

## Under the Sea, a Missing Link in the Evolution of Complex Cells

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A microbe that might help explain evolutionary history was found near Loki's Castle, a hydrothermal vent field along the Arctic Mid-Ocean Ridge. Credit R.B. Pedersen/Centre for Geobiology/University of Bergen

Unlike bacteria, humans have big, complex cells, packed with nuclei containing DNA and mitochondria that produce energy. All so-called eukaryotes share our cellular complexity: animals, plants, fungi, even single-celled protozoans like amoebae.

Scientists estimate that the first eukaryotes evolved about 2 billion years ago, in one of the greatest transitions in the history of life. But there is little evidence of this momentous event, no missing link that helps researchers trace the evolution of life from simple microbes to eukaryotes..

On Wednesday, a team of scientists [announced the discovery](#) of just such a transitional form. At the bottom of the Arctic Ocean, they found microbes that have many — but not all — of the features previously only found in eukaryotes. These microbes may show us what the progenitors of complex cellular organisms looked like.

Dr. Ettema and his colleagues set out to extract the DNA from the sediment and analyze it. But it was a risky undertaking.

Dr. Jorgensen could provide them with only 10 grams of sediment — an amount that could easily fit in a teaspoon. Dr. Ettema also knew that this spoonful of muck would not have many microbes in it.

In their cold, dark, starved environment, these microbes barely grow. By comparison, a spoonful of ordinary backyard soil may have a million times more microbes.

It was clear that Dr. Ettema and his colleagues would have to use up just about all the sediment to find enough DNA to analyze. If they made a blunder along the way, they would have nothing left to study.

“There was just one shot,” Dr. Ettema said.

Fortunately, Dr. Ettema and his colleagues succeeded. It turned out that the sediment contained DNA from a lineage of archaea unlike any previously found. The scientists dubbed it Lokiarchaeum, named for a hydrothermal vent called Loki's Castle near the location where the archaea were found.

Analyzing the DNA, the researchers found that Lokiarchaeum is far more closely related to eukaryotes than any other known species of archaea. But even more surprising was that it had genes for many traits only found before in eukaryotes.

Among these genes were many that build special compartments inside eukaryote cells. Inside these compartments, called lysosomes, eukaryote cells can destroy defective proteins.

All eukaryotes also share a cellular skeleton that they constantly build and tear down to change their shape. Dr. Ettema and his colleagues found many genes in *Lokiarchaeum* that encode the proteins required to build the skeleton.

It's possible that *Lokiarchaeum* use their skeleton to crawl over surfaces as protozoans do. *Lokiarchaeum*'s genes also suggest that it can swallow up molecules or microbes as eukaryotes do.

All in all, *Lokiarchaeum* was much more complex than other archaea and bacteria, although not as complex as true eukaryotes. The new study indicates that they lacked a nucleus and mitochondria.

"This is a genuine breakthrough," said [Eugene Koonin](#), an evolutionary biologist at the National Center for Biotechnology Information who was not involved in the research. "It's almost too good to be true."



The researchers are trying to create conditions in which microbes that might help explain evolutionary history will survive and even grow. Credit R.B. Pedersen/Centre for Geobiology/University of Bergen

In the 1970s, scientists got their first major clue about the origins of eukaryotes. Carl Woese, a microbiologist at the University of Illinois, and his colleagues compared genetic material from different species to reconstruct the tree of life. Their analysis indicated that there were three major branches.

One branch included bacteria, among them such familiar species as *E. coli*. A second branch, which Dr. Woese dubbed archaea, included lesser-known species of microbes that live in extreme environments such as swamp bottoms and hot springs. Eukaryotes, which form the third branch, are more closely related to archaea than bacteria.

Over the past 40 years, as scientists have discovered new species of microbes and developed powerful ways to compare their DNA, the tree of life has come into sharper focus. A number of recent studies have indicated that eukaryotes are not actually a third separate branch. Instead, they evolved from archaea.

Thijs J. G. Ettema, a microbiologist at Uppsala University in Sweden, was struck by the fact that the species of archaea most closely related to eukaryotes lived in the deep seafloor. It was possible that even closer relatives might be waiting to be discovered there.

By a stroke of good fortune, Steffen L. Jorgensen, a microbiologist at the University of Bergen, had been digging up sediment from two miles below the surface of the Arctic Ocean. A preliminary look at the sediment revealed archaea living in some layers. Dr. Jorgensen offered Dr. Ettema some of the sediment to investigate more closely.

But Dr. Ettema's discovery illuminates how a *Lokiarchaeum*-like ancestor could have evolved into the first full-blown eukaryotes.

Once the ancestors of eukaryotes evolved a complex skeleton, the next major step may have been the origin of mitochondria.

Scientists have long known that mitochondria evolved from bacteria. They contain their own DNA, which is more like that of free-living bacteria than the genes in the cell's nucleus.

A number of researchers have proposed that the ancestors of eukaryotes swallowed up free-living bacteria. The bacteria became mitochondria, providing fuel for their host cell.

Lokiarchaeum, with its potential to graze for microbes, is precisely the sort of microbe required in this scenario.

Once early eukaryotes acquired mitochondria, they gained the energy to fuel a much bigger, more complex cell. In 2006, Dr. Koonin and William Martin of the University of Düsseldorf proposed that mitochondria triggered the evolution of a nucleus.

The two sets of genes could wreak havoc if they interfered with each other. Dr. Koonin and Dr. Martin proposed that eukaryotes gradually build a barrier to keep them separated.

As revealing as Lokiarchaeum's genes are, there are limits to what they can tell scientists. "We don't even know how big the cells are," said Dr. Ettema.

Dr. Ettema and his colleagues are trying to study the Lokiarchaeum microbes themselves now. They've gotten new sediment samples, and they can detect the microbes inside them. But the microbes die off before the scientists can learn much about them.

So the researchers are trying to create conditions in which the microbes will survive and even grow, mimicking the cold temperatures and high pressure of Lokiarchaeum's natural environment. But they are still trying to figure out other factors the microbes need to thrive, such as what sort of carbon they feed on.

"It's definitely not easy," said Dr. Ettema, "but we're not giving up. There are so many questions — this is a whole new biology we have to study."