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Origin and Evolution of Life: Endless Ordering of the Earth's Light Elements

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ABSTRACT

The evolution of a living organism, as well as pre-biotic molecular evolution, seems to be inconsistent with the second law of thermodynamics. When a bacterium is compared with some other higher organism, it is clear that all evolution tends to order more and larger molecules into more complex systems. The trick is the radiation of heat from the Earth. The Earth is losing gravitational energy ($\sim 10^{31}$ Joule) obtained from the accretion of asteroids during its birth 4.55 Gyr ago. Energy loss implies a decrease in entropy which in turn requires ordering of the Earth. As components of the Earth, the lighter elements at the surface must also evolve to larger molecules and ultimately to living organisms, so that the entire surface of the Earth is now covered by low entropy materials of life. Thus, the entropy decrease of the Earth is responsible for the evolution of living organisms. The above argument suggests a new scenario for the origin of life. The concept holds that geological events of the early Earth were the environmental pressure for the evolution of organic molecules, which were in turn necessary for evolution of life. The heavy fall of the extraterrestrial objects containing metallic iron into the ocean would produce a reducing atmosphere thus generating a wide variety of organic molecules at about 4.0 Gyr ago. Of these, only hydrophilic and clay-affinitive molecules could have survived the environment of strong UV radiation and weak oxidation, because they could be immersed in sea water and be adsorbed on clay particles that were finally deposited on the seabed. Their polymerization would be a further means of survival for the molecules when deposited in sediment that experienced dehydrating conditions of high-pressures and high-temperatures during diagenesis. These polymers would then have had to survive hydrolysis through composite or cell formation, when the polymer-containing sediments reached an accretionary prism of a plate end where might be soaked by hydrothermal water. Cell fusion might be a mechanism to evolve a better cell, and lateral gene transfer and genome fusion in microbes might be relics of such cell fusion. By this mechanism, life could have originated under deep subsurface and radiated adaptively into sea water. It is an a priori assumption and there is no proof that life originated in the early ocean.

Keywords: Thermodynamics, Entropy, Ordering, Earth's light elements, Subsurface, Origin of life, Adaptive radiation, Sea water

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INTRODUCTION

“The famous Second Law of Thermodynamics (entropy principle)” says that “everything that is going on in Nature means an increase of entropy”. If so, “How does the living organism avoid decay?” Erwin Schrödinger pondered the physical meaning of life in his book, “What is life? — The Physical Aspect of the Living Cell” [1], and answered that “it feeds on negative entropy”. This is a beautiful explanation of the physical meaning of life. On the other hand, the evolution of a living organism (as well as pre-biotic molecular evolution) seems also to be inconsistent with the second law. It is not explained using Schrödinger’s argument. The first part of this paper is concerned with a clarification of the apparent inconsistency between the second law of thermodynamics and the evolution of the living organism, and will be followed by a proposal for a possible new scenario of the origin of life that is given on the bases of thermodynamic considerations and of the 21st century perspective of the dynamic Earth. The scenario will be found in detail elsewhere [2].

THERMODYNAMIC ASPECTS OF THE EVOLUTION OF LIFE

Known theories of evolution such as the use and disuse theory (De Lamarck), the natural selection theory (C. R. Darwin) and the mutation theory (H. M. de Vries), explain well the natural diversity of living organisms. The giraffe’s long neck and variability in the bills of Darwin’s finches are illustrated in every high school text book to explain their environmental adaptation. However, those theories do not explain the general tendency of evolution seen in the phylogenetic tree from a bacterium to mankind, i.e., all species evolve to larger and more complex bodies and societies. For individual species, e.g., trilobites, ammonites, dinosaurs, etc, almost evolve to larger and more complex forms until extinction. The extinction means the replacement of the species with a more sophisticated species. So the question arises: Is biotic evolution (as well as pre-biotic evolution) inconsistent with the second law of thermodynamics? The question concurrently asks: **Why does the living organism evolve?** The great scientists, E. Schrödinger and also C. R. Darwin could not answer this fundamental question of evolution because recent views regarding the dynamic Earth are essential to the answer.

