

Out of This World?

The Wisconsin Astrobiology Research Consortium

by Clark Johnson

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“What the hell is an astrobiologist?”

Secret Service agent, Presidential detail, April 1996

The first Astrobiology Science Conference, held at NASA-Ames/Moffet Field (California) in April 1996, coincided with a visit to the Bay Area by then President Clinton. Air Force One was parked at Moffet Field immediately adjacent to the conference, and apparently one of the conference participants drifted into a restricted area. Upon being stopped by the Secret Service, this participant was asked who he was and what he was doing. Clearly the Secret Service had not heard of the field of astrobiology, and this participant was detained while the Secret Service determined if this was a “real” field or not (no, I was not the detainee). Of course, the quote became a mantra at the conference.

So what *is* an astrobiologist? An astronomer looking for planets in the “habitable zone” of other solar systems is an astrobiologist. A microbiologist working on bacterial communities in hydrothermal vents at Yellowstone that might be an analog for

the early Earth is an astrobiologist. A paleontologist looking at stromatolites is an astrobiologist. A geophysicist looking at stabilization of cratons and continental shelves as a necessary step in the evolution of life is an astrobiologist. A geochemist studying the isotopic fingerprints of microbial iron cycling is an astrobiologist.

Astrobiology is a rapidly growing field. There are now three major journals dedicated to astrobiology. Major centers for astrobiology exist in the U.S., Japan, Spain, and Australia, and a new Scandinavian center is planned. The major sponsor of astrobiology research in the U.S. is the NASA Astrobiology Institute (NAI) and related programs such as NASA Exobiology, and similar institutes in Europe and Australia sponsor research in other countries. Currently there are 14 teams in NAI that are centered at universities or government labs, which are each funded at the \$1M to \$2M level per year over five year contracts. Our group at UW-Madison also includes scientists at NASA-JPL and the University of Georgia (The Wisconsin Astrobiology Research Consortium, or “WARC”), and ours was one of four new selections approved in 2007. Additional groups selected in 2007 include Montana State, MIT, and the University of Washington. Although NASA’s funding for astrobiology was in doubt last year, things have turned around with a new Director of Science at NASA, and the future of NAI looks very bright.

Our team at Wisconsin is focused on developing biosignatures of life that may be applied to Precambrian rocks on Earth or on Mars. Most geologists are familiar with biosignatures such as fossil dinosaur bones. Humans, of course, are quite prolific in producing biosignatures (Figure 1). Life throughout most of the Precambrian consisted of microbes, and the confidence with which fossil remnants of microbes may be recognized in the Precambrian rock record naturally decreases the older the rock because of degraded preservation. Microfossils of mid- to late-Proterozoic age, such as those preserved in the Bitter Springs Formation, are well accepted as bacteria and bear a striking resemblance to modern bacteria (Figure 2b). More controversial are microfossils or stromatolites of Archean age, including the famous 3.5 b.y.-old rocks in the Pilbara Craton, Australia (Figure 2c). Intense debate has surrounded the proposal that “nanofossils” in the Mars

The over-arching goal of astrobiology is to understand the origin and evolution of life in the universe, and therefore many disciplines and sub-disciplines fit under its umbrella. The earth sciences play a major role because some of our best laboratories include Earth and Earth-like planets such as Mars.

meteorite ALH84001 reflect bacterial life on Mars, and the majority of scientists now reject these as evidence for ancient life on Mars. Developing robust biosignatures is therefore quite a challenge.

The first investigation by WARC involves studies of the inventory of organics that were delivered to early Earth and Mars—our baseline for interpreting organic material in rocks. The isotopic composition of organic carbon has remained one of the hallmark biosignatures for life, where photosynthetic fixation of CO₂ as organic carbon produces a 2 to 3 % decrease in ¹³C/¹²C ratios. Early in Earth’s history, prior to development of oxygenic photosynthesis, the inventory of organic carbon was dominated by extraterrestrial delivery, and C isotope compositions of such carbon overlaps that produced by photosynthesis, potentially limiting our ability to use organic carbon as a biosignature. WARC Co-I and NASA-JPL scientist Pascale Ehrenfreund will lead our studies of the delivery of extraterrestrial organics to Earth and Mars, as well as investigate how this organic matter may be degraded by long-term exposure to severe environments (low temperature, UV-radiation, etc.).

