Advances in Geological Science

Hiromoto Nakazawa

Darwinian Evolution of Molecules

Physical and Earth-Historical Perspective of the Origin of Life

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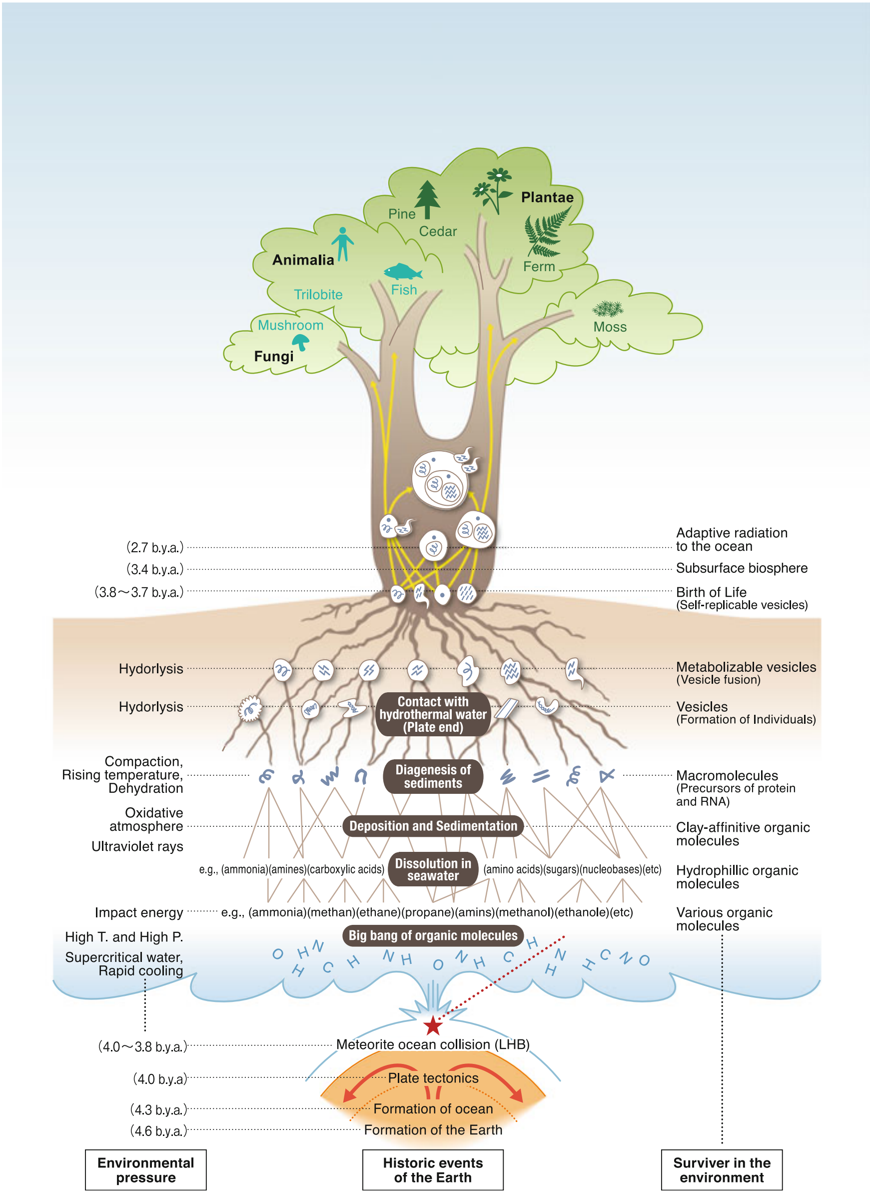

