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PHOTOCHEMICAL PLANETARITY

Under the microscope's lens, vegetal matter started to look different: the view of chlorophyll encased inside transparent lenticular membranes helped also to explain photosynthesis. The plant's surface was understood to be covered with chloroplasts, fueled by the radiant energy of light and several chemical processes inside the plant. During the last decades of the nineteenth century, photometry merged vegetal and photographic surfaces as part of constructing a vegetal growth model that related to light intensity. The photometric sensitivity of the plant guided the formation of the new corpuscles: only certain thresholds in the intensity of light surrounding the plant triggered the formation of new corpuscles of chlorophyll. Julius Wiesner's photometric observations suggested that new vegetal cells were produced only when the intensity of light fell between upper and lower specific measured values. Had Ansel Adams's Zone System been invented in Wiesner's time, plants would have been described as zoning the landscapes of light, foreshadowing the photographic zoning of arable landscapes that we examine in later chapters.

The previous chapter's engagement with Wiesner's double view of the vegetal and the photographic surfaces was one stop along the way of the scalar adventure of this book, and now we turn to the surface of planet Earth. While the book is situated in the broad context of visual culture studies and media theoretical discussions, we are also informed by sources that relate to the shift in the biological and geological sciences to datasets, images, and calculated surfaces. While the story is far from linear—as if we could shift from visual depictions to data, from operations of light to operations of calculation so straightforwardly—it helps to structure our argument according to historical case studies that also bend the scope of mediations in ways that can intersect both operations of knowledge and operations of terraforming.

In this chapter, we turn to the planetary surface, as it was formulated in twentieth-century scientific work in the Russian Empire and, subsequently, the Soviet Union. More specifically, this concerns the famous work by Vladimir Vernadsky, who introduced the notions of the *biosphere* (admittedly, coined some decades earlier by Eduard Suess), the *noosphere*, and, subsequently, the *technosphere*.[1] We address Vernadsky's work not merely for purposes of historical investigation, as interesting as it would be, but as far as it concerns the broader scalar logic of images as surfaces and growing surfaces as nested in a history of technical mediations.

The decades between the late 1800s and the early 1900s were characterized by rapid colonial expansion, massive resource grabs, and the establishment of a global food system that Hannah Holleman, in her work on the Dust Bowl, has described as a "new imperialism."[2] While standard accounts of this period have emphasized the importance of technological developments in communications, management, and transport as driving forces of the acceleration, scholarly work from different perspectives has emphasized the crucial role played by the scale of the territories involved in developing these technologies. For example, in the 1940s, Siegfried Giedion described the experience of seeing the cultivated landscapes of the American Midwest from a train. He writes, "This elimination of time, together with the mystery of dimension, produced the mechanization of agriculture."[3] More recently, Deborah Coen has shown how imperial access to vastly different territories enabled the birth of climate sciences and mapping scales and differences across regions in the Habsburg Empire.[4] A similar realization applies to the Russian Empire: the vast landscape and access to very different regions enabled the emergence of different comparative perspectives and research possibilities, including some that arose for very practical reasons of maintaining the empire. The focus on the study of soil by Vasily Dokuchaev is a good example of the interest in mapping the extent of the steppes and the variations in their geography.

His work gained further institutional support when he studied important critical events such as the harvest failure of 1891. This, subsequently, led to the maturing of soil sciences, as Dokuchaev's expeditions evaluated "the soil and natural resources of Nizhnii Novgorod province, in the north of the black earth region, and Poltava province, in the heart of the black earth region in Ukraine."[5]

The steppes, including those in Ukrainian territory, had been turned into agricultural land at the same time as being captured as visual landscapes in nineteenth-century painting, which codified them as part of the Russian Empire. In some ways, we see how plowing and (imperial) visual production went hand in hand with expeditions in the 1880s and 1890s that observed the constitution of the fertile, moist black soil. Furthermore, from the perspective of the Russian war on Ukraine that started in 2022, we must be aware of the long imperial politics of the state, part of which is found in this scientific story of how the planetary living surface became defined—englobing, in its definition of fertile soil and farmlands, those in Ukraine—or controlled, as in energy networks such as gas pipelines. Finally, the broader context of the discussions in the late nineteenth century recalls many of the current practices and discourses around climate change and land use: deforestation is suspected as a cause of environmental issues, with afforestation as one often suggested remedy, alongside other projects for systems of artificial irrigation.[6]

Within this lineage of thought, we propose to read the narrative and scientific description of planetary envelopes and surfaces that feature in Vernadsky's writings and beyond. While there is a lineage from Dokuchaev's research on soil (the black earth), cultural techniques of plowing and grazing, and other terrestrial forms of "terraforming," Vernadsky's perspective emerges in the context of further industrialization. In other words, Vernadsky's work has a foot in earlier soil research, but it also emerges against the backdrop of the cultural technical resurfacing of the world through chemical industries. In his own words, the First World War "radically changed my geological conception of the world."[7] The recently recurring terminology of "planetary scale" revives some of Vernadsky's ideas. One is tempted to add that the continuity of chemical industries and the weaponization of biosphere dynamics are crucial contexts in the twenty-first century. We want to approach Vernadsky's work as highlighting the importance that the planetary scale had in the elaboration of a biogeochemical model of the living. In this task, we understand scale as a perspective for critically analyzing a process of mediation to unveil otherwise invisible aspects and relations: it emerges both as a subject of research and as a methodological cue. Max Liboiron recently examined harm and violence produced by the pollution of microplastics: "Knowledge systems such as political ecology, cultural geography, and environmental justice are just some of the ways to look at how systems of value and knowledge animate relations. Scale is another."[8]

