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INHALT

LIVING MATTER
A KEY CONCEPT IN VLADIMIR VERNADSKY'S BIOGEOCHEMISTRY

Georgy S. Levit and Alexander A. Protasov

»Living matter is the totality of all organisms present on Earth at any one time«.
V. I. Vernadsky: »Biosphere and Noösphere«, 1945[1]

INTRODUCTION

Vladimir Vernadsky's concept of living matter is central to his biogeochemistry, the science he founded. For several reasons, his original understanding of living matter is one of the most complex notions in the history of the life sciences. First, biogeochemistry is by definition an interdisciplinary enterprise that embraces biology, including evolutionary theory, geology, and chemistry, and combines them into a unique research program. Second, if understood in the original sense as used by Vernadsky, living matter is a concept built into idiosyncratic metaphysics constructed around the so-called principle of life's eternity. Third, the concept of living matter reflects the specificity of Vernadsky's sophisticated philosophy of science as he insisted that ›scientific thought‹ is a planetary phenomenon as well as a geological force.

In our contribution, we will introduce Vernadsky's concept of living matter in its historical context. Accordingly, we will also give some chronology of Vernadsky's work related to the growth of his biosphere concept highlighting the ›Ukrainian‹ period as it is in this period that he intensively elaborated on the notion of living matter. This will be followed by his theory of living matter as it was formulated in his major works of the later period. We are going to locate the notion of living matter within Vernadsky's theoretical system and demonstrate that he regarded his theory of the living as an evolutionary theory complementary to that of Charles Darwin from the very beginning. Additionally, we will briefly present Vladimir Beklemishev's concept of ›geomerida‹ which he developed at approximately the same time as Vernadsky was elaborating on his ›living matter‹ to highlight the specificity of the latter's methodology.

THE GROWTH OF VERNADSKY'S CONCEPT OF LIVING MATTER

The third edition of the *Great Soviet Encyclopedia* (1968–1975) insisted that Vernadsky coined the term living matter (»zhivoe veshchestvo«[2]). This thesis was repeated many times. The co-founder of the International Vernadsky-Fund Guenzel Guegamian recently claimed that Vernadsky »was the first who introduced the fundamental notion of living matter into science«.[3] This is true to the extent that Vernadsky's notion was idiosyncratic both in a philosophical sense and as an empirical research program. Also, nobody before him used ›living matter‹ as a geochemical term. However, the very combination of the words ›living matter‹ was not invented by Vernadsky. In the context of natural science, the term was already employed by the French naturalist Georges Louis Leclerc de Buffon, whose works Vernadsky studied thoroughly. For Buffon, organized matter (*matière organisée*) corresponds with living matter (*matière vivante*). In certain cases, he refers to the distinction between living and dead sub-

1 W[ladimir] I. Vernadsky: »The Biosphere and the Noösphere«, in: *American Scientist* 33 (1945), no. 1, pp. 1–12, here p. 1; Rus.: »Живое вещество есть совокупность всех организмов Земли находящихся на ней в данный период времени«. V[ladimir] I. Vernadskii: *Biosfera i Noosfera*, Moscow: Nauka 1989, p. 139.

2 A[natolii] N Tiuriukanov: »Zhivoe veshchestvo« [Living matter], in: *Bol'shaia Sovetskaia Ėntsiklopediia* [Great Soviet Encyclopedia], vol. 9: *Evklid–Ibsen*, Moscow: Sov. Ėntsiklopediia[3] 1972, pp. 183–184.

3 Genzel' V. Gegamian [Guenzel V. Guegamian]: »O zhivom veshchestve v biosferologii V.I. Vernadskogo« [On living matter in the biosphereology of V.I. Vernadsky], in: *Zhizn' Zemli* [Life of the Earth] 43 (2021), no. 2, pp. 258–269.

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stances instead of the distinction between organized and raw matter (*matière brute*).[4] Diderot, who advocated the imperishability of life, distinguished between dead matter (*matière morte*) and living matter (*matière vivante*); the term living matter appears in his discussion with Maupertuis and was employed on both sides of the discussion.[5] In 19th-century French-language literature, the expression *matière vivante* was nothing exceptional. In 1884, for example, Belgium-born psychologist Joseph Delboeuf published a paper titled *La matiére brute et la matière vivante: L'origine de la vie et la mort* (Crude matter and living matter: The origin of life and death).[6] The German notion Lebensstoff (living substance, living matter), which was being used in the vitalist circles at the turn of the century, is reminiscent of Vernadsky's wording. However, this term referred to a mystical self-organizing material substrate.[7] In the context of vitalist discussions, Driesch also mentioned Kant's claim that »the possibility of a living matter is quite inconceivable«.[8] Kant's critique was directed towards hylozoism and has no relation to Vernadsky's use of the term.

In 1902, Jacques Loeb gave a series of lectures at Columbia University which was later published as a book titled *The Dynamics of Living Matter*.[9] Loeb used the term as both an opposition to »inanimate matter« and as a tool to demonstrate the affinity of his methods to the »chemistry of the laboratory«.[10] A champion of chemical determinism and reductionism, he regarded living matter as a mixture of various compounds, such as proteins, fats, carbohydrates, and salts. Nevertheless, this does not render his use of living matter inalienable from his theory. The term was abandoned for the title of the German version of his book *Vorlesungen über die Dynamik der Lebenserscheinungen* (Lectures on the Dynamics of the Manifestation of Life).[11]

Vernadsky himself credited Alexander von Humboldt with an understanding of global life akin to his own: »For him [Humboldt] living matter is an inseparable and lawful part of the Earth's surface, inseparable from its chemical environment«.[12] However, Humboldt never used living matter. Instead, he spoke in more traditional terms of »living and non-living nature« (*belebte und unbelebte Natur*). Another conceptual influence was certainly Lamarck, especially his *Hydrogeology*, which highlighted the influence of living organisms on the earth's crust.[13] Yet, in the introduction to his *Histoire Naturelle*[14], Lamarck explicitly stated that »there is no such thing as general living matter; each living body has a specific organization«.[15]

Vernadsky's diaries, accounts by contemporary witnesses, and other related documents clearly prove that the initial period of his work on living matter and biogeochemistry almost completely coincides with the so-called Ukrainian period of his biography. Although Vernadsky already used this term sporadically in the 1900s, he began to systematically elaborate on the concept of living matter in 1916.[16] Vernadsky's longtime secretary Anna Schakhovskaya remembers that he started working on the issue of living matter in 1916 and intensified this work in the following years: »As the beginning of his works on ›living matter‹, i.e. on biogeochemistry, Vernadsky himself considered 1916 […]. In July 1917, Vernadsky had to go to the hamlet Shishaki of the Poltava Province [central Ukraine – *auth.*] and there he was completely embraced by a burst of intensive creativity; there he wrote down his thoughts on living matter. From that time, especially in 1918,[17] and until 1920 he worked intensively on this

4 Georg Toepfer: »Organisation«, in: id.: *Historisches Wörterbuch der Biologie Geschichte und Theorie der biologischen Grundbegriffe*, vol. 2, Stuttgart/Weimar: J. B. Metzler 2011, p. 754–776, here p. 757.

5 Aram Vartanian: »Diderot and Maupertuis«, in: *Revue Internationale de Philosophie* 38 (1984), no. 148/149 (1/2): *Diderot et l'encyclopédie (1784-1984)*, pp. 46-66; Charles T. Wolf: »Endowed Molecules and Emergent Organization: The Maupertuis-Diderot Debate«, in: *Early Science and Medicine* 15 (2010), no. 1/2, pp. 38–65.

6 Joseph Delboeuf: »La matière brute et la matière vivante: L'Origine de la vie et de la mort«, in: *Revue Philosophique de la France et de l'Étranger* 18 (1884), pp. 24–56.

7 Hans Driesch: *Der Vitalismus als Geschichte und als Lehre*, Leipzig: Johann Barth 1905, p. 240; Id.: *Geschichte des Vitalismus*, Leipzig: Johann Barth 1922, p. 105.