Plantae
Pine
Cedar
Ferm
Moss
Animalia
Fish
Trilobite
Mushroom
Fungi
(2.7 b.y.a.)
Adaptive radiation to the ocean
(3.4 b.y.a.)
Subsurface biosphere
(3.8～3.7 b.y.a.)
Birth of Life
(Self-replicable vesicles)
Hydorlysis
Metabolizable vesicles
(Vesicle fusion)
Hydorlysis
Contact with hydrothermal water (Plate end)
Vesicles
(Formation of Individuals)
Compaction, Rising temperature, Dehydration
Diagenesis of sediments
Macromolecules
(Precursors of protein and RNA)
Oxidative atmosphere
Deposition and Sedimentation
Clay-affinitive organic molecules
Ultraviolet rays
e.g., (ammonia)(amines)(carboxylic acids)
Dissolution in seawater
(amino acids)(sugars)(nucleobases)(etc)
Hydrophillic organic molecules
Impact energy
e.g., (ammonia)(methan)(ethane)(propane)(amins)(methanol)(ethanole)(etc)
Various organic molecules
High T. and High P.
Big bang of organic molecules
Supercritical water, Rapid cooling
(4.0～3.8 b.y.a.)
Meteorite ocean collision (LHB)
(4.0 b.y.a)
Plate tectonics
(4.3 b.y.a.)
Formation of ocean
(4.6 b.y.a.)
Formation of the Earth
Environmental pressure
Historic events of the Earth
Surviver in the environment

Preface[1]

The origin of life is a concept that everyone, at some point or other, contemplates. The challenge of solving this mystery is filled with high scientific anticipation, and many hypotheses and opinions have been proposed over the years. The theory on which modern scientific studies for the origin of life are based was first published in the book, "*Origin of life*" *(1924)* by Alexander I. Oparin, a Russian biochemist (Oparin AI, 1924). He proposed that the organic molecules that compose life, including amino acids and nucleobases, were synthesized from simple molecules such as ammonia and methane, which were present in the Earth's early atmosphere over rocks and minerals. He stated that these organic molecules reacted together in large quantities forming polymers such as proteins and nucleic acids (RNA/DNA) and then combined in a specific manner leading to life.

After Oparin, studies of how proteins and nucleic acids could be formed in "abiotic" chemical reactions yielded a wide range of theoretical and experimental results. Chemists examined the synthesis of these bioorganic molecules in water solutions since it was then a common belief that life had been initiated in ancient seawater that had a "soup"-like composition containing many different types of organic molecules. They studied the mechanisms of formation of bioorganic molecules on basic principles of chemical synthesis, i.e., that when compounds A and B are dissolved in water under certain conditions, they will react leading to compound C: $A + B \rightarrow C$. However, these studies failed to take into account initial differences and variations in the environments of compounds A, B, and C, thus neglecting the possibility of "natural selection of molecules." Charles R. Darwin showed, in his book *"On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life" (1859)*, that the evolution of creatures occurs by natural selection, i.e., the survival of the fittest in a range of newly born mutations under varying environmental conditions (Darwin CR, 1959).

[1]The content of this book was originally written in Japanese and published with the title, "Seimei Tanjou (in Japanese, Birth of Life)" from Kodansha, Tokyo, in 2014 and with the title "Seimei-no-kigen chikyuu ga kaita shinario (in Japanese, Origin of life scenario written by the Earth)" from Shin-nihonshuppan, Tokyo, 2006.

Colonies of Drosophila, a species of fly, were housed in controlled environments at high or low temperatures. After 120 generations, new species, which had adapted to the different temperature environments, had emerged due to the environmental pressures (Gribbin J, 1985). During breeding of lady (ladybird) beetles with the aim of developing a biological control agent for the elimination of aphid pests, artificial selection of flightless lady beetles over 30 generations resulted in the creation of a new “flightless species” (Nakayama et al. 2010).

The appearance of new mutations and their natural selection is an essential process of evolution. Although the natural selection of molecules needs to be taken into account when studying the *molecular* (chemical) evolution[2] of the origin of life, Oparin and the chemists that followed him did not attach much importance to it perhaps because of the lack of information about the dynamically changing Earth.