Scale features in this chapter in multiple ways: the planetary becomes an instance of mapping large-scale systems of precybernetic feedback loops. Such processes interact in ways that scale up and down across the dynamic boundaries of the planet. Here, "planetary" does not refer solely to a particular space but to the system of biogeochemical transformations at play. In addition, the planetary takes up the role of an interface: an epistemic handle on things beyond our immediate grasp. This has a political angle, too, when we read it in relation to the question of scale, for example as it emerges in Anna Tsing's note on the plantation logic of scale.[9] This mode of scaling subsumes specificities into large-scale units, cultivates particular kinds of modular worlds, and becomes an epistemic operation with a particularly violent history, too. In Tsing's words, "Scalability is, indeed, a triumph of precision design, not just in computers but in business, development, the 'conquest' of nature, and, more generally, world making. It is a form of design that has a long history of dividing winners and losers. Yet it disguises such divisions by blocking our ability to notice the heterogeneity of the world; by its design, scalability allows us to see only uniform blocks, ready for further expansion."[10]

Consider the point about scalability in relation to the subsequent discussion of Vernadsky's surfaces: Are we dealing with preparing readymade units of knowledge that program and stamp the world according to its own image? With what kind of scalar inscription is Vernadsky operating? While we focus primarily on his work in this chapter, we must note that these questions go far beyond Vernadsky. Hence, we also consider the question of scales in relation to parallel studies of the period, such as the thermodynamic-based work of US biophysicist Alfred Lotka, summarized in his book *Elements of Physical Biology* (1925). Lotka boldly addressed "the entire body of all these species of organisms" as a "World Engine," and characterized it as "a vast unit, one great empire."[11] These sorts of scalar operations visible in rhetoric and scientific method prompt us to ask: What empires do scaling operations establish? What forms of supposedly natural growth are already included in calculations and projections of empires and other units of measurement? Any discussion of scales bends in many ways: some have imperial aims and some aim to facilitate the understanding of the complexity of surfaces that incorporate more than spatial dimensions. To quote Liboiron again: "Scale is not about relative size" but about "what relationships matter within a particular context."[12]

Reading Vernadsky's work and concepts regarding dynamic surfaces presents a significant case of planetarity far beyond its own scientific context in biogeochemistry. The model of the planet as a cosmic entity where the thin critical zone of life enveloped in dynamics from bacterial populations to atmospheric chemistry becomes the synthesizing site of different scales of surfaces that we are interested in mapping. Bruno Latour went so far as to claim that it is this "biofilm, a varnish, a skin, a few infinitely folded layers," where all the stakes for the terrestrial dynamics of knowledge, as well as their bespoke politics, lie: "Speak of nature in general as much as you like, wonder at the immensity of the universe, dive down in thought to the boiling center of the planet, gasp in fear before those infinite spaces, this will not change the fact that everything that concerns you resides in the minuscule Critical Zone. This is the point of departure and return for all of the sciences that matter to us."[13]

As such, this cartography of multiscalar planetarity not only echoes the more recent Gaia and Anthropocene discussions but it also connects to contemporary issues of planetarity from media studies to speculative design, without forgetting the context of environmental sciences. The link to Anthropocene discussions is relevant in terms of how the earth systems sciences are one version of a longer history of understanding the interconnected dynamics of different planetary forces, where knowledge of and through surfaces (such as remote sensing and satellite imagery of geographical landscapes) plays an instrumental role.[14] As Lynn Margulis and Dorion Sagan put it in their popular science book *What is Life?*, "Vernadsky dismantled the rigid boundary between living organisms and a nonliving environment, depicting life globally before a single satellite had returned photographs of Earth from orbit."[15] The envelopes, films, and other spatial concepts for solar-driven energetic transformation of the living matter addressed by Vernadsky that we discuss in this chapter are examples of planetarity read from the perspective of its growing surfaces and "the slow penetration into the Earth of radiant energy from the sun."[16] In other words, even before the actual cosmic perspectives enabled by space technologies, Vernadsky's reading and insights about the earth were cosmic in how they included the key driving force of living matter that was not present in the theories of physics or mechanics.[17] This view was material, even empirically concrete (even if full of abstractions, too), while it referred to a surface that was not just geophysical but full of biogeochemical processes from soil to the atmosphere and that bundled up into a view of geopolitics that is even more prominent now, in the 2020s, with energy and land use being central components of distribution of power.

THE BIOSPHERE

Let us rewind to the 1920s and the most central term in this chapter. In 1926, Vernadsky published *The Biosphere*, one of the first attempts to describe the ensemble of living processes on the earth as a holistically dynamic. Scientific domains such as geology, physics, and chemistry had already probed into the problem of creating models of the entire planet, producing their views as a result.[18] *The Biosphere* was Vernadsky's proposition to analyze life at a similar scale but, in his words, not as an abstract geometrical model or as inert matter.[19] His project aimed to describe the domain of biochemistry—the transformation of matter and energy as they link to questions of life—through a set of laws analogous with those of physics, though not irreducible in the same way. To do this, observations and data all around the planet enabled the interactions between living and nonliving entities to be quantified and compared from the point of view of the circulation of energy and the movement of matter. *The Biosphere* was the result of this project, and biogeochemistry was the practice that was perceived to be able to account—at the same time—for considering biological, chemical, and geological phenomena at the scale of the planet.

The term biosphere had been coined earlier, though, when it was introduced in 1875 by the Austrian geologist Eduard Suess. In 1899, the oceanographer Sir John Murray pointed to the multiple coatings of planetary phenomena, including the notion of geosphere:

When we regard our globe with the mind's eye, it appears at the present time to be formed of concentric spheres, very like, and still very unlike, the successive coats of an onion. Within is situated the vast nucleus or centrosphere; surrounding this is what may be called the tektosphere, a shell of materials in a state bordering on fusion, upon which rests and creeps the lithosphere. Then follow hydrosphere and atmosphere, with the included biosphere. To the interaction of these six geospheres, through energy derived from internal and external sources, may be referred all the existing superficial phenomena of the planet.[20]

