INTRODUCTION

The Encounter

Between 1967 and 1970, NASA funded four annual conferences, organized through the New York Academy of Sciences, on the Origins of Life. Their format was conversational, reflecting the eminence of the central attendees, including Frank Fremont-Smith, Norman Horowitz, William McElroy, Philip Abelson, Sidney W. Fox, Leslie Orgel, and Stanley Miller.[1] A number of those present were already professional mentors or colleagues of Lynn Margulis, or would soon become so – Cyril Ponnamperuma, Elso Barghoorn, J. William Schopf, Joan Oró, and Philip Morrison. Margulis participated in all four meetings and was tasked to edit their transcripts into volumes (published between 1970 and 1973). The co-chair of these gatherings, Norman Horowitz, also happened to be Lovelock's colleague as the director of the biology section at NASA's Jet Propulsion Laboratory (JPL). This relationship likely had some role in Lovelock's invitation to the second Origins of Life meeting in May 1968. His attendance brought about his first encounter with Margulis: "Margulis, as the youngest member present, had the job of rapporteur. … Perhaps the task of reporting everything we said was onerous and she had no time or opportunity to think about it. Certainly, I had no contact or discussion with her at the meeting. My fruitful collaboration with Lynn was not to begin until some time later" (Lovelock 2000: 254).

Margulis at that moment was rapidly gaining professional momentum in her scientific career. She had always been precocious, entering the undergraduate program at the University of Chicago at the age of 15 and marrying Carl Sagan at 19, soon after receiving her baccalaureate degree in 1957. She gave birth to two sons while earning a master's degree in zoology and genetics from the University of Wisconsin in 1960 and a doctorate in genetics from the University of California, Berkeley in 1965. Margulis divorced Sagan that same year but maintained a professional relationship with him within the close milieu of NASA science. As it happened, Carl

[1] Biographical entries on professional colleagues will be footnoted or placed in the glossary of names.

Sagan was also an occasional attendee of the Origins of Life meetings as well as an occasional colleague of Lovelock's at JPL. Around 1970, Margulis had conceived research questions of her own regarding biological contributions to the planetary atmosphere. She asked Sagan whom to contact for expert opinion about the composition of the atmosphere, and he suggested Lovelock. Thus, when she wrote to Lovelock, initiating their correspondence in the summer of 1970, both parties had already had an opportunity to observe the other in professional action.

Careers and Personae

Lovelock

Lovelock often describes himself as both an "inventor" and an "independent scientist" (Lovelock 1979b, 2000). An inventor and engineer he certainly was. When his collaboration with Margulis began, Lovelock was a seasoned 52-year-old investigator, married to Helen Lovelock and the father of four grown children. Trained as an analytical chemist, he worked for 20 years (between 1941 and 1961) at the National Institute for Medical Research, an institute of the Medical Research Council, based in Mill Hill, North London, on various technical and scientific problems. One was the effects of heat and cold on living tissues and blood coagulation: his pioneer works in cryobiology – freezing hamsters and trying to resuscitate them – are still cited today. He studied the aerial transmission of cold infections and carried out various investigations into the biochemistry and biophysics of cells. While at Mill Hill, he invented numerous devices, from a pen able to write on cold and wet glassy surfaces to a sensitive anemometer for measuring the velocity of gases, leading to his utmost specialty, instruments for analytical chemistry – gas chromatography more specifically – that were able to detect and measure minute traces of chemical compounds. His most famous invention remains the electron capture detector (ECD), invented in 1957, which enabled the sensitivity of chemical measurements previously possible to increase by several orders of magnitude. This invention and his unique expertise in gas chromatography earned him an international reputation. Lovelock's taste for invention and engineering shows through the correspondence, for instance, when he begs to differ with "the comment 'you can't make a wristwatch to run on steam.' Want to bet? This is the sort of challenge that diverts me from other work" (Letter 99). On the strength of these accomplishments, in

1961 he left a comfortable salaried position at Mill Hill to establish himself as an "independent scientist."

An early instance of Lovelock's self-presentation as such can be found in Margulis's edition of the transcript from the 1968 Origins of Life meeting:

> I am not any sort of specialist. I guess I am a scientific general practitioner. This, of course, means that you cannot work in any institution anywhere, because there is no general practice in science. So I operate a one-man laboratory about 10 miles south of Stonehenge, which is both an observatory and a computer, and what more, really, could one want? (Margulis 1971c: 11).

Lovelock has enjoyed retelling the romantic story of a secluded scientist, retired far from the agitation of the world and "buried" in the countryside of Bowerchalke, where he could think more freely about Gaia, life, and nature. His 1961 invitation from NASA to work at JPL, on gas chromatographs for extraplanetary duty on landing modules, was certainly an important starting point for his professional establishment in this regard. But during this same period, an impressive number of both scientific institutions and private companies – primarily Shell and Hewlett Packard, but others on occasion, such as DuPont – hired Lovelock as a consultant. Over the next 20 years, these included the federal US scientific organizations of NASA, NOAA, and NCAR.[2] He was also employed in the UK by the secret service MI6. Original as it may seem to some, Lovelock's professional status was not that exceptional. As the historian Steven Shapin neatly documented, the status of "scientist entrepreneur ... people with one foot in the making of knowledge and the other in the making of artifacts, services, and, ultimately, money" (Shapin 2008: 210) was literally booming right at that time, the paradigmatic example being the biotech startups in Silicon Valley. In many ways Lovelock fits neatly into this category (Briday and Dutreuil 2019, Dutreuil 2017). Other examples could be found within Lovelock's close circle, for instance, Archer Martin – Nobel prize winner, father of partition chromatography, with whom Lovelock worked at Mill Hill – who tried Lovelock's path of scientific independence for a while from the late 1950s onward (Lovelock 2004a), but with less success, and James Lodge, a chemist and colleague of Lovelock's at NCAR, who sought

[2] These acronyms and other instances of technical nomenclature are spelled out in the glossary of terms.

Lovelock's advice on establishing professional autonomy in the early 1970s (Dutreuil 2016).

For Lovelock, the label "independent" is important in two ways. On the one hand, it evokes his ideal of scientific activity, modeled on the nineteenth-century image of a solitary genius, a savant and inventor doing "small science," for instance, with equipment compact enough to carry into the field and transport around the world on one's own. What he despised was its obverse, the "big science" of the twentieth century, reduced to routine by collectives of functionaries in large civil institutions. On the other hand, without a doubt Lovelock was advertising his independent status in order to counteract the numerous accusations in the 1970s that targeted him with conflicts of interest. This line of defense would be especially important when Lovelock – who, thanks to his ECD, became the first scientist to measure atmospheric CFCs (chlorofluorocarbons) – started saying publicly, including in testimony on behalf of DuPont before a committee of the US Congress, contrary to alarms raised in other quarters, that the human release of CFCs was not imminently harmful to the ozone layer. In his own defense, Lovelock argued that the very diversity of his clients preserved his independence. He hired himself out too broadly to be accused of any singular conflict of interest, and he could drop any client or employer if he did not feel morally at ease with what was asked of him.

Nevertheless, just as it would be misleading to see Lovelock as a romantic thinker, retired in the countryside, so it would also be incorrect to see him as one of Shapin's "scientist entrepreneurs" whose ethos was "having fun, making money." Lovelock's goal has never been self-enrichment. He is as genuinely fascinated by and devoted to the natural world as the nineteenth-century naturalists. The passages in his autobiography describing how, with a guidebook in one hand and his chromatograph in the other, he would measure the chemical substances emitted by algae around his Irish cottage, are certainly revealing. But more telling than an autobiography – in which one consciously presents oneself to the public – is the private correspondence of this volume, as when he informs Margulis: "Helen and I also go to the beach and gather sea water and algae looking for sources of new and even stranger compounds coming from the sea; this I do not regard as work" (Letter 58).

