Archean eon life forms

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Online exhibits : Geologic time scale The Archean Eon and the Hadean The Archean eon, which preceded the Proterozoic eon, spanned about 1.5 billion years and is subdivided into four eras: the Neoarchean (2.8 to 2.5 billion years ago), Mesoarchean (3.2 to 2.8 billion years ago), Paleoarchean (3.6 to 3.2 billion years ago), and Eoarchean (4 to 3.6 billion years ago).* If you were able to travel back to visit the Earth during the Archean, you would likely not recognize it as the same planet we inhabit today. The atmosphere was very different from what we breathe today; at that time, it was likely a reducing atmosphere of methane, ammonia, and other gases which would be toxic to most life on our planet today. Also during this time, the Earth's crust cooled enough that rocks and continental plates began to form. It was early in the Archean that life first appeared on Earth. Our oldest fossils date to roughly 3.5 billion years ago, and consist of bacteria microfossils. In fact, all life during the more than one billion years of the Archean was bacterial. The Archean coast was home to mounded colonies of photosynthetic bacteria called stromatolites. Stromatolites have been found as fossils in early Archean rocks of South Africa and western Australia. Stromatolites increased in abundance throughout the Archean, but began to decline during the Proterozoic. They are not common today, but they are doing well in Shark Bay, Australia (see photo below). Former UCMP grad students Allen Collins (left) and Chris Meyer stand among living stromatolites in Shark Bay, at the westernmost point of Australia. The Hadean Hadean time (4.6 to 4 billion years ago)* is not a geological period as such. No rocks on the Earth are this old, except for meteorites. During Hadean time, the Solar System was forming, probably within a large cloud of gas and dust around the sun, called an accretion disc. The relative abundance of heavier elements in the Solar System suggests that this gas and dust was derived from a supernova, or supernovas — the explosion of an old, massive star. Heavier elements are generated within stars by nuclear fusion of hydrogen, and are otherwise uncommon. We can see similar processes taking place today in so-called diffuse nebulae in this and other galaxies, such as the Nebula M16, below left. Left: A Hubble Space Telescope image of a star-forming region of Nebula M16 (Eagle Nebula). Right: Asteroid Ida and its moon as imaged by the Galileo spacecraft in 1993. The spacecraft was about 10,500 kilometers (6,500 miles) from the asteroid. The sun formed within such a cloud of gas and dust, shrinking in on itself by gravitational compaction until it began to undergo nuclear fusion and give off light and heat. Surrounding particles began to coalesce by gravity into larger lumps, or planetesimals, which continued to aggregate into planets. "Left-over" material formed asteroids and comets, like asteroid Ida, above right. Because collisions between large planetesimals release a lot of heat, the Earth and other planets would have been molten at the beginning of their histories. Solidification of the molten material into rock happened as the Earth cooled. The oldest meteorites and lunar rocks are about 4.5 billion years old, but the oldest Earth rocks currently known are 3.8 billion years. Sometime during the first 800 million or so years of its history, the surface of the Earth changed from liquid to solid. Once solid rock formed on the Earth, its geological history began. This most likely happened prior to 3.8 billion years, but hard evidence for this is lacking. Erosion and plate tectonics has probably destroyed all of the solid rocks that were older than 3.8 billion years. The advent of a rock record roughly marks the beginning of the Archean eon. Resources and references Bengtson, S. (ed.) 1994. Early Life on Earth. Nobel Symposium 84. Columbia University Press, New York. Schopf, J.W. (ed.) 1983. Earth's Earliest Biosphere: Its Origin and Evolution. Princeton University Press, Princeton. 543 pp. Read more about Shark Bay and its stromatolites or stromatolites in general on Wikipedia. Learn more about the Archean and Hadean on Wikipedia. Find out more about the Precambrian paleontology and geology of North America at the Paleontology Portal. The Archean Eon, which lasted from 4.0–2.5 billion years ago, is named after the Greek word for beginning. This eon represents the beginning of the rock record. Although there is current evidence that rocks and minerals existed during the Hadean Eon, the Archean has a much more robust rock and fossil record. Figure \(\PageIndex{1}\): Artist’s impression of the Archean. Objects were chaotically flying around at the start of the solar system, building the planets and moons. There is evidence that after the planets formed, about 4.1–3.8 billion years ago, a second large spike of asteroid and comet impacted the Earth and Moon in an event called late heavy bombardment. Meteorites and comets in stable or semi-stable orbits became unstable and started impacting objects throughout the solar system. In addition, this event is called the lunar cataclysm because most of the Moons craters are from this event. During the late heavy bombardment, the Earth, Moon, and all planets in the solar system were pummeled by material from the asteroid and Kuiper belts. Evidence of this bombardment was found within samples collected from the Moon. Figure \(\PageIndex{2}\): 2015 image from NASA’s New Horizons probe of Pluto. The lack of impacts found on the Tombaugh Regio (the heart-shaped plain, lower right) has been inferred as being younger than the Late Heavy Bombardment and the surrounding surface due to its lack of impacts. It is universally accepted that the solar system experienced extensive asteroid and comet bombardment at its start; however, some other process must have caused the second increase in impacts hundreds of millions of years later. A leading theory blames gravitational resonance between Jupiter and Saturn for disturbing orbits within the asteroid and Kuiper belts [33] based on a similar process observed in the Eta Corvi star system. Figure \(\PageIndex{3}\): Simulation of before, during, and after the late heavy bombardment. Figure \(\PageIndex{4}\): The layers of the Earth. Physical layers include the lithosphere and asthenosphere; chemical layers are crust, mantle, and core. In order for plate tectonics to work as it does currently, it necessarily must have continents. However, the easiest way to create continental material