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Physical aspects of early life evolution

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Physical approach to the problem of origin and early evolution of life is certainly underestimated and still poorly developed in spite of the fact that the mechanisms of energy metabolism are universal for all living organisms through the whole history of life. The key features of energy metabolism such as the electron transfer from the donor to acceptor, proton (ion) gradients, oxidation/reduction (redox) potentials, etc. seemed to be formed in the energy-rich primary environment of early Earth at the pre-organic stage of the evolution of life. These features were inherited (and partially replaced) by the energy-generating mechanisms as a part of the cell metabolic system.

Hydrogen, the most abundant element in the Universe, was the primary fuel for early life. The availability of hydrogen on early Earth was much higher than at present. The major sources of hydrogen were (1) the degassing of the Earth mantle, (2) the serpentinization, reaction of the rocks, rich with olivine and pyroxene, with water, (3) photolysis of water by the energy of UV light, and (4) radiation-induced dissociation of H2O. Abundance of hydrogen on early Earth gave easy access to the protons and electrons, the very motor of the life's energy machine.

Evolution of the energy metabolism can be described in terms of the bootstrapping process. The first stages of evolution have been dominated by the reactions of hydrogen with relatively heavy non-metals having a large ion radius. This provided conditions for the reversible reactions of association/dissociation of the molecules without specific enzymes. These redox reactions of hydrogenation-dehydrogenation dependent on the exchange of electrons were catalyzed by some transition metals (Fe, Ni, W) that still play the same role in metal cofactors of many proteins. On the second stage of the metabolic evolution the acid-base reactions important for condensation-hydrolysis cycles have been added due to more active involvement of the redox dependent proton dislocations. These cycles result in condensations – polymerizations, as well as in the hydrolysis that are of vital importance in the present biochemistry of the cell, and in particular, it concerns the nucleotide coenzymes. In this stage, lipids could have been formed that encapsulated the developing system. The third stage was related to use of solar energy for the photolysis, first of H_2S and then of H_2O. Initial over-abundance of obtained energy could promote the development of biochemical storage and release systems, for instance, carbohydrates.

The early evolution of life was in a great extent driven by the competition for access to hydrogen. Decline of the primary sources of hydrogen mentioned above made life to switch for the simple hydrogen compounds such as H_2S, CH_4, NH_3, and at last, H_2O in the case of oxygenic photosynthesis, and later on to more complex hydrogen compounds. The succession and degree of involvement of these molecules into early metabolic evolution could correlate to the energy required for breaking their chemical bonds in the conditions of early Earth. This concept helps to understand the historical causes of the atmosphere chemistry, in particular, the high content of nitrogen and oxygen as the byproducts of hydrogen metabolism.

Early kinds of biochemistry, once established, have been saved throughout of the later history of life via compartmentalization and addition of complementary metabolic modules in respond to the irreversible changes of the environment. These processes were resulted the higher biological complexity. Distribution of metabolic types along the environmental gradients in the present day biosphere as well as the structure of the metabolic pathways in the living cells can be interpreted in terms of the co-evolution of life and the physical-chemical conditions on early Earth.

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Traversing Fitness Landscapes by Changing Environments

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Since its introduction by Sewall Wright (1932), the fitness landscape has been a popular metaphor for describing how populations evolve. In these landscapes, where elevation represents fitness, populations move via small, mutational steps. In cases of strong selection, a population can become trapped on a sub-optimal peak, unable to further improve its fitness. Wright explanation for how populations escape these sub-optimal peaks involves genetic drift. However, an understudied mechanism for escaping sub-optimal peaks is the effect of changing enviroments (Fisher 1932). Using two rapidly evolving systems - E. coli and Avida (an artificial life platform for studying evolutionary biology) - we take a top-down approach that involves repeatedly evolving populations, manipulating the environment with fine precision. We find that populations exposed to varying environments reach global optima faster than when the environment is held constant.