

First signs of life

Melishia I. Santiago-Ramirez
University of Massachusetts, Amherst
misantia@geo.umass.edu

Resumen

La presencia de vida es lo que hace especial al planeta Tierra. No hay vida en ninguna otra parte de nuestro sistema solar. Esto es a pesar que la Tierra se formó de la misma nube gigante de gas y polvo de donde se formaron los planetas Marte, Venus, y el resto del sistema solar alrededor de 4600 billones de años atrás. ¿Qué es lo que hace al planeta Tierra especial? Hay diferentes hipótesis que tratan de explicar cómo se formaron las primeras células procariotas, probablemente semejante a células de bacterias modernas. Pero en realidad nadie sabe cómo y de dónde salieron esas primeras células de vida.

Palabras clave: life, early Earth, prokaryotes, and eukaryotes

Abstract

The presence of life on its surface makes the Earth unique. No evidence of living organisms exists in any other part of our solar system even though the Earth was formed in the same giant clouds of gas and dust that formed the Sun, Mars, and Venus and the rest of the solar system over 4600 million years ago. Why is the Earth so special? Although different hypotheses exist, no one knows how life originated. The earliest life forms on Earth probably resembled modern bacterial cells.

Keywords: life, early Earth, prokaryotes, and eukaryotes

The presence of life on its surface makes the Earth unique. No evidence of living organisms exists in any other part of our solar system. The Earth was formed in the same giant clouds of gas and dust that formed the Sun, Mars, and Venus and the rest of the solar system over 4600 million years ago (Margulis, 2004; McElroy, 2000). These three inner planets share similarities but many differences. Earth's average temperature is 17°C, and therefore completely differs from cold Mars and hot Venus of -47°C and 477°C, respectively (Lovelock, 2000). The Earth became an unpleasant ice world and severely glaciated when the average temperature dropped about 8°C at the end of the Proterozoic eon (Lovelock, 1988). But it never either froze entirely nor did the oceans boil. Why is the Earth so special? Life detected as fossils (microfossils, stromatolites, and "organic geochemical" fossils) has a history on Earth that began at least 3400 million years ago (Schopf, Kudryavtsev, Czaja, & Tripathi, 2007; Strother and Barghoorn, 2000).

Possible answers for the origin of life

Many scientists have tried to answer the question of the origin of life. Charles Darwin, who wrote *The Origin of Species* (1859), sent a letter to Joseph Hooker explaining that he thought it was possible life began on Earth in a warm salt water pond (Lazcano, 2000). At the same time Darwin published his book, Louis Pasteur conducted in 1859 a series of experiments with food materials in a sealed flask (Lazcano, 2000). Pasteur proved that spontaneous generation does not occur; his flask, open to the air but facing down, still sterile, is on display today at the Institute Pasteur in Paris. Other scientists, for example, Ernst Haeckel (1834-1919) and Hermann von Helmholtz (1821-1894) tried to answer this question (Lazcano, 2000). Haeckel theorized that the origin of all living organisms could be traced by investigating their ancestors. But what if those ancestors came from another part of the universe as Helmholtz's proposed? This concept, called *panspermia*, means "universality of the germs of life" (Lazcano, 2000). The implication is that how life originated was unknown. Helmholtz's idea was widely accepted at some point because there were no alternatives. Fred Hoyle and Francis Crick agreed with Helmholtz many years later, but this idea simply pushes back in time and off the Earth the problem of the origins that has now been abandoned (Lazcano, 2000).

The physicist Leonard Troland and his colleagues hypothesized in 1914 that some type of spontaneous and abiological formation of catalytic molecules could be found in the early (Archean eon) oceans (Lazcano, 2000). If this were true, some molecules self-replicated and catalyzed reactions in solution. Such ideas were developed by geneticist Herman J. Muller (1890-1967) (Lazcano, 2000). Muller believed a gene able to mutate and develop gradually was the first form of life on Earth. Scientists rejected Muller's idea since no gene is found outside a cell. The Mexican scientist Alfonso Herrera (1868-1942) experimented in his laboratory and conceived the idea of *plasmogenesis* (Lazcano, 2000). Herrera tried for more than fifty years to create living photosynthetic cells: autotrophic units capable of producing of their own organic cell material from CO₂, H₂, and other inorganic molecules (Lazcano, 2000). Alexander Ivanovich Oparin (1894-1980) rejected Herrera's idea when he published a book proposing that the first organisms to arise were anaerobic bacteria (they metabolized without oxygen) and heterotrophic (not able to produce their own food molecules but

