Chapter 1

GAIA, THE GRAND IDEA

This first chapter introduces the Gaia hypothesis and two competing hypotheses.

1.1. A Brief History

Gaia, the idea that life moderates the global environment to make it more favorable for life, was first introduced in 1972 in an academic paper titled "Gaia as Seen through the Atmosphere" in the journal *Atmospheric Environment*, followed rapidly by two other papers both in 1974: "Atmospheric Homeostasis by and for the Biosphere" in the journal *Tellus*, and "Biological Modulation of the Earth's Atmosphere" in the journal *Icarus*.[1] James Lovelock was sole author of the first paper and coauthor with Lynn Margulis of the latter two. Both were already scientists of some note. Lovelock had already pursued a successful career inventing chemical instruments, including, most famously, the electron capture detector. This device, when coupled to a gas chromatograph, allows for the detection of trace chemical substances even at extremely low concentrations. Before that, Lovelock had worked for twenty years at the United Kingdom's National Institute for Medical Research in Mill Hill, London, carrying out research in biomedical science.

Use of the electron capture detector started to become widespread due to its great utility, and through his consultancy work with it Lovelock was invited to participate in a NASA project to work out how to ascertain if Mars contained life. The two Viking spacecraft, now revered in history as the first spacecraft ever to land on the surface of another planet, were just then being designed, and a major priority was to decide which instruments to put on board. Reflection on this problem of how to detect the presence of life stimulated Lovelock's first thoughts on the Gaia hypothesis.

Lynn Margulis was a groundbreaking microbiologist at Boston University. She had long been championing her own (separate) revolutionary idea, one that is now widely accepted. It proposed that in the evolutionary distant past one primitive cell managed to "enslave" another (engulf it without killing it) and in the process benefited from the new capabilities of the enslaved cell. She proposed that such “endosymbiosis” had occurred a number of times. Mitochondria, chloroplasts, and flagella are all part of the machinery of individual cells; they are subcomponents of many single-celled creatures and of individual cells in multicellular organisms. According to the endosymbiosis theory they are all suggested to be relics of long-ago-assimilated single cells.[2] Each cell of every animal and plant, including those making up human bodies, is from this perspective seen as an evolutionary amalgam of several different ancient lineages. This theory, initially treated with some considerable skepticism (an early Margulis paper on it was rejected by as many as fifteen different scientific journals before being accepted), is now the consensus view. Although she was not the first to conceive of the idea, Margulis was the first to support it with direct microbiological observations, and it was in large part thanks to her continued championing of it, against strong opposition, that it came to be widely accepted. It has considerable implications. For example, it requires some modification of the idea that evolution proceeds solely by selection among organisms, each of which is a slightly modified descendant of the previous generation. Among the unicellular microbes at least, evolution has at times created a radically new species in a single jump, as a novel intracellular symbiont has been acquired.

Although Margulis jointly authored some of the early papers and remained a champion of Gaia, the hypothesis has always been first and foremost the brainchild of James Lovelock. Following the Lovelock and Margulis papers and some other papers in academic journals, none of which generated large amounts of interest or attention, Lovelock brought out a book called *Gaia: A New Look at Life on Earth*.[3] When this book came out, in 1979, it brought Gaia to scientific prominence at last. The book stimulated a mixture of admiration and opposition among scientists. Many evolutionary biologists, in particular, were very critical, for reasons that will be explained in the next chapter. Some of the biologists’ objections were subsequently countered by modifying the hypothesis and also by the production of a now-famous model, Daisyworld. This model demonstrated the theoretical possibility of stable regulation of planetary temperature by organisms that are still adhering to biologically plausible rules of behavior and reproduction.[4] The Daisyworld paper, by Andrew Watson and James Lovelock, came out in 1983 in the academic journal *Tellus*. In the ensuing years Lovelock produced two more books: *The Ages of Gaia: A Biography of Our Living Earth*, in 1988, and *Gaia: The Practical Science of Planetary Medicine*, in 1991.[5]

In the 1980s the Gaia hypothesis was considered both interesting and controversial and continued to attract a mixture of agreement, interest, doubt, and rejection. By the mid-1980s it was decided that there was sufficient interest to merit organizing an international conference. In 1988 a prestigious Chapman Conference of the American Geophysical Union brought together advocates and interested skeptics in a wide-ranging scientific discussion of the hypothesis.[6] Further international conferences on Gaia were convened at Oxford University in 1994, 1996, and 1999, with membership primarily by invitation. In 2000 a second open Scientists on Gaia Chapman Conference was held in Valencia, Spain.[7]

