock. This correlation can be explained by two interrelated circumstances. In the first place, magnesium, as we know, enters into the composition of chlorophyll (its content there reaches 2%), and an enhanced productivity of autotrophic living matter may result in a rather high percentage of magnesium in bottom sediments. On the other hand, ammonia, originating in the decomposition of neobiogenic organic matter, renders the reaction of the medium alkaline, this, in its turn, favouring the formation of magnesium hydroxides and carbonates. The latter, combining with carbonate sediment, form dolomite.

There exist various proofs of dolomite formation as a result of the vital activity of organisms. Thus, as early as the end of the last century the Russian scientist, Professor Alexander Andreevich Verigo (1837-1905) reported on interesting experiments for the elucidation of the influence of bacteria on the formation of dolomites. According to those data, ooze,

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* C.C. von der Borch, D. Lock, "Geological Significance of Coorong Dolomite", *Sedimentology*, 1979, v. 26, 6, pp. 813-824.

** L. Wright, E.G. Williams, P. Cloud, "Algal and cryptalgal structures and platform environments of the late pre-Phanerozoic Noonday Dolomite, eastern California", *Geol. Soc. Amer. Bull.*, 1978, v. 89, 3, pp. 321-333.

Cambrian dolomite composed of the remains of blue-green algae of the genus Collenia. Siberian Platform.

placed into a test tube and infected with the bacteria Proteus vulgaris, substantially changed after a period of one and a half years: yellowish-white beads appeared in it, which, upon analysis, proved to be dolomite; in control test tubes formation of dolomite was not observed.

In the 1950s similar experiments in aquaria were conducted by the French researcher C. Lalo who came to the conclusion that bacteriogenic carbonates (including dolomite) can be obtained from any sediment, provided that the quantity of organic matter is sufficient, the temperature is high enough, and the bacterial processes proceed in shallow water under the conditions of intensive illumination. All these factors are characteristic of tropical lagoons.

By now the wide-spread occurrence of dolomites composed of the remains of Cyanophyceae is established in deposits of various ages: Permian (the Donets Basin, the Urals Territory, North America); Cambro-Silurian (the Siberian Platform); and Late Cambrian (north of Siberia, the Kara-Tau Range). Most characteristic of them are dolomites produced by various species of Collenia, though other forms of Cyanophyceae are also encountered. Reef and other biogenic structures are often composed of such protosedimentary dolomites. Still another possibility of the formation of dolomites with the participation of biogenic matter has recently been demonstrated: their formation inside the shells of dead gastropods*. In this case the formation of carbonates (including protodolomite) proceeds with

* L. E. Sterenberg, L. S. Fomina, A. B. Sheko, "One of the ways of formation of carbonate minerals", *Doklady AN SSSR*, 1976, v. 229, 6, pp. 1430-1432.

the participation of microorganisms which process organic matter (the body of the dead mollusk and the matter which gets inside the shells together with terrigenous material).

The mystery of dolomite is beginning to be solved.

So, biogenic carbonate rocks are formed as a result of the activity of both the planktonic and (to a lesser extent) the benthic film of life in the ecosystems of the World Ocean and of inland water bodies. The intensity of carbonate accumulation in the geological past was to a considerable extent determined by paleogeographic situation and by the content of carbon dioxide gas in the atmosphere, evolved there owing to volcanic processes. Alexander Borisovich Ronov, Corresponding Member of the USSR Academy of Sciences, formulates the main law of carbonate accumulation in the following manner: "The quantity of carbonate sediments deposited during this or that epoch after the pre-Cambrian was directly proportional to the intensity of volcanic activity and to the area of inland seas."*

Let us recall the tables illustrating the character and localization of the processes realized by living matter, and its main functions in the biosphere (see Tables 3-4). From these Tables it can be seen that in the formation of calcite rocks the function of living matter, which is most manifest in that of concentration, realized inside the organism (construction of skeleton). As to dolomite rocks, they are formed through the agency of both the concentration and medium-formation function of living matter, formation of dolomite occurring not inside but outside the organism.

Siliceous rocks in their origin are similar to the carbonate ones in many respects. Siliceous rocks are those consisting in the main of silicon minerals: opal, chalcedony, or quartz (clastic quartz rocks – sandstones and aleurolites – do not belong to this group).

"The entire history of silicon in the ocean is altogether dependent on life processes", wrote V.I. Vernadsky**. Advances made in science during the last half century have confirmed this thesis. The mechanism of concentration of silicon by living

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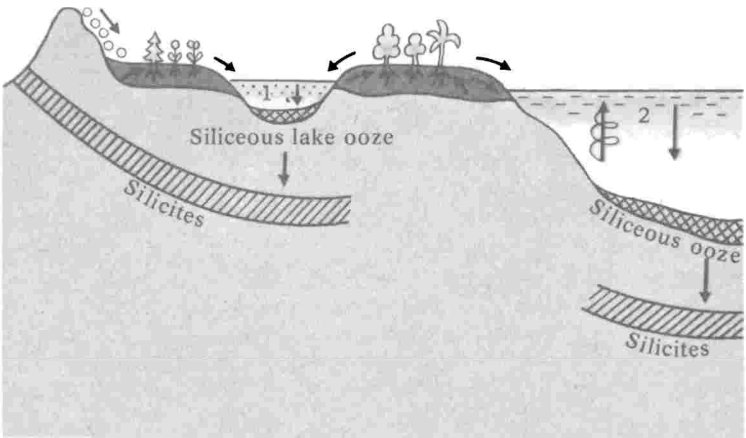
* A.B. Ronov, "Volcanism, carbonate accumulation, life (regularities of the global geochemistry of carbon)", *Geochemistry*, 1976, 8, p. 1268.

** W. Vernadsky, "La matière vivante et la chimie de la mer.", *Rev. gén. des sci.*, 1924, t. 35, 1, pp. 5-13; No. 2, pp. 46-54.



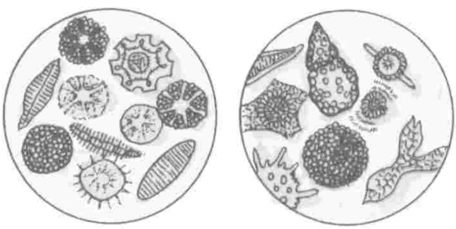


Fig. 20. Diagram of formation of siliceous rocks:

1 – fresh-water siliceous plankton; *2* – marine siliceous plankton

matter has recently been studied by W. Heinen and J. H. Oehler*.

It has been established that deposition of siliceous sediments takes place mainly in marine ecosystems and, to a smaller degree, in the ecosystems of inland water bodies (Fig. 20). This is so in spite of the acute shortage of silica in sea water: normal solubility of silicon is 0.012% and the real solubility is 30 times less: only 0.0004%.

Organisms responsible for the precipitation of silica have long been called "siliceous". These are diatoms (containing 90% of all the silica suspended in the World Ocean), radiolarians, sponges, and silicoflagellatae (flagellate algae); in fresh-water lakes these are almost exclusively diatoms. No signs of chemogenic

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* W. Heinen, J. H. Oehler, "Evolutionary aspects of biological involvement in the cycling of silica". In: "*Biogeochemical Cycling of Mineral-Forming Elements*" (ed. P. A. Trudinger, D. J. Swain), Elsevier, Amsterdam a.o., 1979, pp. 431-443.

Modern marine diatoms. Scanning electron micrograph. 2000-fold magnification.

precipitation of silica have been detected in modern aqueous ecosystems.*

Among siliceous rocks, composed predominantly of the skeletal remains of organisms, four types are distinguished: diatomites, silicoflagellites, radiolarites, and spongolites. The first three types of siliceous rocks are planktonogenic; spongolites are benthogenic formations.

Localization of silicon accumulation in the ocean is associated mostly with areas of mass development of diatoms (small concentrations of them are observed in upwelling zones as well). In the contemporary biosphere, however, siliceous sediments are accumulated not in all the places where diatoms are extensively developed. Hydrodynamic factor and supply of terrigenous and carbonate biogenic material also play an important role: pure siliceous sediments, naturally, do not accumulate in such places where the role of these sedimentation components is significant).

Diatomites are light (white or yellowish) finely porous rocks, the main bulk of which is composed of the microscopic exoskeletons of diatoms. The number of integral exoskeletons of diatoms in 1 cm^3 reaches several million. Diatomites exhibit uncommon properties for rocks: they are very soft (so that you can write with a piece of diatomite on a board), porous (their porosity reaches 70-90%), and, finally, they are light-weight: their volume weight in a lump does not exceed unity, and in some

* H. E. Harper, Jr., A. H. Knoll, "Silica, diatoms, and Cenozoic radiolarian evolution", *Geology*, 1975, v. 3, 4, pp. 175-177.

cases comes down to 0.5-0.7 and even 0.25-0.30 g/cm^3 (there is a story about A. E. Fersman: when A. E. Fersman was on leave, he collected stones all the same. The porter at the railway station could not help wondering: "What a heavy suitcase! You have not stuffed it with stones, sir, have you?" Had Fersman collected diatomites, the porter would have had no grounds for grumbling).

To understand the unusual properties of diatomites, one should consider the initial material they are composed of: diatoms.

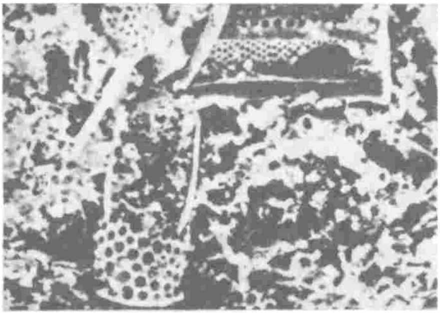
The word "diatom" stems from the Greek 'diatomos', cut in two. Exoskeletons of diatoms, indeed, consist of two parts, one part entering the other. If we compare the exoskeleton of diatoms with things customary to us, then, perhaps, the closest resemblance will be found with a perforated split case for a toothbrush, the difference being in that diatoms are porous over the entire surface of their body and have a more diverse shape: they can be disk-shaped, fusiform, prismatic... Small wonder then, that rock consisting of these exoskeletons is lighter than water and avidly absorbs moisture (apply the test rock to your tongue, and, if the rock is diatomite, it will stick to it).

Diatoms proliferate at a tremendous rate. Under favourable conditions the number of cells may be doubled every 4 hours. The layer of biogenic silica accumulating in the World Ocean through the agency of diatoms alone may reach from 7.5 to 30 cm in one thousand years.

Marine diatomites have been known since the Late Cretaceous period and occur as strata with a thickness of dozens and even hundreds of metres. The thickest beddings of diatomites, reaching 1600 m are known in the United States, in California (Lompoc Field of Miocenic age).

Lake diatomites are younger (fresh-water diatoms appeared only in the Eocene period) and are less wide-spread; they are known in the Caucasus, in the Far East, in the Carpathians, in the north of Western Europe.

The regularities of silicon accumulation in small lakes have been studied in detail by L. L. Rossolimo. Lake silicon accumulation was established to be localized mostly in moderate and high latitudes. In some cases (but far from always) it is located in volcanic areas: volcanism is an additional source of mineral food for diatoms. If volcanic material is not introduced, a prerequisite for lake silicon accumulation is an extensive development of persilicic crystalline rocks subject to intensive



Marine diatomite. Scanning electron micrograph. 750-fold magnification.

weathering. Morphological specific features of the lakes in which silica is accumulated have also been established: shallow water (predominantly down to 3-4 m) ensuring sufficient aeration of the entire mass of water, and a small water area of the lake or its subdivision into autonomous parts (this precluding the motion of water at a considerable speed and hindering the accumulation of oozy sediments). Subdued relief of the surroundings and the presence of mossy cover favour silicon accumulation.
A. A. Arutyunyan has noted that diatomites of small lakes are characterized by high purity, whereas in large lakes it is usually low, and the integrity of the exoskeletons of diatoms is poor. As regards silicon accumulation in large lakes, it obeys marine rather than lake "laws".

If diatomites are most wide-spread among biogenic siliceous rocks, silicoflagellites, which have been recently described for the first time, are most rare ones. They are composed of the skeletons of other representatives of phytoplankton – siliceous flagellate algae or silicoflagellatae. Usually skeletons of these algae can be encountered in small quantities in diatomites too, but in neogenic formations of South-East Europe silicoflagellites make up individual strata.

