Lynn Margulis: Science's Unruly Earth Mother

Lynn Margulis' partisanship of Gaia enrages her colleagues in evolutionary biology, but nobody dismisses her out of hand—because she's been right before

"ANY *REAL* BIOLOGISTS HERE?" THE LECTURER asks. "You know, like molecular biologists?" Several hands go up. "Good," the lecturer says, laughing. "You're going to *hate* this."

The lights go out; slides flash on the screen. And Lynn Margulis, Distinguished University Professor of Botany at the University of Massachusetts at Amherst, begins to do what she has been doing for more than 20 years—amusing, exasperating, and enlightening her colleagues. A nonstop provocateur, Margulis has sparked scientific controversy since her 1965 Ph.D. thesis, which spawned a series of papers arguing a then radical notion: Cellular bodies such as mitochondria and plastids, she posited, evolved from bacteria and algae that were long ago incorporated into cells. To Margulis, it was not a given that eukaryotic cells (cells with nuclei) are individual entities. She viewed them as populations, composed of vestiges of organisms that interact within the boundary of the cell membrane. "We are walking communities," she says. "Ten percent or more of our body weight is bacterial [in its evolutionary origins], and it's just foolish to ignore that."

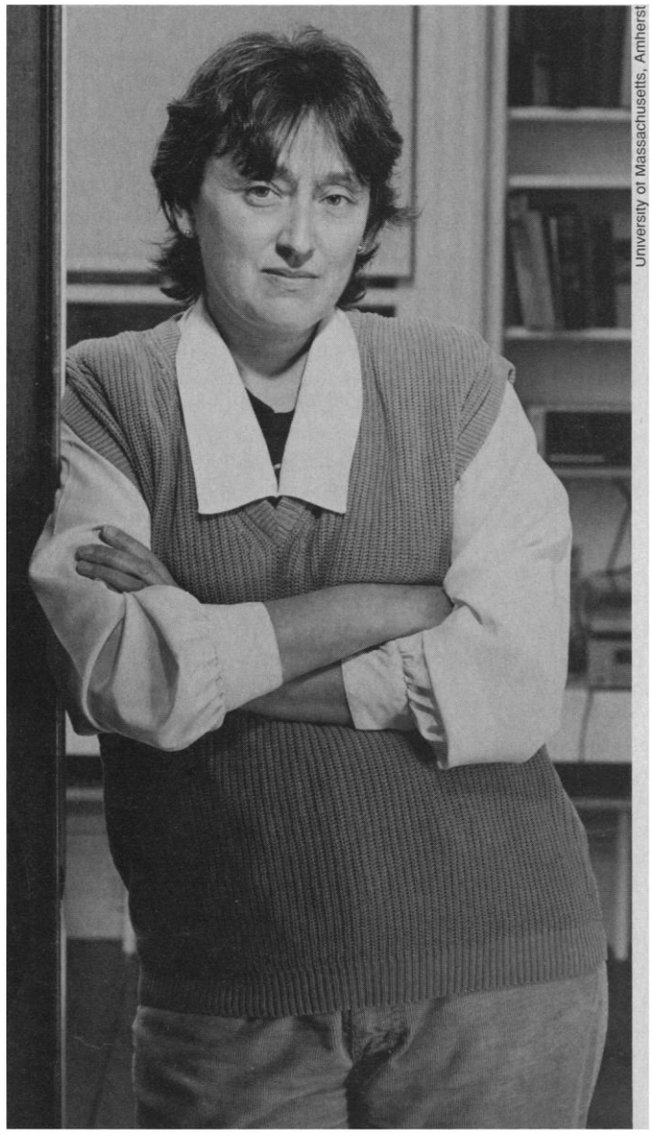
Margulis' view of the origins of eukaryotic cells was long neglected, even derided. Today it has been embraced. "The evolution of the eukaryotic cell was the single most important event in the history of the organic world," says Ernst Mayr of Harvard, one of the century's most important evolutionary biologists. "And Margulis' contribution to our understanding the symbiotic factors was of enormous importance." Then Mayr shifts ground, as do many scientists asked to evaluate Margulis' recent work. "But what she's saying now. . ." he pauses, "it's startling to find a reputable scientist arguing such fantasies."

