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100th Anniversary Special Paper:

On Hydrothermal Convection Systems and the Emergence of Life

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Abstract

Not only have submarine hydrothermal systems been responsible for a variety of mineral deposits, they may also have contributed to the emergence of life in the Hadean. Sulfide deposits can be precipitated where metal-bearing hydrothermal solutions invade bacteriogenic H_2S-bearing wet sediments and the overlying seawater or brine. Similarly, life might be viewed as a complex organic product that emerged when and where hydrothermal H_2 and other reduced chemical species reacted with CO_2 and other mildly oxidized molecules dissolved in the Hadean ocean. Semipermeable and semiconducting FeS barriers or membranes would have precipitated spontaneously where H_2 and HS^--bearing alkaline waters at ≤110°C seeped into the cool mildly acidic Fe-bearing Hadean ocean at a submarine hydrothermal mound on a ridge flank or on the deep ocean floor. The mound, consisting of Mg-rich clays, ephemeral carbonates, green rust, as well as the sulfides, acted as a natural, self-restoring hydrothermal reactor. In particular, the sulfide barriers, composed of mackinawite and greigite, prevented the immediate titration of the two fluids and controlled their interactions. Metal sulfides were, and in tiny amounts are still, vital to all cells. Among other reactions they help catalyze the reduction of CO_2 in autotrophic bacteria, including photosynthetic organisms. And the structure of greigite ($NiFe_5S_8$) is remarkably similar to the active sites (e.g., $NiFe_4S_5$) of the enzyme promoting the early metabolic pathway that generates acetate (CH_3COO^-) and H_2O from CO_2, H_2, and a methyl group ($-CH_3$). So clusters of greigite, sequestered in a simple organic envelope, could have acted as a protoenzyme, catalyzing the synthesis of acetate in the hydrothermal mound in the same way.

Although, like "spent" ore fluid, most of the acetate and all of the water would have been lost to the Hadean ocean, an acetate fraction retained in microcavities within the mound could have combined to form the simple organic building blocks of life. Hydrothermal ammonia and minor cyanide also would have contributed to the synthesis of amino and nucleic acids. Traces of phosphorylated organic molecules, such as RNA (ribonucleic acid), would have adhered to mineral surfaces in the membranous barriers. Once their phosphates were bonded to such a surface, short RNA strands could have polymerized and provided a crude code for the assembly of variable sequences of amino acids (incipient proteins) generated in the same milieu. Alternatively, they could have replicated further RNA. Amino-acid sequences were a significant component of the first membranes and would have influenced membrane and cell survival. Once RNA codes for successful amino-acid sequences were passed on to daughter cells then life could be said to have emerged and evolution to have begun. Bacteria have flourished around hot springs ever since and on occasion have been responsible for the deposition of giant base metal sulfide deposits at or below the sea floor.

Hence the study of life may be best begun by the study of those physico-chemical phenomena which result from the contact of two different liquids.
Stéphane Leduc, 1911, p. xiv.

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