Baas Becking's Geobiology

Edited by Don E. Canfield

WILEY Blackwell

Baas Becking's: Geobiology

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Or Introduction to Environmental Science

Dr. L. G. M. Baas Becking (1895–1963)
Professor at the University of Leiden

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Editor's Introduction

Lourens G. M. Baas Becking was born on January 4, 1895, in the town of Deventer, the Netherlands.[1] Little is written of Baas Becking's childhood, but early in his career he studied at the Technical University of Delft under the influence of Martinus W. Beyerinck. These were heady times at Delft. In the late 1800s Beyerinck was instrumental in establishing virology as field, and, perhaps of even greater importance, he perfected and applied the enrichment culture technique to understanding the diversity of microbes and microbial metabolisms in nature. Along the way, he discovered both nitrogen fixation and sulfate reduction. Baas Becking, however, did not finish his studies at Delft. Instead, he switched to the University of Utrecht, where he studied botany under the tutelage of Friedrich August Ferdinand Christian Went. His PhD studies included a visit to Stanford, and on his return to Utrecht he delivered his thesis, "Radiation and Vital Phenomena," published as a well-known book that is easily available today from multiple booksellers. After delivering his thesis, Baas Becking returned to Stanford as an assistant professor.

Baas Becking's time in California was of huge importance to his development of the concept of geobiology. He became especially fascinated with saline lakes and the adaptation of organisms to extreme environments. He was a keen observer of nature, unraveling how elements became biologically cycled and how this cycling both responded to and influenced the chemical environment. One can link this approach directly with Baas Becking's early experience at Delft and his exposure to Beyerinck's view of how chemical and physical factors (such as temperature) controlled the distribution of organisms in nature. The coupling of these insights, led to the famous quote "*everything is everywhere*: but *the environment selects*," as developed in Chapter II of this book. Indeed, this sentiment in general, and the interplay between organisms and the chemical environment in particular, provided the foundation for Baas Backing's view of geobiology. Overall, Baas Becking's California experience is well expressed in the pages of this book.

While at Stanford, Baas Becking was appointed director of the Jacques Loeb Marine Laboratory in Pacific Grove, California, but he elected in 1930 to return to Leiden as professor of general botany. He continued his work on the

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[1]In summarizing the history of Baas Becking's life, I have borrowed heavily from: Quispel, A. (1998) Lourens G. M. Baas Becking (1895–1963), Inspirator for many (micro) biologists, *International Microbiology*, 1, 69–72, and Oren, A. (2011) The halophilic world of Lourens Baas Becking. In Ventosa, A. *et al.* eds, *Halophiles and Hypersaline Environments*, Springer-Verlag, Berlin, pp. 9–26.

adaptations of organisms to the environment and summarized his thinking in a series of lectures to the scientific society "Diligentia" in The Hague, and these lectures formed the basis of the present book, *Geobiologie of inleiding tot de milieukunde*, published in 1934.

After returning to Leiden, Baas Becking continued his work on salt environments, on photosynthesis, and on symbiotic associations. His zest for botony, however, remained, and while researching geobiological themes he also oversaw the restoration of the botanical gardens in Leiden. Continuing on this theme, he moved with his family to Java in 1940 to help restore the Botanical Garden of Buitenzorg. He returned to Leiden to deliver his valedictory lecture on April 24, 1940, just before the Nazi invasion of the Netherlands. Unable to travel, he was separated from his family for the next five years. During the occupation he tried twice to escape, was imprisoned, and was nearly executed. In regaining contact with his family after the war, he learned of the tragic death of his son in battle on the Java Sea. Tragedy continued in 1948 with the death of his wife in an auto accident, shortly after he had moved to New Caledonia to take up a post with the newly established South Pacific Commission.

From New Caledonia, Baas Becking moved to Australia, occupying a number of positions before passing away on January 6, 1963. In recognition of his great contribution to Australian science, and to geobiology as a field, the Bureau of Natural Resources opened in 1965 the Baas Becking Geobiological Laboratory. This was, as far as I know, the first dedicated geobiological laboratory in the world. The initial focus of the Baas Becking labs was to explore how biological and chemical processes conspired to form stratiform ore deposits. By the time I learned of research from the Baas Becking Labs, the mission had broadened. When I was doing my PhD, the laboratory was quite famous for its work on modern stromatolites, and how these informed the interpretation of their ancient counterparts.

