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OUR HOUSE IN THE COSMOS: ASTRONOMICAL ORIGIN OF LIFE

Prof. A. B. Bhattacharya[1]
B. Raha[2]

[1]Professor, Department of Physics, University of Kalyani, Kalyani;
Email: *bhattacharyaasitbaran@gmail.com*
[2]Department of Physics, University of Kalyani, Email: *bipasa.raha@gmail.com*

Abstract :

Geological time scale related to age of earth has been critically examined by scientists measuring the ages of rock layers on earth as well as using radiometric dating. Origin of species has been considered from the point of view of biochemical pathways and formation of ATP using iron-sulphur world theory. The roles of nutrient conversions, proto-ecological systems and DNA in the exploration of evolution are also focused including metabolism-first vs. replicator-first hypotheses.

Keywords: *Cosmos, Astronomical origin, Darwin's theory*

1. Introduction:

Geologists recognized that rocks formed slowly as mountains eroded and sediments settled on the ocean floor. But they were unable to determine or even assume how long this process had taken or how old their fossils were. It was Darwin who first strongly argued that the Earth was immensely old to provide his gradual process of evolution. The dates that radioactive clocks have put on evolutionary history are surprising. Life is more than 3.5 billion years old and until about 600 million years ago, the planet was dominated by microbes. Radioactive clocks have indicated that evolution can change its pace. Some of the geological methods have supported to pin down that anatomically modern humans evolved about 100,000 years ago.

2. Terminologies:

Darwin described that variation exists among individuals of a species and scarcity of resources in a growing population would lead to competition between individuals of the same species as all species use the same limited resources of the environment. The type of competition would lead to the death of some individuals but others would survive. Darwin from this consideration concluded that individuals having beneficial variations are more likely to survive and reproduce in comparison to those without the advantageous variations.

2. Terminologies :

He introduced a terminology called natural selection for describing the process by which organisms with favourable variations survive and reproduce at a higher rate. An inherited variation which increases the chance of survival of an organism in a particular environment is known as an adaptation. Thus evolution by natural selection would occur which can ultimately lead to the formation of new species. In some occasions many species evolve from a single ancestral species which is called adaptive radiation. It occurs most commonly when a species of organisms invades an isolated region where few competing species exist. Depending on the availability of new habitats new species evolve. In fact, adaptive radiation is one example of divergent evolution which is the process of two or more related species becoming more and more dissimilar. On the contrary in convergent evolution, unrelated species become more and more similar in appearance as they adapt to the same type of environment.

Co-evolution is the joint change of two or more species due to close interaction. An example of co-evolution is between the animals and plants that pollinate them. Co-evolution and the divergent and convergent evolution are different ways organisms adapt to the environment. These explain how the diversity of life on earth occurs due to the ever-changing interaction between a species and its environment.

2.1 Geological Time Scale related to age of Earth

According to the geological time scale a reasonable estimate is that the earth coalesced into an approximate solid sphere about 4.6 billion years ago. This is considered as the beginning of the time scale which can be divided into the Precambrian and Phanerozoic periods.
Precambrianstretches across 90% of geological time which is subdivided into:

(i)*HADEAN* (means "below"): The geological records from this time covered over by subsequent events and are "below" the rocks we have access to. The date of earliest known rocks is about 4400 million years ago (MYA).

(ii)*ARCHEAN* (means "ancient"): Starts at 3700 MYA with the first fossil bacteria and blue green algae.

Terminologies :

(iii)*PROTEROZOIC* (means "first life"): Starts at 2500 MYA with the first fossil evidence of organisms with modern (eukaryotic) cells. Later on, but during this period organisms that reproduced sexually evolved as did organisms formed by colonies of cells. By 660 MYA organisms almost similar to modern jellyfish evolved. The Proterozoic extends from 2500 to 540 MYA.

(iv)*PHANEROZOIC*: This period came after the Precambrian. It extends from 540 MYA to the present.