It is natural to assume that molecular and biological evolution continued through the birth of life without interruption. Therefore, the mechanisms and principles involved in molecular evolution ought to be the same as, or at least very similar to, those underlying biological evolution. If this is not the case, the epic mystery of the origin of life will be difficult to decipher, and the scenario “*Birth of Life*” will not be possible to establish.

For instance, the following reaction occurs in the Earth’s open and dynamic environment but not in a flask in a laboratory. In the chemical reaction, A + B = C, C is the final product of the reaction, but there are normally some contaminants, such as intermediates, D, and metastable products, E, present in the system. In closed systems, these contaminants, D and E, may gradually convert to C and are consumed. However, in an open system, such as that of the Earth’s environment, it is possible that D and/or E escape the reaction locale, survive, and have an impact on the evolution of molecules. The final products of molecular evolution might then be quite different from those anticipated based on laboratory investigations. This is analogous with the mechanism that enabled the aforementioned new species of flightless lady beetles to appear in spite of the low probability of the animal gaining existence.

Moreover, Earth’s molecular environment itself varies over time. The selection of molecules of A, B, C, D, and E which survive and evolve during subsequent variations of environment will differ depending on the system conditions. These mechanisms of molecular evolution suggest the “*Darwinian Evolution of Molecules*”.

When we consider the scientific literature describing the study of the origin of life, we can recognize that theories, hypotheses, and experiments do not always take into account the physicochemical questions surrounding molecular evolution. Why did organic molecules appear on the early Earth, which was composed only of inorganic rocks and minerals? Why are bioorganic molecules such as amino acids

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[2] The term “molecular evolution” is used in this book instead of “chemical evolution,” “abiotic evolution,” and “prebiotic molecular evolution,” which are commonly used in the field related to the study of the origin of life, because they are redundant in this book and are indirect expressions of evolving subjects.

and nucleobases all water-soluble and have clay mineral affinity? Why did these bioorganic molecules react forming polymers, macromolecules, and giant molecules such as proteins and nucleic acids? Why did these giant molecules not decompose but combined to form life? Although these are all well-known phenomena and facts of molecular evolution, their physical and chemical inevitability has not been considered.

The fundamental question regarding the origin of life is why did life occur and evolve on the Earth. As far as this author knows, a response to this question based on physicochemical considerations has not been proposed in the literature. For instance, there is no chapter by any author that addresses this essential question in any of the seven series of monographs entitled "*Lectures, The Evolution*" published by the Japanese scientific community studying the origin of life and its evolution (Shibatani A et al. ed. 1991) suggesting that the authors might not have contemplated this question. They might consider a priori that life has a different physical nature to that of abiotic substances and that it has occurred and evolved spontaneously. It is likely that the readers of this book currently agree with that line of thought.

Evolutionary theories are introduced in high school textbooks such as "Lamarck's *Use and disuse theory,*" "De Vries's *Mutation theory*," and "Darwin's *Natural Selection theory.*" They explain the reasons for the evolution of different species with special features, such as a giraffe's long neck or the variable bills of finches, but they do not explain the reason why creatures exist. When we consider only the evolution of a species, the essential question of why life occurred and evolved is difficult to answer because of the narrow scope of available materials, time, and space. As the physical phenomena underlying the evolution of creatures from bacteria to the present biodiverse multicellular organisms occurred in the Earth's system, all materials, space, as well as the Earth's history must be taken into account when considering the physical inevitability of an organism's evolution. This is also true when considering the physical inevitability of the origin of life. Thus, it is indispensable to take into account the 4.6 billion years of Earth's history, and the materials of Earth that became available during its different eras.

"Earth's history" does not only refer to the extended period of 4.6 billion years but also to the chronological order of changes occurring in the Earth's materials and environment. This is because the products of the relevant chemical reactions must have varied depending on the physical conditions of the reaction system and on the order in which substances appeared in the system.