First signs of life

taking sustenance from organic material already present on the early Earth) (Lazcano, 2000). Oparin's ideas were tested for the first time by Harold C. Urey and his student Stanley L. Miller. Miller-Urey's experiment simulated an early Earth atmosphere. Their first experiments used organic chemical compounds such as methane (CH_4) and inorganic compounds like ammonia (NH_3) and water vapor (H_2O) which were hypothesized to be present in the prebiotic atmosphere (Lazcano, 2000). Scientists assume a transition from organic compounds to reproducing organisms occurred somehow. All organisms now have DNA, with RNA-directed protein synthesis as the basis of their replication and growth. Whether or how RNA or DNA proceeded is not clear, but either way, the evolution of RNA and DNA must have occurred rapidly before the first microfossils of 3400 million years ago in Australia and South Africa (Lazcano 2000; Margulis 1993).

Bacteria: our first lineage

Thus how did life originate? The origin of life is still a mystery; however, it is probable that the first life on our lineage began as bacteria (Margulis, 1993). We are led to the conclusion that bacteria are the ancestral forms of life for at least two reasons. The fossil record shows them to be earlier than all eukaryotes, and they represent all the major modes of metabolism without which no ecosystem can function (Margulis, 1993). Most people think that bacteria only cause most widespread diseases, but this is hopelessly naive. Bacteria perform all the major processes that maintain soil, water, and atmospheric environment (Margulis, 1993).

Bacteria remove intractable nitrogen (N_2) from the air and transform it into usable chemicals (NH_4^+ , as amino acids, other organics, or nitrates) (Margulis, 1993). These are all usable compounds used by most organisms for synthesis of proteins, for instance. Only bacteria can use the unreactive $\text{N}\equiv\text{N}$ from the air (Margulis, 1993). Larger life on Earth would stop immediately without bacteria.

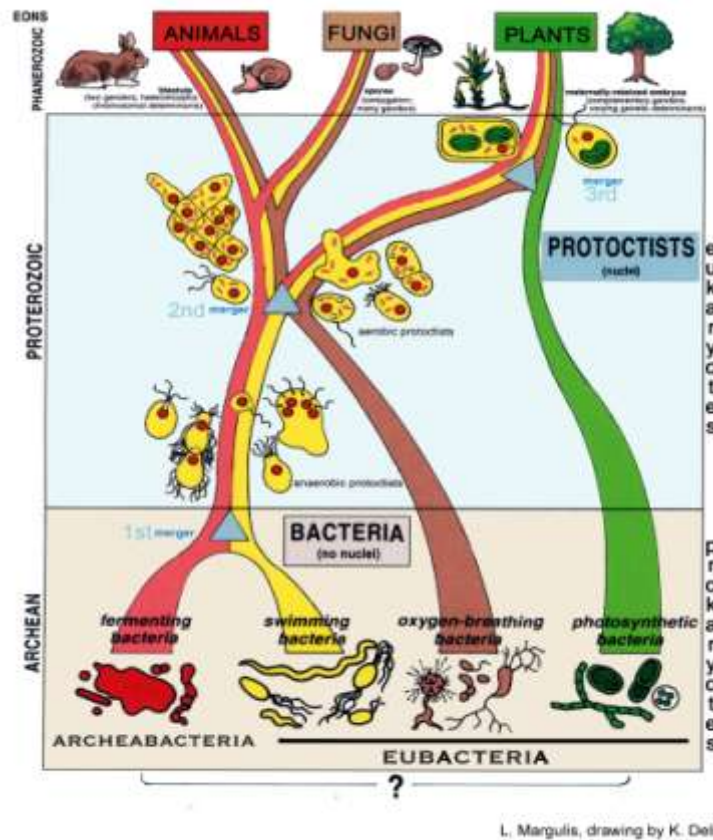
Prokaryotes, we assume (both archaeobacteria and eubacteria) have been documented in the fossil record (Margulis, 2000; Strother and Barghoorn, 2000). However, the enigma remains: how and where did bacteria originate? We don't know, but we do have detailed ideas about how nucleated cells evolved from bacteria.