Phanerozoic means "open" - i.e. not hidden - "life" At the very beginning of the Phanerozoic a staggering abundance and diversity of living organisms suddenly appeared in the fossil record. This is assumed to be due to the primitive atmosphere of the earth gaining enough oxygen so that an ozone layer could be formed in the upper atmosphere which protects surface dwelling organisms from excessive ultraviolet radiation. The Phanerozoic is divided into:

(i)*PALEOZOIC* (means "old life"): Starts at 540 million years ago (MYA) and is subdivided as (a) ***Cambrian:***At the early stage of this period the marine animals with shells appear in the fossil record and now extinct trilobite arthropods became dominant. The Cambrian extends from 540 to 505 MYA. (b) ***Ordovician:***A now extinct animal known as graptolite becomes abundant. Echinoderms, then mollusks also become abundant. The first corals and armored fish evolve. (c) ***Silurian:***The now extinct eurypterid arthropods become dominant. The earliest land plants and animals appear. The earliest insects appear. This period extends from 438 to 408 MYA. (d) ***Devonian:***In the ocean shelled forms known as brachiopods are diverse and abundant. The heavily armored fish are replaced by more lightly armored forms, then sharks and some modern fish evolve. A type of mollusk known as ammonoid evolves. (e)***Mississippian:***In the ocean sharks become dominant. On land amphibians dominate in forests formed of scale trees and seed ferns. This period extends from 360 to 320 MYA. (f) ***Pennsylvanian:***In the ocean changes were little. On land the great coal forming forests dominate the landscape. The amphibians still dominate but the earliest reptiles evolve. (g) ***Permian:***Little changes in the ocean or land until the very end of the period when many of the most common types of marine invertebrates, including the trilobites, eurypterids, and graptolites, become extinct. The period extends from 286 to 245 MYA.

Terminologies :

(ii) *MESOZOIC* (means "middle life"): Starts 245 MYA and is subdivided into: (a) ***Triassic:***On land the earliest dinosaurs and flying reptiles evolve replacing the early reptiles. Cycads and conifers evolve and form abundant forests. In ocean modern coral groups evolve. The period extends from 245 to 190 MYA. (b) ***Jurrasic:***On land the dinosaurs dominate all ecosystems. The early birds and mammals evolve. In the ocean the ammonoid mollusks are very abundant. This period extends from 144 to 66 MYA.

(iii) *CENOZOIC* (means "new life"): This is the third subdivision of the Phanerozoic. This period extends from 66 MYA to the present.

In Figure 1 we have illustrated how Scientists measure the ages of rock layers on Earth using radiometric dating while Figure 2 shows radiometric dating to measure the age of Earth.

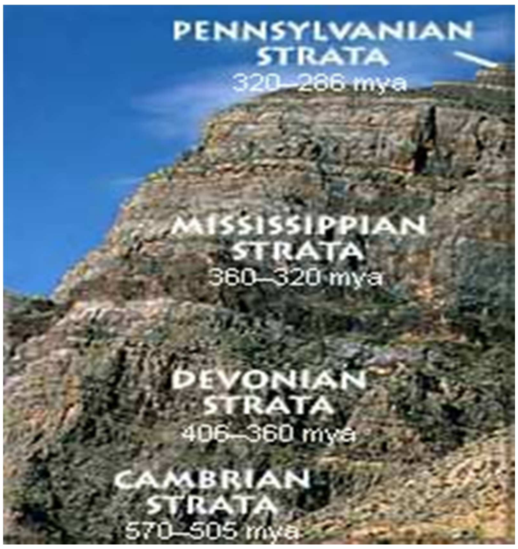

Figure 1: Scientists measure the ages of rock layers on Earth using radiometric dating

