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Chapter 2

V. I. Vernadsky—A Philosophy for the Space Age*

William Jones†

Abstract

Vladimir Ivanovich Vernadsky was the single most important scientific figure in Russia during the first half of the twentieth century. Renowned for his authorship of *The Biosphere,* he also founded the fields of biogeochemistry and cosmochemistry. In 1921, as a member of the scientific commission investigating the 1908 Tunguska explosion, Vernadsky hypothesized that the explosion, instead of emitting debris, may have simply dispersed a mass of "cosmic dust." This led to his intense study of the effects of cosmic radiation on the biosphere.

With the appearance of man in the biosphere, the forces of nature become subject to the direction of man's reason, initiating a new era which Vernadsky, borrowing the term from Edouard LeRoy, called the noosphere ("noos" mind). At its appearance, the noosphere began to encompass and subsume the biosphere itself, in the same way that the biosphere, at its first appearance, quickly expanded to encompass the entire surface of the Earth.

This, Vernadsky reasoned, would be paradigmatic for the further development of the universe. Man, with his unique intellectual capabilities, would begin to create "artificial" environments for life, based on the advance of his technol-

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† Washington Bureau, Executive Intelligence Review, Washington, DC, U.S.A.

ogy. Traveling to space and pushing the limits of Earth's biosphere farther out into space would only be a lawful consequence of man's creative activity. In fact, in his last unfinished work, "The Chemical Structure of the Biosphere and Its Surroundings," Vernadsky revisited his earlier analysis of the biosphere from the standpoint of the creation of that biosphere by the forces of the galaxy, with which it conducts continual exchanges. Because of these continual exchanges, Vernadsky thought, we must not assume that life itself is a phenomenon restricted to Earth. Vernadsky's interest in the science fiction writings of Kurt Lasswitz and Konstantin Tsiolkovsky characterize this aspect of his thought. In his final years, during World War II, Vernadsky, aware of the latest advances in aviation and in rocket science, clearly saw that man was already preparing to expand the noosphere/biosphere well beyond the ionosphere. A proper understanding of the role of space exploration in the life of man, and the role of the Earth as an integral part of the galaxy, requires an understanding of Vernadsky's rather unique concept of the noosphere.

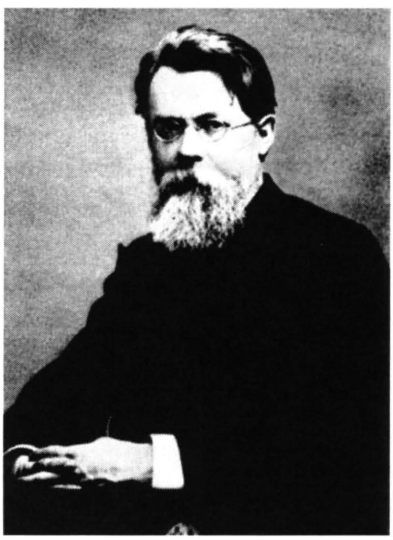

Figure 2–1: Vladimir Ivanovich Vernadsky.
Credit: Russian Academy of Sciences (RAS).

Introduction

With *Curiosity* now scouting for a spot to do some serious digging, it is probably not a bad time to recount the story of a man whose life was dedicated to such research, the mineralogist, geologist and biogeochemist, Vladimir Ivanovich Vernadsky. While Vernadsky died in 1945 before the start of the Space Age, he

was already mentally a part of it. His examination of meteorites and cosmic rays were a part of his investigation of the environment surrounding our remarkable planet, an environment out of which it had emerged. Such an examination was also connected to his lifelong preoccupation with the phenomenon of life, which he strongly suspected was not limited to our own small part of the universe here on Earth. And the investigation of the role of man and of man's intellect in transforming the shape of the Earth, Vernadsky always viewed in its "cosmic" dimensions.

The name of Vladimir Ivanovich Vernadsky may be familiar to many people involved in the area of science, particularly in the geological and so-called "earth" sciences, but most of these, without a good working knowledge of Russian, will probably only have known his work through the publication of his 1926 monograph, *The Biosphere,* which brought him immediate international attention since it soon appeared (in 1929) in a French edition, and during the last couple of decades in several English editions.[1] In Russia and Ukraine, however, his name is as familiar as that of Pasteur or Curie or Einstein.