The key lies in the radiation of heat from the

Earth. The Earth is losing gravitational energy ($\sim 10^{31}$ Joule) obtained from the accretion of meteorites, planetesimals and asteroids during its birth 4.55 Gyr ago [5]. The dynamics of the Earth at present, including continental drift, plate tectonics and plume tectonics, are all mechanisms for transportation of heat from the core to the surface of the Earth.

Energy loss implies a decrease in entropy. Thus, the molten Earth ordered such that heavy metals like Fe and Ni sank to the core, Mg silicates settled in the mantle, light Al and Si occupied the crust as silicates, and the lightest elements H, C, N, O were concentrated at the surface. Entropy decrease required further evolution of the Earth to a more three-dimensionally complex structure. As components of the Earth, the lightest elements at the surface must also evolve to larger molecules and ultimately to living organisms, so that the entire surface of the Earth is now covered by low entropy materials of life. The evolution of living organisms is considered to be the ordering process of the Earth’s light elements.

Thus, the entropy decrease accompanying the temperature decrease of the Earth is responsible for the evolution of living organisms as well as for pre-biotic evolution. The theater of life’s origin had to be the early Earth with the players of the Earth’s light elements. The scenario was written by the thermodynamic principle.

ENDLESS ORDERING OF THE EARTH’S LIGHT ELEMENTS

1. The big bang of organic molecules on the Earth

Urey and Miller’s experiments on the natural synthesis of organic molecules necessary for life’s origin assuming atmospheric gases of H_2 , CH_4 , NH_3 and H_2O are known very well [3, 4]. Subsequently, it is now widely believed that amino acids were so synthesized in the early atmosphere by electric discharge i.e. lightning. However, recent geo-scientific research suggests that the composition of the early atmosphere was not reducing, as had been supposed, but slightly oxidizing being made up of N_2 , H_2O and CO/CO_2 , a mixture in which natural synthesis of organic molecules is difficult. Also, ammonia, a necessary precursor of amino acids, was not present [5]. The above thermodynamic consideration suggests, however, that light elements on the early Earth might have ordered to form organic molecules through reactions during geological events on the

Earth.

The 21st century view of the early Earth has it that accretion of asteroids, planetesimals and meteorites formed the Earth at 4.55 Gyr ago [6]. Heavy bombardment of them melted the Earth entirely or partly and a magma ocean appeared [5]. With a decrease in impact frequency of extraterrestrial objects at 4.0 to 3.8 Gyrs ago or even earlier [7], appearance of an early ocean occurred. Plate tectonics might also have started at that time. Rocks of sedimentary origin in Isua, Greenland, suggest that before 3.8 Gyr ago, probably at about 4.0 Gyr ago, the Earth was covered by ocean [8]. Heavy bombardment of the Earth by extraterrestrial objects continued into the early ocean [9–11].

Since the oceanic heavy bombardment was at the tail-end of the accretion of extraterrestrial objects that formed the Earth, their average composition might be similar to that of the entire Earth, i.e., 70–80% silicates, 20–30% metallic iron together with a proportion of the other elements including carbon. This is consistent with the composition of ordinary chondrite and the fact that more than 85% of collected meteorites are ordinary chondrites [12]. Because these chondrites contain 20–30% metallic iron, a heavy shower of such extraterrestrial objects into the ocean would produce a reducing atmosphere in post-impact plumes by impact-induced reactions of metallic iron and super-critical water. This local and transitional reducing atmosphere might generate a wide variety of organic molecules

as well as ammonia. I have named the phenomena “the big bang of organic molecules” [2], although a detailed experimental proof is still under investigation. A possible synthesis of ammonia has already been proven using impact experiments [13] with the geological implications of ammonia formation at that time being known [14].

2. Survival of bio-organic molecules

Organic molecules formed in post-impact plumes were small but variable in structure because they were produced by hydrocracking of graphite and/or amorphous carbon contained in extraterrestrial objects [15–17]. Following synthesis of organic molecules in an impact event, they were finally accumulated in the early ocean after having been dispersed in the atmosphere for several months or more (Fig. 1). Of those, hydrophobic molecules would float on the surface of the ocean in contact with the oxidizing atmosphere and under strong irradiation by ultraviolet light. They would, therefore, be decomposed. On the other hand, hydrophilic and clay-affinitive molecules could have survived an environment of strong UV radiation and oxidation because they would have been dissolved in sea water with subsequent adsorption on clay particles that were finally deposited on the seabed (Fig. 2). This may be the reason why all fundamental bio-molecules such as amino acids are hydrophilic. This might be the first natural selection of organic molecules.

