The Renaissance of V.I. Vernadsky

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In The Geochemical News No. 120, Nathan Yee and Carla Koretsky presented the biographies of 10 outstanding Geochemists as an attempt to assemble a list of the 10 most notable Geochemists of the 20th century. With great interest I read the biographies of these exceptional scientists and the article aroused my curiosity in the history of geochemistry and its protagonists. I guess Nathan and Carla achieved their goal when I started to think about who else would deserve to be listed in a top ten list when I had finished the article. All the presented scientists were born, or spent at least an important part of their carrier, in Anglo-American countries and all were male. Have there been no women? Who of the Japanese Geochemists has to be included in the top ten list? What about scientists from Eastern Europe? In particular the last question kept me busy. How many important scientific achievements in the former USSR have not reached the western scientific community because of the impermeability of the iron curtain? How many outstanding East European scientist were not noted or their names forgotten in the western countries due to political and lingual barriers?

Vladimir Vernadsky, (1863 - 1945), the patriarch of biogeochemstry and founder of systematic biosphere studies..

When exploring the history of Geochemistry in Russia the first name one comes across is Vladimir Ivanovich Vernadsky (1862-1945). The Vernadsky Institute for Geochemistry and Analytical Chemistry in Moscow is named after him. He is considered to be the father of geochemistry, biogeochemistry, radiogeology and cosmochemistry in Russia [1]. L. Margulis states in the foreword of the English version of V.I. Vernadsky's book *The Biosphere* that "*Just as all educated westerners have heard of Albert Einstein, George (Gregor) Mendel, and Charles Darwin, so all educated Russians know of V. I. Vernadsky"* (Margulis, 1998). However, for most people in the West V.I. Vernadsky is largely unknown, although he was connected to and cooperated with leading Western European scientists and spent part of his carrier in France and Germany. K. E. Bailes pointed out in Vernadsky's biography that Vernadsky "…*was to remain to the end of his life a strong advocate of close scientific ties with other countries, traveling abroad almost every summer in order to stay current with Western developments, until he was forbidden to do so by the Soviet government in the mid-1930s"* (Bailes, 1990). Hence, in his lifetime, his scientific and philosophic thoughts were spread across the Russian borders. Although he predominately wrote his books and articles in Russian, some of his work was published in French, English, German, and Japanese in his lifetime. In the early 1950's Vernadsky was mentioned in the major books on geochemistry, but then his name apparently became forgotten outside the Warsaw Pact countries (Margulis, 1998). After his death, even in the Soviet Union of the late Stalin era, Vernadsky's name threatened to be buried into oblivion. However, with the onset of de-Stalinization the fame of Vernadsky experienced a renaissance. With a significant time-lag the "Silent Vernadskian Revolution" also started to reach the Western World. Important milestones in this development have been the publication of V. I. Vernadsky's biography by K. E. Bailes in English (Bailes, 1990) and the publication of the complete annotated English translation of Vernadsky's book *The Biosphere* in 1998 (Verndadsky, 1998). The first shortened and bowdlerized English translation of this book had already appeared by 1986, published by Synergetic Press, Biosphere 2's publishing arm. A recent highlight of the (re-) awakening of interest in Vernadsky in the West is the introduction of the Vernadsky medal by the European Geophysical Society in 2003[2], which was then presented to P. Westbroek.

