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Gaia's evil twin: Is life its own worst enemy?

By Peter Ward



Toxic gases and mass extinctions mean Earth isn't always life friendly
(Image: Sarah Howell)

Interactive graphic: *Medean extinctions throughout evolutionary history*

THE twin Viking landers that defied the odds to land on Mars in 1976 and 1977 had one primary goal: to find life. To the disappointment of nearly all concerned, the data they sent back was a sharp dash of cold water. The Martian surface was harsh and antibiotic and there was no sign of life.

To two NASA scientists, James Lovelock and Dian Hitchcock, this came as no surprise – in fact, they would have been amazed to see any evidence of life on Mars. A decade before Viking, Lovelock and Hitchcock, both atmospheric scientists, had used observations of the Martian atmosphere to deduce that there could be no life on the planet.

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From their research arose one of the most influential, ground-breaking scientific ideas of the 20th century – the Gaia hypothesis, named after the ancient Greek goddess of

the Earth, a nurturing “mother” of life. But is it correct? New scientific findings suggest that the nature of life on Earth is not at all like Gaia. If we were to choose a mythical mother figure to characterise the biosphere, it would more accurately be Medea, the murderous wife of Jason of the Argonauts. She was a sorceress, a princess – and a killer of her own children.

The Gaia story starts in the 1960s, when Lovelock and Hitchcock showed that the Martian atmosphere was in a state of chemical equilibrium – a stagnant pool of carbon dioxide with a dash of nitrogen but very little oxygen, methane or hydrogen. They contrasted it with our own, which they recognised as being in chemical disequilibrium, with CO₂ and oxygen levels in constant flux. The key driver of this flux is life: photosynthesis exchanges CO₂ for oxygen, and aerobic metabolism does the opposite. Without life, our atmosphere would radically change from the oxygen-rich and life-sustaining gaseous mix we breathe to one in chemical equilibrium – one that, like the Martian atmosphere, would be inimical to life.

Earth’s atmosphere is not only in flux, it is welcoming to life, and has been for billions of years. Similarly, Earth’s surface temperature, acidity and ocean chemistry seem to have been stable for billions of years, hovering around mean values that allow continued habitability. Pondering these implications, Lovelock began piecing together a novel view of life and its interaction with the planet that hosts it. Although he focused on Earth, his ideas have implications for any habitable planet, and he has spent the rest of his career honing them.

Stated briefly, the Gaia hypothesis is that life as an aggregate interacts with the physical environment in such a way that it not only keeps the Earth habitable but continually improves the conditions for life. It does this through a series of feedback systems similar to biological homeostasis, the mechanism by which living organisms maintain a stable internal environment. Those aspects that most affect the habitability of the planet – temperature, the chemical composition of the oceans and fresh water, and the make-up of the atmosphere – are not just influenced by life, they are controlled by it.

Lovelock’s concept has evolved over time, and Gaia has speciated into several different hypotheses (see “The many faces of Gaia”). Within a decade of his first writings he elevated his hypothesis to the scientifically stronger Gaia theory. In the mid-1970s he described his view of things as follows: “The Gaia theory says that the temperature, oxidation state, acidity and certain aspects of the rocks and waters are kept constant, and that this homeostasis is maintained by active feedback processes operated automatically and unconsciously by the biota.”

Lovelock eventually began to refer to the planet itself as some kind of superorganism. “The entire range of living matter... from whales to viruses and from oaks to algae could be regarded as constituting a single living entity capable of maintaining the Earth’s atmosphere to suit its overall needs and endowed with faculties and powers far beyond those of its constituent parts,” he wrote in his 1979 book *Gaia: A new look at life on Earth*. In other words, the Earth is not simply a planet that harbours life, it is itself alive.

The idea was simple and elegant, and quickly attracted many adherents, both scientists and non-scientists. Some researchers saw in Gaia a new way of thinking about the cycles of organic components and elements. Some followed Lovelock’s lead in searching

for scientific support for the idea that life regulates conditions on the planet. Some, mainly non-scientists, saw in it a new view of how humans should relate to the planet and the rest of life. Some even found the face of god in the concept.