Gradually, geospheric thinking spread far beyond the initial sciences to contexts as varied as meteorology and geophysics, where terms such as the troposphere, stratosphere, and asthenosphere were coined to designate different layers inside and outside of the earth.[21] While Suess understood the biosphere as the planetary envelope that encompasses all life on earth, Vernadsky added to this definition an interfacial character between the earth and the cosmos: it became "the envelope of life where the planet meets the cosmic milieu."[22] In contrast to Suess's descriptive under, Vernadsky's definition entailed an organized approach to the activity of the whole as if it were a self-regulated entity in continuous exchange with its surrounding environment.[23] The biosphere became understood as an active geological layer, which thus involved a central methodological problem in relation to the notion of scale and its epistemic implications: when dealing with the planet as a whole, individual phenomena had to be reframed at a larger scale to account for the cascading series of interlocking dynamic patterns that could not be understood merely locally. In his words:

Historically, geology has been viewed as a collection of events derived from insignificant causes, a string of accidents. This of course ignores the scientific idea that geological events are planetary phenomena, and that the laws governing these events are not peculiar to the Earth alone. As traditionally practiced, geology loses sight of the idea that the Earth's structure is a harmonious integration of parts that must be studied as an indivisible mechanism.[24]

In the context of the earth's structure, understood as a "harmonious integration of parts," *The Biosphere* defined the "planetary" as the scale at which the relationships between biochemical phenomena and geology mattered. The study of the planet required it to be addressed as a "holistic mechanism."[25] Despite the explicit reference to a "mechanism," his work should not be linked to a mechanistic representation of life, which he explicitly rejected.[26] It is instead an all-encompassing metaphor that describes a system of linked phenomena which, in opposition to a multiplicity of "essentially blind"[27] accidents, sense each other and make sense of the presence of a different scale, where scale "permits us to make sense of mediated, extended, and projected experience."[28] Geological events, including such as those linked to biological life, were suggested as connected to each other, giving rise to a dynamic system in equilibrium. In other words, *The Biosphere* needed to be understood from the central position of the scale of the planet in relation to the mediating role of the practices of *biogeochemistry*.

The biosphere envelops the planet as its uppermost layer, from a depth of a few kilometers below the sea level up to the troposphere's limits. In current environmental sciences, this is also referred to as the thin sphere of the Critical Zone itself, often defined through its heterogeneous multiscalarity, "ranging in scale from the mineral-water interface to the globe."[29] No forms of life are known outside this thin sphere, and barely any knowledge of the planet could be experimentally produced outside this zone. As chemist Frank W. Clarke put it in his influential *The Data of Geochemistry*, "Our knowledge of terrestrial matter extends but a short distance below the surface of the earth, and beyond that we can only indulge in speculation. The atmosphere, the ocean, and a thin shell of solids are, speaking broadly, all that we can examine."[30] Later, ocean-floor research, as well as space travel, might have changed parts of this claim, but the basic point is still valid when it comes to the biospheric context of knowledge as a keyhole through which broader planetary and interplanetary systems are understood.

While this merger of the living and the knowable would give rise to Vernadsky's later work on the noosphere, Clarke's reference to "all that we can examine" was already included in the scope of *The Biosphere*. Vernadsky's new science of biogeochemistry was also to move beyond any single discipline in its holistic take on such dynamic phenomena. It was to be grounded in results from different fields; Vernadsky proposed to rely on a series of "empirical generalisations," which allowed him to introduce principles and distinctions needed to elaborate his model and to strengthen its scientific validity in the eyes of his peers.[31] In order to be able to develop his arguments, he required the formulation of such statements, arguing that they were not introduced as theoretical hypotheses. They were formulations grounded in induction, well established by experience, which could not be fully proved due to the scale and variety of their domain. Throughout *The Biosphere*, he postulated a series of such positions and claims, among them, for instance: the permanent difference between inert and living matter, the presence of life during all geological periods, and the invariability of the chemical influence of living matter. In the context of this book, one of these—the ability of plants together with autotrophic bacteria to transform the energy of the sun and provide the other beings and processes on the earth with free chemical energy—is particularly relevant to our argument. This is what he named "the cosmic function of plants," an empirical generalization that worked as an interscalar vehicle where the cosmic scale was brought into the molecular level of photosynthesis.[32]

THE COSMIC FUNCTION

Immersed in space, the planet receives incoming electromagnetic flows. In the uppermost layer, they are transformed into free terrestrial energy. As an early version of the trope of Spaceship Earth, Vernadsky's biosphere, absent from other known planets, is an active envelope, which in the encounter with the surrounding "cosmic force" differentiates the flows into a variety of chemical, mechanical, and molecular forms of work:

> A new character is imparted to the planet by this powerful cosmic force. The radiations that pour upon the Earth cause the biosphere to take on properties unknown to lifeless planetary surfaces, and thus transform the face of the Earth. Activated by radiation, the matter of the biosphere collects and redistributes solar energy and converts it ultimately into free energy capable of doing work on Earth.[33]

Concerning such phenomena of life at the scale of the entire planet, matter is "activated" by the cosmic radiation that reaches the earth, which is mostly light coming from the sun. This process of activation by light recalls the photochemical domain of phenomena that we examined in the previous chapter. In this broad context, practitioners such as William Henry Fox Talbot wrote about light exerting an action that caused changes in material bodies while investigating whether these changes could be made visible on surfaces such as paper.[34] Later, in Vernadsky's work, vegetal surfaces made visible the action of light on the surfaces of the earth: "In the impact of a forest on the steppe, or in a mass of lichens moving up from the tundra to stifle a forest, we see the actual movement of solar energy being transformed into the chemical energy of our planet."[35] The growth of forests or the spread of lichen acted as evidence of one form of the activation of the matter referred to by Vernadsky. However, one might ask: What is the relation between photosynthesis and such an abstract notion of activation of matter in the biosphere? Also, taking into account the discussion from chapter 2, is Vernadsky's idea of activated matter related to a model of calculated photosensitive surfaces akin to the photometric surfaces used in photography?