This book explains why life has occurred and evolved from the historical and physical point of view of the Earth and also proposes a new scenario for the birth process of life on Earth based on the mechanism of the Darwinian evolution of molecules. As the scenario includes the physicochemical processes that occurred throughout the Earth's history, all the individual processes are normal phenomena that were common in nature. Thus, the study of the origin of life is not scientific romance but becomes a real science.

The birth process of life on Earth scenario is based entirely on scientific reports that have appeared in renowned scientific journals including several from the author's group. The reader may at first view the scenario as heresy because it is far from the familiar commonly accepted origin of life scenarios. However, the reader will agree with the scenario after reading the book because it discusses and explains the origin of life based on physical phenomena often perceived in daily life, and not on bold hypotheses such as "Life's embryo might have come from Mars or somewhere else in the universe," "If RNA/DNA was present," and "Life might be on Enceladus."

Of course, the processes underlying the birth of life have not yet entirely been made clear and thus some parts of the scenario remain presently unresolved. The author expects that some readers of this book will be critically or agreeably make further efforts towards elucidation of the origin of life.

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Contents

Chapter 1
The Dynamic Earth: A Recent Concept Necessary for the Study of the Origin of Life

At the end of the twentieth century, 2000, the international scientific journal *Nature* published a "News and Views" review paper by Euan Nisbet entitled "Palaeobiology: The realms of Archean life." Nisbet included "a map of Archean ecology—places where early life may have flourished," which suggested locations containing liquid water, such as lakes, seas, and coasts. (Nisbet 2000). The Archean is the geological eon between the Hadean and the Proterozoic Eons, from 4.0 to 2.5 billion years ago in absolute age. Presently, it is believed that life on the Earth first emerged during this eon. Nisbet writes that "early life may have flourished" suggesting he supposes that life originated in an aqueous environment somewhere on the early Earth. Because *Nature*, like the journal *Science*, is a highly competitive journal to which top scientists around the world submit their findings, it can be inferred that the international consensus is the belief that "an Ancient seawater was mother of life."

As discussed below in detail (Chap. 6, Sect. 6.1), it is chemically unreasonable that organic molecules such as amino acids would react together to form proteins and other such bioorganic macromolecules in water because proteins decompose faster in water than amino acids polymerize. Moreover, large bodies of water, which has a large specific heat capacity, usually present mild conditions suitable for the persistence of bioorganic molecules so that there is no "environmental pressure" for the necessary organic chemical reactions to evolve. That such an unreasonable assumption remains widely accepted may be ascribed to insufficient dissemination of the understanding of the dynamic Earth concept that has been revealed by recent advances in the geosciences. Since the time of A. Oparin, investigations of the origin of life have been mostly conducted by organic chemists. These researchers may have continued to study molecular evolution processes despite sometimes lacking sufficient information about the environments of the organic molecules. It is therefore still commonly believed that life emerged in an ancient seawater that contained organic molecules as some kind of primordial "soup."

Erwin Schrödinger, the well-known theoretical physicist who opened a new world of quantum physics, switched research fields from physics to molecular

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biology and published the book *What is Life? The Physical Aspect of the Living Cell* in 1944, one year before the end of World War II. In the book's preface, he stated the reason for its publication as follows: "A scientist is supposed to have a complete and thorough knowledge, at first hand, of some subjects and, therefore, is usually expected not to write on any topic of which he is not a master." Science has progressed considerably "both in width and depth," and therefore interdisciplinary research, such as the study of the origin of life, is often challenging. In this situation, Schrödinger said, "some of us should venture to embark on a synthesis of facts and theories" because "the universal aspect has been the only one to be given full credit."

The book was published in the middle of the twentieth century. Since then, science has become progressively "deeper" in terms of specialization and subdivision such that professional barriers between fields have become higher. These high barriers may have divided organic chemistry from the geosciences. Recent developments in geoscience therefore have not been available to influence the study of molecular evolution in organic chemistry.

