Introduction

I Gaia: An Overview

At the outset it is necessary to describe what the Gaia hypothesis is. The best and most appropriate way to accomplish that task, we believe, is to do it in the words of its progenitors, James Lovelock and Lynn Margulis. Each presented a paper at the first session of the Chapman Conference, and their papers are the first to appear in the introductory section. At the San Diego meeting, presentation of their Gaian perspective was followed by a Darwinian critique by Paul R. Ehrlich of Stanford University. His very different view of the coevolution of organic and inorganic processes provides a strong counterpoint to Gaian philosophy, and it focuses the debate that took place at the meeting and subsequently. Ehrlich's paper is followed by a general article describing a number of potential processes in which biogenic influences relevant to the Gaia hypothesis could manifest themselves.

II Philosophical Foundations of Gaia

It is most unusual for physical or biological scientists to have philosophers of science at their meetings, let alone to have an entire evening session devoted to epistemology. Yet this session proved to be one of the most intense and stimulating intellectual evenings we have ever attended at a scientific forum. Largely divergent views were aired, by James Kirchner, a philosopher and physicist at the Energy and Resources Group at the University of California at Berkeley, and by David Abram, a philosopher from State University of New York at Stony Brook. Kirchner cited the historical evolution of Margulis' and Lovelock's thoughts on Gaia, categorizing not one but five hypotheses, from weak to strong, critiquing some as already known and challenging others as either untestable or extreme. He concludes that the most radical version of Gaia (i.e., the theory that the planet is capable of self-control) is more likely a metaphor than a hypothesis. Abram, on the other hand, challenges most biogeophysical science as "mechanical" and suggests that the Gaia hypothesis represents an "organic" alternative. To be frank, Abram's paper was controversial in the review process. We asked him to shorten and sharpen the piece, which he did, but not to the satisfaction of all the reviewers. We believe the reader, rather than the reviewers or editors, should decide on the merit of his arguments, particularly given the controversial nature of his views. John Visvader introduces the philosophical debate with a historical commentary on Gaia on the context of epistemological scholarship. We are indebted to David Hawkins for helping to organize and run the session and for helping to translate some of the philosophical language into familiar terms that natural scientists could more easily digest.

III Theoretical Foundations of Gaia

What are the properties of Gaia and how do they fit in with other well-established principles of natural science? The papers in the section on theoretical foundations of the Gaia hypothesis address this knotty, central arena for disagreement. The players may have different opinions about Gaia, but all are sizing her up next to the Procrustean bed of science-as-we-know-it. How well does she fit . . . and how many toes have to be severed to make the necessary adjustments?

Chapters in this part explain ecological and climate fundamentals, devise several tests for possible Gaian processes, and explore the realm of hypothetical climate-life feedbacks on make-believe planets.

IV Mechanisms: Sulfur

In the mid-1980s, James Lovelock visited the University of Washington in Seattle and met with an interdisciplinary team of scientists, including cloud microphysical chemist Robert Charlson, sulfur cycle biogeochemist Meinrat Andreae, and climate theorist Stephen Warren. Together they conceived a potential biogenic feedback process whereby dimethylsulfide produced in some phytoplankton escapes into the oceans and eventually is chemically transformed into atmospheric sulfur dioxide. Sulfur dioxide then is later chemically converted to sulfuric acid droplets that can serve as cloud condensation nuclei in the sparsely polluted oceanic regions of the Earth. Such nuclei can multiply substantially the number of droplets in a cloud, which in turn increases the reflectivity of the cloud, in ways that could affect the climate. It had been suggested in 1983 by Glenn Shaw that the Gaian mechanisms might operate through the Earth's sulfur cycle by involving biologically produced particles of sulfuric acid. Shaw was hesitant to extend this suggestion to cloud-climate modulation because of the complex nonlinear connectivity that exists between the acid droplets and the cloud properties, a topic summarized in his chapter. Charlson, on the other hand, discusses the cloud nuclei component. Ken Caldeira of New York University discusses evolutionary aspects of planktonic dimethyl sulfide production, and Meinrat Andreae reviews the global sulfur cycle in this context. This area of research, which involves substantial possibilities for hypothesis testing and experimental validation, has evolved substantially since the 1988 San Diego meeting, and these papers recount that debate in the light of what is known as of the end of 1990.