As Lovelock, now in his nineties, has become less active, others have taken up the torch. Tim Lenton, for instance, an Earth system scientist at the University of Exeter, has written many papers on Gaia, including a review article in *Nature* in 1998.[8] The Gaia hypothesis had achieved a degree of scientific respectability.[9] However, a brief review of its reception in books published since 2007 shows that while it is now accepted gladly by some, it also continues to stimulate intense debate.[10] This was also revealed in back-and-forth exchanges in the pages of the journal *Climatic Change* in 2002 and 2003.[11] Nevertheless, when interviewed for a biography published in 2009, Lovelock claimed that Gaia has made the transition from being just a hypothesis to being solid science.[12]

The degree to which Gaia has been accepted by a large part of the scientific community, including those in its higher echelons, was highlighted by the Amsterdam Declaration on Global Change.[13] This document is a synthesis of the work of four international research umbrella organizations, including the International Geosphere-Biosphere Programme (IGBP) and the World Climate Research Programme (WCRP) and was discussed at a conference attended by more than one thousand scientific delegates. The second paragraph of the declaration asserts: "Research carried out over the past decade under the auspices of the four programmes to address these concerns has shown that: The Earth System behaves as a single, self-regulating system comprised of physical, chemical, biological and human components." The wording could almost have been lifted from one of Lovelock's books. A *Nature* editor, reporting on the second Chapman Conference in 2000, judged that "James Lovelock's theory of the biotic regulation of Earth has now emerged with some respectability following close scrutiny by the biogeochemical community."[14]

Is the scientific respectability and the continuing prominence justified? Read the rest of this book if you want to find out.

1.2. The Hypothesis

The Gaia hypothesis is nothing if not daring and provocative. It proposes planetary regulation by and for the biota, where the "biota" is the collection of all life. It suggests that life has conspired in the regulation of the global environment so as to keep conditions comfortable. During the more than two (probably more than three) billion years that life has existed as a continuous presence on Earth, Lovelock suggests that life has had a hand on the tiller of environmental control. And the intervention of life in the regulation of the planet has been such as to promote stability and keep conditions favorable for life.

That, in a nutshell, is the hypothesis. Providing a more precise definition is, however, made difficult by a couple of factors: (1) the hypothesis has not stayed constant but instead has been modified over time in response to criticisms; and (2) Lovelock's publications do not provide a completely clear definition, although others have tried subsequently to clarify it for him, as described below.

Gaia is not a hard-and-fast, well-defined concept. It is not a "set menu." Rather it is more like a loosely defined smörgåsbord, from which "diners" can take their pick from a collection of several related hypotheses, often couched in rather vague terms. The lack of clarity presents a problem for those of us who want to analyze and evaluate Gaia. It may even seem a poor basis for a book such as this one. However, fortunately, there are central components of Gaia that are fundamental to all definitions, and it is these that I examine in this book. These concepts are at the heart of the hypothesis and are present regardless of which variant is chosen:

A. Earth is a favorable habitat for life.
B. It has been so over geologic time as the environment has remained fairly stable.
C. This is partly due to life's role in shaping the environment. For instance, life has influenced the chemical composition of the atmosphere and the sea.

In Lovelock's own words, the hypothesis has been defined in various different ways over the years:

> We have since defined Gaia as a complex entity involving the Earth's biosphere, atmosphere, oceans and soil; the totality constituting a feedback or cybernetic system which seeks an optimal physical and chemical environment for life on this planet. The maintenance of relatively constant conditions by active control may be conveniently described by the term "homeostasis." (Lovelock 1979)
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> The main part of the book . . . is about a new theory of evolution, one that does not deny Darwin's great vision but adds to it by observing that the evolution of the species of organisms is not independent of the evolution of their material environment. Indeed the species and their environment are tightly coupled and evolve as a single system. What I shall be describing is the evolution of the largest living organism, Gaia. (Lovelock 1988)
>
> The concept that the Earth is actively maintained and regulated by life on its surface. (Ibid.)
>
> Gaia theory predicts that the climate and chemical composition of the Earth are kept in homeostasis for long periods until some internal contradiction or external force causes a jump to a new stable state. (Ibid.)