Sadly, the Baas Becking labs closed down in 1988. Ironically, this was some 10–15 years before geobiology began to emerge as a recognized scientific discipline with dedicated university programs, its own journal, and high exposure in international meetings such as the annual Goldschmidt Conference. Laurens Baas Becking and his legacy institute were well ahead of their time.

The current volume, or in reality collection of essays, elaborates on the geobiology of a wide variety of natural systems. In coining the term *geobiology*, Baas Becking was careful to insist that he was not trying to invent a new field, but rather, he was merely trying to express the relationship between organisms and the Earth. Perhaps this modesty respected earlier contributions of those like Vladimir Vernadsky, and particularly Sergei Vinogradsky, who, each in their own way, shared similar views to Baas Becking. Or perhaps this modesty was part of his character. In any event, these pages reveal a carefully developed consideration of the "geobiology" of organisms. The focus in these pages is largely, but not exclusively, on microorganisms, and one can clearly feel the influence of Beyerinck throughout the essays. Also, in a nod to Vinogradsky, and perhaps a nod away from Vernadsky, Baas Becking is almost exclusively concerned with modern environments. Therefore, the "geo" in Baas Becking's "geobiology" is the geosphere as it reflects a collection of environments, but it only casually considers (in Chapter VI) geologic time and geologic processes. Indeed, Baas Becking's "geobiology" has much in common with modern environmental microbial ecology and could equally be viewed as an instigator of this important field.

The book starts with a general introduction (Chapter I), a rather philosophical discourse on nature and science that ends with Baas Becking's definition of geobiology. In Chapter II, on the environment, he explores the metabolic diversity of life, as it was known then, and develops, with heavy inspiration from Beyerinck, the concept of "*everything is everywhere*..." as discussed above. Light is the focus of Chapter III, where Baas Becking explores how the availability of light impacts photosynthetic organisms in nature, a subject of particular interest to him given his background as a botanist. Indeed, in this chapter, Baas Becking makes some remarkable conjectures as to how photosynthetic organisms, like anoxygenic phototrophs for example, are well adapted to the spectra of light available to them. Chapter IV discusses temperature as it influences the physical environment, but of most interest (to me anyway) is Baas Becking's exploration of how organisms are adapted to the temperature of their environment. This chapter clearly demonstrates the author's interest in how organisms adapt to extreme environments. Chapter V then examines the chemical environment, with topics ranging from gases, to pH and how it is controlled, to the limiting constituents of life. What is inspiring here is Baas Becking's continued exploration of how organisms both respond to and control the chemical environment. Chapter VI considers element "cycles," and provides a remarkable integration of available knowledge (some of it just emerging at the time) to draw now iconic cartoon visualizations of the carbon, nitrogen, and sulfur cycles. It is both humbling and inspiring to appreciate how much Baas Becking knew about the biological control of element cycling.

These first chapters, in sum, could be viewed as the book's introduction. The following chapters explore diverse environments, including oligotrophic waters (Chapter VII), eutrophic fresh water (Chapter VIII), the oceans (Chapter IX), and brine (Chapter X). Each of these offers fascinating insights into the relationship between organisms and the environment, with, in many cases, observations from his own work and the work of his immediate colleagues. It is clear that, of these, "brine" was Baas Becking's favorite topic, with this chapter by far the longest and most comprehensive in the book.

Overall, Baas Becking provides us with a wonderful series of essays clearly establishing geobiology as a new integrated way to view organisms in their various natural environments. It is a pity that these essays, with their key insights, have been so long unavailable to other than the Dutch-speaking world. This, however, has changed with this new translated volume. Therefore, I wish first to thank Deborah Sherwood and Mishka Stuip for their expert translation of Baas Becking's *Geobiologie* into English. These two translators took a strong personal interest in producing the best and most accurate translation possible. They have also tried, as far as they could, to preserve Baas

Becking's original language, which was quite "old fashioned" and sometimes difficult to follow. My job was to check the translations for meaning, and the language for "flow" (within reason, given the primary objective to preserve Baas Becking's voice). I have also added some footnotes offering expansions and clarifications of Baas Becking's text, and each chapter is finished with "editor's notes" where I try to summarize the high points of the chapter and to put them into a modern context. Ultimately, any inconsistencies in style in the text and inaccuracies in meaning are my responsibility alone.

