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ON THE CREATION OF LIVING CELLS IN SUBMARINE HOT SPRING FLOW REACTORS: ATTRACTORS AND BIFURCATIONS IN THE NATURAL HIERARCHY OF DISSIPATIVE SYSTEMS.

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This hypothesis proposes that submarine hot springs which cooled the earth's early ocean crust provided an environment which created self-replicating organic structures and nurtured them as they evolved into the first living organisms on earth. It suggests that prebiotic synthesis, the subsequent molecular and cellular self-organization, and evolution leading to living cells took place sequentially in Archaean submarine hot springs.

Any viable model for the origin of life must explicitly account for the creation of highly ordered systems. This hypothesis describes such systems as attractors in the phase space of natural thermodynamic systems open to the flow of matter and energy; i.e. as equilibrium structures and dissipative structures appearing during the evolution of the natural hierarchy of dissipative systems. This hierarchy is created by the flow of energy outward from centers of gravitational accretion, a fundamental characteristic of our expanding, boundless universe.

Submarine hot springs are a key element in the hierarchy of dissipative structures created by the flow of energy from the earth; they are packed-bed, mixing-gradient,

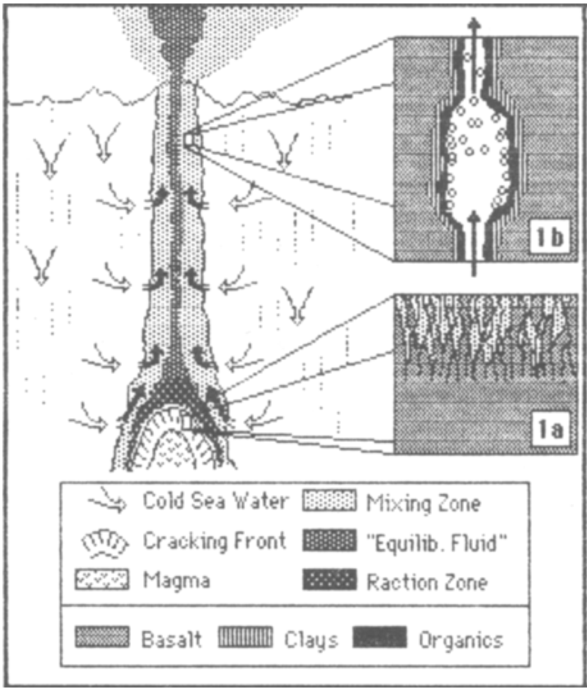

Figure 1. The submarine hot spring flow reactor.

1a. The cracking front. The site of the transfer of heat, gases, and soluble ions from magma to sea water at temperatures to 600° C, and the reactions:

$$2FeO + H_2O \rightleftharpoons H_2 + Fe_2O_3$$

$$CO_2 + 4H_2 \rightleftharpoons CH_4 + 2H_2O$$

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

1b. The "evolution reactor". A steady-state flow reactor with an influx of high-energy molecules and a steady-state population of competing, self-replicating primitive cells forming "quasi-species" (Eigen, 1971; Feistel, 1983).

continuous-flow chemical reactors (Fig. 1). The phase space trajectories which the hot spring fluid components are constrained to follow can lead to the assembly of complex organic molecules and organized structures which are thermodynamically inaccesible to near equilibrium systems or unconstrained chaotic dissipative systems. The hypothesis proposes that:

(1) At the cracking front (Lister, 1974)(Fig. 1a) sea water is heated rapidly to ~600°, carbon is extracted from the rock, reactions with ferrous iron in the rock produce a reduced fluid containing methane and hydrogen. This fluid reacts and equilibrates with the rock as it mixes with cooler sea water to about 350° C. This equilibrium fluid then rises, either directly to the sea floor, emerging as "smoker" plumes, or mixing in the rock with cold sea water to emerge at ~5-30° C, following a highly constrained mixing trajectory.

(2) High-energy organic monomers are synthesized in the fluid at or near the cracking front, and then rapidly quenched by mixing. The mixing trajectory followed by the fluids allows the "freezing" of thermal energy into the high energy bonds of these molecules.

(3) The flow reactor solves the serious problem of short-lived intermediates (hydrogen cyanide, sugars, etc) in prebiotic synthesis. The rapid rise of the fluids allows very short-lived intermediates to participate in the hierarchical chain of synthesis reactions.

(4) Fractures in the upper parts of the hot spring flow reactors (Fig. 1b) are the optimal geochemical environment for the synthesis of clay minerals (saponite, nontronite, ...). They can extract and accumulate organic matter, thus solving the problem in prebiotic synthesis of achieving high concentrations of organic matter from an initially very dilute aqueous solution.

(5) These fractures provide a space where the organic components can leave the mixing trajectory and enter a fluctuating steady-state (Fig 1b). The catalytic surfaces of clay minerals can provide initial information to organize organic components in the fluids, creating high concentrations of various random polymers. The steady flow provides a constant supply of energy-rich molecules, including simple high-energy organic molecules as well as a disequilibrium assemblage of oxidized and reduced inorganic molecules and ions.

(6) Eigen (1971) has proposed that such a flow reactor is the site of the emergence of autocatalytic self-replicating cycles of interacting protein and nucleic acid fragments, as attractors in the phase space, which evolve to form "quasi-species" of information-bearing molecules. The flow provides a dilution flux to maintain a constant population of information bearing molecules, a necessary condition for competition and evolution of the "quasi-species".

(7) It is reasonable that lipid vesicles (or proteinoid protocells) might form in such an environment as stable equilibrium structures, attractors in the phase space. Such permeable, bounded volumes in a steady state flow reactor are examples of the classic reaction-diffusion systems which have been the focus of the physical and thermodynamic description of self-organizing behavior (Turing, 1952, Nicolis and Prigogine, 1967).

(8) The growth and replication of such primitive cells in such a flow reactor would lead to selection and evolution of the most rapidly growing "quasi-species" of cells (Feistel, 1983); i.e. selection of those entities at the hierarchical level of cells which contain the most efficient self-replicating entities at the hierarchical level of molecules. Thus began the feedback cycle between between entities at these two levels, between code and structure, and the hierarchical evolutionary ascent to present-day life on earth.

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