Radiolarites, like the preceding types of siliceous rocks, are also composed of plankton remains, but, in contrast to diatoms and silicoflagellatae, radiolarians pertain to zoo- rather than to phytoplankton. Accordingly, the area of their occurrence lies below the euphotic zone and embraces a portion of the aphotic zone. The major part of the radiolarian biomass is, nevertheless, confined to the upper 250 metres of the water mass of the ocean (radiolarians are exclusively marine animals). The name "radiolarian" stems from the Latin 'radius', ray. The microscopic skeleton of radiolarians is an intricate spherical open-work structure, with long spicules extending in all directions from the sphere with strict regularity. One might think that radiolarians were created by nature specially to illustrate the laws of symmetry and perfection.

In one book radiolarians were called the "most elegant and beautiful formations existing of fauna". And though I am inclined to share the opinion of the ancient Greeks who maintained the beautiful human body to be the most perfect creation of nature, the elegance of radiolarians is, indeed, worthy of our admiration (Fig. 21).

Radiolarians are known of the Cambrian period. They belong to the number of those rare organisms which were first discovered in fossil state and only then found in the present-day biosphere.

Radiolarites are less wide-spread in the metabiosphere than diatomites, but the thickness of their strata reaches 38 m (Paleogene of Barbados). The distribution of radiolarites in the sedimentary shell of the Earth has recently been studied by H. R. Grunau*. Radiolarian clays, i.e. rocks in which radiolarian skeletons are liberally diluted with terrigenous material, are considerably more wide-spread (compared with "normal" radiolarites).

As concerns spongolites, some time ago they were regarded as quite rare, but now beddings of marine spongolites, with a thickness of up to 10-15 m, are known in the Cretaceous and Paleogene deposits of the Ukraine, in the Paleogene of the Caucasus, in the Cretaceous deposits of Central Europe, in the Paleozoic of the Urals Territory and the North-East of the Soviet Union, and in other regions. Fresh-water spongolites have also been found; their thickness in the Eocene of Kazakhstan reaches 6-10 m.

Spongolites are rather diverse in appearance; they are homogeneous fine-grained rocks, greyish-green and black in colour, consisting of spicules of bottom-dwelling animals, so-called "siliceous"sponges. Spicules are structural elements of the skeleton of sponges. When sponges are alive, these structural elements are bound together into a skeleton by organic matter; after the death of sponges their skeleton disintegrates into separate spicules. The length of the spicules may reach 2 to 3 mm, their cross-section comes down to hundredth fractions of

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* H. R. Grunau, "Radiolarian cherts and associated rocks in space and time", *Ecl. Geol. Helvetica*, 1965, v. 58, pp. 157-208.

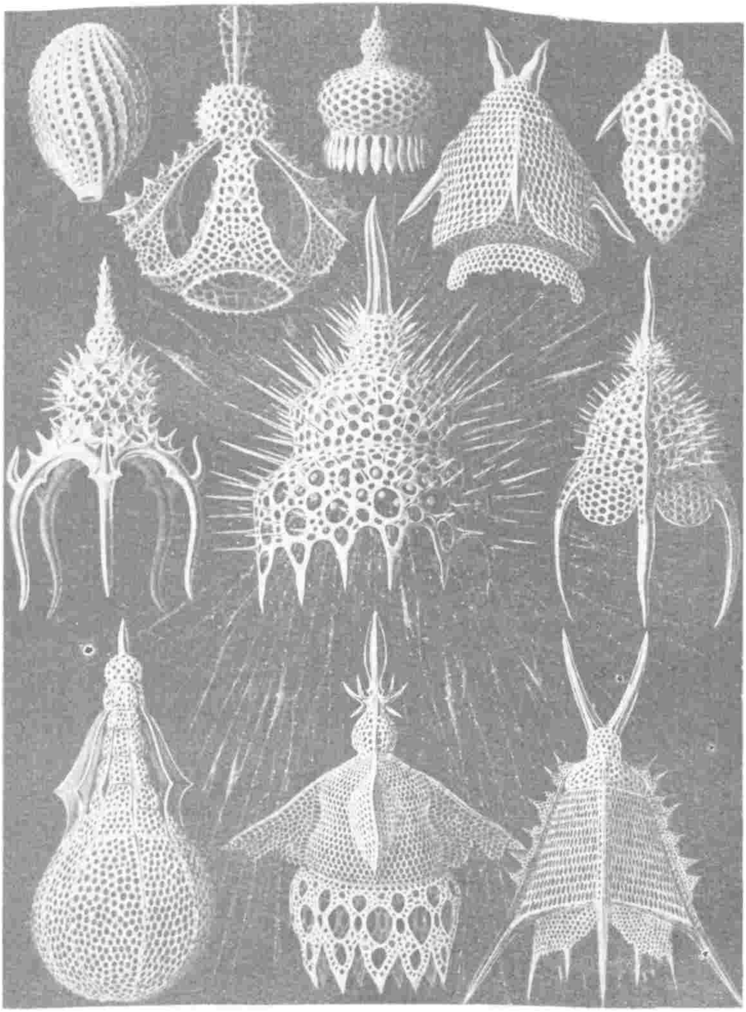

Fig. 21. Radiolarians (sheets from E. Haeckel's album "The Beauty of Forms in Nature")

a millimetre, and their shape may be quite diverse: from simple (needle-like) to bent and star-like. The spicules can resemble the letters "C" and "S", all kinds of fish-hooks, tridents, yokes...

Recent spongolites are known in the Barents Sea, where "glass wool" from the spicules of siliceous sponges makes up a layer as thick as 30 to 60 cm. Since spicules account for only a few per cent of the total volume of the body of siliceous sponges, considerable accumulations of these organisms are required for the formation of spongolites. Recent spongolites are encountered at depths of 250 to 500 m; at greater depths the density of population of sponges is, evidently, insufficient for the accumulation of pure varieties of spongolites.

All the four types of rocks considered above are, undoubtedly, composed of biogenic silica (opal). The origin of some other siliceous rocks: tripolis, gaizes, jaspers, is a subject of discussions. Organic remains in them are rather rare, and many lithologists consider these rocks to be chemogenic. There exists an opinion, however, that gaizes and tripolis have formed from diatomites, and spongolites and jaspers, from radiolarites, which lost their initial structure in the course of the diagenesis and katagenesis processes.*

As early as the end of the last century Academician Feodosi Nikolaevich Chernyshev, after whom the Museum of Geological Prospecting in Leningrad is named, found remains of a rich fauna of radiolarians in jaspers of the South Urals. "Our jaspers are, no doubt, abyssal slime," wrote Chernyshev in 1889, "and the silica of radiolarian skeletons furnished the fundamental material for the accumulations of quartz, scattered throughout the rock mass." In the first decades of the twentieth century the idea of the predominantly biogenic origin of siliceous rocks was expressed by Yakov Vladimirovich Samoilov**.

Siliceous sediments are formed in the biosphere as a result of the concentration function of living matter. Both in the recent geological epoch and in the geological past (starting from the Cambrian Period) accumulation of biogenic silica has proceeded mainly in marine ecosystems; if initially it was effected by the benthic film of life (siliceous sponges) and by zooplankton (radiolarians), starting from the end of the Mesozoic Period the main role in silicon accumulation has been taken over by phytoplankton (diatoms).

Lake silicon accumulation began only in the Eocene Period with the appearance of fresh-water forms of diatoms and sponges, and its significance is subordinate.

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* S. I. Shumenko, "Nanopetrography of tripolis and gaizes in connection with the question of their genesis", *Doklady AN SSSR*, 1978, v. 240, 2. pp. 427-430.

** Ya. V. Samoilov, E. V. Rozhkova, "Deposits of silica of organic origin", *Trans. of the Institute of Applied Mineralogy*, 1925, Issue 18, pp. 1-76.

A specific factor controlling the biogenic accumulation of silicon is an intensive supply of silica to the ecosystem. This can be effected in different ways: in marine and fresh-water ecosystems – through the supply of volcanism products or dissolved products of weathering of percilicic rocks; in marine ecosystems, in addition, this may occur owing to the raising of abyssal water, enriched with silicon and phosphorus.

It has been established, proceeding from the geological (starting from the Paleozoic Period) and recent material, that the supply of volcanic products intensifies the vital activity of all groups of siliceous organisms. These organisms, however, are not omnivorous, and the character of volcanism products determines the predominant development of this or that species. As has been shown by I. V. Khvorova, the formation of substantially radiolarian deposits in geosynclinal masses is localized in areas of development of main effusive volcanism, while the accumulation of diatomites is associated with the appearance of large masses of a fine suspension of volcanic glass in the mass of water.

When an undertaking is hopeless, people sometimes say, "going on a wild-goose chase". A task, perhaps still more difficult than wild-goose chasing, is that of tracing currents which existed millions of years ago in the sea. Siliceous rocks offer us a clue here: guided by these rocks, one can successfully reveal ancient upwelling concentrations of life. Thus, recently the Ukrainian scientist Yu. N. Sen'kovsky, proceeding from the investigation of siliceous rocks, has outlined an upwelling in the sea which existed in the Cretaceous Period on the territory of the Carpathians, and N. A. Brewster of the United States has outlined an upwelling in the Neogene sea of the Antarctic.

We shall conclude our story about siliceous rocks with the recently published words of Vernadsky: "Though in the history of silicon the role of organisms is not as dramatic as in the history of calcium, but even here the history of the given chemical element cannot be understood by us without it either."*

Caustobioliths are a third group of sedimentary rocks, characterized by considerable concentrations of biogenic matter. Mankind was forced to become interested in caustobioliths about one hundred years ago. "Now, when Russia will shortly

* V. I. Vernadsky, *Living Matter*, Nauka Publishers, Moscow, 1978, p. 60.

be pierced by railways in various directions, when even in Moscow one has sometimes to pay 45 roubles in banknotes for a tolerable sazhen of birch firewood, now public attention is of necessity directed to finding new combustible material, which is expected to be obtained either in coal, or in peat." These lines date back to 1857, and nowadays mankind annually burns as much caustobioliths as bygone biospheres could accumulate over a million of years. Humanity has again of necessity turned its attention to renewable sources of energy, to living matter, and more particularly, to the green mass of plants, from which, by processing with anaerobic bacteria, combustible gas is produced.*

The term "caustobioliths" is composed of three Greek words: 'kaustos', burning, 'bios', mode of life, and 'lithos', stone. Peats, sapropels, coals, combustible shales and petroleum – recent sediments and rocks, composed mainly of biogenic organic matter, are caustobioliths.

"Organic matter, penetrating all the substances of the earth's crust accessible for study, is all of biogenic origin... Through the agency of slow geological processes these organic substances, the remains of the bodies and metabolism of organisms enter the stratisphere from the biosphere, into the metamorphic envelope,"** wrote Vernadsky.

The most intensive accumulation of organic matter in the present-day biosphere proceeds in swamps and in some lakes. Accumulation of neobiogenic organic matter in oceans is a separate question.

It is not always easy to define everyday concepts. For instance, it is not so easy to define what a swamp is. One definition reads: "Swamp can be characterized as a lake, but with bound water, or as land usually containing 90% water and only 10% dry matter." Indeed, one part of dry peat is capable of retaining from 15 to 25 parts of water! Vast areas of the Soviet Union are characterized by optimal conditions for peat accumulation: adjacent to the Baltic Sea, Byelorussia, and the northern part of the Ukraine, the north of the European part of the USSR, East Siberia, the Far East. Sixty per cent of the world's resources of peat are in the Soviet Union.

Climatic conditions are a "triggering mechanism" for the

* J. G. Zeikus, "Chemical and fuel production by anaerobic bacteria", *Ann. Rev. Microbiol.*, 1980, v. 34, pp. 423-464.

** V. I. Vernadsky, *Works*, v. 4, Bk. 2, p. 93.

formation of swamps. In the course of the development of peat bog the role of climatic factors diminishes. The leading factor becomes the accumulation of peat as such, which changes all the environmental conditions. Swamp gradually turns into an ecosystem, developing to a considerable extent in accordance with its own internal laws and relatively independent of the environment.

In addition to the landscape-climatic prerequisites of peat accumulation there also exist ecological ones; these are factors limiting the development of consumers of autotrophic living matter (we have already discussed this in the preceding chapter), e.g. deficiency of nitrogen. Thus, for intensive mineralization of neobiogenic organic matter by saprotrophs it is necessary that the carbon/nitrogen content ratio should be within the range of 20 to 25. In swamps this ratio is higher, and therefore the decomposition of biogenic organic matter proceeds there at a slower rate.