Margulis' unique mix of "fantasy" with ideas of "enormous importance" fascinates and exasperates her peers. Having gained acceptance for her work on the origin of eukaryotic cells, she seems willing to take on any sacred cow. Indeed, she is now aiming for the biggest target in evolutionary biology: neo-Darwinism. First named in 1896, neo-Darwinism is the synthesis of Darwinian natural selection and Mendelian-style genetics. Today, it is the reigning paradigm of the discipline, but to Margulis it is little more than a "quaint, but potentially dangerous aberration" that needs to be tossed out in order for science to answer "basic questions" like why stasis is so prevalent in the fossil record, and how one species can evolve from another. In Margulis' view, these questions can be answered only by embracing what she calls "autopoietic Gaia."

As first advanced by the unorthodox British chemist and inventor James Lovelock, the "Gaia hypothesis" makes one especially widely known—and controversial—contention: that Earth as a whole is alive. Lovelock has vigorously promoted Gaia in his native Britain, but in the United States his efforts have been eclipsed by the preternaturally energetic Margulis, who has promulgated Gaia in dozens of articles, TV and film documentaries, and public lectures. In turn, the media have given her wide, and often adulatory, coverage. Last year, *Smithsonian* magazine ran what could only be termed a breathless paean to her, and Gaia has been awarded extraordinary coverage in *Time* and *Newsweek*. The spotlight on Margulis will get even brighter with this fall's publication of *Scientists on Gaia* (MIT Press), the long-awaited proceedings of the first major scientific congress devoted to exploring the subject. "Gaia is warm and fuzzy and it strikes a chord," says Stephen J. Gould, the essayist and evolutionary biologist. "I can hardly get through a talk to the public now without being asked about it."

Such attention, in the view of Margulis and other Gaia supporters, is nothing more than the idea's due. According to the Swiss historian of science Jacques Grinevald, Gaia "is the major cultural and scientific revolution of our time"

Others believe Gaia to be completely unscientific, though Mar-



University of Massachusetts, Amherst

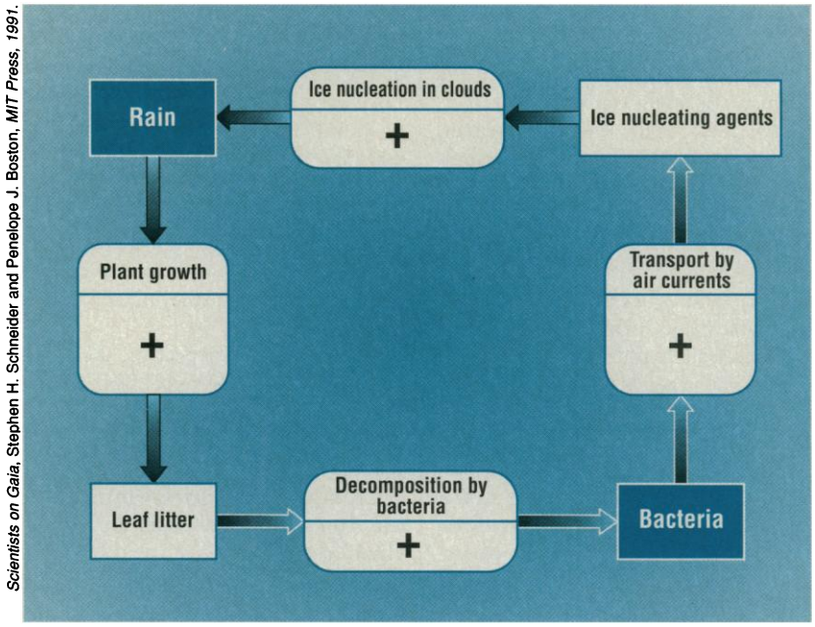
Amusing, exasperating, enlightening. *Lynn Margulis*

gulis' track record makes many of her colleagues reluctant to attack her directly. "Every science needs a Lynn Margulis," says John Maynard Smith of the University of Sussex, renowned for his work on the evolution of sex and the introduction of game theory to animal behavior. "I think she's often wrong, but most of the people I know think it's important to have her around, because she's wrong in such fruitful ways. I'm sure she's mistaken about Gaia, too. But I must say, she was crashingly right once, and many of us thought she was wrong then, too."

