Origin of Life on Earth

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How did Life on Earth Originate?

An Ancient Building Block of Life

December 18, 2006 by David Tytell

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Astronomers have long assumed that organic molecules — compounds fundamental to life — were among the primary components available to build the solar system. Now they have physical evidence to support this idea. The smoking gun comes from measurements of the famed Tagish Lake meteorite. The bolide, whose fragments fell to Earth on January 18, 2000, landed on a frozen lake in northwestern Canada. It represents one of the most pristine meteorite samples ever collected. Since the rock's fragments stayed frozen and were barely exposed to the terrestrial environment before they were collected, the pieces are chock-full of volatile (easily vaporized) compounds that date back to ancient times.

How ancient? A team headed by Keiko Nakamura-Messenger and Scott Messenger (NASA/Johnson Space Center) analyzed organic globules within the sample and found them to be more than 4.5 billion years old — hundreds of millions of years older than the most ancient terrestrial rocks. What's more, the globules inside the rocks likely predate our solar system and formed either in the outermost reaches of the protosolar disk or in a cold molecular cloud. "These organic grains are still intact in the meteorite, which means that we have direct samples of organic materials that formed in a distant cosmic environment before the planets did," says Messenger.

Behold a piece from the Tagish Lake meteorite fall of January 2000. The fragments — one of which seen here still encased in a chunk of ice — represent one of the oldest and most pristine samples of the early solar system.
Alan Hildebrand (University of Calgary)

Summary

On 18th January 2000, the famous Tagish Lake meteorite fell on a frozen lake in northern British Columbia. It consists of compounds that date back to ancient times, even before the birth of the solar system which was more than 4.5 billion years ago. Upon further research, organic grains were found still intact in the sample fragments of the meteorite. These organic grains consist of fundamental molecules that form the basic structure for the simplest life form.

This discovery raises profound questions about where the molecules of life had originated – was it far out in the cosmic galaxies and far back into time even before the birth of the solar system?

Search for Life

It goes against nature in a large field to grow only one shaft of wheat, and in an infinite universe to have only one living world

– Metrodorus of Chios, Circa 400 BC

What is the history of life?
Are we alone in the universe?
What is the future of Life?

These words by Greek atomist philosopher Metrodorus [1] aims to make us aware that we are not alone in the universe. Metrodorus reasons that the process by which life on Earth was created can also be replicated on other planets in the universe. However, is this argument a viable one? Scientists have been working on this exciting field for the search of life with 3 key fundamental questions: What is the history of life? Are we alone in the universe? What is the future of Life? They have also been trying to understand whether life is a normal part of the universe or whether our Earth is the only world that harbours living creatures.

This essay will examine the very elements that make up life and how it originated on Earth. The focus will go on to the early life on Earth and what factors might have caused life to come into existence.

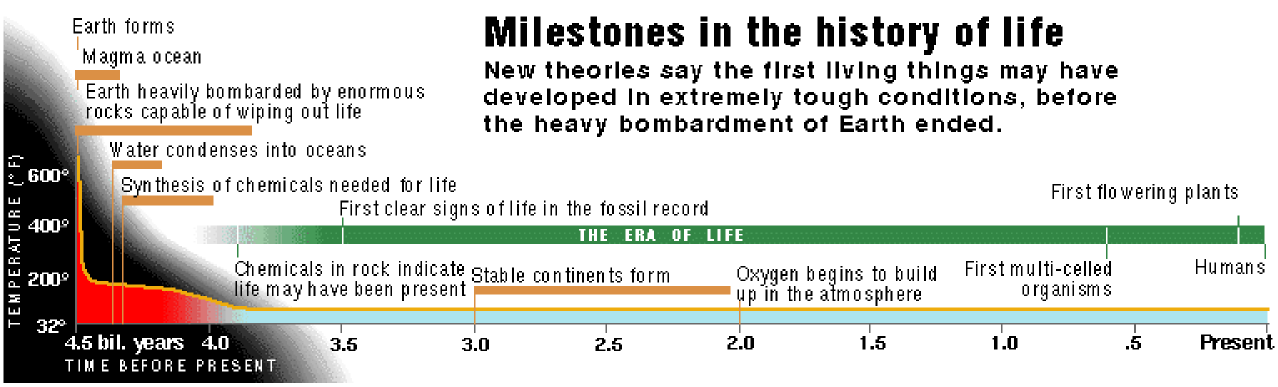

Figure 1: Timeline of Origin of Life [2]

Conditions for Life

Upon years of research, scientists have concluded that there are 4 main ingredients required for life to exist. They are building blocks of life, a medium where chemical reactions can take place, a source of energy and an atmosphere to protect this life form.