8 Immanuel Kant: *Critique of Judgement*, transl. by J.C. Meredith, Oxford/New York: Oxford University Press 2007, p. 222.

9 Jacques Loeb: *The dynamics of living matter*, N.Y.: *The* Columbia University Press 1906.

10 See ibid., p. 29.

11 Jacques Loeb: *Vorlesungen über die Dynamik der Lebenserscheinungen*. Leipzig: Barth 1906.

12 V[ladimir] I. Vernadskii: *Ocherki geokhimii* [Essays on Geochemistry], Moscow: Nauka 1983, p. 19.

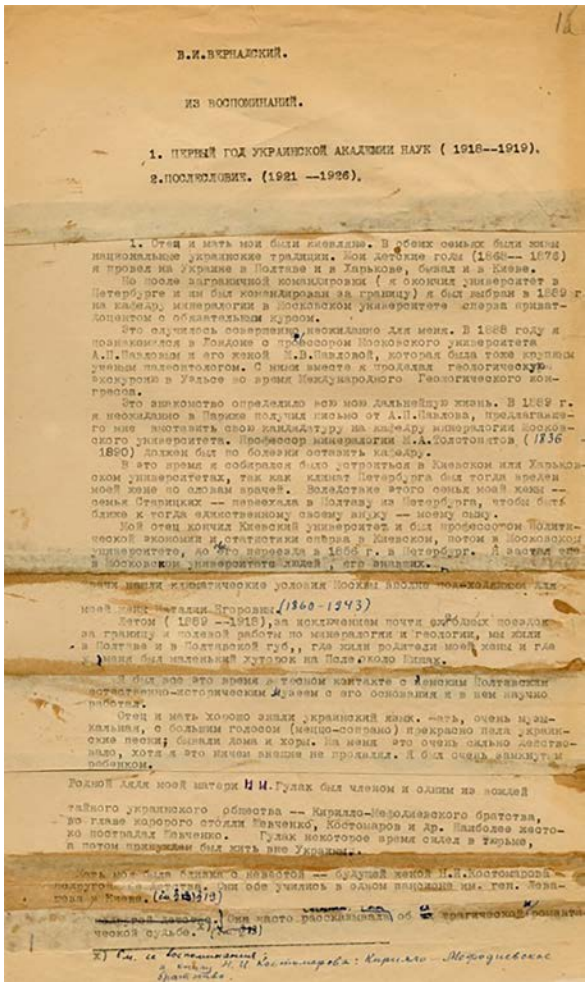
13 Albert V. Carozzi: »Lamarck's Theory of the Earth: Hydrogeologie, in: *ISIS* 55 (1964), no. 3, pp. 293–307.

14 Jean-Baptiste de Lamarck: *Histoire Naturelle des Animaux sans Vertébres*, vol. 1, Paris: Verdiere 1815, p. 12.

15 Frans A. Stafleu.: »Lamarck: The Birth of Biology«, in: *Taxon* 20 (1971), pp. 397–442. In his so-called 4th fundamental principle, Lamarck literally claimed that there is no matter in nature that by itself has the ability to live. See Lamarck: *Histoire Naturelle* 1 (note 14), p. 12.

16 See Gegamian (note 3).

17 Vernadsky's diaries from 1918 are full of notes proving that, at that time, he was working on living matter. For example, in an entry titled »8. III/23. II. 1918«, he literally notes: »I work on living matter«. In an entry titled »15/28.



В.И.ВЕРНАДСКИЙ.

ИЗ ВОСПОМИНАНИЙ.

1. ПЕРВЫЙ ГОД УКРАИНСКОЙ АКАДЕМИИ НАУК (1918--1919).
2.ПОСЛЕСЛОВИЕ. (1921 --1926).

Fig. 1: Page from the typescript of Vladimir Vernadsky's Reminiscences: »1. The First Year of the Ukrainian Academy of Sciences (1918-1919) … 1. My father and mother came from Kyiv. Ukrainian national traditions were alive in both families. I spent my childhood years (1868–1876) in Poltava and Kharkov, I was also in Kyiv. ...« Source: Archive of the Russian Academy of Sciences, fond 518, inv. no. 2, box 70, p. 1.

topic, it occupied a lot of place in his life and reached a great dimension«.[18]

Organizational work at the Ukrainian Academy of Sciences, of which Vernadsky became the first president in 1918, was not only a time-consuming activity that kept him from investing more work into the expanding theory of living matter, but it also opened up new possibilities. In 1918, Professor Solomon Frankfurt established a research institute at the experimental station of the All-Russian Association of Sugar Manufacturers (the station had well-equipped labs); here, Vernadsky began his experimental work on biogeochemistry. This was »the first biogeochemical laboratory in the history of natural science«.[19] A year later, Vernadsky noted: »In 1919, at the expense of the Ukrainian Academy of Sciences, we succeeded in organizing a systematic collection of animals and plants for chemical and spectroscopic studies«.[20] The resources he received (59400 carbovans) allowed him to conduct some quantitative research by employing three research assistants. This marked the very beginning of biogeochemistry and thus the beginning of the systematic research of living matter.

Vernadsky's notion of living matter is essential to his research program and becomes comprehensible only within biogeochemistry; nobody before him defined living matter as the sum total of all living organisms from a geochemical perspective. At the very initial stages of his work, Vernadsky already formulated the following empirical tasks: 1) to calculate a quantitative elementary composition of the different species; 2) to investigate the geochemical history of silicon, copper, zinc, lead, silver, and some other elements; 3) to determine some other geochemical characteristics of living organisms such as the average weight and water content as well as the percentage of carbon in the organisms.[21] Vernadsky was interested in the purely geochemical characteristics of living organisms while excluding their physiology, morphology, and other traditional biological fields. At the same time, he realized early on that his »doctrine of living matter« is »a new form

III.1918« he writes: »I was somehow captured by the work on living matter, which I have been thinking over, rethinking and processing, as well as by the thoughts on the current situation. But I can write solely about living matter, since I am barely finishing my work on it in the evening and I no longer have the desire and energy to write about the current moment«. V[ladimir] I.Vernadskii: *Dnevniki 1917–1921* [Diaries 1917–1921], ed. K[onstantin] M. Sytnik/B[oris] V. Levshin, Kyiv: Naukova dumka 1994, p. 63. On July 18, 1918, i.e., already in Kyiv, where he was occupied with establishing the Ukrainian Academy of Sciences, he wrote: »Today – these days – I nicely worked on living matter«. (Ibid., p. 118) On November 13, 1918, one day before Hetman Skoropadsky approved the foundation of the Ukrainian Academy of Sciences, Vernadsky wrote: »Today I worked on living matter, finished the 2nd lecture on geochemistry«. (Ibid., p. 125) All English translations are mine unless noted otherwise.

18 See V[ladimir] I.Vernadskii: *Zhivoe veshchestvo* [Living matter], Moscow: Nauka 1978, p. 325 (»From the editors«).

19 Konstantin M. Sytnik/Olena M. Apanovich/Stepan M. Stoiko (eds.): *V. I. Vernadskii: Zhizn' i deiatel'nost' na Ukraine* [V.I. Vernadsky: Life and Work in Ukraine], Kyiv: Naukova Dumka 1988, p. 72.

20 K[onstantin] M. Sytnyk/V[ira] V. Shmigovska: *Volodimir Vernads'kii i Akademiia* [Volodimir Vernadsky and the Academy], Kyiv: Naukova Dumka 2006, p. 161.

21 A[ndrei]V. Lapo/A[natoliy] A. Smyslov: »Biogeokhimiia: osnovy, zalozhennye V. I Vernadskim« [Biogeochemistry: The Foundations Laid by V.I. Vernadsky], in: A[leksandr] L. Yanshin (ed.): *Nauchnoe i social'noe znachenie deiatel'nosti V.I Vernadskogo* [Scientific and Social Significance of Vernadsky's Work], Moscow: Nauka 1989, pp. 54–61.

