Origins of life

Hydrothermal vents too hot?

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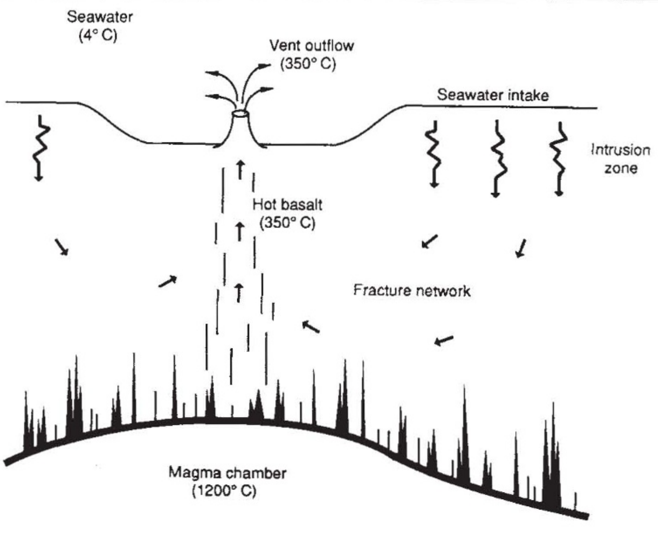
DID life on Earth originate in the outflow from a submarine hydrothermal vent? After careful examination of the relevant prebiotic chemistry, Miller and Bada, on page 609 of this issue[1], conclude that this is exceedingly unlikely. The hydrothermal vents are certainly a remarkable environment and are thought to have changed very little over the the past 4×10^9 years of Earth history. They offer a carbon source which is exposed to high temperature (above 300 °C) under strongly reducing conditions. However, Miller and Bada consider such conditions to be unfavourable for the synthesis of biological polymers in aqueous solution.

The discovery of large-scale hydrothermal activity at submarine ridge crests is one of the most significant findings in oceanography. A volume of water equivalent to the entire ocean passes through the ridge lavas every 8–10 million years (Myr), profoundly affecting the chemical balance of the ocean and of the Earth as a whole[2]. Because this is a phenomenon that has been operating continuously since before life began, it is reasonable to ask whether it had some influence on the chemical events that led to life's origins. Undoubtedly there were indirect effects resulting from the influence on the global environment. It has been proposed that a direct connection existed as well: that life began in the outflow tract of a hydrothermal-vent system[3].



Hydrothermal circulation at submarine vents, such as those found along the East Pacific Rise (after ref. 9).

There are several features of the environment of a hydrothermal vent that make it an attractive candidate for the origin of life. The main biogenic elements were present in the form of H_2, N_2, H_2S, CO, CO_2 and possibly CH_4; several metal ions were available, including Fe^{2+} and Mn^{2+}; the hot magma chamber provided a continuous source of thermal energy; and the entire system was shielded by the ocean from the destructive effects of ultraviolet irradiation. It has recently been pointed out that a submarine environment is also relatively protected from the deleterious effects of meteoric impacts, which were frequent before 4,000 Myr ago[4]. Finally, there is the intuitive notion, which dates back to the pre-socratic philosophers, that life is a geophysical phenomenon. Archelaus proposed in about 450 BC that "when the Earth was first being warmed, in the lower part where the warm and cold were mingled together, many living creatures appeared . . . deriving their sustenance from the slime"[5]. Setting intuition aside, one must ask whether hydrothermal-vent conditions are consistent with the chemistry required to synthesize sugars, proteins and nucleic acids.

Miller and Bada[1] note that the high-temperature synthesis of amino acids is a very inefficient reaction in an aqueous environment. Whatever amino acids were produced would have decomposed within a few minutes under hydrothermal-vent conditions. The half life of sugars and of hydrogen cyanide would have been of the order of seconds, so it is difficult to imagine how mononucleotides could have formed. In an aqueous environment, peptide synthesis by thermal dehydration is out of the question. Peptide synthesis using prebiotic condensing agents such as hydrogen cyanide and cyanamide remains a possibility, although these agents are highly susceptible to hydrolysis at 200–300 °C and 200–400 atmospheres (atm) pressure. One would have to propose a mechanism to ensure their rapid use in driving the synthesis of more stable compounds. The lability of peptide bonds and the extreme lability of internucleotide bonds under hydrothermal-vent conditions poses yet another difficult problem.

In 1983, Baross and Deming[6] described a community of extreme thermophiles that were cultured from the 350 °C waters of the hydrothermal vents along the East Pacific Rise. They claimed that these 'black smoker' bacteria could be grown in the laboratory at 250 °C and 265 atm. Subsequent investigation showed that the evidence for bacterial growth was likely to be the result of artefacts introduced during sample processing[7]. There is still no solid evidence for organisms growing at temperatures above 105 °C. Biology has apparently been unable to overcome the physical limitations imposed by extreme temperature conditions — it would be surprising if the first living organisms had managed to do so from the start.

This, of course, raises the question of what is meant by 'the start'. "Most biologists would agree that every living system must at the very least be capable of both replication and evolution."[8] The first living system, therefore, was an entity that was capable of evolving but had not yet embarked on a particular evolutionary pathway. Without the benefit of evolutionary improvement, such an entity must have been biochemically inept in the extreme. It is almost inconceivable that it could have been anything other than a heterotroph, deriving structural materials and energy from compounds that already existed in the environment. Theories suggesting that the first living organisms arose in hydrothermal vents and obtained their energy by carrying out anaerobic fermentation[3,9] must address the problem of how primitive metabolic pathways arose spontaneously in the prebiotic environment.

Is there any hope, then, for the hydrothermal-vent hypothesis for the origins of life? The problems of conducting useful chemical syntheses in the high-temperature outflow tract seem to be insurmountable. Perhaps life originated in low-temperature vents, such as those at the Galapagos rift or in the intrusion zone surrounding the site of hydrothermal discharge[9]. One would then have to postulate an energy source other than contact with the underlying hot basalt, which Miller and Bada show to be incompatible with the synthesis of biological polymers. The further one backs away from the hot magma chamber, the more the hydrothermal-vent hypothesis begins to sound like other theories that do not invoke a direct connection between the vents and the origins of life. □

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