Vernadsky's biography

The biography of Vernadsky has been in large part transcribed from chapter 1.1 of G. S. Levit's PhD thesis on the theoretical system of V. I. Vernadsky (Levit, 2001) and from the biography of Vernadsky by K. E. Bailes (Bailes, 1990). Vernadsky was born in 1863 in Saint Petersburg. His father, I. Vernadsky, was a professor of economics and statistics in the Alexandrovsky Lycee. From 1881-1885 Vernadsky was a student of the physical-mathematical faculty (natural-scientific section) of St. Petersburg University. The most influential of his teachers was V. Dokuchaev, who was a founder of modern soil sciences and of a large naturalist school. V. Dokuchaev became the supervisor of Vernadsky's master and doctoral theses. Dokuchaev's integrative approach of considering soil formation as a product of different environmental factors, including the interactions between living and dead matter, might have laid the cornerstone of V. I. Vernadsky's theory of biosphere. In 1888 V. I. Vernadsky left St. Petersburg to study mineralogy in Munich. He then moved to Paris in 1889 where he worked with Le Chatelier, who helped him to find his dissertation subject in the field of silicate mineralogy. One year later Vernadsky settled in Moscow, where he started a twenty-year professorship in crystallography and mineralogy at Moscow University. In this period, Vernadsky founded a new scientific school detached from soil sciences and mineralogy. His first major scientific book *The Fundamentals of Crystallography* was published in 1903. In 1909 he read *The Data of Geochemistry* by F. W. Clarke, which stimulated him to turn to geochemistry. Only a few years after Becquerel and the Curies discovered radioactivity Vernadsky organized the first radiological laboratory in Russia in 1909, inspired by the work of J. Joly whom he met at a conference sponsored by the British Association for the Advancement of Science. Also of importance for his scientific development was his meeting with the geologist E. Suess in 1910 in Vienna (Austria). E. Suess had introduced the term *biosphere* in his book *Das Antlitz der Erde* (The Face of the Earth) and was, by the way, the grandfather of H. E. Suess whose biography was presented in Nathan and Carla's article. In 1911, in protest against political repressions, Vernadsky resigned, together with other professors of Moscow University, and moved to St. Petersburg where he headed the newly established mineralogical laboratory of the Academy of Sciences. One year later Vernadsky was elected as an ordinary member of the Academy of Science.

In addition to laboratory work and theoretical statements, one of Vernadsky's major activities in the period until the 1917 Revolution and the beginning of the Civil War was carrying out and organizing expeditions to the more remote parts of the Russian Empire in order to find new mineral deposits. Before World War I his major interest was mapping and finding radioactive minerals, while after the beginning of World War I the major goal was the exploration of strategic minerals, which were until then imported from Germany. Vernadsky became the moving force behind the creation in 1915 of a commission within the Academy of Sciences, the Commission for the Study of the Natural Productive Forces of Russia (KEPS). Their assigned tasks were to strengthen the nation's defense during WWI, explore and develop mineral resources, and establish new scientific institutes.

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In 1917, afflicted by tuberculosis, and finally after the Bolsheviks came to power in Petrograd (St. Petersburg) Vernadsky moved to the Ukraine, where he took part in the organization of the Ukrainian Academy of Sciences. He was elected as the first president of this Academy in 1918. In his Ukrainian period he elaborated the basic principles of biogeochemistry and founded the first biogeochemical laboratory in the history of natural science in a former sugar plant laboratory. One major objective of this laboratory was studying the chemical compositions of different types of organisms. In the communities of the Civil War Vernadsky was down in Typhus, Ukraine, and his family became stranded in Crimea in 1919, which was at that period under White rule, but was taken by the Red Army in the following year. While his son, G. Vernadsky, who later became professor of Russian history at Yale, was evacuated, V. Vernadsky, his wife and daughter remained and were transferred to Moscow. Later, on his way to Petrograd in order to resume his position in the Academy of Sciences, Vernadsky was arrested and thrown into prison, but due to the intervention of the permanent secretary of the Academy of Sciences, S. Oldenburg, and other outstanding personalities he was released after three days.

In 1921-22 Vernadsky organized the Radium Institute based on his radiological laboratory in the Academy. At the end of 1921 Vernadsky received an invitation to teach geochemistry at the Sorbonne, the University of Paris. He left in 1922 and stayed in Paris until the Academy of Science exerted pressure on Vernadsky to return to Russia in 1925. Based on his lectures at the Sorbonne he published *La Géochemie*, which was later translated into Russian, German, and Japanese. During his stay in Paris he also conducted research at Marie Curie's institute and developed the basis of his book, *The Biosphere.* This was published in 1926 in Russian after Vernadsky had returned to Leningrad (St. Petersburg, Petrograd). Back in Leningrad, Vernadsky organized a Living Matter Research Group within the KEPS. On October 1, 1928, the Group was officially reorganized into a Biogeochemical Laboratory (BIOGEL), which moved to Moscow in 1934 and later became the Vernadsky Institute of Geochemistry and Analytical Chemistry of the Academy of Sciences.