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of understanding« life and nature, which he noted in one of his letters to his colleague Boris Lichkov.[22]

In the summer of 1919, Vernadsky was threatened to become the target of political repressions and, following the urgent advice of his friends, decided to move to the biological station in Starosel'e and ›wait out‹ the troubled times, 20 kilometers up the River Dnieper from Kyiv.[23] It is during this period that the »nice and talented young zoologist« Theodosius Dobzhansky (future co-architect of the Modern Synthesis) assisted Vernadsky in overcoming these difficult times and became involved in his biogeochemical research.[24] Dobzhansky recalled: »When that thing [Red Terror – *auth.*] started, I believe it was May, 1919, my professor, Kushakevich and Vernadsky decided, probably quite reasonably, that it would be better for their health to move from hell's way and to disappear«.[25] Concerning Vernadsky's interests at that time, Dobzhansky commented: »And since the problem in which he was interested was the role of *living matter* [*auth.*] in geological processes, Kushakevich recommended to him that he hire me as a collector of the living material for his work«.[26] At the biological station Starosel'e in 1919, Vernadsky wrote his first paper that was explicitly devoted to the role of living matter in geological processes – »On the participation of living matter in the soil formation«. However, the paper that summarizes experimental studies conducted by Vernadsky in 1917–1919 was published only in 1984.[27] In this paper, Vernadsky provided a definition of living matter: »By the name of living matter, I mean the total sum of all organisms, plants, and animals, including humans. From the geochemical point of view, this totality of organisms has a significance only as the mass of matter it is made of, as a chemical composition, and as the energy connected to it«.[28]

Referring specifically to the role of living matter in soil formation, Vernadsky determined six crucial points[29]:

1. Living matter acts through the mass and composition of the substance it is made of. As such, living matter constitutes a part of the soil, either as it is or as the products of its transformation, i.e., a dying and dead substance.

2. Living matter determines the fineness of the soil.

3. Living matter changes the soil's structure, either due to the loosening or cementing activity of organisms dwelling in it or due to the character of their post-mortem destruction.

4. Living matter directly affects chemical processes within the soil, turning them into biochemical processes.

5. Living matter causes an extraordinal compounding of soil chemical elements, being the main factor in their mixing, and this determines the course of all chemical reactions taking place in the soil.

6. Living matter transports matter from afar and introduces it to the composition of soils, thereby violating the relationship between soil and subsoil. In this respect, it acts either by its own mass or in an indirect way.

»All these changes have been produced over the past millennia with an extremely intense, ever-increasing force by that part of the living matter that makes up cultural humanity«, Vernadsky argued.[30] As with »cultural humanity« with which Vernadsky referred to the growth of human civilizations, this early paper not only presented the concept of living matter but already contained a first nod towards the future noosphere theory.[31]

22 V[alentina] S. Neapolitanskaia (ed.): *Perepiska V.I. Vernadskogo s B.V. Lichkovym* [Correspondence of V.I. Vernadsky with B.V. Lichkov], *1918-1939*, Moscow: Nauka 1979, p. 31.
23 Sytnyk/Shmigovska: *Volodimir Vernads'kii i Akademiia* (note 20), p. 189.
24 V[ladimir] I. Vernadskii: *Dnevniki 1921-1925* [Diaries 1921-1925], ed. V. P. Volkov, Moscow: Nauka 1999, p. 164.
25 Theodosius Dobzhansky: *The reminiscences of Theodosius Dobzhansky*, typewritten transcript of interviews conducted 1962–1963 by B. Land. Oral History Research Office, New York, NY: Columbia University 1975.
26 See ibid.
27 Sytnik/Apanovich/Stoiko: *Vernadskii* (note 19), pp. 186–213, commentaries of publishers: pp. 338–345; see also G[leb] V. Dobrovolskii: »Poluzabytaia, no ochen' vazhnaja dlia pochvovedeniia i ucheniia biosfere stat'ia V.I. Vernadskogo« [A half-forgotten, but very important article by V.I. Vernadsky for the soil science and the biosphere study], in: *Zhivye i biokosnye systemy / Live and bio-abiotic systems. Scientific electronic periodical* (2013), no. 2, https://jbks.ru/archive/issue-2 (accessed on 01.03.2023).
28 See Sytnik/Apanovich/Stoiko: *Vernadskii* (note 19), p. 193.
29 Ibid., pp. 194–195.
30 Quoted after ibid., p. 195.
31 Jesse P. Hiltz/Georgy S. Levit: »The Biosphere and Noosphere: Vladimir Vernadsky and Teilhard de Chardin«, in: SynergieWissen (15.10.2012), https://www.synergiewissen.de/doku.php?id=features:biosphere_and_noosphere (accessed on 01.03. 2023).

At the end of August 1919, the Bolsheviks abandoned Kyiv and the city was occupied by the troops of General Anton Denikin. Following his negotiations with the new authorities, Vernadsky left Kyiv in November 1919 for Rostov-on-Don, where Denikin was residing, and never returned to Kyiv. In January 1920, Vernadsky moved to Crimea (to the ownership Gornaia Shel', near Yalta), where he contracted typhus and experienced what his biographers call a »spiritual turn«.[32] Vernadsky realized that he was about to formulate a completely new doctrine which would revolutionize science. Despite his illness, Vernadsky continued to contemplate on living matter; in January 24th, 1920, he wrote the following note into his diary: »I am in bed with a high temperature. Yesterday it was 39 degrees. The head is mentally clear and fresh, but heavy. Yesterday I was thinking over the composition of my work on living matter all the time, which I am writing ...«.[33] After waking from a three-week long unconsciousness, Vernadsky immediately designed the experimental study of living matter and asked his wife to write it down.[34] During this spiritual turn, Vernadsky clearly realized that he was creating another kind of evolutionary theory which complemented Darwin's doctrine: »I am amazed by the awareness that, in my work on the living matter, I created a new doctrine which represents the other side, another aspect of the evolutionary theory, and this became clear to me only now after the sickness«.[35]

In Crimea, Vernadsky was, among others, teaching at the newly established Taurida University. In September 1920, he was approved as the new rector of this university, which today bears his name. In March 1921, however, Vernadsky returned to Petrograd (since 1924: Leningrad) where he continued his work on living matter. In his letter to Lichkov (28.04.1921), Vernadsky wrote that he was »mostly working on living matter« and gave lectures on »living matter and geochemistry«.[36] One of these lectures was his programmatic address »The Beginning and Eternity of Life«, in which he presented the concept of living matter as a cosmic phenomenon for the first time. It was published as a separate brochure the following year.[37]

In this small but seminal publication, Vernadsky formulated a philosophical premise that would determine his whole way of thinking on living matter: »Pointing out the logical necessity of the beginning for the evolutionary process is more of philosophical than of scientific interest«.[38] The idea of the beginning of life is closely related to the doctrine of the beginning of the world in the Judeo-Christian religious tradition. However, this is not the only way of thinking. Buddhists, for example, do not ask for the world's beginning. Vernadsky himself would approach the beginning of life as a scientist, not as a philosopher. The idea of the eternity of life, Vernadsky continued, opens up the broadest horizons for scientific creativity. The acceptance of life's eternity would, in turn, lead to the idea of a crucial difference between life and death. Thus, in 1922, Vernadsky clearly formulated three hypotheses, which he would continue to develop throughout the rest of his scientific career: living matter is a cosmic phenomenon, living matter differs crucially from inert matter, and therefore the evolutionary process had no beginning in the biosphere, there was no empirical evidence of abiogenesis. The very term biosphere still wasn't central to Vernadsky's paper as he only employed it once and without providing any explicit definition.