In some ways, Margulis' push for Gaia is an extension with her original focus on the genetics of the microworld. That focus is demonstrated in the images she shows to accompany her lectures. Like most biologists, Margulis travels with a packet of slides and films. But rather than portraying birds, mollusks, or mammals—the organisms most life scientists grew up watching—Margulis' pictures are exclusively concerned with the microworld, and especially the Protista: the vast kingdom of more than 250,000 protozoa, algae, seaweeds, molds, and microbes that she has made her professional specialty. It is from this kingdom that Margulis draws her lessons. Says Maynard Smith: "She knows an incredible amount about strange beasts most of us don't know anything about. There's a real appreciation for the diversity of life." Predation, photosynthesis, communication, social organization, motion—all the important evolutionary landmarks occurred first in bacteria.

Up to this point, most evolutionary biologists agree with her. They agree, too, that the field has concentrated too much on the natural history of large animals—creatures Mayr believes should be classified as only a small branch of one subdomain of the eukaryotes (creatures with eukaryotic cells). The controversial part of Margulis' argument comes after that: her insistence that such changes could not have come through the slow buildup of chance mutations, and that therefore "neo-Darwinism, which insists on that, is in a complete funk."

"I have seen no evidence whatsoever that these changes can occur through the accumulation of gradual mutations," she told an audience recently at the University of Massachusetts. "There's no doubt, of course, that they exist, but the major source of evolutionary novelty is the acquisition of symbionts—the whole thing then edited by natural selection. It is never just the accumulation of mutations."



Scientists on Gaia, Stephen H. Schneider and Penelope J. Boston, MIT Press, 1991.

Loopy? *Elements of a feedback loop for the stimulation of rainfall by bacteria as proposed by Gaia partisans.*

Exasperated by the silent skepticism of the *real* biologists in her Massachusetts audience, Margulis challenges them to name a single, unambiguous example of the creation of a new species by the building up of chance mutations. After a while, one man mentions a type of corn—only to be contradicted by another.

"See?" Margulis says, triumphant. Then she puts up a slide of *Mesodynium rubrum*, a "red tide" organism found in Finnish lakes. Inside each thin, translucent *M. rubrum* are more than 20 small blobs, the vestigial remains of another organism called a cryptomonad. "Long ago," she says, "one of these guys ate but did not digest the other. Now they require each other to reproduce, meaning they are reproductively isolated, and that speciation occurred. I can give you a dozen of these examples—and you give me a type of corn, maybe. Maybe....I have the evidence. So why do you think I'm wrong?"

"I think she's often wrong, but most of the people I know think it's important to have her around, because she's wrong in such fruitful ways."

—JOHN MAYNARD SMITH

"I don't think she's wrong," responds Niles Eldredge, a paleontologist at the American Museum of Natural History in New York City in an interview with *Science*. "I think she's being simple-minded.That view of neo-Darwinism is a cartoon—and I say this as a critic of some aspects of neo-Darwinism. Understanding speciation is indeed difficult, but biology is not in the straitjacket she says it is. Evolutionary biology is much richer than she is portraying it to be."

Because, in Margulis' view, symbiosis is the major force behind evolution, the unit of biological study is not the individual but the symbiotic system, which is primarily characterized by the property of "autopoiesis"—a relatively obscure term that means "self-maintenance." Autopoietic systems conserve their boundaries and regulate their biochemical compositions. Most are capable of reproduction; some are not. Some things that reproduce, such as viruses, are not autopoietic, because they are too simple to maintain themselves biochemically. The smallest autopoietic entity is the bacterial cell. The largest, Margulis says, is Earth.