Gaia is the Earth seen as a single physiological system, an entity that is alive at least to the extent that, like other living organisms, its chemistry and temperature are self-regulated at a state favourable for life. (Lovelock 1991)

The top-down view of the Earth as a single system, one that I call Gaia, is essentially physiological. It is concerned with the working of the whole system, not with the separated parts of a planet divided arbitrarily into the biosphere, the atmosphere, the lithosphere, and the hydrosphere. (Ibid.)

Organisms and their environment evolve as a single, self-regulating system. (Lovelock 2003b)

The hypothesis that living organisms regulate the atmosphere in their own interest. (Ibid.)

By the end of the 1980s there was sufficient evidence, models and mechanisms, to justify a provisional Gaia theory. Briefly, it states that organisms and their material environment evolve as a single coupled system, from which emerges the sustained self-regulation of climate and chemistry at a habitable state for whatever is the current biota. (Ibid.)

In Gaia theory, organisms change their material environment as well as adapt to it. (Ibid.)

And from Tim Lenton:

The Gaia theory proposes that organisms contribute to self-regulating feedback mechanisms that have kept the Earth's surface environment stable and habitable for life. (Lenton 1998)

Some changes have been made to the hypothesis over time. A first correction was to alter the proposed life effect on the environment, from one of making it optimal to one of making it comfortable:

The first edition of this book used the terms optimum and optimize too freely; Gaia does not optimize the environment for life. I should have said that it keeps the environment constant and close to a state comfortable for life. (Lovelock 1979, in the preface to a 1987 revised edition)

A second clarification was to renounce any ascribing of purpose or intent to the biota. It was made clear that any biotic regulation of the environment must be automatic and unconscious. The reason for their impacts on the environment is not because the organisms responsible consciously want to help out their brothers in life:

At first we explained the Gaia hypothesis in words such as "Life, or the biosphere, regulates or maintains the climate and the atmospheric composition at an optimum for itself." This definition was imprecise, it is true; but neither Lynn Margu-

> lis nor I have ever proposed that the planetary regulation is purposeful. (Lovelock 1991)

This topic is returned to in the next chapter.

An attempt to seek greater clarity of definition came from James Kirchner, an Earth scientist at the University of California, Berkeley. The first Scientists on Gaia conference, in 1988, was the first time that large numbers of both proponents and interested skeptics got together in open debate. As might be expected, there were some surprises. One novel contribution was a paper by James Kirchner titled “The Gaia Hypotheses: Are They Testable? Are They Useful?”[15] This paper revealed significant differences between the definitions of Gaia in the various papers and books and attempted to classify them. Kirchner proposed the following taxonomy of hypotheses, on a gradient from weakly to strongly controversial: (1) *influential Gaia*, which asserts only that biology affects the physical and chemical environment to some degree; (2) *coevolutionary Gaia*, which limits itself to stating that the biota and environment are somehow coupled; (3) *homeostatic Gaia*, which emphasizes the stabilizing effect of the biota; (4) *teleological Gaia*, which implies that the biosphere is a contrivance specifically arranged for the benefit of the biota; and (5) *optimizing Gaia*, which suggests that the biosphere is optimized in favor of the biota.

Kirchner’s paper was perhaps unreasonable in one regard, in that the two weakest forms were weaker than adopted in any major Gaian publication. Nevertheless, the paper made a vital contribution by pointing to ambiguities in how Gaia was defined. It was an important influence on thinking at that time. Lovelock later retreated from the two stronger forms of Gaia. Even with regard to homeostatic Gaia, Kirchner called for greater clarity in terms of the definition: “What is stability? Does it mean resistance to change, resilience under change, or bounds on the magnitude of change?” Stability is dealt with in greater detail in chapter 8.

1.3. Supporting Evidence

It is one thing to form a hypothesis, but something else entirely to show that the hypothesis should be taken seriously. Anyone can formulate a hypothesis, in seconds. Demonstrating that it is a true picture of reality is quite another matter. Why should we believe the Gaia hypothesis? What reasons are there to suggest that it corresponds to nature, or, in other words, that it accords with the reality of how the Earth’s environment has been regulated and maintained? In his books and papers, Lovelock has presented a wide variety of evidence. There are three main facts, or classes of facts, that he has advanced in support of the hypothesis. These three assertions are carefully examined in this book:

Assertion No. 1: the environment is very well suited to the organisms that inhabit it.

In the first and subsequent Gaia books, the tolerances of organisms for temperature, pH, salinity, and other environmental parameters were described. The fact that the Earth environment satisfies these tolerances (is habitable) is put forward as strong evidence for Gaia. This assertion is critically analyzed in chapters 3, 4, and 5 of this book.