Emphasizing the specific character of caustobiolith formation conditions, the well-known Soviet geologist K. G. Voinovsky-Krieger (1894-1979) wrote: "Accumulation of vegetable mass, evidently, obeys other regularities than accumulation of sand and aleurite: in addition to the geomorphological factor in this case a biological factor participates, and perhaps even plays the main role."

Thus, the accumulation of the neobiogenic organic matter of peats is controlled by the ecological factor. The transition of peats into paleobiogenic matter is determined by another factor: the geological one (tapho-factor). Seaside and littoral-lake peat bogs in the zones of sagging of the earth's crust have maximum chances of passing over to the fossil state.

Another type of ecosystem in which accumulation of neobiogenic organic matter takes place is inland water bodies. It is of interest to consider the relationship between the depth of the water body and the percentage of organic matter subject to burial. Thus, in the lakes of Lithuania with an average depth of 3 m, 2/3 of the annual production of phytoplankton is buried; with the depth from 3 to 10 m, 1/3; and in those deeper than 10 m, only 1/10.

In contrast to peat bogs, in inland water bodies there takes place accumulation mostly not of the remains of higher plants, but of sapropel (from the Greek 'sapros' + 'pēlos', "rotten slime"): a deposit of debris of phyto- and zooplankton, bottom-dwelling and freely floating organisms, and excrements of animals. A large contribution to the study of recent sapropels has been made by Nina Vitalievna Cordet.

Finally, biogenic organic matter in the present-day biosphere accumulates in marine ecosystems, mainly in shallow lagoons. The basic factor which controls the accumulation of neobiogenic matter in the World Ocean is circumcontinental zonation. According to the data reported by the Soviet geochemist E. A. Romankevich,* V. I. Vernadsky prize winner of 1978, in the peripheral areas of the ocean, comprising shelves, continental slopes and near-continent abyssal troughs, 87% of the entire organic matter of the ocean is accumulated; in the marginal portion of the ocean bed, 10%; and in central areas, about 3%.

This is how accumulation of organic matter occurs in the present-day biosphere. (Formation of caustobioliths is shown diagrammatically in Fig. 22.) The accumulation of biogenic organic matter in the geological past proceeded in a similar manner. "The formation of coals is associated with bogs, with large accumulations of plants, characteristic of countries with moist climates, in the outfalls and deltas of large rivers, in the plains of their basins, on the coasts of continents and islands, in tidal flats. All these are large concentrations of life, where the mass of organic matter, found in the state of slow decomposition, is tremendous. Possibly, these are the largest concentrations of life on land that we know of",** wrote Vernadsky.

Fossil coals have been known since the Devonian, i.e. since the time when plants came from the sea to the littoral areas of continents. Black and at first sight unprepossessing, fossil coals in sections, when viewed under a microscope, fascinate with the range of orange-red hues they display. They are composed mainly of carbonified vegetable tissues (which are called phyterals: the suffix is the same as in the word "mineral", and the Greek root 'phyto-' means a plant). In recent years methods for their analysis have been elaborated: with these methods the initial organ of a plant, its taxonomy, and the process of conversion are determined***. From these data an idea can be obtained about the vegetation which served as the initial material for the formation of coal.

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* E. A. Romankevich, *Geochemistry of organic matter in the ocean*, Nauka Publishers, Moscow, 1977, p. 256.

** W. Vernadsky, *La géochimie*, Alcan, Paris, 1924, p. 253.

*** A. V. Lapo, "Phyterals of Jurassic coals of Tuva", *The Palaeobotanist*, 1976 (1978), v. 25, pp. 205-216.

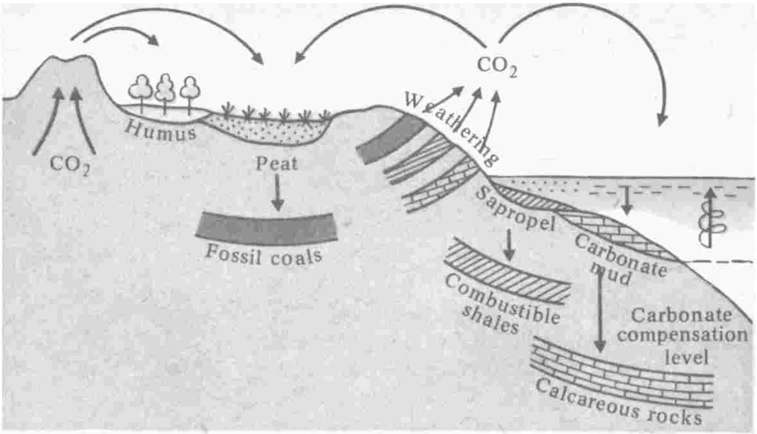

Fig. 22. Diagram of formation of caustobioliths and carbonate rocks:

1 – sapropel-forming organisms; *2* – carbonate organisms

The composition of coal was subject to substantial changes in the course of geological history*. In Carbonaceous coals there are many spores; in Late Carbonaceous coals solid trunks of woody plants appear for the first time (earlier woody plants were predominantly tubular, as present-day bamboo, or had a loose central portion, as reed); in the Mesozoic Period coals are encountered pressed from leaves or from tar needles; for the Paleogene and Neogene periods lignites are characteristic: remains of conifers with a macroscopically distinguishable structure of wood, etc. From the composition of phyterals it is possible to determine approximately the age of coals.

Biogenic matter formed by heterotrophs is rather seldom encountered in coals. These are mainly fungi, most wide-spread in Paleogene and Neogene coals. Remains of bacteria, anthropods, and vertebrates have also been found. The most

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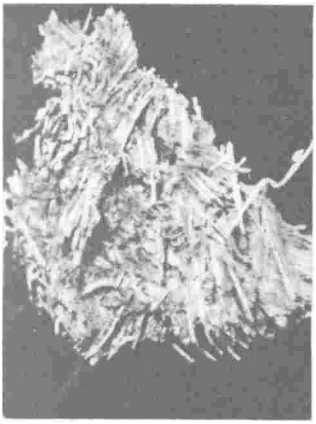
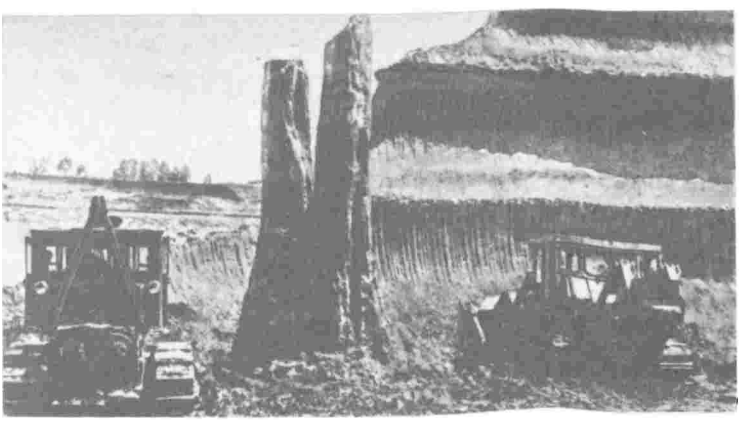
* Yu. A. Zhemchuzhnikov, "Development of coal accumulation in geological history", *Izv. AN SSSR*, geol. series, 1955, 3, pp. 57-82.



Mesozoic fossil coal composed of compressed leaves of Czekanowskia. The Lena Coal Fields.

surprising findings were made in two brown coal fields of Central Europe: Geiseltal (Paleogene) in the German Democratic Republic and Turow (Neogene) in Poland. Remnants of a surprisingly rich and diverse fauna of vertebrates were found there (let us recall the above-cited words of Vernadsky about the "largest concentrations of life"): fishes, amphibians, reptiles – crocodiles, lizards, snakes, birds, and, finally, mammals: tapirs, horses, marsupial rats, bats, prosimians. In the coal from one of the small coal fields of Italy M. Teichmüller, the



Lignite – a trunk of Sequoioxylon, buried at the site of its growth in a coal bed of Neogene age. Hungary.

prominent West German specialist in coal petrography,* found the remains of a young individual of a "near-man" – of an anthropoid ape belonging to the genus allied to ours. The baby was drowned in a swamp...

While fossil coals correspond to ancient peats, combustible shales were formed from sapropels which sometimes accumulate in lacustrine, and more often, in marine ecosystems. Academician Nikolai Mikhailovich Strakhov, who studied this problem in detail, distinguishes the following types of combustible shales: (a) pelagic planktonogenic combustible shales; (b) pelagic benthogenic combustible shales; (c) combustible shales of flood and pre-estuarine types; (d) combustible shales of reef type (the latter are rarely encountered). It is easy to see that these types of combustible shales are formed by various concentrations of life; by the planktonic and benthic films of life, by the littoral and reef concentrations of life.

In all cases the biogenic material of combustible shales was intensively processed by benthic organisms, and therefore it is rather difficult to identify organic remains in combustible shales. Nevertheless, the Soviet paleobotanist Mikhail Dmitrievich Zalessky (1877-1946) has carried out classical investigations of the initial vegetable material of some Paleozoic and Mesozoic combustible shales. The French specialist in coal petrography Boris Alpern came to the conclusion that the predominant constituent of the organic matter of Paleozoic combustible shales are the remains of the fresh-water alga Botrycoccus braunii, while for Mesozoic combustible shales large algae Tasmanites and small Cyanophyceae Nostocopsis are characteristic. In the Ordovician deposits of the Baltic Region so-called "dictyonemic shales" occur, in which organic matter is represented by the remains of graptolites – extinct organisms related to the phylum of coelenterates.

At one time the problem of the genesis of petroleum caused a lot of argument. With time, however, owing to the investigations carried out by the school of petroleum scientists, headed by the Corresponding Member of the USSR Academy of Sciences Nikolai Bronislavovich Vassoyevich, the origin of petroleum from biogenic organic matter was open to less and less doubt.

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* M. Teichmüller, "Die Oreopitecus – führende Kohle von Bacinello bei Grosseto (Toskana, Italien)", *Geol. Jahrb.*, 1963, Bd. 80, SS. 69-80.

The school of N. B. Vassoyevich developed a theory of petroleum formation called "sedimentary-migrational". According to this theory petroleum is "a child of lithogenesis". Remains of the organisms of the planktonic film of life served as the raw material for petroleum. If the depth of the water body is not great and the conditions of burial are favourable, organic matter, comprising remains of plankton, passes over to the fossil state. The "birth" of petroleum as a liquid phase of hydrocarbons, separating from scattered organic matter, takes place in the earth's crust within the so-called "main petroleum-formation zone" located at a depth of 2 to 6 km below the earth's surface, where temperatures of 60 to 160°C are prevalent (it is precisely in this sense that petroleum is "the child of lithogenesis").

The proof that petroleum really formed from biogenic organic matter is in the isotopic composition of carbon which composes petroleum: in biogenic and abiogenic matter the ratio of carbon isotopes is not the same, and they can be distinguished by this characteristic. Moreover, "biomolecules" were found in petroleum, i.e. such compounds which have analogues in living nature and which, thus, also bear witness to the biogenic character of the initial material of petroleum.*

N. B. Vassoyevich has shown** that Vernadsky's views to a considerable extent served as the basis for these conceptions. In the world literature the organic theory of the origin of petroleum is dominant.*** - ****

The overall resources of caustobioliths are expressed by a figure of $n \cdot 10^{13}$ tons. However, according to the calculations carried out by N. B. Vassoyevich, this makes only 0.36% of the entire organic carbon contained in the sedimentary envelopes of the continental sector of the Earth's sedimentary shell. Biogenic organic matter, alongside silica and possibly carbonates, is represented in the metabiosphere mainly in dispersed form.

Thus, paleobiogenic organic matter of the metabiosphere has formed both on land (owing to the activity of the terrestrial

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* N. B. Vassoyevich, A. N. Guseva, I. E. Leifman, "Biogeochemistry of petroleum", *Geochemistry*, 1976, 7, pp. 1075-1083.

** N. B. Vassoyevich, "Vernadsky's views on the origin of oil", *Int. Geol. Review*, 1965, v. 7, 3, pp. 507-517.

*** J. W. Hunt, *Petroleum Geochemistry and Geology*, Freeman a. Co., San Francisco, 1979.

**** B. P. Tissot, D. H. Welte, *Petroleum Formation and Occurrence*, Springer, Berlin a.o., 1978, p. 538.

film of life) and in the ecosystems of inland water bodies and of the World Ocean (in the case of aquatic ecosystems – mainly because of plankton). Investigations carried out by A. V. Van showed that volcanic activity strongly intensifies the accumulation of biogenic organic matter, first of all, owing to an enhancement of the productivity of living matter (discussed in Chapter Four). In the formation of caustobioliths the concentration function of living matter is manifested, but the energetic function is dominant. This very circumstance enables us, when we burn caustobioliths, to use the energy of sunbeams dating from millions of years back. It is not without reason that caustobioliths are called "tinned solar goods".