Even at an early stage Vernadsky, working primarily in the area of geochemistry, always fixed his gaze on the larger universe surrounding our Earth. When he was a boy, he was very close to his maternal uncle, E. M. Korolenko, who had a powerful influence on his early development and on his interest in science. Korolenko was a follower of the utopian socialist ideas of Charles Fourier, and an avid devourer of popular scientific literature. He would take young Volodya out in the field at night near Kharkov in Ukraine to view the starry sky. In a letter to his wife-to-be and lifelong collaborator, Natalia Egerovna Staritskaia, on 6 June 1886, Vernadsky writes of these nights:

> I always loved the heavens; the stars, the Milky Way in particular attracted me, and on those nights I loved to listen to him explain them to me; for quite some time afterward, I found it hard to fall asleep. In my imagination, comets streaked through the infinite space of the universe; falling stars animated the horizon; I could not come to terms with the lifelessness of the Moon, so I populated it with a whole array of creatures, formed from my own imagination. Those simple tales had made such an impression on me that it seems that even now I am not free of them.[2]

Vernadsky started his career in mineralogy and crystallography. He helped revolutionize the science of mineralogy by viewing it, not in the form of static fixed deposits, but in terms of its paragenesis, its process of transformation on the Earth's surface. With a growing interest at the turn of the last century in the study of the atom, Vernadsky turned his attention to examining minerals from the standpoint of their atomic structure, moving into the relatively new field of geochemistry, which he effectively put on the scientific map. When he began to in-

vestigate the influence of living matter on the formation of the Earth's crust, he opened up an entirely new field of science, which he called biogeochemistry.

Politics and Science

Studying during one of the most fertile periods in Russian science under the great chemist Dmitry Mendeleyev, and the renowned soil scientist V. I. Dokuchaev, Vernadsky was drawn to the study of crystallography and mineralogy. Vernadsky went on expeditions with Dokuchaev to study the fertile "black earth" of Ukraine, where his attention was first attracted to the elements of life that contributed to that soil's tremendous productivity.

While Vernadsky devoted himself to science, he was at the same time very much politically engaged in the social conflicts of his time. His father, Ivan Vasilievich Vernadsky, had been a prominent economist who played a key role in the movement toward liberalization of the Tsarist regime which led to the freeing of the serfs in 1861. It was in such an environment that young Vladimir was raised.

Vernadsky would take part in the liberal movement in those years with a group of close friends he maintained throughout his life. He helped to found abroad the illegal Union of Liberation, which later become the basis for the Constitutional Democratic Party (Kadets), on which Central Committee he would serve from 1907 to 1917.

Figure 2–2: Vernadsky elected to the Duma as a representative of the Academy of Sciences 1906. Credit: RAS.

When Russia entered the war, many Russian intellectuals were mobilized to assist in the war effort. In 1915, at the urging of Vernadsky, the Tsarist government established the Commission for the Study of the Productive Forces of Russia under the Academy of Sciences to examine and to inventory the raw materials and mineral resources of the Russian Empire during a period when imports had been cut off. After the Bolshevik takeover, Vernadsky, fearing that he would end up in prison like many of his party comrades, shifted his activities to Ukraine, which was still beyond the Bolshevik reach. In Ukraine, he founded in 1920 the Ukrainian Academy of Sciences, anxious to consolidate the scientific resources of that country for whatever regime was to follow. He was also eager to maintain the circle of scientific collaborators in Ukraine, both Russian and Ukrainian, within the broad cultural realm of Russian science, of which they had always been an integral part. Vernadsky was also instrumental in establishing the National Library of Ukraine which still bears his name. During this entire turbulent phase of his life, he was at work on his groundbreaking thesis on the biosphere, resulting in a paper to which he gave the working title "Living Matter."[3]

The Role of the Biosphere

In Ukraine under the wartime conditions, Vernadsky was beginning to elaborate the ideas that would be most closely associated with him. As he contemplated the lush nature around him in his beloved Ukrainian woods and fields, he developed the notion of encompassing all living matter as an integral whole, the notion of the biosphere. And also in this first seminal work on the subject, "Living Matter," published only after his death, we can follow his attempt to encompass man and man's productive activities as a force in the biosphere. Although man, with the gift of his intellect, intervenes consciously in nature, transforming it to meet his needs, he also becomes himself a force of nature, or as Vernadsky characterizes it, a "geological force," whose activity comes evermore to predominate in the biosphere.

