Comment

Archaea are really mesophiles with attitude!

Mention the *Archaea* to most microbiologists and they instinctively think of extremophiles. This is to be expected for the *Archaea* were originally recognized as a distinct group because of the common properties of various extremophiles. As this knowledge spreads into the wider culture, especially to those for whom environmental microbes are of but passing interest, a certain amount of extrapolation goes on. The *Archaea* are described as 'primitive', similar to organisms from early Earth, where the conditions are perceived as extreme compared with today. Second, the *Archaea* are still considered to be extremophiles, restricted to growth in places where sensible organisms can only be found dead. These two perceptions are self-reinforcing, producing the impression that the *Archaea* are survivors, clinging to niches resembling the conditions on Earth aeons ago.

We actually know little about the conditions on the early Earth with any certainty and almost all of what we know has been revealed in the past couple of decades. The Solar System formed around 4·56 Gyr ($4{\cdot}56 \times 10^9$ years) ago from a collapsing molecular cloud of gas and dust. Aggregation of that dust produced the Earth and planets, which continued to grow by accretion of small bodies. A combination of energy from impacts, radioactive decay and gravitational energy heated the growing planet, to the extent that it had a molten surface. As the number of small bodies available to be captured fell, the planet cooled and in due course a solid crust formed. The crustal surface of the Earth is recycled through plate tectonics and the oldest surviving bits of crust have been subjected to considerable heat, so the nature of the original crust has to be surmised from indirect evidence. As the early Earth continued to cool, the atmosphere stabilized, allowing an ocean to form. It is believed that the early Earth was completely covered in water, so no 'warm little pond' for Darwin's cradle of life. Relative age-dating of craters on the Moon show that the Earth–Moon system suffered heavy bombardment by asteroids and comets, forming craters around 4·0 Gyr ago. The impact energy generated by collisions probably evaporated much of the water on the planet. The oldest piece of sedimentary crust that is currently known is about 3·6 Gyr old and contains fossils which bear a striking resemblance to cyanobacteria. These fossils are found in cherts and a chert is formed when pieces of rock fall into a sediment, like pebbles carried into an estuary. The sediment is 3·6 Gyr old, but the fossils are found in the pieces of rock and are therefore older. So, the most plausible sequence of events would seem to be that life formed in the oceanic early Earth. The heavy bombardment did not evaporate all water, but the elevated temperature put a severe bottle-neck in evolution so that only thermophilic strains survived, which explains why the earliest branches to emerge from the 16S rDNA tree of life were thermophiles.

So far so good. The advent of molecular biology and its application to microbial ecology has revealed that the world is full of *Archaea* in perfectly normal environments. Many of these branch very deeply and disrupt the 'thermophiles-at-the-bottom' view of evolution. What is more, when the microscope of molecular biology is turned on these extremophiles, the underlying chemistry proves to be very similar to that of mesophiles, but with certain modifications to protect the mechanisms from these extreme conditions. It is difficult to see how evolution could produce vulnerable chemistry and protective mechanisms at the same time. It is more reasonable to conclude that extremophiles are adapted mesophiles and not the font from which mesophiles emerged.

This version of the story would be more convincing if we could manage to cultivate some of these lineages whose existence is known only from environmental rDNA samples. What role are they playing in the environment? Is there anything special about their chemistry? The questions are legion, but the only method we have to address them requires cultivation as a first step. Suffice it to say that we have a very poor knowledge of the extent of diversity in the *Archaea*.

The purpose of this comment is to illuminate a view of the *Archaea in toto*. For those already involved in microbial ecology there will be nothing new here, but as the field is burgeoning and funding opportunities are increasing, more people are being tempted into the water. Come on in and welcome, but it is a great help to read widely and to pay attention to the bits between the lines.

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