As a characteristic feature of caustobioliths Vernadsky emphasized the evolution of their composition and properties. "They (caustobioliths.– *A. L.*) display individuality and uniqueness in geological time and are a historical phenomenon, expressed in their extreme chemical diversity and can be simply explained by that for every geological moment the organisms whose bodies they represent were unique, sharply different chemically, as different as those microbes which had caused their formation and whose bodies enter into their composition... In caustobioliths we see a clear manifestation of the evolutionary process."* Extensive investigations in this direction are being undertaken.

Biogenic matter is not present in such high concentrations in all sedimentary rocks as in carbonate rocks, siliceous rocks, and in caustobioliths. In phosphate, ferruginous, and manganese rocks the content of biogenic matter is lower.

Usually phosphate rocks are those containing at least 10% phosphorus oxide. The main minerals containing phosphorus are finely dispersed minerals of the apatite group. Useful minerals – phosphorites – are phosphate rocks containing 12 to 40% phosphorus oxide. Several types of phosphorites are distinguished: land phosphate rocks, concretionary or septarian phosphorites, shelly phosphorites, bone breccias, and guano. 95% of all reserves of phosphorites are confined to marine sediments.

The thickness of land phosphate rocks reaches 15 to 17 m. There is nothing specific in their appearance. Sometimes they are white like chalk, but more often their colour is dark, almost black. Absence of distinct macroscopic features in phosphorites

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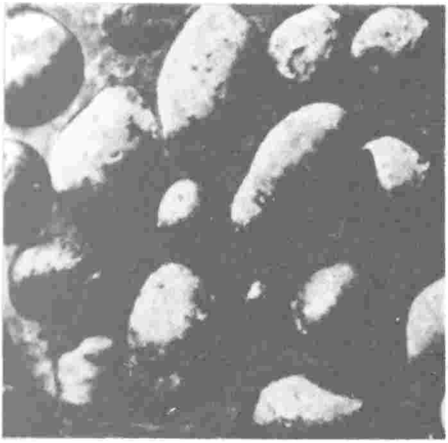
* V. I. Vernadsky, *The Chemical Structure of the Earth's Biosphere and of Its Surroundings*, Nauka Publishers, Moscow, 1965, p. 269.

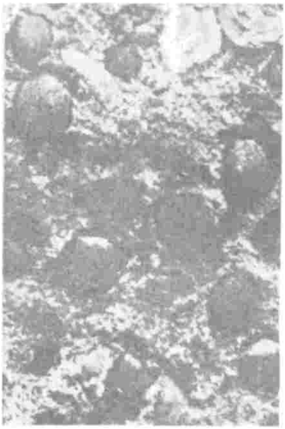


Small phosphatized coprolites. 25-fold magnification. Kazakhstan.

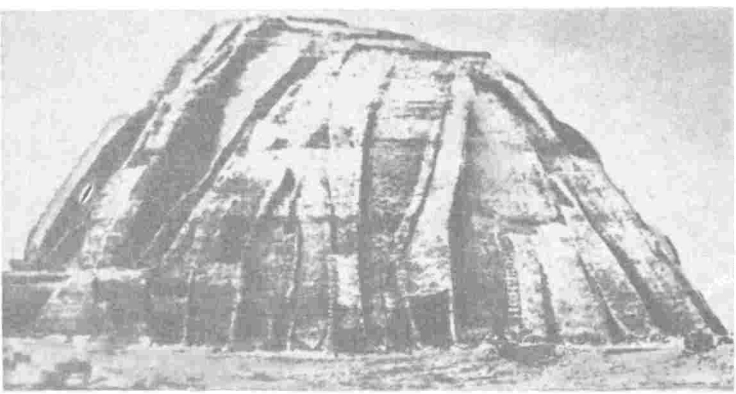
is often misleading for geologists. Thus, in the thirties in Kazakhstan (Karatau) phosphorites were first mistaken for bauxites. One Siberian deposit was discovered not in the field, but on the upper floor of the Palace of Geology, in the Chernyshev Central Museum of Geological Prospecting. There in 1949 N. A. Krasil'nikova, a prominent expert in phosphorites, while looking through the collection at the museum, came across an interesting specimen. According to the inscription on the label of the specimen, dating as far back as twenty five years, the specimen was classified as sandstone, but in reality it turned out to be a high-quality phosphorite. Evidently, such mistakes happened earlier too: the very name "apatite" stems from the Greek 'apatao' which means "I deceive"...

The discovery of a large deposit of phosphorite on the small island of Nauru, lost in the expanses of the Pacific to the south-east of Australia, is just as unusual.

They say that everything began in 1897, when an Australian sailor, who happened to be on that island, picked up a strange stone from the ground and brought it to his native land. In Sydney it was used for propping open the door of an office, until in 1900 A. Ellis, a geologist from New Zealand, noticed it. On the basis of chemical analysis Ellis came to the conclusion that the stone was top-quality phosphorite. The following year the geologist already set off for Nauru and established that almost the entire surface of the island was covered with a thick layer of phosphorite. Now the phosphorite quarry occupies 1/3



Sandstone with numerous shells of Obolus - so-called "obolus sandstone". The Ordovician of Estonia.



Working of guano on the Islands of Chincha (Peru).

of the territory of the island, and the annual output of phosphorite for each inhabitant of Nauru, old men, women and children inclusive, is 250 tons. Naturally, almost all the phosphorite is exported.

Septarian phosphorites are aggregates of individual or partially fused-together concretions. The saturation of rock with concretions varies; pieces of bones and phosphatized organic remains: wood, shells of mollusks, etc. are also encountered. Sometimes phosphatized coprolites are present too.

Shelly phosphorites occur mainly in Ordovician deposits. These are sandstones or conglomerates, crammed with shells of inarticulate brachiopods. So-called "obolus" sandstones of Estonia, with a thickness of up to 11 m and including the remains of Obolus and Schmidtia, furnish a typical example.

A rather rare type of phosphorites are bone breccias – porous rocks, yellow-brown in colour, consisting of fragments of fish skeletons or those of cave vertebrates. Finally, the last item in the list of phosphorites is guano – tremendous accumulations (as thick as 35 m) of excrements of sea birds (on islands and ocean coasts) or of bats (in caves). On the Islands of Cincha, near the coast of Latin America, a layer of guano accumulated annually is 8 cm thick. A classical investigation of guano deposits was carried out in the late forties by G. E. Hutchinson. His bulky, over 500-page monograph* so far remains unsurpassed in the profound and thorough treatment of the material. It is usually referred to in almost any publication dealing with the geochemistry of phosphorus.

Such are the most characteristic types of phosphorites. Their origin has been the subject of discussion for many years. The difficulty of the problem resides in that the remains of organisms which formed phosphorites are rarely preserved in them (bone breccias and obolus sandstones are an exception). At the same time, scientists have long supposed that living matter must play an important role in the formation of phosphorites (Fig. 23).

The biogeochemistry of phosphorus on a global scale was considered by G. E. Hutchinson**. D. McConnell*** has listed 76 phosphorus-containing minerals which are formed, most likely, as a result of the activity of living matter. Bones of vertebrates contain up to 60% calcium phosphate. Its content is still higher in the shells of inarticulate brachiopods (in addition to Obolus and Schmidtia the still existing Lingula, which has already been mentioned in Chapter Two with the persistents, also belongs to them). It is of interest to note that the shell of brachiopods belonging to a different order, to the order of articulates, consists not of phosphate, but of calcium carbonate. In plankton

* G. E. Hutchinson, "Survey of contemporary knowledge of biogeochemistry. 3. The biogeochemistry of vertebrate excretion", *Bull. Am Muss. Nat. Hist.*, 1950, v. 96, p. 554.

** G. E. Hutchinson, "The biogeochemistry of phosphorus". In: "*The Biology of Phosphorus*" (ed. L. F. Wolterink), St. Coll. Press, Mich., 1952, pp. 1-35.

*** D. McConnell, "Biogeochemistry of phosphate minerals". In: "*Biogeochemical Cycling of Mineral-Forming Elements*" (ed. P. A. Trudinger, D. J. Swaine), Elsevier, Amsterdam a. o., 1979, pp. 163-204.

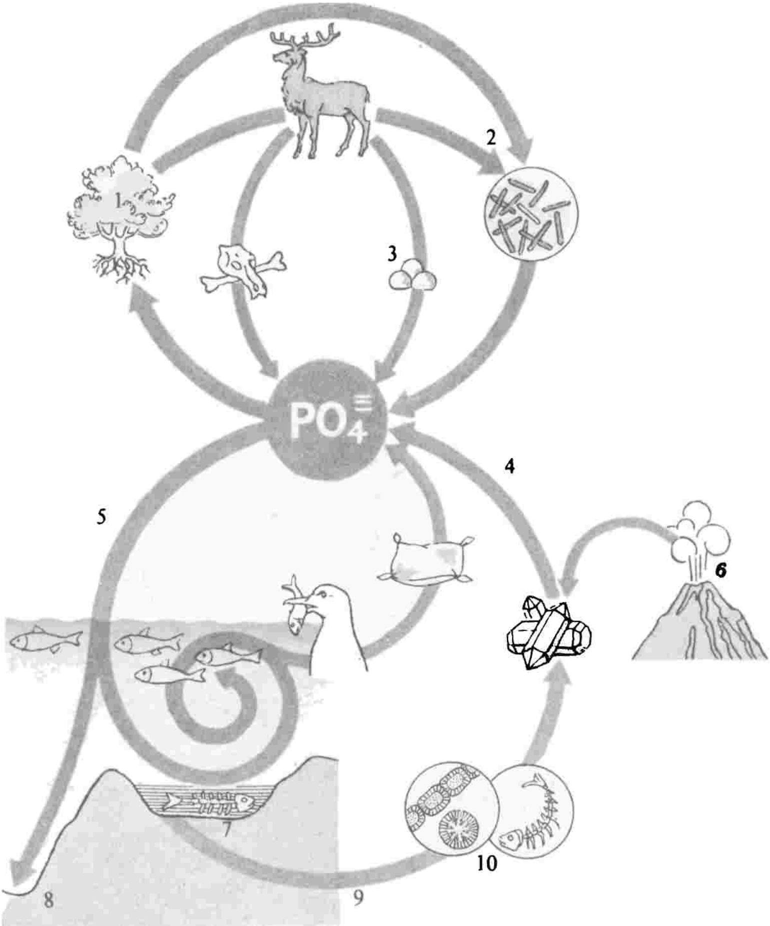


Fig. 23. Diagram of the biogeochemical cycle of phosphorus (after Duvigneaud, 1974):

1 – accumulation of phosphorus by higher plants; *2* – decomposition of neobiogenic organic matter; *3* – excrements; *4* – erosion; *5* – coming to the ocean; *6* – volcanic apatite; *7* – precipitation in bottom sediments at small depth; *8* – precipitation in bottom sediments at considerable depths; *9* – transition to fossil state; *10* – involvement into biological cycle by diatoms as a whole the content of phosphorus dioxide is a thousand times higher than in sea water. Fish scales and skeletons are also rich in phosphorus. Carapaces of crustaceans contain up to 50% calcium phosphate. If we take into account that crustaceans, as has already been mentioned in Chapter Two, frequently change their "clothes" and their lower forms occur in seas in tremendous quantities, the role of crustaceans in the creation of phosphorites may prove to be of no small importance.

Phosphorus oxide is also concentrated in the excrements of animals (the 1st kind of geological activity, effected outside of the organism). Thus, in the excrements of marine animals the content of phosphorus oxide is 3.25 times higher than in the enclosing bottom sediments. An important piece of evidence arguing for the participation of living matter in the formation of phosphorites is also a high percentage of organic matter (up to 36% organic carbon) in many phosphorites. Numerous examples of deposits of such phosphorites were cited by Vyacheslav Leonidovich Librovich in his paper read at the V Session of the All-Union Paleontological Society.

At the end of the nineteenth and the beginning of the twentieth century the hypothesis was advanced on the formation of phosphorites as a result of the mass death of organisms (J. Murray, R. Renard, and L. Cayeux, A.D. Arkhangelsky). A strong argument in favour of this hypothesis are bone breccias. In modern seas the sea floor in some areas is covered with a layer of dead fish up to 2 metres thick. The hypothesis of J. Murray had been criticized for a long time, but it has now been shown* that mass asphyxiations of fish occur systematically with an interval of several years. These very phenomena could lead to the accumulation of bone breccias.