Assertion No. 2: the Earth's atmosphere is a biological construct whose composition is far from expectations of (abiotic) chemical equilibrium.

Comparison of the atmospheres of Earth and of neighboring lifeless planets (Mars and Venus) shows that the Earth's atmosphere contains an unusually high percentage of oxygen and an unusually low percentage of carbon dioxide (CO_2). The extraordinarily high (21%) proportion of oxygen in Earth's atmosphere persists in spite of high annual production rates of methane (CH_4) and other substances that are highly reactive with oxygen, depleting atmospheric oxygen as they combine with it to form new molecules. The reason that the atmosphere has remained rich in oxygen in the face of ongoing large sinks for oxygen is that it is also continually replenished, by photosynthesis. It is argued that the atmosphere is, therefore, the result of a dynamic equilibrium between different biological fluxes. This assertion is considered in chapter 6.

Assertion No. 3: the Earth has been a stable environment over time, despite variable external forcings.

The Earth has remained habitable for billions of years of geological time and, Lovelock argues, has been rather stable. And this is despite various assaults on planetary regulation that have taken place. Comets and asteroids have hit the Earth, one of which killed the dinosaurs at the end of the Cretaceous around sixty-five million years ago. But after each assault conditions have improved once again and life has eventually recovered from the perturbations. The standard model of how stars change with time strongly suggests that the Sun was ~30% fainter four billion years ago, and has become steadily and progressively brighter (hotter) over time, but the Earth's oceans have not boiled away as a result (this is known as the "faint young Sun paradox"). Lovelock, in tune with the understanding at the time the books were written, suggested that Earth's climate has remained fairly stable over time, and that if anything it has become cooler rather than warmer. The stability of the environment is assessed in chapter 8.

1.4. Alternative Hypotheses

1.4.1. The Geological Hypothesis

The Gaia hypothesis is not the only hypothesis concerning the relationship between life and environment on Earth. At the time that the Gaia hypothesis was first proposed, the dominant paradigm among geologists and others was that the nature of the Earth's environment is principally determined by a mixture of geological forces and astronomical processes.

Geological processes affecting the environment include: (1) changing continental configuration due to plate tectonics (continental drift); (2) variations over time in the rates of volcanic activity, including occasional enormous outpourings of lava (the "flood basalts" such as those making up the Deccan Traps in India and the Siberian Traps in Russia); and (3) fluctuations in mid-ocean ridge spreading rates.

Astronomical processes of relevance to Earth habitability include: (1) changes in solar heating due to increasing luminosity of the Sun over time; (2) periodic changes in Earth's orbit around the Sun, known as Milankovitch cycles; and (3) collisions of extraterrestrial bodies with the Earth.

According to this way of thinking life has been a passenger on Earth, helplessly buffeted around by externally driven changes in the environment. Life adapts to the changing environment but does not itself affect it. Throughout the rest of this book this hypothesis will be referred to as the geological hypothesis.

1.4.2. The Coevolutionary Hypothesis

A second competitor hypothesis to Gaia derives from the ecological/evolutionary concept of coevolution.[16] If you watch even a small proportion of the natural history programs on TV, you cannot fail to be impressed by the precise matches between certain organisms living in close dependence with each other. Take for instance flowers such as *Passiflora mixta* and sword-billed hummingbirds (*Ensifera ensifera*) in high Andean forests. The *Passiflora* hold their nectar at the inner end of long, pendent floral tubes. The length of the tubes makes their nectar almost inaccessible. However, sword-billed hummingbirds can feed from these flowers because they alone in these forests possess sufficiently long beaks—up to 10 centimeters in length, as long as the whole of the rest of their bodies (fig. 1.1). It is agreed that this strange and intricate coupling between the two organisms is a result of the process of coevolution. The plant depends on the bird for pollination, which it brings about by dusting the bird's head with

a

b

Figure 1.1. Coevolved species. (*a*) sword-billed hummingbird (*Ensifera ensifera*) feeding from the long tubes of *Passiflora mixta*, (*b*) cuckoo chick ejecting one of the host's eggs from the nest; a host chick has previously been ejected, as shown at the bottom of the drawing. (*a*) Luis A. Mazariegos H. (*b*) Adapted from an original by David Quinn. In *Cuckoos, Cowbirds, and Other Cheats*, by N.B. Davies. T & AD Poyser, an imprint of Bloomsbury Publishing, Plc (2000).