For what matters in the context of this volume, it suffices to recall that Lovelock was neither outside the production of scientific knowledge, as some critical accounts that discounted the science of Gaia might suggest, nor outside the political, institutional, and academic world, as his narrative of independence might imply. During the heyday of his collaboration with Margulis, Lovelock was *the* international expert in gas chromatography. He had an intensely active scientific life with a strong empirical and engineering bent – measuring chemical compounds on oceanographic vessels crossing the Atlantic, in military planes sampling the stratosphere, and in the air of the English and Irish countryside; writing papers for *Nature* about these measurements; advising Shell in Thornton (UK) and HP in Avondale (USA) on engineering issues; writing on climate change, both internal reports for Shell and academic papers, and participating in major conferences on the topic; advising the British secret service how to detect explosives or track an individual through chemical marks; and keeping the accounts of his companies, Ionics Research and Brazzos Limited. Numerous letters document Lovelock's demanding travelling schedule. Margulis comments: "You love the remote countryside because you travel so much your life is too hectic otherwise" (Letter 61).[3]

Margulis

At the outset of her collaboration with Lovelock in 1972, Margulis was 33 years old, now married to crystallographer Nick Margulis, and the mother of four children from a toddler to a teenager. Five years earlier, after 15 rejections, she had published what would later be recognized as a landmark article, "On the origin of mitosing cells" (Sagan 1967). Within her dedicated biological specialization of microbial evolution, she had already published a book-length version of that article's thesis, *Origin of Eukaryotic Cells* (Margulis 1970a). This work is a remarkably monumental accomplishment for a debut volume in any discipline, documenting a steady command in the exposition of highly specialized content combined with the courage to synthesize and speculate. It develops what soon came to be called "serial endosymbiosis theory," an innovative account of the evolutionary assembly of the eukaryotic or nucleated cell from the merger of prokaryotic precursors. Margulis would become mindful how far out on another speculative limb Lovelock was taking her on what in 1973 he called "this Gaia adventure" (Letter 52). However, regarding serial endosymbiosis theory, as historian of biology Jan Sapp has summarized the matter, "the field of molecular evolution . . . closed the debate over the symbiotic origin of chloroplasts and mitochondria in the early 1980s" (Sapp 2015: 118) by cementing the key

[3] See also Letters 82 and 87.

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components of Margulis's theory with evidence drawn from matching the genetic sequences of these eukaryotic organelles with their prokaryotic origins. While the evidence for other aspects of her entire theory – in particular, for the spirochetal origin of the mitotic apparatus – had not yet arrived, Margulis never gave up that search. At the end of an interview with Dick Teresi, published in *Discover* a few months before her death, he asked, "Do you ever get tired of being called controversial?" Margulis replied, "I don't consider my ideas controversial. I consider them right" (Teresi 2011).

The Gaia adventure Margulis embarked upon with Lovelock in 1972 became a lifelong side project flanking her dedicated research on the theme captured in the title of a co-edited essay collection, *Symbiosis as a Source of Evolutionary Innovation* (Margulis and Fester 1991). Her Gaia research was largely unfunded, save for occasions when she succeeded in bootlegging it into funded projects in "planetary biology" and "environmental evolution." For Margulis, too, Gaia was a staunch pursuit carried out alongside a range of teaching duties, regular research commitments, and professional initiatives in a hyperactive academic calling. For most of her university career, Margulis shouldered relentless teaching responsibilities and directed a research laboratory while mentoring scores of graduate students; her letters to Lovelock detail on occasion the exhausting schedule she maintained. She also arranged yearly field excursions to locations such as Laguna Figueroa in Baja California; chaired numerous professional, executive, and advisory committees; sat on the editorial boards of multiple academic journals; managed the creation and production of teaching materials such as booklets, audiotapes, and CD-ROMs; organized frequent professional symposia; and co-directed a legendary NASA-sponsored summer research and internship program, while also publishing a constant stream of professional articles and books and meeting increasing requests for her appearance on the domestic and international scientific lecture circuit. Her devotion of energies on behalf of Gaia is threaded through these many other activities and obligations.

The 1980s saw the publication of her first volumes co-authored with her son Dorion Sagan – their first book-length foray into popular science writing, *Microcosmos* (Margulis and Sagan 1986a), and a provocative co-authored offshoot of her research on early evolution, *Origins of Sex* (Margulis and Sagan 1986b). In 1993, she published the second edition of *Symbiosis in Cell Evolution* (Margulis 1993a). In her last two decades, Margulis continued to produce prolifically on multiple fronts, including Gaia. If we review, for instance, just a selection of her books and edited collections over this final period, her output is remarkable: *What is Life?* with Dorion Sagan (Margulis and Sagan 1995); *Slanted Truths: Essays on Gaia, Symbiosis and Evolution* with Dorion Sagan (Margulis and Sagan 1997); her memoir, *Symbiotic Planet* (Margulis 1998); second editions of *Diversity of Life: An Illustrated Guide to the Five Kingdoms* with Karleen Schwartz and Michael Dolan (Margulis, Schwartz, and Dolan 1999), *Environmental Evolution: Effects of the Origin and Evolution of Life on Planet Earth* with Clifford Matthews and Aaron Haselton (Margulis, Matthews, and Haselton 2000), and *Early Life: Evolution on the Precambrian Earth* with Michael Dolan (Margulis and Dolan 2002); *Acquiring Genomes: A Theory of the Origins of Species* with Dorion Sagan (Margulis and Sagan 2002); her second essay collection co-authored with Dorion Sagan, *Dazzle Gradually* (Margulis and Sagan 2007), her venture into literary fiction, *Luminous Fish: Tales of Science and Love* (Margulis 2007); and her last publication before the mortal stroke in 2011, *Chimeras and Consciousness: Evolution of the Sensory Self* with Celeste Asikainen and Wolfgang Krumbein (Margulis, Asikainen, and Krumbein 2011).

It's revealing to put all that alongside a message she sent in 1995 – capped with a postscript to Jim and Sandy Lovelock – to her partner, microbiologist Ricardo Guerrero, who was then hosting the Lovelocks in Barcelona. This epistolary occasion, meant primarily to bring Guerrero up to speed on her doings, provides a rare but telling view of her in-house academic tribulations as well as her own dedicated research in microbial evolution and eukaryotic microbes (protoctists) at that moment: "Both the National Academy and Lounsbery turned down (rejected) my request for funds. I am going to have terrible money problems for the next two years" (Letter 243). Nevertheless, her work needed to go on. She had to "do properly the chimeric model of the eukaryotic nucleocytoplasm: archaebacteria (*Thermoplasma*) + (eubacteria) *Spirochaeta* in detail since the data is coming in very quickly now. It is important to make people understand that protoctist symbionts aren't lichens." She wittily transformed the political slogan "power to the people" into "power to the protoctists," a shout-out to the most neglected and disrespected biological kingdom (with which, one imagines, she particularly identified): "Between the protein/nucleic acid sequence data and the fossil materials power can be delivered to the protoctists (both live and fossil) but no one can do this work for me" (Letter 243).

With regard to their respective careers, then, we think that it is worth recalling the impressive accomplishments Lovelock and Margulis had both already achieved when their collaboration began. Their actual professional standing contrasts with a typical account that puts Gaia outside the realm of scientific institutions (e.g., Postgate 1988). As Lovelock asserted to Margulis early on, "Gaia is no half-baked notion of a pair of amateurs to be demolished by the first glance of criticism" (Letter 50). However, we can note another aspect of the personae common to both Lovelock and Margulis: they both presented themselves as professional contrarians standing out from the usual fray. With respect to scientific institutions, Lovelock emphatically branded his "independent" status, to the extent that Margulis had to remind him that "the independent scientist" as a generic species was, like the unicorn, "an utterly mythical beast" with an "example of one: you" (Letter 156). Lovelock also assumed a contrarian stance toward those he called "the greens," in spite of his having entertained close ties with leaders of these heterogeneous movements, such as Jonathon Porritt, Edward (Teddy) Goldsmith, Satish Kumar, and Stewart Brand. And Margulis was able to position her combative character both as a woman holding her own in rooms full of men and as a scientist with strong views often at odds with mainstream positions within evolutionary biology and environmentalist circles.

On the Materiality and Sociality of Collaborations

Studying the private correspondence between scientists enables historians to shed light on the material aspects of their collaboration: how often did they meet? What kind of documents and information did they exchange? Through which mediums? Most of the items transcribed in this volume originate from the last period in contemporary history when physical letters rather than emails record the exchanges between collaborating scientists. For instance, in both Lovelock's archives and Margulis's papers the gradual appearance of printed emails indicates their progressive replacement of letters and even faxes. The historical span of this correspondence from 1970 to 2007 allows one to question the significance of the medium conveying the content of the exchanges. Our impression, however, is that for these correspondents, the more recent emails do not differ in any crucial way from the earlier holograph and typewritten letters. In whatever medium, some are long and written with care to discuss scientific issues or technical and practical matters (bearing on measuring instruments or recent advances in computers, etc.); others are short and bear on the organization of collaborative activities, obtaining specific pieces of information, or sharing personal doings between friends. Occasionally the letters accompany the

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exchange of materials such as manuscripts, tables and diagrams, and 35-mm slides, the coin of the pedagogical realm before digital projection. The earliest years are marked by intensely active exchanges, with immediately following replies often crossing in the mail. Later periods experience occasional lulls. Sometimes the phone was preferred over letters, although as the correspondence shows, Lovelock developed a telephone phobia that hindered Margulis's prodigious dialing habit.

