The Hazy Details of Early Earth’s Atmosphere

IN THEIR REPORT “FRACTAL ORGANIC HAZES PROVIDED AN ULTRAVIOLET SHIELD FOR EARLY Earth” (4 June, p. 1266), E. T. Wolf and O. B. Toon base their fractal haze theory on the assumption that the Archean atmosphere was primarily N$_2$. The Report includes no reference for this “prevailing view,” and much evidence can be amassed against it. Geologists since Darwin have uniformly argued for a CO$_2$-dominant atmosphere for the early Earth (1, 2).

The evolutionary roots of biochemistry draw on CO$_2$ and H$_2$ as the main nutrients of life. Life also requires the extra proton power afforded by chemiosmosis, an energy source that must have been available to emergent life (3–5). Primordial metabolism may have been based on minerals catalyzing the reaction between CO$_2$ and H$_2$ via the acetyl coenzyme-A pathway (6). Furthermore, data that enzymes involved in synthesizing sugars predate those that catalyze them (7) does not support the theory that catabolism of preformed organic molecules was the driver to life’s emergence.

C. F. Chyba (“Countering the early faint Sun,” Perspectives, 4 June, p. 1238) offers one alternative (i.e., autogenic) model: Wächtershäuser’s surface metabolism (8). However, this hypothesis fails because the initial conditions invoked offer neither a natural proton motive force to drive biosynthesis, nor a compartment for its focus. The alkaline hydrothermal hypothesis does address this (8) and other aspects of life’s onset, in a model that leads logically to the acetyl coenzyme-A pathway, without resorting to contingency (9).

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References

Response

RUSSELL ARGUES THAT A TITAN-LIKE VIEW of the early Earth is inaccurate and that a CO$_2$-dominated atmosphere is more likely. This view dominated thinking in the 1980s and 1990s, but has since been in decline. Geochemical arguments have been made supporting low CO$_2$ abundances. Rosing et al. argue that the presence of magnetite in banded-iron formations constrains atmospheric CO$_2$ to a mere 3 times the present atmospheric level (1). Moreover, vigorous plate tectonics would likely have sequestered most CO$_2$ within the mantle (2). Russell assumes that N$_2$ was not likely the dominant gas. However, Goldblatt et al. (3) suggest that a higher fraction of Earth’s total nitrogen budget was present in the young atmosphere than today. In contrast to Russell’s assumptions, these recent studies point toward a young atmosphere dominated by N$_2$ and requiring greenhouse gases in addition to CO$_2$ to keep the young Earth warm.

Admittedly, achieving high methane concentrations before organic material existed on Earth is difficult (4). However, methane concentrations of 1000 parts per million or higher supplied by methanogens are predicted for the postbiotic Earth (5). When the CH$_4$/CO$_2$ ratio rose above 0.1, N$_2$–CH$_4$ photochemistry could proceed (6), creating the ultraviolet-shielding fractal organic haze we described. Ammonia could have been protected from photolysis beneath the haze, yielding an atmosphere rich in both CH$_4$ and NH$_3$, thus making it possible for these inorganic material to yield organic compounds (Miller-Urey chemistry), as we noted in our Report.

Although our work makes no attempt to address the specific biochemical mechanisms that lie at roots of life, we do address important questions regarding the atmospheric composition and climate of the Earth at the time when life first flourished. Recent studies (6, 7) along with the evidence amassed against a CO$_2$-rich atmosphere indicate that the Archean was at least mildly reducing. Whether the very first life was formed as a direct result of chemical reactions of inorganic material, as indicated by Miller-Urey chemistry, is up for debate, but given the emerging new picture of the Archean, surely Miller-Urey chemistry would have proceeded at some point early in the Earth’s history. The haze chemistry itself would have produced organics at a rate that would likely dwarf the production of organics from the hydrothermal vent systems favored by Russell (5). Laboratory studies have confirmed that complex organics are readily produced in early Earth-like environments.

Titan’s haze. Early Earth’s atmosphere may have resembled that of Saturn’s moon Titan.
containing N₂, CO₂, CH₄, and H₂ (8). The organic haze particles may have been edible and would have precipitated into the young oceans, creating an organic soup consistent with Miller-Urey (9).

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References

Response

RUSSELL PROPOSES THAT EARLY EARTH’S atmosphere contained primarily CO₂ and lacked N₂. For this idea to make sense, one must explain how volcanic outgassing or comet/asteroid impact delivery of the early atmosphere’s constituents could provide CO₂ yet sequester N₂.