Yakov Vladimirovich Samoilov was an active supporter and propagandist of the idea of the biogenic origin of phosphorites. "All deposits of phosphorites, with rare exceptions, are of organic origin; phosphorus comprised in them has passed through the body of an animal," he wrote. Indeed, coprolites are often encountered in phosphorites. Small coprolites, of 0.2 to 1.0 mm in diameter, are frequent, but sometimes one may come across phosphatized coprolites of large animals, for instance, of ichthyosauri.

* G.N. Baturin, "On the geological consequences of mass asphyxiations of ichthyofauna in oceans", *Oceanology*, 1974, v. 14, 1, pp. 101-105.

A biochemical hypothesis of the formation of land phosphate rocks was put forward in 1966 by G. I. Bushinsky.* According to this hypothesis phosphorus in the sea was concentrated by organisms (mainly planktonic ones) which after their death drifted down to the bottom of the sea basin. Part of the phosphorus from the died-away organic matter returned to benthic water, and from this water, to the biological cycle. Another part of the phosphorus deposited in bottom sediments. According to Bushinsky, conditions for the formation of phosphorites are as follows: (a) bumper development of plankton; (b) small depth of the water body, required for the dead organisms not to decompose while freely falling to the bottom; (c) considerable temperature of the water, contributing to the decomposition of neobiogenic organic matter on the bottom of the water body.

Much new evidence has been brought to the cognition of the genesis of phosphorites by the investigation of recent phosphorite concretions discovered in the late sixties and early seventies on the shelves of South-West Africa, Chile, and Peru. The very presence of such concretions was indicative of the fact that the situation as now observed on these shelves could serve as a model of phosphorite formation.

The above-mentioned regions are located in zones of upwelling, ensuring a high productivity of phytoplankton. Phosphorus reaches the bottom as a constituent of planktogenic detritus, remains of fish, and coprolites of micro- and macrofauna. No signs of chemogenic precipitation of phosphorus in bottom sediments were traced (the impossibility of phosphate formation without the participation of living matter was also proved experimentally).** In the opinion of G. N. Baturin the phosphorites found on the summits and slopes of the sea-mounts in the Pacific Ocean could have formed from guano: there are proofs that formerly these sea-mounts appeared above sea level as islands.

Living matter is likewise an important agent for the diagenesis of neobiogenic phosphate containing bottom sediments. In fact, the ultramicroscopic biogenic formations abstracted recently from modern bottom sediments on the shelf

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* G. I. Bushinsky, "The origin of marine phosphorites", *Lithol. a. Miner. Resour.*, 1966, 3, pp. 292-311.

** I. Nathan, J. Lucas, "Expériences sur la précipitation directe de l'apatite dans l'eau de mer: implication dans la genèse des phosphorites", *Chemical geology*, 1976, v. 18, 3, pp. 181-186.

of South-West Africa are most likely to be the remains of bacteria having been involved in the diagenetic production of phosphorites. Diagenetic phosphorite-forming processes run a wide gamut, from phosphorite production by phosphatization of diatom oozes to phosphate concretions forming in ooze-eaters' tracks. Indeed, it was selective phosphatization of coprolites and ooze-eaters' tracks that suggested to researchers the idea, proposed earlier by G. I. Bushinsky though in general terms, of enzymes having a part in the production of phosphorites*.

Therefore, one can be virtually certain today that the main bulk of phosphorite production in the contemporary biosphere develops in marine ecosystems, chiefly in upwelling life assemblages, with the plankton film a leading element in the accumulation of phosphorus.

It is on these grounds that old phosphorites, too, are assumed to have been formed in similar conditions. The phosphorus from seawater was concentrated by phytoplankton**, of which dinoflagellates must have been an important contributing factor***. Thus, the concentrative function of living matter was nowhere more evident than in phosphate rock production, especially of phosphorites. And, whilst in combustion of fossil fuels mankind makes use of the energy that living matter had stored up millions of years ago, phosphorite fertilization of fields brings back into biological circulation the phosphorus of the inhabitants of old seas. Transfer of non-biogenic substances from the sea to the continents – the transport function of living matter – is readily apparent in the accumulation of guano. Next to be considered are the ferruginous and manganese groups of sedimentary rocks. Since living matter performs similar functions in their production, both will be treated together.

Ferruginous sedimentary rocks occur as layers, lenses or nests. The layers are sometimes tens of kilometres in extent and reach tens of metres in thickness. By the mineral composition, their constituent rocks are classified into oxidic, comprising iron

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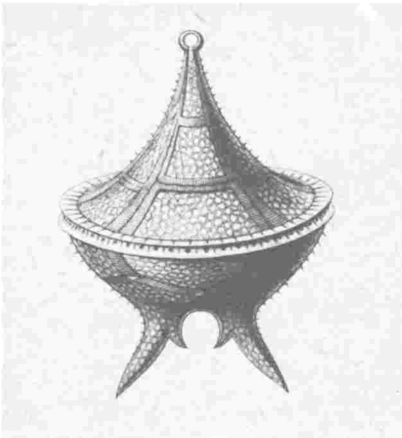
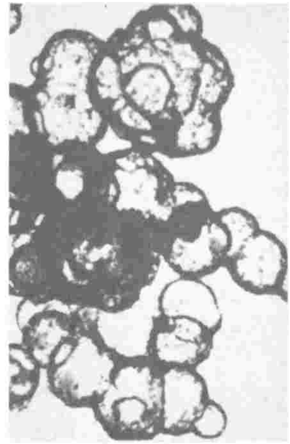
* G. I. Bushinsky, "Inhibitors and stimulators in lithogenesis", *Lithology a. Miner. Res.*, 1967, 4, pp. 495-497.

** P. A. Trudinger, "Microbiological controls on phosphate accumulation", In: *Proterozoic-Cambrian Phosphorites* (ed. P. J. Cook, J. H. Shergold). Canberra Publ., 1979, pp. 87-92.

*** D. Fauconnier, M. Slansky, "The possible role of dinoflagellates in phosphate sedimentation", *Ibid.*, pp. 93-101.



A dinoflagellate
Peridinium
divergens. Strongly
magnified.



Ferrihydrite composed of
remains of Gallionella.
30,000-fold magnification.
Electron micrograph.

oxides and hydroxides; carbonate, consisting mainly of siderite ($FeCO_3$); silicate, with dominant ferric chlorites; and mixed, involving ferruginous rocks of oolitic texture and complex composition (hydroxides + silicates + iron carbonates, or hydroxides + iron silicates, and so on). The pre-Cambrian of the metabiosphere holds numerous occurrences of ferruginous quartzites and jaspilites – both iron-rich metamorphic rocks. They represent clearly bedded rocks, with thin intercalations, iron- and silica-rich in varying degrees, succeeding each other there. The key minerals are quartz, magnetite (Fe_3O_4) and hematite (Fe_2O_3), the percent iron content reaches 30 to 40 and the jaspilites' age approximates two billion years.

Sedimentary iron ores were produced in seas and lake-swampy locations, through the agency of interaction with minor quantities of terrigenous material. The proposition about the marsh-lacustrine origin of Paleozoic and Mesozoic ferruginous rocks was first made by Ya. V. Samoilov in a brief notice titled "On the genesis of iron ores in Central Russia" (1931), published posthumously.*

* Ya. V. Samoilov, "On the genesis of iron ores in Central Russia", *Trans. of Miner. Institute, USSR Academy of Sciences*, 1931, v. 1, pp. 1-3.

The main bulk of iron hydroxide entered the basins where it was transformed apparently in the form of ferrihydrite, a recently discovered mineral from the group of iron hydroxides.* The nature of the transformations undergone by the iron minerals was controlled, largely, by the organic matter content of the sediments. Given a low content of non-biogenic organic matter in the riparian sections of the basins, ferrihydrite would convert to hematite and ferruginous oxidic rocks evolved as the result. With a high organic matter content, ferrihydrite would be reduced to ferrous-oxide minerals (siderite, chlorites, etc.) and the ores evolved were silicates with a varying siderite content. Finally, frequent changes of the geological environment led to the production of mixed rocks.

"There is hardly a single metal for whose production in large concentrations life plays such a role as it does for manganese," said Vernadsky in his address to the Conference on the Genesis of Iron, Manganese, and Aluminum Ores in April 1935. "In the same way, biogenic calcium and magnesium formations are associated with their largest natural masses except that for them, along with the concentration of that origin, one is aware of equivalent concentrations bound up with igneous processes, that are altogether divorced from the biosphere. Nothing of the kind is known for manganese"**.

The sedimentary rocks which are most manganese-abundant contain 80% or more manganese oxide. But because such high concentrations are rare, it is rocks with an over 10% concentration of the element's oxide that are usually called manganese. They share with ferruginous rocks the mode of occurrence in deposits up to 20m-thick and sheet-like or lenticular in shape. Manganese deposits are not as large in dimensions as iron-ore reserves, but still they may extend to a few kilometres' length and several hundred metres in width. Oxidic and carbonate manganese rocks are recognized, the latter being significantly more common.

The oxidic rocks are usually dark, with an earthy, sometimes coarse-grained fracture. Not infrequently, their texture is either concretionary or oolitic. They accumulated in the water medium – a lake-palustrine or marine environment. At entry into

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* F. V. Chukhrov, L. P. Yermilova, B. B. Zvyagin, A. I. Gorshkov, "Genetic System of Hypergene Iron Oxides", *Proc. Int. Clay Conf.*, Appl. Publ., Wilmette (USA), 1975, pp. 275-286.

** V. I. Vernadsky, *Works*, v. 1, p. 537.

basins manganese had apparently the form of manganese hydroxide colloids and partly the ionic form. The manganese compounds precipitated through coagulation of the colloids in an oxidizing medium. The manganese ores of the weathering crust present a special facial type of oxidic manganese rocks. The major minerals of the type include manganese oxides and hydroxides, one of which, in Vernadsky's honour, has been named vernadskite.*

Carbonate manganese rocks, light grey or pinkish, with a fine- or coarse-grained texture and sometimes thin-layered, resemble limestones. They are also produced like oxidic rocks but in the process of reduction. Alexander V. Khabakov, a leading Soviet lithologist, noted to that effect back in 1944, "It is not known in what way the manganese oozes, upon termination of their mundane terrestrial journey, could have entered upon new geochemical wanderings among lagoon and marine carbonate sediments. Manganiferous accumulations on land lead to finite, exceedingly stable and almost insoluble forms of tetravalent manganese (MnO_2), whereas in the lagoon and littoral-marine carbonate oozes manganese precipitates in a bivalent form. One wonders if the very environment of life, bacteria above all, together with the products of organic vital activity (humates, for example) is the cause for the geochemical revival of manganese."**

The issue of the role of life in the production of ferruginous and manganese rocks has excited geologists for over a century now. And, perhaps, in no other field in the science of sedimentary rocks has the clash opinions been so bitter, indeed sometimes dramatic, as on that one issue.

C. G. Ehrenberg, whose name was previously mentioned on account of his research into writing chalk, detected microbiogenic structures in the so-called "marshy", or "lake", iron ores as long ago as 1836.*** Iron-concentrating bacteria were discovered late in the past century. Our great microbiologist S. N. Vinogradsky proposed "iron bacteria", the term now used

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* F. V. Chukhrov, A. I. Gorshkov, V. V. Berezovskaya, A. V. Sivtsov, "Contributions of the mineralogy of antigenic manganese phases from marine manganese deposits", *Mineralium Deposita*, 1979, Bd. 14, 3, pp. 249-261.

** A. V. Khabakov, "Ulu-Telyak, a new deposit of oxidized carbonate manganese ores in the Permian deposits of Bashkiria (the western slope of the South Urals)", *Izv. AN SSSR*, Geolog. series, 1944, 3, pp. 19-38.

*** C. G. Ehrenberg, "Weitere vorläutige Nachrichten über fossile Infusorien", *Annalen der Physik u. Chemie*, 1836, Bd. 38, SS. 455-464.

for them. Early in our century microbiogenic sedimentation was suggested also for manganese*. Later on, many of the geologists active in the early half of the 20th century, based on microbiologists' data, favoured widely the bacteriogenic origin for ferruginous and manganese rocks.

At the V Session of the National Paleontological Society a report about the bacteriogenic origin of manganese ores was delivered by Alexander M. Obut. Still there was a school of thought which supported the purely abiogenic genesis of ferruginous and manganese rocks.