Gaia continues to generate scientific interest and debate: there have been three international conferences devoted to the hypothesis, the most recent in 2006.

The ground is shifting, though. A number of recent discoveries have cast serious doubt on the Gaia hypotheses. Two lines of research are especially damning: one comes from deep time – the study of ancient rocks – and the other from models of the future. Both overturn key Gaian predictions and suggest that life on Earth has repeatedly endured “Medean” events – drastic drops in biodiversity and abundance driven by life itself – and will do so again in the future (*see a timeline of Medean events*).

Let us turn first to the deep-time discoveries. One of the most powerful arguments made by Gaia proponents is that planetary temperatures remain steady and equable thanks to feedbacks that are caused, or at least abetted, by life.

The single most important of these various “thermostats” is the carbonate-silicate weathering cycle. Because of the constant volcanic activity that is a feature of our planet, there is an unceasing but variable input of CO₂ into the atmosphere. CO₂ is a potent greenhouse gas. Without some way of scrubbing it out, it would build up to the point where the Earth would experience runaway warming that would ultimately cause the oceans to boil away – the fate of Venus some 4 billion years ago.

That scrubbing is provided largely by chemical weathering of silicate-rich rocks such as granite. This weathering drives a chemical reaction with CO₂ that removes the gas from the atmosphere and locks it away as limestone (calcium carbonate).

The rate of this reaction is increased by land plants, whose roots break up rock and allow water and CO₂ to penetrate. Plants also directly remove CO₂ from the atmosphere through photosynthesis.

So far, so Gaian. But as scientists have made ever more precise estimates of past global temperatures, the constancy predicted by Gaia theory has been found wanting. In fact there has been a rollercoaster of temperatures, caused by the evolution of new kinds of life (*see a timeline of Medean events*).

Around 2.3 billion years ago, for example, Earth endured a gigantic episode of glaciation that lasted 100 million years. It was so intense that the oceans froze completely, creating a “snowball Earth”. The cause was life itself. Around 200 million years earlier, evolution had come up with a novel way to make a living: photosynthesis, the process that uses the energy in sunlight to convert inorganic CO₂ into sugars. Photosynthetic microbes sucked so much heat-trapping CO₂ out of the atmosphere that the planet was plunged into the freezer.

A second episode of snowball Earth, brought about by the evolution of the first multicellular plants, happened 700 million years ago. Much later on, the evolution of land plants gave the climate a double whammy. As well as reducing CO₂ by photosynthesis, their deep roots dramatically increased weathering rates. The result was that soon after the appearance of forests near the end of the Devonian period (416 to 360 million years ago), the Earth entered an ice age that lasted 50 million years. The warm, verdant planet cooled rapidly and vast swathes of life died out. Not a very Gaian

result.

In fact, for as long as life has existed it has been well able to devastate itself. Charles Darwin envisaged newly evolved life forms entering the world like a wedge, easing into a narrow vacant niche then expanding it gradually. Some do. But others enter like a sledgehammer, smashing away entire branches of the tree of life as they arrive.

This has been the way since the very earliest life. Around 3.7 billion years ago, we think a “methane crisis” nearly wiped life off the face of the Earth almost as soon as it had got going. Methane-belching microbes filled the atmosphere with a hazy smog that all but blocked out the sun (*see a timeline of Medean events*).

Perhaps the worst Medean event of all was precipitated by the same biological innovation that led to the first snowball Earth: the evolution of photosynthesis and the concomitant rise of atmospheric oxygen. Until that time, living things could not tolerate oxygen – it was a deadly poison to the microbes that constituted life before 2.5 billion years ago. With the evolution of photosynthesis a weapon of mass destruction was unleashed, creating the first, and perhaps the most extreme, of all mass extinctions. Life was devastated. All that survived were photosynthesisers and microbes that evolved rapidly to tolerate oxygen.