By contrast to Mars and Venus, Earth has a surprisingly alkaline surface and a chemically unstable atmosphere, with abnormally high levels of nitrogen, oxygen, methane, hydrogen, ammonia, and other gases. "Lovelock's concept, with which we en-

tirely agree," Margulis and a former student, Gregory Hinkle, write in *Scientists on Gaia*, "is that the biota (the sum of all the live organisms at any given time), interacting with the surface materials of the planet, maintains these particular anomalies of temperature, chemical composition, and alkalinity." In Margulis' view, Earth is a "single enormous system deriving from a 3500-million-year-old common ancestor."

Lovelock, who works out of a barn-turned-laboratory in Cornwall, first formally proposed the Gaia hypothesis in 1972. He and Margulis began collaborating in 1974 and are still Gaia's only prominent scientific exponents. To Margulis, the theory is another blow against the empire of neo-Darwinism. Just as she regards symbiosis, rather than the accumulation of chance mutations, as the major source of evolutionary novelty, she views the reciprocal actions between organisms and the environment, rather than competition among individuals, as the chief agent of natural selection.

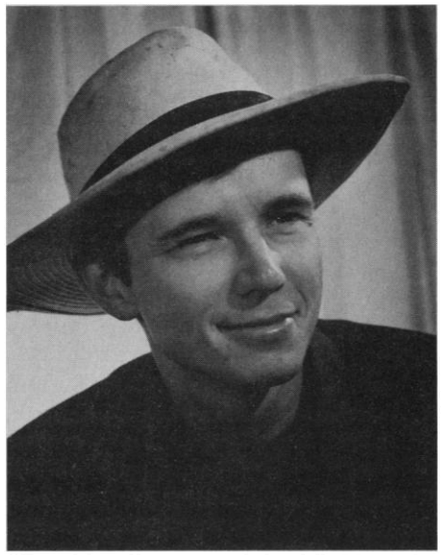
Margulis works from a deep conviction that biology is in need of a Copernicus of its own, a scientist who will remove human beings and big land animals from their privileged position in the field and focus attention on the tiny entities and chemical cycles that she regards as the dominating features of the biosphere. At present, she believes, Lovelock's Gaia is like the original proposal of continental drift in the 1920s by the German meteorologist Alfred Wegener. Wegener was not believed until 40 years later, when the mechanism of continental drift, plate tectonics, was discovered. But that, she says, did not mean that continental drift was false. Indeed, it revolutionized geology.

From a Gaian perspective, she wrote last December in *American Zoologist*, neo-Darwinism will ultimately be viewed as only "a minor 20th-century religious sect within the sprawling religious persuasion of Anglo-Saxon biology." Which is why neo-Darwinians "must hate and resist an autopoietic, Gaian worldview."

"Gaia," she says, "threatens everything they do."

At least publicly, few biologists feel threatened. "I just haven't paid all that much attention," says Gould. "Gaia's a pretty metaphor, and not much more. I can't say I've lost sleep over it."

Margulis' critics' comments are surprisingly mild, considering that many regard autopoietic Gaia as an unscientific attempt to deify the biosphere. The civility is partly because, as Alexander Rosenberg, a philosopher of science at the University of California, Riverside, points out, these theoretical issues, vital as they are, have little day-to-day import for most working scientists.



Joachim Hampel/UC Berkeley

"Frankly, I'm astonished." *Margulis skeptic James W. Kirchner*

Another part of the reason is that many

Gaia: Myth or Mechanism?

Is Gaia a mechanism—a bona fide scientific explanation—or merely a metaphor? Its supporters answer firmly that it does have real scientific explanatory power. As evidence, Lynn Margulis cites a list of biological or chemical processes that might constitute part of the "autopoietic" system whereby "Gaia" regulates itself. All of them, it should be noted, are subject to argument and criticism from nonbelievers.

■ **Carbon dioxide.** The "paradox of the faint young sun," first enunciated by Carl Sagan, among others, is that terrestrial temperatures seem to have stayed roughly constant in the 4 billion years that life has existed. Yet during that time the luminosity of the sun increased by about a quarter. It is generally believed that the requisite drop in the atmosphere's capacity to absorb solar radiation has to do with a global decline in carbon dioxide levels. Gaian advocates argue that this decline was greatly augmented by the biosphere's compensatory tendency to fix carbon dioxide in the form of calcium carbonate shells, creating limestone. Skeptics counter that the requisite loss could be due to nothing more complicated than rainwater, which dissolves carbon dioxide, forming carbonic acid, which in turn dissolves calciferous rock. The neutralized acid runs into the sea in a process of chemical weathering. Both sides have produced computer models supporting their hypotheses.