I would further like to thank Peter Westbrook for finding these two talented translators and for his great encouragement of this project. I wish to thank the Baas Becking family for permission to produce this translation and for general encouragement. I also wish to thank Ian Francis of Wiley for his encouragement and patience and the drafts people at Wiley-Blackwell for their excellent reproductions of Baas Becking's original figures. The translations were financed by the Royal Netherlands Academy of Arts and Sciences and the Agouron Institute, where I would particularly like to thank John Abelson for his enthusiasm for this project and for his general service to geobiology as a field. I would also like to thank the Danish National Research Foundation and the European Research Council (ERC)for support, and Aharon Oren for help with historical facts regarding Baas Becking's life. Finally, it has been a privilege to be involved in this project and to be the first non-Dutch-speaker to read these priceless words.

Don E. Canfield
Odense, Denmark

CHAPTER I
Introduction

The natural environment is something completely different to the observant enthusiast – Jules Renard's *chasseur d'images*[1] – than it is to the researcher attempting to discover the order and patterns of various life forms in a laboratory. The former, the field biologist, views nature as an enormous, composite work of art. This manner of regarding nature is wholly satisfactory, so long as one is concerned only with "what." One can name the organisms he sees and, led in part by intuition, one can likewise appreciate systems of organisms: communities of life forms that are often associated with a certain type of landscape (heath, dune, etc.). One can distinguish these communities even further and note the propagation of certain organisms (for example, the spread of cross-leaved heath in a field of heather).

However, in addition to the question of "what," human beings also ask the questions of "how" and "why" (53),[2] because the "what" – necessary as it may be – leads only to cataloging inventories, and by simply naming the parts one can never learn to understand the whole.

One can attempt to answer the question of "how," the second step toward understanding the natural world around us, without experimental tools. Yet in doing so, one encounters great difficulties. Both the external surroundings and the internal properties of organisms, which make possible the existence of large natural systems, often resist even the simplest attempts to analyze them. In order to study organisms, one must first study their environment. This can only be done in a place where the environment can be controlled, namely in a laboratory. Thus, under certain circumstances, an analysis is made of the relation between certain organisms and the controlled laboratory environment. Such an environment can be *homogeneous*, i.e., the external conditions in the experimental space either remain constant or change continually. When carrying out such an analysis in the field, one stumbles upon larger, in most

[1]Jules Renard (1864–1910) was a highly influential French author and keen observer of the natural world.
[2]Numbers placed between parentheses refer to the References at the end of this book.

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cases even insurmountable, difficulties. First of all, the external conditions are variable. Anyone who has recorded the intensity of sunlight in measurements separated by several minutes is aware of this. The same is true for temperature and many other factors. Furthermore, these circumstances are *heterogeneous*, meaning that they differ in space. Places separated from each other by only a few decimeters can have entirely different climates. This phenomenon is known as "microclimate." For example, humus-rich soil is often acidic, yet fragments of shells, etc., can make the soil locally alkaline, such that the acidity level differs from centimeter to centimeter. Such measurements, when conducted in the field, show us the hopelessness of reaching a binding analysis, but can nonetheless be useful in certain cases when they delimit the boundaries of biological possibilities.

However, in all scientific observations it is important to be aware of variability (over time) and heterogeneity (in space).

While the field biologist speaks of "tamed creatures" in the laboratory and complains that laboratory methods are "unnatural," the experimenter has just as much right to reproach the field biologist for his apparent certainty gained by attempting to measure that which cannot be measured.

This contrast is not always as sharp as presented here, however, because whereas the immeasurability of various factors in certain environments (soil and atmosphere) is undeniable, this difficulty is not present – at least to the same extent – in other environments (particularly water).

An aqueous environment – be it bog, lake, or ocean – is certainly variable, but it is nonetheless much more homogeneous than other environments. Aquatic field biology is, perhaps for this reason, also much further developed than terrestrial field biology, and the biology of both fresh water (limnology) and salt water have long been sciences in which the question of "how" has often been answerable. Yet even here, the laboratory experiment must inspire.

The highest question a person can ask is "why." We ask this question in relation to the natural world around us in order to understand the appearance and behavior of organisms. This "why" is always causal and never goal-oriented.[3]

No matter how one analyzes vital functions in the laboratory, the organism is part of the Earth and its lot is interwoven with that of the Earth. Once again, in this context we must think of the enthusiast, he who opts for the out-of-doors. He is an "image seeker" and has perhaps been so since he was a boy. Later, in the laboratory, he becomes acquainted with experiments. Let him now return with confidence to the wilderness. Though aware of his limits and no longer so unbiased, he can test his knowledge on this natural environment. The Earth "as it is" remains the most important testing ground for our understanding of biology.

