

The Gaia Hypothesis by James Lovelock:
Does This Hypothesis Have Meaning
to the Scientific Community?

An Honors Thesis (Honors 499)

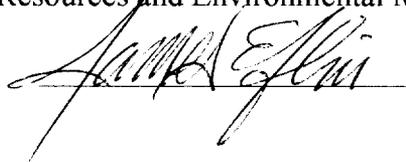
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Abstract

Throughout history, the Earth has been questioned. How did it come into existence? Why is the atmosphere composed of the gases that are found in it? How does one organism, one event, affect the entire planet? When will life cease to exist on this planet?

Studies concerning the natural sciences explore such questions concerning the Earth. Studies such as biology, geology, chemistry, and natural resources and environmental management explore individual characteristics of the Earth's organisms and environment. How do these studies work together in creating an understanding of the Earth?

This paper explores the ideas of a few scientists who have attributed to various ideas dealing with the Earth and its workings. These ideas will have a particular focus on geology and biology with a discussion concerning the Russian scientist Vladimir Vernadsky who proposed the concept of a biosphere. This discussion will be followed by an examination of the Gaia hypothesis, and the evidence that James Lovelock has found to support the contention that the Earth is alive. The evidence involves both the biota and the environment of the Earth. The paper will conclude with support and criticisms that have followed Lovelock's Gaia hypothesis and include additional closing remarks.

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Introduction

The Earth. When people hear these two words, various images come to mind. For some, the Earth is everyone's home, a place that is comforting and hopeful. For some, the Earth is a dangerous land that needs to be conquered if humans are to survive. Yet for many others, the Earth can be associated with life. Life is defined as "the property or quality that distinguishes living organisms from dead organisms and inanimate matter, manifested in functions such as metabolism, growth, response to stimuli, and reproduction" (The American Heritage Dictionary, 1985). Can the Earth itself be considered alive?

This question is one that has been asked by many scientists and nonscientists throughout time. Another curiosity that seems to accompany this question of life is that of the environment. How does the atmosphere, the biota, the water, the land play into the life of the Earth? The Gaia hypothesis is the scientific expression of the Earth as a living creature. James Lovelock, a British chemist, in collaboration with Lynn Margulis, a biologist, view the Earth as a superorganism. The Earth, as this superorganism, has the ability to sustain and regulate itself.

This paper investigates the study of the Earth through evidence and hypotheses formulated by scientists and includes a few philosophical thoughts. Early scientists and their ideas concerning the Earth are examined including the concept of the biosphere by the Russian scientist Vladimir Vernadsky. This discussion is followed by James Lovelock and the Gaia hypothesis and the suggestion that the Earth is alive. The evidence to support this hypothesis includes the biota and the Earth's environment. The paper concludes with support and criticisms concerning the Gaia hypothesis and includes closing remarks on its importance to the scientific community.

Early Scientists and the Earth

Throughout history, individuals have been trying to explain the Earth and the apparent harmony between living beings and their environment. Philosophers of ancient Greece and Rome regarded the Earth as a living, intelligent organism. The Earth was viewed as delicate, and any injuries inflicted by humans would have serious consequences (Visvader, 1991). As time wore on, the Earth began to be studied by early scientists who eventually described the mechanical philosophy. This philosophy of the seventeenth and eighteenth centuries implied that the Earth is a predictable entity, created by an outside source. This allowed for a scientific study of the planet while being accepted by the Church, the dominant social paradigm of the day. This philosophy has been carried into the nineteenth and twentieth centuries by scientists, but changes are occurring. Today, the study of the Earth has become a science that wishes to cooperate with nature and the environment, not to defeat it (Abram, 1991).

