The Beauty of Early Life

Traces of Early Life

A cooperation with the State Museum of Natural History Karlsruhe

26.3.–10.7.22

> “Biodiversity is our most valuable but least valued resource.”
>
> — Edward O. Wilson (1929–2021), US-American biologist

When Charles R. Darwin published his seminal work *On the Origin of Species* in 1859, he lacked fossil evidence from life's earliest beginnings to prove that evolution was not merely a theory but a fact. Today, more than 150 years later, Darwin's dilemma has been solved: the evolutionary processes he described have been confirmed by fossil finds from across all continents.

Ever since life began, organisms have lived in relationships of mutual influence and interdependence. Living beings do not exist on their own, but live off and with one another. The Garden of Eden, that paradise of peaceful coexistence, may be a vestigial memory of the Ediacarian Period, a geological age before the evolution of predators.

The Beauty of Early Life is an exhibition approaching the scientific discourse on the origins of life. Its focus is on Earth's earliest history, from the Precambrian to the Cambrian and Ordovician periods, beginning roughly 3.8 billion years ago up to 444 million years ago. Fossils, the petrified evidence of past life forms, play a very significant role. Since the dawn of life on Earth, countless animal and plant species, fungi, and microorganisms have developed. Most of them later went extinct, and it is likely that less than one percent of this plethora of species has been preserved in the fossil record.

Our fossil fuels are derived from the remnants of marine organisms and plants. We make use of the conserved history of life on Earth, taking a few hundred years to consume a treasure trove built over millions of years. Over a third of all species alive today are threatened by extinction through the consequences of human action. What is more, through those same actions, humanity is endangering its own survival as well.

In this exhibition, fossil finds are combined with artworks from classical modernism to contemporary media art. This intersection of art and science for the first time reveals the so far underappreciated beauty and variety of Earth's earliest life in its entire scope.

Milestones on the Path to Life on Earth

How life arose continues to be one of the hardest problems in the natural sciences. The following ten chapters explain the important steps of the process—from the formation of the Solar System and the Earth through the origins of water all the way to the development of the first cells.

1 How did the Solar System and Earth form?

Our Solar System formed 4.75 billion years ago through the compression of cosmic dust and the condensation of gases, which formed a spiral nebula, or dust cloud, with the Sun at its center.

Only about 10 million years after the formation of the Solar System, the first planets began to form when cosmic dust and smaller aggregations collided on their orbits around the Sun. As the mass of these agglomerations grew, so did their gravity—the force with which a solid body attracts other material. This meant that they continued to grow and finally became planets. That is how the Earth and all the other terrestrial planets and gas giants formed 4.56 billion years ago.

The Earth and the Moon are an inseparable system. The Moon, however, was formed not simultaneously with the Earth, but a little later, 4.51 billion years ago. At first, the Earth formed a double-planet system with a planet called Theia, roughly the size of Mars today. Theia, however, collided with the Earth, ejecting debris outward. This debris accumulated in a ring around the Earth and over a few million years gradually clumped together to form the Moon.

Earth's collision with Theia released so much thermal energy that the Earth's solid crust melted completely. Seen from space, the Earth most likely resembled a globe with an ocean of molten rock (magma).

Over the course of millions of years, the Earth cooled and its surface hardened. At first, small islands of solid rock formed in the vast "magma ocean" covering the Earth, until the cooling of the Earth's crust and thus the formation of the first continents was completed 4.4 billion years ago. Until 3.9 billion years ago, meteoroids and asteroids continued to collide with the Earth, destroying parts of the new surface of the Earth. However, they brought not only destruction, but also important components of life.

2 Where does the Earth's water come from?

Water is a fundamental component of life. Only if liquid water is present on the surface of the Earth for long enough life can arise. However, where this water comes from has not yet been fully clarified. There were probably several processes that turned the Earth into a "blue planet" with oceans, lakes, and rivers:

1. The Earth was significantly hotter early in its history than it is today. This meant that volcanic activity was

also more intense, so that large amounts of gas, including water vapor, were released into the atmosphere.

As the Earth continued to cool and the temperature finally fell below 100 °C 4.2 billion years ago, the water vapor in the atmosphere condensed. The amount was probably so large that it rained for several tens of thousands of years. The water pooled in depressions and oceans formed.

2. During Earth's early history, countless asteroids and comets collided with our planet, bringing water. Comets come from the outer reaches of the Solar System. Because they derive far away from the sun, it is so cold that their main components water, carbon dioxide, nitrogen, and methane occur not as gases but as ice. When a comet falls on earth, its ice turns into water or steam.

Meteoroids are fragments of asteroids catapulted out of the asteroid belt by collisions. If moving in the direction of the Earth, they may impact as meteorites. The latter also contain water and other components essential for the emergence of life.