Nataliia and Vladimir Verndasky, 1910 (used with permission from Bailes, 1990)

The BIOGEL increased from about 10 to around 30 scientists in the next decade and by the start of Word War II the BIOGEL was recognized as a highly productive and creative part of the Academy of Sciences. In the first period of work the main activity of Vernadsky's laboratory was to determine the average composition of various individual species. Later, the BIOGEL began to work on the determination of rare and radioactive elements in different organisms. One of the scientists working at the BIOGEL was Vinogradov, the later president of the Vernadsky Institute of Geochemistry and Analytical Chemistry. In continuation of Vernadsky's approach he published in a series of papers his fundamental work on the composition of sea organisms and established his reputation as one of the Soviet Union's leading oceanographers. In the late 1930's the BIOGEL developed strong ties with the ministries for health and agriculture and fulfilled a number of research projects for them. In this context, scientists in Vernadsky's laboratory studied chemical deficiencies or excesses in the environment and the effects of imbalances on the health of local inhabitants. Conclusions from these investigations were first presented in 1936 at a meeting of the Moscow Therapeutic Society entitled *Biogeochemical Provinces and Illnesses*. In this presentation, Vernadsky and Vinogradov demonstrated that endemic illnesses resulted from the environmental lack, or oversupply, of certain chemical elements, such as iodine, strontium, barium, and calcium. The third main activity of the BIOGEL was related to Vernadsky's strong interest in radioactivity. During the 1930's the institute began to map the radioactivity of the Soviet Union's surface and they tried to determine the age of geological strata using radioactive methods. Vernadsky was particularly concerned with locating Soviet deposits of radium and other radioactive elements. In 1932 Vernadsky and his student Khlopin began to build the first cyclotron in the Soviet Union. Although insufficient material support and technical difficulties caused severe problems in both getting and maintaining an operational cyclotron, the instrument was used to train the Soviet Union's leading atomic physicists, including I.V. Kurchatov, the man who eventually led the project building the Soviet Union's first atomic weapons after World War II. In 1935 the BIOGEL became the site for the construction of the first apparatus in the USSR for making heavy water. Another important contribution of Vernadsky to the Soviet Union's transformation into an atomic superpower was his active part in setting up a Uranium Commission during WWII. The role of the Uranium Commission was to ensure the supply of sufficient uranium for research and for development of a nuclear programme.

After the German invasion of the USSR in June 1941 Vernadsky and his wife were evacuated to a health resort in Kazakhstan. In 1943 his wife Nataliia died and Vernadsky returned to Moscow where he published his last work *A Few Words About the Noosphere*. On 6 January 1945 Vernadsky died from a cerebral haemorrhage at the age of 82.

In 1936 he had begun to work on two books *The Chemical Structure of the Earth's Biosphere and Its Environment* and *Scientific Thought as a Planetary Phenomenon*. Vernadsky intended to express his thoughts and scientific work in these two books, the first mostly scientific, the latter more philosophical. Vernadsky completed these works, although he did not write the final chapter of *The Chemical Structure.* Both books were published decades after Vernadsky's death and can be regarded as his scientific and philosophic legacy.

> ***"Whichever phenomenon one considers, the energy liberated by organisms is principally (and perhaps entirely) solar radiation. Organisms are the intermediaries in the regulation of the chemistry of the crust by solar energy."***