Christian Gottfried Ehrenberg.

Alexander Grigorievich Vologdin.

The January 1947 Session of the USSR Academy of Sciences' Department of Geology and Geography was addressed by Alexander G. Vologdin** (1896–1971), Corresponding Member of the USSR Academy of Sciences and winner of the International Paleontological Prize and the Charles Walcott medal "For the Study of pre-Cambrian Organisms". Vologdin gave an account of his experience with microscopic studies covering a broad range of geological objects. Unlike the futile attempts of G. Molish, Ya. V. Samoilov and V. S. Butkevich to discover

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* G. A. Thiel, "Manganese precipitated by microorganisms", *Economic Geology*, 1925, v. 20, 4, pp. 301-320.

** A. G. Vologdin, "The Geological activity of microorganisms", *Izv. AN SSSR, geolog. series*, 1947, 3, pp. 19-38.

biogenic structures in iron rusts, Vologdin was fortunate to find mineralized remains of iron bacteria in ferruginous and manganese rocks.

A. G. Vologdin's report aroused severe criticism from the audience present. The speaker was reproached for his failure to substantiate his major points, excessive enchantment with microscopy while ignoring other methods of research, unconvincing photographs of microorganisms, and other sins. It was over a quarter of a century later that A. G. Vologdin's work was given a different appreciation.

"Vologdin's hypothesis was turned down by the geologists of the day as being totally unfounded. In part, this was because the geological public was unprepared to perceive the formulated ideas. Yet the main reason was, or so it seems to us, the indistinct quality of the microphotographs supplied by the author and the inadequate knowledge of the iron-bacterial flora at that time. Many of the group's now familiar specimens were yet to be described in the 40s, so the microbe-like structures discovered by the author had no living analogues that would be sufficiently similar morphologically." The words belong to Tatyana V. Aristovskaya, a microbiologist.

A major break-through in the study of the iron bacteria which T. V. Aristovskaya referred to, was achieved by microbiologists as they examined modern iron- and manganese-ore formation in what might be called the laboratories of Nature. One such laboratory is found in the lakes of the North-Western Soviet Union – Karelia and the Leningrad Region.

That the lakes of the North-West contain concretionary iron and manganese ores has been known since times immemorial. The first iron-smelting and cannon works were built here in the 17th century. Under Peter the Great iron-ore production was expanded and the Petrovsky plant, one of a number of new production developments, from which the city of Petrozavodsk arose, was established.

Lake ores present, in effect, concretions with up to 80% of iron and manganese oxides. By the size of the concretions the ores were classed into types, to-wit: gunpowder, hail-like, bean, coin, plate, pancake, shield-like, and others.

In 1926, the year "The Biosphere" came off the press, the studies of Karelia's lake ores hit upon an outstanding discovery. It was made by Boris Perfiliev, (1891-1969), later to become a professor and holder of the Lenin and State Prizes.

He managed to discover undisputed bacterial structures* in the lake ores of the North-West and a microzonality in the bottom sediments which he ascribed to the varying intensity of iron-bacterial activity. B. Perfiliev hypothesized that in the past geologic epochs, too, the mechanism of iron accumulation had been likewise bacterial.

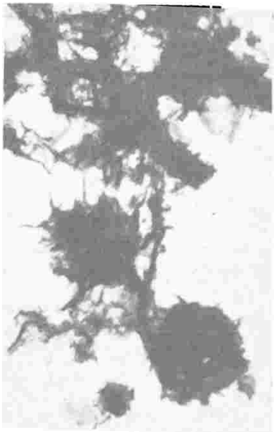
B. V. Perfiliev's discovery gave an impetus to further progress of research in bacterial ore-formation.** New iron-bacterial genera and species, more or less importantly involved in the process, were described. In 1936 B. V. Perfiliev described a new genus of bacteria which today's evidence identifies as playing the major role in manganese and iron concentration in bottom sediments. Perfiliev called it "Metallogenium", or "metal-breeding". Another worker, V. O. Kalinenko, in 1949 named the newly-discovered bacterial species Leptothrix Wernadskyi – after V. I. Vernadsky. Since the late 1950s, ingenious studies into recent lacustrine iron and manganese ore-formation have been initiated by Galina A. Dubinina of the USSR Academy of Sciences' Institute of Microbiology.***

Boris Vasilievich Perfiliev.

* B. V. Perfiliev, "New data on the ore-forming role of microbes", *Izv. Geolog. Comiteta*, 1926, v. 45, 7, pp. 795-819.

** B. V. Perfiliev, D. R. Gabe, et al., *Applied Capillar Microscopy. The Role of Microorganisms in the Formation of Iron-Manganese Deposits*, Consultant Bureau, N. Y., 1965.

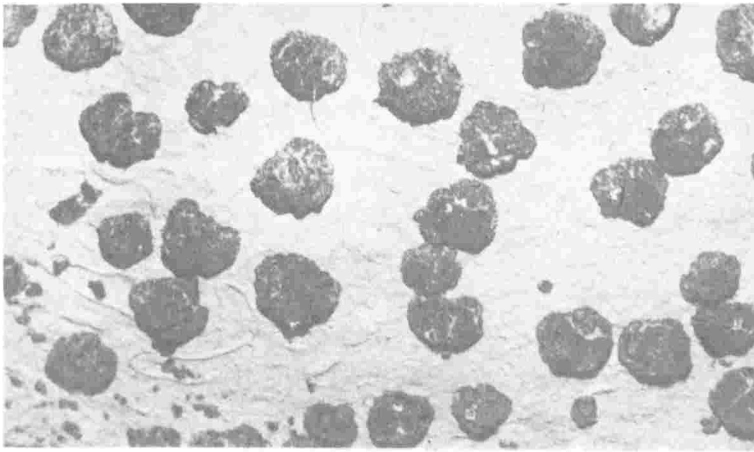
*** G. A. Dubinina, "The siginificance of microbiological processes in lacustrine manganese-ore formation", *Verh. int. Ver. Limnol.*, 1973, Bd. 18, pp. 1261-1276.



Vernadite composed of remains of Metallogenium. 17,000-fold magnification. Electron micrograph.

Research conducted by microbiologists has found that some iron-bacterial species exclusively concentrate manganese oxide, another only iron oxide and a third, both these components. Hence the term "iron-manganese" is sometimes applied nowadays to describe the iron bacteria. Productivity flare-ups in different iron-bacterial species govern the zonality of bottom sediments, or the pattern of alternation in them of layers with varying iron-manganese oxide ratios. The amplitude of the physicochemical bottom-sediment environments making possible the bacteria's existence and ore-forming activity proved fairly wide, with pH ranging from 5.8 to 7.5, Eh from +20 to +700 mV, and oxygen content from trace quantities to 10 mg/l.

Formation of iron-manganese concretions is a two-stage process. At first, the metals' oxidic compounds are reduced in the bottom sediments by sulphate-reducing and other bacteria and the reduced iron and manganese compounds move on from ooze into water. In the second stage a reverse process occurs – that of iron bacteria oxidizing the benthic water solutes of iron and manganese oxidous compounds, to yield ferrihydrite, vernadite and other minerals. Vernadite production has been found possible only with very fast oxidation of bivalent manganese to tetravalent – so fast that it cannot be accomplished except with the participation of living matter. Under these circumstances, bacteriogenic iron and manganese oxidation proceeds at sufficiently low concentrations of the solutions to exclude chemogenic precipitation. The oxides precipitate in part during mineralization of metallo-organic compounds, known to



Iron-manganese concretions on the floor of the Pacific Ocean at a depth of 5145 m.

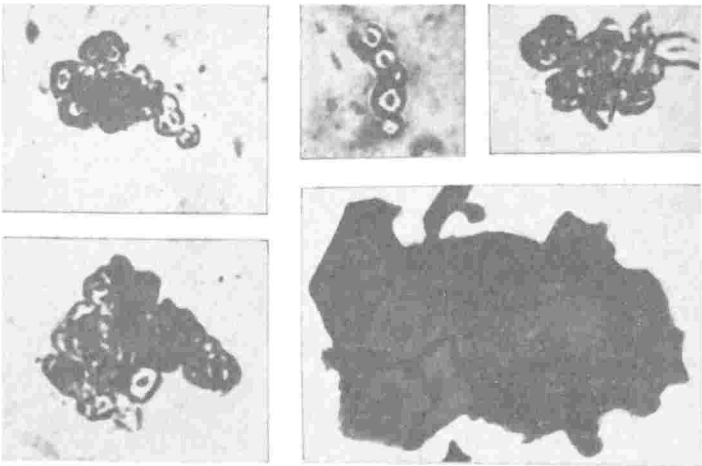
be rather resistant to abiogenic chemical oxidation. This provides evidence in support of A.V. Khabakov's hypothesis on the role of living matter and humates (complex-organic compounds) in manganese-ore formation.

Another natural proving ground where microbiologists conducted their research was the formation regions of iron-manganese concretions in the World Ocean. In the depth range from 4 to 6.5 km the concretions sometimes form a solid cover on the ocean bed, recalling a boulder pavement. The cover area accounts for about 10% of the World Ocean bottom. Manganese and iron represent respectively around 25 and 15% in the concretions, the remainder consisting of nickel, cobalt, copper and the other 35 elements of the periodic table. Like peat, but unlike all old minerals, concretionary phosphorites and lacustrine iron and manganese ores are a renewable raw-material resource. The reserves of the iron-manganese concretions grow by many million tons a year.

Though the concretions are believed by some to be abiogenic, the latter-day research findings have shown bacteria to be an important ingredient in their formation.* - ** It is probable that

* *Biogeochemical Cycling of Minerals-Forming Elements* (ed. P.A. Trudinger, D.J. Swaine), Elsevier, Amsterdam a.o., 1979, pp. 211-292.

** B.K. Dugolinsky, S.V. Margolis, W.S. Dudley, "Biogenic influence on growth of manganese nodules", *J. sediment. Petrol.*, 1977, v. 47, 1, pp. 428-445.



Comparison of the microstructure of ferruginous minerals and bacteria: *1, 2* – bacteria Siderocapsae (culture); *3, 4* – "siderocapsa-like cells" in limonite; *5* – magnetite, displaying complete absence of bacterial structure. 1,000-fold magnification.

benthic Foraminifera are also part of the process, for there are forms among them with a shell composed of various kinds of debris and cemented with iron compounds. It is more probable however that iron finds its way into the sediments with dead plankton or has an altogether different origin, entering the benthic seawater layers from fractures in the Earth's crust. Based on the microbiologists' experience of the past two decades, T. V. Aristovskaya performed a revision of A. G. Vologdin's inferences. She picked out for research samples of a few ferruginous minerals: limonite, hepatite and magnetite. The research was done microscopically, in transmitted light, following special treatment of the preparations. What was it, then, that T. V. Aristovskaya saw?

The hepatite and limonite turned out to consist wholly of ferruginous deposits which duplicated the cell outlines of the iron bacteria embedded there*. By comparing the microscopic structure of the mineral masses with the growth patterns of the

* T. V. Aristovskaya, "Role of microorganisms in iron mobilization and stabilization in soils", *Geoderma*, 1974, v. 12, 1/2, pp. 145-150.

iron bacteria, it has been possible to trace some similarities between the remains of the microorganisms comprising the minerals and fragments of the colonies of some contemporary bacteria. The magnetite, as distinct from the hepatite and limonite, exhibited a total lack of bacterial structure.

T. V. Aristovskaya focused on ferruginous rocks only. The manganese ores of the Paleogene of the Chiatura and Tetritzkaro deposits had been surveyed earlier by the Moscow geologist Lazar E. Sterenberg*. In preparations of oxalic acid-treated ores, L. E. Sterenberg detected and described biogenic structures, not unlike the colonies of the genus Metallogenium already familiar to us.

Following these studies of T. V. Aristovskaya and L. E. Sterenberg, the biogenic origin of modern iron-manganese ores, and their old analogues as well, may be thought to be proved beyond doubt. Many workers view as biogenic not only Phanerozoic iron and manganese ores but also pre-Cambrian ferruginous quartzites** - ***.

Production of the biogenic matter of ferruginous and manganese ores follows a somewhat different course than in carbonate, cherty and phosphate ores, in that it is the benthic film of life, and not the plankton one, playing the leading role in the process. They have in common, however, the conditions of their formation, as biogenic matter keeps accumulating at all events in aquatic ecosystems, whether continental water bodies or at sea, while the key factor on the stage of sedimentogenesis and diagenesis is the concentrative function of living matter.

