An Origin of Life through Three Coupled Phases in Cycling Hydrothermal Pools with Distribution and Adaptive Radiation to Marine Stromatolites

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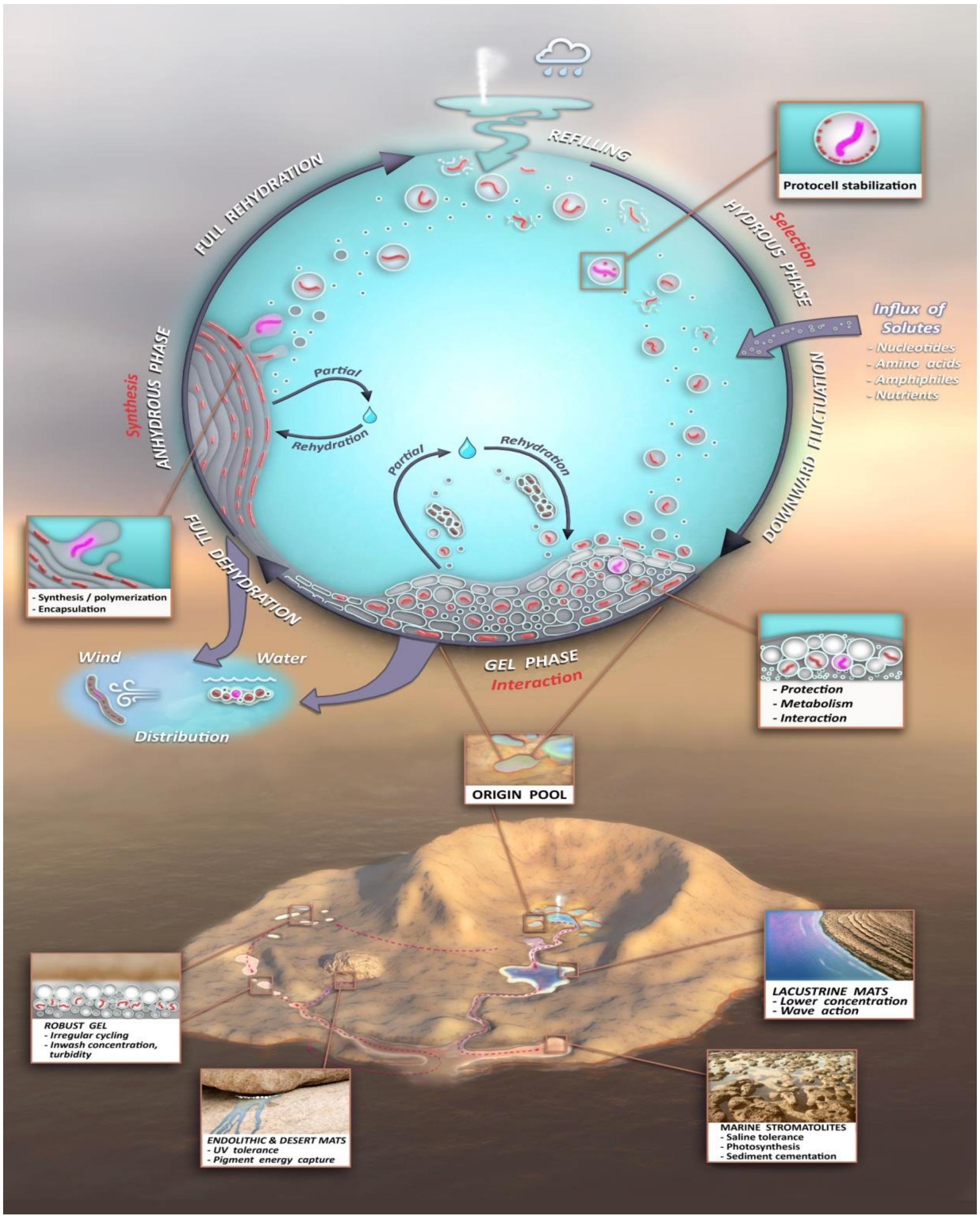

Figure: Chemical and geological frameworks supporting an origin and adaptive radiation of life from cycling hydrothermal pools to marine stromatolites. Find this poster, handout and other resources at:

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Abstract
We present a novel model for an origin of life situated within inland freshwater hydrothermal pools subject to periodic filling and evaporation. The model incorporates the combinatorial selection and evolution of systems of functional polymers enclosed in anhydrous, hydrated, and gel phases of lipid membranes cycling in a kinetic trap (figure-upper). The anhydrous phase supports synthesis of random polymers between dehydrating lipid lamellae. Upon rehydration these polymers become encapsulated in lipid compartments (protocells). The hydrous phase selects the encapsulated polymers for their ability to stabilize the surrounding membrane. Stable protocells survive and accumulate along with concentrated solutes in a gel phase during downward pool fluctuation. We predict that the gel phase will exhibit properties of growth and adaptation and is a prototypical microbial community undergoing a transition to life through a network of shared metabolic and genetic functions, competitive and cooperative interactions, niche construction, and adaptive radiation through distribution to a variety of venues.