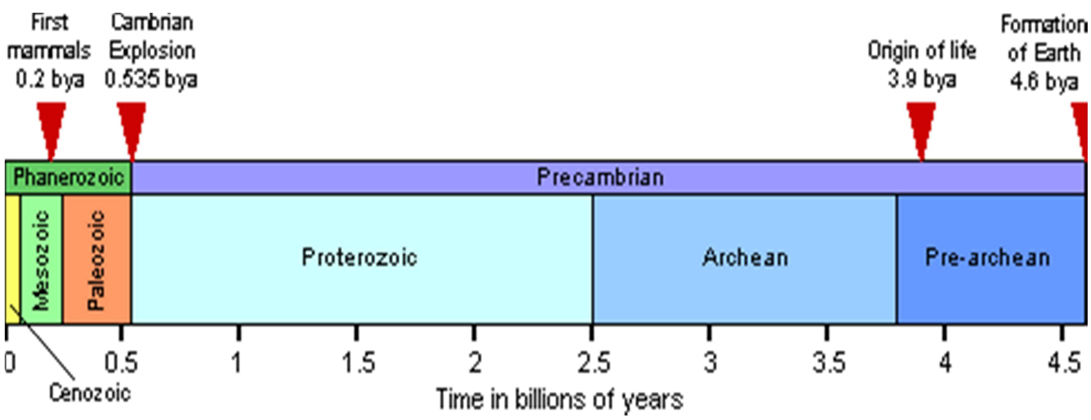

Figure 2 Radiometric dating to measure the age of Earth

3. Origin of Species :

Lamarck theory of transformation is important theory who first proposed a mechanism related to the gradual change of species and proposed that life started out simple and became more complex. Lamarck suggested about "natural tendency toward perfection" as well as a mechanism involving the inheritance of acquired traits.

Darwin's theory of origin of species is largely different from that of Lamarck's theory. An arrow of complexity was not accepted by Darwin. He argued that complexity evolved owing to life adapting to its local conditions from one generation to the latter. On the other hand Lamarck suggested that life evolved from simple to complex form explaining the concept of use and disuse but Darwin used the concept of variation. Lamarck suggested the theory of transmission of acquired characteristics while Darwin suggested the theory of inheritance and argued that species could go extinct rather than change into new forms, though Lamarck did not explain the concept of extinction. A comparison between Lamarck's and Darwin's theory is presented in Table 1.

Table 1 Comparison between Lamarck's and Darwin's theory

Lamarck's theory	Darwin's theory
Increasing complexityUse and disuseTransmission of acquired characteristicsNo extinction	Differential survivalVariationInheritanceExtinction

4. Biochemical Pathways and Formation of ATP:

Many reactions whose occurrences are in sequence called biochemical pathways. In it exergonic reactions involve a release of free energy without the net input of energy while endergonic reactions are the addition of energy. Chemical energy powers metabolism by endergonic reactions using ATP. Chemical energy creates ATP, and its splitting is completed by endergonic reactions, giving the necessary energy. Figure 3 reveals the steps of biochemical pathways related to metabolism.

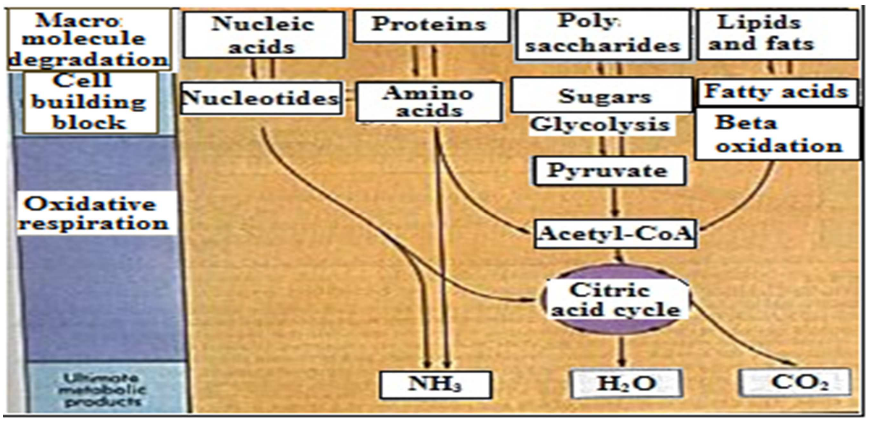

Figure 3 Biochemical pathways related to metabolism

Due to the formation of ATP from ADP + inorganic phosphate (Pi) an input of free energy is necessary. Formation of ATP is endergonic and it never occurs spontaneously. If coupled to an exergonic reaction the synthesis of ATP from ADP + Pi does take place as other release of energy from the exergonic reaction at such times is greater than the input of energy essential to drive the synthesis of ATP. This mechanism is called substrate level phosphorylation. Many bacteria subsist entirely on ATP generated in by following this mechanism.

Chemiosmotic generation of ATP is another important way of generation. Almost all organisms' possess transmembrane channels which function in pumping protons out of cells. Proton-pumping channels use a flow of exited electrons for inducing a change in the shape of a transmembrane protein. This in turn causes protons to pass outward. As the concentration of proton outside the membrane rises greater than that inside, the outer protons are driven inward by diffusion. As a result it passes backward through special proton channels that use their passage induce the formation of ATP from ADP + Pi. As the chemical formation of ATP is obtained by using diffusion force similar to osmosis, this process is called chemiosmotic generation. Figure 4 reveals the formation of ATP in two different stages.