3 Where do we find the oldest minerals and rocks today?

The oldest currently known minerals—zircons found in a sedimentary layer of the Jack Hills Range in Western Australia—date back to 4.4 billion years ago. Also among the oldest rocks are the Acasta gneisses from northern Canada (4.31 billion years), amphibolites from Nuvvuagittuq in north-eastern Canada's Hudson Bay (4.28 billion years) and the Isua gneisses found in Greenland (3.8–3.7 billion years).

The age of these earliest rocks was determined using radiometric dating methods. Rocks consist of many different minerals formed by crystallization when magma cools. Methods such as uranium–lead dating make use of the natural decay of the radioactive isotopes in the minerals. As soon as a mineral forms, the contained uranium isotopes ^{238}U will decay into the lead isotopes ^{206}Pb, and ^{235}U uranium decays into ^{207}Pb lead. The decay of the original (parent) isotope into a stable product (daughter isotope) occurs at a constant rate (half-life). The half-life is defined as the time after which half of the parent isotope has decayed, and the amount of daughter isotope accordingly increases over time. A mass spectrometer is used to measure the number of parent and daughter isotopes. Using this ratio of parent to daughter isotopes, one can then determine the time that was required to form the amount of daughter

isotopes detected. This allows for the calculation of the age of the mineral.

4 What is life?

Before asking how life arose, one must answer the question of what life is. To this day, there is no generally accepted definition. But there are certain chemical and physical properties that are essential for a living system:

1. Barriers

The development of an inside and an outside is one characteristic of life. These two must be distinguishable from one another. Biologically speaking, the model of this concept is the cell, the smallest living unit of all organisms. All processes of life rely on activity in cells bounded by a membrane barrier.

2. Exchange of substances and information with the environment

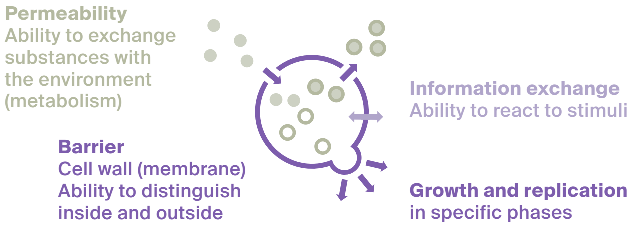
The cell membrane is permeable. This allows a controlled metabolism, an exchange of substances, with a variety of chemical reactions: Food is taken in, providing energy and material for building the cell. The cell metabolism also creates “waste products” which are eliminated by the body. Additionally, cells can exchange information by reacting to stimuli in their environment.

3. Growth and reproduction

Life is not a one-time process, but a continuous process with constant changes and repetitions. A vital characteristic of life is therefore the capacity to grow and reproduce (replication).

If all these criteria are met, life can arise and evolve.

Incidentally, viruses—such as the coronavirus SARS-CoV-2—are *not* considered living beings. They have neither the capacity for independent replication nor their own metabolism, but depend on host cells for both.



Defining characteristics of living systems

5 “Primordial soup” and “primordial pizza”—how did it all begin?

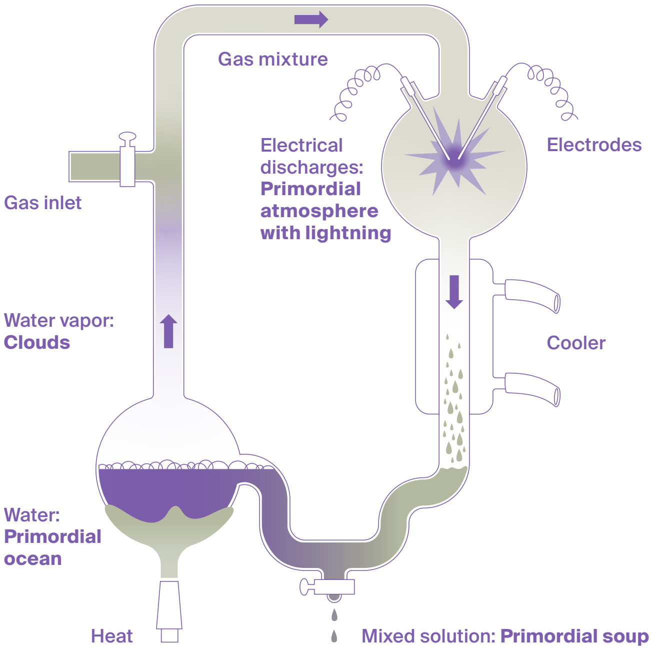
As early as 1871, Charles Darwin suspected that life might have arisen in a “warm little pond” of proteins. Later, in the early twentieth century, the Russian biochemist Alexander Oparin hypothesized that organic molecules might have formed in the early hydrosphere as a result of lightning, sunlight, and volcanic activity, and that these organic molecules might have been the basis for the earliest life-forms. To describe this environment, he coined the term “primordial soup.”