Comte Georges Louis Leclerc de Buffon (1707-1788), a French naturalist, argued that the Earth was much older than Biblical text had set forth. In the first volume of *Histoire naturelle*, Buffon described the Earth as a solar fragment of the Sun detached long ago by the impact of a comet. The Earth condensed from this gaseous solar fragment, and its mass, continents, and land structures were created by forces active in the seas and in the atmosphere. Buffon based his history of the Earth's development from evidence he found to be visibly evident in geological sequences, erosion, sedimentation, and volcanic activity within land structures (*Collier's Encyclopedia*, 1996). In addition to this evidence, he considered the rate at which hot bodies of known size and temperature cooled. From such observations, he estimated the Earth to be 78,000 years old and that it would only exist to be 93,000 years old. He viewed nature as a continuum and attempts to divide nature into separate classes were truly misguided (Daintith *et al.*, 1994). Buffon's disagreement with the Biblical idea of the day led the path into viewing the Earth as more than a creation by a single source. Scientists began to look at what the Earth contained and how it came to be.

The German mineralogist and geologist, Abraham Gottlieb Werner (1750-1817), explained the surface of the Earth through the neptunian theory. His theory involved the idea of some unique deluge being the chief agent in producing the Earth's topography. He believed the distribution of rocks and rock formations were laid down in a specific sequence when the flood subsided. When the water had completely disappeared, Werner believed local volcanic activity produced lava and other deposits on the surface. Unfortunately, upon further study, Werner's neptunian theory was found to be applicable only to his area of investigation, the region of European Saxony. James Hutton (1729-1797), a British geologist, questioned the neptunian theory because he saw water as an erosive force. Therefore, it could not account for rock folding and rock intrusions found within the Earth. According to Hutton, the Earth's heat was the productive power that caused sedimentary rocks to fuse together to form granites, cause the folding and twisting of rocks, and create mountains. The theory of uniformitarianism originated by Hutton and established by Charles Lyell (1797-1875), also a British geologist, became the view for modern geology to follow. The theory states that the geological processes that formed the earth's features are still observable in the present time. Essential to the theory is the idea of unlimited time. The natural forces of erosion, sedimentation, and the Earth's own heat work together over time in shaping the Earth's crust. Hutton concluded that on the face of the Earth, there is "no vestige of a beginning, no prospect of an end" (Daintith *et al.*, 1994).

Alexander Humboldt (1769-1859) was a German naturalist who wished to study nature as a whole. He believed laws governed the relationship between historical life and geological structure. He also believed there was a unity between the organic world and the variety and types of landscapes present on the surface of the Earth (*Collier's Encyclopedia*, 1996). After an investigation of American volcanoes, Humboldt concluded there was a tendency for volcanoes to follow geological faults and that volcanic activity played a major role in the development of the Earth's crust. In addition to his geological studies, he introduced the subject of climatology. He also initiated ecological studies concerning the relationship between a region's geography and its flora and fauna (Daintith *et al.*, 1994). Humboldt's ideas concerning nature as a whole and those dealing with relationships in the world soon began to come of interest to others.

During Humboldt's and Thomas Malthus' (1766-1834) days of study, people believed they were progressing towards an ideal society. Malthus was an English economist who studied population ecology. He believed that technological advancement would be accompanied by increases in human population. However, the human population would increase at a much greater rate than the means for existence. This difference, he believed, would result in an overall unimproved human condition and that the population would be controlled by famine, disease, and war. Malthus' ideas influenced Charles Darwin (1809-1882), a British naturalist. Instead of studying human population, however, he studied species and their adaptation to environmental pressure. He studied how environmental pressures, particularly the availability of food, affected the survival of species into subsequent generations. He concluded that those individuals with the most advantageous traits would survive, and the trait could be found in the next generation. If the environment changed, the species at question would adapt over time to the new conditions. Over a long enough period of time, a new species would form, the process of natural selection (Daintith *et al*, 1994).

While Buffon, Werner, and Hutton contributed to studies dealing with the structure of the Earth, Humboldt began an investigation of nature and geology together. Malthus contributed to studies concerning the human population. Other scientists contributed to studies dealing with chemistry, physics, and physiology. In biology, Darwin began the argument that all life descended from a remote ancestor (Margulis and Sagan, 1995). He also understood intuitively that the creatures present in a region shape the physical environment while the physical environment shapes the creatures present (Kelly, 1994). Vladimir Vernadsky (1863-1945) also believed this. He extended Darwin's outlook and believed all life inhabited a "materially unified place" (Margulis and Sagan, 1995). He named this place the biosphere, a term proposed in 1875 by the Austrian geologist, Edward Suess (Ghilarov, 1995).

