ASTROBIOLOGY
Volume 5, Number 3, 2005
© Mary Ann Liebert, Inc.

News & Views

Cutting Anthropic Knots and the Rise of O_2

NORMAN H. SLEEP

IS LIFE COMMON OR RARE away from the Earth? How common is complex animal life? What are its requirements? As is well known, our existence does not provide a tight constraint. Life and then complex life needed to originate for us to be here to speculate. Two papers in this volume of *Astrobiology* address these basic questions in novel ways.

Davies and Lineweaver (2005) consider a way to cut the anthropic knot. If the origin of life is easy, a second example of life may lurk beneath our noses. We have the technology to commence our search.

The idea is not far fetched. Most of the free-living microbes on the Earth have not been studied. Methods involving extraction of DNA or ribosomal RNA are hopelessly biased toward finding our microbial kin. There is plenty of food for organisms that eat wrong-handed organic matter, the bounty of natural decomposition. Hot rocks provide sterile environments that, upon cooling, could nurture independent life. Looking up, we might find that independent life arrived on the Earth as passengers on martian (or even Ceres or Venus) meteorites in the deep past. This life may have managed to eek out an existence. It may have taken center stage, relegating primordial native biota to the far wings.

A semantic problem cloaks a real challenge. Defining when autocatalysis is well enough organized to be life is about as productive as searching for the world's smallest giant. At this transition, numerous molecules acted as a consortium in the original soup. I agree with the authors that we do not count organisms, perhaps viruses, that branched out at the soup stage as truly independent. Even a cellular microbe is far from straightforward. We will be hard pressed to tell whether it branched at a time that both chiralities were still in use. Conversely, our alien microbe has had billions of years to exchange with ordinary microbes. It is likely to be tainted. Could the alien have fouled our ancestors? Could molecular evidence of independent life be right in the cells of our noses?

Catling *et al*. (2005) focus on the rise of oxygen. They contend that significant oxygen in the air and ocean is essential for the evolution of multicellular organisms. Recent sulfur and iron isotopic work has put the timing in context. There was less than 2 ppm of O_2 in the air before 2.45 Ga. By 2.2 Ga, the O_2 level was significantly higher. By 1.8 Ga, sulfide became rare in the oceans (Rouxel *et al*., 2005). O_2-producing photosynthetic organisms obviously had to evolve for this to happen. The oxygen output had to outpace the sink from the back reaction of respiration and geological sinks from oxidizing rock. The 1.8 Ga event may indicate that the last major oceanic sink was overwhelmed, that is, oxidation of sulfides vented to the surface at ridge axes. After that time, physical buffers and data constraints on the oxygen level in the air become less obvious until the advent of forest fires, which required at least 15% O_2, by 350 Ma.

Terrestrial animals do need oxygen. Catling *et al*. (2005) contend that this need is universal. Anaerobic metabolism is just too inefficient. In particular, a sulfuretum system with sulfide to sulfate photosynthesis and sulfide to sulfate respiration is wanting.

Department of Geophysics, Stanford University, Stanford, California.

Here evolution is a mixed blessing. Life is nicely fit for the conditions we actually find. There are real limits that are not transgressed even where continuous gradients persist. For example, in hydrothermal fluid a 121°C microbe, the most extreme thermophile, could get first crack by evolving to 122°C. On the other hand, we do not expect to find terrestrial organisms capable of living in Titan-like liquid methane conditions, which have never existed here.

Which case applies to animals? Suboxic to anaerobic conditions have existed locally since the rise of animals. There is nothing that prevents suboxic animals, but their environment is a transient dead end. Opportunistic species like the Cambrian trilobite, *Elrathia kingii* (Fig. 1), have strutted upon the stage only to perish (Gaines and Droser, 2003). Most animals, including humans, evolved in the more widespread oxic environments. If suboxic environments were common and oxic ones rare, we would likely be suboxic.