In my Perspective, I focused on the implications of the Wolf and Toon Report for early Earth’s greenhouse; I only briefly touched on its implications for the origin of life. Wolf and Toon’s model removes one of the long-standing objections to an early atmosphere with substantial methane and ammonia, and therefore to the Miller-Urey organic “building block” approach to the origin of life. Their model cannot speak to other important objections to the building-block hypothesis. I contrasted the Miller-Urey picture with metabolism-first theories in which life originates with autocatalytic cycles (cycles in which the product of the chemical reaction is also a reactant) that use inorganic carbon such as CO₂ (1). Clearly, metabolism-first theories are now a burgeoning subfield of their own (2). More recent discoveries of hydrothermal venting far from ocean ridges (3) have propelled alkaline-environment metabolism-first theories, such as the one Russell describes, into the spotlight (4).

Huber and Wächtershäuser (5) showed that the crucial reaction in the acetyl coenzyme-A pathway that Russell favors could have occurred prebiotically (before life existed), supporting the idea that metabolism
could have evolved from prebiotic chemistry. A centrality of the acetyl coenzyme-A path to the origin of life is therefore broadly consistent with the Wächtershäuser approach, although there are important differences, which Russell argues favors his model (6). The alkaline model for life’s origin may also be relevant to Jupiter’s moon Europa (7).

Complex environmental questions about early Earth and the origin of life may well have composite answers. Researchers need to understand the strengths, weaknesses, and possible complementary roles of multiple approaches to the problem.

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References

Funding for Chinese Collaboration

IN THEIR EDITORIAL “CHINA’S RESEARCH CULTURE” (3 September, p. 1128), Y. Shi and Y. Rao describe an example of the rampant problems in China’s research funding allocation, namely the selection of recipients for “mega-project grants.” I often hear stories about very expensive equipment left packed in hallways or labs for years without being used. The funding agencies often have very strict guidelines for using the funding on salaries, even though a research group’s ability to hire the talent they need is often the most important factor in the success of the research program.

China’s funding strategy for overseas Chinese scientists is also problematic. As part of an Asia-wide trend, China has been trying to recruit talents from overseas (1). To attract established overseas Chinese researchers with advanced education from western countries, China has devoted billions of Chinese yuan to talent programs [such as the Thousand Talent program (2) recently established by the central government] that require overseas scholars to relocate to China to accept prestigious full-time positions. However, many recipients of these awards cannot relocate because of practical and family obligations.

China should focus instead on grants that fund collaborative research between overseas Chinese scholars and their peers in China. Collaborative programs are more cost-effective and more practical for those who cannot relocate. One such program is the Joint Research Fund (JRF) for Overseas Chinese Scholars and Scholars in Hong Kong and Macao, administered by the National Natural Science Foundation of China (NSFC). In 2006, a mere 0.7% of the NSFC budget was allocated to this worthy program (3). In 2008, the maximum grant was reduced from 400,000 Chinese yuan over 3 years to 200,000 Chinese yuan over 2 years (4, 5). By dedicating such a small budget to this program and others like it, China misses an opportunity to engage overseas Chinese scholars and benefit from their contributions to the country’s research and education.

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References
2. Thousand Talent program [www.1000plan.org (in Chinese)].

CORRECTIONS AND CLARIFICATIONS

Brevia: ”Pulsar discovery by global volunteer computing” by B. Knispel et al. (10 September, p. 1305). The Einstein@Home data are transferred to the Albert Einstein Institute (not Liebniz Universität) in Hannover, Germany.

Reports: ”Prediction of individual brain maturity using fMRI” by N. U. F. Dosenbach et al. (10 September, p. 1358). In Fig. 2, the labels in the bottom-right image (anterior view) were incorrect. The “L” and “R” labels should be switched.

Reports: ”Unprecedented restoration of a native oyster metapopulation” by D. M. Schulte et al. (28 August 2009, p. 1124). Reference 19 was incorrect. The correct reference is ”K. Greenhawk, T. O’Connell, L. Barker, Oyster Population Estimates for the Maryland Portion of Chesapeake Bay 1994–2006 (Maryland Department of Natural Resources, 2007), Table 7; www.dnr.state.md.us/fisheries/oysters/mgs/MDOysterPopEst_07_27_07.pdf.”

Letters to the Editor

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