Vernadsky was a Russian scientist who received little worldwide credit for his view concerning the Earth. The Earth, he believed, was a biosphere. A biosphere is defined as the area of the Earth's crust that contains life. According to Vernadsky, life included rocks, wind, water, plants, and animals as living and sustaining the environment. Life is the chemical force that is acting constantly on the Earth, changing and shaping its existence (Ghilarov, 1995). He viewed life as "temporary chemical storage units for the mass flow of energy around the world" (Kelly, 1994). In this sense, living matter of plants and animals were geological forces. People, in particular, could redistribute and concentrate chemical elements such as oxygen, hydrogen, nitrogen, carbon, sulfur, and phosphorus, the same elements that constitute the Earth's crust. He believed plants and animals were moving minerals. He also believed that humans and technology made up a special thinking layer of the biosphere he called the noosphere. This sphere, he stated, played an integral part in changing the Earth's surface as well (Margulis and Sagan, 1995). This idea enraged biologists. Geologists did not agree with Vernadsky either for he defined rocks, mountains, water, and gases in the atmosphere as being alive. Their gradual interaction with living organisms meant rocks were the slowest part of life. Together, his ideas portrayed life as an ever-renewing mineral with the organism behaving as the environment and the environment behaving as the organism (Kelly, 1995).

Throughout his work, Vernadsky believed there was an order to the structure, function, and evolution of the Earth's biosphere, that life was not an accident (Ghilarov, 1995). He believed that the organisms and environment exhibited a type of self-governance. He also believed the entire system, the planet's environment and the organisms contained within it, were coevolving (Kelly, 1994). Vernadsky claimed that planetary characteristics influenced the rate of natural increase and dispersal of any organism due to a connection between all organisms and the planet. In other words, the finite size of the planet can only support a certain number of organisms (Ghilarov, 1995). Today, it is known that living organisms are largely responsible for the unusual properties of the Earth's atmosphere with nitrogen, oxygen, and carbon dioxide (Margulis and Sagan, 1995). Vernadsky realized this and believed that if life vanished from the Earth, the planet would die. Without life, a "chemical calm" or equilibrium would be established, and the Earth's landscape would retreat. As Vernadsky stated, "without life, the face of the Earth would become as motionless and inert as the face of the moon" (Kelly, 1994).

The Gaia Hypothesis

Fifty years after Vernadsky's proposal of a biosphere, James Lovelock (1919-), a British scientist, in collaboration with Lynn Margulis (1938-), an American biologist, proposed the Gaia hypothesis. The hypothesis began when Lovelock was asked to examine the planets of Mars and Venus for life forms. What he discovered was that the atmospheres of the two planets were in a chemical state of equilibrium. Earth, however, is in a state of disequilibrium. He speculated that the Earth had been transfigured and transformed over its four billion years of existence by a self-evolving and regulating living system (Lovelock, 1979).

In the study of natural sciences, the predominant view in 1970 was that life was a passive entity on the planet. Life could respond to non living forces such as volcanic eruptions, severe storms and droughts, and even drifting continents by changing itself and, to some extent, the surrounding environment and atmosphere. Lovelock wanted to take these ideas a step farther. He wanted to convince the scientific community that the Earth's biota, the collection of living organisms, can effectively and directly manipulate the environment. Through this manipulation, life and the environment (the biota and the biosphere) work together in forming an optimal, homeostatic place to live (Schneider, 1990). Lovelock (1988) writes in *The Ages of Gaia*, "the Gaia hypothesis says that the temperature, oxidation state, acidity, and certain aspects of the rocks and waters are kept constant and that this homeostasis is maintained by active feedback processes operated automatically and unconsciously by the biota." Together, the biosphere, atmosphere, oceans, and life form the living system known as Gaia.

