Evolution may have moved at a furious pace on a much warmer Earth

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A composite image of the Western hemisphere of the Earth. Credit: NASA

Early life forms on Earth are likely to have mutated and evolved at much higher rates than they do today, suggests a new analysis from researchers at the University of North Carolina.

In a study published this week in the *Proceedings of the National Academy of Sciences*, Richard Wolfenden, PhD, and his colleagues found that the rate of a certain chemical change in DNA - a key driver of organisms' spontaneous mutation rates and thus of evolution's pace—increases extremely rapidly with temperature. Combining that finding with recent evidence that life arose when our planet was much warmer than it is now, the scientists concluded that the rate of spontaneous mutation was at least 4,000 times higher than it is today.

"At the higher temperatures that seem to have prevailed during the early phase of life, evolution was shaking the dice frantically," said Wolfenden, Alumni Distinguished Professor of Biochemistry and Biophysics at the UNC School of Medicine.

A much faster pace of evolution means that species could have proliferated much more rapidly than they do now, affording the flora and fauna of Earth ample time to acquire their enormous diversity and complexity.

That issue—whether life could have evolved to its present level of complexity within the time available—has lingered ever since Darwin published his theory more than a century and a half ago. Throughout that debate, both skeptics and proponents of evolutionary theory have often assumed that evolution's pace has stayed more or less constant over the eons.

The planet formed about 4.6 billion years ago from the cloud of dust and gas surrounding the early sun, and began as a hellish world of molten rock. It cooled until a crust condensed, and eventually, around 4.3 billion years ago, liquid brine began to fill the lower elevations, forming oceans.

"Recent evidence from rock samples in Australia indicates that life forms arose on Earth as early as 4.1 billion years ago - almost in the blink of an eye after the appearance of liquid oceans," Wolfenden said.

At that time, the average temperature at the Earth's surface would have been near the boiling point of water - 100 degrees Celsius, about 75 degrees higher than today.

To get some idea of the effect of such a high temperatures on the rate of evolution, Wolfenden's team examined a chemical reaction known as cytosine deamination, which occurs from time to time in all cells and may be the single most frequent cause of spontaneous DNA mutations.

In the deamination reaction, cytosine—the DNA base molecule known as "C" in the genetic code—loses an ammonia-like "amine" group of atoms. Deamination leads to the mutation of the cytosine into the DNA base thymine ("T" in the genetic code).

Wolfenden's team experimentally determined the rates of spontaneous deamination at different temperatures for cytosine and several cytosine-related molecules. In collaboration with the UNC lab of Ronald Swanstrom, PhD, the Charles P. Postelle, Jr. Distinguished Professor of Biochemistry at UNC, the researchers also measured the rates of cytosine deaminations and spontaneous C-to-T mutations in single-stranded DNA from the HIV virus that causes AIDS. The results showed that the rates of cytosine deamination, for isolated molecules and for single-stranded DNA, rose very steeply as the temperature increased. The scientists then added the assumption that Earth's surface temperature has itself changed exponentially - following Newton's law of cooling - over the period in which life has existed.

"Cytosine-based mutations, when the temperature was near 100 degrees C, occurred at more than 4,000 times the modern rate,"Wolfenden said. "To me, that was surprising. I thought the ancient rate would be more rapid than the modern rate, but not that rapid."

How could early life forms have coped with a high-temperature environment where their genetic material was being altered so rapidly?

"That question is still out there," Wolfenden said. He noted, though, that there are microorganisms even now that normally live in hot springs or deep-sea thermal vents, and somehow survive and multiply at temperatures as high as 120 degrees C.

Originally, DNA was stabilized to some extent by the presence of a complementary strand of DNA, and as life forms evolved, they developed increasingly sophisticated mechanisms for repairing DNA damage.

"These findings give us some idea of the burden faced by primordial organisms before they evolved sophisticated systems for repair," Wolfenden said. "And they offer another clue about how evolution kick-started the creation of the diverse world we see today."

More information: Cytosine deamination and the precipitous decline of spontaneous mutation during Earth's history, *PNAS*, www.pnas.org/cgi/doi/10.1073/pnas.1607580113

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