■ **Dimethyl sulfide**. Another temperature-linked feedback mechanism may be controlled by phytoplankton, which produce dimethyl sulfide. After the dimethyl sulfide is released into the atmosphere, Gaia supporters suggest, it is chemically converted into particles of sulfuric acid, which serve as cloud-condensation nuclei. This produces thicker clouds, which scatter more sunlight, cooling the oceans. "Unfortunately," says James Kirchner of the University of California at Berkeley, a Gaia critic, "the data, if anything, suggest that the interaction works the wrong way, cooling the earth." Lovelock has suggested that this means that Gaia's "preferred state" might be an Ice Age.

■ **Ocean salinity**. Weathering releases salts into the oceans at a rate that would soon make the water too salty for life. Yet geological evidence shows that the oceans have remained at a salinity less than 10% of saturation for hundreds of millions of years. It has been suggested that the excess salt is removed through salt flats, which are hosts to dense colonies of bacteria. The bacteria, which can survive in water too saline for almost anything else, trap salts and other minerals to form a sheath within which the community lives. Thus the regulation of salinity may have an important biological component.

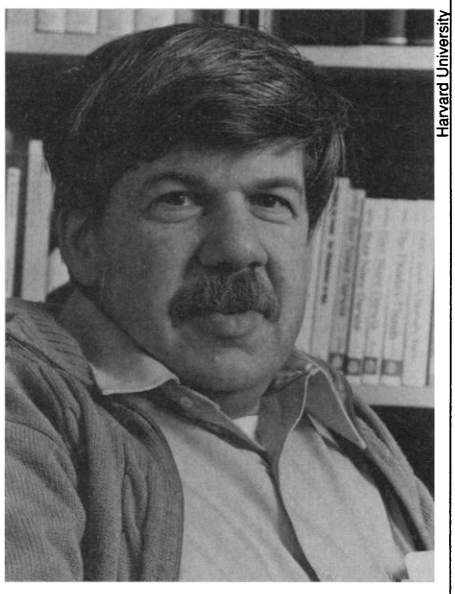
■ **Plate tectonics**. If the life-induced drop in carbon dioxide was responsible for a global cooling billions of years ago, then life may also drive plate tectonics. The reasoning is that the sudden drop in temperature chilled the upper mantle. This in turn might destabilize the lower crust, causing the shifting of continents described by plate tectonics. ■ **C. M.**

researchers agree with her on one point: her contention that biology historically has paid insufficient attention to the microworld, and to its large-scale, long-term interactions with the environment. "There's no question that there's this 3-billion-year dance between life and the environment," says Eldredge. "It's endlessly fascinating and well worthy of study. But what I, and most of my colleagues would say is, Why do you need the Gaia hypothesis to do it?"

The belief that living creatures affect the composition of the atmosphere has a long intellectual pedigree. Noting that Herbert Spencer, one of Darwin's most important backers, examined the relation between photosynthesis and atmospheric oxygen back in 1844, James W. Kirchner, an earth scientist at the University of California at Berkeley, observes that the influence of the biota on the environment is now, 150 years later, so "thoroughly documented" as to be less a hypothesis than an observation. "If that is a radical departure," he remarks, "then some people have been radically departing for a long time."