The correspondence reveals certain matters one would expect from any other candid scientific correspondence, things that go on "behind the scenes," common practices of working scientists, known to historians and sociologists of science but often concealed by idealist and naïve depictions of science in action. For instance, the letters show the strategies Lovelock and Margulis occasionally used to navigate around, and sometimes bypass, the perils of peer review.[4] The various materials of their correspondence also offer glimpses into the frequency and manner of their social encounters, enabling an appreciation of their differences in style. Margulis was continually around other people. She ran a lab with a constant complement of graduate students. She also delighted in gathering teams of colleagues to bring on elaborate trips to the field, usually to go microbe hunting. So, on the occasion of Lovelock's visits to the States, where he would combine appointments at HP, JPL, or NCAR with sundry meetings and conferences at other companies and universities, she would invite him to visit her lab or to come along on her excursions.

While Lovelock's own lab was truly a one-man operation, he did possess a "tribe" (as he would say) of close professional friends and colleagues, dispersed in universities on multiple continents and in the companies for which he worked. When it came to Gaia, Lovelock's manner was indeed tribal. He made strong demarcations between Gaia-friendly associates and those not so friendly, between critics of Gaia with whom it was acceptable to discuss the topic and others to be avoided. Lovelock would often invite persons from both receptive and wary camps to his place for the weekend, or longer for close friends. Margulis was herself a frequent guest, as much as her schedule allowed. Most of the scientific discussions would take place during walks (Merchant 2010). Besides the specific case of Margulis, to meet with people personally, and even more so at his own home, was a way for Lovelock to ease tensions and criticisms. As he confessed in an

[4] A good example is Letter 42. On this score, see also further details provided by Betsey Dyer's article in this volume.

interview with one of us, when it comes to one's critics, it's easier to write nasty things about other people's ideas when you are not facing them (Lovelock, personal communication, during an interview with Dutreuil in 2016).

As Lovelock recalls in the interview with Merchant, "Gaia was very much a part-time job." As we have noted, so it was for Margulis as well: "During the 1970s and until 1982, when I fell ill, Lynn Margulis and I spent as much of our time developing Gaia as we could. Neither of us received support for our work, and both of us were busy with other work. Lynn had her teaching and other duties at Boston University, and I had my customers" (Lovelock 2000: 260–261). And in the mid-1970s, as we will go on to detail, Lovelock found himself distracted from Gaian matters by his immersion in the "Ozone War." This is not to say that Gaia was of secondary importance for Lovelock: notwithstanding his "hectic" life, he considered Gaia of the utmost importance, as the correspondence testifies: "It would be lovely to be able to concentrate on a good book on Gaia and not be pressured by a lot of bread and butter tasks to pay the way" (Letter 161). Thus, we can think of their Gaia collaboration not as a primary, unique, and central preoccupation, but rather, as something that became essential to pursue even while it also had to be fitted in among many other commitments and preoccupations. For example, for most of the 1980s, Lovelock also had to deal with the progression of his wife Helen's multiple sclerosis, ending with her death in February 1989.

Lovelock's subsequent marriage to Sandy Orchard shortly thereafter coincided with his oft-expressed desire to withdraw somewhat from the usual professional fray and with his concern to insulate himself from the growing clamor of media interest: "We have changed our unlisted number repeatedly, but always it reaches the pests, the intrusive media people and other nuisances that we both know" (Letter 190). Finding herself behind the same barriers, Margulis complained to Lovelock that she felt personally cut off. He replied: "Dear Lynn, please don't assume that my desperate attempts at a quiet life are meant to exclude you" (Letter 190). Lovelock's excuses appear to have appeased Margulis at that moment: "Stay well and avoid the vultures" (Letter 191). But such difficulties eventually became endemic. Her later letters expressed unrealized hopes to recover opportunities for the fertile exchange of ideas that marked their collaboration in the 1970s. Margulis continued to struggle with these new circumstances in Lovelock's affairs, but the social conditions of their working relationship were now irrevocably changed.

The Authorship and Joint Elaboration of Gaia

Lovelock's collaboration with Margulis raises the question of authorship. If Lovelock is often considered as *the* author of Gaia, is this not the consequence of an all too frequent amnesia regarding women's contributions to science? As pointed out above, even without her work on Gaia, Margulis would still be reckoned as one of the great scientists of the twentieth and twenty-first centuries. The legacy of her championing of symbiosis in biology and in wider cultural discussion is as strong as that of Gaia in the Earth sciences and environmental politics. Nevertheless, we still need to consider the question of the origin of Gaia. As one of us has argued elsewhere, much of the evidence leads to the conclusion that Lovelock is the central figure in the story (Dutreuil 2016). The first written formulation of the core of the Gaian idea – namely, that "the climate of the Earth and the chemical composition of the surface, air and sea have evolved with life to provide optimum conditions for its survival; furthermore, this optimum was actively maintained by biological cybernetic processes" – can be found in a prospective note written by Lovelock for Shell in 1966, several years before he met Margulis (Lovelock 1966). The first published article presenting the word "Gaia" lists Lovelock as the sole author (Lovelock 1972). Their correspondence allows us to note, however, that Lovelock invited Margulis to co-sign that article: "on rereading it I see that the views have been modified by our exchanges . . . Would you join with me in this one" (Letter 18). However, Margulis declined that invitation: "I really have not done the methane argument for myself in the detail I would like to before signing on. Please go ahead and get it out on your own" (Letter 19). In like manner, Margulis always publicly and privately attributed Gaia's invention to Lovelock himself. Finally, after the close collaboration of Lovelock and Margulis in the 1970s loosened in later decades, Lovelock remained Gaia's primary disciple and herald, while Margulis carried forward the torch of symbiosis, of which Gaia is the consummate planetary manifestation. The last of their co-authored articles, "Gaia and geognosy," was published in 1989. But its main composition occurred years before, and it is essentially a recap and retrospective of past work (Margulis and Lovelock 1989). During their entire collaboration, they exclusively authored nine published papers together.[5]

These considerations should in no way diminish our appreciation of Margulis's strong and numerous contributions to the science and public

[5] A list of their joint publications is at the head of the Bibliography.

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profile of Gaia. For instance, Margulis asserted at the 1988 American Geophysical Union conference that "geophysicists and atmospheric scientists must study biology and biologists must know something of geophysics and atmospheric science. For too long, we have had atmospheric chemists wondering 'Where does all that methane come from?,' and biologists ignorant of 'Where all that methane goes'" (Margulis and Hinkle 1991: 12). We think that this statement nicely describes the mutual apprenticeships of Margulis and Lovelock in each other's specializations at the beginning of their collaboration. Margulis sought Lovelock's tutelage on the atmospheric compositions of the Earth and other planets as well as on the fundamental dynamics of atmospheric chemistry, while Lovelock absorbed key knowledge from Margulis regarding the rich diversity of bacterial metabolisms that contribute copious quantities of various gases to the biosphere.

Instead of trying to unify Gaia and to decipher who contributed what to a given definition, another historical approach pluralizes Gaia and then follows its different uses and meanings.[6] Just as there is Lovelock's Gaia, there is also Margulis's Gaia (Clarke 2017, Hache 2012). As we will discuss in a moment, the different possible conceptions of Gaia were underscored by the divergences in emphasis and occasional disagreements between Lovelock and Margulis themselves. Thus, if one properly speaks of Lovelock's Gaia as distinct from Margulis's presentation of the concept, one can also speak of Tyler Volk's Gaia or Watson and Lenton's Gaia, developing alongside the influential appropriations of the figure of Gaia by philosophers such as Bruno Latour and Isabelle Stengers (Clarke 2020, Stengers 2015b, Latour 2017a, 2017b).