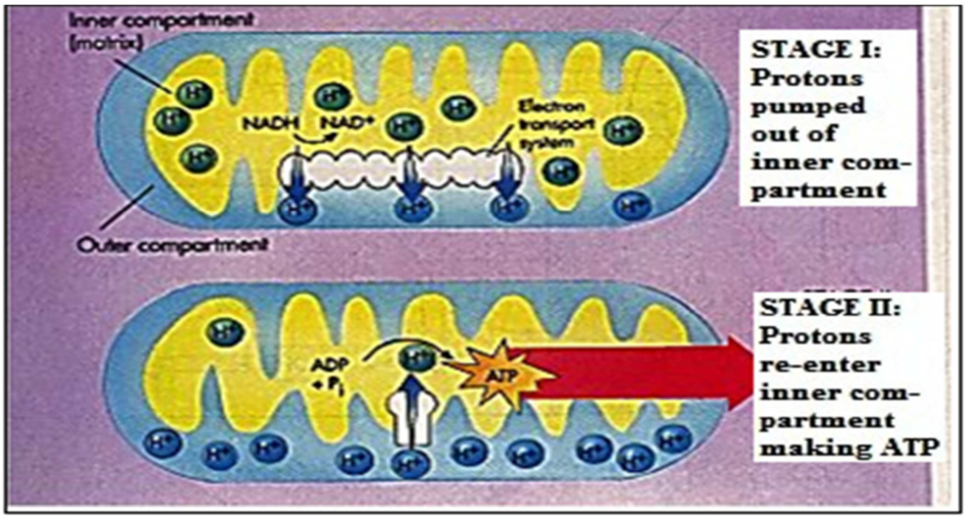

***Figure 4** Formation of ATP in two stages*

5. Iron-Sulfur World Theory for Origin of Life :

This theory is a proposal related to the origin of life as well as the early evolution of life. It proposes that early life may have formed on the surface of iron sulphide minerals[1-4]. The theory was developed by retrodiction from extant biochemistry in conjunction with some chemical experiments.

Wächtershäuser[4] suggested that the earliest form of life, called "pioneer organism", originated in a volcanic hydrothermal flow at temperature 100 °C and at high pressure. It had a composite structure of a mineral base, mainly iron and nickel and also perhaps cobalt, manganese, tungsten and zinc with catalytic transition metal centres. The catalytic centres catalyzed autotrophic carbon fixation pathways generating small non-polymer molecule organic compounds from inorganic gases like carbon monoxide, carbon dioxide, hydrogen cyanide and hydrogen sulphide. All these organic compounds were retained on or in the mineral base as the organic transition metal centres with a flow retention time in correspondence with their mineral bonding strength and thus defining an autocatalytic "surface metabolism". The catalytic transition metal centres eventually became autocatalytic due to acceleration by their organic products. The carbon fixation metabolism became autocatalytic owing to formation of a metabolic cycle in the form of a primitive sulphur-dependent version of the reductive citric acid cycle. The metabolism is expanded by the accelerated catalysts and new metabolic products so formed are used for further accelerating the catalysts. Once such a primitive autocatalytic metabolism was established, its intrinsically synthetic chemistry began to produce ever more complex catalytic centres and ever more complex organic compounds and ever more complex pathways. According to the iron-sulphur world theory the fundamental idea of the origin of life can be simplified considering pressure and heat flow with dissolved volcanic gases like carbon monoxide, ammonia and hydrogen sulphide.

Early evolution may be defined as a start with the origin of life and ending with the last universal common ancestor (LUCA). Following the iron-sulphur world theory it covers a coevolution of cellular organization, the genetic machinery and enzymatization of the metabolism. Cellular organization may alternately be called as cellularization which occurs in several stages. It starts with the formation of primitive lipids like fatty acids or isoprenoid acids in the surface metabolism. This lyophilizes the outer or inner surfaces of the mineral base to promote the condensation reactions over the hydrolytic reactions by lowering the activities of water and protons. In the next step lipid membranes are produced. While still anchored to the mineral base they produce a semi-cell bounded by the mineral base partly and also the membrane. Lipid evolution leads to self-supporting lipid membranes and closed cells. The earliest closed cells are pre-cells as they allow frequent exchange of genetic material by fusions and other processes. This exchange of genetic material is due to the existence of the common stem in the tree of life.

