The energetic origins of life

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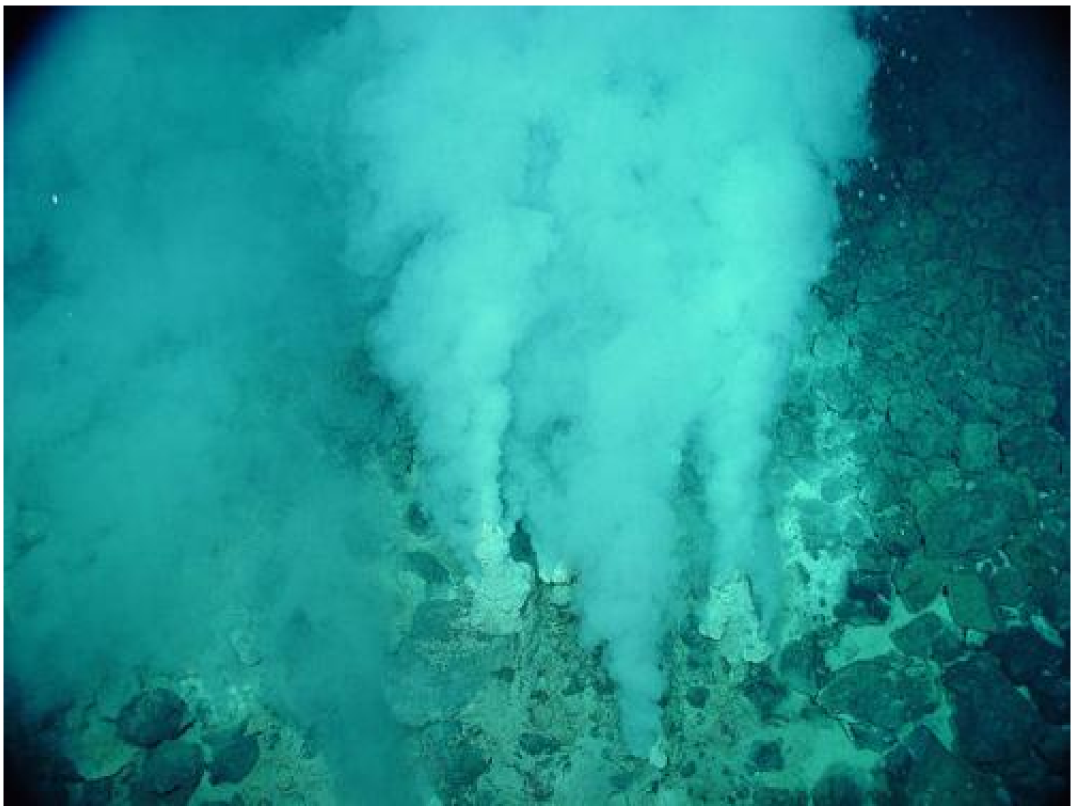

Alkaline hydrothermal vents, like the Lost City, may have been key to origins of life. Credit: commons.wikimedia.org

(Phys.org) —Imagination is perhaps the most powerful tool we have for creating the future. The same might be said when it comes to creating the past, especially as it pertains to origin of life. Under what conditions did the energetic processes of life first evolve? That question is the subject of a remarkable perspective piece just published in *Science*.

Authors William Martin, Filipa Sousa, and Nick Lane come to the startling conclusion that the energy-harvesting system in ancient microbes can best be understood if it is viewed a microcosm of the larger-scale geochemical processes of the day. In particular, they imagine a process by which natural ion gradients in alkaline hydrothermal vents, much like the "Lost City" ecosystem still active in the mid-Atlantic today, ignited the ongoing chemical reaction of life.

When it comes to origin of life discussions the so-called "RNA World" often comes to mind. While fascinating, that set of ideas is not what is under discussion here. According to the authors, it's all about the acetogens, the methanogens, and the chemical transformations that were key to their evolution. These microorganisms synthesize ATP using electrons from H+ to reduce CO2. In the process they generate either acetate or methane. The shared backbone in the energy metabolism of these microorganisms is the most primitive CO2-fixing pathway we know of—the acetyl-coenzyme A pathway. This pathway is generally referred to as the hub of metabolism as is links glycolytic energy production in the cell with oxidative energy production in its endosymbionts, the mitochondria.