Bacteria and four kingdoms

Bacteria teamed up in a given sequence to the ancestors of nucleated cells: the eukaryotes of today (Margulis, 2000). Four “form-kingdoms” of organisms evolved from the earliest nucleated cells that themselves evolved from integrated communities, mergers of more than one different kind of bacteria. The four largest inclusive taxa (kingdoms or sub-kingdoms) are Protoctists, Animals, Fungi, and Plants (Margulis, 2000; Margulis & Chapman, 2009). Protoctists are multigenomic aquatic eukaryotes excluding plants, animals, and fungi (Margulis, 2000). Within the protoctists, we can find organisms like all the algae, the amoebae, foraminifera ciliates and reticulomyxids, all the slime molds, water molds, and many other unicellular protists and their multicellular descendants. Animals, fungi, and plants (the only nonprotoctist eukaryotes) are also composed of nucleated cells (Margulis, 2000). These are the organisms in which complex structures like multi-layered tissues, bone shell, blood or hemolymph, cellulosic cell walls evolved. Fungi all make “resting propagules” called spores, for example asco or basidiospores (Margulis, 1993). A basidiospore is a reproductive spore produced by a type of fungi called basidiomycete (Margulis, 1993). Some mushrooms and molds are fungi, for instance (Margulis, 1993). Even though mushrooms and molds are known for causing diseases, some mushrooms are useful for cooking and molds are used in the production of antibiotics, beverages, enzymes, etc.

Each kingdom is depicted in the geological eon in which examples appear first in the geological fossil record (Figure 1). The colored lines trace the origin of cell organelles from associations of given bacteria lineages. The red and yellow lines show the evolution of nucleocytoplasm, from the hypothesis that bacteria mergers originate [eubacteria (e.g., spirochetes) and archaebacteria (e.g., thermoacidophiles)]. The evolution of ancestors to the mitochondria and to the chloroplasts is shown in brown and green, respectively. Photosynthetic oxygenic bacterial cells (cyanobacteria) that evolved into the chloroplasts associated with heterotrophic protoctist formed algal and subsequently plant cells.

First signs of life



L. Margulis, drawing by K. Delisle

Figure 1: Drawing by Kathryn Delisle courtesy of Lynn Margulis

Although the origin of life is still an unsolved problem, all life is either bacterial (archaea or eubacteria) or resulted from specific permanent mergers of bacteria that evolved to be ancestors of Proterozoic eon Protocists or the Phanerozoic animals, fungi, and plants. Humans entered a fertile and diverse Earth only after 3 thousand million years of prior evolution (Margulis, 2000). We as *Homo sapiens* have only been detected in the fossils of the very recent Pleistocene, the last 2 million years or so.

How did eukaryotes originate?

The theory of Lynn Margulis has precedents in the Russian literature that date back to 1924 (Khakhina, 1992; Margulis; 1993). The modern symbiogenetic view that attempts to explain the fusion of archaebacteria and eubacteria in the symbiogenetic origin of eukaryotes were named the “serial endosymbiosis theory” (SET) by Prof. F.J.R. Taylor of University of British Columbia, Vancouver, Canada (Margulis, 1993). The SET

explains how nucleated cells (animals, plants, fungi, and protoctists) derived from tightly integrated bacterial communities. Bacteria not only tolerate extreme environments but have the most diverse metabolism of all organisms (Margulis, 1993).