As Vinogradov pointed out in his homage on the occasion of Vernadsky's 100th birthday (Vinogradov, 1963), Vernadsky's intellectual interests were extremely broad: mineralogy and crystallography, geology and radiogeology, geochemistry and biogeochemistry, chemistry and biochemistry, pedology and hydrology, meteoritics, and the history of science and philosophy. He belonged to the founders and pioneers of several of these disciplines and his original contributions to many of those fields had an important impact on their development. His work lived on in the schools of geochemistry, mineralogy, radiogeology, and biogeochemistry he created, and in the research institutes, laboratories, commissions, and committees he founded. In addition to his intellectual and scientific achievements, Vernadsky's more practically-orientated activities, in particular those related to the discovery and exploration of mineral resources, have been of major importance for the development of the Soviet Union. The industrial revolution in the late 1920's and early 1930's and the rising of the USSR to a nuclear superpower after World War II significantly profited or might only have been made possible by Vernadsky's efforts in exploring industrially-significant and radioactive minerals. Vernadsky's practical contributions were motivated by his patriotism. The scientific, economic, social, and cultural development of Russia was one of his major concerns. However, his patriotism did not make him a silent and passive follower of the ruling powers and he openly expressed his critical attitude towards the Tsarist and Stalinist regimes, in particular when he believed scientific progress was being encumbered by the sovereigns. In his awareness of the societal and economic implications of his applied research, Vernadsky also realized the possible negative consequences of industrialization and putting radioactivity under human control. In his opening speech of the Radium institute he stated:


Vladimir Vernadsky, 1890s.

"Soon man will have atomic power at his hands. This is a power source which will give him a possibility to build his life just as he wishes. Will he be able to use this force for good purposes and not for self destruction? A scientist must feel responsibility for the results of his studies!"

He also was very upset when he discovered hazardous and wasteful mining activities during his expeditions. The experience of the "*terrible plundering of its* [Ural's] *richness"* led him to start a campaign to put the Lake Ilmen area (one of the areas in Ural rich in radioactive minerals) under state protection. This campaign succeeded and Lenin placed the Lake Ilmen area under governmental protection, thus creating the first nature preserve or national park in Soviet Russia.

Of his philosophical and scientific legacy, Vernadsky's theory of the biosphere is plausibly the contribution which accounts for most of the recent interest in Vernadsky's work, in particular in the Western scientific community. In his book *The Biosphere* the major conceptual ideas about the biosphere are elaborated and in the following section some of its aspects will be illuminated.

The Biosphere

Following Vernadsky's systematic division of the Earth into spherical segments, the biosphere is one of the paragenetic envelopes of the Earth. Envelopes are defined as subunits of concentric regions, called concentres; the biosphere forms one of the envelopes of the Earth's crust. Different criteria can be used to classify envelopes. Envelopes can be separated based on prevailing thermodynamic conditions, characteristic chemical compositions, etc. The paragenetic envelopes are distinguished based on the occurrence of atoms in specific modes, which in turn are characterized by *1. a thermodynamic field, specific for each mode 2. a particular atomic configuration 3. a specific geochemical history of the element's migration; and 4. relationships, often unique to the given mode, between atoms of different chemical elements (paragenesis)*. Within this systematic the existence of chemical elements in living matter should be regarded as one particular mode of occurrence. Elements are extensively cycled within the biosphere and the flux of elements leaving or entering the biosphere is small compared to the internal fluxes. It is important to notice that Vernadsky's biosphere comprises dead (inert) and living matter, and includes soils, lakes, oceans, sediments, and the troposphere. This implies that living organisms are an integral part of the Earth's upper crust and the lower atmosphere. This conceptual idea differs, for example, from Goldschmidt's view of the biosphere as the sum of living organisms *senso stricto*. According to Vernadsky, vadose minerals, the minerals belonging to the biosphere, differ from minerals from other (deeper) paragenetic envelopes, e.g. the magmatic envelope, in so far that their mode of occurrence is a consequence of the activity of living organisms. The formation and transformation of vadose minerals is a product of the free chemical energy created in the biosphere by the transformation of cosmic radiation, in particular the utilization of solar radiation by photosynthesis. In a section about the role of living matter in the oceans Vernadsky lists prominent examples for the action of living matter on mineral formations, including deposits of calcium carbonates, of calcium phosphates, and of biogenic silicates. He further states that the largest known concentrations of manganese and iron in the Earth's crust resulted from biochemical reactions and he also conceives banded iron formations as a product of biogenic origin. Vernadsky concludes "*that the deposits of marine mud and organic debris are important in the history of sulfur, phosphorus, iron, copper, lead, silver, nickel, vanadium, and (according to all appearances) cobalt, and perhaps other rarer metals*" (he also mentions barium, strontium and uranium earlier in this context).

