Tangled Up in Gaia

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My first wide-eyed jolt from a comment by Lynn Margulis came in a 1977 issue of *CoEvolution Quarterly* on space exploration. Given a question about whether we should be trying to establish colonies in space, she cut to the chase: when a biological species is able to move into a new environment, it will do so. End of debate! Margulis appeared in those pages often, as professional biologist and big thinker. I read her book, *Origin of Eukaryotic Cells*, several years prior to entering graduate school. Two decades later, I was able to refer to her pioneering work on the evolution of the eukaryotic cell in my first book, *Metapatterns: Across Space, Time, and Mind* (Volk 1995). A nexus of ideas for the community that Bruce Clarke felicitously calls the systems counterculture, *CoEvolution Quarterly* also introduced me to James Lovelock and the Gaia hypothesis. Furthermore, both Lovelock and Margulis became Fellows of the Lindisfarne Association. While working as a carpenter and plumber and writing unpublished books on patterns, I regularly attended mind-opening lectures, notably by Gregory Bateson and Francisco Varela, among many others, at Lindisfarne's downtown Manhattan campus. In 1979, I heard Lovelock speak at the Cathedral of Saint John the Divine in upper Manhattan, a dramatic event that Lovelock discusses in his autobiography, his initiation into what was, for a hardcore scientist, a shockingly non-traditional setting and audience. I recall the moment as a victory for bold, big thinking. So Lovelock and Margulis were individually operating on my mental screen, although not via their peer-reviewed papers, which at that time I would have been too unschooled to tackle. But their technical works would enter my life after I completed my PhD thesis at New York University in 1984, modeling the role of life in the global ocean's carbon cycle. Thereafter, my entanglement with Gaia grew to an intensity I would never have imagined a few years before.

As my professional scientific career began, my personal and academic concerns were with Earth's current and future state and with improving predictions of the absorption of atmospheric CO_2 into the global ocean. At the 1983 Chapman Conference on the global carbon cycle, witnessing papers on the very long-term, multi-million-year carbon cycle, I even recall thinking to myself that I would never want to "waste time" on such recondite, archaic matters. Little did I know at that moment how much my doctoral

work and my ongoing interest in evolution, together with my exposure to Lovelock's first book *Gaia*, would pull me toward the thought that this Gaia idea of life's participation in regulatory feedbacks could be showing us in the Earth sciences that we might be missing something big about the Earth system. I was strongly influenced by Lovelock's observation, in his book *Gaia* and in a technical paper with Whitfield (Lovelock and Whitfield 1982), that the partial pressure of CO_2 in the soil, where rock weathering takes place, because of soil respiration from organisms, was ten or more times higher than in the atmosphere. The Yale geochemist Robert Berner and colleagues had made a model of CO_2 over geological time scales that included rock weathering, but formulated that flux as dependent on atmospheric CO_2. I put together a simplified version of Berner's model with the fact (bringing in data from agricultural journals) that life in the soil pumps up its CO_2, and showed that reasonable shifts in life's activities could mitigate the perturbations to CO_2 caused by changes in the plate tectonics that Berner had concentrated on. The result was not what I would call Gaian regulation; nonetheless, my eyes were opened to the potential of quantifying multiple global processes. The entanglement had deepened and I was off and running on Gaia-relevant research.

In 1988, under the initiative of climatologist Stephen Schneider, the American Geophysical Union sponsored a Chapman Conference on the Gaia hypothesis. The Chapman Conferences are a prestigious scientific forum for issues deserving a major debate. Four of us from the same Earth Systems group at New York University presented a series of papers. Although disappointing for Lovelock, as he notes in a letter to Margulis, the meeting was peak excitement for me. It was exactly what I wanted, a forum for debates about the operating principles for the Earth system. There I met Connie Barlow; we eventually went on to live together for more than 10 years and to co-author two papers (with Barlow as first author) on the relative material closure of the Gaian system compared to its internal ecosystems. I also met David Schwartzman there, a geochemist with whom I would publish some of my most significant work, specifically on the multiple factors and implications of biotic enhancement of weathering on Earth's CO_2 levels and thus climate. I also met and later published with Lee Kump, currently Dean of the College of Earth and Mineral Sciences at Pennsylvania State University. Indeed, I also met Lovelock for the first time and had a stimulating dinner conversation with him, and I finally met Margulis as well, albeit too briefly at a conference filled with more than a hundred fascinating scientists, and even a few philosophers in the mix.

