100% oxygen environment maintained at a pressure of 0.2 atm. I think that "The tremendous fire hazard that would be presented by the absence of some inert gas in the atmosphere could in itself prevent the development of life on earth." (Gilbert, Respir. Physiol., 5 (1968) 68).

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Authors' reply:

One point is made by both of our critics—that the contemporary pool of labile carbon is too small to significantly alter the concentration of atmospheric oxygen. We agree with them on this point, and in fact, our estimate of 10^4 years as the shortest time over which biological regulation of atmospheric oxygen might be important may be too short. However, our proposals remain valid over longer time intervals.

Large fluctuations of oxygen occur on a time-scale defined by the size of the O_2 reservoir and the rate of exchange of material with the lithosphere. A 1% variation in concentration would require on the order of 5×10^5 years if we accept the figures of Garrels et al. (1976). Processes capable of causing large fluctuations much more rapidly than this have not been identified.

It is necessary, however, to postulate some kind of bio-geochemical mechanism for the regulation of oxygen over time-scales of the order of 5×10^5–10^8 years, as we may see by looking at the history of atmospheric O_2: in the Archean period (>2 billion years ago) there was little if any oxygen in the atmosphere. The ocean carbon reservoir was probably not significantly bigger than it is now, so that the same limitations on changes in the O_2 concentrations must have applied. Despite this, the concentration rose into the range 10–25%, attaining these levels by one billion years ago at the latest. Subsequently, it has remained within this range up to the present time, despite the fact that it might have been expected to double or halve over periods of the order of 10^7 years. This behavior is strongly suggestive of a system subject to negative feedback (over the past eon at least) and having a time constant short by comparison to the time over which natural variations might be expected to occur, i.e., $<10^7$ years. Purely geological control mechanisms might be expected to operate on the time-scale over which sedimentary rock is recycled, i.e., $\gtrsim 10^8$ years. Bio-geochemical feedback mechanisms are therefore indicated.

We have postulated that these controls, including the role of methanogenic organisms, came into existence as a result of selective pressures acting on communities of micro-organisms from Archean times. Over periods of 10^5–10^8 years, changes in the volume of methane produced by the methanobacteria could provide a strong negative feedback to any unfavorable change in O_2 concentration—such as might arise from say, an alteration in the rate at which reduced minerals are exposed to oxidative weathering by global erosion. Over these time-scales no net transfer of carbon into or out of the biosphere need be implied. Changes in the rate of carbon burial would be compensated by processes such as the weathering of organic sediments and solution/precipitation of carbonates in the ocean.

The correct approach to this problem must ultimately involve an attempt to model the evolving biosphere-atmosphere-lithosphere system in all its immense complexity. In the meantime, an analogy with physiology may be of some use. A man in the desert may avoid pyrexia by sweating provided he has an adequate supply of drinking water. The fact that his internal supply of water is too small for more than a few hours of sweating does not deny the importance of this mechanism as an efficient cooling process. What is important is that a control mechanism exists which ensures that he takes in water at the same rate as it is lost. In the same way, the smallness of the contemporary pool of labile carbon does not in itself mean that the modulation of the fluxes into and out of this reservoir may not be important in maintaining the biosphere at an optimum.

The flux of methane from the sediments probably serves to considerably alter the rate at which carbon is lost from the biosphere by burial. If this flux did not take place burial would proceed at a much greater rate than it presently does, until most of the free carbon presently available to the biota was locked up in sediments. The pool of labile carbon would be much reduced and this would presumably be detrimental to the biosphere as a whole. Following the Gaia hypothesis, therefore, we suggest that the "purpose" of the methane production is the regulation of carbon burial. In this we are being no more teleological than when we say that the "purpose" of sweating is to avoid pyrexia. Both are responses that have arisen as the result of natural selection because they tend to perpetuate the system.

Finally, we should like to clarify Dr. Gutschick's statement that our paper proposed the regulation of oxygen "by probability of fire". We are certainly not suggesting that the consumption of oxygen that occurs during burning has any relevance to the problem of O_2 regulation. Rather we simply point out that an oxygen concentration very much greater than the present 21% would be incompatible with the existence of a large land-based biomass because of the high fire probability. On the Gaia hypothesis, we believe that the biota would tend to evolve such that such high oxygen levels were seldom if ever obtained. We do not know the details of the cybernetic link between the frequency of fire and oxygen regulation, but we suggest that it is related to activities of the anaerobic biota.

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