Archaea hold clues to ancient ocean temperatures

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Solving a decades-old mystery, Stanford researchers have discovered proteins that enable hardy microbes called archaea to toughen up their membranes when waters are overly warm. Finding these proteins could help scientists piece together the state of Earth's climate going back millions of years to when those archaea were cruising the ancient oceans.

"People have been looking for these proteins for 40 years," said Paula Welander, an associate professor of Earth system science in Stanford University's School of Earth, Energy & Environmental Sciences (Stanford Earth), and lead author of a study describing the finding published Oct. 7 in *Proceedings of the National Academy of Sciences*.

With this finding scientists can more accurately use the lipids—or fats—found in archaeal membranes and preserved in the ocean's sediments to estimate historic ocean temperatures, Welander said.

Battening down the hatches

When under stress, archaea fuse their usually double-layered cell membranes into a single layer. Battening down the hatches in this manner firms up the membranes, which, being mostly made of fat, can get too floppy when the temperature spikes—like butter left on a kitchen counter.

Some archaea further modify the structures that fuse their membrane layers by adding on ring-like pieces that make the membranes even more compact and sturdy. These adaptations are helpful from a climatology perspective, since the membrane-linking structures—along with those sets of rings—readily preserve in marine sediments. By examining the numbers and kinds of rings, climate scientists can gauge surface water temperatures where and when those archaea lived. This technique has been used as evidence of the warmer seas of the Jurassic era, dating back more than 150 million years to the heyday of the dinosaurs.

Finding the proteins involved in making those structures resolves some uncertainties scientists have had about inferring ancient temperatures from archaeal lipids—what they call the paleotemperature proxies.

Climatologists have presumed that a single group of archaea, the

Thaumarchaeota, are responsible for making lipids with rings found in open oceans and that they add those rings in response to water temperature changes. But if other environmental factors such as salinity and acidity trigger ring production in other marine archaeal groups, that could scramble how they read the temperature signals.

According to the new study, climatologists can breathe a sigh of relief. By finally nailing down the proteins in play, the Stanford researchers show that Thaumarchaeota are indeed the dominant source of the ring-bearing membrane structures in ocean waters, supporting previous ideas of ancient sea surface temperatures.

"With that critical information now in hand, we can start to constrain some of the uncertainty about this particular archaea-based paleotemperature proxy," Welander said.

Pursuing the proteins

Although not identified until the late 1970s, archaea have since been recognized as constituting a whole new third domain of life, alongside the more-familiar bacteria and eukaryotes—multicellular organisms, including humans. Although archaea superficially resemble bacteria, biochemical and reproductive differences testify to their uniqueness. Many archaea are also extremophiles, which thrive in austere environments like hot springs where other life cannot survive.

To find the ring-making proteins, the Stanford team experimented with Sulfolobus acidocaldarius, among the least difficult archaea to grow and manipulate in a lab.

"This organism is one of the very few archaea that has a genetic system where we can do the kind of work we like to do," Welander said.

Her team set out to find which proteins enabled S. acidocaldarius to attach rings to its membrane-spanning structures. The researchers first found three possible genes by looking across the genomes of archaea that do and don't construct rings. They then created mutants in the lab lacking one, two or all three genes and, ultimately, two of these genes proved integral to the ring structures.

Those genes failed to turn up in another group of archaea that share marine environments with Thaumarchaeota and were considered as a possible, additional source of ringed structures in sediment samples. With that contribution ruled out, the sea temperature estimates derived from the paleotemperature proxy in question look more robust.

Taking it global

Welander said that scientists can now look into extending the Stanford team's findings into well-sampled marine regions worldwide. Her team picked through a genetic dataset from the north Pacific Ocean, and it therefore only directly speaks to that particular biome. Other datasets from the Atlantic Ocean and the Mediterranean Sea, for example, should reveal if Thaumarchaeota are also responsible for laying down the molecular fossils of interest in those areas. These paleotemperature proxies could even be extended into lakes and other environments, Welander said, opening up still more pages in Earth's climate chronicles.

Going beyond the climatological aspects of the findings, Welander noted that figuring out how the archaeal proteins handle the arcane work of membrane fusing could reveal compelling new biochemistry for potential real-world applications, such as drug discovery and materials science.

"Microbes invent all kinds of weird biochemistry to do all kinds of weird reactions," Welander said. "Anytime you can expand that chemistry of what is possible, it's really exciting from just a basic science perspective."

More information: Zhirui Zeng el al., "GDGT cyclization proteins identify the dominant archaeal sources of tetraether lipids in the ocean," *PNAS* (2019). www.pnas.org/cgi/doi/10.1073/pnas.1909306116

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