All bacteria are made of prokaryotic cells that are autopoietic: “self maintaining” membrane-bounded, protein-synthesizing, and self-referential systems that require a continuous supply of specific usable energy (chemical or light) and matter (e.g., organic components of food) (Margulis, 1993). All bacteria have DNA and messenger, ribosomal, and transfer RNA. The serial endosymbiosis theory (SET) posits three classes of hereditary organelles of eukaryotic cell that began as bacteria: undulipodia (cilia, eukaryotic “flagella”, sperm tails, etc.), mitochondria, and plastids (Margulis, 2000). Each by hypothesis originated from specific bacterial symbionts in a certain order. “Symbiosis” refers to long-term physical association between organisms of different species (Margulis, 2000). Margulis hypothesizes the process of eukaryosis was the first step to the permanent fusion of an archaebacterium like *Thermoplasma* and eubacterium like members to genus *Spirochaeta*. The integration of *Thermoplasma* and *Spirochaeta* produced a type of protist with modern descendants like some we know today. These include today’s archaeotists that have evolved from presumably ancestral early eukaryotes (Margulis, 2000; Margulis & Chapman, 2009). Today’s archaeotists include mastigamoebae and parabasalid, such as *Calonympha* and *Trichomonas*. These swimming cells all lack any vestige of mitochondria. Some of their descendants acquired oxygen-respiring bacteria symbionts by phagocytosis and failure of ingestion. Fungi and animals evolved directly from aerobic (mitochondria-containing) mastigonts. The ancestors led to algae and plants that had obtained further photosynthetic oxygenic bacterial symbionts (cyanobacteria) (Margulis, 1993).

Although the origin of life is still unknown, scientists have been able to investigate how the earliest bacteria evolved to become more complex organisms, such as protoctists, fungi, plants, and animals. Life is what makes the Earth unique.

Acknowledgments

I want to thank Dr. Lynn Margulis for her unconditionally support of my work and her useful criticism. I also thank Dr. Michael Dolan, Celeste Asikainen, and other members

of the Margulis Laboratory as well as Charlena Seymour of the University of Massachusetts, Amherst, Graduate School.

References

- Khakina, L. N. (1992). *Concepts of symbiogenesis: A historical and critical study of the Russian botanists*. New Haven, CT: Yale University Press.
- Lazcano, A. (2000). Origins of life: History of ideas. In L. Margulis, C. Matthews, & A. Haselton (Eds.), *Environmental evolution: Effects of the origin and evolution of life on planet Earth* (2nd ed.) (pp. 84-94). Cambridge, MA: MIT Press.
- Lovelock, J. E. (1988). *The ages of Gaia: A bibliography of our living Earth*. New York: W. W. Norton & Company.
- Lovelock, J. E. (2000). The Gaia hypothesis. In L. Margulis, C. Matthews, & A. Haselton (Eds.), *Environmental evolution: Effects of the origin and evolution of life on planet Earth* (2nd ed.) (pp. 1-27). Cambridge, MA: MIT Press.
- Margulis, L. (1993). *Symbiosis in cell evolution: Microbial communities in the Archean and Proterozoic eons* (2nd ed.). New York: W.H. Freeman.
- Margulis, L. (2000). Symbiosis and the origin of protists. In L. Margulis, C. Matthews, & A. Haselton (Eds.), *Environmental evolution: Effects of the origin and evolution of life on planet Earth* (2nd ed.) (pp. 141-157). Cambridge, MA: MIT Press.
- Margulis, L. (2004). Introduction: Gaia by any other name. In S. H. Schneider, J. R. Miller, E. Crist, & P. J. Boston (Eds.), *Scientists debate Gaia: The next century* (pp.7-12). Cambridge, MA: MIT Press.
- Margulis, L., & Chapman, M. J. (2009). *Kingdoms and domains: An illustrated guide to the phyla of life on Earth*. San Diego: Academic Press-Elsevier.
- McElroy, M. (2000). Comparison of planetary atmospheres: Mars, Venus, and Earth. In L. Margulis, C. Matthews, & A. Haselton (Eds.), *Environmental evolution: Effects of the origin and evolution of life on planet Earth* (2nd ed.) (pp. 29-44). Cambridge, MA: MIT Press.

- Schopf, J. W., Kudryavtsev, A. B., Czaja, A. D., & Tripathi, A. B. (2007). Evidence of Archean life: Stromatolites and microfossils. *Precambrian Research*, 158(3), 141-155.
- Strother, P. K., & Barghoorn, E. S. (2000). Clues to life in the Archean eon. In L. Margulis, C. Matthews, & A. Haselton (Eds.), *Environmental evolution: Effects of the origin and evolution of life on planet Earth* (2nd ed.) (pp. 97-115). Cambridge, MA: MIT Press.

Citación de este artículo:

Santiago-Ramirez, M. (2009). First signs of life. *Revista Umbral*, 1, 13-20. Disponible en: <http://ojs.uprrp.edu/index.php/umbral/article/download/20/11>