To answer the first of these questions, it is important to acknowledge that Vernadsky described plants, together with autotrophic bacteria, as the only living beings able to transform incoming cosmic radiation into chemical energy. In his words, "All living matter can be regarded as a single entity in the mechanism of the biosphere, but only one part of life, green vegetation, the carrier of chlorophyll, makes direct use of solar radiation."[36] The biogeochemist, emphasizing the importance of plants in the order of the biosphere, established a parallelism between their role and the "cosmic force" of light by addressing the plants' photosynthetic singularity as their "cosmic function."[37] This phrasing had been used before: Vernadsky alluded with it to the title of a well-known lecture given in 1903 by Russian plant physiologist Kliment Timiriazev, “The Cosmical Function of the Green Plant.” In the lecture, Timiriazev referred to the oxygenation of the atmosphere as the cosmical function of the plant. That is, he named the terraforming character of plants that we discussed in chapter 1 in relation to the cultural technique of experiments with plants in transparent cases in enclosed environments. In the earlier discussion, the recursive character of the cultural technique mediated between the different globes concerned, from the glass jar to the Wardian case to the planetary globe. In this chapter, the cosmic force arrives from outer space to become the energy-transforming ability of a plant. Such a biogeochemical model of life proposes that the cosmic perspective involves a reflexive recursion; in Katherine N. Hayles’s words: “Reflexivity is the movement whereby that which has been used to generate a system is made, through a changed perspective, to become part of the system it generates.”[38] This recursion among scales abstracts plants as vegetal surfaces, vegetal surfaces as living matter, and living matter as an activated geologic coating responding to the cosmic energy of the sun.

SCALING MATTER

The Biosphere was written between the First and Second World Wars. As Etienne Benson has observed, the supply chains and the international networks of finance, trade, and communications of the second half of the nineteenth century were ripped apart during the First World War. This led to a widespread interest in the question of self-sufficiency at the scale of the nation-state—that is, the problem of territorial autonomy in relation to food, energy, and manufacturing systems—expanding a long-standing agricultural question. It was important to acquire reliable knowledge of available resources and to develop a logistical understanding of “their accessibility and value in relation to changing levels of supply and demand, the availability of substitutes, new methods of extraction and processing, and economic and geopolitical constraints.”[39] In Benson’s words, “Ecologists, demographers, and geochemists applied techniques and concepts developed to manage strategic materials during the war to the study of exchanges of matter and energy between organisms and their environments."[40] Before writing *The Biosphere*, Vernadsky founded an institute devoted to the inventory of Russia's strategic materials, even proposing the completion of an "international radiography of the earth's crust."[41] He also advocated for a nationwide program devoted to research on radioactivity.[42] The metabolic circulation of matter and energy on a global scale remained a central part of Vernadsky's work, continuing earlier developments of the bioenergetic notion of metabolism, such as were proposed by the physician Julius R. von Mayer and chemist Justus von Liebig in Germany, and the Ukrainian physician Sergei A. Podolinsky.[43]

We want to pay special attention to the scale of the planet that emerges in bioenergetic notions of metabolic flows. *The Biosphere* can be described in terms of Zachary Horton's theorization of scale as both a producer of difference, which gives rise to stable entities, and a milieu of relational dynamics between them.[44] In order to elaborate the model of the interaction between the cosmic radiation and the surfaces of matter on the planet, Vernadsky established as an empirical generalization a central distinction: "Two distinct types of matter, inert and living, though separated by the impassable gulf of their geological history, exert a reciprocal action upon one another."[45] Living matter encompassed the total sum of living organisms, while inert matter referred to the ensemble of solid, liquid, and gaseous formations that envelop the living, such as soils, oceans, rivers, and the atmosphere. The idea of "activated matter" operated in two senses: first, as we have just seen in relation to the cosmical function of plants, as a diagram of living matter, where radiation is transformed into free chemical energy; second, in a logistical manner, as a "conveyor and a storage of cosmic energy,"[46] circulating it and retexturing with it the inert shells of the biosphere. This version of a planetary conveyor belt consisted of living and inert matter, as well as the logistical processes and circuits among them where energy and matter were transferred in both directions.[47]

Furthermore, the planet was modeled as a surface. Vernadsky's research program unfolded through a vocabulary that flattened the differences inside living matter to consider it instead as a continuous surface: "Living matter clothes the whole terrestrial globe with a continuous envelope."[48] Emphasizing this surface condition, Vernadsky addressed assemblages of vital matter at a smaller scale as "living films." Such films were, for instance, the continuous layers of green life (green autotrophic organisms) that cover the surface of oceans alongside phytoplankton or, in the case of land, "one living film, consisting of the soil and its population of fauna and flora."[49] While mostly continuous, this film was however remarkably thin. Vernadsky added:

> Only some tens of meters above the surface in forest areas; in steppes and fields it does not reach more than a few meters. . . . The living film thus covers the continents with a layer that extends from several tens of meters above ground to several meters below (areas of grass). Civilized humanity has introduced changes into the structure of the film on land which have no parallel in the hydrosphere. These changes are a new phenomenon in geological history, and have chemical effects yet to be determined. One of the principal changes is the systematic destruction during human history of forests, the most powerful parts of the film.[50]

What is interesting is that this film is not merely an empirical description, it has become an aesthetic and epistemic device for understanding scales. It includes a way to characterize the distribution of different vegetation (and other living) formations, while it becomes an abstract notion holding the planetary reference in place. To add, the tension between the differences inside the ensemble of entities encompassed in such films and the abstract and unifying character of the notion of the surface itself defines, in Horton's terms, scalar media: "A 'scale' is a singular resolution of ontological difference between two surfaces."[51] Here, Horton's focus includes the operational rendering of complex formations into surfaces that can also encode depths or, in the case of vegetal surfaces, all sorts of photosynthetic and energetic processes. Indeed, while paying attention to examples such as films, Horton's definition of media as a "series of machinic differential operations within [a] cosmic-historical flow of matter-energy"[52] further underlines the connection to fundamentally material kinds of surfaces that are instrumental in recursive operations of scaling. Indeed, the scalar media of living films, patches, and vegetal zones become way of underlining the stakes of planetary mediations. Furthermore, these mediations depend on not just what scale is identified as relevant but how this scale embodies, counts, resolves, dissolves, negotiates, and amalgamates relationships.[53]

