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A hydrothermal-sedimentary origin of life scenario

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Introduction: Many locations, ranging from hydrothermal vents, pumice rafts, to continental springs and rivers, have been proposed for the emergence of life on Earth 1-3]. Hydrothermal edifices, in particular, offer a combination of characteristics that make them particularly attractive: concentration of organic molecules in the porous edifices, disequilibrium conditions and protection from harmful UV radiation, presence of transition metal-rich mineral surfaces upon which molecules can condense, be structured and complexify [4,5].

Hypothesis: However, there is another, hitherto unnoticed, environment that, on the Hadean Earth (4.5-4.0 Ga), was more significant than the other proposed locations in terms of spatial and temporal scale: the sedimentary interface between hot oceanic crust and seawater [6].

Results: Using evidence from the oldest, well-preserved volcano-sedimentary rocks (3.5-3.3 Ga), the best available analogues to Hadean sediments, we document from the macrosopic to the microscopic and elemental scale that these porous volcanic sediments (originating from mafic and ultramafic crust) were permeated by hydrothermal fluids at all scales, gently infiltrating between the pores or sometimes more dynamically mixing the volcanic particles (Figure 1 [6, 7]).

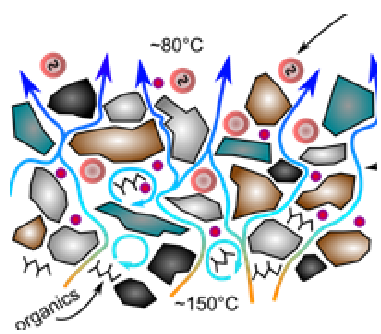

Figure 1. Hot alkaline fluids carrying dissolved carbonacoeus matter + small organics mix with extraterretsrial organics and carbonaceous matter previously eluted from the volcanic sediments. Fluids permate and mix with porous volcanic sediments in temperature and pH disequilibria. Convection of warm, carbon-bearing hydrothermal fluids allowed prebiotic molecules to concentrate and self-assemble in pore spaces and on the surfaces of chemically reactive minerals, resulting in the formation of increasingly complex molecules.

Discussion: Reduced carbon was brought in by the hydrothermal fluids although carbon of meteoritic origin would also have been relatively abundant, especially in the Hadean era. This UV-protected, subaqueous sedimentary environment, characterised by physical and chemical disequilibria (gradients in temperature, pH, redox and relatively diverse mineral speciation), represented a globally distributed system of miniature chemical reactors in which the production and complexification of prebiotic molecules could have led to the origin of life.

Conclusions: The fundamental importance of these observations is that hydrothermal sediments and these kinds of organic reactions occurring at mineral interfaces must have been ubiquitous on the Hadean Earth, and life could have emerged anywhere all over the early Earth – at temperatures (<100°C) conducive to prebiotic chemistry.

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