Already by 1916, Vernadsky's interest in the chemistry of the soil had led him to study the all-important influence of life as an elemental force transforming the Earth's surface. There were a number of elements in particular which attracted his attention. First was the rapid proliferation of life itself. A quantitative analysis had revealed to him the tremendous speed with which life spreads wherever it takes hold, encompassing everything in its grasp, as exemplified by the rapid spread of weeds in a field, or the spread of locusts over an entire region. Second, he was focused on the question of how living matter transforms nonliving matter. It was his firm contention, (and this was far from mainstream scien-

tific thinking in his day), that living matter acts on nonliving matter and gives it a specific "directionality," imbuing it with capabilities that it otherwise would not have. Third, of importance for him was the fundamental, but still unsettled, question of the actual origin of life. In his first lengthy trip abroad, Vernadsky had visited the Curie Institute in Paris. Here he became acquainted with the work of Louis Pasteur and Pierre Curie on the notion of dissymmetry in living substances. As life seemed to have a different geometric structure than nonlife, a specific chirality, either right-or left-handedness, rather than the symmetry exhibited generally in the inorganic universe, was it thus possible for life to have developed from nonlife? Vernadsky thought that the scientific evidence showed that not to be the case, adopting the position of seventeenth century Italian scientist and physician, Francesco Redi, (omne vivum e vivo), that life can only proceed from life.[4]

Figure 2–3: Vernadsky and his students at the Higher Women's Course 1906. Credit: RAS.

Figure 2–4: Francesco Redi, 1626–1697. Credit: National Library of Medicine at NIH, Bethesda, Maryland.

For Vernadsky, as for Redi, this was not the result of a philosophical or religious conviction, but rather the result of the scientific evidence. Nowhere can we find, in all of geological time, and perhaps not even in cosmological time, an instance of life proceeding from nonlife, Vernadsky said. How then can one adopt the thesis, as many had done, of abiogenesis, or spontaneous generation, namely, the theory that life in some mysterious manner arises from nonliving matter? Writing in 1919–1920, Vernadsky reasons:

> Observing the course of thought on this issue, we are immediately struck by a peculiar, and even paradoxical, situation. Whenever the question of the origin of organisms has been broached in science beginning in the 17th cen-

> tury, we see that it has continually in the course of time always been decided quite straightforwardly—always and continually without exception, reaching the conclusion that a living organism proceeds from a similar living organism. And all those cases, which claimed a different origin, were shown to be untrue and received a different explanation. Thus was resolved the entire matter.

Vernadsky felt that the contrary assumption was not based on scientific observation, but on religious or philosophical persuasion alone. In this he was also reflecting the view of Pasteur himself and of many other naturalists. The other related question for Vernadsky was the following: Is life only a byproduct of our Earth or is it of cosmic origin? And if so, might not one rightly assume that we will find life elsewhere in the universe? Vernadsky felt that there was absolutely no reason to exclude that possibility.

Even at an early stage of his investigations one discovers his interest in the phenomenon of "cosmic" matter, in the form of particles or "cosmic dust" which continually enter the Earth's biosphere through the atmosphere. Since the universe is one, Vernadsky reasoned, the elements of one part should not be very different from those of another, a thesis that was largely corroborated during his lifetime with the development of spectroscopy, which found the same elements of the Periodic Table on other planets as existed on Earth, although in different proportions. Vernadsky even mooted the possibility of life being a constituent element of the universe itself, equal to energy and matter.

In a letter to his colleague, Yakov Samoilov in 1908, Vernadsky writes:

> I am reading in the biological sciences. Much of it is interesting. It has forced me to rethink a bit. Among other things it is clear that the amount of living matter in the Earth's crust is an unchanging quantity. Consequently, is not life then an eternal part of the Cosmos, like energy and matter? And in fact doesn't the entire discussion about the transmission of the "germs" of life to Earth from other celestial bodies have as a basis the assumption of the eternity of life?

