How did Life on Earth Emerge?
The Undertaking by the Foundation for Applied Molecular Evolution and the John Templeton Foundation

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Where did we come from? This is one of the earliest questions humankind ever asked. The answers of the Hebrew fathers are recorded in Genesis 1. The Aztecs had the myth of the five suns. The Daodejing tells us that "The Way gave birth to unity; unity gave birth to duality; duality gave birth to trinity; trinity gave birth to the myriad creatures."

Not entirely clear as to what that means, come to think of it. And one would have hoped that the Enlightenment of Galileo, the scientific method that he revived, and the triumphs of the sciences in the 19th century, where we came to understand the movement of planets, electromagnetism and the speed of light, the atomic structure of matter, the existence of radioactivity, and the cellular structural biology, would have made progress. A little progress, perhaps, but much of the progress was backwards.

For example, in 1850, the notion of "spontaneous generation" was still … alive. People thought that if they mixed water and dirty socks, or water and cornmeal mash, life would spontaneously emerge after time. After all, if you try this on your patio, you *do* get life. However, Louis Pasteur, killjoy that he was, killed spontaneous generation. He showed that any life that emerges from these experiments is life that drifted in on spores, floated in on aerosols, or germinated from tiny seeds. Life from life.

But if the Earth has not been around forever (radioactivity makes us confident that it has been around not longer than 4.54 billion years), at some point working backwards, no life was there from which the next generation of life could have emerged. Leaving aside the problematic definition of life (people like Carl Sagan argued is "a self-sustaining chemical system capable of Darwinian evolution"), this was when life began. Unless, of course, you believe that life came to the newborn Earth from elsewhere, a concept known as "panspermia", and featured in many scientific and popular descriptions (such as *Star Trek TNG*, "The Chase", Season 6, Episode 20). But that just moves the same problem to somewhere else in the galaxy.

We have incomplete models for what the Earth looked like 4.5 billion years ago, but we have some. Organic molecules were present containing the atoms (carbon, hydrogen, oxygen, nitrogen, sulfur, and phosphorus) that modern life relies on. Further, every school child is taught that in the 1950's, Stanley Miller sparked electricity (lightning) through gas mixtures of these organic materials and obtained amino acids, the building blocks of proteins. Heroes in the field named Juan Oro and Leslie Orgel got building blocks for parts of DNA and RNA from pre-biotic organic molecules, and even found that clays could generate small nucleic acids. Not RNA big enough for biology, of course, but it seemed to have been an auspicious start.

And then, around 1965, half century ago, the field seemed to stall. More and more Miller, Oro, and Orgel experiments were done, but they produced nothing particularly new. The 1976 Viking mission to Mars found some intriguing evidence for biology there, but nothing that the community found conclusive. The 1980s discovered that RNA, better than DNA, might have been able to do both genetics and metabolism in one molecular species. This meant that life might have originated with just one biological polymer (RNA) doing all of the work that modern life today does with three biological polymers (DNA, RNA, and proteins). Things were looking up, since this meant that one needed to figure out only how RNA might have emerged on a prebiotic Earth; we did not need to also figure out how proteins and DNA both emerged at the same time.

Unfortunately, RNA turned out to be a really problematic molecule. RNA seemed to function only in water, consistent with the widely held view that water is essential for life. However, water corrodes RNA, breaking apart the chemical bonds that hold together the critical atoms four RNA molecule to perform genetics. To catalyze metabolism, RNA must fold into a compact three-dimensional structure. However, for genetics, RNA must be unfolded in a linear state that can template the synthesis of its complement. How could a molecule be both folded and unfolded? Also, while RNA molecules were found in the laboratory that could catalyze chemical reactions, one of the easiest reactions for RNA to catalyze was the destruction of RNA.

To top it off, the new push for an ancient spontaneous generation seemed to contradict an experiment that has been done all around the world in kitchens after a distracted cook leaves on the stove for too long. When left to its own devices, organic chemical matter exposed to energy does *not* create biology. Quite the opposite. Organic molecules exposed to energy devolve to give asphalt, tar, material suited for paving roads, not for jumpstarting Darwinian evolution.

And so the field languished until about 10 years ago, before things started to change. In part, the change began because scientists started to recognize that whatever organic chemistry occurred on early Earth, it occurred in a geological context in contact with rocks and minerals. And these could help. My laboratory, for example, showed that minerals found in many deserts, most notably borax minerals such as those found in Death Valley, could prevent the devolution of organic molecules that on their way to RNA. Raffaele Saladino in Italy and Nick Hud at Georgia Tech, among others, found solvents in the cosmos other than water that allowed pieces of RNA to be assembled without being destroyed by water. Matt Pasek at USF found ways to manage phosphorus coming from meteorites.

Today, from these and other advances that place organic chemistry into a planetary context, an imperfect but seemingly robust discontinuous model has emerged that gets (at least some)

RNA having (at least some) ability to do both genetics and metabolism from prebiotic atmospheres and their carbon-containing molecular constituents.

And private philanthorpies have taken notice. As Tom Wolfe noted in "*The Right Stuff*", money is essential for science: "No bucks, no Buck Rogers". And while NASA has long supported “origins” research to support its missions to search for life in the solar system, private interest in supporting “origins” research has been a welcome addition as private donors from all around the world have recognized that perhaps now, the time is right, to solve this, one of the earliest questions that humankind has ever asked.

Just a few years ago, Harry Lonsdale, an Oregon chemist, entrepreneur, and Senate candidate, just before his death, assigned some of his personal fortune to a few research groups to make advances in RNA chemistry. Soon after, the mathematician, hedge fund manager, and philanthropist Jim Simons directed the Simons Foundation towards a much larger program in origins research, one that extended past the origins of life to the origins of planets and the origins of advanced life.

Today, the Foundation for Applied Molecular Evolution (FfAME), a nonprofit research organization based in Alachua Florida, announced the start of a third major private philanthropic venture in this area. With a $5.4 million commitment from the John Templeton Foundation, the FfAME is supporting research not only greater Gainesville area, but also around the world, to complete the picture that joins chemistry via geology to biology.

The FfAME-Templeton “Chemistry to Life” origins program includes an international team of field geologists led by Stephen Mojzsis at the University of Colorado who will spend summers in Northern Canada, where the glaciers have scraped the rock down to some of the oldest rocks accessible on Earth, some older than 4 billion years, 90% of the way back to the origin of the planet. Hyo-Joong Kim at Firebird Biomolecular Sciences LLC will join this geological information with organic chemistry to complete models for the emergence of RNA on early Earth. Andrej Luptak at the University of California at Irvine and Niles Lehman at Portland State University will resolve problems in how RNA catalyzes metabolism. George Fox and Maxim Paci at the University of Houston, and Charles Carter, Rihe Liu, and Eric Brustad at the University of North Carolina, will bring proteins into the mix. Andrew Ellington, at the University of Texas, will generate replicating species reminiscent of the first Darwinian systems.

The program starts today. We have 33 months to complete it. You can follow our progress on the internet (http://templetonorigins.ffame.org/home.aspx).

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