By viewing the Earth and the life it contains as a living system, it has the ability to regulate the temperature, the composition of the Earth's surface, and keep an environment comfortable for living organisms. This self-regulation by the biota is driven by the free energy available from the sun (Lovelock, 1988). Vernadsky's definition of life included rocks, wind, water, and atmospheric gases (Kelly, 1995). Lovelock on the other hand, bases his definition of life upon

the Austrian physicist, Erwin Schrödinger's (1887-1961) generalizations about life. According to Schrödinger, living systems have boundaries. In a sense, living systems are open systems because they take and excrete energy and matter, but they are enclosed by internal boundaries. Lovelock applies this idea to Gaia. When the Earth is approached from space, the atmospheric boundary of Gaia can be seen. As the Earth's surface is approached, there is the boundary of an ecosystem such as a forest, then the skin, or the bark, of living plants and animals. Inside the skin, there are numerous cell membranes and eventually DNA, or the structure of life. If the definition of life is stated as a self-organizing system composed of an assembly made from a vast set of "parts," what lies within is alive. Gaia includes:

- living organisms that are capable of growing and exploiting environmental opportunities; these organisms are also subject to the rules of Darwinian natural selection.
- organisms that can affect both their physical and chemical environment through the use and exchange of energy and matter.
- constraints, or boundaries, establishing the limits of life; there is a preferred state that organisms try to maintain.

The Earth, as a living system, is alive, according to the Gaia hypothesis (Lovelock, 1988).

According to Lovelock, the most compelling evidence for Gaia's existence is that of the Earth's atmosphere and climate. The Earth's atmosphere has been manipulated by the life that is upon it by using the atmosphere as a transfer medium for waste products and raw material (Lovelock, 1991). Over three billion years ago, the earliest life forms of bacteria and photosynthetic algae began extracting carbon dioxide from the atmosphere and releasing oxygen back into it. Over geological time, the atmosphere changed from one dominated by carbon dioxide to one dominated by nitrogen and oxygen. The Earth was able to support both aerobic and anaerobic organic life (Mountain Man Graphics, 1996). Since then, the constant oxygen concentrations in the environment suggest the presence of an active control system between the biota, biosphere and other gases contained in the atmosphere. According to Lovelock, such a control system involves Gaia sensing a departure from the optimal state of gas mixture. Therefore, the total ensemble of gases must be considered when maintaining the Earth's atmosphere (Lovelock, 1979). Although the Earth's atmosphere is not alive, its elemental and compound gases strongly interact with and are a part of life (Margulis and Hinkle, 1991).

For the last three and one half million years, sedimentary rock records show evidence that the Earth's climate has never been unfavorable for life (Lovelock, 1979). According to Lovelock and Margulis, such evidence suggests the Earth has the ability to control its climate through both the emission and removal of greenhouse gases such as methane, ammonia, carbon dioxide, and water vapor by various organisms, especially oceanic phytoplankton. These organisms are able to incorporate carbon dioxide from the atmosphere into carbonate shells. During this same time, the Sun has increased in luminosity and heat according to principles of nuclear physics. This increase in heat would have warmed the Earth's surface, stimulating plankton to take up carbon dioxide more efficiently thus changing their metabolic activity. Upon death, their shells would have become incorporated into the ocean floor sediment, thus removing carbon dioxide from the atmospheric system. With the warmer conditions, there would have been an increase in water

evaporation with a subsequent increase in rainfall. The rainfall could have aided the removal of carbon dioxide as well, but Lovelock viewed the rain as causing more runoff from the land which provided nutrients to increase phytoplankton populations and consequently increased the removal of the greenhouse gas. Another Gaian mechanism for climate control involves marine plankton that produce dimethylsulfide (DMS). Dimethylsulfide can be converted to sulfur dioxide and then to sulfuric acid particles which are incorporated into low altitude clouds over the ocean. An increase in cloud cover creates a greater albedo, or reflectivity, over the Earth's surface, keeping temperature hospitable for life (Schneider, 1990).