Might not then life, in some form, Vernadsky reasons, have been originally brought to us from elsewhere through Earth's continual exchanges with the surrounding universe? And then finding here most propitious conditions, taken root and flourished? Long before NASA would ever launch its own search for "life in the universe," Vernadsky was convinced that that is exactly where one ought to look for it. To investigate the origins of life here on Earth, one might just have to look for it elsewhere in the universe.

Return to Russia

But in 1920, Vernadsky had reached the end of his flight from the Bolsheviks. He had seriously considered emigrating, as a number of Russian scientists had done after the Bolshevik Revolution. When Kiev was taken by the Bolsheviks, Vernadsky retired to Crimea where he was involved in setting up Tauride University. Here many of the émigré Russian professors found their last refuge in what was the only university in the former Russian Empire in which the president was actually elected by the faculty. Vernadsky at the time thought seriously of coming to the United States, where his son had already immigrated and where his daughter would ultimately end up. There he might be able to establish a Biogeochemical Laboratory under the Carnegie Institute, he thought. It was, in fact, at the very point in time when he was preparing to take what looked like a similar offer from the British for such a project, when he was asked, on the occasion of the sudden death of the rector of Tauride University, to become their new rector. Vernadsky, fearing a disastrous fate for scientific research under the Bolsheviks, was hard-pressed not to turn down the pleas from his colleagues to take the position, which they insisted, and he himself felt, was necessary for the survival of their institution. Shortly thereafter, the Bolsheviks overran Crimea, and it looked as if Vernadsky might be headed off to the Gulag.

Matters, however, took an entirely different course. One of the members of Vernadsky's close circle of university friends, Sergei Oldenburg, had remained in Russia during the revolution. He requested a meeting with Vladimir Lenin, with whose family he was acquainted as a young man. Lenin told Oldenburg that he would maintain the Academy of Sciences as an autonomous institution as long as the academicians didn't engage in counterrevolutionary activity. With Lenin's assurances, Oldenburg arranged for a train to travel to Ukraine to bring back the scholars from Crimea to St. Petersburg, including Vladimir Vernadsky.

While Vernadsky always remained critical of the Soviet regime, his decision to return was also rooted in his deep concern for the fate of Russian science. Returning to Russia, Vernadsky was brought face to face with the tremendous destruction that had been dealt Russian science during the revolution and subsequent civil war. Some of the leading scientists had emigrated and much of the technical apparatus was in shambles.

Once he arrived in the first half of April 1921, he wasted no time in getting to work. But not before he himself was arrested and held a few days for interrogation. He was, however, soon reinstated in his post as director of the Geological and Mineralogical Museum of the Russian Academy of Sciences and as the chairman of KEPS, the Commission for the Study of the Natural Resources of

Russia. Vernadsky appointed a commission to travel to Siberia to investigate the still mysterious cosmic event that had occurred in the Tunguska region in 1908. The study of meteorites, Vernadsky reasoned, would tell us much about the chemical composition of the other planets, and perhaps even provide an answer to some of the questions regarding the cosmic origins of Earth and of life on Earth. In the spring of 1921, Maxim Gorky, who was in charge of these "gray beards" from the old regime, held a meeting with Lenin, who hoped to mobilize the academicians to assist in building a socialist Russia. In the meeting, they also discussed the work of Vernadsky. This is attested by a note found in Lenin's handwriting following the meeting simply stating: "Vernadsky—the structure of the Earth s crust."[5]

In May 1921 Vernadsky began to give lectures on geochemistry, where he presented his new theories on life. Out of this public activity, he began to create a new cadre for the various scientific departments which he would set up in the years to follow.

Already in 1908, following a lecture in Dublin at a conference sponsored by the British Association for the Advancement of Science, where Irish physicist, James Joly, presented a paper on the issue of radioactivity in the Earth's core.[6] Vernadsky had become totally focused on the need for Russia to begin looking on its territory for that elusive radioactive substance, radium, and to begin work on its utilization. In 1921, he established the Radium Institute, with himself as its head, a position which he would hold until 1939 until he turned it over to one of his closest colleagues and assistants, V. G. Khlopin. Almost instinctively aware of the tremendous potential of the discovery of the atom, Vernadsky urged the Soviet authorities to establish a science center around the Radium Institute and to make this a major focus of science work in Soviet Russia, but his pleas went largely unheeded.