The role of life in the production of allites and salts remains a more debatable issue.

Allites, or aluminiferous rocks, are defined as being rich in free aluminum oxide (alumina). They include bauxites, the aluminum source material – a rock consisting primarily of hydrous aluminum minerals. Iron oxide has a large presence in bauxites, ranging from 10 to 30%, while the silica content stands at a low percent for high-grade and up to 20% for

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* L. E. Sterenberg, "Biogenic structure in manganese ores", *Microbiology*, 1967, v. 36, pp. 710-712.

** G. L. La Berge, "Possible biological origin of Precambrian iron-formations", *Econ. geol.*, 1973, v. 68, 7, pp. 1098-1109.

*** D. D. Klemm, "A biogenic model of the formation of the banded iron in the Transvaal Supergroup of South Africa", *Mineral Deposits*, 1979, v. 14, 3, pp. 381-385.

low-grade types. As with phosphorites, bauxites vary widely in external appearance. They may be coloured black, white, yellow, red and cherry-like, porous or dense, clayey or sandy. During laboratory exposure in the course of general geology first-year students, by way of practical joke, are sometimes presented, among a collection of rocks, with crushed brick – and the neophytes to geology define it without hesitation and altogether as bauxite. Once this author also committed this sin...

The term "bauxite" originates from Les Baux, a smallish hamlet in the south of France where bauxites had been first discovered in 1821. Bauxite formation is usually explained in terms of a variety of chemical processes, with almost all the theoretically conceivable chemical agents cited in the geologists' hypotheses, as Ya. V. Samoilov had already perceived in his time.

British oceanologist John Murray (1841-1914).

The dominant view of bauxites is as a fossil weathering crust of aluminosilicate rocks or products of the latter's redeposition. Early indications that aluminosicates could be split biogenically, by the action of diatom algae, were provided by the British scientists J. Murray and R. Irvine* as far back as the end of the last century. More recently Vernadsky and Coupin**–*** repeated these experiments and reported back the same year in the same journal. Their findings left no room for doubt: diatom algae do split aluminosilicates and utilize silica to build their carapaces whereas the alumina persists in the water medium as a colloidal solution.

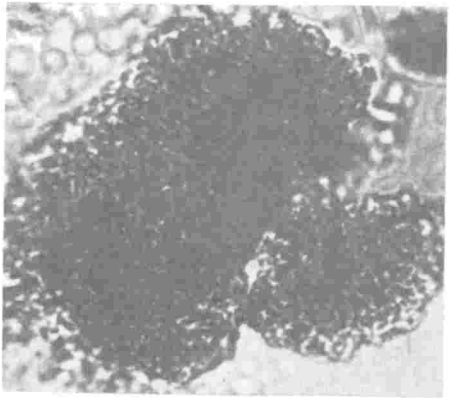
Bauxites were noted earlier to contain impressive quantities of iron oxide. Mindful of the fact, T. Holland**** proposed in

* J. Murray, R. Irvine, "On the silica and the siliceous remains of organisms in modern seas", *Proc. Royal Soc.*, Edinb., 1891, v. 18, pp. 229-250.

** W. Vernadsky, "Sur le problème de la décomposition du kaolin par les organismes", *C. R. Acad. Sci.* (Paris), 1922, t. 175, pp. 450-452.

*** H. Coupin, "Sur l'origine de la carapace silicense des diatomées", *Ibid.*, 1922, t. 175, pp. 1226-1229.

**** T. Holland, "On the constitution, origin and dehydration of laterite", *Geol. Mag., new ser.*, 1903, decade IV, v. 10, pp. 59-69.



Bauxite particle consisting of microbial cells cemented together. 1,000-fold magnification.

1903 that bauxite formation might be attributed, if only in part, to the activity of iron bacteria. Still, this remained merely a proposal unsupported by any factual evidence until A. G. Vologdin paid attention to the broad distribution of iron bacteria, besides ferruginous rocks, also in allites where they claim between 40 and 45% of the rock volume.

It was not until a few decades later that the National Geology Institute, USSR, came up with a program of experiments in biogenic decomposition of volcanic rocks by bacteria. In their own experiments, L. E. Kramarenko and O. F. Safonova* watched gabbro labradorite, on exposure to microorganisms, convert totally to alumina – the process taking one and seven years, respectively, in an aerobic and anaerobic medium. It was inferred that in the anaerobic medium the biogenic decomposition of alumina slowed down to two fifths the rate in the aerobic media and none at all occurred when microorganisms played no part in the process. Shortly before, G. Taylor and G. W. Hughes** demonstrated that recent volcanic ashes, and not just old igneous rocks, were susceptible to biogenic decomposition yielding bauxites.

To sum up: one opportunity for living matter to become involved in bauxite production is through the decomposition of

* L. G. Kramarenko, O. F. Safonova, "Some findings with respect to the influence of microorganisms on decomposition of gabbro labradorites", *Proc. VSEGEI*, 1976, v. 209, pp. 112-117.

** G. R. Taylor, G. W. Hughes, "Biogenesis of the Rennel Bauxite", *Econ. Geol.*, 1975, v. 70, 3, pp. 542-546.

abiogenic matter, brought about by the processes of vital activity of microorganisms.

There may be also another alternative though. Some of the plants on the ground surface are known to build up aluminum in their body, as in club-moss ash containing up to 30% aluminum. A detailed study of the subject was performed as early as the 1940s by G. E. Hutchinson in cooperation with A. Wollack*; the geological aspect of the problem was first perceived by Academician Lev S. Berg (1876-1950), a man whose speciality is as hard to define as V. I. Vernadsky's. For he was, all at once, a geographer, ichtiologist, theoretical biologist and a historian of science. Though somehow not generally considered a geologist, among L. S. Berg's works there are some like "On apparent periodicity in the formation of sedimentary rocks" (1944), "Life and soil formation on the pre-Cambrian continents" (1944), "On the origin of the Ural bauxites" (1945), "Soils and aquatic sedimentary rocks" (1945), "On the iron ores of the Krivoi Rog type" (1947)... Through these works L. S. Berg inscribed his name in the annals of geological science.

Lev Semenovich Berg.

L. S. Berg** considered that bauxites might have originated from the mineralization and redeposition of the remains of higher plants containing significant amounts of alumina. Bauxites, according to Berg, were deposited on land, in marshes or in shallow waterlogged fresh water bodies.

For a long time L. S. Berg's hypothesis failed to win support among the geological community. Corroborating evidence, all of a sudden, came from where it was least expected – the experimental work of microbiologists.

Aluminum has been known for some time to form complex alumminorganic compounds in the plant body.

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* G. E. Hutchinson, A. Wollack, "Biological accumulators of aluminum", *Trans. Conn. Acad. Arts. a. Sci.*, 1943, v. 35, pp. 73-128.

** L. S. Berg, *Works*, v. 2, AN SSSR Publ., Moscow, 1958, pp. 170-207.

T. V. Aristovskaya and L. V. Zykina* examined in experiment the compounds' decomposition under the action of iron-manganese bacterium, Metallogenum, only to find aluminum hydroxide precipitation to be the case there. "The metal-breeding" bacterium proved capable of breeding actually not only iron and manganese, but also aluminum. With full reason, the authors concluded, "We believe the phenomena discovered by us can provide a clue to the mystery of bauxite formation."

Probably, bauxite's traditional label of "chemogenic rock" will have to be taken off now, for it is no longer doubted that, at the stage of hypergenesis, the destructive role of living matter is decisive for their formation. It is not improbable either that the concentrative function of living matter responsible for the increased aluminum content in the bauxite source material is also of importance.

It is customary to class salts – the sedimentary rocks consisting of readily water-soluble minerals – with purely chemogenic formations. Indeed, that vaporization of saturated solutions and crystallization of salts, the spectacular process we remember from our school years, follows an abiogenic course, is not questionable any more. If so, where does the salt in the solution come from?

In the regions of progressive salt accumulation the plants contain a lot of mineral salts, up to 40 to 55%; so, too, the composition of their ash fraction is quite extraordinary, what with a sodium concentration reaching 65% (for ash), chlorine as high as 48%, SO_4^{2-} up to 36% and magnesium 4.5%. While shedding leaves, the plants salinize soil; for example, saxaul litter contains 50% of readily soluble salts. In decomposition of the dead organic matter, $NaCl$, Na_2SO_4, and $MgCl_2$ are the first salts to be leached out. Living matter does not assimilate the salts, as they become toxic in large quantities and are only consumed by plants as "compulsory assortment". The remainder of the plant ash substance comprises calcium, potassium, phosphorus, iron and silicon – the elements slow to free themselves during mineralization of the dead organic matter but quick to be captured by living matter.

The sodium and magnesium chlorides and sulfates extracted from the dead organic matter, migrate in the surface and

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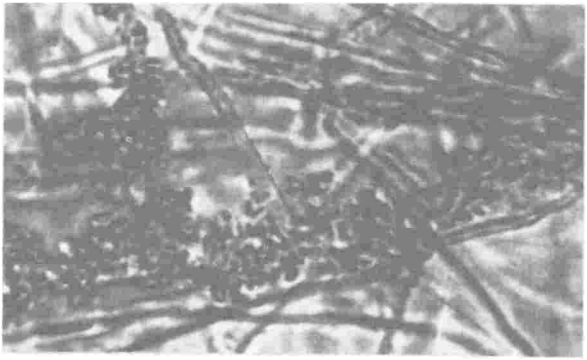
* T. V. Aristovskaya, L. V. Zykina, "Biological factors of aluminum migration and accumulation in soil and weathering crusts". In: *Problems of Soil Sciences. Sov. pedol. XI Int. Congr. Soil Sci.*, Moscow, 1977.



Deposits of aluminium hydroxide on accretions of iron-manganese bacteria Metallogenium. 1,000-fold magnification.

ground runoff flow, to gather in hollows without natural outlet (salt accumulation centres) or in the World Ocean. V. A. Kovda estimated* that 16 of salts, or one half million tons arrived annually at the Aral Sea from nonbiogenic matter. Life dumps here the excess salts it does not need - chlorides and sulfates. The salts precipitate abiogenically from super-saturated solutions in salines or isolated sea lagoons. This is also the way soda deposits are formed - with the only difference that in this case sodium combines with atmospheric carbonic acid** as it migrates.

Yet the contribution of living matter in fossil salt production is not limited to the concentrative function alone. It has long been known that reefogenic formations appear frequently among salt deposits. Why? To that, no plausible answer existed for a long time. And only very recently three Rostov-on-Don scientists, V. I. Sedletsky, V. S. Derevyagin and N. I. Boiko, showed nothing other but the reefogenic formations to be most often the ones "isolating" saliferous basins from the World Ocean. They thus become the automatic natural regulators to stabilize the latter's hydrodynamic regime. This means that the medium-forming function of living matter becomes also manifest in salt production.

* V. A. Kovda, "Biological cycles of salt migration and accumulation", *Soil Sci. Mag.*, 1944, 4-5, pp. 144-158.

** N. I. Bazilevich, *The Geochemistry of Soda-Saline Soils*, Nauka Publ., Moscow, 1965, p. 352.

We have individually discussed eight groups of sedimentary rocks and found everywhere explicit signs of activity of living matter in one form or another. Of all existing groups only two still remain unattended, clastic and clay. Both these groups are known to be produced by weathering and redeposition of primary volcanic and also sedimentary rocks.

Addressing himself to the overstated role frequently assigned to mechanical weathering, Academician B. B. Polynov said in 1952, shortly before his death, "We are having to give up at present these habitual notions; conversely, the very concept that there is going on some sterile–abiotic–weathering is, no doubt, totally unrealistic, thought-up and unconfirmed by facts. Far be it from me to deny that thermal fragmentation of massive rock is possible, as I do not deny that reactions of oxidization and carbonatization are possible. What I do deny outright is that it is possible for these processes to show up in an isolated, sterile manner"* (to be more precise, one should add 'in the conditions of the biosphere').

Consequently, with respect to clastic and clay rocks, as also in the case of allites and salts, the activity of living matter becomes obvious at the stage of hypergenesis where its main function is one of destruction, leading to decomposition of dead abiogenic matter. Clay rocks, at least partially, could have also evolved, as B. B. Polynov suggested, from complete mineralization of dead organic matter. Whether this is so is still not clear. In addition to inorganic material, clastic and clay rocks contain a proportion of biogenic organic matter–an average 0.9% in the clay and 0.2 to 0.5% in the clastic. Negligible as these contents may seem, clay rocks are known to hold over three fourths and clastic rocks over 15% of the whole paleogenic organic matter of the Earth's sedimentary crust.