Despite his tendency towards generalizations on a metaphysical level, Vernadsky was first of all an empirical scientist. At the initial stage, he formulated the following tasks: 1) to calculate a quantitative elementary composition of the different species; 2) to investigate the geochemical history of silicon, copper, zinc, lead, silver, and some other elements; 3) to determine some other geochemical characteristics of living organisms such as the average weight and water content as well as the percentage of carbon in the organisms.[39]

Vernadsky's concept of living matter was developed as part of his geochemical research. Two years after the publication of the booklet *The Beginning and Eternity of Life*, he published his seminal *La Géochemie*[40] followed by *The Biosphere* in Russian,[41] which can be considered the first attempt to offer a general concept

32 G[ennadii] P. Aksenov: *Tri biografii Vladimira Vernadskogo* [Three Biographies of Vladimir Vernadsky], Moscow: Archiv RAN 2014, p. 13.
33 See Sytnik/Apanovich/Stoiko: *Vernadskii* (note 19), p. 86.
34 G[ennadii] P. Aksenov: *Vernadskii*, Moscow: Molodaia Gvardiia 2010.
35 See Sytnik/Apanovich/Stoiko: *Vernadskii* (note 19), p. 88.
36 See Neapolitanskaia: *Perepiska* (note 22), p. 21.
37 V[ladimir] I. Vernadskii: *Nachalo i vechnost' zhizni* [The Beginning and Eternity of Life], Petrograd: Izdatel'stvo Vremia 1922.
38 Ibid., p. 55.
39 Lapo/Smyslov: »Biogeokhimiia« (note 21), p. 55.
40 W[ladimir] Vernadsky: *La géochimie*, Paris: Félix Alcan 1924.
41 V[ladimir] I.Vernadskii: *Biosfera*, Leningrad: Nauchno-Technicheskoe Izdatel'stvo 1926.

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of global ecology and energy transformation. However, it does not contain his complete theory. In *La Géochimie*, Vernadsky gave the first comprehensible geochemical definition of living matter: »[…] We must define all organisms only in relation to their weights, chemical composition, and energy. By defining all living organisms with these parameters, it is necessary to introduce new notions into the phenomena of life, to introduce these unstable phenomena into the framework of chemistry, into the set of almost immutable products, raw materials, minerals, and rocks. What we will call living matter is the entirety of all organisms, expressed in weight, in chemical elements, in energy«.[42] From a purely biogeochemical viewpoint, living matter is reducible to its mass, energy, and chemical composition, varying both spatially and temporally. Still, several further steps were needed to complete the theory's methodological basis.

The Biosphere was completed at the end of his research stay in France (1922–1925), after the publication of *Geochemistry*. In part, it coincides with the unpublished report to the Rosenthal Foundation titled »Living Matter in the Biosphere«.[43]

In 1926, Vernadsky returned to Leningrad from his long trip abroad and, in 1928, he gave a talk to the *Leningrad Society of Natural Scientists* (Obshchestvo Estestvoispytatelej) in which he formulated the first and the second biogeochemical principles. These would form the foundation of his doctrine of living matter.[44] The independent *Biogeochemical Laboratory of the Academy of Sciences* was officially founded in the same year (1928) on the basis of the *Department of Living Matter* of the *Commission for the Study of the Natural Productive Forces of the Country* (KEPS)[45] and existed as an independent unit until 1947. Thus, both the theoretical foundation (biogeochemical principles) and empirical basis for the study of living matter were established in 1928, initiating what is referred to as the ›mature period‹ of Vernadsky's developing theory of living matter. As one of his contemporaries reported in *Nature*: »Vernadsky is convinced that the geochemical role of organisms is grossly misunderstood and underrated. This fascinating problem was raised by him so far back as 1918, and in 1928 a special laboratory was created for the purpose of investigating it«.[46]

A year later (1929), a slightly expanded version of *The Biosphere* was published in French in Paris.[47] That same year, Vernadsky prepared a collection of papers under the joint title *Living Matter* for publication. However, due to the increasing censorship and ideological control following the restructuring of the Soviet Academy of Sciences of the USSR in 1929–1930, this book remained unpublished. The second attempt to publish *Living Matter* dates back to 1935 but also remained unsuccessful. Only 33 years after Vernadsky's death was the book finally published.[48]

In the mid-1930s Vernadsky began planning what he would call ›the book of my life‹, which was ultimately split into two projects. The first was completed in 1938 under the title *Scientific Thought as a Planetary Phenomenon*[49], an expression of his mature ›philosophy‹. Due to strong state censorship, the second project, which Vernadsky considered the final manifestation of his theory of the biosphere, was published as late as 1965 under the title *The Chemical Structure of the Earth and its Environment*.[50] This is Vernadsky's opus magnum, which was mostly written during the Second World War. It consists of two parts titled »Geological and geochemical manifestation of the Earth as a planet in the Solar System and Milky Way« and »Geochemical Structure of the Biosphere. The Planetary

42 Vernadsky: *La géochimie* (note 40), p. 54.

43 See Gennadii Aksenov: *Vernadskii*, Moscow: Molodaya Gvardia ²2010.

44 W[ladimir] Vernadsky: »Über die geochemische Energie des Lebens in der Biosphäre«, in: *Centralblatt für Mineralogie, Geologie und Paläontologie*, Abt. B (1928), no. 11, pp. 583–594.

45 L[oriana] D. Vinogradova: *Istoriia biogeokhimicheskikh issledovanii* [History of Biogeochemical Research], in: *BIOGEL AN SSSR. Trudy XII mezhdunarodnoj biogeokhimicheskoi shkoly* [Proceedings of the 12th International Biogeochemical School], Tula: TGPU 2021, pp. 33–42.

46 B[oris] P. Uvarov: »Geochemistry of Living Matter«, in: *Nature* 134 (1934), pp. 11–12.

47 W[ladimir] Vernadsky: *La Biosphere*, Paris: Félix Alcan 1929; Alexei M. Ghilarov: »Vernadsky's Biosphere Concept: An historical perspective«, in: *The Quarterly Review of Biology* 70 (1995), no 2, pp. 193-203.

48 Vernadskii: *Zhivoe veshchestvo* (note 18); Sergii M. Kirzhaev et. al: *V.I. Vernads'kii i Urkaina: z listuvannya* [V.I. Vernadsky and the Ukraine: Correspondences], vol. 2, Kyiv: Natsional'na biblioteka Ukraini imeni Vernads'kogo/Institut arkhivoznavstva 2019.

49 V[ladimir] I. Vernadskii: *Nauchnaia mysl' kak planetnoe iavlenie* [Scientific Thought as a Planetary Phenomenon], Moscow: Nauka 1991.

50 V[ladimir] I. Vernadskii: *Khimicheskoe stroenie biosfery zemli i ee okruzheniia*, Moscow: Nauka 1965. A[leksandr] L. Yanshin: »Zhivoe veshchestvo I biosfera v trudakh V.I. Vernadskogo« [Living matter and the biosphere in the works of V.I. Vernadsky], in: V[ladimir] I. Vernadskii: *Zhivoe Veshchestvo i Biosfera* [Living Matter and the Biosphere], Moscow: Nauka 1994, pp. 5–15.

role of living matter«. Vernadsky also planned a third part devoted to the noosphere. However, although he worked on the book until his last days, it was never realized. The most comprehensive and mature form of Vernadsky's theory of living matter in the biosphere in the context of biogeochemistry may be found in *The Chemical Structure,* even though this work was not finished by the author as planned.

