Early Earth – August 13, 2015

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1 Early earth conditions from [1]

When Did Life Begin? Earth was well formed by 4.5 billion years ago, but the time at which life began remains uncertain. The evidence rests on two types of fossil record in ancient geological strata. Hard fossils include microscopic structures that resemble organisms in thin sectionsof rocks, and macroscopicstro- matolites, laminated mounds with structures of a type often associated with mats of microorganisms (Schopf and Walter, 1983). Another type of fossil record relies on the fact that biological reactions commonly select for lighter isotopes of carbon (reviewed by Schidlowski, 1987). There- fore, the enrichment of 12C/3C in organics extracted from ancient rocks, relative to abiogenic carbon, is some evi- dence for the occurrence of life. The very early traces of life are sketchy, however, because there are only a few remnants of the early crust in which to prospect. The action of plate tectonics has erased, by subduction, most early strata. Carbon isotope fractionation studies show enrichment for C12/C13 in kerogens (carbon-containing polymers) extracted from some of the oldest known rocks, about 3.8 billion years in age, from the lsua supracrustal geologic formation (Greenland). Such evidence for life is compro- mised, however, because thermal processes also can cause isotopic fractionation, and the lsua rocks have been deeply buried and heated at least once.

Putative microfossils and stromatolites of the 3.5- billion-year-old Warrawoona (Australia) and Swaziland (South Africa) geological formations are generally consid- ered more convincing as evidence for early life (reviewed by Schopf and Walter, 1983). This evidence, however, is also compromised. Based on the character of kerogen associated with putative microfossils and the morphology of stromatolites, there is reasonable doubt as to the biolog- ical origin of those features (Buick, 1990). The earliest unambiguous fossil microorganisms and stromatolites are in rocks of about 3.1 billion years in age (Mason and Von Brunn, 1977). Our notion as to the time of lifes emergence clearly is tenuous. Certainly it occurred before 3-3.5 billion years ago; however, 4 billion years ago or even earlier seems possible, depending on the compatibility of the physical conditions at that time.

What Was the Character of Earth at the Tim of the Origfn of Life?

- Surface of Earth was molten $4.2 - 4.5 Ga$

- There is not much actual knowledge about that time. However theories provided some satisfying models (Chang et al., 1983).
- From model to model:

  ∘$T = 500℃ - 1000℃$

  ∘pressure $500atm\, H_2 0$, $40atm\, CO/CO_2$, $10atm\, H_2$
- The surface of Earth was reducing: $Fe^{2+} \gg Fe^{3+1}$
- Atmosphere would have been mildly oxidizing ($[CO/CO_2] \gg [CH_4]$, regardless of model.
- High temperature of that time would prevent life from forming. It is however unclear how much it was necessary to cool in order to provide an environment suitable for the origin of life.
- The only clue to the rate of cooling from the geological record is that some of the earliest crustal remnants, such as the Isua rocks, are sediments and therefore there must have been liquid water by 3.8 billion years ago.
- It seems likely that Earths entire surface was covered with water, but if pressure was high, water temperature could be $> 100℃$
- As an estimation of the upper bound of temperature at which life could occur people use temperatures at which modern organisms can live. Clear boundary hasn't been established yet. Some organisms were grown in a lab at 100℃-110℃(reviewed by Stetter et al., 1990), and some with temperatures up to 122℃[2]
- Surface chemistry could've been of use to help life to form: Pyrite (Wachtershauser, 1988) and basaltic glasses also would have been abundant on early Earth, and could provide surface support for complex chemistry.

References

[1] N. R. Pace. Origin of life - Facing up to the physical setting. *Cell*, 65(4):531–533, 1991.

[2] K. Takai, K. Nakamura, T. Toki, U. Tsunogai, M. Miyazaki, J. Miyazaki, H. Hirayama, S. Nakagawa, T. Nunoura, and K. Horikoshi. Cell proliferation at 122 C and isotopically heavy CH4 production by a hyperthermophilic methanogen under high-pressure cultivation. *Proceedings of the National Academy of Sciences*, 105(31):10949–10954, August 2008.

[1] A reducing agent (also called a reductant or reducer) is an element or compound that loses (or "donates") an electron to another chemical species in a redox chemical reaction. Since the reducing agent is losing electrons, it is said to have been oxidized.