Even more damning to the Gaia hypothesis are new results from the study of the mass extinctions that have occurred since the evolution of animals 565 million years ago, of which there have been five big ones and about 10 more minor ones.

When in 1980 geologists made the ground-breaking discovery that the Cretaceous/Tertiary mass extinction of 65 million years ago was caused by an asteroid hitting the Earth, it soon became orthodoxy that all mass extinctions had been caused by extraterrestrial events: either impacts or, in the case of the Ordovician extinction 443 million years ago, a gamma-ray burst. These events are termed “Gaia neutral”, because life has no way of preparing for them.

Researchers quickly identified impact craters apparently associated with mass extinctions, including the huge Permian/Triassic event of 251 million years ago and the Triassic/Jurassic event 200 million years ago. Yet the evidence that impacts cause mass extinctions has not stood up to scrutiny. Most are now seen as “microbial” mass extinctions, caused by huge blooms of bacteria belching poisonous hydrogen sulphide gas (*New Scientist*, 9 February 2008, p 40). These blooms thrive in the stagnant oceans that arise during intense episodes of global warming, such as the one at the end of the Permian, when prolonged volcanic activity vented vast amounts of CO₂ into the atmosphere. According to Gaia theory, life should have buffered these events. But it did not. Far from being Gaian, their existence seems to strongly support the Medean view, as do many other events in the history of life including, arguably, the human-induced mass extinction that is going on around us now (*see a timeline of Medean events*).

What of the future? Here too we can refute Gaia, and this is perhaps the most interesting – and shocking – of discoveries. Life seems to be actively pursuing its own demise, moving Earth ever closer to the inevitable day when it returns to its original state: sterile.

How so? The starting point is that the sun is getting hotter. It has increased in brightness by about 30 per cent over the past 4.5 billion years and will carry on doing so. As the sun continues to burn brighter it will cause global warming, which will

translate into increased weathering of silicate rocks – the rate of weathering rises with temperature. This will remove CO₂ ever faster from the atmosphere, aided and abetted by photosynthesis and plant roots.

Calamity strikes

At first, this removal of CO₂ will buffer the solar-induced temperature increase. But there will come a time – possibly as early as 500 million years from now – when there is not enough CO₂ in the atmosphere to support photosynthesis. When that calamitous day arrives, a very pronounced end of the world as we know it will begin.