THE PHOTOMETRIC PLANT AS SCALAR MEDIA

Once the living is abstracted as flat surfaces of living matter, *The Biosphere* turns to the operations of energy of sunlight. We have already seen how important plants are for Vernadsky, who described them as having a "cosmic function." Earlier research in plant physiology had a significant impact on his thinking, not least the work of Timiriazev and Wilhelm Pfeffer.[54] However, the influence of Julius Wiesner has remained underestimated. In other words, the research by Wiesner that we discussed in the previous chapter can also be identified in Vernadsky's ideas. By engaging with this connection, we will see how the cosmical function of the plant appears not only as a recursion within the multiscalar model but also as a significant case of scalar media included in Vernadsky's arguments. The photometric growth as a model for the surface of the plant in Wiesner's work becomes, for Vernadsky, a model for the logic behind the distribution of the surface of living matter that envelopes the planet. Whereas Wiesner described the structure and growth of the "living substance" in the plant in detail,[55] Vernadsky addressed instead the scale of biogeochemical multiplication of "living matter" on the earth. The "movement of life"[56] in relation to the presence of light was mapped by Vernadsky following Wiesner's model of the growth of the plant. As a consequence of this epistemic mapping, it was also rendered calculable. The photometric surface of the plant becomes a form of scalar media of the biosphere. Plant life is scaled up to the planetary in order to arrive at a biogeochemical model of life on earth.

In order to see this point more clearly, we should recall how, right after his initial description of living matter as a biogeochemical assemblage of entities and processes, Vernadsky turned to the unique role of plants as and on living surfaces. He subsequently explained how several studies, including those by Wiesner, had shown these organisms had evolved and adapted to the cosmic function. In particular, Wiesner's idea that light "exerted a powerful action on the form of green plants" was emphasized in *The Biosphere*.[57] In order to underline that the form of the vegetal is affected by light, Vernadsky quoted the Austrian plant specialist: "One could say that light moulded their shapes as though they were a plastic material."[58] He postulated this behavior again as an empirical generalization: "The green apparatus which traps and transforms radiation is spread over the globe, as continuously as the current of solar light that falls upon it."[59] Moreover, if plants inside transparent cases had been shown to actively produce the necessary gaseous equilibrium for their survival, the surface of living matter on top of the earth was also able to autonomously regulate the gaseous mixture in the atmosphere. The photochemical morphogenetic dimension of the interweaving between vegetal matter and the rays coming from the sun provided him with an explanation for the efficient spreading of life all over the terrestrial surface.[60]

The influence of plant physiologists can also be witnessed when Vernadsky wonders about the cause of plant-light interaction. Do plants grow and adapt their shape to a passive background of light or, conversely, does light sculpt them as if it has invisible fingers? This was exactly the old and polemical dispute between Darwin and the German physiologists in relation to the sensitivity of plants that grounded the work on photographic plant growth that we discussed in the previous chapter.[61] Following what Wiesner had proposed two decades earlier in his research on phototropism, Vernadsky suggested a synthesis of sorts: "The solution should probably be sought in a combination of both approaches."[62] Wiesner, as we have shown previously, explained how the shape of plants must be understood as an adaptation to their active environment of light. Neither accumulations of vegetal matter reacting to external forces nor free organisms with the ability to experiment with their own form, plants developed leaves where the intensity of light equaled their Lichtgenuss. This feature of plants was scaled up by Vernadsky to the planetary: "The firm connection between solar radiation and the world of verdant creatures is demonstrated by the empirical observation that conditions ensure that this radiation will always encounter a green plant to transform the energy it carries."[63] Like individual plants, whose leaves are placed where the intensity of light coincides with the value of their Lichtgenuss, the living surface is presented in a dynamical equilibrium with light in such a way that every incoming ray ends up meeting the appropriate creature that efficiently metabolizes it.

As discussed in chapter 2, in the context of this experimental plant physiology, vegetal growth was measured and modeled through cameraless photographic techniques. In the already mentioned conference on the cosmical function of plants, Timiriazev discussed their photographic character: "Chlorophyll plays in the living organism the part of an optical sensitiser."[64] In a similar vein, Wiesner provided a photochemical model for plants' ability to deploy their surfaces against the varying environment of luminous conditions. Likewise, Vernadsky proposed a biochemical model to explain the capacity of living matter to spread and perform its photosynthetic function everywhere on the earth. The green apparatus, the latent disposition to transform the rays of light into the chemical energy necessary both to sustain and expand the living, was spread as an active interface all over the surfaces of the earth. In other words, Vernadsky took note of the work of a previous generation of plant physiologists on the interaction of plants with light and scaled it up to the planetary. He postulated that the ensemble of all life forms could be understood as a holistic entity tied together through the metabolism powered by the energy of light. He named this totality *the living matter* and characterized it as a surface in continuous formation, as if it were a vegetal organ adapting its shape in relation to the light. The photographic character of the surface of plants that resulted from turn-of-the-century continental plant physiology was brought to the planetary by Vernadsky. By doing this, life on earth was modeled as a photographic development of the light of the sun or, in other words, as an image of chemical energy in continuous formation—as if developing an ever-changing photosensitive film.

While living matter grounded the oxygenation of the planet, they simultaneously refashioned its uppermost geologic crust: "Seen from space, the land of the Earth should appear green."[65] The carpentry of living on the planet became an interfacial layer that shifted from the metaphorical face of the earth (such as in Suess's vocabulary) to a technique of registering and processing cosmic rays. All these different examples made the media-specific and technical issue of the sensitivity of the photographic surfaces into a generalized feature of living surfaces in an energetic ontology of light.