In 1953, chemists Stanley Miller and Harold Urey tried to replicate the early chemical evolution with their “primordial soup experiment.” Using a specially constructed apparatus, they produced water vapor, mixed it with ammonia, methane, hydrogen, and carbon monoxide, and sent electric energy in the form of lightning through the mixture. The result was a sensation: the solution they produced contained amino acids, fatty acids, carbohydrates, and other organic compounds—important carbon-bearing components of life on Earth.

More recently, there has also been scientific evidence that meteorites contain amino acids. Thus, without doubt, organic molecules necessary for life can form in different places. What remains unsolved is the question of how life arose from these components. An ocean of “primordial soup” is not a suitable environment for such a development, because the substances in it would be too diluted to allow life to emerge.

The theory of the “iron–sulfur world” offers a possible answer to this question. According to the theory, organic molecules such as peptides and ribonucleic acid (RNA) could have been naturally synthesized on the surfaces of minerals. There, the molecules might have collected in cell-like structures and then developed further. Bound to the surfaces by electromagnetic forces, they would have had the opportunity to react with one another. Hence, mineral surfaces might have served as stand-ins for a cell membrane. Based on the term “primordial soup”, this process is often referred to as the “primordial pizza.”

Today, iron sulfide minerals such as pyrite, tend to form near hydrothermal deep sea vents, so-called “Black Smokers.” Their environment approximates the oxygen-free conditions of early Earth.



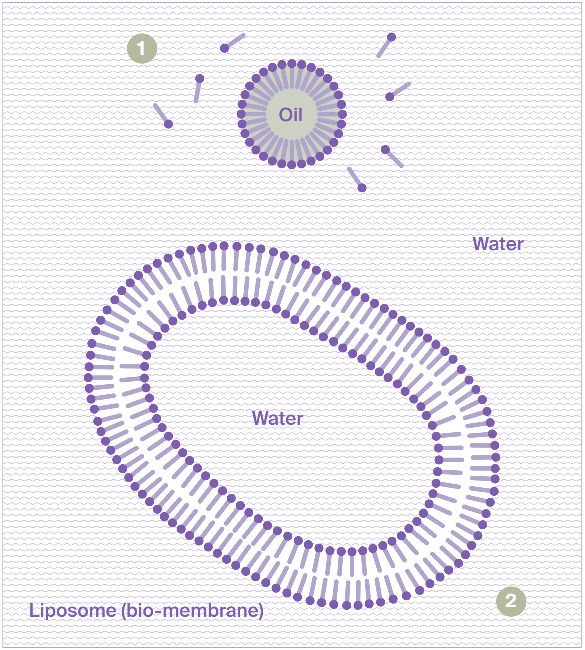
Schematic drawing of Stanley Miller’s and Harold Urey’s “primordial soup experiment” testing the abiotic synthesis of organic molecules

6 The "RNA World"—no life yet, but getting ever closer

Organic molecules may be the basis for the initiation of life, but systems for enabling a metabolism and replication are necessary as well. How do these develop? The theory of the "RNA World" attempts to answer that question.

A lot of evidence suggests that at an early stage of evolution, ribonucleic acid took on the role of genetic storage—long before DNA appeared. RNA is probably the first molecule in the history of life that was able to both catalyze chemical reactions as well as copy and multiply itself. This answers the question of whether metabolism or replication came first: RNA first inherited the function of metabolism and then also of replication in the form of so-called ribozymes (folded RNA molecules).

It is generally supposed that with the arrival of RNA, the time had come for the development of the first cell-like forms with a system similar to life. These forms, known as proto-cells, had a simple membrane consisting of proteins or fat molecules (lipids). Such simple membranes can form spontaneously in aqueous solutions. It is quite likely that in life's early stages, RNA became encased in proto-cells and began to catalyze its own synthesis in several cycles.



Development of a proto-cell with a cell membrane
Molecules with a hydrophilic and hydrophobic side, such as lipids, automatically form small, oil-filled bubbles in water (1).
If these molecules become organized in lipid bilayers, with the hydrophilic sides both outwards and inwards, they form water-filled bubbles – proto-cells, the earliest form of biological cells (2).

7 Life begins—when and where did the earliest cells form?

When RNA became enveloped in proto-cells, biological evolution began. The earliest cells might have formed as long as 4.3 billion years ago, but at the latest after a phase of increased meteorite impacts 3.9 billion years ago.

What remains unclear is where the first cells to produce all later life were formed. It is possible that this process occurred simultaneously or successively in several different places. Most likely, the formation of the earliest cells is linked to hot water. The focus is therefore primarily on the following environments:

1. Hydrothermal deep sea vents (such as Black Smokers and White Smokers);
2. Hydrothermal springs on the Earth's surface (such as the Yellowstone Caldera, USA);
3. Hydrothermal fissures in rocks of the continental crust.

All three areas are characterized by hot water flowing through porous bedrock. The water contains a large variety of anorganic compounds: carbon dioxide, carbon monoxide, ammonia, methane, hydrogen cyanide, sulfides, and phosphates. This chemical cocktail offers all the substances needed to form amino acids, saccharides, and nucleobases and thus all the molecules necessary for forming biologically functioning cells.