VERNADSKY'S MATURE DOCTRINE OF LIVING MATTER

Vernadsky argues that living matter is a planetary constant. Across the earth's entire geological history beginning with the Archean, its quantity and average chemical composition fluctuated around a certain parameter.[51] Both the chemical structure of inert and living matter remained in a state of dynamic equilibrium. Vernadsky thus distinguished between biological evolution as reflected, for instance, in the changing morphological structures and biogeochemical evolution. As a constant value for living matter in general, particular biological species may be characterized biogeochemically as they differ in their chemical composition and ability to accumulate chemical substances. Vernadsky noted that the chemical composition of various organisms is very similar with regard to certain elements such as carbon, nitrogen, or sulfur, but it differs with regard to the quantity of other elements such as iron, manganese, iodine, bromine, arsenic, boron, etc., which are subject to great variations in various species.[52] Currently, the study of the concentration function of various organisms is a biogeochemical routine. However, Vernadsky's original idea was not to simply point out that different species accumulate different substances, but to claim that the chemical compounds of living matter do not reflect that of their environment. Rather, life seems to determine the geochemical history of almost all the compounds of the earth's crust in the process of the interaction between living organisms and their environment.[53] To a certain extent, a biogeochemical function is primal in relation to an organismic function, and the same biogeochemical function may be fulfilled by different species. In that sense, biological evolution would not necessarily violate biogeochemical functions as the earth's crust experiences a series of cycling processes.[54] This was later reformulated by Georgy Zavarzin as the concept of the »space of logical possibilities« for microbial communities.[55] In terms of the functions performed by different organisms, the space of logical possibilities must be comprehensively fulfilled and it does not matter which specific organisms will complete this task. Vernadsky insisted that all biogeochemical functions can be carried out by the simplest unicellular organisms.[56]

Due of the biogenetic control of the flow of chemical elements, Vernadsky considered living matter to be the major factor in terrestrial geological evolution. Life is not a superficial or an accidental phenomenon.[57] Living matter is the most powerful chemical force on the Earth and »no other geological force can be even compared to it considering its intensity and continuity in time«; living matter »in essence, determines all basic chemical regularities in the biosphere«.[58] The biosphere is a peculiar layer of the earth embraced by life, which has had a »very lawful structure« for at least two billion years. The structure of the biosphere is characterized by a dynamic equilibrium fluctuating around a certain statistical value. Vernadsky labeled this dynamic structure »the organization of the biosphere« in order to distinguish it from purely mechanical structures: »The organization of the biosphere – the organization of living matter – should be regarded as equilibria, moving, constantly fluctuating within historical and geological time around a precisely expressed average. Displacements or fluctuations of this mean value continuously manifest themselves not in the historical, but in the geological time«.[59] In other words, the biosphere is a self-regulating system comprising the totality of living matter and various geospherical layers that serve as its inert environment.

From a chemical perspective, the most general manifestation of the ›organization of the biosphere‹ is the so-called biogeochemical functions of living matter that influence the entire planet and do not constrain on the ›territorial‹ (regional) conditions of the

51 See Eduard Mirzoian: »Teoriia zhivoi materii V.I. Vernadskogo« [V.I. Vernadsky's Theory of Living Matter], in: *Zhurnal Obshchei Biologii* 55 (1994), no.1, pp. 13–28.
52 See Uvarov: »Geochemistry of Living Matter« (note 46).
53 V[ladimir] I. Vernadskii: *Zhivoe veshchestvo i biosfera* [Living Matter and Biosphere]. Moscow: Nauka 1994.
54 See Mirzoian »Teoriia zhivoi materii« (note 52).
55 Georgii Zavarzin: *Fenotipicheskaia sistematika bakterii. Prostranstvo logicheskikh vozmozhnostei* [Phenotypic Systematics of Bacteria. The Space of Logical Possibilities], Moscow: Nauka 1974.
56 Vernadskii: *Dnevniki 1917-1921* (note 17), p. 458.
57 Alexei M. Ghilarov: »Lamarck and the Prehistory of Ecology«, in: *International Microbiology* 1 (1988), pp. 161–164.
58 Vernadskii: *Khimicheskie stroenie* (note 50), p. 236.
59 Vernadskii: *Nauchnaia mysl'* (note 49), p. 16.

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geosphere. The biogeochemical functions determine the basic chemical manifestation of life and describe the most fundamental chemical reaction of living matter impacting its environment. These functions include 1) gas functions, which regulate the gaseous structure of the atmosphere as well as of submarine and subterranean environments; 2) the already mentioned concentration functions, which allow organisms to capture and concentrate the chemical elements of their environments; 3) oxidation-reduction functions; 4) various biochemical functions wherein the feeding, breathing, multiplication, and destruction of organisms redistribute and mix matter; and 5) the biogeochemical functions of humans.[60]

Since relatively closed biogeochemical cycles determine the structure of the biosphere, it »appears in biogeochemistry as a peculiar envelope of the Earth clearly distinct from the other envelopes of our planet«.[61] A good example of a dynamic equilibrium in the biosphere is the troposphere: »All basic gases of the troposphere and of the higher gaseous envelopes – N2, O2, CO2, H2S, CH4, etc., – are produced and quantitatively balanced by the total activity of living matter. Their sum total is quantitatively invariable over geological time […]«.[62] Vernadsky concludes that »life, i.e. living matter establishes the troposphere and constantly maintains it in a dynamic equilibrium around a certain static equilibrium«.[63] In his terms, the troposphere is a »planetary« phenomenon as it was »created by living matter«.[64]

The basic laws regulating the dynamics of living matter on earth are three so-called biogeochemical principles (BGCPs). Here, we provide the first two BGCPs in two versions as Vernadsky's concept of energy may be misinterpreted.

First BGCP:

a) Geochemical biogenic energy tends towards its maximum in the biosphere.[65]

b) Biogenic migration of chemical elements tends towards its maximum in the biosphere.[66]

Second BGCP:

a) »Organisms survive in evolution only if they increase biogenic geochemical energy«.[67]

b) »The evolution of species (over geological time) tends toward the creation of stable life forms in the biosphere and aims to increase the biogenic migration of the atoms«.[68]

The *third BGCP* can be seen as a logical consequence of the first two principles. It states that, over geological time and since the Cryptozoic era, »the population of the planet has always been at the maximum possible level for all living matter«.[69]

The BGCPs fulfill a fundamental role in Vernadsky's theoretical system. He considered the first BGCP a so-called empirical generalization. Within Vernadsky's hierarchy of ›scientificity‹, this is the most reliable form of knowledge as empirical generalizations are immediately made on the basis of raw empirical data. The first BGCP refers to the fact that every biological species aims for the maximum possible quantitative value and this value can be redefined in biogeochemical terms.

Vernadsky admitted that the second BGCP »contains some assumption« as the biological data is incomplete.[70] It stands at a crossroads between the Darwinian theory of evolution and biogeochemistry as the struggle for existence guarantees that there can be no decrease in biogenic migration. Vernadsky's ›stable life forms‹ approximately correspond to the Darwinian-Spencerian concept of the ›survival of the fittest‹ even though Vernadsky's ›stable life forms‹ do not necessarily evolve as long as they fulfill their biogeochemical role in the biosphere. Vernadsky highlighted the unequal velocity of the evolutionary process for various species and the virtual immutability of certain ›species-persistents‹ that remained unchanged over millions of years (he provides examples of some *radiolaria* and *Lingula*).

60 Vernadskii: *Khimicheskie stroenie* (note 50), p. 237.
61 Vernadskii: *Nauchnaia mysl'* (note 49), p. 120.
62 Vernadskii *Khimicheskie stroenie* (note 50), p. 238.
63 Ibid.
64 Ibid., p. 238.
65 V[ladimir] I. Vernadskii: »Izuchenie iavlenii zhizni i novaia fizika« (1931) [The study of the phenomena of life and the new physics], in: id.: *Zhizneopisanie. Izbrannye trudy. Vospominaniia sovremennikov. Suzhdeniia potomkov* [Vladimir Vernadsky. Biography. Selected works. Reminiscences of contemporaries. Opinions of descendants. Sovremennik], Moscow: Sovremennik 1993, pp. 355–394.
66 Vernadskii: *Khimicheskie stroenie* (note 50), p. 283.
67 Vernadskii: *Izuchenie iavlenii zhizni* (note 66), p. 372.
68 Vernadskii: *Khimicheskie stroenie* (note 50), p. 270.
69 Ibid., p. 286.
70 Ibid., p. 285.