Disciplines

Lovelock's work at Mill Hill had a medical bent: he knew about microbes, but only the pathogenic ones with any specificity. In the 1960s and 1970s, Lovelock progressively shifted the application of his training as a chemist from medical and biochemical issues to the Earth and environmental sciences. For instance, he thought with Shell about climate change or ways to transport methane in tankers; he built chromatographs for NCAR; and conceived chemical means to follow air masses for NOAA. The contemporary sciences he brought to the initial conception of Gaia were mostly atmospheric and oceanographic – analytical chemistry, geochemistry, and

[6] Suggested in a personal communication from Bruno Latour.

climate science – and a bit of physiology concerning the functioning of cells. Margulis brought all the rest. The published version of her own introduction at the 1967 Origins of Life conference reads in part (Margulis 1970b: 23):

> . . . I have always been very interested in the evolutionary relationships between prokaryotic microbes (bacteria and blue-green algae) and eukaryotic cells (those of animals and plants and other higher organisms). . . Until Dr. Barghoorn and Bill Schopf showed me how to hang my thoughts on the geochronological framework, I never realized the implications these ideas could have for the early terrestrial atmosphere and the discontinuity in the fossil record at the base of the Cambrian.

Margulis's remarks indicate that the paleontological work of Barghoorn and Schopf had already extended her biological thinking toward what would emerge as its Gaian complexion, with a focus on the deep time of geological and atmospheric transformations. That Margulis brought microbial ecology to the development of the Gaia hypothesis is generally known, but that she also contributed her knowledge of the deep geology of Earth's history is less often recognized. In the 1960s and until the early 1970s, what mattered for Lovelock above all was the contemporary functioning of Gaia. The correspondence, Letter 51 in particular, makes it easy to recognize Lovelock's own voice in the last two sentences of their most famous joint paper: "Proof of Gaia's existence may never approach certainty but further evidence is more likely to come from the study of the contemporary Earth. Astronomical evidence is notoriously fickle and although geological evidence is rather more certain one learns less about a person from the study of his grandfather's bones than from talking to him face to face" (Lovelock and Margulis 1974a). Nevertheless, the correspondence shows that Margulis insisted that Lovelock read geochemists and Earth historians such as Heinrich D. (Dick) Holland. This he did, especially for his second book, *The Ages of Gaia* (Lovelock 1988), informed by correspondence with Robert M. (Bob) Garrels, thoroughly reviewed by Holland prior to publication, and closely edited by Margulis.[7] Finally, Margulis introduced Gaia to evolutionary biologists, beginning with W. Ford Doolittle. Given the weight of their criticisms since the early 1980s, this has been an important hurdle for the theory to clear.

[7] See however footnote 167.

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Thus, it is somewhat too simplistic just to say, as one hears on occasion, that Lovelock's perspective on Gaia came "from above," as in the popular tale about Gaia's origins in the Earth viewed from space, or that Margulis's perspective on Gaia came "from below," with the planetary contribution of the tiny microbes. A more accurate picture of Margulis's contributions to the Gaia concept will also credit her knowledge of geological history in evolutionary context, what she herself called "environmental evolution," and what NASA came to call planetary biology. Lovelock's decades of work on the biochemistry of cells did assist his fruitful reflections on Gaia's own biochemistry, and moreover, his "small science," carried out on foot with a chromatograph at hand, did effectively bring his atmospheric chemistry down to Earth.

Geography and Institutions

Lovelock and Margulis were complementary not only in terms of disciplines but also in terms of geographical locations and national institutions. From her position at Boston University, Margulis had entrée to an impressively eminent body of senior researchers along the Harvard–Yale corridor. They greeted her own presentations of the Gaia hypothesis with some encouragement but also bracing criticism. For his part, although Lovelock worked his contacts with both American and Continental colleagues, his efforts were mostly anchored in Britain. Most of Gaia's story is British: when it comes to the modest amount of literature that has discussed what was labelled "Gaia theory" after the early 1980s, most of the handful of scientists taking part in it were in Britain, centered in East Anglia for a while, before moving to Exeter with the arrival there of Andrew Watson and Tim Lenton. Within the UK, Lovelock has enjoyed a wide network of connections, both with private companies and in the political and diplomatic realms, for instance, through relationships with Jonathon Porritt, a prominent member of the Green Party; with the distinguished United Nations diplomat, Sir Crispin Tickell; and, even earlier, with the former British prime minister Margaret Thatcher, who gave her support to Lovelock's Gaia charity.[8] Their correspondence also indicates how Margulis and Lovelock kept each other informed about the fortunes of Gaia in Europe and in the USA. And while they both had important connections with NASA, Lovelock's ties with the US space

[8] Lovelock asked for her support of his charity in a letter dated December 4, 1990. Margaret Thatcher replied that she would be honored to become a patron of the Gaia charity on December 14, 1990.

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administration decreased after the mid-1970s. By the 1980s, as NASA was planning new initiatives for planetary biology and Earth system science, it was Margulis who participated directly in these developments.[9]

Disagreements

Lovelock and Margulis came to disagree over a number of issues. In the introduction to Part III, we discuss how the gradual loosening of their collaboration began in the early 1980s. Here we review recurring topics of disagreement. For one, Margulis always disliked mathematical models and computational methods insofar as they bid to displace the immersive insights of field work. This was part of the "big trouble in biology": "Computer jocks (former physicists, mathematicians, electrical engineers, and so forth), with no experience in field biology, have a large influence on the funds for research and training in 'evolutionary biology,' so that fashionable computable neo-Darwinist nonsense perpetuates itself" (Margulis 1991: 214).[10] When one of us was visiting Margulis at her lab in Amherst, Massachusetts, walking through her biology department building one afternoon we happened to pass a room full of beige computers and pasty persons hard at work before inorganic screens, at which she uttered a sigh, said "Look at them!" and shook her head. But while she took her stand as a naturalist and field researcher, planting her boots in the Archaean mud of her beloved microbial mats, Lovelock and Andrew Watson invented Daisyworld – a credible and expandable computer simulation of planetary self-regulation – and cannily caught the coming wave of scientific cyberculture.[11]

Another major and famous disagreement between them bears on the conceptual propriety of calling Gaia an "organism." To tell from its frequency in his statements, Lovelock was never too bothered by this usage, which he would justify on occasion as a useful metaphor for the idea of a "living planet." Moreover, his cybernetic idiom of *homeostasis* was initially extended from the physiological origin of that term as a name for the tendency of organisms to hold their operations at a "steady state," and was then applied to designed or technological systems applying negative-

[9] See for instance Letter 139 and her contribution to the important NASA meeting for Earth system science (Goody 1982).

[10] See also Ruse 2013 on this point.

[11] For an analysis of Margulis's style of research within evolutionary biology and the way it could lead to prediction in a manner different from the study of mathematical models, see Winther 2009.

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feedback dynamics to achieve self-regulation. Thus, insofar as Gaia's operations as a system may be described as *homeostatic*, that definition is cybernetically indifferent between an organism and a mechanism.[12] However, for Margulis the arch biologist, this issue concerns a matter of rigor in scientific terminology over which she was willing to come to verbal blows. From the correspondence in 1992, we learn that Margulis threatened to sue *Science* over her objections to their printing the following characterization of her, which submerged the acclaim she had rightly earned for contributions in her own field beneath the most simplistic definition of Gaia: "Lynn Margulis . . . who is best known as a fervent proponent of the controversial Gaia hypothesis, which sees the whole planet as a single organism woven from billions of interconnected life forms" (Travis 1992: 1299). *Science* resolved the issue by publishing her rebuttal, which reads in part: "Because no single organism ever supports its growth solely by eating its own waste and entirely cycling the carbon, hydrogen, sulfur, and so forth needed for its body, I have always clearly maintained that 'the Earth is a single live organism' is *not* the Gaia idea. It is a misstatement that encourages critics and cranks to flourish and prevents the job, begun by Lovelock, of integration of Earth system science data" (Margulis 1993c).

Gaia's Reception

What Is Gaia?