pollen as it dips its beak into the flower. Therefore if the bird's beak evolves to get longer, so too must the length of the flower, because all short-flower variants will not exchange pollen and so will fail to contribute genes to the next generation. Likewise, the bird depends on the flower for food (nectar), and genetic mutations leading to beaks that are too short and unable to reach the nectar will quickly be culled from the population by natural selection. On the other hand, the bird is not much disadvantaged if its beak is too long, because it is still able to access the nectar. The only stable outcome to the evolutionary interaction between these two species is one in which the bird's beak is exactly the right size for the flower, even if this entails what seems to us to be a ridiculously long beak and flower. It should be said that there are many other codependent pollinators and flowering plants. In all cases there are close-fitting matches between flowers and beaks[17] (in some cases both are curved), but usually involving more economical shorter flowers and beaks.

Coevolution is also apparent in the interactions between predators and prey and between hosts and parasites or diseases. The human immune system, for instance, consists of a wonderfully complex array of systems evolved to combat infection by viruses and bacteria. Our bodies, when infected with an illness, develop specific antibodies that in time can clear us of the disease and prevent reinfection. However, viruses have evolved in turn so as to be better able to penetrate the massed defenses of the immune system. The ability to mutate rapidly into new forms that the antibodies no longer recognize allows the AIDS virus (and, slightly less rapidly, the influenza virus) to overcome human immune systems with such devastating effects.

The phenomenon of coevolution is also apparent in the interactions between cuckoos and their hosts. Birds susceptible to cuckoo deception pay a high price. All their own young (whether eggs or chicks) are mercilessly ejected from the nest by the growing cuckoo chick, which has evolved an appropriately shaped hollow in its back for the purpose (fig.1.1b). Host reproduction is thereby prevented for the season, leading to a strong evolutionary pressure for the host to respond with countermeasures. Recent research shows, intriguingly, that in some cases they do; the hosts are not always unwitting dupes. Many hosts have a first line of defense in that they are able to discern even small differences between their own and parasitic eggs. Cuckoos have responded in turn by evolving eggs that are effectively indistinguishable in appearance from those of their host. Recent research[18] has shown that one potential host, the Australian superb fairy-wren, has developed a second line of defense against those cuckoos that take advantage of it. Whereas hosts are usually rather bad at identifying the interlopers once they have hatched out, even when the interlopers are up to five times the size of bona fide chicks, in this case the fairy-wren has evolved to be able to distinguish its own chicks on the basis of the sound of their begging calls. The arms race has been escalated and taken to a new level. And the next stage? You may have guessed it already: Horsfield's bronze cuckoo chicks now mimic the call of fairy-wren chicks.

Another curious detail of a coevolutionary arms race involving cuckoos, this time concerning the use of identifying patterns on the eggs, will be described in chapter 3. But the main point here is not specific to cuckoos. Coevolutionary arms races of various types are apparent all over the natural world,[19] wherever two species subject to evolution are highly dependent on each other.

Climate scientist Stephen Schneider first proposed, in 1984 with Randi Londer,[20] that this concept of coevolution could be relevant to describing the interaction between climate and life:

> In a sense, climate and life grew up together, each exerting fundamental controlling influences on the other. Climate and life have *coevolved*, to borrow a term developed by population biologists Paul Ehrlich and Peter Raven. (Schneider and Londer 1984)
>
> Over the geologically long term, life contributes to the evolution of the environment, just as the changing environment shapes the formation or sustainability of organisms. . . . Life and climate can be said to have coevolved; their mutual influence is well-established over geological history. (Ibid.)

In contrast to the geological proposal, Schneider and Londer's proposal asserts that life has had an enormous impact on the planetary environment. The reciprocal is obviously true, that changes in the planetary environment have had an enormous impact on life. This coevolutionary hypothesis, unlike the geological hypothesis, assumes a two-way traffic. Not only does the nature of the environment shape the nature of life, but, according to this hypothesis, life also acts as a force that shapes the planetary environment.

There is one obvious difference, however, between the coevolution of climate and life and the coevolution of two life forms. Climate cannot evolve back, in the normal sense of the word. Whereas biological species have been shaped by mutation-prone reproduction followed by natural selection of the resulting variable descendants, climate has not evolved in this way. There is no equivalent cumulative process that builds better-adapted oceans or atmospheres over time. At any one time there is only one atmosphere and so there is no selection between variants. According to Schneider and Londer's coevolutionary hypothesis, the Earth's environment has undoubtedly been affected by the presence of life, and has changed over time, but not under the influence of the optimizing process of evolution by natural selection.