6.Nutrient Conversions :

In volcanic fluids the water gas shift reaction ($CO + H_2O \rightarrow CO_2 + H_2$) occurs with diverse catalysts or without catalysts[5]. The combination of ferrous sulphide and hydrogen sulphide as reducing agents in conjunction with pyrite formation – $FeS + H_2S \rightarrow FeS_2 + 2H^+ + 2e^-$ (or H_2 instead of $2H^+ + 2e^-$) – has been treated under mild volcanic conditions[6, 7]. However, this key result has been disputed[8]. Nitrogen fixation has been demonstrated for the isotope $^{15}N_2$ including pyrite formation[9]. Ammonia is produced from nitrate with FeS/H_2S as reductant[10]. Methylmercaptan [CH_3-SH] and carbon oxysulfide [COS] are formed from CO_2 and FeS/H_2S[11], or from CO and H_2 in the presence of NiS[12].

7. Proto-Ecological Systems :

Martin and Russell suggested that the first cellular life may be formed inside alkaline hydrothermal vents at seafloor spreading zones in the deep sea[13, 14]. These structures consist of micro-scale caverns, coated by thin membranous metal sulphide walls. The concerned model locates the "last universal common ancestor" (LUCA) within the inorganically produced physical confines of an alkaline hydrothermal vent, rather than considering the existence of a free-living form of LUCA. The last evolutionary step is responsible for free-living cells and would be the synthesis of a lipid membrane which finally permits the organisms to leave the micro cavern system of the vent to postulate the late acquisition of the biosynthesis of lipids.

A thermo cline of temperatures and a chemo cline in concentration are associated in an abiotic world with the pre-biotic synthesis of organic molecules. The migration of synthesized compounds from areas of high concentration to areas of low concentration provides a directionality to provide both source and sink enabling a proto-metabolic process to produce acetic acid. Thus many individual reactions, now found in central metabolism could initially have occurred independent of any developing cell membrane.

A significant factor to these ideas was added by Russell, pointing out that an iron sulphide mineral and silicate membranes could naturally develop under these conditions and electrochemically link reactions are separated in space, in particular[15].

8. Metabolism-First vs. Replicator-First Hypotheses :

A very important property of life is its capacity to experience Darwinian evolution. The replicator concept is at the centre of genetics-first theories of the origin of life, which suggest that self-replicating oligonucleotides or their similar ancestors may have been the first living systems. This may have led to the evolution of an RNA world. However, problems with the nonenzymatic synthesis of biopolymers and the origin of template replication have spurred an alternative metabolism-first scenario, where self-reproducing and evolving proto-metabolic networks are considered to have predated self-replicating genes.

Metabolism-First vs. Replicator -First Hypotheses:

Theoretical study suggests that the compositional genomes, which are the counts of different molecular species in an assembly, are able to propagate compositional information. It provides a setup on which natural selection acts. If the notion of replicator as an entity is accepted that passes on its structure in successive replications then those macromolecular aggregates could be dubbed as “ensemble replicators” which is quite different from the genes and memes. It appears that the limitation of ensemble replicators give cautions against metabolism-first theories of the origin of life. Metabolism-first theories clearly indicate that life, in a deep sense, crystallized as a collective self-reproducing metabolism in a space of possible organic reactions[16]. An important property of such systems must be the capacity for robust self-maintenance, though problems arise when side reactions are taken into account that may deplete certain reactants[17] and dynamical aspects of autocatalytic cycles if they are considered to coexist in abstract space[18].

9. DNA in the Exploration of Evolution :

In the exploration of evolution, DNA discovery was a remarkable milestone. Experiments suggest that nucleic acids which are arranged on a twisted ladder, with two runners made of phosphates and sugars, and a series of rungs made of pairs of organic compounds known as bases could affect hereditary traits. Figure 5 shows the double helix structure of DNA.

