a3 The Gaia metaphor < Lovelock, geophysiology >

> Those of you who *have* heard the other two lectures will also find this lecture incomprehensible, but you know that that's all right: as I explained in the first lecture, the way we have to describe Nature is generally incomprehensible to us. —Richard P. Feynman, *QED*, 1985.[3]

To focus interest on the ecology of our world since its birth, the Gaia metaphor likens Earth to a living organism that is actively involved in maintaining itself. Stony planets on which life has not taken hold can evolve geologically to exclude life because they, like Venus, become too hot or, like Mars, become too cold. Our stony planet remains just right for life, possibly because it has life.

As a purely geological body, stony Earth could have evolved to become unsupportive of life (and the story of Goldilocks). But life has more than coped.[4] From putative first microbials have evolved bacteria, archaea, and eucarya.[5] Runaway trends leading to the shut down of all life have not occurred. How come? Has life itself steered Earth's geological evolution? Has life by its own evolution regulated the environment so that runaway trends that could make our planet unsuitable for life were headed off?

On Earth, life early evolved from inorganic materials. Since then, life has operated to radically alter the evolution of the inorganic components (atmosphere, oceans, and weathering processes) of the biosphere (word coined in 1926 by Vladimir Ivanovich Vernadsky for the environ of all living organisms of a planet).[6] By partitioning materials that subduction carries down, life has even influenced the evolution of the lithosphere and the mantle. By life's activity, inorganic compositional changes of the environment were to an oxidizing from a reducing atmosphere and to an alkaline (pH 8.1-8.2 on average at present)[7] from an acidic ocean. Life has reacted to extrinsic (insolation, bolide) caused variation in Earth's global climate and to volcanism that has waxed and waned.

James E. Lovelock (***Figure a3.1***), after years of measuring atmospheric gas abundances, suspected that living organisms had a greater effect on the atmosphere than was generally recognized. It dawned on him (September 1965, his memoirs record) that an understanding of the ecology of this world could be inspired by thinking of Earth as a superorganism. (Not believing for one minute that Earth is actually a living entity), he whimsically named his hypothesis Gaia (for the ancient Greek earth-goddess and on the suggestion of this name for his agnostic world view by an intrigued friend William Goldberg: "Now we ... see our earth, our mother, Gaia Mater, set like a jewel in space").[8] A living organism can flourish in chemical disequilibrium with its surrounds while it has life. Without life, it forthwith decays. So the atmosphere in strong chemical disequilibrium (methane and oxygen to its upper reaches) for billions of years, can have had this as a stable state only if continuously regulated. Lovelock likened Earth to a self-regulating superorganism that reacts to sustain its existence. Gaia is a metaphor for discoverable webs of bio-physio-feedback mechanisms that are emergent in the coupled evolution of physical and biological systems that do keep, and have kept, Earth just right for life.

For example, Lovelock and Lynn Margulis have proposed: 1) that global temperature is moderated by the release and absorption of greenhouse gases by plankton at sea and by organisms in bogs and peat lands that shrink and grow. Glaciation is thereby regulated. 2) Bacteria and other microbes in tidal mud flats, process enough salt to help keep ocean salinity fairly consent.

The Gaia metaphor, like the concept of The Rock Cycle (*see* Topic *a17*), is an organizational principle. The value of Gaia is that those who contemplate her are encouraged to consider multiple working hypotheses for good geology, as was demonstrated in 1886 by G. K. Gilbert (*see* Topic *b20*), and urged in 1890 and 1897 by T. C. Chamberlin, to explain the subtle and so not necessarily self-evident workings of nature. Modeling organic/inorganic negative-feedback loops is the science of Gaia.[9] Two examples are:

