From hot springs to rice farms, scientists reveal new insights into the secret lives of archaea

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In the world of microbes, as in politics, some groups just can't seem to shake the label "extremist." So it is with archaea (ar-KEY-uh), a collection of bacteria-like microorganisms whose unique genetics and chemical structure separate them from all other living things.

For years, biologists have pigeonholed archaea as extremophiles-creatures that live in extreme conditions. Indeed, many species of archaea thrive in environments that would kill other organisms, from Yellowstone hot springs to the hyper-salty Dead Sea to streams polluted by mining waste where the pH level is equivalent to battery acid. Archaea even inhabit the warm, dark environs of our intestines and mouth.

While extremophiles have been the subject of intense research, scientists are just now beginning to focus on the large number of archaeal species that inhabit more mundane environments, including soils and seawater.

On Monday, Dec. 11, an international panel of researchers will present new findings about the extreme and not-so-extreme world of archaea during the annual meeting of the American Geophysical Union (AGU) in San Francisco's Moscone Center South. The session will be moderated by Chris Francis, assistant professor of geological and environmental sciences at Stanford University, and David Valentine, associate professor of Earth science at the University of California-Santa Barbara.

"Archaea have been a pretty hot topic for a number of years in the microbial ecology and physiology realm," Francis said, noting that most biology textbooks now divide life into three domains-Archaea, Bacteria and Eukarya, a category that includes plants, animals, fungi, algae and protozoa.

Scientists believe that the most recent common ancestor of all three domains was a single-cell organism that lived in extreme conditions when the Earth was very young and very hot, and the atmosphere contained large amounts of methane instead of oxygen. Although similar in size and shape to bacteria, genetic analysis reveals that archaea are actually more closely related to humans and other eukaryotes.

Ancient origins

Although archaea are believed to be among the oldest organisms on Earth, finding paleontological evidence of these ancient microbes has proven elusive. At the AGU session, G. Todd Ventura of the University of Illinois-Chicago will describe what may be the earliest archaean fossil evidence yet discovered-rock samples that are 2.71 billion to 2.65 billion years old that were collected from a deep underground gold mine in Ontario, Canada. Ventura and his colleagues discovered that the rocks contained a type of lipid, or oily compound, found only in archaeal cell membranes. This finding indicates that an archaean community may have inhabited the region more than 2.65 billion years ago when the area was submerged and inundated with hydrothermal vents that eventually produced a gold deposit in what is now modern Ontario.

In another AGU presentation, Roger Summons of the Massachusetts Institute of Technology will report on the discovery of novel organic compounds recently extracted from the lipids of contemporary archaea. It is likely that many of these compounds have "chemical structures that are new to science," he said.

Karyn Rogers of the Woods Hole Oceanographic Institution will discuss the effect of temperature and chemistry on archaeal communities inhabiting marine hydrothermal vents on the island of Vulcano, Italy. Several species of thermophilic archaea live in these shallow waters, where temperatures sometimes approach the boiling point. Rogers found that there were more than twice as many archaeal species at relatively moderate temperatures of 59 C (38 F) than at hotter vents where the thermometer reached 94 C (201 F).

Climate change

Three AGU presentations will focus on surprising new findings about the significant impact of archaea on global climate and nutrition. In recent years, scientists have discovered that methanogenic archaea play an important role in the build-up of methane gas in the atmosphere. According to the Environmental Protection Agency, methane is about 20 times more efficient at trapping atmospheric heat than carbon dioxide, the more famous greenhouse gas. A United Nations panel also found that methane levels in the atmosphere have increased by 150 percent since 1750.

It turns out that the international demand for rice is one of the main drivers of methane production on the planet. Studies have shown that rice farming contributes between 10 and 25 percent of global methane emissions, thanks in large part to methanogenic archaea, which crank out tons of methane gas when they break down organic matter in flooded rice fields. AGU panelist Ralf Conrad of the Max-Planck-Institute for Terrestrial Microbiology in Germany will describe a group of archaea known as Rice Cluster I, which he and his coworkers have identified as the predominant methane producers in rice paddies worldwide. Last July, Max-Planck-Institute researchers were the first to map the genome of Rice Cluster I species. This gene sequencing effort may one day help scientists find a way to reduce agricultural-based methane emissions through genetic engineering.

Non-extremophiles everywhere

"For many years, we always thought of archaea as extremophiles-halophiles [salt-loving], thermophiles [heat-loving], acidophiles [acid-loving] or methanogens [methane producers]," Francis said. Indeed, some Crenarchaeota are truly extreme. The species Pyrolobus fumarii holds the world temperature record for surviving in waters of 113 C or 235 F, well above the boiling point.

"However, in the early '90s, it was discovered that non-extremophilic archaea were ubiquitous and abundant in the marine environment, but it was unclear exactly how these organisms were making a living," Francis said. "Then, in 2005, our understanding of what some of these organisms are doing in the environment shifted dramatically."

That year, Francis and other scientists conducted independent studies on Crenarchaeota, a division of the Archaea domain that includes thermophiles and non-extremophiles. "Crenarchaeota are everywhere-in soils, sediments, the deep subsurface and the ocean," he said. "They are potentially the most abundant organism on Earth, yet we really had no idea how they survive in the ocean."

Non-extremophilic Crenarchaeota are fascinating, according to Francis, in large part because of their potentially vital role in cycling the global supply of nitrogen. All living things need nitrogen to make proteins, DNA and other biomolecules. Nearly 80 percent of the atmosphere consists of nitrogen gas, which, unlike oxygen, cannot be absorbed by most organisms. Getting usable nitrogen turns out to be a complicated biological process. First, special "nitrogen-fixing" bacteria in the environment convert atmospheric nitrogen into ammonia, then "nitrifying" bacteria oxidize the ammonia into nitrites and nitrates, which are readily absorbed by plants or removed by other microbes. Animals and people, in turn, obtain nitrogen by eating plants and other herbivorous animals.

That was the dogma taught for decades in biology classes-until September 2005, when David Stahl of the University of Washington showed that bacteria do not have a monopoly on nitrification. In a unique laboratory experiment, Stahl and his colleagues demonstrated for the first time that archaea-in this case, marine Crenarcheaota-also oxidize ammonia into nitrite.

Less than a month later, Francis and his colleagues published a paper in the Proceedings of the National Academy of Science (PNAS) showing that ammonia-oxidizing Crenarchaeota are pervasive in water columns and sediments throughout the ocean. Then in July 2006, German microbiologist Christa Schleper showed that nitrifying eota were up to 3,000-times more abundant in European soils than their bacterial counterparts.

Mexico to Iceland

At the AGU meeting, Francis and former Stanford graduate student Mike Beman will discuss the role of marine archaea in Mexico's Gulf of California, where nitrifying Crenarchaeota appear to be extremely abundant, even at depths of 2,000 feet.

In Iceland, Schleper and her colleagues recently identified the first ammonia-oxidizing extremophiles-a group of Crenarchaeota that inhabit several acidic hot springs where temperatures reach 80 C (176 F). "Collectively, our study provides evidence that ammonia-oxidizing archaea are present in hot springs and are actively nitrifying," said ecologist Andreas Richter of the University of Vienna, who will present the group's findings at AGU.

"Ammonia-oxidizing bacteria were discovered more than 100 years ago, and ammonia oxidation was previously thought only to exist in the bacterial realm," Francis said. "Nobody ever guessed that members of the Archaea were also involved in this process. We're still figuring out how all the pieces fit together."

Source: Stanford University