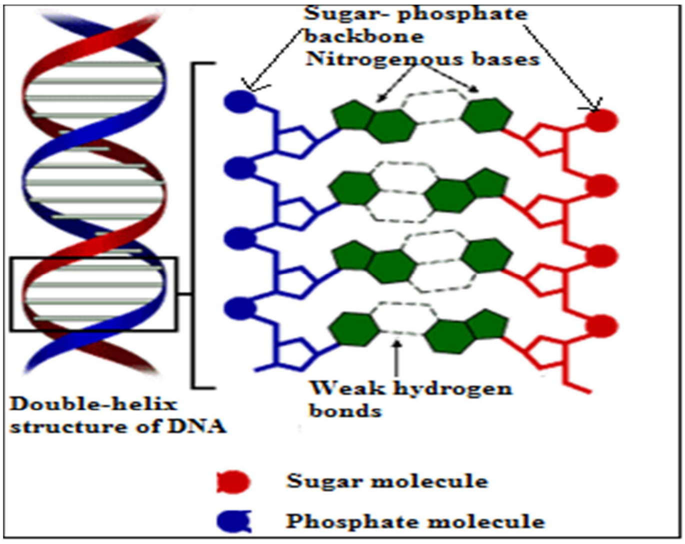

Figure 5 Double helix structure of DNA

Researchers attempted to figure out the basics of how DNA works. They realized that each gene consists of a stretch of base pairs. A single-stranded copy of the gene known as messenger RNA was created and transported to protein-building factories in the cell known as ribosome. The sequence of the bases there guided the assembly of a string of amino acids to make a new protein. The double helix is unzipped due to cell division and the DNA is replicated.

DNA in the Exploration of Evolution :

Scientists working on the chemistry of DNA moved closer to actual sequences. The use of DNA kinetics was found to be important to investigate evolutionary relationships using a technique known as DNA-DNA hybridization. Each DNA molecule is made of two strands of nucleotides. When the strands are heated, they separate and as they cool, the attraction of the nucleotides makes them bond back together again. In order to compare different species, the DNA of the species may be broken into small segments, separating the strands, and mixing the DNA together. If the two species' DNA bonds together, the match between them will not be perfect as there are genetic differences between the species. The more imperfect the match is, the weaker the bond between the two strands which may be broken with just a little heat. Closer matches need more heat to separate the strands again. DNA hybridization can be used to measure how similar the DNA of different species is. Similar DNA hybrids "melt" at higher temperatures. If this technique is applied to primate relationships, it suggests that humans and chimpanzees carried DNA similar to one another.

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References :

1. G. Wächtershäuser, Microbiol. Mol. Biol. Rev.52, 452–84 (1988).
2. G. Wächtershäuser, Proceedings of the National Academy of Sciences of the United States of America87, 200–204 (1990).
3. G. Wächtershäuser, Progress in Biophysics and Molecular Biology58, 85–201 (1992).
4. G. Wächtershäuser, Chemistry & Biodiversity 4, 584–602 (2007).
5. J. S. Seewald, M. Yu. Zolotov and T. McCollom, Geochimica et Cosmochimica Acta70, 446–460 (2006).
6. P. Taylor, T. E. Rummery and D. G. Owen, Journal of Inorganic and Nuclear Chemistry41, 1683–1687 (1979).
7. E. Drobner, H. Huber, G. Wachtershauser, D. Rose and K. O. Stetter, Nature346, 742–744 (1990).
8. C. L. Cahill, L. G. Benning, H. L. Barnes and J. B. Parise, Chemical Geology167, 53–63 (2000).
9. M. D. Mark, J. Käßbohrer, R. Grunert, G. Kreisel, W. A. Brand, R. A. Werner, H. Geilmann, C. Apfel, C. Robl and W. Weigand, Angewandte Chemie International Edition42, 1540–1543 (2003).
10. E. Blöchl, M. Keller, G. Wachtershäuser and K. O. Stetter, Proceedings of the National Academy of Sciences of the United States of America89, 8117–20 (1992).
11. H. Wolfgang and A. M. Lauwers, Origins of Life and Evolution of Biospheres26, 131–150 (1996).
12. C. Huber and G. Wächtershäuser, Science276, 245–247 (1997).
13. W. Martin and M. J. Russell, Philos Trans R Soc Lond B Biol Sci.358, 59–83 (2003).
14. W. Martin and M. J. Russell, Philos Trans R Soc Lond B Biol Sci.362, 1887–1925 (2007).
15. M. J. Russell, American Scientist94, 32 (2006).
16. S. A. Kauffman, The Origins of Order (Oxford University Press, New York, 1993).
17. E. Szathmáry, Philos Trans R Soc Lond B Biol Sci.355, 1669–1676 (2000).
18. E. Szathmáry, Philos Trans R Soc Lond B Biol Sci.361, 1761–1776 (2006).