V. I. Vernadsky (right front) at the Russian Academy of Sciences. Leningrad, 1920s.

> ***"[I believe] in the strength of the human reason and suppose that the team scientific thought will overcome the negative results of the technogenesis and will secure, in future, the rational transformation (and not annihilation) of the natural components of the biosphere, for a maximum satisfaction of the material and spiritual demands of the mankind which is growing quantitatively"***

Regarding the interaction between dead and living matter Vernadsky not only focuses on the solid Earth but also emphasizes the effect of living organisms on the composition of the atmosphere. Vernadsky points out that the "*gases of the entire atmosphere are in an equilibrium state of dynamic and perpetual exchange with living matter*". He refers to a presentation of J. B. Dumas and J. Boussingault given at a conference at Paris in 1844 when stating that living matter can be taken as an "*appendage of the atmosphere*". Thus Vernadsky anticipates the idea of J. Lovelock that the composition of the atmosphere is an indicator for life, which later led to the development of the

Gaia theory by Lovelock and Margulis. Margulis and Lovelock were not aware of Vernadsky's work when they introduced the Gaia theory but they later acknowledged Vernadsky as "*their most illustrious predecessor*" (Grinevald, 1998). Vernadsky did not elaborate explicitly in his book *The Biosphere* the idea that the biota create and control the abiotic environment, which is the central concept of homeostasis in the Gaia hypothesis. However, Vernadsky points out that the ozone layer, which is protecting life on Earth from harmful UV radiation, originates from the oxygen produced by photosynthesis, and by this Vernadsky gives an example of how living organisms create an ambient environment on Earth. A comprehensive comparison between Vernadsky's biosphere theory and the Gaia theory can be found in G. L. Levit's PhD thesis (Levit, 2001).

Besides qualitative aspects of processes in the biosphere, Vernadsky also aims at a quantitative understanding of these processes. The numbers he derives for the quantity of free oxygen on Earth, the global net primary production, or for the total biomass on Earth vary significantly from recent data but the approach of creating global budgets of biogeochemical cycles was very innovative when *The Biosphere* was written and is still a major subject of present biogeochemical research. Vernadsky uses quantitative considerations in particular to illustrate the effect of the totality of living matter on element migrations on a global scale and to support his idea of living matter as a major geological force on the Earth's surface. In addition to budget calculations Vernadsky derives an expression for the "*kinetic geochemical energy of living matter*". The kinetic geochemical energy of an organism is related to its mass and its speed of transmission. The latter depends on the size of the organism and the optimal number of generations per day and is normalized to the surface area of the Earth. Vernadsky frequently refers to the geochemical energy in *The Biosphere* especially to emphasize the enormous biogeochemical potential of microorganisms. The third quantitative section in *The Biosphere* is devoted to calculations on the fraction of total solar energy used by photosynthesizing organisms to produce biomass. In the context of these calculations Vernadsky argues that it is an inherent characteristic of the biosphere that living matter is distributed on the Earth's surface in a way that solar radiation is completely captured. In order to optimize the utilization of solar energy and to create a sufficient surface, green biomass appears in different forms in different biotopes. On land, plants have to develop three-dimensional structures in order to create a sufficiently thick film for optimal use of solar radiation. In oceans, primary production is dominated by phytoplankton because it can easily distribute over the depth of the photic zone. He further concludes that the biomass on Earth did not vary considerably over geologic time. This conclusion is a consequence of the assumptions that solar radiation was constant over geological time, that usage of solar radiation is always optimized in the biosphere, and that the efficiency of photosynthesis did not vary. The constancy of biomass over geological time is a part of the empirical generalizations Vernadsky formulates at the beginning of *The Biosphere*:

1) During all geological periods there have never been traces of abiogenesis (direct creation of a living organism from inert matter).

