Study discovers how primordial bacteria adapted to arsenic

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An area of Yellowstone National Park with high levels of arsenic. Volcanic hot springs like these are the closest example that can be found today to what the earth looked like when life first evolved. The photosynthetic algae in this picture can grow because they have one of the arsenic resistance genes described in this study. Credit: Florida International University

If you could borrow H.G. Wells' time machine and travel back three billion years, it would take your breath away, literally. There was no oxygen in the air. You wouldn't be able to breathe.

"The Earth was as alien as another planet, with no oxygen in the atmosphere, acid oceans and high levels of toxic elements like arsenic," said researcher Barry Rosen, a Distinguished Professor at the FIU Herbert Wertheim College of Medicine and a world-renowned expert on arsenic. "The first organisms had to evolve ways to detoxify arsenic to survive in that hostile environment."

Those organisms developed arsenic resistance genes that had genetic information for transport systems that pumped arsenic out of the cells and for enzymes that transformed arsenic into more complex molecules.

In a study just published in the *Proceedings of the National Academy of Sciences*, Rosen and his collaborator Yongguan Zhu of the Chinese Academy of Sciences, along with colleagues from Germany, China, and the United States, discovered that life evolved new ways to adapt to the changed biotoxicity of arsenic after what is known as the Great Oxidation Event (GOE). The adaptations included the evolution of novel enzymes and new pathways that use oxygen to carry out their reactions.

About 2.5 billion years ago, during the Grand Oxidation Event, photosynthetic bacteria called cyanobacteria learned how to use the energy of sunlight. In the process, these bacteria produced large amounts of oxygen that completely changed the atmosphere and geochemistry of the earth.

Scientists have known this for a while, but figuring out what happened next has been much more difficult.

"We are only beginning to understand how biology adapted to this key transition in the story of life," Rosen said.

One major consequence of the GOE was a change in the chemical nature and toxicity of arsenic. Arsenic is the most common toxic substance in our environment. It ranks first on the Environmental Protection Agency's Superfund list of hazardous substances. Discovering how bacteria adapted to arsenic exposure allows scientists an opportunity to understand how humans' continual exposure to arsenic causes cancer, diabetes, and childhood developmental delays.

The international team of researchers used complex molecular clock analysis to determine the evolutionary history of the genetic system for arsenic detoxification. A molecular clock doesn't tell time like a regular clock. It is a technique used in evolutionary biology that estimates how long ago genes evolved by comparing differences in DNA.

Today every living organism, from bacteria to humans, is exposed to arsenic daily.

"Our results provide new insights into microbial evolution—how life learned to live with arsenic," Rosen said.

More information: Song-Can Chen et al. The Great Oxidation Event expanded the genetic repertoire of arsenic metabolism and cycling, *Proceedings of the National Academy of Sciences* (2020). DOI: 10.1073/pnas.2001063117

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