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A Comment on Methanogenic Bacteria and the Primitive Ecology

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Summary. The phenotype and antiquity of methanogenic bacteria suggest them to have been one of the major factors determining a dynamic balance between CO_2 and CH_4 in the primitive atmosphere.

Key words: Methanogenic bacteria – Primitive atmosphere – Evolution – Ecology – Methane-carbon dioxide cycle.

It is important to realize that the phenotype of the methanogenic bacteria is particularly well suited to an environment such as that thought to have existed on the primitive earth, which suggests these organisms to be very ancient.

The members of this little known group of bacteria derive their sole source of energy and of carbon from a unique anaerobic metabolism that reduces carbon dioxide to methane and water (McBride and Wolfe, 1971). Some are also able to utilize a carbon source readily convertible to carbon dioxide, such as formic acid, but none can metabolize the more typical organic carbon sources (Wolfe, 1972).

It has been argued that the primitive earth never possessed a highly reduced atmosphere – one comprising the hydrides, methane, ammonia, etc. Rather, the virtual absence of the heavier noble gases signals a loss of all gases (that occurred *as* gases) during the earth's formation. The earth's original atmosphere, then, was one formed by outgassing of its interior (Rubey, 1955; Abelson, 1966; Cloud, 1968). The composition of present-day volcanic gases suggests that the primitive atmosphere for the most part contained carbon dioxide, water, nitrogen, and hydrogen. Although carbon dioxide and hydrogen convert to methane, the rate of this reaction at typical atmospheric temperatures, is slow enough that carbon dioxide would remain the major carbon species (Rubey, 1955; Abelson, 1966; Cloud, 1968). Methanogenic bacteria could then live by catalyzing this conversion.

The suggestion that methanogens are well suited to a primitive environment and so represent an ancient phenotype cannot be novel. The idea is too simple not to have occurred to those familiar with the facts. Yet, it has not been incorporated into conventional wisdom regarding the origin of life, which appears to suggest that the notion has been rejected out of hand. Perhaps this is because the methanogenic phenotype ostensibly contradicts the central dogma that aboriginal living forms must be heterotrphic; and methanogenic bacteria are chemolithotrophic. Since their phylogenetic relationship to other bacteria is unknown, one could safely assume the methanogenic phenotype to be a late creation in the bacterial line of descent, and so to have no relevance to bacterial origins.

It has recently been determined, however, that the methanogenic phenotype in all probability is an ancient one. Through comparative characterization of their ribosomal RNA, it has been shown that the divergence of methanogens from the line of bacterial descent is by far the most ancient divergence yet detected among the bacteria (Balch et al., 1977). Within the methanogens a major subdivision that appears to be as old as that which separates the gram-negative from the gram-positive bacteria, is also seen (Fox et al., unpublished results) – further strengthening the case for the antiquity of their phenotype.

Accepting the antiquity of methanogens, we can then envision an era in the earth's history when the atmosphere was anaerobic and the conversion of carbon dioxide into methane was a reaction supporting life on a global scale. However, such a picture cannot be complete, such a reaction the only (major carbon) one in a primitive ecology. It, as any energy yielding reaction, would shortly be taken to equilibrium – exhausting the supply of either carbon dioxide or hydrogen, whichever was limiting. Arguing in terms of life on earth today, we know that this type of situation would not occur; all such energy yielding reactions are parts of larger energy cycles – driven ultimately by photosynthetic processes. A priori one should not assume it would be otherwise in a primitive era.

Fossil evidence for the antiquity of blue-green algae (Schopf, 1970), and the fact that photosynthetic bacteria in general appear to be phylogenetically diverse, provide adequate rationale for assuming some photosynthetic species to be contemporaneous with the methanogenic phenotype. On a primitive earth that was already reducing – i.e., in a situation where living systems lacked more for oxidizing than for reducing potential – a photosynthetic process might be expected to yield appreciable hydrogen as a by-product (through hydrogenases), thus providing the hydrogen source for methanogenesis.

To complete this primitive carbon cycle, carbon dioxide needs to be regenerated – necessitating the oxidation of methane. The ultimate source of oxidizing compound would again be a photosynthetic reaction. (It is conceivable that in a primitive reducing atmosphere local oxidizing niches occurred analogous to the local reducing niches found on earth today). It remains to be seen whether contemporary methane oxidizing bacteria are direct descendants of the primitive organisms postulated to complete such a cycle. In any case, I feel it is now necessary to take seriously the possibility that a carbon dioxide-methane cycle, driven by photosynthesis, was the major carbon cycle at an early stage in the earth's history.

Clearly, the methanogenic phenotype does not necessarily violate the Oparin concept of a heterotrophic origin to life (Oparin, 1957). In fact, ancient methanogens may correspond to the hypothetical point in the Oparin scheme when the primitive supply of energy-rich compounds becomes exhausted, and organisms are forced to evolve autotrophic phenotypes.

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