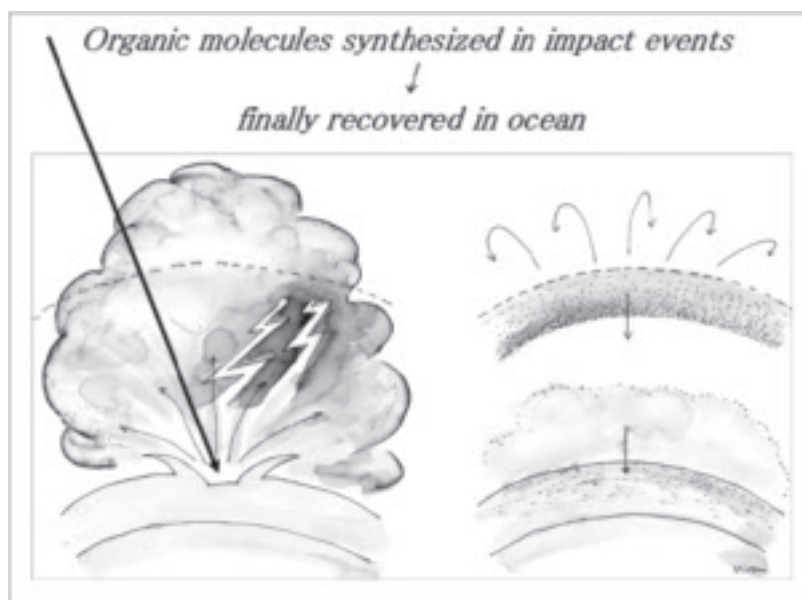


Fig. 1 The big bang of organic molecules in a locally reductive atmosphere of a post-impact plume.

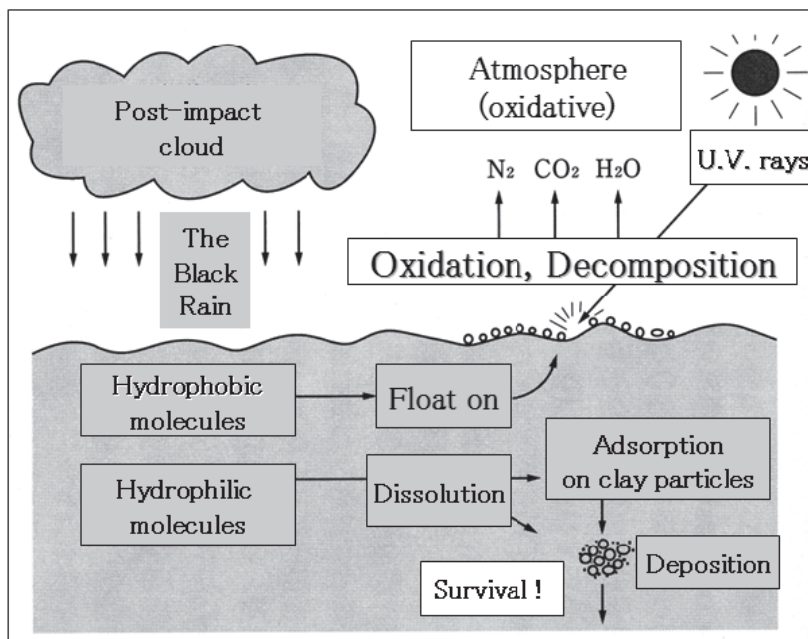


Fig. 2 Natural selection of bio-organic molecules: Survival of hydrophilic molecules in an environment of strong UV radiation and an oxidizing atmosphere.