Figure 2–5: Original Main Building, Radium Institute, St. Petersburg.
Credit: V. G. Khlopin Radium Institute.

In 1922, he had sought permission to travel abroad to conduct research and to reestablish many of the contacts lost during the war with the other European scientists. Having been invited to the Sorbonne to give a series of lectures during the following semester, Vernadsky was permitted to travel to Europe. In addition he was also tasked by the Soviet government to investigate the various possibilities for the nation offered by the recent discovery of the atom. Vernadsky's lectures on geochemistry in Paris in 1923 achieved great notoriety, and were attended by, among others, French philosopher Edouard LeRoy and the Jesuit paleontologist and theologian Teilhard de Chardin. LeRoy would label this new geological era characterized by the activity of man, which Vernadsky had outlined in his lectures, the "noosphere," after the Greek word for reason "noos" to distinguish it from the simple sphere of life, the biosphere. Vernadsky readily adopted this term.[7] What was intended as a one-year sabbatical, however, became a three-year stint in which Vernadsky would see his lectures on the topic of the biosphere published in Paris in a monograph titled *La Geochimie*. While in Paris he also began to work at the Radium Institute headed by Nobel Prize winner Marie Curie, with whom he would maintain a cordial relationship until her death in 1934.

Figure 2–6: Marie Curie in her laboratory.

In addition to his personal interest in nuclear physics, he also further pursued his investigations of Pierre Curie's study of dissymmetry in life structures, which Curie had developed on the basis of the initial discoveries of Louis Pasteur. Vernadsky would return to these issues of the "geometry of life" toward the end of his life.[8] His interest in atomic theory led him to probe somewhat deeper into the question of human life, and particularly, into the question of the prolif-

eration of life at the atomic level, a phenomenon which he characterized as the "migration of atoms." It was these "migrations" which had in fact led to the creation of the upper layers of the Earth's geospheres, the stratosphere and the ionosphere, layers also dominated by life, by the biosphere. While in Paris, Vernadsky received a grant from the Rosenwald Fund to pursue his experiments in the area of the "migration of atoms," particularly focusing on the isotopes that characterized and distinguished life on this planet from nonlife, creating the beginnings of a new science, the science of biogeochemistry. This work would lead in 1926 to the first major publication of his theory in the monograph, *The Biosphere.*

In examining the influence of the biosphere on the Earth's development, Vernadsky also focused on the unique role of man, seeing man's emergence as a qualitative shift in the continual transformation of energy characterizing the biosphere, in which man's creativity, or reason, which, once appearing on the scene, began to take on a preponderant role. As the energy of the biosphere had penetrated several kilometers into the Earth's crust as well as into the upper reaches of the Earth's atmosphere, so also would the activity of man, as he developed the technical means of expanding his own reach in the universe. As Vernadsky expressed it in a 1925 article published in Paris titled "The Autotrophic Nature of Humanity":

> There exists in the biosphere a grand geological force, perhaps even cosmic in nature, whose planetary action is generally not taken into consideration in our concept of the Cosmos, that is, concepts based on science. This force neither appears as a new special manifestation or form of energy, nor may it simply be an expression of known energies. Nevertheless, the action of that force exerts a profound and powerful influence on the course of the Earth's energetic phenomena and consequently must undoubtedly have reverberations, albeit less powerful, beyond the Earth's crust, in the existence of the planet itself. That force is the intellect of man, directed and organized through the volition of man in his social being.[9]

Returning from France in 1926, Vernadsky began to set into motion an entire series of new initiatives and institutions that would propel scientific research in the Soviet Union forward. He also organized two more expeditions to investigate the Tunguska cosmic event, led by Leonid A. Kulik. While Kulik found no debris in the Tunguska area, and felt frustrated as a result, Vernadsky surmised that the explosion may have been an event leaving only traces in the atmosphere, i.e., cosmic dust, or cosmic radiation, perhaps the remains of a collision with a comet or a part of a comet, which left only gaseous traces.

