STEPS TO THE RNA WORLD: NUCLEOBASE SURVIVAL AND EVOLUTION IN WARM LITTLE PONDS.

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Introduction: Darwin first suggested that warm little ponds (WLPs) might be the natural sites for the origin of life. Models have since been proposed which describe the evolution of biomolecules in such systems [1,2]. Meteorites and interplanetary dust particles (IDPs) would have delivered biomolecules such as nucleobases to these environments on the early Earth [3,4]. However, Chyba & Sagan [3] came to the conclusion that given a non-reducing atmosphere, IDPs would be the dominant source of prebiotic organics. Nucleobases could then become concentrated in WLPs as water evaporates. Hydrothermal vents, on the other hand, due to the great volumes of water where they are located, have a "concentration problem" [5].

The RNA world hypothesis suggests that the first forms of life on Earth were strands of self-replicating RNA molecules, built out of nucleotides [6]. The first steps to the RNA world would involve forming nucleotides in environments favourable for RNA synthesis on the early Earth. One pathway to form a nucleotide could be meteorite-delivered adenine reacting with ribose to form adenosine [7], and adenosine reacting with a meteoritic phosphorous source to form AMP [8].

Motivated to understand the fate of nucleobases once delivered to the Earth, we numerically model the survival and accumulation of nucleobases in WLPs. Our model functions on the basis of well-documented rates of the sources and sinks of both pond water and nucleobases in early Earth conditions. For pond water, we consider precipitation as the source, and evaporation and seepage as sinks. For nucleobases, we consider carbonaceous meteorites and IDPs as sources, and hydrolysis, seepage, and UV photodissociation as sinks.

Results: Our results present a paradigm shift on three fronts:

(1) Contrary to Chyba & Sagan [3], we find IDPs delivered a negligible abundance of nucleobases to early-Earth WLPs which survived for subsequent synthesis into nucleotides and RNA. Meteorites on the other hand delivered a dominant abundance of nucleobases possibly accumulating to ppb–ppm level concentrations for up to half a year (see Figure 1).

(2) An RNA world could not emerge on a hot early Earth, where temperatures remain from 50–80 °C. Nucleotides, once formed in WLPs, can only survive for a few years at such temperatures [9]. Since Darwinian evolution requires thousand-to-million year timescales to form the ribosome beginning from self-replicating RNA strands, nucleotides would also need to survive for such timescales. This requires sustained temperatures closer to ~5–35 °C, implying the RNA world emerged in colder regions on the early planet.

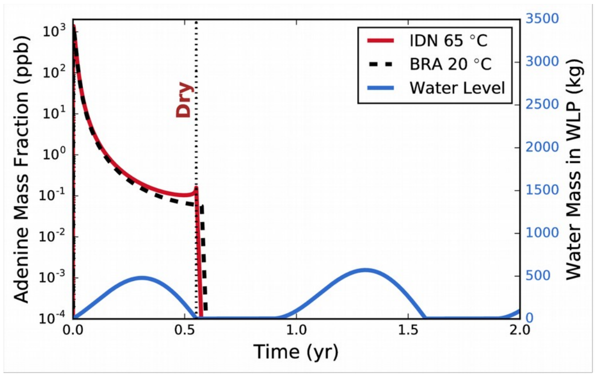

Figure 1. Red and black curves: The accumulation of adenine from small fragments of an initially 40-m radius carbonaceous meteoroid in a WLP with a 1 m radius and depth. The hot early Earth model at 65°C (red) and the warm early Earth model at 20°C (black) use annual rainfalls representing some locations in Indonesia and Brazil today. Blue curve: The matching wet-dry cycles of the hot and warm early Earth WLPs.

(3) The late heavy bombardment, occurring from ~3.9–3.8 Ga, probably had little effect on the emergence of the RNA world. We calculate only a 5% chance that carbonaceous meteorites entered a WLP during that time. However, we calculate approximately 2–1750 carbon-rich meteoroids led to warm little pond depositions over the entire 4.5–3.8 Ga period.

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