Methane-Belching Bugs Inspire a New Theory of the Origin of Life on Earth

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Two laboratories at Penn State set out to show how an obscure undersea microbe metabolizes carbon monoxide into methane and vinegar. What they found was not merely a previously unknown biochemical process -- their discovery also became the inspiration for a fundamental new theory of the origin of life on Earth, reconciling a long-contentious pair of prevailing theories. This new, "thermodynamic" theory of evolution improves upon both previous theories by proposing a central role for energy conservation during early evolution, based on a simple three-step biochemical mechanism.

Their results also provide insights into the evolution of the microbial production of methane, the primary component of natural gas. A detailed understanding of methane biosynthesis could lay the foundation for a new alternative energy source, by raising the possibility of cost-efficient conversion of renewable biomass into clean fuel.

James G. Ferry is Stanley Person Professor of Biochemistry and Molecular Biology, and Christopher House is Assistant Professor of Geosciences, both at Penn State. They will announce their new theory in the June issue of *Molecular Biology and Evolution*. William Martin, editor-in-chief of that journal, says "The paper is a very significant contribution, and a wonderful example of interdisiplinary work as well."

"We've taken a new approach to thinking about the evolution of life from a thermodynamic perspective," Ferry says. "It reshapes the two previous theories of life's origin, it shows how they overlap, and it extends both of them significantly." The apparently irreconcilable "heterotrophic" and "chemoautotrophic" theories of the origin of life both focus on the processes by which chemical building blocks first appeared for primitive life to assemble into complex molecules. "But that's not really what the driving force was in early evolution," Ferry asserts. "Nobody had properly considered thermodynamics."

"The problem of early energy sources has largely been ignored by the classical origin-of-life field," Molecular Biology and Evolution's Martin says, "which has largely been the domain of chemists. But microbiologists are the only ones who understand where the origin of life needs to get--modern microbial life."

According to the heterotrophic theory, a primordial soup of simple molecules arose first, driven by nonbiological energy sources like lightning, and led eventually to primitive life forms. One difficulty with this theory is due to the huge variety and complexity of organic molecules that would have had to arise spontaneously. In contrast, the chemoautotrophic theory rests on the idea that primitive life forms themselves, perhaps associated with catalytic iron and sulfur minerals, gave rise to the first simple biological molecules. The obstacles to this theory are the large number of steps in the biochemical cycles that have been suggested, and the staggering structural complexity of the only known enzyme complexes that drive those reactions. Debate between the two camps has raged for two decades.

By studying a microbe that Ferry discovered thriving in the oxygen-free, carbon-monoxide-rich sediment beneath kelp beds, he and his group have helped to break this impasse. Life may have emerged in just such an environment, and this microbe's unique biochemistry may harbor the molecular fossil of the first metabolism on Earth.

While other microbes make methane from carbon monoxide, this particular species (one "Methanosarcina acetivorans") also produces acetate--better known as vinegar. Ferry and House, in collaboration with Barry Karger at Northeastern University, showed how carbon monoxide is converted to acetate in a biochemical pathway that includes a well-known pair of enzymes, called Pta ("phosphotransacetylase") and Ack ("acetate kinase"). The two researchers realized that, in the presence of minerals containing iron sulfides, acetate could have been catalytically converted to a sulfur-containing derivative called an acetate thioester. Attached to the mineral surface, a "protocell" containing primitive forms of these two enzymes could then have generated biochemical energy by converting this derivative back to acetate. Excreting acetate would have completed the cycle. "Our paper," House suggests, "contains a very sensible early metabolism." "It is quite possible," Ferry says reverently, "that this could be the first metabolic cycle."

As in virtually every metabolic reaction on Earth, the energy produced by these reactions is stored in a molecule called ATP. The Ack enzyme catalyzes the synthesis of ATP directly. On the other hand, most ATP molecules--including those that this microbe makes by converting carbon monoxide into methane--are produced by multi-enzyme protein machines within the cell membrane that get their energy indirectly, from yet another protein machine that pumps an osmotic imbalance across the membrane. "It's difficult to imagine that something so complex could have emerged all at once," Ferry says, as the chemoautotrophic theory requires.

The acetate-producing species appears to be the direct descendant of one of the earliest true microbes. "We know that this bug is very ancient indeed," Ferry told the Penn State Astrobiology Research Center's annual meeting earlier this week. "There is strong phylogenetic evidence that acetate kinase is a very ancient enzyme." No such evidence can pinpoint the age of Pta, "but these two enzymes always work together," suggesting that they evolved together. The two enzymes' primeval genetic provenance and the simplicity of the three-step cycle, House says, "are absolutely central to the idea."

"This longstanding debate between the heterotrophic and chemotrophic theories," House continues, "revolved around carbon fixation." The new thermodynamic theory inverts the focus, Ferry says. "All these pathways evolved first to make energy. Afterwards, they evolved to fix carbon. These ideas suggest a totally new perspective. It's truly a quantum leap--a milestone."

The paper also proposes mechanisms by which Ferry and House's mineral-bound protocell could have evolved into a free-living cell, and how the metabolism of acetate to methane could have evolved based on the pathways they discovered. The genomic and proteomic analyses of carbon monoxide conversion to methane and acetate, carried out in collaboration with Northeastern's Karger, will appear later this year. The Department of Energy and the NASA Astrobiology Institute sponsored the research.

Source: Penn State

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