Response to Comment on "Arsenic(III) Fuels Anoxygenic Photosynthesis in Hot Spring Biofilms from Mono Lake, California"

R. S. Oremland, *et al.*

Science **323**, 583d (2009);
DOI: 10.1126/science.1166435

Response to Comment on "Arsenic(III) Fuels Anoxygenic Photosynthesis in Hot Spring Biofilms from Mono Lake, California"

R. S. Oremland,[1]* J. F. Stolz,[2] M. Madigan,[3] J. T. Hollibaugh,[4] T. R. Kulp,[1] S. E. Hoeft,[1] J. Fisher,[4]† L. G. Miller,[1] C. W. Culbertson,[5] M. Asao[3]

Schoepp-Cothenet *et al*. bring a welcome conceptual debate to the question of which came first in the course of planetary biological evolution, arsenite [As(III)] oxidation or dissimilatory arsenate [As(V)] reduction. However, we disagree with their reasoning and stand by our original conclusion.

Schoepp-Cothenet *et al*. (*1*) challenge our conclusions regarding dissimilatory arsenic reduction on primordial Earth (*2*). The authors argue their points based on suppositions concerning the redox state of the Archean, and their entrained bioenergetic/phylogenetic reasoning. With regard to their point about redox state, although Fe(II) is believed to have been abundant in the anoxic Archean, this chemical species does not reduce As(V) to As(III). Free sulfide can reduce As(V), but this requires a very low pH for any reasonable kinetic resolution (*3*). In addition, the production of As(V) by As(III)-linked anoxygenic phototrophy would have opened localized niches for As(V) respiration without affecting the overall redox balance of the Archean Earth. This is similar to what has been proposed for photosynthetically linked Fe(II) oxidation and banded iron formations (*4*). Indeed, the tight coupling of As(V) reduction/As(III) oxidation has been seen in periphyton samples (*5*) and salt-saturated anoxic sediments from Searles Lake (*6*). We have also observed this phenomenon in "red" hot spring biofilms from Mono Lake as part of an ongoing study. Finally, although in silico phylogenetic analyses of genomes can provide grist for evolutionary schemes, their validity is dependent on correct annotation. Unless proof of function is known for a given homolog, biochemical or genetic confirmation is necessary (*7*). For example, the dimethyl sulfoxide reductase family of molybdenum enzymes is composed of oxidases, reductases, and dehydrogenases, and enzymes sharing high sequence identity can have very different functions (*8*). Moreover, arsenate respiration has been demonstrated in two *Pyrobaculum* species; however, the respiratory arsenate reductase in these organisms has yet to be identified. Investigations of the *arrA* amplicons obtained from the extreme environment of Searles Lake, California, suggest unexpectedly high sequence diversity, with most lying well outside the boundaries established with cultured anaerobes from the domain Bacteria (*9*). Such observations indicate that there are many more "novel" prokaryotes out there (including Archaea) with the capacity to respire As(V), awaiting isolation and characterization and, ultimately, genomic analysis.

[1]U.S. Geological Survey (USGS), Menlo Park, CA 94025, USA. [2]Department of Biological Sciences, Duquesne University, Pittsburgh, PA 15282, USA. [3]Department of Microbiology, Southern Illinois University, Carbondale, IL 62901–6508, USA. [4]Department of Marine Sciences, University of Georgia, Athens, GA 30602–3636, USA. [5]USGS Water Sciences Center, Augusta, ME 04330, USA.

*To whom correspondence should be addressed. E-mail: roremlan@usgs.gov

†Present address: Division of Earth and Ecosystem Science, Desert Research Institute, Las Vegas, NV 89119, USA.

References

1. B. Schoepp-Cothenet, S. Duval, J. M. Santini, W. Nitschke, *Science* **323**, 583 (2009); www.sciencemag.org/cgi/content/full/323/5914/583d.
2. T. R. Kulp *et al*., *Science* **321**, 967 (2008).
3. J. A. Cherry *et al*., *J. Hydrol. (Amst.)* **43**, 373 (1979).
4. A. Ehrenreich, F. Widdell, *Appl. Environ. Microbiol.* **60**, 4517 (1994).
5. T. R. Kulp *et al*., *Appl. Environ. Microbiol.* **70**, 6428 (2004).
6. R. S. Oremland *et al*., *Science* **308**, 1305 (2005).
7. R. S. Oremland *et al*., *Nat. Rev. Microbiol.* **3**, 572 (2005).
8. J. F. Stolz *et al*., *Annu. Rev. Microbiol.* **60**, 107 (2006).
9. T. R. Kulp *et al*., *Appl. Environ. Microbiol.* **72**, 6514 (2006).

25 September 2008; accepted 31 December 2008
10.1126/science.1166435