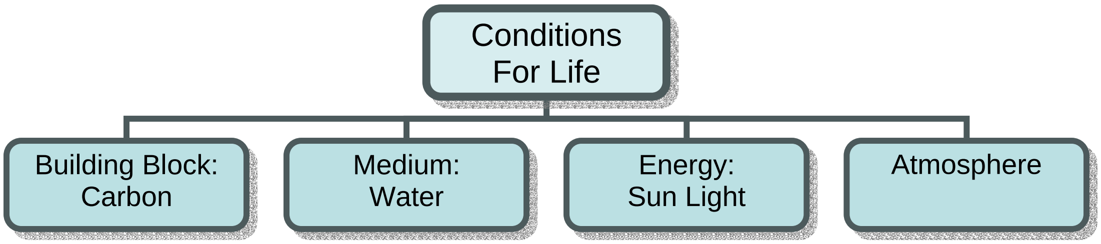

Figure 2: The 4 Conditions for Life

Building Blocks of Life: Carbon

All life form on Earth is made up of long chains of carbons which form the organic molecules. Carbon [3] also links easily with other atoms like oxygen, hydrogen, nitrogen to form living organisms. Because it is so versatile, it can join to form ladders, rings, tubes and springs. Its versatility and abundance is also the reason why scientists are looking for carbon-based life forms in the universe. One of the important carbon compounds in living organisms is buckyball which resembles a dome and has about 60 carbon atoms.

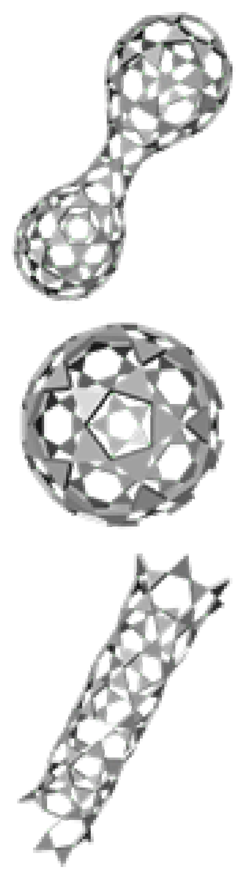

Figure 3: Types of Carbon Molecules [6]

Medium: Water

For any life form to exist, it needs a solvent in which chemical reactions can take place. Water [4] is that solvent on Earth and almost any chemical element readily dissolves in it. Water also has a unique attribute. Its solid ice form is less dense than its liquid form. Ice floats on liquid water. Water beneath the cold ice is protected by the freezing air temperatures above. Life may have begun in water and it was not frozen out of existence even during the many bitter and long Ice Ages that have periodically enveloped the Earth.

Ice has been discovered on Earth's Moon, Mars, Jupiter's Galilean Satellites, and Saturn's rings. Water is the most common tri-atomic [5] molecule. But liquid water is another issue. The chemistry of life takes place in liquid water here on Earth and not in ice or steam. Earth is the only place we know that has vast oceans of liquid water covering its surface.

The first steps in the creation of life may well have happened in the icy bodies of comets. Comets bombarded the Earth early in our planet's history, bringing much water to our world. They may as well have also brought the earliest forms of life, microscopic spores that arose in the carbon laced ice that forms the bodies of the comets.

Energy: Sunlight

Our main source of energy comes from the Sun and living organisms harness it converting this energy into living tissues in the process. During photosynthesis, plant cells which contain chlorophyll use this energy and create carbohydrates which constitute the food source for herbivores and omnivores. Any intricate food web on Earth starts with plants as a primary producer. As such, the search for life in the universe focuses on celestial objects which has a 'Sun' that can provide them with this energy.

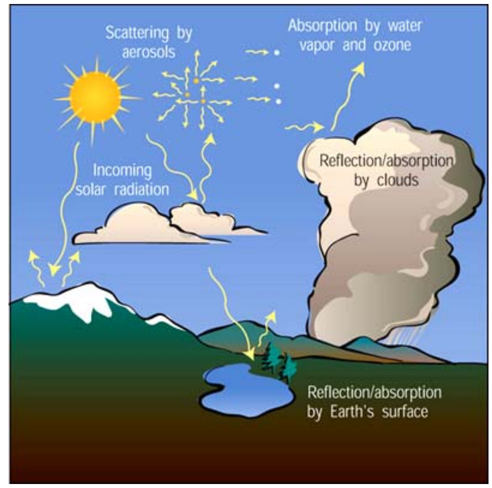

Figure 4: Energy Cycle of the Sun. [7]

Atmosphere

Earth's atmosphere protects living creatures beneath it by blocking out ultra-violet radiation from the Sun. It is made up of a mixture of gases composing of nitrogen, oxygen, and other gases. Some of the oxygen converts to ozone over time and this layer filters out the Sun's harmful rays. This protection also keeps the climate of our planet reasonably stable and traps heat to keep us warm at night.