V Mechanisms: Oxygen

One of the critical gases under the control of life is oxygen. The production of oxygen by photosynthesizing organisms is unquestioned among earth scientists, but what happens to that oxygen once emitted depends on inorganic processes such as weathering and other chemical transformations, as well as oceanic and atmospheric circulation and temperatures. Fires, if they transform organic matter to charcoal, a relatively inert form of carbon, can increase oxygen by burying carbon. Robert Berner of Yale University and Heinrich Holland of Harvard, in particular, discuss not only oxygen but the biogeochemical processes and methods that are used for carbon cycle analysis as well.

VI Mechanisms: Carbon and Biomass

On a world of carbon-based life forms, where else to look for Gaian mechanisms than carbon itself? This most ubiquitous and massive of biogeochemical cycles has countless subcycles turning at vastly different rates through the ages. If you do geology, you see the big slow cycles of mountains and oceans. If you do biology, you see the little, fast cycles of a microbe, a plant, or a whole population. Meeting participants bravely tried to drop their own cherished disciplinary blinders and see this massive cycle as others see it.

The chapters in this section span the geological timeline from the early history of our planet and life, 3.5 to 4 billion years ago, to the thousands-of-year timescales of glacial intervals. In addition, several contributors consider the relationship of carbon to biomass and biological evolution, certainly carbon's most elegant and complex manifestation.

VII Other Mechanisms

Gaian principles can extend not only to the dominant biogeochemical cycles, the Big Three already discussed, but also to any other material and energy cycling processes on Earth. The section on other mechanisms offers a sampler of how Gaian processes may or may not involve trace gases, silica in the oceans, humus and biomineralization, weathering, fire, and even the cell walls of plants!

VIII Gaia, Catastrophes, and Other Planets

If Gaia works on Earth during the general course of evolution, what happens when something disrupts business-as-usual wandering asteroids or comet nuclei, for instance? Just how robust is a Gaian system to outside perturbation from astronomical forces and what would it take to overwhelm it?

If Gaia works on Earth, is it a one-shot success story, or can Gaian principles be generalized to other planets in our Solar System or other planets in the Galaxy? To be truly generalizable, Gaian principles would have to be shown to be naturally emerging properties of planetary biological systems in the same way that we imagine (but have no current evidence for) life to be a naturally emerging property of matter in the universe. The chapters in the section on Gaia, catastrophes, and other planets deal with these intriguing, logical, but far-flung ramifications of the Gaia hypothesis.

IX Political Implications

Part of the controversy associated with the Gaia hypothesis in the early 1970s was that some people argued that if biological homeostasis were a reality, then human pollution might be offset by a controlling biota. However, as the chapters in this volume amply demonstrate, not only is it premature to judge the extent to which biological homeostasis has been validated, it also appears that many of the processes by which such feedback might exist take place in geological timescales. Clearly, the rate at which civilization is modifying the atmosphere and environmental landscape is so rapid relative to many of these processes that substantial global change will probably occur during the twenty-first century. Although understanding in quantitative terms the extent to which biological, physical, or chemical processes might damp or enhance the effect of any human disturbance to the environment is the goal of global change research, we believe it will be decades at least before such quantitative knowledge is at hand. Therefore, whether to risk radically modifying the Earth in pursuit of human goals is not a scientific question per se; rather, it is a fundamental political value choice that weighs the immediate benefits of population or economic growth versus the potential environmental or societal risk of a rapidly altered Earth. As Congressman George Brown's article, delivered and edited by Anthony Scoville, amply demonstrates, that choice is both risky and one that is increasingly weighing on the minds of decision makers as the buildup of greenhouse gases, deforested lands, and other environmental disturbances continues with the waning of the twentieth century.

Penelope J. Boston — Stephen H. Schneider