This exhibition introduces you to the main stages of the history of our planet, from the formation of the solar system 4.57 billion years ago until the emergence and diversification of life on Earth.

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The Solar System’s gestation
From an interstellar cloud to a circumstellar disk

4.57 billion years ago, somewhere in our galaxy, the Milky Way, a condensation of gas and dust within an interstellar cloud, collapsed under the influence of gravitation.

At its center, an embryonic core formed, the origin of our future star, the Sun. The rest of the condensation became a relatively isolated envelope, which fell more slowly onto that core via a circumstellar disk (which surrounded the star).

After one hundred thousand years, a protostar was born.

This star-to-be subsequently underwent a true metamorphosis: in a million years its envelope became progressively more tenuous, the central star grew at the expense of the circumstellar disk, along with ejection of material in the form of bipolar jets.
The Solar System’s birth
The formation of the giant planets

The circumstellar disk underwent significant transformations. Through mechanisms that are still very poorly understood, the grains of dust that it contained, grew rapidly, until they formed “clumps”, a kilometer in radius, which are known as planetesimals. The latter, in turn, collided with one another and, in a few million years, gave birth to planetary embryos. Subsequently, these embryos very rapidly “accreted” the gas from the disk in their vicinity, until they reached several tens of Earth masses. This is how the giant planets were born.

At the end of ten million years, the disk had disappeared, so in the Solar System there remained:

- the giant planets, formed in the outer regions of the disk;
- those planetesimals that had escaped the planetary-formation process;
- meteorites, which are the debris resulting from collisions between planetesimals.
The Solar System’s infancy

The formation of the rocky planets

From the multitude of planetesimals that still existed and influenced by the gravitational perturbations caused by the giant planets, a second category of bodies formed, but much slower this time. These are the rocky or terrestrial planets, Mercury, Venus, Earth and Mars.

Collisions that became rarer and rarer, but which were also violent, occurred over some tens of millions of years.

It was the last of these collisions, between the young Earth and a body the size of Mars, that gave birth to the Moon.
Bringing water to Earth
The significance of extraterrestrial sources

Water was brought to the Earth at the end of the formation of the rocky planets - or in the period immediately following it - when our planet had cooled sufficiently.

Comets, consisting of ice and dust, could be one of the sources. However, study of their hydrogen-isotope composition (the hydrogen/deuterium ratio) indicates that 20% at the most of the Earth’s water could be of cometary origin. It seems, therefore, that the water in the oceans must have been gained either during the final phases of accretion, by the planetesimals originating in the outer asteroid belt, or somewhat later, by meteorites, through a meteoritic bombardment after the Earth’s formation. Thereafter the water provided by micrometeorites represented a non negligible supplementary supply to the hydrosphere.

Fig. 4 – The asteroid 433 Eros as seen by NASA’s NEAR–Shoemaker spaceprobe. This small body (33 km long) now belongs to our Solar System’s asteroid belt. Between 4.56 and 4.50 Ga, such bodies, which were then lying sufficiently far from the Sun to contain a lot of ice, probably contributed a significant amount to the water on Earth.
The beginning of the differentiation of the Earth

The separation of the core and the mantle, the formation of a magma ocean

During the Solar System’s first 70 million years, planetary accretion led to the formation of a homogeneous Earth. Around 4500 million years ago, the iron and silicates separated. Due to its greater density, iron concentrated at the center of the planet and formed the core. The silicates, being lighter, remained outside and formed the mantle.

The rotation of the solid inner core within the liquid outer core is the source of the Earth’s magnetic field which, even today, still protects the surface of the planet from the solar wind.

At the same time, the gravitational energy released during Earth’s accretion together with that due to the disintegration of radioactive elements (which were very abundant), caused the melting of the whole outermost portion of the mantle, which gave rise to a magma ocean.

Fig. 5 – A schematic section of the present-day Earth, showing its structure in concentric layers. A solid inner core (turquoise), a liquid outer core (grey), a mantle (green), oceanic and continental crusts (brown).
The first continents, the first oceans

Towards an Earth that was potentially habitable?

Because of the high temperature that prevailed on Earth, water was vaporized first into the atmosphere. Subsequently, it condensed and formed oceans.

The analysis of oxygen isotopes within zircon crystals discovered in Australia, and with ages between 4400 and 4300 million years, indicate the presence of liquid water (and thus perhaps of oceans) on the surface of the planet 4400 million years ago. Those same zircon crystals also show that a stable, granitic, continental crust existed at that time, less than 200 million years after the beginning of the Earth’s formation.

With a continental crust and oceans, the Earth was thus potentially habitable from 4400 million years ago… which does not mean that it was inhabited.