Tiny pores in the bedrock acted as permeable "reaction chambers" in which organic compounds were transformed into biomolecules that would later take on important functions in cells. It is possible that the walls of these pores initially served as a kind of cell membrane. Only later, true cells with organic cell membranes developed.

Regardless of the precise environment where the first cells originate from and thus where life on Earth began, the location must have had lasting protection from solar wind, UV radiation, meteorite impacts, droughts, and erosion. Fluctuations of temperature and pH would also have had to be minimal, as otherwise important chemical building blocks such as RNA and proteins would have been in danger of being destroyed soon after they had formed.

8 Where did the air we breathe come from?

While the first cells formed, the composition of the atmosphere changed. The primordial atmosphere had developed more than 4 billion years ago as a result of volcanic outgassing, which released ammonia, carbon monoxide, carbon dioxide, methane, nitrogen, water, and hydrogen.

Up to 3.7 billion years ago, the atmosphere was anoxic which means it contained no free oxygen. This changed when cyanobacteria began to produce oxygen through photosynthesis. This element, so vital to our life, is merely a waste product of their metabolism. Over the course of the following 1.2 billion years, iron and other elements which had until then been dissolved in the ocean were oxidized and precipitated. The precipitates formed sediments, today known as banded iron formations, or BIFs. These are the Earth's largest deposits of iron ore.

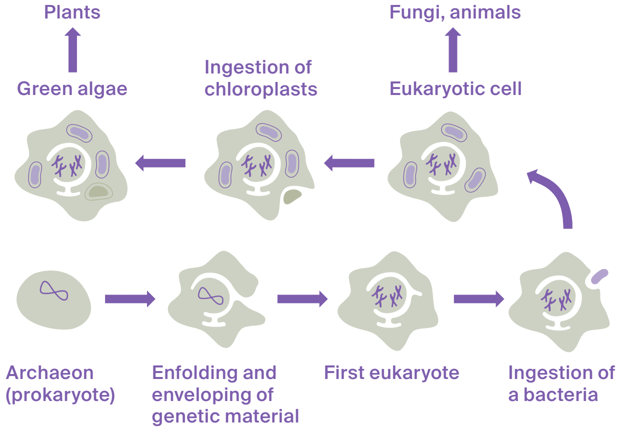
Accordingly, at the beginning of the Paleoproterozoic 2.5 billion years ago, iron and other elements existed largely in mineral compounds. The excess oxygen now began to build up in the atmosphere, and the Earth could breathe again. This period is known as the "Great Oxygenation Event" or even as the "Oxygen Catastrophe"—because for anaerobic organisms that are adapted to a life without free oxygen, it is toxic.

Some life-forms did not only tolerate oxygen, but over time actually came to effectively metabolize it. In contrast to anaerobic respiration, the aerobic respiration—breathing and metabolizing oxygen—offers a substantially greater amount of usable energy. In the end, aerobic respiration became the precondition for the development and eventual triumph of multicellular organisms.

9 How did the first eukaryotic cells develop?

The first true cells were so-called prokaryotes (Greek for "pre-kernel"; cells without a nucleus). These include archaea (once called archaebacteria) and bacteria. It is likely that eukaryotes (Greek for "good kernel"; cells with a true nucleus) evolved from prokaryotes. By enveloping its genetic code in a membrane, an archaeon became the primordial eukaryote. Later, it engulfed a smaller, aerobic bacterium without digesting it, a process known as endosymbiosis. The bacterium then became the cell's power station, the mitochondrion. This new cell consisting of several prokaryotes thus became the precursor of all animal and fungal cells. As evolution progressed, several of these eukaryotes engulfed cyanobacteria as well, which developed into the chloroplasts performing photosynthesis. This endosymbiosis led to the development of plants.

It is essential for any kind of symbiosis that both sides draw some advantage from it. In this case, the larger cell offers a consistent living environment, while the smaller produces energy or take on some other important function within the larger cell.



Endosymbiotic theory
(after the American biologist Lynn Margulis)

1

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10 What was Earth’s first life-form?