While most acetogens are classified as bacteria, the methanogens belong to kingdom Archaea. This domain was only recently classified as distinct from bacteria and eukaryotes in 1977 by the late Carl Woese. Methogens are key to a bold leap of thought primarily made by Martin, which has come to be known as the "hydrogen hypothesis". Martin had seen a slide at a lecture which showed clusters of methogens inside eukarytoic cells nestled up right against hydrogenosomes, presumably feeding off the hydrogen they generate. Hydrogenosomes are similar to mitochondria in that they generate energy, put they are a paired-down version in that they do not contain any genome of their own.

Martin imagined that this cozy relationship he observed could have existed billions of years ago—only not as parasitic residents of a host eukaryotic cell, but rather as free residents at niche energy-producing locations within host earth. The host that then acquired what was to become the future mitochondrion was not a eukaryote with a fully-formed nucleus, but instead a prokaryotic and hydrogen-dependant methanogen. The future mitochondria then, was a facultative (as opposed to obligate) anaerobic eubacterium that in alternate incarnations also become the hydrogenosome.

The key feature and prediction of the theory is that the mitochondria created the nucleus, and therefore eukaryotes. This processes entailed massive transfer of most of the mitochondria's own genetic material to the host, which swelled the original genetic rank and congealed as chromosomes, simultaneously evolving the cyctoskeletal provisions for a complicated division cycle. The theory also neatly explains the lack of mitochondria in several eukaryotes through their loss, rather than as a failure to ever acquire them. The bio-existential question of whether the host "stole" the genes from the symbiont, or whether the parasite donated them becomes one of relativity and viewpoint. It is the same dichotomy as whether to say engulf or infect, or perhaps whether the assorted neurotransmitter packages dispensed by neurons are wastes, gifts or irritants.

Few researchers have done more than co-author Nick Lane towards uncovering the role of mitochondria in nearly every major process of the cell. He has summed up many of these ideas in his book *Power, Sex, Suicide: Mitochondria and the Meaning of Life*. In it he observes many things that like the hydrogen hypothesis, are now becoming accepted reality. Of note, he maintains that using those few genes preserved as local copies in the mitochondrial genome, different regions of the cell can rapidly tailor their energy output. In the case of the extended trees of neurons, this might also contribute to structural alterations and perhaps even memory.

As far as the origins of life, we need to turn back into the opposite direction now to try to un-create what might have happened prior to the eukaryotic merger, or at least led to it. In 2012 Martin and Lane published their thought-advances in imagining some of the geochemical processes which were later sped up, compacted, and made more efficient inside cells. These include how ion-gradients were set up at hydrothermal vents, bandied about, and later swapped H+ ions for Na+ ions as both the carriers and composers.

One such process they detail in their new paper is known as serpentinization. In this sequence of geochemical reactions, seawater percolating through submarine crust exothermically oxidizes Fe2+ to Fe3+ along with the release of H2 and energy. Serpentinization taking place at the Lost City formation, for example, generates a strongly reducing environment (reducing CO2), and it also makes the effluent alkaline with a pH of around 10, essentially controlling the fluid composition of the vent. Natural proton gradients are spontaneously set up with the same magnitude and orientation as occurs inside modern autotrophes (self-nourishing, producing cells).

What were the first ion-pumping mechanisms?

These vent features make them naturally chemiosmotic. In chemiosmosis, as also occurs in mitochondria, ions flow down natural gradients which can potentially be harnessed to produce energy. In the case of life, which universally employs multi-tool pumps known as ATP-ases, this energy is deposited as phosphate bonds in ATP. If the primordial ATP-ase harnessed these alkaline vent gradients, a first step could have involved a simple H+/Na+ antiporter. This kind of a device (now also protein-based like the ATP-ase) could have converted the initial vent gradient into the Na+ gradient the acetogens and methanogens use today. These complexes still use iron-sulfer clusters and methyl groups as substrates, and could have enabled the emergence of free-living prokaryotes.

Our understanding of chemiosmosis today is still incomplete. The so-called "proton-motive force" which couples proton and electron transfer across nebulous barriers still defies exact quantification. The flow of electrons through proteins, and the membranes which house them, continues to be one of the most exciting areas both in the origins of life, and in the creatures later evolved.

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