TECHNOLOGIES OF LIFE

To understand the significance of the change of scale in the approach to life and the nuances of taking the surface of the plant as well as vegetal formations as scalar media, it is worth observing that the notion of living matter was outside the scope of the research carried out by most of

Vernadsky's contemporaries. At the beginning of the twentieth century, living matter was conceptualized as an abstraction, where life was understood outside the standard categories of species and individuals operating in the disciplines linked to biology.[66] Aware of this, in a conference two years after the publication of *The Biosphere*, Vernadsky emphasized that his work had proposed a completely different (biogeochemical) model of life. In his words, understanding life as a planetary phenomenon involved "fundamental conceptions of biology," mostly focused on morphological characteristics of species, which had to be "submitted to radical modifications."[67] The scale of the entire planet was brought to the foreground and, as a result, the distinction between the living and the inert at that scale could be understood only by using a series of new knowledge tools, different from those taken from biology. This already, in some ways, hinted at the later theorization of the noosphere as a *bio-techno-sphere*, where "man and its exosomatic instruments, the earthly environment, and all technologies became inseparable."[68]

By the late 1920s, Vernadsky's materialism had grown to be similar to the philosophical critiques of hylomorphism featured in the work of Alfred North Whitehead and Henri Bergson, which acknowledged the constitutive links of organisms with their environments. Their names feature explicitly in Vernadsky's writing. As Vernadsky emphasized, organisms cannot be understood and should not be studied as independent from their living environments, nor should the two be opposed either: organisms and environments are tightly coupled in a dynamic ontology of living and nonliving matter.[69] For Vernadsky, though, the focus was on proposing new ways of understanding biogeochemical phenomena as *technologies of life* that were operating at the back of the *biogenic migration* of living matter.[70] While his position was incurably teleological in how he read paleontological observations as proof of a unified, determined direction of evolution, it still afforded interesting, even radical, ideas about originary technicity that resonated as part of the broader media cultural enthusiasm not only with new technologies of early twentieth century but with their "natural" counterparts too.[71]

Understood under the umbrella of such a technology of life, for example, the biogeochemical view of a "swarm of locusts" depicts them not only as a biological species but as exoskeletons made of minerals:

geological matter animated, "extremely active chemically, and found in motion."[72] Living and inert matter were found to be always in circulation, where the observation of the movement of the former anticipates the distribution of the latter and vice versa.[73] Such a position provided a radical ontology of movement that allowed such seemingly mistaken interdisciplinary jumps to emerge that also saw geology as part of living surfaces. The Russian geologist Andrei Lapo, one of the early specialists of Vernadsky's work, points to how fundamental this position was to the model of planetarity that Vernadsky presented: "Living matter is a specific kind of rock . . . an ancient and, at the same time, an eternally young rock. A rock which creates itself and destroys itself to originate again in new generations in the innumerable forms constituting it."[74] In other words, this theory of the planet as a field of capture of cosmic energies connected the earth-sun system to the reshaping of the earth's crust and strata, with mineral and gaseous consequences beyond living matter, including fuels, carbonate, and phosphate deposits, soils, atmospheric gases, and so on. It is as if the radiation of the cosmos, thanks to these technologies of life, left its print on the earth, a dynamic geological print made up after the biogeochemical activation of the surface by the living films on top of the planet. One could refer to these large-scale prints, traces, and marks also as *autographic visualizations* that remain as one form of an archive of environmental changes.[75]

While we pay attention to such models of light and inscription of surfaces, at the back of Vernadsky's argument was also an "arithmetic point of view."[76] This approach to the biosphere required a way to deal with the living and the nonliving at the same time, without assuming either a mechanistic reduction or a vitalistic position, both of which he disregarded as "alien to science."[77] As an alternative, Vernadsky abstracted the model of gaseous diffusion and turned it into a general archetype of biogeochemical movement. "The diffusion of life is a sign of internal energy . . . and is analogous to the diffusion of a gas."[78] Living matter spreads like a gas thanks to its ability to grow by multiplication. In fact, multiplication was precisely the key feature for Vernadsky that distinguished living from inert matter. He described both processes of diffusion, gas, and living matter in the same terms as fluidly overcoming obstacles and producing pressure in the surrounding environment:

The dimensions of the planet also impose limitations. The surfaces of small ponds are often covered by floating, green vegetation, commonly duckweed (various species of Lemna) in our latitudes. Duckweed may cover the surface in such a closely packed fashion that the leaves of the small plants touch each other. Multiplication is hindered by lack of space, and can resume only when empty places are made on the water surface by external disturbances. The maximum number of duckweed plants on the water surface is obviously determined by their size, and once this maximum is reached, multiplication stops. A dynamic equilibrium, not unlike the evaporation of water from its surface, is established. The tension of water vapor and the pressure of life are analogous.[79]

In this universe of life and numbers, he also described a "speed of transmission of vital energy,"[80] which was meant to estimate, numerically, the intensity of the reproduction of the living surface in a specific place.[81] Mimicking what physicists had done with the kinetic theory of gases—the statistical approach to gases and their thermodynamics—he even defined the "internal energy" of this spreading and calculated it as the sum of "the separate energetic movements of its component particles."[82] The spreading of the surface of the animate layer was modeled as if it had acquired the characteristics of a gaseous substance. Vernadsky transferred the statistically measured architecture of the gaseous envelope to the behavior of life at the scale of the biosphere. That is, the living was not reduced to the physical so much as it was transported by it. Broadcast as a gaseous signal, it enveloped the globe and exerted pressure on its obstacles. And beyond that, it could be appraised by calculation. Even in the material world, numbers provided the backbone for how growth, reproduction, distribution, and other forces could be described without losing any sense of their vitality as active dynamics of planetary scale "terraforming."