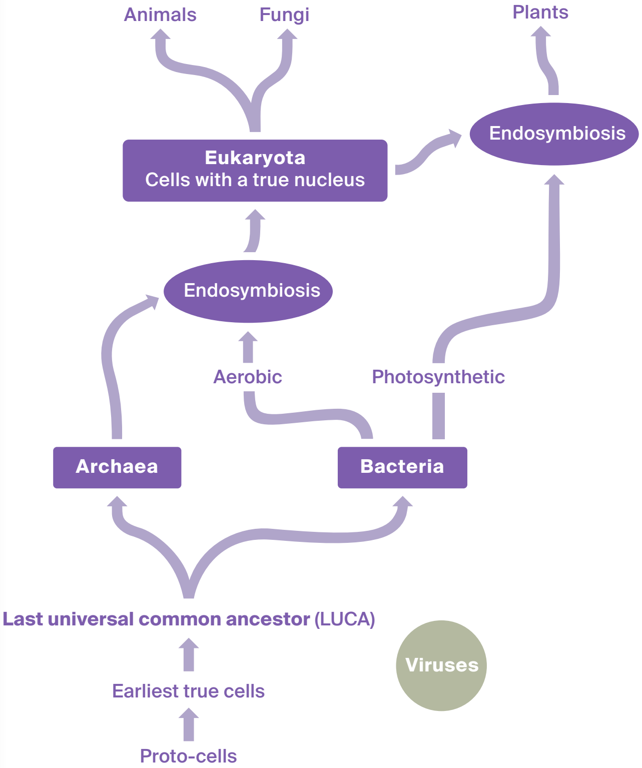
The oldest organism from which life in its present form evolved is hypothetical, rather than directly attested to by evidence such as a fossil. But according to the evolutionary theory, there must have been what is known as a “Last Universal Common Ancestor,” or LUCA. This ancient being represents the most recent primordial ancestor shared by the three domains of life: Archaea, Bacteria, and Eukaryota.

The oldest known Precambrian and undoubted fossilized remains are deposits created by metabolism processes of microorganisms. Microbial activity produces finely layered rocks known as stromatolites—Greek for “layered stone”—and classed as biogenic sediments. The oldest stromatolites date back as far as 3.8–3.7 billion years and were discovered in the Isua Greenstone Belt in south-western Greenland. Moreover, stromatolites have been found in Western Australia, in the Dresser Formation (3.49 billion years), and the Strelley Pool Formation (3.42 billion years).

While stromatolites were globally widespread during the Precambrian, they can today be found only in extreme environments. One example is the hypersaline water of Hamelin Pool in Western Australia’s Shark Bay. The stromatolites there grow very slowly, at a rate of roughly 0.3 mm per year.

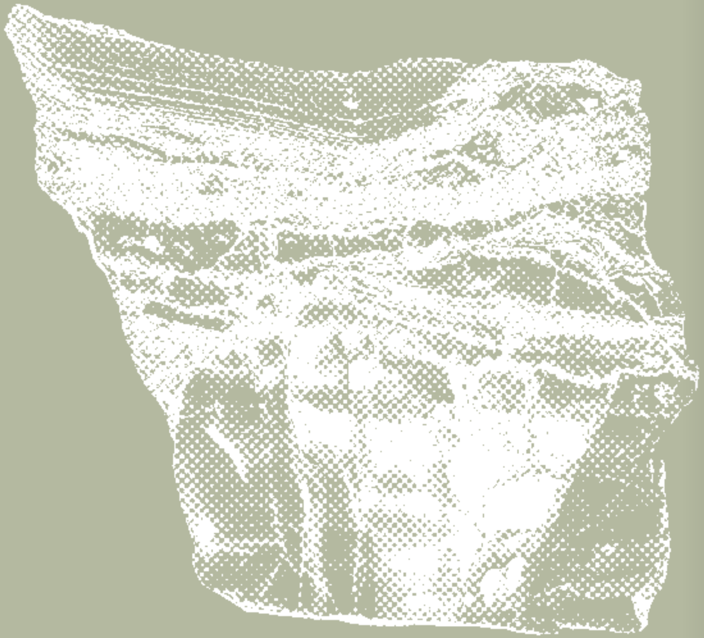
The oldest fossils ascribed to the domain Eukaryota are 2.3–1.9 billion years old and were discovered in the Gunflint Chert of the Minnesota–Ontario borderlands. These microfossils are fossilized single-celled organisms.

Fossils of the species *Chuaria*, *Grypania*, and *Horodyskia* are also over a billion years old, but their taxonomic classification is still a matter of debate. They may have been large eukaryotes or colonies of cyanobacteria. As interest grows in how today's wide variety of organisms developed, such finds are increasing. Perhaps better preserved fossils or new analytical approaches will soon be able to shine more light on the dark early days of life.



The evolution of the three domains of life: Archaea, Bacteria, and Eukaryota (including animals, fungi, and plants)

The Proterozoic



The Proterozoic was an eon in geological history which extended from the end of the prior Archean eon 2.5 billion years ago until the beginning of the Palaeozoic 541 million years ago. During the early Proterozoic 2.4 billion years ago, the Great Oxygenation Event occurred, an incident in which the concentration of atmospheric oxygen (O_2) rose rapidly within a relatively short time. This was a waste product of earlier anaerobic monocellular organisms for which oxygen was fatal or at least inhibited their metabolism. The release of so much oxygen caused atmospheric methane to be oxidised at a greater rate, which led the earth to cool and brought about glaciation on a global level.

English palaeontologist Martin Brasier called the period of 1.85-0.85 billion years ago the *boring billion*: climate conditions on earth stabilised during this time, and it appears that hardly any advances took place in the evolution of life forms.