Our second investigation will develop biosignatures that extend beyond those involving organic matter, specifically the chemical and isotopic compositions of minerals that may be uniquely produced by life. The footprint for mineral-based biosignatures should be large relative to organic material or microfossils, and mineralogical biosignatures are more likely to survive alteration by radiation exposure or metamorphism. Our work will focus on minerals that are likely to have been produced by microbial processes, as well as those thought to exist on Mars early in its history, including oxides, sulfates, sulfides, and carbonates. There are already some promising results. For example, WARC Co-I’s Max Coleman (NASA-JPL), Christopher Romanek (Univ. of Georgia), and Eric Roden (UW-Madison) have shown that bacterial reduction of Fe(III) oxides in fluids of typical seawater composition appears to

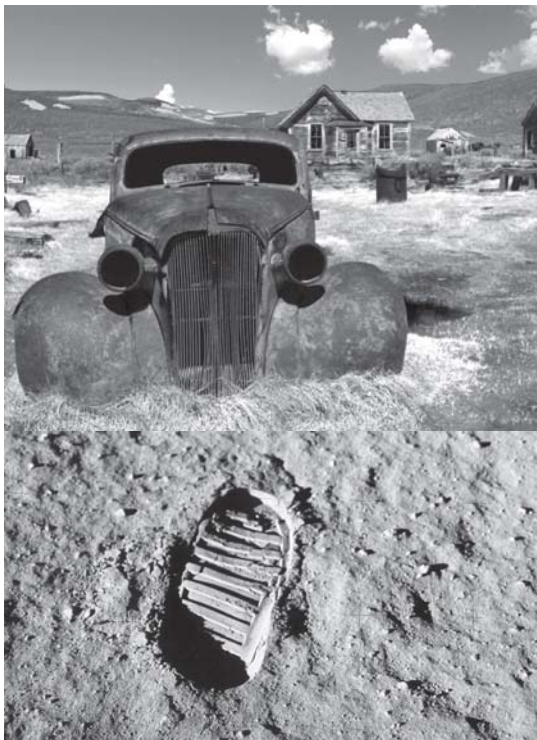


Figure 1. Some biosignatures of humans. Upper: Old car and abandoned houses, Bodie, California. Lower: Astronaut footprint, the Moon.

produce carbonate minerals that have relative proportions of Ca, Mg, and Fe that are not in thermodynamic equilibrium, suggesting that something as simple as a chemical analysis of carbonates may be a biosignature. The mechanisms behind this effect are unknown, however, and WARC Co-I's Nita Sahai and Huifang Xu (UW-Madison) will investigate this through the approaches of computational geochemistry and electron microscopy. In addition, aqueous Fe(II) produced by bacterial reduction of Fe(III) oxides has unique isotopic compositions as compared to those produced by abiologic reduction, particularly in the presence of other ions in solution. This may reflect the unique machinery that microbes have for pumping electrons to the surface of Fe(III) oxides as part of ATP synthesis that does not, of course, exist in an abiologic system of aqueous Fe(II) and Fe(III) oxide; this work is being pursued by WARC investigators Clark Johnson, Eric Roden, and Brian Beard (UW-Madison). In addition to Fe isotopes, we will be developing C, O, S, Mg, and Ca isotope biosignatures, and this work will involve a large portion of the WARC team, including Beard, Coleman, Johnson, Roden, Romanek, and Xu noted above, as well as John Valley (UW-Madison).

The third investigation of our program will involve "field-testing" our biosignatures. A modern terrestrial analog for the acid-sulfate environments that likely existed on ancient Mars can be found in Rio Tinto, Spain, where WARC Co-I Coleman is studying bacterial oxidation of pyrite deposits that have produced a wealth of Fe(III) and sulfate minerals that are remarkably similar to those on Mars. Moving deep into Earth's past, WARC scientists Beard, Johnson,