In 1929 Vernadsky established the first-ever Biogeochemical Laboratory under the Academy of Sciences with himself as director. In 1934 he urged the

creation of a Commission on Heavy Water, of which he also became the chairman. Vernadsky also urged the Academy to begin a serious study of permafrost, and a commission was set up for that purpose, again under his direction. Here we have the beginnings of the science of permafrostology, or cryology. Until 1936 Vernadsky would be allowed to travel abroad each year for working and collaborating with scientific colleagues in the other European countries. In 1934 he took part in a conference on the study of the stratosphere, an issue of great interest for him.[10] But by 1934, conditions for Russian science had become increasingly oppressive. In 1929, the bylaws of the Academy of Sciences, under pressure from the Bolshevik government, were changed, reducing the relative autonomy the Academy had maintained since its founding and permitting the influx of "politically correct" scientists. Vernadsky fought to maintain the autonomy of the Academy from the new restrictions placed on it by the government. But the fight was an unequal one, and Vernadsky ultimately had to concede to the influx of new members, many of them simply political appointees, and often not up to par intellectually.[11]

Figure 2–7: Tunguska region after 1908 cosmic event.
Credit: Photo by Leonid Kulik, courtesy of apod.nasa.gov.

Vernadsky's remaining years, in which he would become increasingly isolated from the major decision making in the scientific bureaucracy, would nevertheless be very fertile with regard to his scientific productivity. And although regarded as something of a "dissident" philosophically, his intellectual preeminence was such that his advice on matters of science was still sought. Fearless in confronting the authorities when he felt it justified, he made it a point to intervene whenever possible if a colleague or a friend were unfairly caught up in the police state machinery to try to prevent them from being sent to the Gulag. In this he was not always successful.

Man in the Cosmos

Even as he approached his seventieth year in 1933, Vernadsky still felt that he maintained a young active mind, capable of new and revolutionary ideas. In 1931 he had begun work on what he regarded as his magnum opus, "The Chemical Structure of the Earth's Biosphere and Its Surroundings,"[12] which he compared to the "Cosmos" of his revered predecessor, Alexander von Humboldt. He also authored in 1939 a tract on the noosphere, "Scientific Thought as A Planetary Phenomenon."

Figure 2–8: Vernadsky at work in his study circa 1940. Credit: RAS.

In these two works, neither of which would be published in his lifetime, Vernadsky was able to elaborate ideas which he had begun to formulate as early as 1916. In addition, the characteristic "galactic" nature of the origins of the universe and the role of man in the universe, assumed a more prominent place in his thinking. And, indeed, much was happening in the environment around him with regard to man's "galactic" existence.

Already at the beginning of the century, the work of Robert Goddard in the United States and Hermann Oberth in Germany, as well as the initially lesser known work of Russia's own Konstantin Tsiolkovsky, were pointing in the direction of man's entry into space.[13] Vernadsky's interest and work in establishing the Commission on Meteorology, which was responsible for the expeditions investigating the Tunguska incident, had brought to his attention the importance of these "space objects." By beginning to examine the chemical composition of other planets through an examination of these "messengers from space," we could learn more about our own Earth, and the environment of which it is an integral part, he felt. In the late 1930s, Vernadsky's interest in this area became more focused and he called for a rigorous program to examine the influence of

"cosmic dust" in the atmosphere. In "The Chemical Structure of the Biosphere and Its Surroundings," Vernadsky describes the ongoing exchanges between the Earth's biosphere and the space around it, beginning his work with an initial description of our galaxy, which, as he notes, was the womb out of which the Earth was formed, under the influence of the universal force of gravity. Today's study of planetary chemistry or cosmochemistry has its direct origins in these late scientific endeavors of Vernadsky.

Vernadsky prided himself on being one of the first to seriously consider the concept of the stratosphere, which he introduced in his 1924 lectures in Paris. He also took a great deal of interest in the stratospheric investigations being done with hot air balloons, which could ascend even higher than airplanes, serving in that way as the actual forerunners of our latter-day space travelers, the astronauts.[14] In a diary entry on 20 June 1931, Vernadsky writes about the latest achievements of Swiss physicist and balloonist Auguste Piccard. On 27 May 1931, Piccard took off from Augsburg, Germany in his "vehicle," a spherical, pressurized aluminum gondola and rose to a height of 15,785 meters where he collected data on the upper atmosphere and measured cosmic rays. "And yet the results are clear." Vernadsky writes in his diary.