I went on to publish a series of papers on various impacts of biological evolution on the structure of the biosphere (which term I use synonymously with Gaia). Some biological factors that came in with evolutionary innovations could have driven CO_2 up (and temperature down), and some did the reverse. Furthermore, through this work I eventually developed a viewpoint that Gaian effects came about from the free byproducts of metabolisms of living things, such as the commonly known waste oxygen from plants, or the less-well-known evolutionary invention of calcium carbonate shells by marine microorganisms, which inadvertently started distributing those shells into deep ocean sediments and thereby changed the carbon recycling by geological processes. This concept of byproducts was in line with the approaches that Tim Lenton and David Wilkinson were also taking at about the same time.

My entanglement with Gaia kept me focused on big-picture directions. In the 1990s, Lovelock invited me to all three of the Gaia in Oxford conferences. They were filled with important scientists across the spectrum of disciplines. At one of these events, an informal evening pub conversation that I had opened up to others to focus on the issue of the "parts of Gaia" generated ideas I used in my 1997 book *Gaia's Body: Toward a Physiology of Earth* (Volk 1997). That book developed the concept of byproducts and, in addition, concepts of "biochemical guilds" and "cycling ratios," towards understanding the workings of what I was always willing to call a global metabolism (while also always avoiding saying that Gaia was alive or a superorganism). Furthermore, I was firm in my own take that Gaia is not so much a hypothesis as a hypothesis generator. I used this term when asked about Gaia by other Earth scientists or by the press. As discussed in *Gaia's Body*, my "prime directive" of Gaian inquiry was to ask about the planet's state with life compared to no life or compared across a variety of evolutionary modifications to the biochemical guilds of living things.

At the second Chapman Conference on the Gaia hypothesis in 2000, I organized and chaired the opening night's session, assembling speakers who were not only disciplinary experts but who had also developed and published direct takes on the nature of Gaia. For example, a colleague and friend, Andrew Watson, presented for the first time, I believe, his ideas that it's a major question if Gaia's persistence is lucky or determined. In fact, at the conference's public forum, geochemist Dick Holland (much mentioned in these letters) asked me frankly if I now saw Gaia as equivalent to the global biogeochemical cycles. I concurred and was pleased that he got the main point of my talk. It's not that such questions could not have been asked

from the framework of Earth system science, or from general work within the global biogeochemical cycles. I could have done certain work without the Gaia hypothesis, but I personally would not have, because I would not have been asking those particular questions. That is why I am so thankful to Gaia as a hypothesis generator.

So my professional life has been very much entangled with Gaia. One of my last personal talks with Margulis was at a 2006 conference just outside Washington, DC. She told me she agreed with what I had written in a just-published review in *Nature* of Lovelock's *The Revenge of Gaia*, in which I lauded Lovelock's concerns about our planetary trajectory but criticized his language about goals of Gaia (Volk 2006). My last published encounter with Lovelock records some sparring we did in the pages of *Climatic Change* in 2003, in which we debated our ideas about the future of Gaia theory (see Lovelock 2003c, Volk 2002, 2003). This was all to the good. To me, the joy of science is in wrestling toward truth with the right people even when often only a handful are asking the detailed, specific questions one is engaged with. In 2009, Margulis published my book *Death and Sex*, co-authored with her son Dorion Sagan, via their Sciencewriters imprint with Chelsea Green Publishing. I recall with delight a phone talk just after receiving her written comments on a draft printout, marked up to a degree of detail that blew me away. How did she have the time? She made me promise to send back the marked-up manuscript when I was done, for her records.

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