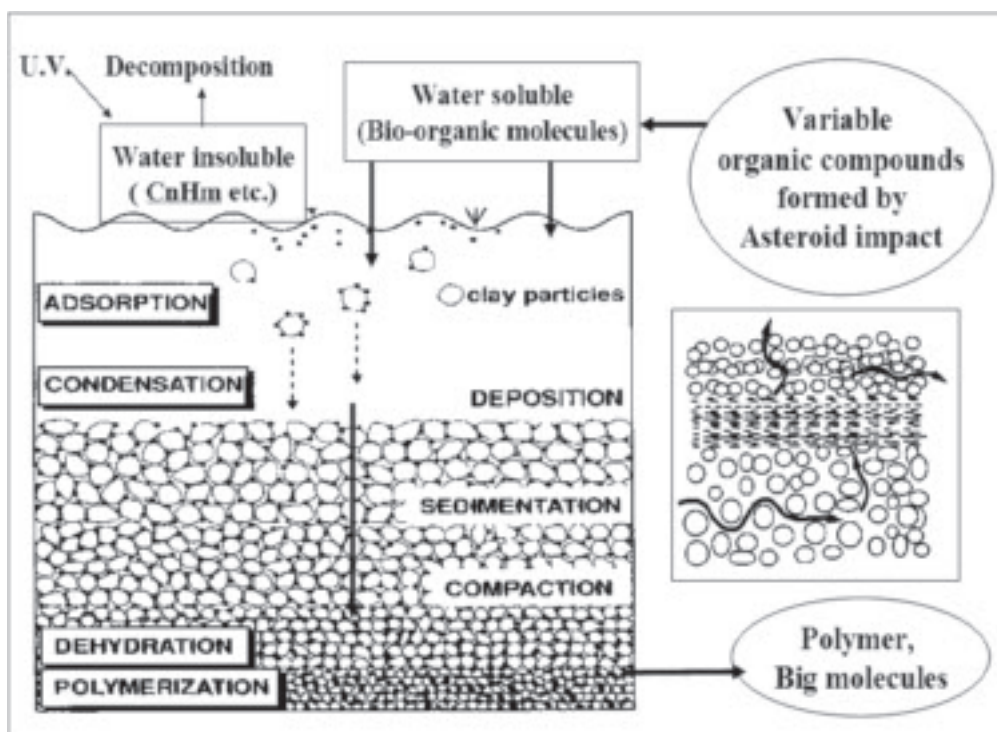


Fig. 3 Polymerization mechanism of bio-organic molecules under deep sediments.

3. Polymerization of organic molecules in deep sediments

Polymerization of organic molecules would be a

further means of survival for the molecules when deposited in sediment that experienced dehydrating conditions of high pressures and high temperatures

during diagenesis. For polymerization and the consequent survival of these organic molecules under the deep sediments, it might be a necessary condition that the surrounding sediment contained predominantly reducing, or at least poorly oxidizing, minerals such as olivine, metallic iron and wustite. Such a combination was probably only available for the sediment of heavy impact origin on the early Earth before 3.8 Gyr ago. If that were not the case, e.g., if clay minerals like montmorillonite were dominant in sediments, such as during the phanerozoic era, organic molecules might have been oxidized (dehydrogenated) and finally crystallized as graphite. Polymers so formed in deep sediments during the late Hadean or early Archaean periods might have been transferred to the plate end by the mechanism of the plate tectonics that probably started at that time.

A recent high pressure and high temperature experiment supports this model of polymerization, i.e., glycine has been easily polymerized without any catalyst to a 10-mer oligopeptide under 100 MPa and 150°C for 8 days [18]. As the experiment was performed in a simple gold capsule, the dehydration environment of deep sediments was not simulated but the results suggested strongly a probable mechanism for the pre-biotic polymerization of organic molecules under deep subsurface or under a superficial crust.

4. Organization of polymers at the plate end

Because of plate tectonics the polymer-containing sediments traversed the Earth's surface ultimately reaching a plate end where part of the sediment was subducted deep into the mantle but the remaining part aggregated on the opposite plate as an accretionary prism (Fig. 4) [19]. The polymers in the former might be the source of diamond [20, 21] while those in the latter might be the source of life since they must have encountered hydrothermal water in the accretionary prism and then survived hydrolysis, for instance, through composite or cell formation [22]. By forming cells with hydrophobic polymers and/or inorganic materials such as clay minerals, the encapsulated polymers could survive hydrolysis. There might be a variety of cells formed, composed of organic and/or inorganic materials. Fusion of these cellular species presents a potential mechanism for evolution to a better cell. The metabolism necessary to maintain the cell in a state of low entropy could have been attained at this stage. Since the species of life later multiplied in the ocean, a functioning heredity might also have been gained at this stage. Lateral gene transfer and genome fusion in microbes might be relics of the cell fusion process attained at this stage [23–27].