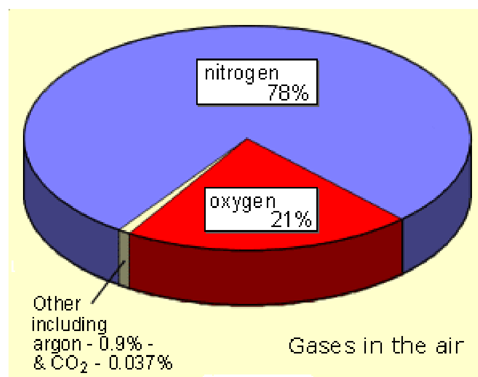

Figure 5: Composition of Earth's Atmosphere [8]

Molecules of Life

Astronomers have confirmed that atoms are indeed the same throughout the cosmos [9]. For example, a carbon atom in the Andromeda Galaxy is identical to the one on Earth [10]. The five main elements that make up organic molecules are carbon, oxygen, hydrogen, nitrogen, and phosphorus. These elements have been found to be plentiful in the universe. Among these, carbon is the most vital one. It is the main element found in proteins and DNA where these compounds are the main building blocks of life.

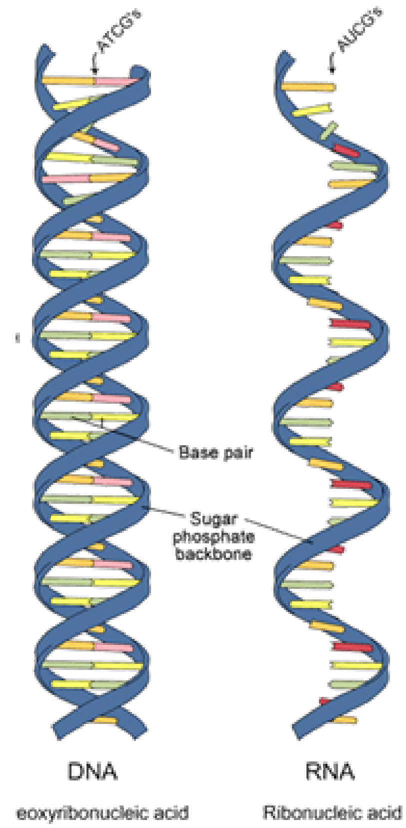

Figure 6: Molecules of DNA and RNA. [11]

In 1963, MIT's Lincoln Laboratory was startled to discover that hydroxyl radicals existed in interstellar clouds of gas and dust. The hydroxyl radical (OH) is two-thirds of a molecule of water. In addition, radio telescopes detected many other organic molecules in the interstellar clouds, including water, ammonia (NH_3), formaldehyde (H_2CO), and hydrocyanic acid. These chemical compounds prove that the essential molecules that make up life exist far out in space and are embedded in the thick interstellar clouds of gas and dust. Life depends on proteins and nucleic acids which comprises of RNA and DNA to reproduce and carry out life processes that needs energy.

When chemical reactions take place in carbon, water-bearing meteorites, and the icy bodies of comets, organic molecules that become the building block for living organisms are formed. This is known as Prebiotic Chemistry.

In many laboratories around the world, scientists are attempting to reproduce these early molecules of life. If they succeed in producing protein-based protocells, they will generate living metabolized entities out of non-living chemicals. "Life in a test tube" will become a reality. Scientists will then understand how life is formed and will have a clearer idea of what to look out for in other worlds.

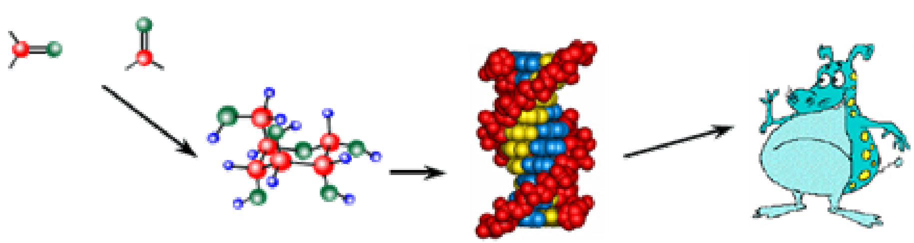

Figure 7: Pre-Biotic Chemistry [12]

Creation of the Solar System and the Earth

Creation of the Solar System

Scientists have come to understand that our planet did not come to existence in isolation. The Earth was born together with all the other components of our solar system, both large and small. The creation of life on Earth depended at least in part on the materials, energies and the chemical processes brought to our planet Earth by these smaller objects.