A CHEMICAL RECOATING

The world was anyway radically geoengineered around the early twentieth century. Chemical industries recoated so-called natural surfaces, adding a further twist to the notions of geospheres that had been circulating for some decades. As Esther Leslie shows in *Synthetic Worlds*, the chemical industry founded an empire of analogs and replacements.[83] Manufactured materials as varied as aniline-based colors, plastics, celluloid, surface coatings, and synthetic oils took the place of organic originals such as natural pigments, ivory, or bones. Vernadsky was aware of this change, as he reflected in the mid-1940s: "Chemically, the face of our planet, the biosphere, is being sharply changed by man, consciously, and even more so, unconsciously. The aerial envelope of the land as well as all its natural waters are changed both physically and chemically by man."[84] His work on the "movement of life" inevitably connects *The Biosphere* to the parallel chemical gasification of agriculture brought about by corporations. For the sake of periodization, let us note that *The Biosphere* was published the same year IG Farben was founded, the infamous cartel that gathered the biggest German chemical corporations of the moment, including BASF, AGFA, and Bayer.

Crop dusters and other fogging techniques were not yet present in everyday agriculture in the early twentieth century, except for some early experiments during the 1920s in the United States. The Haber-Bosch process that synthesized ammonia as a fertilizer had, however, already been developed and introduced on an industrial scale in 1913. Since the mid-nineteenth century, following an agricultural crisis due to the depletion of soils by intensive practices, there was full awareness that the fixation of nitrogen was essential for the growth of plants.[85] Nitrogen could be extracted from the vast deposits of guano in South America and added as manure to fields. This improved the yields considerably, and it also fueled the development of "the new agricultural chemistry" initiated by the German chemist Justus von Liebig.[86] As nitrogen is the most abundant gas in the atmosphere, many attempts to extract it directly from the open air followed. These were, however, unsuccessful. The situation changed in the first decade of the twentieth century with the development of a process by Fritz Haber and Carl Bosch. Nitrogen-based fertilizers could be produced in factories. As a result, the use of synthetically fixed nitrogen spread immediately after its commercialization. Furthermore, it could be used in the production of explosives as well as in chemical warfare.[87]

Since the early twentieth century, the air has been artificially circuited to the soils of the planet in the form of synthetic nitrogen. The

Haber-Bosch process becomes then part of the recursive operations that link synthetic chemistry with the redefinition of growth and agricultural lands and, in the process, trigger large-scale repercussions for a variety of issues from geopolitics to climate change. As a matter of fact, after the Second World War, the growth of the use of these fertilizers was exponential; they even forced researchers to look for high-yielding varieties of crops, since the standard ones could not absorb the extra nutrients. Water consumption increased, and large-scale irrigation infrastructures were needed, together with different types of pesticides and their related techniques of fogging. Over several decades, this was marketed as the "Green Revolution,"[88] which refers to the ensemble of technoscientific developments, patents, management, and communication strategies that led to the planetary-scaled spread of industrial agriculture. The scale is huge: as chemist Paul J. Crutzen put it in his oft-cited paper on the Anthropocene, "more nitrogen fertilizer is applied in agriculture than is fixed naturally in all terrestrial ecosystems."[89]

To read Vernadsky's living matter in relation to industrial agriculture highlights a material and epistemic context that goes beyond plant physiology and other life sciences. It brings up a chemical background of operations that, interestingly, did not solely exist in the agricultural domain but also permeated the production of images. The planetary, as understood in this chapter and the book, started to include this mode of transformation of soil and surfaces as it was also connected to an entangled sphere of images. New chemical production was driving both kinds of surfaces. Photography, in particular, experienced a revolution thanks to the development of new and faster sensitizers.[90] With their aniline dyes, corporations such as Bayer, AGFA, and BASF transferred their industrial mastery of chemical cycles to shortened photographic exposure times and, by doing so, in turn expanded the operational space of photography itself. Measurements and scientific practices rely on chronophotography, for example the experiments discussed in chapter 2. Another clear case involves aerial photography: during the First World War, the new dyes gave rise to specific sensitizers that, as Michelle Henning says, "reshaped photography in response to the demands of aerial reconnaissance."[91] Sensitizers were developed to allow aerial cameras to see through the atmospheric haze. In this way, chemistry sensitized the exhausted soils of agriculture to produce faster developments of photosynthetic matter and increased the rate and range of images produced by photographic surfaces. Chemistry refashioned all the world's surfaces anew: photographic plates, soils, and, as demonstrated, vegetable surfaces, including agricultural ones. All kinds of surfaces emerged as central elements of knowledge and operations: first, planetary-scale life as envelopes of interactions of energy, and second, an experimental set of practices that fed into reforming those surfaces while also fixing new kinds of images to make sense of those surfaces. The recursive features of this operational sphere are both the key focus of our book and the site of epistemic inquiry that pertains to the environmental modes of interaction that have become again central in the past decades of debates, not least about the Anthropocene.

In Vernadsky's biosphere, as in Priestley's jar, a shell of inert matter encloses the living surface: gases above, rocks below. The photosynthesis of the green component of living matter requires a gaseous background to absorb and secrete its chemical sources and wastes. In Vernadsky's words, the movement of life can occur "only through a gaseous exchange between the moving matter and the medium in which it moves."[92] One could think of inert matter as a sort of infrastructure of the living, echoing Paul N. Edwards's words about nature as "the ultimate infrastructure."[93] The inert, however, needs to be understood as being adapted, transformed, and shaped by the living surface it hosts, problematizing any final difference between the two. (Furthermore, in the light of more recent developments in material sciences, Anthropocene research, and humanities—for example, in new materialism—it is impossible to claim that matter is just bluntly *inert*). This was, after all, one of the key points developed in this take on the planetary scale of biogeochemistry. In Vernadsky's words, "The organism deals with the medium to which it is not only adapted but which is adapted to it."[94] Like the plant that oxygenates the glass jar in Priestley's experiment discussed in chapter 1, living matter is, in Vernadsky's model, a "medium-forming" force[95] and requires an environment while it contributes to shaping and maintaining itself.[96] Matter is fundamentally reflexive in this material sense.