CONCLUSION

A new scenario for the origin of life is presented here based on the entropy principle consideration

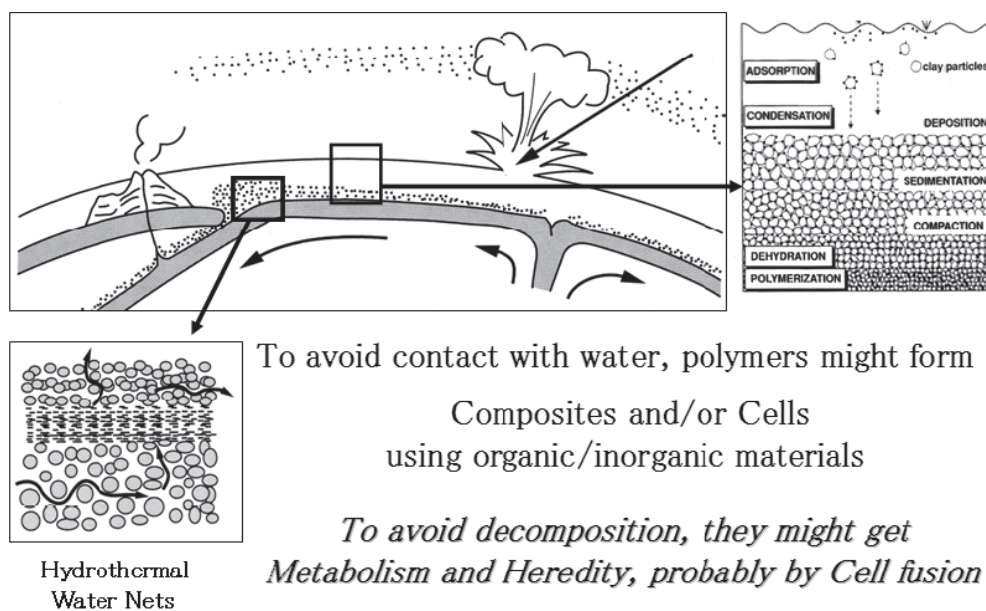
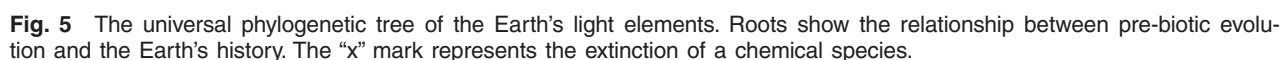


Fig. 4 Organization of bio-polymers at the plate end for surviving hydrothermal environment.



The scenario is illustrated in a universal phylogenetic tree with roots (Fig. 5). The roots show the processes of pre-biotic evolution. Bonding, connecting, composite formation and fusion were the principles for formation of lower entropy structures and for survival of environmental variations. An infinite number of organic molecules, polymers, composites and cells might have become extinct prior to the initiation of life. Chemical extinctions are indicated in the figure with “x” (Fig. 5). After life appeared mechanisms of heredity formed the next generation of lower entropy materials. Through pre-biotic and biotic evolution the Earth’s light elements have been ordered into larger and more complex bodies as well as their societies. This is the requirement of the thermodynamic principle and will be continued in perpetuity into the future.

lution and the environmental conditions of the early Earth, e.g., appearance of bio-molecules in a non-reducing atmosphere, their dehydration polymerization in the ocean and lack of the required phosphate in the ocean. It is an a priori assumption and there is no proof that life originated in the early ocean. Although the recent genome informatics proposed a phylogenetic tree having “the ring of life” as the source of all genomes, this ring may be resolved into many roots and branches as in Fig. 5, when the entropy principle and the history of the entire Earth are taken into consideration [26].