Therefore, the metabiosphere is composed of rocks whose production involved the participation of living matter in one form or another. For some part, rocks consist of the remains of the organisms which once lived on the Earth. These include carbonate, cherty rocks and caustobioliths, and in part phosphatic rocks also. Metabolic products of living organisms formed ferruginous and manganese rocks. For still other rocks, apart from those two, the role of living matter was limited, in the main, to the preparation of their source material at the stage of hypergenesis. Such are clastic and clay rocks.

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* B. B. Polynov, *Works*, AN SSSR Publ., Moscow, 1956, p. 468.

No matter how the activity of living matter was actually involved in the production of sedimentary rocks and ores, still the Earth's metabiosphere presents a record documenting the development of the biosphere by which all evolutionary stages of the planet's manifold living matter can be reconstructed. "Perhaps it is least difficult to analyze the most ancient organisms by the concentration of the products of their vital activity, above all by the accumulation of carboniferous, carbonate and ferruginous rocks," stated recently the outstanding Soviet paleontologist, Academician Boris S. Sokolov.

Conclusion

In archaeology there exists a concept of cultural stratum – it is the term applied to the layer of earth which develops on the sites of human settlements and contains the artifacts of man's activity. It is underlain by the so-called mainland – virgin soil or rock.

By the same token, the metabiosphere is the "cultural stratum" of the biosphere while the primary rocks produced outside the biosphere constitute the geologists' "mainland". The two differ basically from each other – the massive, mostly similar, endogenous rocks and the extremely dissimilar sedimentary rocks and ores making up the Earth's metabiosphere.

Life has created this variety.

"Thereby life appears as a great, permanent and continuous infringer on the chemical die-hardedness of our planet's surface... Life is not therefore an external and accidental development on the terrestrial surface. Rather, it is intimately related with the constitution of the earth's crust, forms part of its mechanism and performs in this mechanism functions of paramount importance, without which it would not be able to exist."*

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* W. Vernadsky, *La biosphère*, Alcan, Paris, 1929, p. 30.

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Glossary of special terms

ABIOGENIC MATTER (PROCESSES) - matter (processes) originating (proceed) without the participation of living organisms.

AEROBIC MEDIUM - medium containing free oxygen.

ALUMINA - aluminium oxide (Al_2O_3).

ANAEROBIC MEDIUM - medium devoid of free oxygen.

APHOTIC ZONE - the part of the ocean where photosynthesis cannot proceed because of poor illumination.

ARCHEAN ERA - the earliest era in the development of the Earth.

ARID ZONE - areas with arid climate.

AUTOTROPHS - living organisms which do not use ready organic compounds for producing their own organic constituents; classified into photoautotrophs and chemoautotrophs.

BENTHIC ZONE - the bottom of lakes, seas and oceans.

BENTHOS - inhabitants of the benthic zone.

BIOCOENOSIS - community of living organisms which has historically formed in a given ecosystem.

BIOGENIC MATTER - matter created in the course of activity of living organisms.

BIOLOGICALLY SLUGGISH SYSTEM - natural system in which living and non-living matter interact.

BIOMASS - mass of living matter per unit area or volume.

BIOTURBATION - process of stirring of sediments, conditioned by the activity of living organisms.

BLUE-GREEN ALGAE - see Cyanophyceae.

BRACHIOPODS - class of invertebrate animals resembling mollusks but attributed by biologists to another phylum: Tentaculata (bryozoans also belong to it). Brachiopods flourished in the Paleozoic Era; now they are becoming extinct.

BRYOZOANS - small aquatic animals (about 1 mm in size) of the phylum Tentaculata. Colonies of bryozoans resemble small bushes or prostrate rhizomes.

BYGONE BIOSPHERES - biospheres of the geological past; Vernadsky sometimes included the sediments formed by them in the term as well.

CAMBRIAN PERIOD - the very first period of the Paleozoic Era.

CARBONATE COMPENSATION LEVEL - the depth below which there takes place intensive dissolution of calcium carbonate in the water mass of the World Ocean.

CARBONIFEROUS PERIOD - one of the periods of the Paleozoic Era.

CENOZOIC ERA - one of the geological eras in the development of the Earth.

CHEMOAUTOTROPHS - autotrophic organisms which use the energy liberated in the decomposition of inorganic compounds by themselves to produce their own organic constituents.

CHEMOGENIC ROCKS (SEDIMENTS) - rocks (sediments) formed as a result of abiogenic (q. v.) chemical processes.

CONCRETIONS - dense mineral formations, originating from the cohesion or coalescence of their constituent particles; they clearly differ from the embedding sediment (or rock).

COPROLITES - fossil excrements of vertebrates, consisting mainly of calcium phosphate.

COQUINA - loose sediments consisting mostly or entirely of shells or fragments of shells of mollusks and brachiopods.

CRETACEOUS PERIOD - the last period of the Mesozoic Era.

CRUST OF WEATHERING - the upper layers of the lithosphere (q. v.), transformed under the action of hypergenesis (q. v.) processes.

CYANOPHYCEAE - sub-kingdom of procaryotes, characterized by extreme morphological diversity. Cyanophyceae are otherwise called "blue-green algae".

DETRITUS - fine particles of any substance.

DEVONEAN PERIOD - one of the periods of the Paleozoic Era.

DIAGENESIS - one of the stages in the formation of sedimentary rocks, during which fresh sediments are transformed into dense rock.

DIATOMS - unicellular algae with siliceous cell walls, living either singly or in colonies. They are ubiquitous; are an essential component of the plankton and benthos in seas and land water bodies.

DINOFLAGELLATES (or peridinians) - microscopic algae constituting a considerable proportion of marine phytoplankton. Their mass proliferation is called "red tide".

ECHINODERMS - a phylum of multicellular invertebrates. Most echinoderms have a calcareous exoskeleton provided with diverse protrusions or spines. Echinoderms include star fish, ophiuroids, sea urchins, holothurians, crinoids – typical inhabitants of the benthic film of life of the World Ocean.

ENDOGENIC ROCKS – rocks which owe their origin to abyssal geological processes (these processes are also called endogenic).

ENZYMES – substances that act as catalysts in biochemical processes.

EUCARYOTES – a superkingdom of living organisms characterized by the presence of a typical cell nucleus; comprises plants, fungi, and animals.

EUPHOTIC ZONE – the part of the ocean in which photosynthesis processes occur.

FILTRE-FEEDING ORGANISMS – aquatic animals that obtain their food by actively filtering large amounts of water in which planktonic organisms and organic detritus are suspended.

FORAMINIFERS – representatives of the Protozoa. Chiefly marine microscopic organisms.

GUANO – recent accumulations of solidified excrements of sea birds (on ocean coasts); less frequently, those of bats (in caves).

HETEROTROPHS – living organisms which cannot independently synthesize organic substances from inorganic ones and are dependent on autotrophs for their supply of food.

HUMID ZONE – areas of the Earth with humid climate.

HYPERGENESIS – preparatory stage of formation of sedimentary rocks. At this stage in the weathering of various rocks initial products of sediments originate and are transferred.

JURASSIC PERIOD – one of the periods of the Mesozoic Era.

KATAGENESIS – one of the stages of formation of sedimentary rocks, following diagenesis, during which their further densification and transformation take place.

LITHOSPHERE – the solid outer envelope of the Earth. Its thickness ranges, probably, from 50 to 200 km. The upper part of the lithosphere (within the limits of the occurrence of living matter) is included in the biosphere.

LIVING MATTER – the totality of living organisms of the biosphere.

MELANOBIOSPHERE – a zone of the biosphere, where the processes of photosynthesis are not possible because of poor illumination.

MESOZOIC ERA – one of the geological eras in the development of the Earth.

METABIOSPHERE (according to Vassoyevich) – a part of the lithosphere, either generated by the living matter of past geological epochs or having been under its influence. The present-day biosphere is not included in the metabiosphere.

METABOLISM – all the chemical reactions taking place in living organisms.

MUD-EATERS - bottom-dwelling organisms which indiscriminately swallow mud and pass it through their alimentary tract.

MUSSELS - bivalve mollusks which often make up tremendous accumulations in the near-shore part of the sea (so-called "mussel banks").

NEOBIOGENIC MATTER - biogenic matter formed by the living matter of the contemporary geological epoch (for other epochs, by the living matter of that time). During geological time it is transformed into paleobiogenic matter (q. v.).

NEOGENE - one of the periods of the Cenozoic Era.

OPAL - a mineral; amorphous solid hydrated silica ($SiO_2 \cdot nH_2O$).

ORDOVICIAN PERIOD - one of the periods of the Paleozoic Era.

PALEOBIOGENIC MATTER - fossil biogenic matter.

PALEOGENE - the first period of the Cenozoic Era.

PALEOZOIC ERA - one of the geological eras in the development of the Earth.

PELAGIC ZONE - water mass of lakes, seas, and oceans. In the World Ocean it is subdivided horizontally into two zones: neritic (the mass of water above the shelf) and oceanic (all the rest of the water mass).

PERMIAN PERIOD - the last period of the Paleozoic Era.

PHANEROZOIC EON - the period of time composed of the Paleozoic, Mesozoic, and Cenozoic Eras.

PHOTOAUTOTROPHS - autotrophic organisms which use light energy for producing their own organic constituents.

PLANKTON - living organisms which dwell in the mass of water in a suspended state and are incapable of active flotation.

POLYCHAETES - a class of multicellular invertebrates of the phylum Annelida (annelid worms); with the exception of a few rare cases, they are marine animals.

PRODUCTIVITY (of living matter) - yearly increase of the biomass.

PROCARYOTES - superkingdom of living organisms characterized by the absence of a real cell nucleus; comprises bacteria and Cyanophyceae.

PROTEROZOIC ERA - one of the early geological eras in the development of the Earth.

QUATERNARY PERIOD (or Anthropogene) - the period of the Cenozoic Era, which has lasted up to and includes the present.

RADIOLARIANS - subclass of unicellular invertebrates with a siliceous exoskeleton; typical representatives of the zooplankton of the World Ocean.

SAPROTROPHS - living organisms feeding on degrading organic matter.

SEA URCHINS - one of the classes of echinoderms (q. v.).

SEDIMENTARY ROCKS - rocks occurring in the lithosphere in the form of strata and having formed by abiogenic and biogenic sedimentation of substances, followed by transformation of the sediments in the course of diagenesis and katagenesis processes (q. v.).

SEDIMENTOGENESIS - one of the stages in the formation of sedimentary rocks, during which accumulation of sediments takes place.

SHELF (or continental platform) - shallow zones of sea around continents, extending from the shoreline to the depth at which the sea floor begins to descend steeply. Average width of the shelf is about 70 km; its average depth is about 140 m.

SILICA - silicon dioxide (SiO_2).

SILURIAN PERIOD - one of the periods of the Paleozoic Era.

SLUGGISH MATTER (after Vernadsky) - the same as abiogenic matter (q. v.).

SPONGES - a phylum of multicellular aquatic sessile invertebrates attached to the bottom or to other solid objects under the water. Sponges usually have the shape of a sack opened at the top, or of a deep goblet.

STRATISPHERE (according to Suess) - sedimentary envelope of the Earth.

SULPHATE-REDUCING BACTERIA - heterotrophic bacteria which reduce sulphates and use the energy obtained in the oxidation of organic substances.

THALLOME - the body of lower plants (including algae), without differentiation into stem, leaves, and root.

THIOBACTERIA - chemoautotrophic bacteria which oxidize sulphurous and ferrous compounds.

TRIASSIC PERIOD - the very first period of the Mesozoic Era.

UPWELLING - a process of vertical motion of water in the ocean, as a result of which abyssal water rich in nitrogen, phosphorus, and other elements important for life, rises to the surface.

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Illustrations

Ill. on p.	203	Bauxite particle consisting of microbial cells cemented together. 1,000-fold magnification. Photographed by T. V. Aristovskaya. (From: T. V. Aristovskaya, *Microbiology of soil-formation processes*, Leningrad, 1980, Fig. 10, *C*)
Ill. on p.	204	Lev Semenovich Berg. (Published in the Russ. ed. of "TBB")
Ill. on p.	206	Deposits of aluminum hydroxide on accretions of iron-manganese bacteria Metallogenium. 1,000-fold magnification. Photographed by T. V. Aristovskaya. (From: T. V. Aristovskaya, *Microbiology of soil-formation processes*, Leningrad, 1980, Fig. 11, *E*)

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