About 4.6 billion years back, it is believed that the solar system was formed when a cloud of gas and dust in space was disturbed, perhaps by a supernova. This explosion made waves in space which compressed the cloud of gas and dust. Slowly, the clouds started to collapse and coagulate. As gravity pulled the gas and dust together, a solar nebula was formed [13].

Our Sun kept spinning off dust-laden disks of gas and accretion disks until about 3.5 billion years ago. Earth was created at the same time that the Sun and other bodies of our solar system came into existence. This was around 4.6 billion years back and the four fundamental conditions of life were in place even at that time.

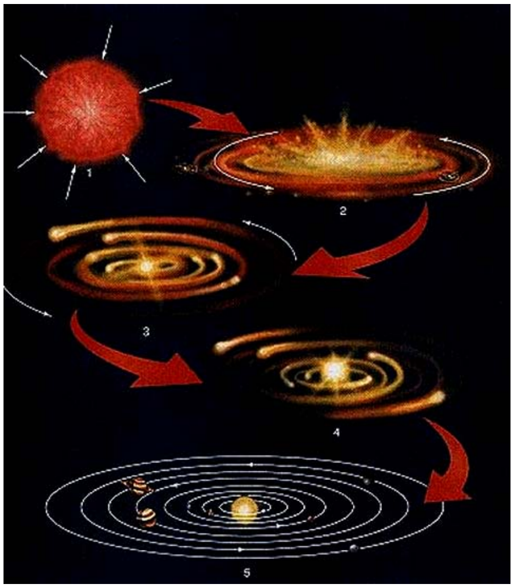

Figure 8: Formation of the Solar System [14]

Creation of Earth

For about 10,000 years, these bodies of gases and dust swelled into enormous sizes where they started orbiting the Sun. At some point of time, Earth was struck by a giant body which tunneled itself into the centre of our planet, forming the iron core. The collision resulted in the lighter mantle being stripped away to form the Moon. From this cataclysm, an enormous energy arose baking the Earth dry of any volatile material.

Over the years, Earth was repeatedly struck. First, it was struck by asteroids from the region between Mars and Jupiter, followed by comets from Jupiter's zone. Icy bodies also smashed onto Earth and added a layer of light rocky material to the Earth's crust as well as the vast quantities of water which makes up the oceans. After about a hundred million years, the formation of Earth was more or less complete. The biggest threat was the collisions from asteroids and comets in space. These bodies continually crashed onto Earth, leaving behind cargoes of ice and organic material.

Now, my own suspicion is that the universe is not only queer, but queerer than we can suppose.

– J. S. Haldane

Creation of Earth's Moon

The Moon is an important stabilizing component for the existence of life on Earth. Our Earth has a relatively big Moon of approximately one-quarter of its size. Due to Moon's gravitational pull, which acts as an anchor on the axial wobble, our Earth is prevented from tilting further than twenty-three degrees and has maintained its tilt for eons. Long-term wise, a stable climate is created and this is necessary for the eventual rise of intelligence on a planet. Thus, only planets with large Moons have the possibility of developing intelligent species. Perhaps Earth is unique or at least, very rare.

Creeping away at about three centimetres every year, the Moon is slowly spiraling away from Earth. Eventually, billions of years from now, the Moon will reach its limit of its drift, called the Roche limit [20]. Gravity holding it will be weaker than the tidal forces acting to pull it apart. At some point of time Earth's gravity will break it up and our world will have a ring of tiny particles orbiting around it. Could life on Earth survive the Moon's demise? Scientists speculate that its break up would shower the Earth with meteors and would very likely turn our world into darkness and pockmarked as our Moon is today.