"I am very anxious to talk to you about science. Our first job is to rename the planet" (Letter 202). This magnificent statement in a letter Margulis sends to Lovelock in 1990 reminds us that, contrary to what this phrase once suggested, the "Gaia hypothesis" today is not so much a proposition waiting to be tested as it is the basis for a new philosophy of nature. We mean *philosophy of nature* here in its standard sense, that is, as the elaboration of a discourse that aims at transforming fundamental concepts – or ontological categories – and so changing the way we think about certain essential entities. Just as Margulis's own scientific endeavors implied a new philosophy of life, radically changing how we think about biological individuals, Gaia, too, has yielded a philosophy of nature, changing the way we think about the Earth by connecting the nature of life and its global environment together as a coupled system. Although the title of Lovelock's and Margulis's

[12] For a discussion of these points, see Clarke 2020, Dutreuil 2016, and Latour 2014.

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first joint paper does name Gaia a *hypothesis*, it is also noteworthy that Lovelock's first paper about Gaia, published two years earlier, presents it straightforwardly as the name of a new *entity* that can be recognized through the observation of the strange properties of the Earth's atmosphere (Lovelock 1972).

Because "Gaia" far exceeds the mere proposition of a hypothesis to be tested against evidence, we often talk as well about the "Gaia concept" that is elaborated in "Gaia discourse" (Clarke 2020). Additionally, we argue that, whether one consults Margulis's and Lovelock's prose or the wider literature on Gaia, at least four different attitudes toward Gaia can be discerned (Dutreuil 2016). It certainly has been considered by some as a *hypothesis* ready for testing against empirical facts (Kirchner 1989, Tyrrell 2013); but also as a *theory*, elaborated with abstract models, examining the conditions under which planetary self-regulation could emerge – this approach encompasses the whole Daisyworld literature (Watson and Lovelock 1983; Wood et al. 2008); as a *research program* aimed at changing the methodology of, entities considered by, and questions asked in the Earth, life, and environmental sciences; and as a *philosophy of nature* that changes our philosophical and anthropological categories about Earth, life, and nature (Callicott 2014, Clarke 2020, Latour 2017a, Lovelock 1979a, and Midgley 2001). Others have used different terms – a world view, a metaphysics, a paradigm, a new conception of the Earth, and so on – to encompass these larger dimensions of Gaia discourse.

When it comes to Gaia's effect on the research programs of the Earth and environmental sciences, both Lovelock and Margulis were clear about how their large ambitions exceeded the clinching of a hypothesis. Early in the correspondence, Lovelock tweaked the word Gaia into "Gaiology," transforming it into the name of an entirely new science.[13] As Margulis writes at the very outset of their Gaia adventure: "After all we are involved in attitudinal (scientific paradigm – Kuhn) change" (Letter 19). Lovelock repeatedly makes assertions such as, "Gaia is a new way of organizing the facts about life on Earth, not just a hypothesis waiting to be tested" (Lovelock 2004b: 3). At the Gaia 2000 conference in Valencia, Spain, Margulis underscored Gaia's philosophical dimensions by comparing the rise of Gaian science to the emergence of natural history out of natural theology at the end of the eighteenth century: "That age of exploration of the seas and lands

[13] See Letters 70 and 72; see also Letter 39 on the importance of Gaia as a transformational science.

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generated natural history in the same way that satellite technology and the penetration of space brought forth Gaia theory." She emphasized Gaia's potential to reunite natural disciplines splintered by modern trends toward specialization, insisting that Lovelock's science offered a "return to the respected natural history, the enterprise from which biology, geology, atmospheric science, and meteorology had not yet irreversibly divorced themselves" (Margulis 2004: 8). Here we will briefly further explore the manifest effects that Gaia has already had both in various scientific disciplines such as evolutionary biology, Earth sciences, complexity sciences, and astrobiology, and in broader philosophical and political fields.

Evolutionary Biology: Was There a Controversy?

The popular story as written by evolutionary biologists has it that the Gaia hypothesis was effectively abandoned after Doolittle's review of Lovelock's first book (Doolittle 1981a) and the few pages Dawkins dedicated to Gaia in *The Extended Phenotype* (Dawkins 1982). About this latter text, Lovelock offered Margulis the reflection that "Dawkins spends about 1/3 of a chapter in his new book waving his well-manicured hands in a denial of Gaia on the grounds that there is no way from natural selection to reach planet scale homeostasis" (Letter 136). This story is too well known to merit more than a mention here. Doolittle and Dawkins argued at that time that Gaia was impossible in theory: given what was known or believed about natural selection, no mechanism for global homeostasis and regulation could arise through that blind and individualized process.[14] Regardless of which of the two leading conceptions of natural selection one adopted, that of Lewontin (1970) or of Dawkins (1976), at that time it was thought that the reproduction of biological individuals was necessary for natural selection to occur. Thus, because the Earth does not reproduce itself (Dawkins 1982), Gaia's purported planetary dynamics had no way to arise or evolve. Moreover, for evolutionary biologists, Gaia reignited former heated debates about the role of altruism (Ruse 2013). A broader outlook on this story would say that Gaia's teleological dimension – as worded in the title of the *Tellus* paper, the idea that atmospheric homeostasis arose "by and for the biosphere" – reminded evolutionary biologists of the phrasings of natural theology. This older discourse saw design everywhere in nature as a proof of the existence of God, before the apparent conundrum surrounding the complexity involved

[14] See also Doolittle's commentary, this volume.

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in organismic design had been "naturalized" (or denuded of its theological dimension) by Kant and Darwin (Huneman 2006). Even though a number of passages in the papers published in the 1970s clearly showed that Lovelock indeed thought teleologically, the candid nature of the correspondence provides a definitive confirmation of this point (see, in particular, Letters 16 and 40). It may be fair to say that Gaia discourse contributed to a reopening of thinking around the issues of teleology.

To a certain extent, by making sure to reply to biologists' critiques, Lovelock nourished this idea of a clash between evolutionary biology and Gaia. It bears recalling how popular Dawkins had become, on the heels of *The Selfish Gene,* by the 1980s – as opposed, say, to any climatologist or Earth scientist at that time. Debating with Dawkins was sure to bring Gaia some visibility; hence, even though he himself had never taken a particular interest in that field, Lovelock came to attend closely to Gaia's reception in it.[15] Untrained in this discipline and so unconcerned to contribute to it, when Lovelock spoke of "regulation," he was thinking in terms of cybernetic feedbacks, and not, like Dawkins, of "adaptation by natural selection." Thus, he was happy to have Margulis's company in that arena, the trained geneticist who had actual intra-disciplinary doctrinal battles to wage with the reigning neo-Darwinist orthodoxies. In Gaia's first two decades, Lovelock and Margulis presented a united front against the opposition to Gaia, predominantly from evolutionary biologists. However, the correspondence of the latter two decades documents a gradual truce on Lovelock's part, as key evolutionary thinkers in the British academy such as John Maynard Smith and W. D. (Bill) Hamilton, encouraged especially by the charms of Daisyworld, warmed somewhat to Gaia.

In any event, as one of us has argued (Dutreuil 2016), the idea that there was a "Gaia controversy" within evolutionary biology has been grossly exaggerated. For one thing, Gaia was not set forth as a contribution to this field. With the exception of their article published in *BioSystems*, all of Lovelock's and Margulis's single- and co-authored Gaia papers of the 1970s were published in Earth and planetary sciences and astrobiology journals. For another, with rare individual exceptions such as Bill Hamilton, the whole field of evolutionary biologists simply did not care about Gaia.[16]

[15] For the culmination of Lovelock's changing perceptions of neo-Darwinism, see Letter 270 and Part IV of the correspondence more broadly.

[16] See Letters 244–246 and 270 and our discussion of them later in this volume. See also the paragraph on evolutionary biology after Letter 45.

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After all, Gaia was put forward to explain the stability of the global environment, and so its theory bears most directly on objects foreign to the immediate interests of evolutionary biology, interests focused on diverse populations and adaptation. Pick up any major journal in that discipline and you'll have enough fingers on one hand to count the papers addressing Gaia directly. The fact that the same two critiques by Doolittle and Dawkins, dating 1981 and 1982, are still the only "serious" criticisms of Gaia mentioned decades later is telling regarding the general disinterest of evolutionary biologists, in spite of the painstaking efforts of Gaian theorists to engage with them.[17]

Gaia in the Earth Sciences

To an ear attuned to the recent history of the Earth and environmental sciences – the fields in which Gaia has had the most profound and durable influence – the standard narrative, according to which the Gaia of Lovelock and Margulis floats somewhere outside of the history of the mainstream sciences, sounds extremely misguided. It is true that the word "Gaia" gradually fades away from general scientific discussion (notwithstanding the modicum of scientific literature addressing it explicitly) after the late 1980s. But as Margulis cannily argues at the turn of the millennium, "the name changes ought not to deceive us about the true identities of our friends. 'Astrobiology' is the field of natural history reinvented to be fundable for a wide variety of scientists, whereas 'Earth system science' is none other than Gaia herself decked in futuristic garb and made palatable to the 'hard rock' scientists, especially geophysicists" (Margulis 2004: 8). Indeed, Gaia's core ideas have pervaded contemporary Earth sciences and the climate politics that stand beside them.