2) Throughout geological time no azoic geological periods have ever been observed.

3a) Contemporary living matter is connected by a genetic link to the living matter of all former geological epochs.

3b) The conditions of the terrestrial environment during all this time have favored the existence of living matter and conditions have always been approximately what they are today.

4) In all geological periods the chemical influence of living matter on the surrounding environment has not changed significantly; the same processes of superficial weathering have functioned on the Earth's surface during this whole time, and the average chemical compositions of both living matter and the Earth's crust have been approximately the same as they are today.

5) From the unchanging processes of superficial weathering, it follows that the number of atoms bound together by life is unchanged; the global mass of living matter has been almost constant throughout geological time. Indications exist only of slight oscillations about the fixed average.

6) Whichever phenomenon one considers, the energy liberated by organisms is principally (and perhaps entirely) solar radiation. Organisms are the intermediaries in the regulation of the chemistry of the crust by solar energy.

Based on our current idea of a coevolution of life, environmental conditions, and the geochemistry at the Earth's surface, Vernadsky's uniformitarian view appears obsolete. However, it should be noted that Vernadsky emphasizes that his principles are generalizations derived from facts known at the time and that they are not hypotheses, which go beyond known facts and must be consistent with other dominant theoretical constructions of nature. In particular, he argues against cosmogonic models including a lifeless era in the Earth's past or abiogenesis during some hypothetical cosmic period because they "*originate outside science, in the realms of religion and philosophy*". This implies that he does not exclude the possibility of abiogenesis *per se*, but he rejects the occurrence of abiogenesis as long as no supporting facts are known.

At first glance Vernadsky's substantive uniformitarianism seems to be in contradiction with the evolution of living organisms. However, the constancy of total biomass over geologic time does not exclude that the spatial distribution of the biomass changed in the past and is still changing. In his discussion about the limits of life he points out that the ability of adaptation allows living organisms to displace the limits of animated space and to penetrate into more extreme environments. As an example he mentions that the "*conquest of the air is a new phenomenon in the geological history of the planet*". He considers the "*ozone screen as the potential upper limit for life, which actually stops well below this atmospheric limit*". With respect to the lower limit he writes: "*In a manner analogous to the situation at the upper limit of the biosphere, life is descending slowly but ineluctably to greater depths*". Regarding the lower limit of life he emphasizes the role of anaerobic bacteria in the oxygen free zones of the Earth's crust. Vernadsky perceived the implications of the tremendous progress in the field of microbiology on the understanding of biogeochemical cycles in natural environments, in particular stimulated by the work of S. Vinogradsky. In *The Biosphere,* Vernadsky extensively discusses the different roles of chemo- and photoautotrophic bacteria in the biosphere and he highlights the importance of anaerobic bacteria in biogeochemical processes occurring in subsurface environments in several sections. The appreciation of the importance of microorganisms in element transformations at the Earth's surface is another example of Vernadsky's scientific foresight, which Vinogradov considers to be Vernadsky's greatest gift (Vinogradov, 1963).

Coming back to the discussion of the limits of life Vernadsky notes that the potential of mankind to transcend traditional limits of life is in line with the continuous expanding of the frontiers of the biosphere. Vernadsky understands humanity as another form of life establishing itself as a geological force. This concept is further elaborated in Vernadsky's later work in which he addresses the ability of humans to transfer elements and concentrate them in the biosphere to an unprecedented extend. His last work was dedicated to the noosphere, the following stage in the evolution of the biosphere driven by humanity as the dominating force. In this article he expresses his believe "*in the strength of the human reason and suppose that the team scientific thought will overcome the negative results of the technogenesis and will secure, in future, the rational transformation (and not annihilation) of the natural components of the biosphere, for a maximum satisfaction of the material and spiritual demands of the mankind which is growing quantitatively"* [3].

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Footnotes

[1] **http://www.geokhi.ru/eng/vernadsk.html**
[2] **http://www.copernicus.org/EGU/egs/award6x.htm**
[3] **http://www.tstu.ru/eng/kultur/nauka/vernad/uchver.htm**