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1. Schrödinger, E., 1943. What is life? The Physical Aspect of

- the Living cell, Cambridge University Press, London.
2. Nakazawa, H., 2006. Origin of Life Scenario Written by the Earth (in Japanese), Shin-nihonshuppan, Tokyo.
3. Miller, S.L., 1953. A production of amino acids under possible primitive Earth condition. *Science*, 117, 528–529.
4. Urey, H.C., 1952. *The Planets, Their Origin and Development*, Yale Univ. Press, New Haven.
5. Matsui, T. and Abe, Y., 1986. Evolution of an impact-induced atmosphere and magma ocean on the accreting Earth, *Nature*, 319, 303–305.
6. Yin, Q., Jacobson, S.B., Yamashita, K., Blichert-Toft, J., Telouk, P. and Albarede, F., 2002. A short timescale for terrestrial planet formation from Hf-W chronometry of meteorites. *Nature*, 418, 949–955.
7. Wilde, S.A., Valley, J.W., Peck, W.H. and Graham, C.M., 2001. Evidence from detrital zircons for the existence of continental crust and oceans on the Earth 4.4 Gyr ago. *Nature*, 409, 175–178.
8. Rosing, M.T., 1999. C-13-depleted carbon microparticles in > 3700-Ma sea-floor sedimentary rocks from west Greenland. *Science*, 283, 674–676.
9. Hartmann, W.K., Ryder, G., Dones, L. and Grinspoon, D., 2000. The time-dependent intense bombardment of the primordial Earth/Moon system. In: R.M. Canup and K. Righter (eds.), *Origin of the Earth and Moon*, University of Arizona Press, Tucson, 493–512.
10. Celler, T.S., Becker, T.A., Muller, R.A. and Renne, P.R., 2000. Lunar impact history from $^{40}\text{Ar}/^{39}\text{Ar}$ dating of glass spherules. *Science*, 287, 1785–1788.
11. Valley, J.W., Peck, W.H., King, E.M. and Wide, S.A., 2002. A cool early Earth. *Geology*, 30, 351–354.
12. Norton, O.R., 2002. Summery of meteorites by classification. *The Cambridge Encyclopedia of Meteorites*, Cambridge University Press, Cambridge, 331–340.
13. Nakazawa, H., Sekine, T., Kakegawa, T. and Nakazawa, S., 2005. High yield shock synthesis of ammonia from iron, water and nitrogen available on the early Earth. *Earth Planet. Sci. Lett.*, 235, 356–360.
14. Homma, H., 1996. High ammonium contents in the 3800 Ma Isua supracrustal rocks, central West Greenland. *Geochim. Cosmochim. Acta*, 60, 2173–2178.
15. Tomita, A. and Tamai, Y., 1974. An optical microscopic study on the catalytic hydrogenation of graphite, *Jour. Phys. Chem.*, 78, 2254–2258.
16. Chareonpanich, M., Takeda, T., Yamashita, H. and Tomita, A., 1994. Catalytic hydrocracking reaction of nascent coal volatile matter under high pressure. *Fuel*, 73, 666–670.
17. Chareonpanich, M., Zhang, Z.G., Nishijima, A. and Tomita, A., 1995. Effect of catalysts on yields of monocyclic aromatic hydrocarbons in hygrocracking of coal volatiles matter. *Fuel*, 74, 1636–1640.
18. Ohara, S., Kakegawa, T. and H. Nakazawa, 2007. Pressure effects on the abiotic polymerization of glycine. *Orig. Life Evol. Biosph.*, 37, 215–223.
19. Maruyama, S., 1994. Plume tectonics. *Jour. Geol. Soc. Japan*, 100, 24–49.
20. Deines, P., 1980. The carbon isotopic composition of diamonds: relationship to diamond shape, color, occurrence and vapor composition. *Geochim. Cosmochim. Acta*, 44, 943–961.
21. Galimov, E.M., 1991. Isotope fractionation related to kimberlite magmatism and diamond formation, *Geochim. Cosmochim. Acta*, 55, 1697–1708.
22. Miller, S.L. and Boda, J.L., 1988. Submarine hot spring and the origin of life. *Nature*, 334, 609–610.
23. Margulis, L., 1970. *Origin of Eukaryotic Cells*, Yale University Press, New Haven.
24. Margulis, L., 1981. *Symbiosis in Cell Evolution: Life and Its Environment on the Early Earth*, Freeman, San Francisco.
25. Doolittle, W.F., 1999. Phylogenetic classification and the universal tree. *Science*, 310, 2124–2128.
26. Rivera, M.C. and Lake J.A., 2004. The ring of life provides evidence for a genome fusion origin of eukaryotes. *Nature*, 431, 152–154.