We will give just a few significant examples.[18] In the 1980s, for instance, the major decade for Gaia's progress in the sciences, it was climatologists who took the lead in organizing spaces of discussion dedicated to Gaia. Famously, it was the climate-change scientist Stephen H. Schneider who opened the journal *Climatic Change* to the discussion of Gaia between the 1980s and the early 2000s, and who also lead-organized the famous AGU

[17] The term "serious" only applies to Doolittle. It appears to us that Dawkins did not to read Lovelock's book before panning it, as could be guessed from what he writes about it. Doolittle recently came back to the Gaia debate with a renewed interest: see his commentary in this volume.

[18] For a broader overview of Gaia's reception in the Earth and environmental sciences, see Dutreuil 2016.

Chapman Conferences on Gaia (Schneider et al. 2004; Schneider and Boston 1991). The important climate modeler Ann Henderson-Sellers also made space for Gaia in her journal *Reviews of Geophysics* in the late 1980s, more than a decade after famous meteorologist Bert Bolin welcomed Lovelock's and Margulis's article in *Tellus* (Lovelock and Margulis 1974a).

More broadly, driven by recognitions of political emergency constituted by global climate changes, the 1980s saw the onset of international calls for the constitution of a new Earth science and the formation of a new object to be studied – the "Earth system," constituted by the vast, dense, and complex interconnections of the Earth's various components.[19] Important agencies structuring and funding the sciences, such as NASA, the International Council for Science, the International Institute for Applied Systems Analysis, and the National Science Foundation, wrote major new reports in these areas. NASA itself launched the label "Earth system science," which was then taken up by the International Geosphere–Biosphere Program (IGBP), the major institution to emerge out of this scientific ferment. In short, Gaian thinking directly influenced the IGBP's promotion of Earth system science,[20] which in its turn brought forward the IGBP's major concepts – such as the Anthropocene (Crutzen and Stoermer 2000), tipping elements (Lenton et al. 2008), and planetary boundaries (Rockström et al. 2009) – that now connect climate politics and the planetary sciences. In addition to the institution of Earth system science, Gaia's influence on the Earth sciences is to have obliged several fields within geology to take the influence of life on its environment fully into account: this is particularly the case for geochemistry and in the climate sciences, in which the purely physical climate models of the 1970s and earlier progressively included the effect of life on the climate, and moreover, in the phrase of Peter Westbroek (1991), began to see "life as a geological force."

A more recent example is Hans Joachim Schellnhuber, one of the most famous climatologists in the world, founder of the Potsdam Institute for Climate Impact Research (PIK), head of the central theoretical program of the IGBP for years, a counselor to German chancellor Angela Merkel and to the Vatican for the encyclical *Laudato Si* and its call to global climate action. Schellnhuber is also known as a very early advocate of climate targets, the

[19] On the history of Earth system science and the IGBP see Barton 2020; Conway 2008; Dutreuil 2016; Grinevald 1996; Heymann and Dahan Dalmedico 2019; Höhler 2015; Kwa 2005, 2006; Kwa and Rector 2010; Selcer 2018; Steffen et al. 2020; Uhrqvist 2014.

[20] See the commentary by Chris Rapley in this volume.

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famous 2 °C target in particular (Aykut and Dahan 2015). How did he, great admirer of Lovelock, defend this target at the United Nations, in the Vatican, and in front of European think tanks? Through a patently geophysiological comparison of Earth's rise of temperature to the fever of an organism, which, if prolonged for too long, might lead to the collapse of Earth's major organs – a metaphor directly inherited from Lovelock's Gaia, without the name being pronounced.

Systems Sciences

A neat historical parallel could be drawn between the different generations of Gaian scientists and the heterogeneous history extending from the rise of cybernetics during the Cold War to the biological cybernetics that gave rise to the theory of autopoiesis in the 1970s and the emergence of the complexity sciences of the 1980s.[21] Having started his career in the 1940s, Lovelock's systems thinking was fastened on the first-order cybernetics of self-organizing systems, self-regulation through negative feedback, and the closely allied discourses of energy and entropy that connected thermodynamics to information theory. One generation younger than Lovelock and starting out in the 1960s, Margulis endorsed the second-order cybernetics of Maturana and Varela and their concept of autopoiesis. This theory regarding the form and operation of living systems appeared just as Gaia itself was being introduced through its first publications. For Margulis, the concept of autopoiesis provided a clarifying criterion for the autonomous self-production of living systems in contrast to the more comprehensive and computational cybernetics of control systems. Margulis's theoretical fervor on this issue reads like an implicit counter to Daisyworld's production of digital parables about a virtual planet, in favor of "autopoietic Gaia." In this conception, the Earth system taps the flow of solar energy to maintain and complexify its continuous self-production out of the sum of the biota.[22] Starting in the late 1990s, Lovelock's main heir, Tim Lenton, has approached Gaia's ontology and modes of regulation through theoretical lenses developed in the complexity sciences first disseminated from the Santa Fe Institute in the 1980s, famous for having popularized chaos theory and nonlinear dynamics.

[21] On these histories, see Galison 1994; Keller 2008, 2009; Li Vigni 2018; Pickering 2010.

[22] See Letter 169 for an intensive effort by Margulis, for Lovelock's benefit, to negotiate the distinction between machines and living systems through the concept of autopoiesis. See also Clarke 2020, chapter 6.

Exo- and Astrobiology

Another important starting point for the Gaia hypothesis was Lovelock's reflection, within the context of NASA exobiology, on the use of Earth-based atmospheric analyses of other planets to determine the presence of life (Hitchcock and Lovelock 1967; Lovelock 1965). Famously, he then turned this procedure back onto the Earth. One of his earliest arguments for Gaia pointed to the manifestly low entropy of the Earth's atmosphere, for which only the presence of life seemed able to account, relative to the spent atmospheres of Mars and Venus as indexes of their lifelessness. The criterion Lovelock proposed, namely the observation of a massive thermodynamic disequilibrium (that is, a low-entropy state) in the Earth's atmosphere, catalyzed the realization of the enormous influence that living beings have on this planet's environment. Lovelock's work in this area, leading directly to the consolidation of Gaia as a hypothetical entity, also durably influenced exobiology, relabeled as astrobiology by the 1990s.[23]

Political Ecologies and Environmental Counterculture

In the spring of 1975, Margulis wrote to Lovelock with the news that Stewart Brand, the prime mover behind an important West Coast outlet of alternative thought styles, the *Whole Earth Catalog*, and now editor of its lively spinoff, *CoEvolution Quarterly*, "wants to do what looks like a whole issue on Gaia . . . He is claiming that his journal is responsible and responsive, refuses to compartmentalize science and that my accusation that he's into food faddism and astrology is totally unfounded" (Letter 77).[24] That summer, *CoEvolution Quarterly* indeed arranged for a substantial presentation of Gaia before a consequential audience with deeply environmental leanings, a generally erudite lay readership largely unconcerned with mainstream professional niceties. Replete with scholarly references, detailed tables, multi-sourced sidebars, evocative graphics, and author photographs, "The atmosphere as circulatory system of the biosphere: the Gaia hypothesis" mixed scientific depth and popular appeal (Margulis and Lovelock 1975). Numerous Gaia articles

[23] See Clarke 2020, Conrad and Nealson 2001, and Dick and Strick 2004. In the early 1990s, Carl Sagan and his colleagues employed the close passage of the Galileo space probe by the Earth to revisit Lovelock's criterion and show that, when looked upon from space, the thermodynamic disequilibrium of its atmosphere is the strongest evidence of life's presence on Earth (Sagan et al. 1993)

[24] On the history of Stewart Brand, the *Whole Earth Catalog*, and the American counterculture, see Bryant 2006, Clarke 2020, Kirk 2007, and Turner 2010.