In this chapter, recent views of the dynamic Earth are outlined historically, beginning with the epoch-making proposal of continental drift theory, which was long neglected because of the strength of consensus that continents do not move. After the notion of immovable continents had been dispelled in the latter half of the twentieth century, the concept of the dynamic Earth rapidly emerged.

Readers may wonder why this book commences with an outline of recent developments in geoscience to approach the subject of the origin of life. This is simply because an understanding of the dynamic Earth is crucial from the point of view of the physical inevitability and historical reality of the problem. Why has life occurred then evolved? How, when, and where? These are the definitive scientific questions about the origin of life. The physical inevitability and history of the dynamic Earth are key elements necessary to answer these questions.

1.1 Continental Drift Theory in the Early Twentieth Century

The early twentieth century was the period during which the study of quantum physics was established based on classical physics including mechanics and thermodynamics. A new view that the world is composed of microparticles such as atoms, electrons, and photons was being built. Those particles are difficult to detect at the macroscale by simple observation alone although we may indirectly experience their effects. However, "the micro-particulate world" exists beneath "the macroworld" that we recognize and experience in daily life. In the next chapter, the new concept of "the micro-particulate world" will be used to establish the physical reasons for the generation and evolution of life. The German physicists Max Planck (1858–1947), Albert Einstein (1879–1955), James Franck (1882–1964), Erwin

Schrödinger (1887–1961), and Werner Heisenberg (1901–1976), all Nobel Laureates, played active and brilliant roles in constructing an understanding of the micro-particulate world up until the rise of the Nazis.

During the same period, the German meteorologist Alfred L. Wegener (1880–1930) proposed a novel hypothesis that continents now separated by oceans originally comprised a single large continent (Wegener 1915). For example, he argued that South America and Africa, as well as North America and Europe, had started to separate from the Cretaceous Period of the Mesozoic Era, 150–70 million years ago. This hypothesis was later named the "continental drift theory."

Wegener said that "the first concept of continental drift first came to me as far back as 1910, when considering the map of the world, under the direct impression produced by the congruence of the coastlines on either side of Atlantic." After this initial observation, he collected evidence to support his hypothesis by reading a great deal of published research in related fields, such as botany, zoology, paleontology, geology, mineralogy, meteorology, and geodesy. He published the first edition of his book, titled *The Origin of Continents and Oceans (Die Entstehung der Kontinente und Ozeane)*, in 1915, and its third edition (1923) was translated into a number of languages, including English (1924), French (1924), and Japanese (1926) (Biram 1966; Kitada 1926).

From the perspective of the present consensus, this theory is quite reasonable as are the facts he presented to support this hypothesis. However, the theory was not accepted by the scientific community at that time because the concept diverged substantially from the existing consensus. For example, the existence of fossils of the same non-migratory species found on separate continents would have been explained as having been enabled by a land bridge that had existed in the past. A land bridge is a narrow strip of land between islands that would emerge at low tides. The hypothesis of drifting continents had been suggested earlier by E. B. Taylor (1910) to explain the formation of massive mountain ranges such as the Alps and Himalayas (Miyashiro and Shido 1981). Nevertheless, Wegener and his continental drift theory were met with strong criticism because the theory entirely contradicted what was considered common knowledge at the time. Although the theory became an object of discussion, few members of the scientific community seriously considered his proposal. Therefore, the global consensus that continents were immovable persisted through the early twentieth century, although the new consensus of the "micro-particulate world" became increasingly well-established.

Barriers between fields in science

It is perhaps not surprising that a new theory would be difficult for more orthodox scientists to accept. As scientists conduct research and gain experience in their professional field, it generally becomes more difficult for them to escape from the consensus of their respective fields. This tendency, however, does not fully account for the reasons why continental drift theory was so long neglected by scientists worldwide despite its clear logic—there must have been some other reason.

All names and related technical terms of fossils, minerals, rocks, animals, and plants have strict definitions in each individual field, but these terms often resemble