Was life inevitable? New paper pieces together metabolism's beginnings

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(Phys.org)—Describing how living organisms emerged from Earth's abiotic chemistry has remained a conundrum for scientists, in part because any credible explanation for such a complex process must draw from fields spanning the reaches of science.

A new synthesis by two Santa Fe Institute researchers offers a coherent picture of how metabolism, and thus all life, arose. The study, published December 12, 2012, in the journal Physical Biology, offers new insights into how the complex chemistry of metabolism cobbled itself together, the likelihood of life emerging and evolving as it did on Earth, and the chances of finding life elsewhere.

"We're trying to bring knowledge across disciplines into a unified whole that fits the essentials of metabolism development," says co-author Eric Smith, a Santa Fe Institute External Professor.

Creating life from scratch requires two abilities: fixing carbon and making more of yourself. The first, essentially hitching carbon atoms together to make living matter, is a remarkably difficult feat. Carbon dioxide (CO2), of which Earth has plenty, is a stable molecule; the bonds are tough to break, and a chemical system can only turn carbon into biologically useful compounds by way of some wildly unstable in-between stages.

As hard as it is to do, fixing carbon is necessary for life. A carbon molecule's ability to bond stably with up to four atoms makes it phenomenally versatile, and its abundance makes it suitable as a backbone for trillions of compounds. Once an organized chemical system can harness and manipulate carbon, it can expand and innovate in countless ways.

In other words, carbon fixation is the centerpiece of metabolism – the basic process by which cells take in chemicals from their environments and build them into products they need to live. It's also the link between the geochemistry of Earth and the biochemistry of life.

In a paper earlier this year, Smith and Santa Fe Institute Omidyar Fellow Rogier Braakman mapped the most primitive forms of carbon fixation onto major, early branching points in the tree of life (*PLoS Computational Biology*, April 18, 2012). Now, the two researchers have drawn from geochemistry, biochemistry, evolution, and ecology to detail the likeliest means by which molecules lurched their way from rocks to cells.

Their 62-page "Logic of Metabolism" paper presents a new, coherent picture of how this complex system fits together.

What started as wonky geochemical mechanisms were sequentially replaced and fortified by biological ones, the authors believe. "Think of life like an onion emerging in layers, where each layer functions as a feedback mechanism that stabilizes and improves the ability to fix carbon," says Braakman.

Carbon fixing and other chemical sub-processes that together constitute metabolism each comprise dozens of steps; some are quick and easy turnkey reactions with simple molecules, others require highly specific chemical helpers, or catalysts.

The parts of metabolism that guide carbon fixation through its unstable intermediate stages fall into the latter category, requiring help. But these seemingly unlikely reactions are remarkably consistent across all living systems. In fact, says Braakman, their ubiquity and the difficulty with which they are forged make them the chemical constraints within which all living systems operate – in a sense, the scaffolding for the tree of life.

It's these dependable regularities of hierarchy and modularity, amid the panoply of reactions comprising metabolism, that stabilize the system and enable its complexity.

Braakman and Smith describe specific features of metabolism and sub-divide helper metabolites by their functions. For example, vitamin B9, a complex molecule in the 'cofactor' class, facilitates the (otherwise unstable) incorporation of one-carbon compounds into metabolism.

In mapping the chemical pathways to life's emergence, the researchers touch on a more existential question: How likely was it for life to have developed at all? Extraordinarily so, says Braakman. "Metabolism appears to be an 'attractor state' within organic chemistry, where it was likely to be selected regardless of earlier stages of chemical evolution" in the chaotic, high-energy conditions of prebiotic Earth, he says.

Can it happen elsewhere? Possibly, even probably, he says. Rocky planets usually have cores chemically similar to ours, so if a planet is volcanically (and perhaps tectonically) active and has an ocean, it will probably have hydrothermal vents that spew chemicals, creating the potential conditions for life, Braakman says. In fact, the physics of star and planet formation make the chances of such conditions pretty reasonable.

Smith cautions, however, that we still have much to learn about the chemical and physical conditions that might lead to life-like organization, but he hopes their paper will at least "lead to experimental questions that focus more directly on the key functions that link metabolism to geochemistry."

More information: Read the paper in *Physical Biology* (December 12, 2012): iopscience.iop.org/1478-3975/10/1/011001/article

Provided by Santa Fe Institute

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