To further support the temperature, or climate, control mechanism of Gaia, Lovelock created an imaginary Earth-like planet he named Daisyworld. Early in the planet's history when the Sun is weak, dark daisies would be the species suited for survival. Their dark color would absorb the available energy from the Sun creating local warm spots, increasing the global temperature. The black colored surface and the increasing temperature of the Sun will heat the planet to a temperature that is too hot for black daisy survival. Therefore, white daisies will grow in order to balance the black daisy population and cool the planet due to their albedo effect. The growth of black and white daisies becomes the thermostat that maintains the temperature of the planet. Their absorption and reflective properties control the temperature unconsciously for daisy survival (Shannon, 1992). Over time, neither daisy would be able to moderate the temperature of Daisyworld due to the Sun's increasing heat. Lovelock's model demonstrated how an organism, acting in its own interests can maintain a homeostatic state by changing itself in order to survive in a changing environment (Mountain Man Graphics, 1996)

The biota, interacting with the Earth's surface, maintains an optimal environment for itself. Each organism interacts not only with its local environment but also other organisms. Each organism requires such interactions for obtaining water, minerals, nutrients, food, and the removal of its solid, liquid, and gaseous waste. The Gaia hypothesis is an examination of these interactions on a cumulative, or global, scale. It involves a collective look at the growth, activities, and death of organisms living on the Earth and the feedback mechanisms required for life to respond to changes in the environment or the environment to respond to the changes in life (Margulis and Hinkle, 1991). Lovelock believes that one of the characteristics of living systems is their ability to "develop, operate, and maintain" that system through a process of trial and error. The discovery of such a system operating on a global scale with the goal of maintaining an optimal and chemically stable environment would provide the most convincing evidence of Gaia (Lovelock, 1979). It is thought that the Earth should be studied as human physiology is studied, as a system of interacting components: the atmosphere, biosphere, geosphere, and hydrosphere. The Gaia hypothesis begins this study through investigations of the Earth, life, and ecology (Mountain Man Graphics, 1996).

Support and Criticisms Concerning the Gaia Hypothesis

Since Lovelock's proposal of the Gaia hypothesis, some nonscientists and scientists have shown interest in his views of the Earth. The innovative and controversial part of the Gaia hypothesis suggests that life uses control mechanisms in order to maintain the physical and chemical environment of the Earth. With this being the case, industries support the Gaia hypothesis. They interpret the hypothesis to mean that nature can correct the effects of pollution and keep the planet inhabitable for future generations. Gaia is also supported by those who discount scientific evidence concerning the depletion of the ozone layer and the effect of greenhouse gases. Gaia has been accepted by spiritual environmentalists as well who wish to find a connection between humans and nature (Schneider, 1990). Gaia is viewed as a conscious living entity by those who believe the hypothesis to have a religious meaning. When living beings mistreat the Earth, it can react by creating earthquakes, floods, tornadoes, and extreme climate changes. It is believed by these individuals that Gaia is happy when living organisms understand their "true" relationship and place within nature (Connor, 1993). There are still others who contest that the purpose of Gaia has never been defined and that one condition of Gaia may be suitable for one aspect of life or for one organism but not for another (Wiley, 1988).

Fundamental to the Gaia hypothesis is the interaction between the biota and the geosphere, or the surface of the Earth. It is known that the geosphere influences life depending upon climate, altitude, availability of nutrients, along with several other factors. However, less is known about how the biota influences the geosphere. Walter Shearer, a supporter of the Gaia hypothesis, believes evidence can be found concerning living organisms' influences on the Earth. The evidence includes:

- the presence and type of vegetation; the vegetative cover of an area influences albedo, surface roughness, atmospheric humidity, rainfall, soil erosion, and the nutrient composition of the soil.
- marine coral alters the water surface tension of the ocean and thus the intensity of wave actions by producing a lipid that hydrolyzes to form two powerful surfactants.
- the natural production of chlorocarbon compounds by some fungi species; when these compounds reach the stratosphere, chlorine can decompose the ozone layer.
- acid rain from byproducts of tropical forest ants.
- the weathering of rocks from carbon dioxide released into the atmosphere.
- Lovelock's proposal concerning the idea that living organisms can adjust their metabolic activity in order to maintain atmospheric oxygen concentrations within tolerable limits.
- the production of DMS by some marine phytoplankton which increases cloud albedo over the open oceans and regulates the temperature of the Earth (Shearer, 1991).