This image shifted slowly, since over time more and more fossils of eukaryotes were found – cells with a true nucleus – dating back to the *boring billion*, especially in China. Many of these findings were difficult to classify from a biological perspective, however. For example, even the issue as to whether a fossil of the chronologically and geographically widespread genus *Grypania* is a large single-cell organism or a colony of smaller bacteria is a question that is not yet clear.

By far the most common fossils of the Proterozoic are stromatolites: layered biogenic sedimentary rock formed by the metabolism of microorganisms such as cyanobacteria in particular. This kind of rock has been found at sites all over the globe. Microscopic studies of thin sections of stromatolites have even made it possible to study their cellular structure on many occasions. German geologist Ernst Kalkowsky coined the term "stromatolite" (from the Greek *stroma* = "cover" and *lithos* = "stone") in 1908 based on his findings in the Buntsandstein formation in northern Germany, which is a typical red sandstone.

The Garden of Ediacara: first complex life

The Ediacaran is the last period of the Neoproterozoic era, and thus the end of earth's earliest and longest geological times, the Precambrian. The Ediacaran began around 635 million years ago and ended 541 million years ago. The period was named after the Ediacara Hills, which are located in the Flinders Ranges 650 km north of Adelaide, the capital city of South Australia.

It was in this region that Australian geologist and palaeontologist Reginald C. Sprigg discovered fossils of prehistoric life forms in 1946 while exploring the profitability of decommissioned mines. These are considered to be the first Precambrian macrofossils to be found – in other words, fossils that are visible to the naked eye.

The Australian palaeontologist Martin F. Glaessner and other geoscientists spent decades studying the fossils from the 560 million-year-old Rawnsley quartzite of the Ediacara Hills. In the meantime, dozens of other fossil sites dating back to the Ediacaran have also been discovered. The most important of them are the 570 million-year-old Doushantuo formation from the south Chinese province of Guizhou, the 565 million-year-old Mistaken Point formation from the Canadian island of Newfoundland, the 570-543 million-year-old Nama group from Namibia and the 555 million-year-old Ust´-Pinega formation of the Onega peninsula bordering the White Sea in northwestern Russia.

The extent to which Ediacaran organisms are related to living creatures today is a topic of some debate. In his vendobionta hypothesis in 1989, German palaeontologist Adolf Seilacher postulated that Ediacaran life forms were gigantic single-cell organisms which fed off of microbial mats on the sea floor. American palaeontologist Mark A. S. McMenamin stated in 1998 that Ediacaran biota were to be considered a peaceful "Garden of Ediacara," a biosphere without predators. Irish palaeontologist Breandán Anraoi MacGabhann stated in 2014 that terms such as "Ediacara biota" or "Ediacara fauna" were to be avoided, since they suggested that the organisms found in Ediacaran fossil sites were related to each other, an assertion which has largely gone unconfirmed.

Publications in recent years have been indicating more and more frequently that at least some of the fossils from the Ediacaran period are indeed related to contemporary organisms. On the Onega peninsula, newly discovered specimens of the widespread flat-bodied segmented genus *Dickinsonia* could reach over a meter in length, and organic material was successfully recovered and analysed from these specimens. In the course of this analysis, sterols were identified, which are breakdown products of animal cholesterol, suggesting that *Dickinsonia* belonged to the animal kingdom. The Ediacara genus *Kimberella*, originally considered to be the medusa phase (jellyfish) of a coelenterate (an invertebrate marine phylum), is seen by many palaeontologists as a mollusc: in its search for food, *Kimberella* generated the same characteristic trace fossils which are reminiscent of the scratch marks created by molluscs with their radula (rasping tongues).

The Cambrian Explosion

The Cambrian period began 541 million years ago and ended around 485 million years ago. It is the first period in the Palaeozoic era and was named after the Latin term for Wales, *Cambria*, since many of the fossils dating back to this time were found there. For many years, including in Charles Darwin's lifetime, no fossils were known to have dated from any earlier times. Geologic strata older than Cambrian were referred to as being "Precambrian". There was no evidence that life had existed on Earth prior to this time.

The beginning of the Cambrian period is defined by several clear changes in the fossil record: fossils which were characteristic of the Ediacaran period are largely absent. Instead, trace fossils preserved in Early Cambrian strata show a phenomenal ability of animals which was not yet the case in the Ediacaran: as they could burrow into the sea bed. The mineralized fossils known as "Small Shelly Fauna" were only a few millimetres in size and also marked the transition from the Ediacaran to the Cambrian.

The most commonly known phrase relating to this period is the "Cambrian Explosion". This expression reflects the idea that apparently there was a sudden "explosive" increase in biodiversity within the relatively "short" timeframe (which is to say, "short" by geological standards) of five to ten million years. These new life forms included the first predators. All of the phyla known today were first identified in the fossil record of the Cambrian, although the biodiversity of that period was relatively low. Yet, the foundational physical structures can be seen which define the phyla of the multicellular organisms that have since populated the earth.