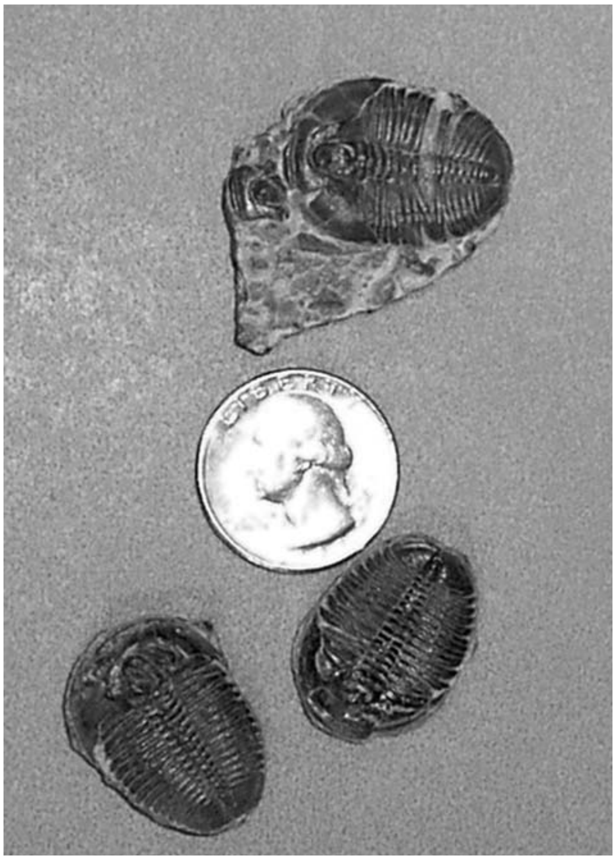

FIG. 1. The Cambrian trilobite *E. kingii* lived in suboxic water in Utah. This rare and transient environment proved to be an evolutionary dead end. The U.S. quarter is shown for scale. Photo by the author.

What about truly anaerobic animals in a sulfuretum? I agree with Catling *et al*. (2005) that the low energy from respiration is a problem. But animals do not go all out all the time; they store energy for use and can build up an oxygen debt. The latter is not possible in a sulfuretum, but storage of sulfate is. It is soluble in water. It is even the dominant available oxygen source in the modern ocean. If the cell has the ability to collect, keep, and concentrate it, calcium sulfate compounds become an even larger reservoir. The organism still needs a way to vent sulfide and CO_2, but this problem is analogous to that faced by aerobes.

How do we resolve this? Time is of the essence. We need measures of the O_2 in the air independent of biota. If oxygen levels remained low until just before the advent of animals, the hypothesis proposed in the paper by Catling *et al*. (2005) would likely be correct. If oxygen reached the levels tolerated by suboxic animals at ~1.8 Ga, a vacancy sign hung on this niche for over a billion years. Then the innovation of control genes for different cell types is the key. Earthly animals merely evolved to the prevailing conditions.

REFERENCES

Catling, D.C., Glein, C.R., Zahnle, K.J., and McKay, C.P. (2005) Why O_2 is required by complex life on habitable planets and the concept of planetary "oxygenation time." *Astrobiology* 5, 415–438.

Davies, P.C.W. and Lineweaver, C.H. (2005) Finding a second sample of life on Earth. *Astrobiology* 5, 154–163.

Gaines, R.R. and Droser, M.L. (2003) Paleoecology of the familiar trilobite *Elrathia kingii*: An early exaerobic zone inhabitant. *Geology* 31, 941–944.

Rouxel, O., Bekker, J.A., and Edwards, K.J. (2005) Iron isotope constraints on the Archean and Paleoproterozoic ocean redox state. *Science* 307, 1088–1090.

Address reprint requests to:
Norman H. Sleep
Department of Geophysics
Stanford University
Stanford, CA 94305

E-mail: norm@pangea.stanford.edu