Fig. 6 - Archean zircon crystals: these are similar crystals, discovered at Jack Hills in Western Australia, who recorded ages as old as 4.4 Ga. Zircon, the composition of which is (ZrSiO$_4$), is a mineral very resistant to alteration, which furthermore, contains radioactive elements such as thorium and uranium, which allows it to be dated easily. So they are an excellent temporal archive of the Earth’s history.
The late heavy bombardment

An temporarily uninhabitable Earth?

Over the first 500 million years of the Earth’s history, the frequency of collisions between planetesimals greatly decreased. However, the 1700 lunar craters, dated to around 3900 million years ago, bear witness to an episode of meteoritic bombardment, as unique as it was intense, which has been attributed to the late reorganization of the orbits of the gas-giant planets. Extrapolating, it is estimated that more than 22000 craters (of which 200 would have had a diameter greater than 1000 km) would have formed on Earth at that period.

If life already existed, either it would have completely disappeared and the process would have had to start again from scratch (undoubtedly in a different form), or there was a mass extinction, but microorganisms living at the greatest depths of the oceans or in subsurface rocks were protected, and they might have subsequently repopulated the planet.

Fig. 7 - The Schrödinger crater, formed on the Moon during the intense bombardment 3900 million years ago. With a diameter of 320 km, it is not, by far, one of the largest lunar craters.
The transition from non-life to life
From prebiotic chemistry to the first cells

Life appeared on Earth at some uncertain date, between 4300 and 2700 million years ago and, probably, between 3800 million and 3500 million years ago (the latter date being the age of mineral microstructures attributed - without any absolute certainty - to being microfossils).

During this interval of time, thermal or photochemical processes in the atmosphere (which primarily consisted of $\text{N}_2$, $\text{CO}_2$, and $\text{H}_2\text{O}$), the action of reducing minerals in hydrothermal systems at the bottom of the oceans, as well as the fall of specific meteorites (the carbonaceous chondrites) were the source of organic material. Networks of chemical reactions developed, and the products became associated with one another in supramolecular systems which, after stages that have not yet been fully elucidated, gave birth to the first cells possessing three fundamental properties: a membrane, a metabolism, and a reproducible genetic system that served as a basis of evolution by natural selection.

Fig. 8 - Bacteria under a scanning electron microscope. Living organisms undoubtedly quite rapidly assumed the form of the most simple prokaryote cells known today. (Like the bacterial cell shown above.)
Biological evolution has started

The first traces of life and the diversification of prokaryotes

The first cells diversified and adapted to various ecological niches. They gave rise to prokaryotes, with a simple structure, which subsequently separated into bacteria and archaea.

The appearance of new types of metabolisms (photosynthesis, methanogenesis, and various forms of respiration) accompanied that separation. Photosynthetic bacteria synthesized organic matter from CO₂, using the energy of light and an electron donor: H₂S, Fe²⁺, H₂, or perhaps even then, H₂O (in oxygenic photosynthesis).

Stromatolites, laminated organo-sedimentary structures formed by complex communities of prokaryotes that induce carbonate precipitation, were widespread.

The oldest of these date back to 3450 million year ago, but their biological origin is questioned, as are those of other very ancient fossil traces. The oldest non-controversial stromatolites have an age of 2700 million years.

Fig. 9 - The oldest fully-recognized stromatolites known (Tumbiana, in Australia). These structures, 2700 million years in age, were formed by the precipitation of carbonates associated with complex microbial communities.
About 2400 million years ago

Oxygen begins to accumulate in the ocean and the atmosphere

The impact of life on the environment

The oxygenation of our planet is the consequence of the presence of life and, in particular, of that of cyanobacteria. This group of bacteria developed oxygenic photosynthesis which breaks apart H$_2$O molecules, releasing oxygen as waste.

In parallel, oxygen respiration spread in different microbial lines. Those organisms that did not succeed in respiring oxygen or tolerating it, found themselves confined to anoxic ecological niches, such as sediments.

Oxygen that had not been entirely consumed by aerobic respiration, first oxidized minerals in the surface rocks of the planet, and then accumulated in the ocean, the atmosphere and in sediments (forming the so-called “banded-iron formations”).

Fig. 10 – Different types of cyanobacteria (coccoidal, top, filamentous, bottom). These bacteria produce oxygen during photosynthesis. They contributed to the oxygenation of the Earth’s atmosphere.
About 2000 million years ago

The appearance of eukaryotes
The first cells with nuclei and their fossil traces

The eukaryotes consist of cells that include a nucleus (which contains the genetic material) and organelles: mitochondria, where oxygen respiration takes place, and in the case of plants, chloroplasts, where photosynthesis occurs.

Mitochondria and chloroplasts derive from ancient bacteria incorporated by a eukaryote cell during endosymbiosis. The eukaryotes are thus partly the product of symbioses that involve prokaryotes.