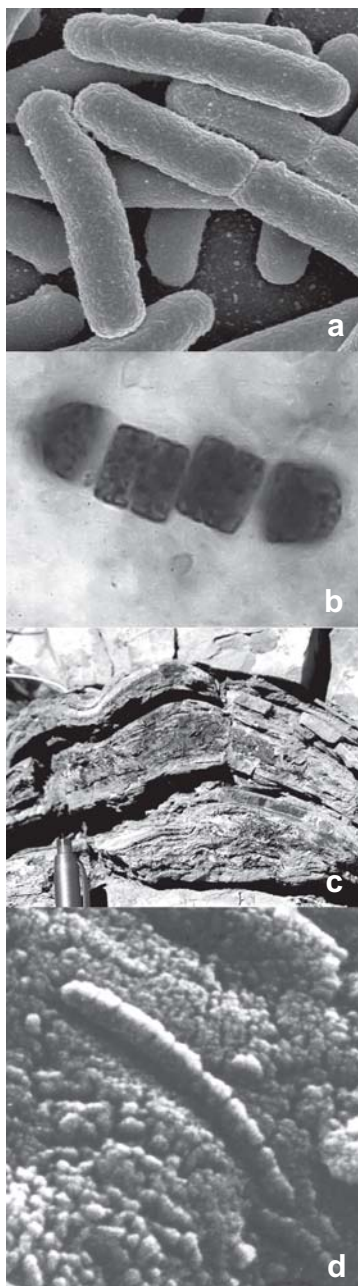


Figure 2. Possible microbial biosignatures/fossils. 2a: *E. coli* bacterium (photo 5 microns across). 2b: 800 m.y.-old fossil bacteria, Bitter Springs Formation, Australia (photo 5 microns across). 2c: 3.5 b.y.-old stromatolites, Pilbara Craton, Australia. 2d: Proposed nanobacteria, Martian meteorite ALH84001 (photo 2 microns across).

increase in precision, as well as the capability of performing *in situ* geochronology. Although the timetable for Mars missions in the next decade is uncertain, it is possible that this instrumentation would fly on the 2016 Astrobiology Mars mission. Mars sample return (Figure 3) is further out, most likely after 2020.

Because astrobiology asks fundamental

Roden, and Valley will be studying the C, O, S, Mg, Ca, and Fe isotope biosignatures in Archean and Proterozoic banded iron formations, stromatolites, paleosols, and chert units in Australia, South Africa, and North America. Our goal is to develop a temporal record of the evolution of inter-related microbial metabolisms over Earth's history, including anaerobic and oxygenic photosynthesis, bacterial sulfate reduction, and bacterial iron oxidation and reduction.

Finding evidence for life elsewhere in the Solar System will depend on obtaining samples from other planetary bodies for study in Earth-based laboratories, or on developing methods for making measurements of the chemical and isotopic compositions remotely on another planet such as Mars. Although miniature mass-spectrometers will fly on the 2009 Mars Science Lab (NASA) and 2013 ExoMars (European Space Agency) missions, these instruments are not capable of determining the chemical and isotopic biosignatures that we think are most promising. WARC scientists Mahadeva Sinha (NASA-JPL) and Beard (UW-Madison) are developing a next-generation miniature mass spectrometer that will offer a dramatic

questions about life in the universe that are of broad, general interest to people, NASA has always had strong education and public outreach (EPO) programs, and WARC is no exception. Led by the UW-Madison Geology Museum, Director Rich Slaughter and Associate Director Brooke Norsted will develop an extensive outreach program that will include new museum displays and K-12 instructional materials on astrobiology. The UW-Madison-based EPO efforts will connect with the extensive NASA-JPL EPO programs in collaboration with WARC Co-I Kay Ferrari (NASA-JPL) and will involve K-12 teachers at several localities in Wisconsin.

Although WARC is less than a year old, our group is growing rapidly. In addition to the people noted above, the group at UW-Madison also includes staff scientists Noriko Kita and Mike Spicuzza; post-doctoral fellows Marco Blöthe, Andy Czaja, Philipp Heck, Adriana Heimann, Reinhard Kozdon, Donald Mkhonto, Taka Ushikubo, and Lingling Wu; graduate students Emily Freeman, Ian Orland, Buddy Tangalos, Andrew Trzaskus, and Fangfu Zhang; undergraduate students Jason Huberty and Caroline Kirby. We will be making twelve offers to our current pool of graduate applicants, and hopefully a good portion of these will join us in fall 2008.

Finding the answers to the questions posed by astrobiology will span multiple generations. Someday, perhaps twenty years from now, in 2028, some young hot-shot graduate student will work on newly returned Martian samples, proving the existence of life on that planet before it evolved on earth using the biosignatures developed by some "old folks" at UW-Madison—I would be content with that! ●



Figure 3. Artist's conception of Mars Sample Return (MSR) mission, where samples collected by rovers will be launched into Mars orbit, to be captured by an Earth-launched return vehicle. The priority for MSR has been moved up by the current NASA Science Director, but MSR still seems likely to be later than 2020.