Chemical Framework
This model is based on previous work that demonstrated nonenzymatic polymerization driven by cycles of hydration and dehydration (Rajamani et al., 2008; De Guzman et al., 2014; Da Silva et al., 2015; Forsythe et al., 2015), but goes one step further to propose a natural combinatorial system of selection and stepwise molecular evolution (Damer and Deamer, 2015). These functions emerge as an evolutionary process that involves the following steps:

- An **S-polymer** arises by chance that **stabilizes** protocell membranes allowing them to cycle their contents through the gel and anhydrous phases forming a kinetic trap.
- Functional polymers are initially produced through random synthesis. However, to support evolution through heritable traits, polymers must become expressed by informational, or **I-polymers**. An I-polymer arising through random synthesis which expresses a useful functional polymer will be selected for. Replication of sets of I-polymers to successive generations of protocells establishes a primitive genetic code.
- Protocells expressing pore-forming **P-polymers** are selected for additional stability through equilibration of osmotically active species and also gain access to nutrients.
- Access to nutrients supports the emergence of **metabolism** through **M-polymers**.
- Metabolism generates products that support **replication (R-polymers)** and systems of molecules that **catalyze (C-polymers)** their own replication. Molecular systems supporting **feedback (F-polymers)** provide controls for the rates of the above processes.

Geological & Evolutionary Frameworks
A recent field trip to Archaean fossil sites of Western Australia placed this model in a geological context. New evidence for fresh water hydrothermal systems at 3.5gya (Van Kranendonk et al., 2015) and other comparative work (Deamer and Georgiou, 2015) provides further support for an origin of life in a terrestrial rather than a marine setting. On a volcanic island (figure-lower), water and wind would dislodge segments of stable, adaptable protocell gel and anhydrous films from the surfaces of a hydrothermal “origin pool”. Downhill water distribution of segments to lakes, estuaries and protected marine shorelines provides an adaptive gradient to saline tolerance. Windborne distribution of segments to isolated pools and moist rock undersurfaces provides the dual selection pressures of varying UV exposure and solute scarcity, selecting for protective pigments, which capture energy for photoautorophy. Protocell communities adapt to sedimentary covering by precipitating carbonate minerals, building the distinctive layers of stromatolites,

which dominate much of Earth's fossil record. These gel protocell communities constitute the roots of the tree of life before the emergence of more evolved microbial mats and free-living prokaryotes.

Experimental and Observational Foundations

The scenario proposed here builds on the results of multiple previous studies, and it is useful to summarize this weight of evidence:

- All of the primary species of organic compounds that are required -- amino acids, nucleobases and monocarboxylic acids -- are present in carbonaceous meteorites. This fact makes it plausible that they were likely to be available in the prebiotic environment, either delivered during late accretion or synthesized geochemically (Chyba and Sagan 1992; Sephton 2002; Pizzarello et al. 2013).
- A variety of amphiphilic compounds form membranous vesicles by self-assembly. Some of these are as simple as fatty acids, also present in carbonaceous meteorites (Deamer and Pashley 1989).
- Cycles of hydration and dehydration are ubiquitous in hydrothermal fields.
- Upon drying, amphiphilic compounds fuse into multilamellar structures that capture and concentrate monomers between bilayers (Toppozini et al. 2013).
- Water activity is reduced during dehydration to the point that condensation reactions link the concentrated monomers into polymers (Rajamani et al. 2008; De Guzman et al. 2014; DaSilva et al. 2014).
- Polymers are readily encapsulated in membranous vesicles by HD cycles (Deamer and Barchfeld 1982).

Testable Predictions

The following is a thought experiment intended to guide experimental designs to test the initial steps of the coupled phases model. The following prediction can be tested utilizing prebiotically plausible conditions, reagents and mineral surfaces. It is predicted that populations of protocells will undergo measurable fluctuations as the innovations of selected functional polymers are expressed. These changes would be most clearly observed through the varying size and longevity of a gel phase which forms as increasing populations of stable, entrapped protocells resist water loss and share functions. Sequencing of distinct, amplifying populations of gel polymers would provide insight into the coupling of emergent function and gel growth. This simple experiment would test whether a system of three coupled phases in a fluctuating hydrothermal pool can promote generations of coherent compartmentalized polymers moving away from equilibrium, suggesting a viable pathway to an origin of life.

Project Web Site

Find a full treatment of the coupled phases model, research results and a guide for experimenters at: **http://origins.biota.org**

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