The first eukaryotes were unicellular. They did not have a mineral skeleton, but an organic wall. However, in the fossil record they can be distinguished from the prokaryotes by their size, generally (but not always) larger and, above all, by the ornamented structure of their walls. The most ancient eukaryote microfossils (acritarchs) are about 1500 to 1800 million years old.

Fig. 11 - Tappania plana, one of the most ancient eukaryote fossils (from the Roper Group, Australia). It is 1500 million years old.
Between 1200 and 540 million years ago

The appearance of the first multicellular organisms

The first traces of algae, animals and fungi

In the fossil record, the first fossils of multicellular eukaryotes date back to 1200 million years ago, then others appeared between 1000 and 750 million years ago (algae, fungi, and unidentified organisms). The most ancient animal fossils date back to about 550-600 million years ago. These are the famous Ediacara fauna, consisting of microscopic fossils, and then macroscopic forms. They were soft-bodied organisms (without a skeleton or shell), which exhibited an enormously rich range of body plans.

The ability of the animals to precipitate minerals and to form skeletons appeared just before the Cambrian (around 540 million years ago).

Plants emerged later, as revealed by fossil moss spores that are about 440 million years old. Differentiated cellular structures, specialized for carrying out specific functions (cellular tissues) appeared in plants and animals.

Fig. 12 – Bangiomorpha pubescens, which is, perhaps, a red multicellular alga, 1200 million years old.
540 million years ago

The Cambrian Explosion
Animal life diversifies, shells and carapaces develop

Most of the representatives of the Ediacara fauna disappeared mysteriously at the boundary of the Cambrian. We then once again see the appearance of a great diversity of fossil animals, but this time, with a lesser range of body plans, but with the presence of shells, carapaces, spines and various appendages. The evolutionary radiation (great diversification in a short period of time) was caused by the appearance of biological innovations (structures for protection and predation, and new lifestyles) that allow new ecological niches to be populated. In parallel with this, prokaryotes and unicellular eukaryotes continued to diversify and evolve.

Fig. 13 – Evidence of the Cambrian Explosion. Anomalocaris, a predator that swam in the ocean 505 million years ago (it was 45 cm long).
Between 540 million years ago and the present

The explosion of macroscopic life

Biological evolution continues...

The last 540 million years are distinguished by the explosion of macroscopic life, which first spread in the oceans, and then on dry land. This period was accompanied by sudden environmental changes - linked to glaciations, to intense volcanism and to the fall of one or more meteorites - that led to massive extinctions of species, particularly macroscopic ones.

The impact of the Chicxulub meteorite, 65 million years ago, eliminated most of the dinosaurs and favored the expansion of present-day lines of mammals, of which one, that of the primates, would evolve into the species Homo sapiens, about 200000 years ago. In parallel with this, other animals, plants, unicellular eukaryotes, and microscopic prokaryotes have continued to evolve.

All present-day organisms, from bacteria to humans, have undergone the same degree of evolution. They have all travelled along the same long evolutionary path. And they continue to evolve...

Fig. 14 - The diversity of life today. Two domains of prokaryote organisms are recognized (the bacteria and the archaea), and one domain of eukaryote organisms, among which there are several multicellular lines.
Between 4,560 and 4,500 Ma
Bringing water to Earth
The significance of extraterrestrial sources

Between 4,570 and 4,560 Ma
The Solar System's gestation
From an interstellar cloud to a circumstellar disk

Between 4,560 and 4,500 Ma
The formation of the rocky planets

Between 4,570 and 4,560 Ma
The birth of the Solar System
The formation of the giant planets

About 4,400 Ma
The first continents, the first oceans
Towards an Earth that was potentially habitable?

Round about 4,570 Ma
The Solar System’s gestation
From an interstellar cloud to a circumstellar disk

Between 4,300 and 2,700 Ma
The transition from non-life to life
From prebiotic chemistry to the first cells

Between 4,500 and 4,560 Ma
The formation of the giant planets

About 4,400 Ma
The first oceans
Towards an Earth that was potentially habitable?

Between 3,500 and 2,700 Ma
Biological evolution has started
The first traces of life and the diversification of prokaryotes

Between 4,100 and 3,900 Ma
The Late Heavy Bombardment
A temporarily uninhabitable Earth?

About 2,400 Ma
The appearance of eukaryotes
The first cells with nuclei and their fossil traces

Between 4,200 and 5,400 Ma
The appearance of the first multicellular organisms
The first traces of algae, animals and fungi

Between 4,100 and 3,900 Ma
The Late Heavy Bombardment
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Between 4,000 and 3,900 Ma
The appearance of the first multicellular organisms
The first traces of algae, animals and fungi

About 2,000 Ma
The appearance of eukaryotes
The first cells with nuclei and their fossil traces

About 4,300 Ma
The Solar System’s gestation
From an interstellar cloud to a circumstellar disk

Between 540 Ma and the present
Explosion of macroscopic life
Evolution continues