Even before *The Biosphere*, Vernadsky had perceived the soil surface as a fundamental scalar media of biochemical forces. Soil might be located physically as a thin layer on earth, but it was a biospheric force greater than its location, as it "wholly matches the huge active energy that is accumulated in soil's living matter and that is capable of transfer by soil penetrating gases."[97] This "medium" of negotiating scales concerned not merely the different spatiotemporal perspectives but a multitude of forces operating on living surfaces. As a model of planetarity, then, it presented a way to appreciate the patchwork of surfaces as reflexive, recursive operations that include multiple scales encoded onto a surface. Furthermore, it was also one variation on the discourse of "the green mantle" that Veronica della Dora skillfully tracks as an art historical and geographical theme. While the nineteenth- and early twentieth-century notions of green mantle found in Thoreau, Muir, and some botanical works "all express an understanding of nature as 'wilderness,' for example, as special areas to be protected by enclosing them within the sacred precincts of natural reserves and parks,"[98] here we have a multicolored and multiscalar patchwork in operation that is defined by biochemically created zones: a mantle, a texture, a cloth that connects across differences from changing ecozones to biomes, biotopes, and more. It represents a continuity in difference. The green mantle had its own version in earlier Russian soil science, too, some of which also included a strong nationalist element even while incorporating the global and the planetary as its reference points. Vasily Dokuchaev, the influential figure in Vernadsky's instruction whom we mentioned above, had referred to the soil as a *global natural object* that on the earth's surface was divided into "soil zones which blanket the entire globe, both the northern and southern hemispheres."[99] Dokuchaev described the earth as "multicolored ribbons of soil," where the color coding not only referred to different amounts of heat and light but also included a racialized reference to changes in human and animal (pigment) surfaces, "from white to grey, black, chestnut and copper-red."[100] With hints of Russian mysticism and nationalist undertones of (superior) soil, Dokuchaev's pedology functions as geopolitically tuned scalar media inscribed on the soil.[101] While soil mapping and coding became thus one form of articulating the reach of the empire and its reliance on logistics of food security that became a crucial issue after the 1891 famine, it was also an articulation of symbolic differences in terms of imaginaries of nation-states and empires: as a matter of fact, Dokuchaev observed the mistaken attempts to apply German agricultural methods to Russian soil while sketching out a proposal how to see these soil zones forming out of cosmic and planetary processes. According to Dokuchaev, the zones were defined by interactive processes between living and inert matter from water, air, and earth to plants and animals as *soil-formers*.[102]

Rather than a model of biological matter built on the resources of the inert, Vernadsky's *The Biosphere* can be read as the production of a synthetic layer of tools and conceptualizations that account for the mediating role of the planetary scale as it folds recursively onto surfaces and terrestrial systems. The planetary becomes not merely about the spatial scale of the planet but about the interlocking dynamics that fold the planetary in different materials, surfaces, and processes. Vernadsky's biosphere is about the transfer of scales and scalar logic, out of which the living and the inert dimensions of matter are imagined and brought back to the planet's surface. Usually, these themes of techniques of planetary scale are read through Vernadsky's idea of the noosphere. Still, as we have argued in this chapter, the environmental and political stakes were evident decades earlier than the actual emergence of the term.[103]

"Environments, like media," writes John D. Peters, "are delicate systems of contingent conditions for the organisms that live in them."[104] They constrain and modulate the forms of life they enable, and they are recursively transformed and even constructed in the process of that modulation. For example, the ozone layer is an interesting case in relation to the double bind between living and inert matter that characterizes Vernadsky's biosphere. It shows that inert matter can take a role as the infrastructure of the living, and at the same time, it shows how the living can be taken as the infrastructure of the dynamics of circulation and regulation of the (seemingly) inert shells of matter on the planet. Living and inert matter are interweaved so that, for Vernadsky, it is not even possible to state which came first. In other words, despite his insistence on differentiating inert from living matter, none of these two systems in *The Biosphere* is privileged,[105] substantiating what Bruno Latour has emphasized in relation to the Gaia model. There is no prominence, priority, or internal hierarchy among the systems in interaction.[106]

Throughout this chapter, we have argued that *The Biosphere* can be read in terms of surface tension between the organic and the nonorganic that is resolved in the gaseous model of living matter. Different dynamics of the circulation of matter—a logistical imaginary of planetary life—become the central driving engine in this model that also works with questions of light and energy. The model is linked to the parallel spread of the chemical industries, which also proposed a gaseous form of agriculture. New clouds started to appear at the back of the infamous industrial smoke clouds captured in Ruskin's poetic words in the nineteenth century.[107] Some decades later, new clouds were also related to new kinds of practices of growth, as well as extermination of life, both human and plant. What is more, this gaseous model of planetary transformation—chemical media or cultural techniques of chemistry—can be related to the visual technologies that had mediated, in the first place, the observation of plant growth. In particular, we have emphasized the infrastructural role of industrial chemical media in the photographic surfaces that allowed the advancement of the operational and measuring techniques of the cameraless experiments addressed in chapter 2. One needs the other to establish the other that comes back to support its foundations.

The techniques and infrastructures that constitute agriculture ultimately rely on the morphogenetic adaptability of vegetal life, its industrious persistence, and its preference for cycles. With minimum requirements, plants inevitably grow and spread. Any sort of modification, acceleration, or control is parasitic on this primary process of life.[108] Husbandry is not an activity geared toward making the plant grow—growth emerges within the plant itself—but is instead concerned with removing its obstacles. Doing this sets up a parasitic mode of relation: growth itself is enclosed, wrapped, enveloped, and measured. It is circuited in categories of scientific observation and classification that help to reoperationalize it. Now, it is not the plants anymore but the crops (including plantations) that grow. It is chemical additives that power their growth, and it is not only chemistry but a set of refined media techniques that model plant growth to close the loop between data-chemistry-crops-plants. This characterizes the different cases of hybridization between images and plants that we examine in the following chapters. But now, we have a sense of this scale of planetarity that comes to haunt not only modeling growth, light, energy, and their interaction but also the political issue of scale we referred to earlier with the help of Liboiron: what matters are the relationships bundled up in scalar media, the forces gathered in scalar operations including the focus on the planetary that is produced through specific cultural techniques of surfaces.

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Living Surfaces

Images, Plants, and Environments of Media

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