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and items variously authored by Margulis and Lovelock subsequently appeared in *CoEvolution Quarterly* and its eventual successor, *Whole Earth Review*.[25] These connections would bring Lovelock and Margulis together with the American systems counterculture, leaving an appreciable intellectual mark on the science writings of Margulis in particular.[26]

The year 1981 also saw the first ripple of published Gaia criticism. However, thanks to Margulis's connections with the Whole Earth network impresario Brand, it washed ashore in a calculated way, within the friendly and eclectic pages of *CoEvolution Quarterly*, in the form of Doolittle's critique of Lovelock's *Gaia* (Lovelock 1979a), "Is nature really motherly?" (Doolittle 1981a). Margulis arranged not only to place her fellow biologist Doolittle's review with this outlet, but also for it to be immediately followed in the same number of that journal with responses and rebuttals by Lovelock and herself.[27] This same year, in a more positive and equally consequential development, the location of the Gaia hypothesis on the margins where normal science meets radical cultural agendas was further confirmed by an important alliance with William Irwin (Bill) Thompson, who sent both Lovelock and Margulis invitations to the heterodox intellectual gathering of the Lindisfarne Association.[28]

Additionally, a decade later, in a belated replay of the American lay reception of Gaia centered on *CoEvolution Quarterly*, with the arrival of supporters such as Peter Bunyard and environmentalist interest in the magazine pages of *The Ecologist* and *Resurgence*, the British popular reception of Gaia took a strong green-political and deep-ecological turn beyond anything rallied by the American greens around California's Whole Earth network. For one instance, as evidenced by the short series of Gaia conferences in Cornwall that began in 1987, by the later 1980s the Gaia concept had captured the imagination of the British environmental community around figures such as Teddy Goldsmith, the conservative environmentalist and founder of *The Ecologist,* and Satish Kumar, the editor of *Resurgence*.[29] These connections also led to the major event of Lovelock's participation in the 1990 founding and subsequent development of Schumacher College. Concurrently, Lovelock forged a new set of London-

[25] For instance, Lovelock 1981c, 1983b. [26] For details, see Clarke 2020.

[27] See Doolittle's commentary in this volume regarding Doolittle 1981a; Lovelock 1981b; Margulis 1981b; and Letters 121, 126, 128, and 130.

[28] See Clarke 2020; Thompson 2016.

[29] Two of the three Cornwall conferences in Cornwall are documented in detail, in Bunyard and Goldsmith 1988, 1989.

based publishing arrangements. Margulis would also be welcomed by these initiatives in British Gaia activism, but as an occasional visitor, not precisely as a compatriot.

In brief, the planetary speculation Lovelock presented to Margulis in 1971 set into motion an unusually robust series of wider scholarly and cultural waves. The Gaia concept progressed from the offbeat thought experiment Lovelock conceived and contemplated in the later 1960s to a viral meme, a mobile intellectual phenomenon comprehending the return of exobiological exploration upon the Earth itself and broad disciplinary upheavals in the Earth and environmental sciences. The variously irritating or irresistible idea of Gaia also tapped into the nascent planetary consciousness announced by Earth Day to build toward a swath of radical countercultural aspirations centered on ecological witness and the remediation of environmental degradation. Lovelock and Margulis were both variously sympathetic to the spiritual and existential currents unfolding from Gaia beyond the academy and mainstream disciplinary activity. They chose to consort with a selection of the intellectual elite among the lay supporters with whom they made common cause. All the same, the correspondence clarifies that while these extracurricular contacts brought certain kinds of social gratification, these connections could not supply them with what they both held to be most important: conceptual validation and the approbation of their scientific peers.[30]

Environment, Pollution, and Politics: Gaia and the Anthropocene

> Dr. Lovelock stressed that he was not suggesting that the Gaia hypothesis implies that we could let nature solve man's problems and that everything would be all right. Instead, he pointed out, if Gaia exists, our approach to environmental problems might be somewhat different from one in which we assumed nature was a passive entity with no homeostatic response

[30] For one instance of this shortfall, Margulis was disappointed when Lovelock and his colleagues Watson and Whitfield unexpectedly failed to show at Bunyard and Goldsmith's third Cornwall Gaia gathering in 1989. She wrote him that if there were to be a next time (there wasn't), she wanted to have a say in the program, complaining to Lovelock with uncharacteristic disapproval: "I do want to help arrange Gaia Cornwall next year (with you in it, or course). I think it might just be called 'The Science of Gaia' to keep away the nonscience... If you guys don't show up though I don't want to go to another meeting with German greens, Sahtouris, Mae-won Ho and computer people, etc." (Letter 191).

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> changes. Gaia might provide a rationale for global studies of environmental issues.
>
> (Kellogg and Mead 1977: 121–22)

This statement occurs in the proceedings of a major conference on climate change organized by the NCAR climatologist Will Kellogg and the anthropologist Margaret Mead. Thanks to his various consultancies both for chemical and petroleum companies and for the scientific institutions studying the contemporary state of the Earth and its environment, Lovelock was at the epicenter of "global pollution" (Dutreuil 2016, 2017). Lovelock was mixed up, sometimes very directly, with a suite of issues classically linked to the emergence of global environmentalism – the insecticide DDT, CFCs, acid rain, climate change, lead in gasoline exhaust, and smog in urban centers. Thus, it should not come as a surprise if, decades before the formulation of "the Anthropocene" to name the current geological epoch, Gaia was probed for ways to think about the global environment (Latour and Lenton 2019). While he was elaborating his ideas on Gaia in spare moments, in the 1960s and 1970s Lovelock's daily activities were immersed in pollution issues. These mundane and murky concerns certainly occupied more of his time than the frequently cited reflections on criteria to detect life on other planets. Lovelock himself testified to that in the introduction to his first book, when he noted the personal benefit he derived from a congressionally mandated postponement of NASA's Voyager program: "By great good fortune, so far as I was concerned, the nadir of the space program coincided with an invitation from Shell Research Limited for me to consider the possible global consequences of air pollution from such causes as the ever-increasing rate of combustion of fossil fuels" (Lovelock 1979a: 8). Lovelock's *Gaia* can indeed be read not only as a philosophical reflection on life and nature but also as an anthropological reflection on pollution (Dutreuil 2016, 2017). Accordingly, Lovelock's vexed relations with environmental politics are rather more complex than the simplistic idea that his long roll-out of Gaia should install him as a "green guru."

The "ozone affair" (Letter 87), regarding the potentially deleterious effects of human-made halocarbons on the stratospheric ozone layer and the policy decisions summoned in response, would loom at least as large over Lovelock's professional life in the mid-1970s as the "quest for Gaia" itself.[31]

[31] See "The Ozone War," chapter 8 of Lovelock 2000: 203–240.

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From the inception of this unforeseen complication in his scientific pursuits, Lovelock was broadly skeptical about the "freon doom story" (Letter 73):

> I am exceedingly busy just now, all through having dabbled in atmospheric chlorine chemistry. . . I doubt if there is anything to fret over. It is probably just another of those academic fashions which serve to keep universities centers of intellectual corruption. . . The Bowerchalke Lab is almost the sole source of atmospheric halogen compound information. You can guess the rest. (Letter 65)

What ensued over subsequent years were varieties of ad hominem attacks on Gaia, guilty by association with its inventor Lovelock's skepticism over a panoply of environmental alarms. Denunciations of conflict of interest for his testimony on behalf of DuPont before the US Congress, stating that CFCs were not as harmful as the worst-case scenarios suggested, led on many occasions to claims that Gaia itself was used to legitimate the suppliers and activities of polluters – a point that did not escape Doolittle's (1981a) critique. Lovelock recalled this attack against his professional integrity on the occasion of Margulis receiving some bad press in the British newspaper *The Guardian*, noting sarcastically how that same outlet once "accused me of being a bought man of the chemical industry (quite untrue – no such luck)" (Letter 222).