A noteworthy milestone is the occurrence of the first trilobites in 521 million-year-old Cambrian rocks. Trilobites, derived from the greek meaning “three lobes,” are a group of marine arthropods (a class of invertebrates) whose diversity rapidly expanded during the Cambrian. Most trilobites had an exoskeleton, i.e. a stable structure on the outside of the body, which is why they fossilised much more frequently than soft-bodied organisms. Consequently, trilobite fossils have been found all over the world, from Spitsbergen to Tasmania. Palaeontologists have discovered over 25,000 species with a broad range of physical characteristics belonging to over 5,000 genera, and previously unknown trilobites are still being discovered. They are seen as the most widely known creatures of the Palaeozoic and became extinct at the end of that era 252 million years ago.

Trilobite fossils were found and described back in the 17th century. It was not until the 20th century, however, that it became clear that trilobites did not dominate the oceans of the Palaeozoic – at least not to the extent that scientists had come to believe based on fossil findings. A new understanding of the biodiversity of the Cambrian era emerged when Cambrian fossil sites were unearthed featuring not only organisms with their exoskeletons but soft-bodied organisms as well. Sites of this nature are referred to by the German technical term *Konservatlagerstätten* or *Fossillagerstätten*.

The two best-known Cambrian *Fossillagerstätten* were discovered in 1909 and 1912. The former was found by American palaeontologist Charles Doolittle Walcott, who came across the Burgess Shale dating back 505 million years near Field in the southeastern part of the Canadian province of British Columbia; the latter were the Maotianshan Shales encountered by a group of French researchers working with palaeontologist Henri Mansuy near Chengjiang in the eastern region of the Chinese province of Yunnan. The full scientific relevance of this discovery was not fully understood until 1984 when Chinese palaeontologist Hou Xianguang discovered the first fossils with soft-tissue imprints. The findings from the Chengjiang region are 13 million years older compared to those from the Burgess Shale, dating back 518 million years. Other Cambrian *Fossillagerstätten* have since been found in other parts of the world, including the USA, Greenland, Sweden and Australia.

The Great Ordovician Biodiversification Event (GOBE)

Named after the Welsh Celtic tribe of the Ordovices, the geological period of the Ordovician began 485 million years ago and ended 444 million years ago. After many species became extinct at the end of the Cambrian, the Ordovician saw the occurrence of what is known as adaptive radiation. In contrast to the Cambrian, no inherently new structures emerged among the life forms of the time, but several new species did, based upon the availability of ecological niches. In other words, there were major changes in the diversity of organisms, although not in disparity between them. This dramatic increase in the variety of life forms during the Ordovician is known as the "Great Ordovician Biodiversification Event (GOBE)."

Many of these new species were filter feeders, i.e. animals which filter their food out – like plankton – of the water. All in all, over 4,000 fossil genera have been described from the Ordovician. A majority of these fossils came from organisms with skeletons (such as arthropods, e.g. trilobites) or from echinoderms, i.e. spiny marine creatures such as sea lilies and feather stars (crinoids), sea stars (asteroids) and serpent stars (ophiuroids).

There are *Fossillagerstätten* where fossils of soft-bodied organisms were found which have not been observed elsewhere. This indicates that the majority of the species which lived during the Ordovician were soft-bodied. Since the number of organisms with skeletons in the Ordovician is estimated to be over 20,000, the total number of species which existed after the exponential growth of biodiversity during this period may well have been within the range of 200,000-250,000 different life forms.

Towards the end of the Ordovician, however, a mass extinction occurred, which ranked amongst the greatest mass extinction events in geological history. Some 85% of species, 60% of genera and 26% of families of all marine organisms died out. This event is correlated with a rapid and dramatic cooling of the earth's surface, which is attributed to a drift of the Gondwana continent towards the South Pole.

A great amount of research confirms that the earth, our home planet, is at the beginning of another extinction event at the beginning of the 21st century.

"So here you stand, in the physical and biological legacy of four billion years. You may walk where trilobites once skittered across an ancient seafloor, where dinosaurs lumbered across Ginkgo-clad hillsides, where mammoths commanded a frigid plain. Once it was their world, and now it is yours. The difference between you and the dinosaurs, of course, is that you can comprehend the past and envision the future. The world you inherited is not just yours, it is your responsibility. What happens next is up to you."

Quoted, with kind permission, from Andrew H. Knoll (*1951), Harvard University, *A brief history of Earth: four billion years in eight chapters*: 230 (New York: Custom House, 2021).

