The Drive to Life on Wet and Icy Worlds

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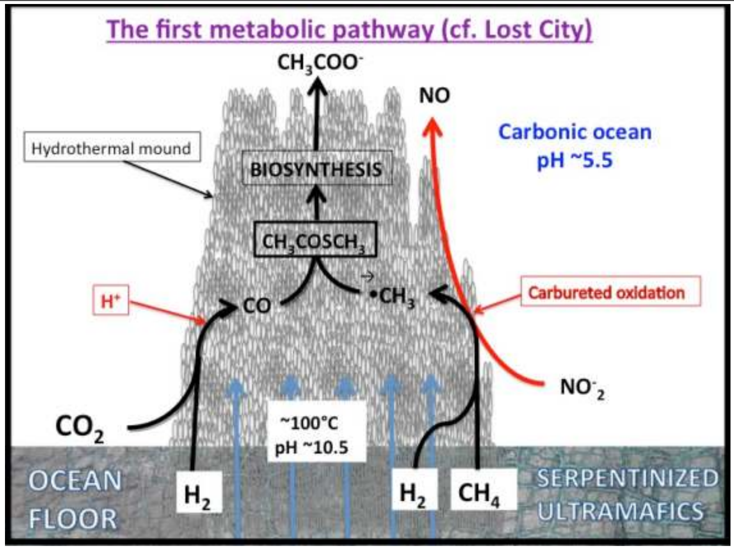

Fig. 1: *Serpentinization generates H_2 and CH_4 which are transferred in alkaline hydrothermal solution toward the outer margins of a growing submarine hydrothermal alkaline mound, Here they interact with electron acceptors nitrite and CO_2 in oceans via Ni-Fe sulfides and redox-active green rust (cf. brucite at Lost City). The entire system is predicted to culminate in a particular metabolic pathway – denitrifying methanotrophic acetogenesis – on any wet and icy globe (Russell et al. 2013).*

Life's onset on any abiotic rocky wet icy world resolves chemical and electrochemical disequilibria (Barge et al., 2012; Russell et al., 2013, and in review). The very first steps leading to metabolism are highly endergonic and thereby beyond the reach of mere geochemistry. Conversions of extraneous free energies are required to surmount these endergonic barriers. Appropriate *free energy converters*, situated in and comprising inorganic membranes harness the two main disequilibria obtaining on such worlds, driving life's emergence and its further evolution. These are i) a redox gradient of ~1 volt between the hydrothermal electron donors, hydrogen and methane, with electron acceptors such as nitrate, nitrite and/or ferric iron in an all-encompassing ocean or hydrosphere, ii) a proton gradient from ocean to hydrothermal solution across a precipitate barrier of around five units (~300 mV) to drive the emergence of biosynthesis. Carbon is fixed partly from CO_2 dissolved in and partly from CH_4. Redox bifurcating catalysts involving molybdenum are involved in both steps, coupling exergonic reactions with lesser endergonic reactions. The free energy converters or auto-mechano-catalysts comprised, and were housed by, the iron-rich layered mineral barriers spontaneously formed from precipitates composing hydrothermal mounds generated on ocean floors, where alkaline hydrothermal solutions met the carbonic hydrosphere. Those exergonic reactions that ensue are generally best served in alkaline solution. The layered double hydroxide, fougerite (~$Fe_2(OH)_5$), maybe common to both mechano-catalysts. The fuel (electron donors H_2 and CH_4) is delivered from exothermic serpentinization reactions – reactions that feed back to augment the thermal gradient driving the open system hydrothermal convection cells supplying the submarine mound. The discovery that a strain of *Methanosarcinales* currently processes these same electron donors, possibly using just this oxidant (nitrite) and emitting just this waste product (acetate), is taken as support for this model (Brazelton et al., 2011).

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