The main difference between the coevolutionary hypothesis and Gaia is that the former makes no claims about the wider outcome of the interaction. Whereas Gaia suggests that the outcome of the interaction has stabilized the planet and kept it favorable for life, coevolution is neutral about any such claims:

> Regardless of whether you believe in a collective biological purpose behind environmental and biological evolution . . . it is a profound realization that the physical, chemical, and biological subcomponents of the earth all interact and, whether by accident or design, mutually alter their collective destiny. (Schneider and Londer 1984)
>
> I saw an apt analogy, in that climate and life have coevolved. In other words, both life and the inorganic environment, including the meteorological elements, have followed evolutionary paths different from what otherwise would have happened over geological time had the other not been there. Coevolution does not require negative any more than positive feedbacks, just mutual interactions. (Schneider 1996)

Coevolution implies only that life and environment have both changed over time, and that changes in either have had effects on the other. There is no imputation that the result of the interaction should be beneficial for life. The coevolution hypothesis is free of any connotations that, once life had evolved and started to influence climate, the planet was bound to remain habitable thereafter.

Table 1.1.
Differences between the three hypotheses compared in this book

	HYPOTHESIS		
	Gaia	Geological	Coevolution
Has the environment played a major role in shaping the biota?	yes	yes	yes
Has the biota played a major role in shaping the environment?	yes	no	yes
Has the role of the biota been generally favorable in terms of keeping the environment comfortable for life?	yes	n/a	no opinion
Once started, was the continuation of life on Earth made more likely by the intervention of the biota?	yes	n/a	no opinion

1.5. Why Should We Care?

A major reason that Gaia has generated such interest, and continues to do so, is that it offers an explanation of how the Earth's climate and environment system works, and of how the Earth has been kept habitable throughout vast stretches of geologic time. Gaia is without doubt big-picture science; it is awe inspiring and majestic in its scope. It proffers answers to deep questions such as "What sort of place is our planet?" "Why has the Earth remained continuously habitable for so long?" "How does our planet work?" "How is a planet kept fit for life?" For all of these reasons it is of considerable interest to probe into whether Gaia is actually a correct or an incorrect view of our world and how it functions.

A second reason for interest does not concern how the Earth has come to be the way it is, but rather concerns how our planet will cope in the future as it continues to be buffeted by human impacts upon it. The last few decades have seen a revolution in our appreciation of the fragility of our planet. Whereas human activities used to be considered trivial (mere "drops in the ocean") in relation to the natural processes of the Earth, we are now rapidly learning otherwise. From the ozone hole to global warming to ocean acidification, our collective capacity to make great changes to our planet is becoming all too apparent. Our ability as a global society to steer a safe course through the next few centuries will depend in large part on our perspicacity in terms of understanding how our planet works and how it will respond to various anthropogenic perturbations.

The sagacity of our collective wisdom about planetary management will be affected by the correctness of our overall paradigm view of how the Earth's climate system works. In the last chapter of this book, I argue that acceptance or rejection of Gaia has the potential to color our view of how the Earth works as a system. In order to be successful stewards of our planet as a life-support system, our understanding of its natural dynamics must be based on a correct overarching view. We will then be better placed to understand how our perturbations will interact with the natural system, and to what degree they will disturb it. For this reason it is of considerable importance to determine whether or not Gaia is an accurate worldview.

1.6. Comparison of Hypotheses

As I review evidence for and against Gaia in the rest of this book, I will also relate it to the other two hypotheses just described. The feasibility of all three hypotheses will be evaluated in relation to the burgeoning knowledge about the Earth system. At the end of this book an assessment is made as to which of the three hypotheses appears to be most compatible with the large classes of facts and bodies of evidence that are introduced through the course of the book. Their explanatory power is compared. The task in this book is therefore not just to evaluate Gaia, but also to compare its performance against that of the other two hypotheses.

This first chapter has set the scene for the rest of the book: the Gaia hypothesis has been described, as have also the major assertions and lines of argument put forward in its support. It has been contrasted with two competing hypotheses. Now, in the following chapters, each assertion and line of reasoning is compared against the available evidence, in particular new evidence unearthed during the last thirty years. Together these chapters go to make up a careful and penetrating evaluation of whether the Gaia hypothesis is supported by current knowledge.