> Man will be departing this planet. That which appeared in the fantasies of the 18th century, and in Jules Verne and Lasswitz—may well now become a reality for my children? And this is not by accident. But perhaps merely a result of the cosmic nature of life? What is now created is of the greatest interest. A maximum of labor with a minimum of results—but even if it is only half successful, more or less, it will be an impressive achievement.[15]

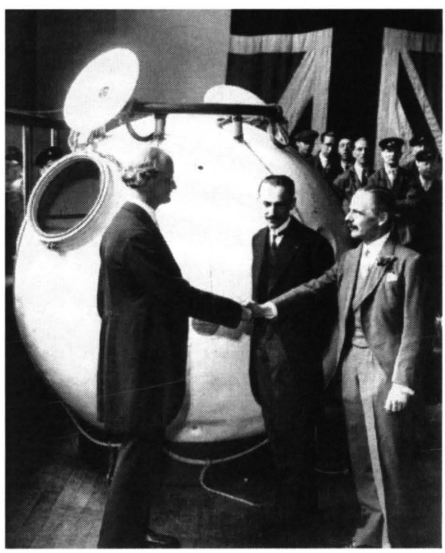

Figure 2–9: Auguste Piccard standing in front of his high-altitude vehicle.

Moscow during the 1920s was also a hot-bed of space enthusiasts.[16] The original work of Konstantin Tsiolkovsky was widely publicized. Vernadsky, like most educated Russians with a scientific bent, had also been acquainted as a young man with *From the Earth to the Moon* by Jules Verne, and later the work of German professor and science fiction writer, Kurd Lasswitz. In 1897, Lasswitz wrote an imaginative science fiction work about the visit of highly intellectual Martians coming to Earth in space vehicles capable of countering gravity and propelled by a force that was vaguely similar to rocket thrust, called by Lasswitz "Repulsit." Vernadsky refers often in his letters and diaries to Lasswitz's work.

Vernadsky was also was aware of the work of Konstantin Tsiolkovsky. As the head of the Commission on the History of Science, Vernadsky in 1939 was engaged in discussions with Petr D. Duz, a young historian, who would publish a work on Russian aviation history, with sections on Tsiolkovsky and his inventions, including Tsiolkovsky's theoretical work on rocket propulsion. In his diary Vernadsky writes of on discussion with Duz on Tsiolkovsky: "Talked about Tsiolkovsky, who sometimes would embark on new paths. He lived in an out-of-the-way place (Kaluga) and yet more than once discovered America."[17]

Vernadsky felt that even in the midst of the terrible conditions of the Second World War humankind was on the verge of a new exciting era of technological development. In his unfinished magnum opus, "The Chemical Structure of the Biosphere and Its Surroundings," he writes,

> In the 20th century for the first time there does not remain on the surface of the planet a single spot where man has not set his foot, and he has achieved conditions such that he everywhere may live and develop comfortably with regard to his needs. And, on the other hand, the simultaneous creation and development of aviation permits man to actually rise to the lower layers of the stratosphere, as the development of technology likewise will also permit him to descend to the subterranean limits of the biosphere... Means of communication are growing and in the near future will undoubtedly reduce the time of travel to a minimum. Actually, man is beginning to consider the possibility of his departure into cosmic space.[18]

Man as a part of the biosphere, as he extends his reach into the stratosphere and beyond, also extends and advances the biosphere. "Terraforming" Mars would not be totally inconsistent with Vernadsky's view of man as a "cosmic force." This optimism is expressed in his final unfinished opus, the "Chemical Structure of the Biosphere and Its Surroundings":

> Apparently the discovery of aeronautics at the end of the 19th century, and its rapid development at the beginning of the 20th, when man first entered the stratosphere, extended the realm of the biosphere, encompassing the stratosphere in its scope. We are experiencing geologically a new phenomenon, in which man, a mammalian organism, is penetrating into the

surrounding atmosphere, where, up until now, only insects and other winged species, mainly birds, held sway.[19]

Figure 2–10: Konstantin Tsiolkovsky (on the right) with other teachers from Kaluga. Credit: Tsiolkovsky Museum of Cosmonautics.