The second BGCP is the most central law with far-reaching consequences as it describes the directionality of evolution which ultimately leads to the transition of the biosphere into the noosphere. Vernadsky understood the noosphere as a lawful stage in the evolution of the biosphere. The crucial characteristic of this last stage of biospheric evolution is the dominance of scientific reason.[71]

THE SPACE-TIME OF LIVING MATTER

Starting in the early 1920s, Vernadsky consequently promoted the concept of the eternity of life in biogeochemical terms. It argued that, for a biogeochemist, life was a systemic property of the entire biosphere and must have occurred on earth immediately as a system that fulfills all basic biogeochemical functions.[72] Abiogenesis, as understood by biologists and chemists, i.e. an occurrence of single organisms in a primordial soup or similar conditions, was unthinkable in Vernadsky's theoretical world: »Talking about the origin of life on our planet we, in fact, are talking exclusively about the formation of the biosphere«.[73] Life is a global systemic property. His theory of a particular space-time of living matter was his most radical attempt to demonstrate the irreducibility of living matter to its inert counterpart.

To distinguish between living and inert substances as fundamentally different states of matter, Vernadsky introduced his notion of a ›state of space‹. This notion allowed him to contrast his views against Kant's concept of space: »Geometry is not a manifestation of the human reason *a priori*«.[74] Instead, it is the manifestation of the states of space that can be examined by investigating the geometrical properties of natural bodies.[75] In Vernadsky's terms, a ›natural body‹ is every natural material-energetic phenomenon separated in space and time from other natural bodies. Living organisms or minerals are examples of natural bodies. Although this definition might seem circular (the space of a natural body will be analyzed under the assumption that the natural body is spatially separated from other natural bodies), Vernadsky, in fact, was trying to liberate the notion of space (and time) not only from Kant's philosophy, but also from both Newton and Einstein. Newton's absolute space and time were based exclusively on negative characteristics, excluding them from scientific investigation (it is independent of the environment, eternal, etc.); Newton's space and time are isotropic. Einstein broke down this Newtonian picture, but he could not foresee the possibility for naturalists to study space-time as well.[76] The space of the naturalist is *anisotropic*, i.e., heterogeneous, and therefore can be approached through methods from natural science.

The state of space of a natural body is indicated by the investigation of its symmetry. For Vernadsky, the principle of symmetry was one of the most fundamental principles of nature. We may argue that, for him, the principle of symmetry was a cornerstone of the problems that were to be discussed. A highly important aspect is that the symmetry principle is fundamental also from the viewpoint of its place within the epistemological hierarchy as constructed by Vernadsky. According to Vernadsky's terminology, this principle is *an empirical generalization of the first kind.* In other words, this empirical generalization is formulated directly on the basis of the ›raw‹ facts.

Considering these two basic notions, ›the state of space‹ and ›symmetry‹, Vernadsky analyzed inorganic crystalline structures and arrived at the conclusion that crystalline matter can be characterized as *an anisotropic state of space that is completely defined by the laws of Euclidean geometry.* Anisotropic space will be defined as »geometrically expressed heterogeneity«.[77] It is heterogenous, but only in a certain sense: »The anisotropic space of the physicist and the crystallographer is discontinuous in the sense of homogeneity since the points that fill it are different from their environment, but it is homogenous in the sense of extension since it uniformly embraces the entire space, no matter what dimensions it may have«.[78] The state of space of inert

71 Georgy S. Levit: »The Biosphere and the Noosphere Theories of V. I. Vernadsky and P. Teilhard de Chardin: A Methodological Essay«, in: *Archives Internationales d'Histoire des Sciences* 50 (2000), no. 144, pp. 160–176.

72 Vernadskii: *Zhivoe veshchestvo i biosfera* (note 54), p. 454 and p. 457.

73 Ibid., p. 457.

74 V[ladimir] I. Vernadskii: *Filosofskie mysli naturalista* [Philosophical Thoughts of a Naturalist]. Moscow: Nauka 1988, p. 260.

75 See Georgy S. Levit/Wolfgang E. Krumbein/Reiner Grübel: »Space and Time in the Work of V.I. Vernadsky«, in: *Environmental Ethics* 22 (2000), no. 4, pp. 377–396.

76 V[ladimir] I. Vernadskii: *Trudy po filosofii nauki* [Contributions on the Philosophy of Science], Moscow: Nauka 2000, p. 134.

77 Ibid., p. 189.

78 V[ladimir] I. Vernadskii: Problema vremeni v sovremennoi nauke [The Problem of Time in Modern Science]. *Izvestiia Akademii Nauk SSSR. VII Seriia: Otd. Matematicheskikh i estestvennykh nauk* [Department of Mathematical and Natural Sciences] 4 (1932), pp. 511–541.

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matter is Euclidean in the sense that processes that take place in such a kind of space show the identity of leftness and rightness physically and geometrically. Furthermore, the inorganic crystals never feature a higher symmetry than one of the 6th and rarely of the 5th order.[79]

However, the situation changes in the world of living matter. Louis Pasteur already described a dissymmetry in the crystals of tartaric acid. Organic compounds, which are typical for all kinds of living matter, differ from compounds that the inert (non-living) parts of the Earth are composed of. Pasteur called these two categories *la nature vivante* and *la nature morte*. There are always two enantiomorphs[80] which could theoretically exist. The protoplasm of living matter consists of pure steric compounds. In the stereochemical equations of these compounds, the atoms preferentially arrange in left-handed or right-handed isomers instead of statistically distributing, something that could be expected as a result of physical/chemical laws alone. Pasteur stated that the biochemical processes of living matter and their crystallization products demonstrate the preferential synthesis and maintenance of left-turning or right-turning isomers.[81]

Vernadsky elevated the dissymmetry and declared it a universal principle, distinguishing the spaces of living and inert matter and reflecting the genetic difference between two kinds of matter: Only dissymmetry can generate dissymmetry. This is an important step that leads towards something he labeled the *Redi principle* (after Francesco Redi, 1626–1697), which claims: *Omne vivum e vivo* [all life from life]. In Vernadsky's terms, this means that »new living natural bodies are born only from pre-existing ones«[82] and this chain of being is eternal from the biogeochemical perspective, i.e., life is geologically eternal.[83]

The orders of the structural symmetry on the macro-level and dissymmetry on micro-level did not exhaust the discrepancy between living and inert states of spaces. These features are complemented by *dispersiveness* (the sharp separateness of a living organism from its environment), *stability* (the constant re-creation of form in a dynamic equilibrium), and *curvilinearity* (the separation of organisms from their environment by *curved surfaces* in contrast to inorganic crystals).

Living matter can also be contrasted with inert matter in relation to temporal properties. Vernadsky derived from his biogeochemical experience that the processes producing the inert natural bodies would feature cyclic, reversible, undirected characteristics in the absence of living matter: »In the cryptozoic era, the same minerals and rocks were being formed which are being formed now«.[84] It seems that only in living matter can there be a substantial irreversibility since evolution (an irreversible process) takes place only among the living natural bodies of the earth.[85]

The irreversibility of time is tightly connected to the anti-entropic properties of living matter. The German philosopher Adolf Meyer-Abich, a younger contemporary of Vernadsky, highlighted the importance of this principle: »The deep rift that Vernadsky tore between the organismic and the inorganic nature is further deepened by the fact that, based on geochemical experiences with the biosphere, he deems necessary a revision of the *entropy principle*, the second law of energetics. What Helmholtz, Maxwell, and others suspected, namely that the phenomena of life do not behave entropically, but rather in the opposite way, ectropically [...], is confirmed by modern geochemistry«.[86]

In his notes from 1941–1942, in the last years of his life, Vernadsky claimed: »Time, which is being expressed by a polar vector in physical-chemical and biological processes in living matter, is irreversible; it does not go back. That shows that entropy will take no place in the material medium of living matter«.[87] In other words, Vernadsky connects the irreversibility of time in living matter with the opposite idea that living natural bodies escape entropy. This idea was not solely Vernadsky's claim. Approximately at the same time (1944), Erwin Schrödinger remarked that living organism »feeds on negative entropy«.[88] Vernadsky, however, speculated on the level of living matter, not