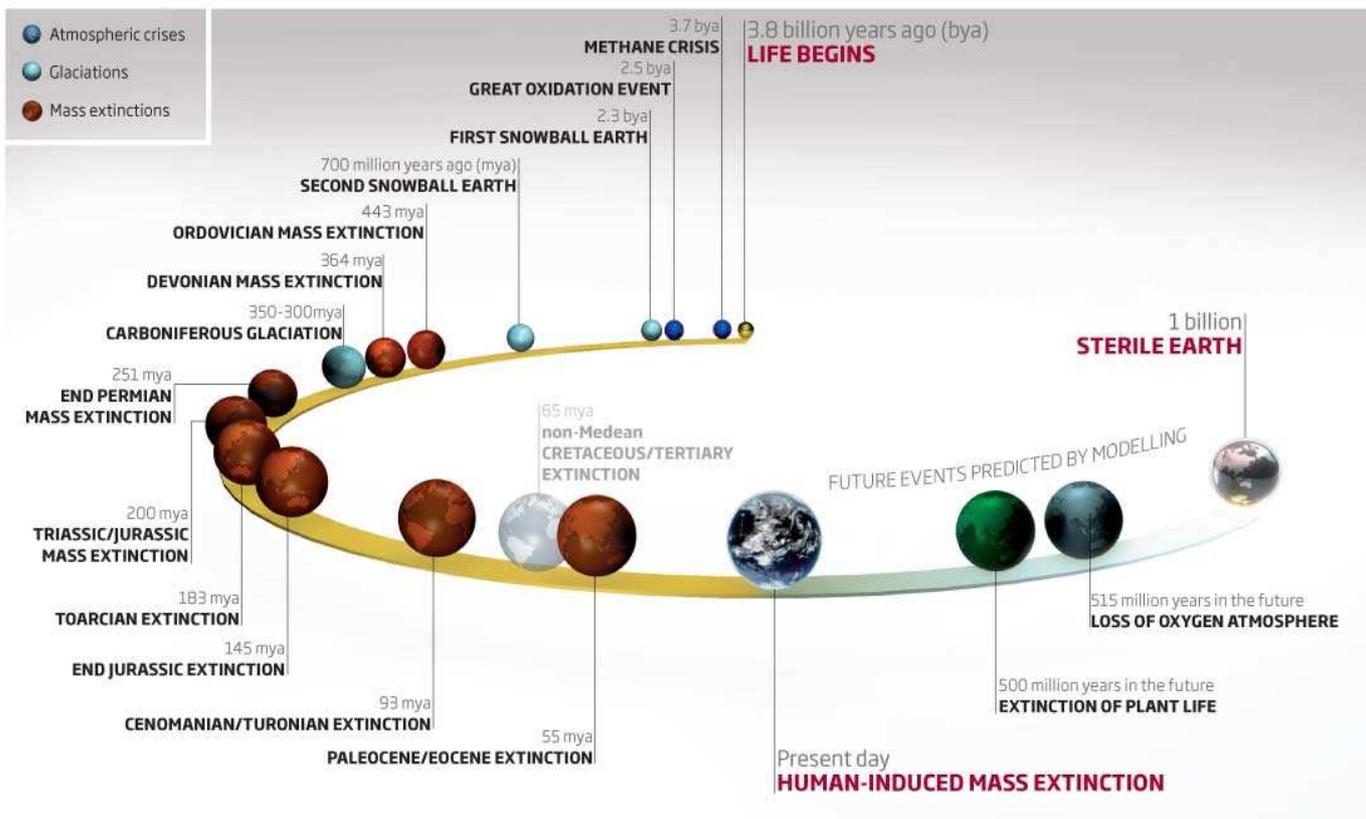
The changes will be dramatic and catastrophic to life. Plants will wither and die, shutting off the main source of biological productivity and atmospheric oxygen. Animals will quickly follow. The loss of plants will also lead to a renewed build-up of CO₂ in the atmosphere, leading to a runaway greenhouse. Eventually, the temperature of the Earth's surface will exceed that of boiling water, and the last microbe will perish. Earth will be lifeless once more. This is very anti-Gaian, since the theory states that the presence of life on a planet should extend its habitability. The opposite is true.

If these models are correct, life on Earth is already in its old age. The adventure that started 3.8 billion years ago, and is still the only life we know of in the universe, has maybe another billion years to run. The long-term, and terminal, decline of CO₂ in the atmosphere has already started – the effect of burning fossil fuels is just a blip. Gaia is dying. Long live Medea. For now.

Interactive graphic: *Medean extinctions throughout evolutionary history*

When life kills life

Almost all mass extinctions have been caused by one type of life killing another, with the notable exception of the Cretaceous/Tertiary mass extinction, which is thought to have been the result of an asteroid impact



The many faces of Gaia

There are at least three different variants of the Gaia hypothesis

Optimising Gaia

This early interpretation remains one of the “strongest” versions of Gaia theory. It implies that life actively controls environmental conditions, including purely physical aspects of the biosphere such as temperature, oceanic acidity and atmospheric gas composition, such that the Earth remains optimally habitable.

Self-regulating (or homeostatic) Gaia

A more recent and slightly weaker incarnation of the theory. Rather than life actively optimising conditions on the planet, it creates negative feedback systems that keep life-constraining factors such as temperature, and more recently atmospheric oxygen and carbon dioxide levels, within certain ranges.

Superorganism Gaia

The Earth isn't just a physical planet that supports life, it is itself alive. This is the strongest interpretation of the theory and tends to be viewed as unscientific.

Peter Ward is professor of biology at the University of Washington in Seattle. This article is based on his new book *The Medea Hypothesis: Is life on Earth ultimately self-destructive?* (Princeton University Press)

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