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J.E. Lovelock: SOME THOUGHTS ON GAIA AND THE SULFUR CYCLE

Hypotheses are tested by the accuracy of their predictions. The gaia hypothesis states that the composition, oxidation-reduction state, and temperature of the troposphere are actively regulated by the biota for the biota (Lovelock, 1979). One of the early predictions of the gaia hypothesis was that there should be a sulfur compound made by the biota in the oceans. It would need to be stable enough against oxidation in water to allow its transfer to the air. Either the sulfur compound itself or its atmospheric oxidation product would have to return sulfur from the sea to the land surfaces. The most likely candidate for this role was dimethyl sulfide.

This gaian prediction has been handsomely confirmed by observations of M. Andreae. DMS was found to be abundantly produced by algal blooms, particularly those over the continental shelf regions. The production is so large that DMS can be considered to be the principal sulfur carrier of the natural environment.

Many biologists who might otherwise favor the gaia hypothesis find it difficult to comprehend the channel of communication that instructs marine microorganisms to produce DMS for the "benefit" of the land biota. The scenario that follows is one possible explanation of the development of this link.

The synthesis of propiothetin (that is, beta dimethyl sulfonioproprionate or DMSP), DMS, and DMSO probably began as a device for the protection of marine microorganisms against salt stress (see Fig. I-2). It may not be so well known that DMSO is the most effective neutral solute for protection against the adverse effects of dehydration or freezing. I proposed its use for this purpose in 1957 and it has been used since then, perhaps unwisely, to freeze human embryos in a viable state. Propiothetin and betaines are able to protect against salt stress (they are osmolytes) (see Fig. I-1). The protective action of betaines and their relation to DMS has been noted (Andreae and Raemdonck, 1983). DMS is a byproduct and an end product of the metabolism of DMSO and of DMSP.

Imagine some early, possibly Archean ecosystem existing on the tidal reaches of the shore of a land mass. When the tide receded the organisms left behind would be subject to severe desiccation and salt stress. The production of the DMSO family of compounds would be one answer to these immediate problems. An unintended consequence would be the escape of DMS to the air as a byproduct. On-shore breezes would deliver sulfur from the DMS to the land biota that previously had been depleted in sulfur. They would then flourish and in time this would lead to an increase in the runoff of nutrients such as nitrates and phosphates from the land. This would encourage the further growth of algae and so on. This process could easily be modeled: there would be a spread of land biota inwards as the DMS penetrated further inland and a spread of the DMS producers as the nutrients spread into the ocean waters. These arguments apply to the production of volatile compounds of other essential elements (e.g., selenium and iodine).

Do the phaeophyte algae, *Laminaria*, that produce methyl iodide in surprisingly large quantities, contain an iodonium betaine?

$$CH_3.I^+.CH_2.CH_2.COO^-$$

Laminarians might be the major source of tropospheric methyl iodide.

Another sulfur compound of interest from a gaian viewpoint is CS_2 (carbon disulfide). If CS_2 is a biological product arising from anaerobic biosynthesis in the sediments, then its production could provide an economic form of climate regulation. CS_2 oxidizes to COS (carbonyl sulfide) in the atmosphere. The compound COS has a residence time of months, long enough to ensure its transfer to the stratosphere. Once in the stratosphere it oxidizes further to form the sulfuric acid aerosol and the presence of this aerosol alters the Earth's radiation balance causing a cooling of the surface.

Bob Garrels wonders if CS_2 played a major role in early Archean biogeochemistry as a surrogate for CO_2 in the metabolism of the photosynthetic sulfur bacteria. Can CS_2 be used as a carbon source instead of CO_2 in anaerobic photosynthetic sulfur bacteria or cyanobacteria? The biochemistry of CS_2 production might be rewarding to study.

Andreae, M.O. and Raemdonck, H., 1983. Dimethyl sulfide in the surface ocean and the marine atmosphere: a global view, Science 221: 744-747.

Lovelock, J.E., 1979. *Gaia: A New Look at Life on Earth*, Oxford University Press, Oxford, U.K.

NOTE: Unfortunately Dr. Lovelock was unable to attend the PBME course. That his enthusiasm for it was unbounded is attested to by this voluntary contribution which he submitted on July 15, 1984. For further references, please see the lecture abstract of M. Andreae at the beginning of this volume.