79 Vernadskii: *Khimicheskie stroenie* (note 50), p. 178.
80 »A structure that is a mirror image of another, being exactly the same shape as the other except for the reversal of left and right« (overview »Enantiomorph«, in: www.oxfordreference.com (accessed on 01.03.2023)).
81 Louis Pasteur: *Oeuvres de Pasteur*, Vol. 1: *Dissymétrie moléculaire*, Paris: Masson et Cie, Éditeurs 1922, p. 343.
82 Vernadsky: »The Biosphere and the Noösphere« (note 1).
83 Vernadskii: *Zhivoe veshchestvo i biosfera* (note 54), p. 452.
84 Vernadsky: »The Biosphere and the Noösphere« (note 1).
85 See Vernadskii: *Filosofskie mysli* (note 75), pp. 30, 175, 181, 286.
86 Adolf Meyer-Abich: *Naturphilosophie auf neuen Wegen*, Stuttgart: Hippokrates 1948, p. 186.
87 Vernadskii: *Filosofskie mysli* (note 75), p. 274.
88 Erwin Schrödinger: *What is Life?* Cambridge: Cambridge University Press 1992, p. 71.

on the level of a single organism. As a biogeochemist, he could see that the evolution of the biosphere is a movement towards a more perfect orderliness and stability. Hence, the evolution of living matter as well as the evolution of the entire biosphere are irreversible processes. This irreversibility is caused by the presence of living matter in the biosphere.

Vernadsky's evolution is not only irreversible due to the immanent properties of living matter, but it is also directed. The evolution of the biosphere generally strives towards increasing the biogenic migration of atoms. However, there are also morphological signs of irreversibility. To illustrate the irreversibility and directedness of evolution, Vernadsky introduced the so-called Dana-principle or *Dana generalization* (after James D. Dana, 1813–1895). Going from his studies of crustacea, Dana formulated a principle: »The fundamental idea, which we shell find at the basis of the various distinctions of structure among species is, *the higher centralization of the superior grades, and the less concentrated forces of the interior* […]. This centralization is literally a *cephalization* of the forces«.[89] Vernadsky reformulated this principle[90] and stated that, with the course of geological time, the central nervous system of some species strives towards perfection (*cephalization*). The thesis on the irreversibility of evolution is one of the arguments in favor of Verdansky's *noosphere concept*.

Thus, Vernadsky's idiosyncratic space-time hypothesis is required to prove the thesis of the crucial difference between living and inert matter and, hence, the irreducibility of the life processes to physical-chemical laws. The cardinal difference between living and inert matter is supported by or associated with all substantial ›principles‹ of his theoretical system: 1. three biogeochemical principles, 2. the Redi principle, 3. the Dana principle, 4. the principle of biospheric evolution, and 5. the noosphere concept.

VLADIMIR BEKLEMISHEV'S ›GEOMERIDA‹ AS A COMPLEMENTARY APPROACH TO LIVING MATTER

Towards the end of the 1920s, the Russian zoologist and morphologist Vladimir Beklemishev developed another concept of living matter, which can be viewed as a complementary approach to Vernadsky's biogeochemical grasp of living organisms.[91] Beklemishev saw the organism as a dynamic equilibrium. However, in contrast to Vernadsky, he interpreted them from a structural rather than a chemical perspective. In 1928, he wrote: »Every organism is part of a semi-parasitic and semi-mutualistic community; the life of any wholeness is based on the conflict and destruction of the parts; the entire world ›lies in evil‹«.[92] Like Vernadsky, Beklemishev approached life on earth from a global perspective, introducing the new term geomerida which labels the totality of all living organisms on earth. For him, a geomerida was »the organism of the highest order« and another term for the biosphere (not to be confused with Vernadsky's use of the term). Formally speaking, Beklemishev did not coin the term geomerida, but he was the first who publically defined it as »the totality of everything alive on Earth«.[93] He adopted the term from the botanist Konstantin Starynkevich via the biologist and philosopher of science Aleksandr Liubishchev[94] who attended Starynkevich's lecture in 1919 at the Taurida University (Crimea). A year later, Vernadsky became its rector. Even though Beklemishev practically abandoned this term after 1931, he upheld the idea of »the living cover« as an object of study: »biology's main object of study is this swarming boundless world of living things – the living cover of the Earth.[95]

A fundamentally new concept that Beklemishev implemented into the debate on living matter and the biosphere is the concept of the morphoprocess, which he developed for »ordinary« living organisms to describe global and cosmic phenomena. On the scale of the biosphere, the morphoprocess is defined as »the totality of all living beings of the earth, this living

89 James D. Dana: »A review of the classification of Crustacea with reference certain principles of classification«, in: *The American Journal of Science and Arts* XXII (1856), p. 14–29, here p. 15.

90 Vernadskii: *Nauchnaia mysl'* (note 49), pp. 21–22.

91 Alexandr A. Protasov: »K voprosu o metodologii ekologicheskogo aktualisma. Liubishchevskie chteniia« [On the Methodology of Ecological Actualsim. Readings], in: *Sbornik materialov vserossiiskoj nauchnoi konferentsii* [Proceedings of the All-Russian Scientific Conference], Ulianovsk, 30.-31.03.2017, Ulianovsk: UlGPU 2017, pp. 114–119.

92 V[ladimir] N. Beklemishev: *Metodologiia sistematiki* [Methodology of Systematics], Moscow: KMK Press 1994, p. 57.

93 Ibid., p. 61.

94 Starynkevich's term ›geomerida‹ was recorded in Liubishchev's diary of the 4th May 1919. See Aleksandr Liubishchev: *Dnevnik, 1918-1922*, Ulianovsk: 2002; e-version: https://prozhito.org/notes?date=%221918-01-01%22&diaries=%5B90%5D (accessed on 01.03.2023).

95 Vladimir N. Beklemishev: »Ob obshchikh printsypakh organizatsii zhizni« [On the General Principles of the Organization of Life], in: *Bulleten MOIP. Otd. Biologii* 69 (1964), no. 2, pp. 22–38.

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crust, spread out on this rocky ball« existing due to its organization, that is, »the continuous preservation of typical forms and relations of the whole in the constant change of its parts«.[96]

Beklemishev developed a methodology for studying the geomerida. Since it was seen as the organism of the highest order and therefore existed as a single specimen, it could not be approached from the viewpoint of taxonomy. He argued that, on the level of the entire biosphere, biological systematics can only be a morphology and this morphology would be subdivided into tektology and architechtonics. In architectonics, every single phenomenon is understood as unique and occupying a certain place in the whole process, describing the relative position of all elements and parts. Tektology looks for similar parts, i.e., structural units of geomerida/biosphere and describes them on the basis of their differences and similarities. Beklemishev understands tektology as the systematics of parts composing a whole. He introduced the notion of the individuality of a system, one of the most important notions in his theory. There are as many systems, he argued, as there are clearly delineated individualities of certain orders. A system in that sense neglects the individualities of the higher orders and operates on the level of lower systemic units on which it depends and to which it is subordinated to. In that sense, the geomerida is the individuality of the highest order, consisting of biocenoses that function as its structural units. Biocenoses, in turn, consist of separate organisms as units.[97] Beklemishev elaborated on statistical methods of studying tektology and architectonics on all structural levels of geomerida. Biocenoses as structural units of geomerida show low levels of individuality, they are unstable and diffuse, but they differ from ›true organisms‹ only in their level of individuality. Since all organisms are ›collectives‹ consisting of subordinated individualities, the concept of individuality is applicable to all levels of the living. Beklemishev considers the totality of every living thing, structured into various ›complexes‹, as The Being, the biosphere. Beklemishev shared Vernadsky's idea that life is a planetary phenomenon. However, he disagreed with Vernadsky on the sharp difference between living inert matter as ›inert material‹ also being part of the living systems; the difference between living and bioinert systems is not a qualitative, but a quantitative one.[98]

This approach stands in sharp contrast to Vernadsky's version of living matter. Whereas Vernadsky focused on biogeochemical functions, i.e., on the biogenic flow of atoms, Beklemishev concentrated on the biospheric system's structural uniqueness from a morphological perspective as well as on the hierarchical relations between the whole and its individual parts. Beklemishev understood geomerida as a morphological phenomenon, not as a sum total of chemical elements. The morphoprocess, Beklemishev argued, is the preservation of certain organismic properties through the constant change of elements within this organismic system. Erythrocytes have their ›individual‹ lifespan of about one month, but the blood performs its gas functions without interruptions. Biocenoses or the biosphere as a whole can also be approached as morphoprocesses. Based on data on the historical development of the biosphere, the geomerida's change of elements is obvious, but it is still necessary to consider the ›permanence‹ of integrity from the viewpoint of actualism.[99]

Despite methodological discrepancies, their approaches are not mutually exclusive, but complementary since geomerida is another name for Vernadsky's living matter. Thus, both theories interpret the same global phenomenon.