Milestones in the History of the Earth

The Beauty of Early Life.
Traces of Early Life

26.3.–10.7.2022

Exhibition

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Opening hours
Monday–Tuesday: closed
Wednesday–Friday: 10:00–18:00 h
Saturday–Sunday: 11:00–18:00 h

ZKM | Center for Art and Media Karlsruhe

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Karlsruhe

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1: Microbial mat, Dresser Formation, 3.49 billion years old, Australia

2: Stromatolite, Strelley Pool Chert, 3.42 billion years old, Australia

3: Ediacara animal *Dickinsonia*, Ust' Pinega Formation, 555 million years old, Russia

4: Sponge-like animal *Chancelloria*, Wheeler Formation, 507 million years old, USA

5: Trilobite *Olenellus*, Pioche Formation, 510 million years old, USA

6: Green algae *Marpolia*, Marjum Formation, 502 million years old, USA

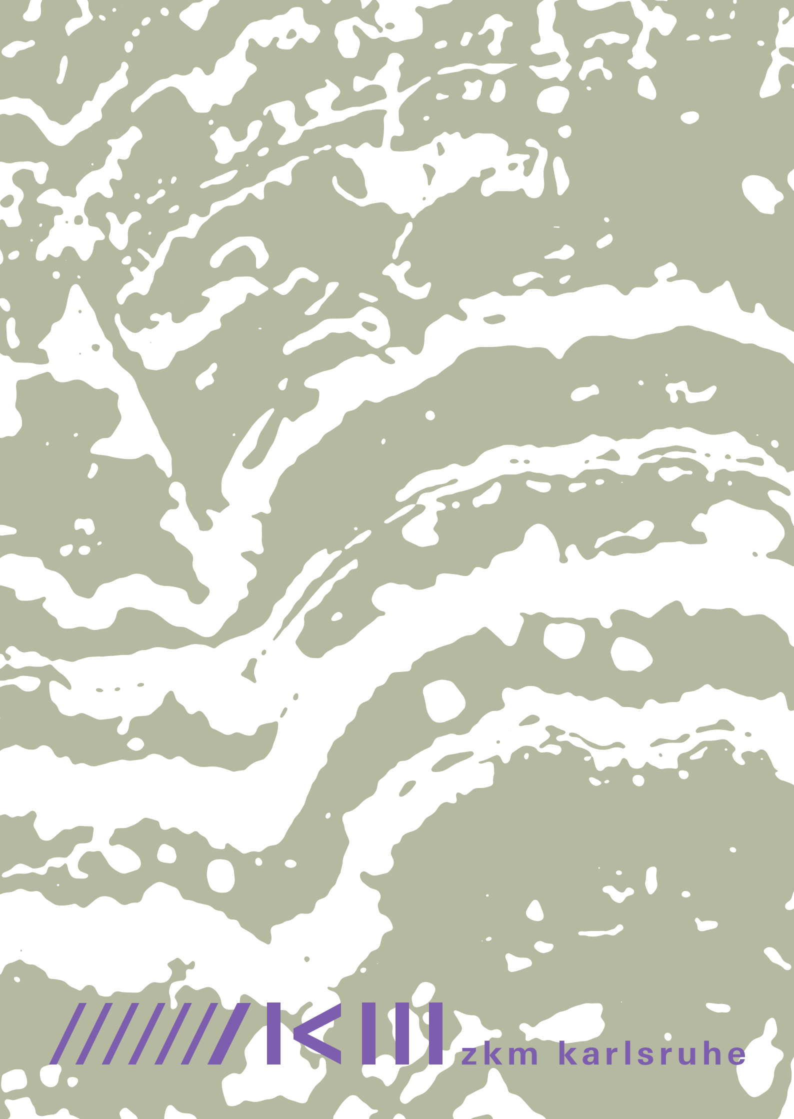
7: Arthropod *Leanchoilia*, Burgess Shale, 505 million years old, Canada

8: Arthropod *Fuxianhuia*, Maotianshan Shale, 518 million years old, China

9: Brittle star *Ophiura*, Ktaoua Formation, 450 million years old, Morocco

Participating artists:

Memo Akten - Suzanne Anker - Hans Arp - Brett Baker & Laura Hug - Willi Baumeister - Sonia Mehra Chawla - Paul Rosero Contreras - James Darling & Lesley Forwood - Anna Dumitriu & Alex May - ecoLogicStudio (Claudia Pasquero & Marco Poletto) - Max Ernst - Thomas Feuerstein - Ernst Haeckel - Jens Harder - Aleš Hieng, Ida Hiršenfelder, Robertina Šebjanič - Institute for Biological Interfaces 1, Karlsruhe Institute of Technology (KIT) - Manfred Kage - Agnieszka Kurant - Sonia Levy - Bernd Lintermann, Derek Hauffen - Martin Lisec - Andy Lomas - Len Lye - Louise Mackenzie - Reiner Maria Matysik - Joan Miró - Jakub Nepraš - OOZE (Eva Pfannes & Sylvain Hartenberg), Marjetica Potrč - Dan Rees - Maija Tammi - Yves Tanguy - Xandra van der Eijk - Martin Walde - Carmel Wallace



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