As the passage from Kellogg and Mead documents, Lovelock's history of statements in this regard has often been reduced to the soundbite that "Gaia will regulate human pollution." A related argument put forward by Lovelock is that "pollution is natural."[32] Because humans and their activities are a part of Gaia, their byproducts are as "natural" as the belching of cows and, what amounts to the same thing, the waste gases of bacterial metabolisms. When a human source of "pollution" is identified, one can always find some equivalent in the non-human world. Stated thus, however, Margulis agreed entirely with this view of the issue: "Pollution is certainly distressing," Margulis and Sagan write in *What is Life?* "But it is hardly unnatural. The pollution crisis effected by all-natural, blue-green bacteria was much worse than any we have seen lately," referring to the Great Oxidation Event of 2.2 billion years ago. Drawing out the irony of framing this massive evolutionary threshold as a pollution event, Margulis and Sagan also point out how "Earth's protective,

[32] On the importance of this argument for Lovelock and its relationship to Gaia, see Aronowsky 2021; and Dutreuil 2016, 2017.

ultraviolet-shielding layer of ozone (O_3, a three-oxygen molecule) was built up largely by 'all-natural' pollution in the first place." Thus, "if pollution is natural, so is recycling . . . One of the greatest turnarounds in evolution was the transformation of a once-fatal form of air pollution – oxygen – into a coveted resource" (Margulis and Sagan 2000: 106). However, even if they agreed philosophically about conceiving pollution as a natural phenomenon, this did not always lead them to the same practical conclusions. Lovelock's claims were indeed frequently controversial or, at least, at odds with most "green" ideologies. Margulis's more occasional environmental remarks tend to cite the Gaian perspective as a sound reason to preserve the ecologies of current natural habitats.

In 1974, at the start of the ozone affair, Lovelock wrote to Margulis: "We have just discovered a huge natural source of methyl chloride (about 5 megatons a year). It is almost certainly of marine origin . . . It means that the input of chlorine to the stratosphere from natural biological sources is probably at least 100 times and possibly 1000 times larger than from the freons" (Letter 69; see also Letter 76). Lovelock's inference from the discrepancy between these natural and anthropogenic proportions was that the drive to ban freons immediately to counteract stratospheric ozone depletion was, at the least, too precipitous, a position he maintained until very late in the scientific controversy (see, for example, Lovelock 1981a). Thus, some have read into Lovelock's statements on pollution the outlines of policy positions that lie in the vicinity of Oreskes's and Conway's (2010) *Merchants of Doubt*.[33]

What matters here is that these issues determined an important part of Lovelock's daily activities during the early years of his collaboration with Margulis. They are indeed bound up with his own development of Gaia, and they constantly come up in the correspondence, especially on Lovelock's side. For her part, Margulis rarely touches upon these matters, and when she does, it is to get back to the science: "What is your current hypothesis for origin of methyl chloride and role of ozone layer in climate regulation (in two sentences or less)?" (Letter 74). In short, in the correspondence between Lovelock and Margulis, the ozone issue is to some extent an annoyance that Lovelock brought upon himself, but it is much more a central node connecting to many other Gaian issues. These include: ozone, nitrous oxides, and the regulation of climate; the natural emission of methyl chloride and

[33] See for instance Aronowsky 2021; and Dutreuil 2016, 2017.

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input of chloride to the stratosphere; and stratospheric ozone as an ultraviolet shield over geological time, its absence before the Great Oxidation Event, and the effects of its destruction today. Moreover, understanding the importance of chlorine compounds in ozone depletion also led Lovelock and Margulis to reflect on other Gaian dynamics and effects, such as the cycle of iodine or the regulation of oceanic salinity. In Gaian relief, ozone is much more than just a human concern.

Finally, politics aside, another way to recognize the complementarity of Lovelock and Margulis is by starting from the chemical compounds that cycle through the natural environments of their respective disciplinary locations. Take another atmospheric organic compound, methane: it is produced by Margulis's methanogenic bacteria in the guts of cows in Devon, where Lovelock is deeply concerned over the pathogenic practices of industrialized agriculture. Methane is also a commodity transported by Shell tankers, raising engineering issues Lovelock had to think about. And it is a natural byproduct of the biosphere involved in one of the primary regulatory mechanisms Lovelock and Margulis proposed for stabilizing atmospheric oxygen. Our point is that the synergetic activities of chemical elements in the Earth system or in Gaia were *embedded* in the materiality of the professional practices and intellectual engagements that the company of Lovelock and Margulis held in common.

A Chronological Outline

Our preface so far has been arranged thematically, cutting across the sequence of the Lovelock–Margulis correspondence. To conclude, we hope to assist the reader's entry into the letters proper by touching on some chronological aspects of their presentation in this volume. The letters are arranged in chronological order and divided into four roughly equal parts, reflecting their gradually diminishing frequency over the span of the correspondence. Each part has its own introduction and is occasionally punctuated by editorial remarks on Lovelock, Margulis, Gaia's story more broadly, and closely neighboring topics of interest.

The first two parts document the beginnings of the correspondence and the origin of the collaboration in Part I (1970–1972), followed by the close, detailed, and technical record of Lovelock's and Margulis's joint work on the main sequence of their co-written papers in Part II (1973–1979). On Margulis's side, during this decade she is still intensely occupied with establishing herself in the academy on the primary basis of her work on

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microbial evolution, while also providing major professional service to the exobiology initiatives of NASA and the National Academy of Sciences. In 1976–77, she spends a semester as Sherman Fairchild Distinguished Scholar at the California Institute of Technology and is promoted to full professor, and in 1979 she is a Guggenheim Foundation Fellow researching early life on Earth. On Lovelock's side, this decade is heavily marked by the ozone affair. He is at the peak of his period of consultancy with a diverse roster of clients and employers, while publishing technical articles on the ECD (Lovelock 1974b), climate change (Lovelock 1971), and atmospheric and oceanic measurements of dimethyl sulfide and halocarbons (Lovelock 1974a, 1975, 1977; Lovelock, Maggs, and Rasmussen 1972). He is elected Fellow of the Royal Society in 1974. His 1975 article co-written with his Shell colleague Sydney Epton and published in *New Scientist* attracts enough interest to have Oxford University Press ask him to develop the idea for what will become Lovelock's first book. In the summer of 1977, Lovelock packs up his lab at Bowerchalke and moves his operations to Coombe Mill on the Devon–Cornwall border.

Part III (1980–1991) picks up with the publication of *Gaia: A New Look at Life on Earth* (Lovelock 1979a). The writing collaboration of the previous decade enters a new, less strenuous phase. Margulis provides close editorial oversight as Lovelock develops his next book, *The Ages of Gaia* (Lovelock 1988). However, with the exception of the retrospective article "Gaia and geognosy" (Margulis and Lovelock 1989), their period of intensive co-authorship on professional and popular articles has closed. Lovelock cultivates a new set of co-authors while Margulis establishes an enduring writing collaboration with her first son, Dorion Sagan. This decade is also marked by the first critiques from evolutionary biologists (Dawkins 1982; Doolittle 1981a) and Earth scientists (Kirchner 1989). Nevertheless, Lovelock and Margulis remain closely engaged in their mutual efforts to respond to such criticisms and to establish Gaia within and without the academy through lectures, symposia, conferences, and sundry organizational initiatives. The 1980s is undoubtedly the most active decade for the history of Gaia, marked by a broad upsurge of interest in both professional and general venues. Lovelock publishes landmark papers moving Gaia from hypothesis to theory (Charlson et al. 1987; Lovelock and Whitfield 1982; Watson and Lovelock 1983). The AGU's first of two Chapman Conferences on Gaia takes place in 1988, alongside debates over Gaia in important journals such as *Reviews of Geophysics* and *Climatic Change*. In the Earth sciences of this decade, Gaia is everywhere, and the scientific ferment it inspires sets the stage for NASA's consolidation of Earth system science and the constitution of the IGBP.

Part IV (1992–2007) starts after the publication of Lovelock's third book (Lovelock 1991a) and with initial preparations for the consequential series of Gaia in Oxford conferences of the 1990s. These meetings are marked by Lovelock's increasing determination to reconcile Gaia and evolutionary biology. Margulis is dubious about such a rapprochement but remains staunch in her advocacy for Gaia. Working with her partner, Ricardo Guerrero, she has a major hand in bringing the second Chapman Conference on Gaia to Valencia, Spain, in 2000. Additionally, by the end of the 1990s, Tim Lenton arrives as an important proponent of Gaia research. Watson and Lovelock supervise Lenton's doctoral work, after which Lovelock passes him the baton to keep Gaia's scientific development going in the academic race. In the 2000s, another notable Lovelock protégé, Stephan Harding, publishes his study of Gaia, *Animate Earth* (Harding 2006), and forms a writing collaboration with Margulis to develop the essay "Water Gaia" (Harding and Margulis 2010), in the mold of the Lovelock and Margulis papers of earlier decades.

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