In his arguments supporting Gaia, Lovelock believes that oceanic phytoplankton played a significant role in climate control over geological time by altering their metabolic activity. However, Stephen Schneider explains that inorganic chemists assert that carbon dioxide could have been removed inorganically as well. Lovelock's model assumes that the temperature of the Earth and oceans increased as the Sun did, increasing the rate of evaporation. Consequently, this would result in more rainfall. In addition to carrying more runoff and nutrients to the ocean, the

rainfall would dissolve carbon dioxide in the atmosphere and form weak carbonic acid which is able to react with rocks to form carbon-containing sediments. Geochemists hypothesized that this weathering could maintain climatic stability as the Sun heated the Earth. Lovelock does not deny this argument, but he, along with others, believes the biota, particularly soil biota, facilitate the weathering process. Whether organic or inorganic removal of carbon dioxide has predominated in climate control of the Earth, a lifeless Earth would have created a much warmer environment than the one that the planet provides today (Schneider, 1990).

Neither supporting nor opposing the Gaia hypothesis, James Kirchner argues that the Gaia hypothesis is not a testable hypothesis. Instead, it is a metaphor, or poetic statement, that the Earth is alive. The hypothesis should not be stated as a single statement but be divided into five hypotheses with individual specifications. These hypotheses, listed from weakest to strongest, include:

- influential Gaia which states that the biota influences certain aspects of the abiotic world.
- coevolutionary Gaia which states that the biota influences the environment and the environment influences the evolution of the biota.
- homeostatic Gaia is represented by stabilizing negative feedback loops which occur due to the interactions between the biota and the environment.
- teleological Gaia which states that the biosphere maintains a homeostatic atmosphere for itself.
- optimizing Gaia which says that the environment is manipulated by the biota in order to create biologically and chemically favorable conditions for itself and the future.

Scientists worldwide agree with influential and coevolutionary Gaia. Atmospheric gas accumulation was prevented years ago by early bacterial and algal action. The proof of homeostatic Gaia is debatable because there is not a clear definition of stability. Stability can mean either the resistance to change or the ability to adjust if necessary. As with homeostatic Gaia, neither teleological Gaia nor optimizing Gaia have been defined. Kirchner asks, what is the purpose behind teleological Gaia, and what is the optimal physical environment when discussion concerns optimizing Gaia? The purpose and optimal conditions for one organism do not necessarily match those of another, so how can such theories be applied to the entire planet? Kirchner believes that Gaian models such as Daisyworld cannot be tested against the behaviors of real world scenarios. He also believes that scientists will be unwilling to test the debatable Gaia hypotheses until a clear, definitive statement is made concerning each (Kirchner, 1991.)

With support and criticisms, the Gaia hypothesis will continue to be questioned throughout the scientific community. If the hypothesis is not testable, as Kirchner argues, the hypothesis has at least suggested to scientists what is yet unknown about the Earth concerning its maintenance and regulation (Shannon, 1992). What is known through studies of biology and ecology, however, is that the biota and the environment are very closely related. It is because of this relationship that humans need to understand and maintain the living and non living environment around them (Lovelock, 1988).

Closing Remarks

For those individuals interested the Earth and its workings, the Gaia hypothesis is an interesting concept to consider. Throughout a person's study of the natural sciences, living and non living systems are considered individually, but not as an entire living system as the Gaia hypothesis suggests. The hypothesis resembles the study of ecological sciences, but it goes a step farther by trying to explain why the Earth has remained as it has for years with a relatively constant temperature and oxygen concentration.

If one species alters the environment in which it lives, how does it affect the entire system? Does the planet modify itself geologically or biologically? How do organisms know when to change their metabolic rates in order to achieve the same exchange of gases with other organisms and the atmosphere? How many more years will the Earth's biota and environment be able to adjust if the Sun is increasing in luminosity and heat? What impact do humans have on the entire living system of Earth? When will the Sun and the Earth cease to exist? These are just a few questions that can begin to be explored by the Gaia hypothesis but much still has to be learned by the scientific community.

In concert with the other animals, with the plants, and with the microbes themselves, we are an active part of the Earth's atmosphere, constantly circulating the breath of this planet through our bodies and brains, exchanging certain vital gases for others, and thus monitoring and maintaining the delicate makeup of the medium.

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