Earth Syst. Dynam. Discuss., 1, C4–C9, 2010
www.earth-syst-dynam-discuss.net/1/C4/2010/

Earth System Dynamics Discussions

Interactive comment on "Thermodynamic origin of life" *by* K. Michaelian

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Received and published: 12 April 2010

General Comments

This is a provocative paper making the case for the self-organization of replicating RNA molecules in the prebiotic oceanic environment, driven by the great increase in entropy production produced by the absorption of uv radiation by the RNA molecules. The author argues that the "function of life is to act as a catalyst for entropy production" (p.22) , quoting his 2009 paper. I have three main observations. First, alternative scenarios for the origin of life are not confronted nor even mentioned, namely metabolism first, followed by replication (e.g., Shapiro, 2007) and the hydrothermal origin scenario, again with metabolic cycles preceding replication, finally evolving into cellular life (e.g., Wachtershauser, 2006; Russell, 2007; Nitschke and Russell, 2009). The author apparently equates life with replication, but this is missing a crucial aspect of life as we know it. Viruses replicate but are essentially crystals without the energetic cycling critical for a living system. And this neglect of metabolism and its coupling with replication to produce the first protocells poses a real challenge to the argument made in this paper. The surface layer of the ocean is proposed for the environment of RNA self-organization. The author argues that the dissipation of heat promotes convection, even hurricanes on the early Earth. But these same processes would likely dilute the environment where biogenesis is supposed to take place, a long challenge to the primordial soup scenario (see Robert Shapiro's critique, e.g., Shapiro, 1986). In contrast, the hydrothermal origin of life, whether in Wachtershauser's scenario with the critical role of strong bonding of organics on mineral surfaces or that of Russell, with the addition of a protected nursery in the alkaline hydrothermal mounts, are proposed where the chemical evolution and coupling of replication and metabolism takes place.

My second observation is to question when RNA and DNA acquired their uv absorption capacity, was it later in evolution or near biogenesis? I note that the author does not reference two papers (26, 27: Cadet and Vigni, 1990; Görner, 1994) which are cited in Biondi et al.'s (2007)'s paper as follows (cited by Anonymous Referee #2): "Effects of UV irradiation on biomolecules such as DNA and RNA range from breaking of the pentose-phosphate backbone to the formation of pyrimidine dimers [26, 27], and are thus considered a major obstacle to the theory of the RNA world.hairpin ribozyme . . ., against UV irradiation." Is this a major obstacle to the author's scenario?

My third observation is to question the reduction of the thermodynamics of self-organizing systems to the property of maximizing entropy production. I suggest the author consider a more complex analysis that confronts the potential modes of entropy production constrained by the real existing system itself (e.g., Volk and Pauluis, 2010). Multiple possible pathways in biospheric and biotic evolution are possible and the actual history does not necessarily have a greater entropy flux to the environment relative to alternative histories. A simple example suffices; if the "function" of life is to serve as a catalyst for entropy production, then once methanogens emerged – plausibly with this metabolism in the first protocells (e.g., Russell, 2007)- why didn't the methane level in the atmosphere increase at some point in geologic history thereby leading to a runaway greenhouse, with Earth losing its water just as Venus, creating a low albedo rocky surface that maximizes the entropy flux to space relative to the prior entropy flux of an Earth with water and an atmosphere ? This is a variant of the Medea hypothesis (Ward, 2009), with life doing away with itself by being a premier catalyst for entropy production. An obvious objection is that methanogen activity and water/atmosphere loss were blocked by physical constraints imposed by the Earth-Sun system as well as biogeochemical cycles. Yes, so the actual entropy flux to the environment (or to space) is constrained by the physical context and history of the system under consideration. Indeed, the emergence of life is constrained by the initial and evolving characteristics of the planet. So life has arguably no function, rather it like every process in the universe in producing a net entropic flux to the environment. And to argue that life is driven to maximize entropy production raises the question, relative to what alternatives? Without confronting these concerns invoking MEP is problematic.

And in contrast to the scenario proposed in this paper is the hydrothermal metabolism first model of biogenesis, by necessity an entropy generator. For example, "Our more profound discomfort with this as well as with all other kinds of heterotrophic scenarios arises from thermodynamics. The oxidation of organic molecules may well provide an (albeit weak) energy source for a fully-ïňĆedged organismal entity. However, in our minds it falls desperately short of allowing life to originate. In the spatial unit cell where life comes into being, the appearance of a walled, structured and metabolizing entity represents an enormous decrease in entropy. The second law of thermodynamics allows such spontaneous structure-formation only in the presence of a very strong ïňĆux of enthalpy (think for example Jupiter's Great Red Spot or the alkaline hydrothermal convection cell itself). Such a spatial and temporal constancy in free enthalpy supply in the form of electrochemical disequilibrium between H_2 and CO_2 is the basic premise of the hydrothermal autogenic scenario and we presently do not know of any other hypotheses for the origin of life on Earth (or elsewhere) which pro-

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poses a comparatively credible energetic driving force for structure-formationâĂŤor as Dobzhansky might have said: Nothing in the origin of life makes sense except in the light of (bio)energetics." (Nitschke and Russell, 2009). Thus, I question whether comparative entropy flux generation can be a predictor of which scenario of biogenesis is more probable since the physics and chemistry of the system and its prior history must be the determinant of the actual pathway, recognizing that entropy generation to the environment occurs in any spontaneous process of self-organization of matter.

Specific Comments

p.4, line 22-25 (and p.22, line 26-28; p.30, line 4-5): See Baaske et al., 2007 and Koonin, 2007 for a potential hydrothermal pathway by by temperature cycling. p.5, line 15-16: There is no evidence for a hot soup of organic material at 3.8 Ga, rather that ocean chemistry was likely not too different from more recent times, except for likely higher salinity in the Hadean/Archean because of smaller continents. p.6, line 26: presence of ammonia is dubious. p.9, line 1-7: see my second observation made above. p.13 (and p.21, line 7-13;): Abiogenic synthesis of organic molecules is demonstrated in hydrothermal experiments (e.g., LaRowe and Regnier, 2008). p.17, line 11-15: But both DNA and RNA stability at hyperthermophilic temperatures is enhanced in salt solution (Tehei et al., 2002; Vergne et al., 2006), and likely by adsorption on mineral surfaces. Since both RNA and DNA function now in hyperthermophiles it is plausible to argue that DNA/RNA and repair mechanisms coevolved in early cells. p.18, line 3-10: there is now a case that the LB didn't occur (Lineweaver and Norman, 2009). In any case, mesophiles could have survived the LB in some interpretations (Abramov and Mojzsis, 2009). p.31, line 22: The origin of life, i.e., replication coupled with metabolism is not described in this paper. Where is the protocell?

Technical Corrections

p.5, line 21 Spelling: lightning, not lightening.

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