Arsenic And Old Life

Arsenic has been a favorite of poisoners through the ages. But for certain bacteria with an ancient lineage, it's the stuff of survival.

by Tim Crosby

Of all the processes on earth, photosynthesis is perhaps the most important to sustaining life. The means by which organisms convert sunlight into chemical energy—food—is a well-understood system. Scientists know what goes in, what goes on, and what comes out.

But two researchers at SIUC were part of a team that recently proved science still has a lot to learn about this critical, ubiquitous process. Their discovery was startling enough that the leading journal *Science* published the findings last August.

Michael Madigan, a professor and Distinguished Scholar of microbiology, and doctoral student Marie Asao worked on a multi-disciplinary team examining a microorganism found in Mono Lake, an alkaline lake in California. The team also included aquatic microbiologists from the University of Georgia and Duquesne University and geochemists from the U.S. Geological Survey.

The study involved a type of bacteria found in hot springs on the shore of Paoha Island in Mono Lake. These bacteria appeared to use an atypical substance to achieve photosynthesis. Within a year, Madigan and Asao showed that what the USGS had discovered was actually an ancient form of photosynthesis not previously known.

The USGS called Madigan because of his expertise with photosynthetic bacteria and his more than 30 years of studying organisms that live in extreme environments, such as the Antarctic or hot springs. Mono Lake contains several hot springs and has a high pH level.

"Last summer, the USGS scientists had found this hot spring that contained a microbial mat, which is a thin structure containing various bacteria. These bacteria appeared to be photosynthetic," Madigan says.

More than that, however, the bacteria appeared to be onto something new in the photosynthesis area.

To carry out photosynthesis, an organism must use the sun's energy to "fix" carbon dioxide—that is, take it in and mix it with something else. In green plants, this additional substance is water. Plants split the water molecules, take some electrons, and mix them with the carbon dioxide to make cell material. Chemically, this process is called a reduction.

Water, in this instance, is known as a "donor" because it donates electrons during the reduction. But considering how widespread photosynthesis is on earth, the list of such known electron donors is almost absurdly small. Green plants use water only, producing oxygen as a byproduct, while previously known photosynthetic bacteria, which cannot split water, use a few reduced sulfur compounds or reduced iron.

Madigan's team, however, was able to expand this list, proving that these bacteria from Mono Lake were actually using a form of arsenic as an electron donor to achieve photosynthesis. The

Left: Mono Lake in California. Right: Samples taken from a red microbial mat yielded (bottom image) bacteria that can carry out photosynthesis with only carbon dioxide and arsenic. *Photos courtesy Ron Oremland; electron micrograph by Marie Asao (color added).*

finding will have a great impact on further research, as it opens an entirely new vein for exploring photosynthesis.

"The significance comes when you look at how widespread arsenic is in nature," Madigan said. "It's present in a lot of ground water and a lot of other things, so it could be driving photosynthesis that we've never been aware of until this discovery.

"Arsenic isn't as common as water, which green plants use as an electron donor, but our findings reveal a much greater diversity in photosynthesis, which is the most important process on earth. We're all dependent on it for life," he says.

The USGS team had suspected arsenic might be involved and had conducted some simple field experiments on site that appeared to confirm their hypothesis. Madigan and Asao set out to prove it.

"When you do field studies like this, they're not absolutely controlled and unequivocal experiments because you don't know everything that's in there," Madigan says. "You're not working with a pure culture."

Back in Madigan's laboratory at SIUC, Asao isolated the organism by growing a culture from one single cell. They then subjected the culture to a series of tests, injecting substances such as hydrogen sulfide (a common electron donor for photosynthetic bacteria) and arsenite, a form of arsenic, and exposing it to light.

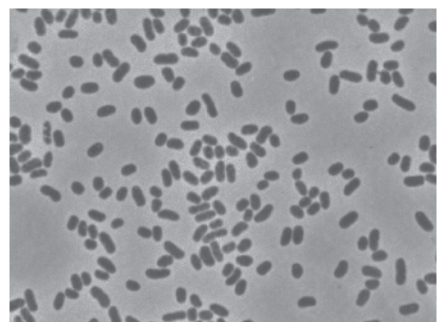
"We demonstrated the organism could grow in culture with just carbon dioxide and arsenite, which proved the process seen back at the lake," Madigan says.

They also conducted molecular characterization of the organism's genes, which gave them a strong idea about its family tree. They could tell, for instance, the organism was related to a genus of bacteria already known to exist in such alkaline environments.

"Where it got its ability to use arsenite for photosynthesis, we don't know," Madigan says. Scientists at Georgia and Duquesne also conducted genetic analyses confirming these results.

While the discovery is new to science, it isn't a new process. To the contrary, Madigan says evidence in the geologic record points to this type of photosynthesis existing billions of years before oxygen existed on earth. Finding the Mono Lake organism was sort of like discovering a living dinosaur at the microbiological level.

"Photosynthesis was invented by bacteria and only picked up by green plants and algae later on, where it was expanded and made more complex,"



Madigan says. "This is an ancient form of photosynthesis. There are still little habitats on earth where these organisms can survive and we kind of stumbled into one."

Much of what scientists know about green plant photosynthesis they learned by studying the simpler processes involved with such organisms. This discovery will have a lasting impact, Madigan says.

"It expands our knowledge of the diversity of photosynthesis and the kinds of organisms and types of processes that can be driven by light energy."

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