The oceans and land surface lag each other in accelerating and, alternately, slowing the carbon dioxide buildup in air (an oscillating system):[10] An El Niño event is when, across the equator, the surface temperature of the Pacific ocean is 0.5ºC above average for more than three months. Then the Pacific absorbs less carbon dioxide than usual from the air. The strongest El Niño on record, beginning in 1997, lasted 13 months and boosted land temperatures by 0.8ºC. The land surface, because warm air increases the rate of rotting vegetation, then begins to emit more carbon dioxide. In the 1980s, a monitored carbon dioxide buildup could be traced to oceanic warming that had depressed the amount of gas absorbed by the upper layer of water. In 1990, global temperatures reached record highs. Then in 1991 the warming spurred the growth of continental vegetation *to absorb* additional carbon dioxide. The measured slowdown in the accumulation of atmospheric carbon dioxide in 1992 and 1993 accords to this hypothesis. A competing hypothesis is that the eruption of Mt. Pinatubo in mid-1991 put into the stratosphere sunlight blocking particulates. Cooling of the globe ensued and atmospheric carbon dioxide accumulation was lessened.

The plankton-cloud relationship: Plankton exudes dimethyl sulfide (DMS), which diffuses into the atmosphere. The DMS precursor, dimethylsulfoniopropionate (DMSP) is produced by phytoplankton (single celled plants) such as diatom *Emiliania huxleyi* (***Figure a3.2***). These also manufacture separately an enzyme DMSP lyase. The two, DMSP and DMSP lyase, when mixed by grazing yields DMS and acrylic acid. The latter is repellent to herbivorous microplankton and Gordon V. Wolfe in 1999 suggested it evolved as a grazing inhibitor.[11] In 1987, Robert J. Charlson proposed that DMS oxidizes in the air to form tiny sulfate particles (on which water will condense) and seeds clouds that cool the world.[12] Investigators have since found a correlation between DMS levels and the brightness of clouds over the Southern Hemisphere. Understanding of how the marine microbial maze and climate can be linked is generating much research.[13]

Daisyworld [14] is a simplistic model for the workings of Gaia. To satisfy those who would that a serious subject have a serious name, Gaia can be called *geophysiology*.[15] In this the Gaia metaphor (which is poetic as in U. S. Grant's "I am a verb.")[16] is replaced by a simile (which is specific as had Grant said "I am a man of action, like a verb.") of liking Earth systems to leaky containers with life working, and evolving ways, to return or clean up spills. As for us, Lovelock warns: "Its much too late for sustainable development. What we need is a sustainable retreat."[17] ❑

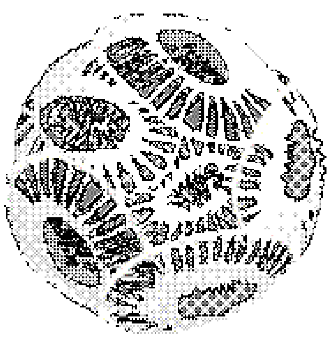

Figure a3.2 The *test* (word used for a shell that, in life, is covered over by soft parts of the organism) of the single celled phytoplankton *Emiliania huxleyi*. The scanning electron micrograph, sketched here, shows the life organization (sphere 0.5 mm across) of calcium carbonate plates called *coccoliths*.[18] These shell components usually fall apart after death and give seawater a milky-turquoise color that is easily imaged by satellite.[19]

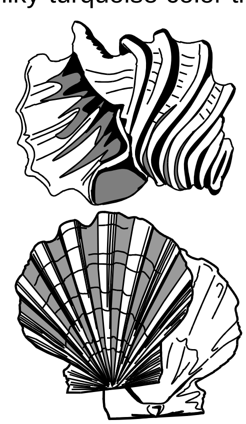

Figure a4.1 William Huddesford's 1770 printing in England of the third edition of Martin Lister's *Historiae Conchyliorum* (History of Conchs) included a sketch of *Ecphora quadricostata* (shown at right top ~1/2 scale), a marine snail, now designated *Ecphora gardnerae gardnerae* (Wilson) and the state fossil of Maryland. Hugh Jones, is thought to have collected it while rector (1696 to 1701) of Christ Church in Port Republic. Also, long prized by Amerindians for plates and scrapers, and washing free from eroding Chesapeake cliffs, is the fossil scallop (extinct since 4 million years ago) named in 1824 *Chesapecten jeffersonius* (shown at right botom ~1/10 scale) and now the state fossil of Virginia.[1] A sketch of *C. j.* appears in the first edition of Lister's *Historiae Conchyliorum*, 1687.[2]