[3]Baas Becking seems to be warning of the difference between hypothesis testing and hypothesis proving.

This discourse is an attempt to describe the relationship between organisms and the Earth. The name "geobiology" simply expresses this relationship. This new word does not attempt to describe a new field. It rather tries to unite phenomena that have thus far been known to the different areas of biology as much as possible under *one* viewpoint.

I would like to thank the Board of the Diligentia Society, and particularly Dr. A. Schierbeek, for this opportunity they have offered me to organize my thoughts on this subject.

EDITOR'S NOTES

In this Introduction, Baas Becking highlights his view of the "geobiological" approach. He distinguishes between the field biologist (or naturalist) who is informed by observable biodiversity and patterns of species distribution, and the experimental biologist who puts the metabolic function of organisms into the context of laboratory controlled variations in environmental parameters. Finally, he argues that real insights ("how" and "why") come from combining these approaches so that the field biologist is informed by controlled and directed experiments on organismal metabolism and adaptation. This combined approach, which seeks to understand "the relationship between organisms and the Earth," is defined as "geobiology" by Baas Becking and bears much in common with the modern view. Baas Becking was modest in offering this definition and was quite specific that this definition "does not attempt to describe a new field." Little could he know that some 75 years later his "geobiology" is a thriving discipline of its own!

Baas Becking also highlights in this chapter the difficulty of placing an organism within an exact chemical and physical context in nature, particularly in terrestrial systems where chemical and physical gradients are large and "climates," as he calls them, are highly variable. Although our ability to determine small-scale variations in chemical and physical parameters (such as temperature, moisture, or oxygen) has advanced greatly since Baas Becking's time, understanding how organisms as individuals, or individual populations, interface with the chemical and physical environment remains a great challenge. For example, while we can measure in various ways the respiration rate of a terrestrial soil or a marine sediment, we still have a poor understanding of how individual members of the population contribute to this respiration. Part of the problem is that even now, we have difficulties in defining the true diversity of populations in nature, particularly microbial populations, and even for those members we can identify, we have difficulties in understanding their level of activity. This understanding, however, is beginning to expand with new approaches in molecular biology, including metagenomic sequencing for population diversity estimates as well as transcriptomic and proteomic approaches for elucidating the activity levels of individual populations in mixed microbial communities.

CHAPTER II
The Environment

Ein kleiner Ring
Begrenzt unser Leben.
Goethe

Imagine an ancient gate. Upon each column rests a sandstone ball, covered by a thin green layer of algae. In a hollow at the top lies a small pool of water, teeming with infusoria.[1] Now imagine a ball enlarged several million times: an enormous stone ball, the Earth, likewise with a thin green layer and a shallow pool, teeming with life. The Viennese geologist Suess named this layer the *biosphere*.[2] It is here, where atmosphere and lithosphere meet, that the highest known organizational form of matter has developed, closely related to – and in a certain sense the counterpart of – the Earth. It is the Earth itself, in its highest expression. This discourse is about this life, of and by the Earth.[3]

One cannot predict *a priori* the properties of molecules based on the properties of their atoms. This higher level of complexity brings with it new properties; the coordinated units together form a higher unit which has new properties. Nor can one predict the properties of the living state of matter based on its molecular configuration; life is a new property. But we can, *a posteriori*, test the properties of living matter against the conditions of its counterpart, inanimate nature: the counterpart, as the nest is to a bird, or as one shell to the other. Life without "counterlife" is unimaginable. This counterlife is the total

[1]This refers to all manner of small aquatic creatures, including ciliates, algae, bacteria, etc.
[2]Eduard Suess stated: "life is limited to a determined zone at the surface of the lithosphere. The plant, whose deep roots plunge into the soil to feed, and which at the same time rises into the air to breathe, is a good illustration of organic life in the region of interaction between the upper sphere and the lithosphere, and on the surface of continents it is possible to single out an independent biosphere." Suess, E. (1885–1908) *Das Antlitz der Erde*, F.Tempsky, Vienna.
[3]This expresses the concept of life as a geological force, as also eloquently described by Vladimir Vernadsky some eight years earlier in *Biosfera* [*The Biosphere*] (Vernadsky, V., 1926, Nauka, Leningrad). Baas Becking was apparently unaware of this, although he cited Vernadsky's *La Géochimie* from 1924 (120).

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