During the last few years of his life, the years of the Second World War, these "cosmic" matters came to dominate his thinking. In 1941, he issued a paper calling for a systematic study of cosmic dust. And, perhaps with a certain pre-science of the coming geological research which something like a *Curiosity*, or even human beings, might someday conduct on Mars, he wrote in 1944 a paper titled, "The Manifestation of Mineralogy in the Universe,"[20] in which he underlined the importance of the geological study of other planets, at that time only limited to the study of meteorites and asteroids or "cosmic dust" penetrating the atmosphere from afar.

Vernadsky probably knew that much of his work, so brilliant and far-sighted, but so far beyond the mainstream of science in his day, not to speak of beyond the rather stultifying atmosphere imposed on scientific thought during the Stalin era, would not be immediately accepted or even published. In spite of his preeminence in Russian/Soviet science, (he was awarded the Hero of Socialist Labor on the occasion of his eightieth birthday) he always had to fight the censors, and didn't always succeed in overcoming them. Vernadsky had been labeled a "vitalist" by the Marxist "philosophers" for his theories about life, a designation that made his most revolutionary work anathema to those worshipping at the altar of dialectical materialism, but his preeminence in science kept him as a "protected person" in the Soviet Union.

And yet, Vernadsky could not entirely be ignored. By 1960, there was a limited collection of his articles and writings published as *Collected Works*, and edited by his colleague, academician Alexander Pavlovich Vinogradov. In 1985,

the Presidium of the Academy of Sciences of the USSR passed a resolution creating a commission to examine the issue of publishing the works of Vernadsky. Since then, there has been a slow but steady stream of material published from the massive amount of Vernadsky papers preserved in the archives of the Russian Academy of Sciences. The task of making this material available in foreign languages is, however, just beginning.

It is not possible within the confines of this chapter to describe the myriad contributions that Vernadsky made in terms of his direct influence on several generations of Russian and Ukrainian scientists. Developments in cosmochemistry, planetology, astrobiology, biogeochemistry, meteorology, crystallography—all can trace some element in their development to the seminal contributions of Vladimir Ivanovich Vernadsky.

Two examples have to suffice in order to indicate the influence of Vernadsky on the following generation of scientists who would be intimately involved in the Russian space program. Foremost among these is the previously cited Alexander Pavlovich Vinogradov, a close associate of Vernadsky, who became the head of the Biogeochemical Laboratory on the death of Vernadsky and reorganized it in 1947 as the Vernadsky Institute of Geochemistry and Analytical Chemistry of the Russian Academy of Sciences, which he would head until 1974. Vinogradov also pioneered the use of chemical and isotopic analysis to study the formation of terrestrial minerals and meteoric material. He also followed up on Vernadsky's investigation of the nature of chemical isotopes. In 1967 Vinogradov was elected vice president of the Russian Academy of Sciences. With the coming of space technology, Vinogradov proposed the use of gamma-ray spectroscopy to study the makeup of planetary crusts. Vinogradov was also the editor of the first collection of Vernadsky's works. For his contributions to space science, a mountain and a crater on the far side of the Moon bear Vinogradov's name.

Another noted Vernadsky protégé was Kirill Pavlovich Florensky. Born in 1915, he was one of the youngest collaborators of the eminent scientist. He was the son of a noted mathematician, electrical engineer, and theologian, Father Pavel Florensky. Kirill Florensky was later appointed the head of the Department of Comparative Planetology at the Vernadsky Institute. In 1958 he led an expedition to study the site of the 1908 Tunguska explosion in Siberia. In the early 1960s, he planned some of the first experiments to chemically analyze the atmosphere of Venus. In 1975 his lab was involved in the study of the rock samples returned by Luna 16, 20, and 24 and planned remote experiments on the Lunokhod rovers.

During the last years of his life, Florensky also devoted a significant part of his time preparing for publication several earlier unpublished works of Vernadsky, his teacher and mentor. A crater on the Moon is named for Florensky, situated, appropriately, close by the crater named in honor of Vladimir Ivanovich Vernadsky.

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