CONCLUSIONS

Vernadsky's theory of living matter was founded on three logically interconnected hypotheses, which he clearly formulated in the early 1920s. First comes the principle of the eternity of life, which suggest that life is not the product of *abiogenesis* or *archeogenesis* (Vernadsky uses it in the sense of primordial origin) in the biosphere, but that it pre-existed the biosphere as a form of matter organization. There is no vitalism in this concept, it is a completely materialistic grasp of living nature. Second, life as a form of matter organization differs significantly from its inert environment, an essential difference that must be described through a separate set of fundamental laws. Third, life is a planetary phenomenon existing only and exclusively as a global unity. These three concepts are mutually dependent in the sense that life is an eternal phenomenon, something that was built into the initial

96 Beklemishev: *Metodologiia sistematiki* (note 92), p. 61.
97 See Pavel G. Svetlov: »Pamiati V. N. Beklemisheva [Memories of V. N. Beklemishev]«, in: ibid., pp. 6–16.
98 Beklemishev: *Ob obshchikh printsypakh* (note 95).
99 O[leksandr] O. Protasov: *Biogeomika. Ekosistemy svitu v strukturi biosferi* [Biogeochemistry. World Ecosystems in the Structure of the Biosphere], Kyiv: Akademperiodika 2017.

structure of the universe and exists only as a global systemic property.

These three basic hypotheses develop into a logically coherent conceptual structure, which we label Vernadsky's theoretical system.

In the mature version of this system, living matter was separated from its inert environment as a result of the very nature of the space-time it occupies (or shapes). The living matter could only be generated by living matter as it exists in a dissymmetric space and in a directed irreversible time. As two modes of matter organization (living and inert) exist in the biosphere in different space-times, the only connection between the two is the biogenic flow of atoms. In other words, Vernadsky's living matter concept presupposes the reality of a certain entirety, the biosphere, consisting of two strictly separate subsystems, living matter and inert matter that act as parts of a higher systemic entity. Thus, Vernadsky described the biosphere as a »bioinert system«.[100] The integrity (of the biosphere), including the integrity of lower-level subsystems, is guaranteed by living matter.

Since living matter consists of both individual organisms and their coenobiotic formations, the existence of these individuals of different levels is simultaneously intermittent and integral. In Vernadsky's theory, this ›discontinuous continuum‹ is a dialectical concept that describes the spatial specifics of living matter and guarantees its cyclical dynamics with the participation of its inert medium. Furthermore, it is facilitated by a constant excess of energy, ultimately emanating from the sun.

The cyclical flow of atoms between living and inert matter is the primary research subject of biogeochemistry, a science founded by Vernadsky. As the biosphere is composed of biogeochemical cycles, it is a self-regulating system. However, it is not the gaia in a strict sense as life doesn't equal its environment and these two modes of organization always remain separate.

The directionality of time along with the leading role of living matter (here, the term inert as employed by Vernadsky to describe non-living matter is very telling) suggests that the biosphere as a whole evolves in a certain direction.

Early on, Vernadsky realized that he was developing an evolutionary theory complementary to that of Darwin and his followers who only studied the transformation of species, but not the changes of the whole biospheric system or subsystems that compose the biosphere. The Vernadskian evolution, in contrast to the Darwinian one, is the evolution of living matter in its entirety towards the acceleration of biogeochemical cycles, i.e., it moves in the direction of the increasing biogenic migration of the atoms. At their core, human civilization and science contribute to the acceleration of atomic migration in a stronger way than any other factor, which means that science is a ›planetary phenomenon‹, i.e., it does not violate the course of the biospheric evolution and instead represents its logical continuation. As its supreme manifestation, human reason and science are not alien to the biosphere, but a part of its evolution, and Vernadsky did believe that it was only a question of time until the biosphere would be fully controlled by scientific thought. The transition from the biosphere into the noosphere, i.e., into the sphere of human reason that controls all biogeochemical cycles will be a major transition in the global evolution and its ultimate outcome/result.

In total, the concept of living matter lies at the core of Vernadsky's theory of the biosphere and is built into a holistic coherent logical structure that describes life as a global and evolving entity.

The comparison of Vernadsky's living matter with other global approaches in Russian-language science allows us to approach the specificity of his methodology. Vernadsky's younger contemporary Vladimir Beklemishev sometimes employed the term geomerida as coined by Konstantin Starynkevich, referring to the ›living cover of the Earth‹. Geomerida is not just another exotic term for the living part of the biosphere. It was coined to describe a purely biotic global system, whereas Vernadsky's biosphere is a bio-inert system.

As Beklemishev approached the global system from the viewpoint of morphology and systematics, he saw it as the ultimate object of biological systematics, not as a Vernadskian ›natural body‹, and described its

100 Alexandr A. Protasov/Chingiz M. Nigmatullin: »K istokam biosferologii: Geomerida K.D. Starynkevicha i V.N. Beklemisheva«, [On the Origin of Biosperology: Germerida of K.D. Starynkevich and V.N Belkemishev], in: *Sbornik materialov vserossiiskoj nauchnoi konferentsii* [Proceedings of the All-Russian Scientific Conference], Ulianovsk, 30-31.03.2017, Ulianovsk: UlGPU 2017, pp. 119–126.

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dynamics as a *morphoprocess*. For Beklemishev, the morphoprocess is the preservation of organismic features through a constant change of elements within this organismic system. In other words, it is not a system that fluctuates around a certain permanently evolving point along with its inert environment (as in Vernadsky's biosphere), but it is a morphologically relatively stable system that exists despite (or due to) an internal cyclical dynamic. Beklemishev implemented his notion of the morphoprocess on a global scale. A morphoprocess on the scale of the entire biosphere is a living crust, spread out on a rocky globe that exists due to its organization, that is, the continuous preservation of the typical forms and relations of the whole throughout the constant change of its parts. In a certain sense, Vernadsky's living matter and Beklemishev's geomerida are closely related notions. The critical difference lies in the methodology applied to its research and correspondingly in their theoretical significance. For Beklemishev, it was crucial to understand form as a biological property, which is why his process is a *morpho*-process. Vernadsky's living matter emphasizes the *matter*, i.e., the chemical composition of ›natural bodies‹. As Vernadsky's object of study crosses the borderlines of the living, his research program is an interdisciplinary enterprise.

The concept of a morphoprocess involves a regular growth and change of the identifiable lasting form. In other words, life as a morphoprocess is characterized by a form lasting throughout the flow of changes. However, at the same time, this ›lasting form‹ lies in the regular growth and change and is seen as a self-organizing process. The morphoprocess is a dynamic form of organization and is not necessarily interrupted when individual parts disintegrate. The global morphoprocess is the totality of all living matter on our planet.

Although Beklemishev's morphoprocess provided both global dimensions for the interpretation of life and the idea of cyclicity, it cannot be equated with Vernadsky's research program. Even though Vernadsky's concept of living matter (in its original idiosyncratic sense) did not uphold in contemporary science, the biogeochemistry, which developed as a result of Vernadsky's concept of living matter, proved itself as one of the fundamentals of modern natural science and even of the modern worldview and politics.