is via assimilation and differentiation of existing continents (see Chapter 4). This chicken-and-egg quandary over how continents were made in the first place is not easily answered because of the great age of continental material and how much evidence has been lost during tectonics and erosion. While the timing and specific processes are still debated, volcanic action must have brought the first continental material to the Earth’s surface during the Hadean, 4.4 billion years ago [18]. This model does not solve the problem of continent formation since magmatic differentiation seems to need a thicker crust. Nevertheless, the continents formed by some incremental process during the early history of Earth. The best idea is that density differences allowed lighter felsic materials to float upward and heavier ultramafic materials and metallic iron to sink. These density differences led to the layering of the Earth, the layers that are now detected by seismic studies. Early protocontinents accumulated felsic materials as developing plate-tectonic processes brought lighter material from the mantle to the surface [36]. Figure \(\PageIndex{5}\): Subduction of an oceanic plate beneath another oceanic plate, forming a trench and an island arc. Several island arcs might combine and eventually evolve into a continent. The first solid evidence of modern plate tectonics is found at the end of the Archean, indicating at least some continental lithosphere must have been in place. This evidence does not necessarily mark the starting point of plate tectonics; remnants of earlier tectonic activity could have been erased by the rock cycle. Figure \(\PageIndex{6}\): Geologic provinces of Earth. Cratons are pink and orange. The stable interiors of the current continents are called cartons and were mostly formed in the Archean Eon. A craton has two main parts: the shield, which is crystalline basement rock near the surface, and the platform made of sedimentary rocks covering the shield. Most cratons have remained relatively unchanged with most tectonic activity having occurred around cratons instead of within them. Whether they were created by plate tectonics or another process, Archean continents gave rise to the Proterozoic continents that now dominate our planet. Figure \(\PageIndex{7}\): The continent of Zealandia The general guideline as to what constitutes a continent and differentiates oceanic from the continental crust is under some debate. At passive margins, continental crust grades into the oceanic crust at passive margins, making a distinction difficult. Even island-arc and hot-spot material can seem more closely related to continental crust than oceanic. Continents usually have a craton in the middle with felsic igneous rocks. There is evidence that submerged masses like Zealandia, that includes present-day New Zealand, would be considered a continent [39]. Continental crust that does not contain a craton is called a continental fragment, such as the island of Madagascar off the east coast of Africa. Life most likely started during the late Hadean or early Archean Eons. The earliest evidence of life is chemical signatures, microscopic filaments, and microbial mats. Carbon found in 4.1 billion-year-old zircon grains have a chemical signature suggesting an organic origin. Other evidence of early life is the 3.8–4.3 billion-year-old microscopic filaments from a hydrothermal vent deposit in Quebec, Canada. While the chemical and microscopic filaments evidence is not as robust as fossils, there is significant fossil evidence for life at 3.5 billion years ago. These first well-preserved fossils are photosynthetic microbial mats, called stromatolites, found in Australia [41]. Figure \(\PageIndex{8}\): Fossils of microbial mats from Sweden Although the origin of life on Earth is unknown, hypotheses include a chemical origin in the early atmosphere and ocean, deep-sea hydrothermal vents, and delivery to Earth by comets or other objects. One hypothesis is that life arose from the chemical environment of the Earth’s early atmosphere and oceans, which was very different than today. The oxygen-free atmosphere produced a reducing environment with abundant methane, carbon dioxide, sulfur, and nitrogen compounds. This is what the atmosphere is like on other bodies in the solar system. Figure \(\PageIndex{9}\): Greenhouse gases were more common in Earth’s early atmosphere. In the famous Miller-Urey experiment, researchers simulated early Earth’s atmosphere and lightning within a sealed vessel. After igniting sparks within the vessel, they discovered the formation of amino acids, the fundamental building blocks of proteins [42]. In 1977, when scientists discovered an isolated ecosystem around hydrothermal vents on a deep-sea mid-ocean ridge (Chapter 4), it opened the door for another explanation of the origin of life. The hydrothermal vents have a unique ecosystem of critters with chemosynthesis as the foundation of the food chain instead of photosynthesis. The ecosystem is deriving its energy from hot chemical-rich waters pouring out of underground towers. This suggests that life could have started on the deep ocean floor and derived energy from the heat from the Earth’s interior via chemosynthesis. Scientists have since expanded the search for life to more unconventional places, like Jupiter’s icy moon Europa. Animation of the original Miller-Urey 1959 experiment that simulated the early atmosphere and created amino acids from simple elements and compounds. Another possibility is that life or its building blocks came to Earth from space, carried aboard comets or other objects. Amino acids, for example, have been found within comets and meteorites. This intriguing possibility also implies a high likelihood of life existing elsewhere in the cosmos. References 18. Wilde SA, Valley JW, Peck WH, Graham CM (2001) Evidence from detrital zircons for the existence of continental crust and oceans on the Earth 4.4 Gyr ago. Nature 409:175–178 33. Desch SJ (2007) Mass distribution and planet formation in the solar nebula. ApJ 671:878. 36. Smithies RH, Champion DC, Cassidy KF (2003) Formation of Earth’s early Archaean continental crust. Precambrian Res 127:89–101 39. Mortimer N, Campbell HJ, Tulloch AJ, et al (2017) Zealandia: Earth’s Hidden Continent. GSA Today 27 41. Noffke N, Christian D, Wacey D, Hazen RM (2013) Microbially induced sedimentary structures recording an ancient ecosystem in the ca. 3.48 billion-year-old Dresser Formation, Pilbara, Western Australia. Astrobiology 13:1103–1124 42. 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