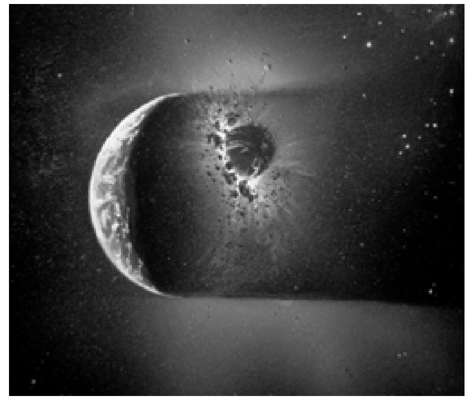

Figure 9: Formation of the Moon [15]

Craters and Meteorites

Around 2 billion years ago, Earth was bombarded continually by fiery meteorites which brought many materials such as organic buckyballs from outer space. Scientists believed that these buckyballs originated from relatively bright and cool stars known as red giants. Consequently, they combined with meteoritic or cometary material that eventually traveled through space and collided into Earth. If these buckyballs had not been encased and protected in a meteorite soon after formation, they could have been destroyed by ultraviolet radiation, solar wind, and energetic particles. In 1986, the Giotto spacecraft found carbon, hydrogen, nitrogen, and sulphur on comet Halley. If comets such as Halley smashed into Earth, there will be enough organic materials supplied to make the entire biosphere.

Biologists refer to cosmic impacts as contingent events. They take no account of terrestrial biology and happen out of the blue without any causal connection to the evolution of life. They create and destroy and are linked to the origin if life on Earth as these bodies supplied us their rich material.

Figure10: Violent Bombardment on early Earth [16]

Early Life on Earth

About 3.5 billion year back, Earth was a hot and unbreathable place. Amazingly, life takes advantage of whatever conditions that exist, as long as those conditions fulfill the four requirements, which are sunlight, energy, an atmosphere, and water, even at extreme temperatures, pressure and salinity. Extremophiles, such as anaerobic microbes, live deep in the underground or in brutal conditions of high temperatures and salinity.

Nature is lazy, but fascinatingly clever

A human would not have been able to withstand a speedy acceleration out of Earth such as this but researchers have discovered that microbes can withstand it. In space, X-rays, ultraviolet light, gamma rays, and cosmic rays randomly alter a bacterium's DNA and temperature swings from one extreme to the other yet some microbes are able to tolerate these harsh conditions. For nearly three years inside NASA's Surveyor 3 lander, about 100 cells of the bacterium *Streptococcus mitis* survived on the Moon before it was ferried back to Earth by Apollo 12 astronauts. Its survival is a major feat as the Moon is known to have a harsh environment of space radiation, vacuum, and extreme temperatures.

Recently, microbiologists have extended their knowledge of these organisms and their significance. Some of these microorganisms seem to be extraordinarily ancient and primitive and scientists are beginning to take on the idea that they could be living fossils which also implies that they may be the closest thing alive to the universal ancestor. If this is so, the extreme conditions in which they thrive might be indicative of what Earth was like 3.8 billion years ago.

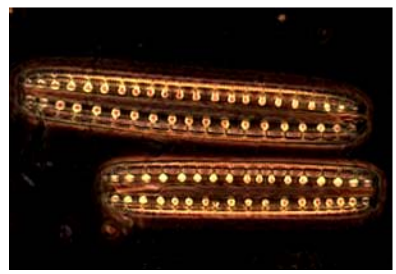

Figure 11: Extremophiles [17]

Comments

Search for Life in the Universe

Upon intensive research, scientists now know the various conditions that life needs to come into existence. They are vigorously looking for Earth-like planets elsewhere in the universe.

Within the Solar system, scientists are investigating Titan, Saturn's moon, for a life signal. Up to date, there has been evidence found for seas, probably filled with liquid hydrocarbons, at the high northern latitudes of Titan by Nasa's Cassini probe. [18]

Europa, Jupiter's moon, has also been a target of interest. Its gravitational interaction with Jupiter creates cracks in its icy surface, where water wells up and then freezes into lakes. [19] With well-supported evidence that water ice is present in Europa and the probability that there are briny oceans, scientists are proposing that there is a possibility of finding life there.

As for other galaxies, the question on whether life forms exist in these territories has been of great interest and widely debated by many. At this point of time, our current technology is not as advanced to the stage where spaceships are able to reach, or even go close enough to these galaxies. Spaceship travel would require an unrealistic amount of time and fuel which makes any form of contact rather impossible. However, this does not hinder scientists from continually making progress with their space technology, with the dream that one day we will be able to explore these mysterious territories.

We are alone in the universe or we are not; either way it's mind-boggling

~ Lee DuBridge, science advisor to President Nixon

Search for Intelligent Life in the Universe

Once we find life on other worlds, no matter whether it is a bacterium or an elephant, the search for intelligent life will intensify. We tacitly assume that intelligence is a natural outcome of life. After all, life on Earth has led to an intelligent species - *Homo sapiens*. But is intelligence an inevitable outcome of life or is it just a useful trait that living creatures might or might not adopt, like wings, gills or tails? Will we find other intelligence somewhere in the vast universe and end our loneliness? Whether we do or do not, the search itself will expand our consciousness as never before.

The quest will continue.

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