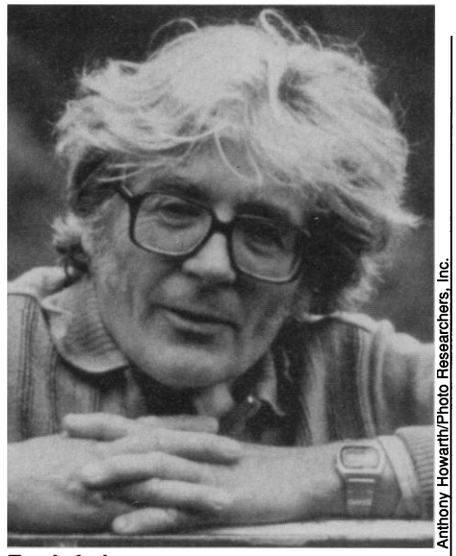
What is new, Kirchner concedes, is the notion that "the earth is alive, or sort of alive, or autopoietic, or whatever it is they call it."

One of Gaia's most public critics, Kirchner thinks this view of Earth, while new, "has implications that are either not testable or, when they have been tested, are not supported by the data. Frankly, I'm astonished by Margulis' claims for Gaia." An example, he says, is the Gaian assertion that tropical forests control the flux of atmospheric water. "That's been measured," Kirchner points out. "At least 85 percent of the net evaporation on Earth comes directly from the surface of the ocean. I haven't come across any convincing evidence for a huge effect of tropical trees on the global water balance."



Harvard University

Not losing sleep. *Stephen J. Gould*



Anthony Howarth/Photo Researchers, Inc.

Earth father. *James Lovelock*

He adds: "Should the interaction of the environment and life be studied? Yes, absolutely. Should it be funded? Yes, enthusiastically. Should it be carried forward under a scheme as grandiose as Gaia? I don't think the case has been made."

Margulis defends herself and Gaia with the rhetorical verve that has long startled her colleagues. Her critics, she said in 1988, just "wallow in their zoological, capitalistic, competitive, cost-benefit interpretation of Darwin—having mistaken him."

Gaia is different from the simple observation that the environment and the biota influence each other, she says, because the closeness of the coupling suggests qualitatively different types of interactions. As proof, she offers a list of theoretical implications that would never have been tested for without Gaia (see box). "It's like what Lovelock quotes from William James," she says, laughing. "'First it's absurd, then maybe, and last, we have known it all along.'"

Confident in the essential correctness of her views, Margulis continues skipping from subject to subject, leaving a trail of controversy in her wake. A gadfly, she focuses debate and forces her adversaries to think through their positions. "There's a role in science for iconoclasts," says W. Ford Doolittle of Dalhousie University, in Nova Scotia, a well-regarded expert on evolutionary theory. "It would be a great mistake to jump on her with both feet. They raise questions even when they're wrong. And, of course, they're occasionally right, as she was."

To raise yet more questions, Margulis traveled with her packet of slides last February to the annual convention of the American Association for the Advancement of Science in Washington, D.C. There she argued at a plenary session that consciousness was by no means restricted to *Homo sapiens*. We infer consciousness because people respond purposively to their environment, she said. She showed films of bacteria reacting in a meaningful way to sensory stimuli, halting motion in the presence of a toxic compound, explosively growing when exposed to water.

"How is this different in kind from a driver stopping at a red light, or children flocking around a Good Humor van?" she asked, speaking with the engagingly conspiratorial air that charms some listeners even as it exasperates others. "Show me any definition of consciousness in the textbook, and I'll show you a protist that can fit it. That should tell you something."

Unsurprisingly, the bald statement that bacteria are conscious enraged some spectators. A chemical engineer stood up. Irate, he shouted, "There's a balloon on the ceiling!"

Chins lifted across the auditorium. A child's balloon was indeed bobbing gently against the ceiling.

"You said that consciousness was. . ." he read from his notes "...the ability to respond meaningfully to sensory perceptions, and that bacteria do this, and therefore bacteria are conscious. Well, that balloon is responding meaningfully to gravity. Is it conscious, according to your definition?"

"I don't know," she admitted. Then, rather than ducking the question, Margulis raised the rhetorical ante. "But you might argue that the balloon is not alive, but that it is conscious."

"It's conscious, but not alive?" the engineer said, infuriated.

"Look," Margulis said, "if you accept the standard definition of consciousness, it's very easy to prove that most people, biologists included, are totally unconscious their whole lives."

That, Margulis surely has proven, could never be said of her. ■ CHARLES MANN

Charles Mann is a free-lance writer based in New York.