

Comment on “A Bacterium That Can Grow by Using Arsenic Instead of Phosphorus”B. Schoepp-Cothenet,¹ W. Nitschke,^{1*} L. M. Barge,² A. Ponce,² M. J. Russell,² A. I. Tsapin²¹Bioénergétique et Ingénierie des Protéines, IFR88, CNRS, 13402 Marseille, France. ²NASA, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109–8099, USA.

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Wolfe-Simon *et al.* (Science Express Research Article, published online 2 December 2010; 10.1126/science.1197258) argued that the bacterial strain GFAJ-1 can vary the elemental composition of its biomolecules by substituting arsenic for phosphorus. Although their data show that GFAJ-1 is an extraordinary extremophile, consideration of arsenate redox chemistry undermines the suggestion that arsenate can replace the physiologic functions of phosphate.

Wolfe-Simon *et al.* (1) described a bacterium isolated from Mono Lake, California, strain GFAJ-1, which they claimed can vary the elemental composition of its biomolecules by substituting arsenic (As) for phosphorus (P). If confirmed, this discovery would point to the possibility that the combination of hydrogen, carbon, nitrogen, oxygen, sulfur, and phosphorus might not be the only recipe for life and that life on other planets and even on Earth might have started with other elements.

In recent decades, many microorganisms able to thrive in diverse extreme habitats have been discovered. These organisms endure, or even require, very high temperatures, extreme acidity, high salinity, or strong radiation. In virtually all of these cases, it was initially suggested that the corresponding conditions might reflect life's origins. To our knowledge, none of these claims survived scrutiny. The elucidation of metabolic and protein structure particularities, as well as specific defense and repair mechanisms, point instead to a no less exciting conclusion: Life manages to adapt to extreme environments on this planet.

We therefore have to ask whether the case described by Wolfe-Simon *et al.* differs fundamentally from other extreme forms of life. To us, the answer is straightforwardly provided by the article itself [see table 1 in (1)]. In the presence of a more than 10,000-fold excess of As over P (the presence of the latter being due to contaminations in the salts used for the culture media), the bacterium integrates only three times (on a molar percentage basis) more arsenic than phosphorus. It is far from proven that As is present in biologically active

molecules in the cell. GFAJ-1 appears to do all it can to harvest P atoms from the medium while drowning in As, with cell division occurring once every 2 days (possibly because of the presence of trace P rather than As). This suggests that GFAJ-1 is an extraordinary extremophile but does not support the more exceptional claim that As replaces the functions of P in this organism.

The simple considerations that the abundance of P in the solar system is more than 1500 times that of As (2), that in the reducing environment of a young rocky planet this limited supply of As would be present as arsenite rather than arsenate (3), and the high chemical instability of arsenates compared with phosphates (4) all point to the unlikelihood of life arising here or elsewhere with this alternative biochemistry. Arsenate indeed structurally resembles phosphate. However, arsenic is redox active in the physiological range of redox potentials, and the arsenate As(V) oxyanion is converted to the arsenite As(III) oxyanion below 0 mV/SHE (standard hydrogen electrode). In the cytoplasm of all extant prokaryotes, the ambient redox potential is considerably lower than 0 mV, and arsenate should correspondingly be slowly reduced to arsenite, a compound that is stereochemically quite different from phosphate. At the very least, the resulting structural rearrangements will certainly impair metabolic processes. Of course, phosphate can also be reduced to phosphite, but only at ambient potentials as low as –700 mV, that is, completely out of the range of physiological redox transitions. Correspondingly, geochemically generated phosphite is used by microorganisms as a bioenergetic fuel (5), but (for the sake of the structural integrity of biomolecules) it is not integrated into organic matter. The comparatively high oxidation/reduction potential of the arsenite/arsenate couple makes this redox element an interesting energy source for life (6, 7), but at the same time a poor choice for a biomass building block.

In summary, the results presented by Wolfe-Simon *et al.* provide a splendid example for life's capacity to cope with extreme conditions but do not reveal that life can emerge based on elements different from the canonical.

References

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