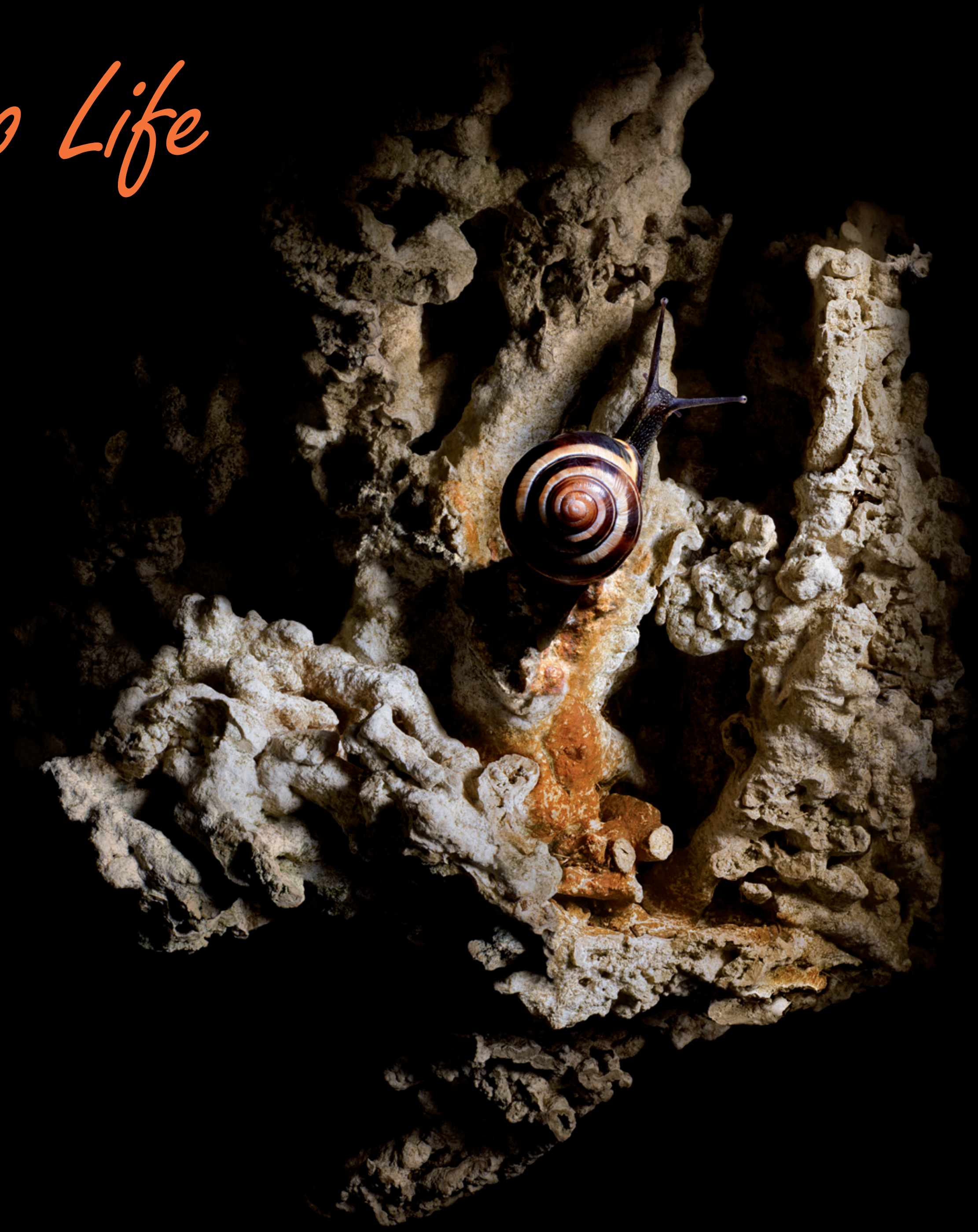
Rocky Roads *to Life*

Special Exhibition

14/3/25 - 15/02/26



Ries
Krater
Museum
Nördlingen

Rocky Roads *to Life*

For billions of years, the world of rocks and the world of life have been closely linked through the action of water. Mineral diversity and biological development are therefore interrelated.

It is precisely in the dialog with rocks that paths to a deeper understanding of life are revealed. Central questions open up these paths and lead to the origins, relationships and characteristics of the living world: What role do rocks play in the origin of life? What are the relationships between life and rocks? What are the characteristics that make life fundamentally different from rock?

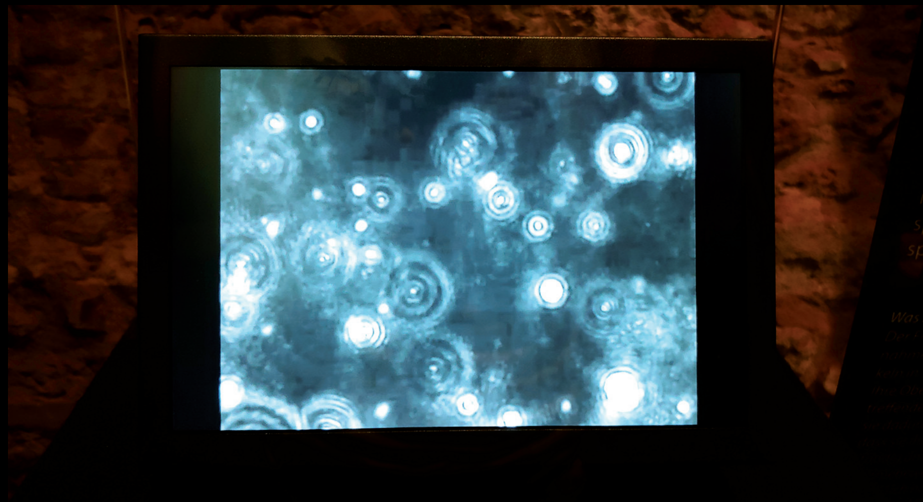
Three rocky roads lead through this exhibition:


From life to rock


From rock to life


The difference between rock and life

Origin in nanofluid water



Water is a great mystery when it comes to the origin of life. It prevents the formation of vital proteins and nucleic acids or even destroys them if they are present. At the same time, however, water is the basis of all life. How can this contradiction be resolved?

Background

Water can take on completely different properties than usual if it is highly confined.4 This happens, for example, when tiny mineral particles are densely packed within it. Water is then predominantly present as a thin film a few nanometers (billionths of a meter) around the particles or between them. Geologically, this occurs in rock crevices in the earth's crust and in asteroids, as well as in deep-sea vents, loose sediment layers, hot springs and cloud droplets in particular.

What does this mean for the origin of life?

The interior of living cells is densely packed with tiny bioparticles, including proteins. Between them, but also within some proteins, water is very spatially limited. Just as in geological environments, it becomes a nanofluid and takes on very exotic properties. However, it is precisely these properties that are indispensable in a cell for the formation and stability of DNA and proteins. The importance of these properties for biology and their bridge to geology resolves the contradictions regarding the role of water in the origin of life.

What does the exhibit show?

The movie shows a real-time image of carbon nanoparticles in water. Their surface scatters the incident laser light, making them visible. It can be seen that they constantly change their distance from each other. This is due to thermal movement. As they approach each other, nanofluid water forms between the mineral particles. With its exotic properties, it was possible to produce RNA from molecular building blocks without the help of living cells.12 The video was made with a NanoSight Analyzer at the Center for Ries Crater and Impact Research Nördlingen (ZERIN).

Origin through lightning

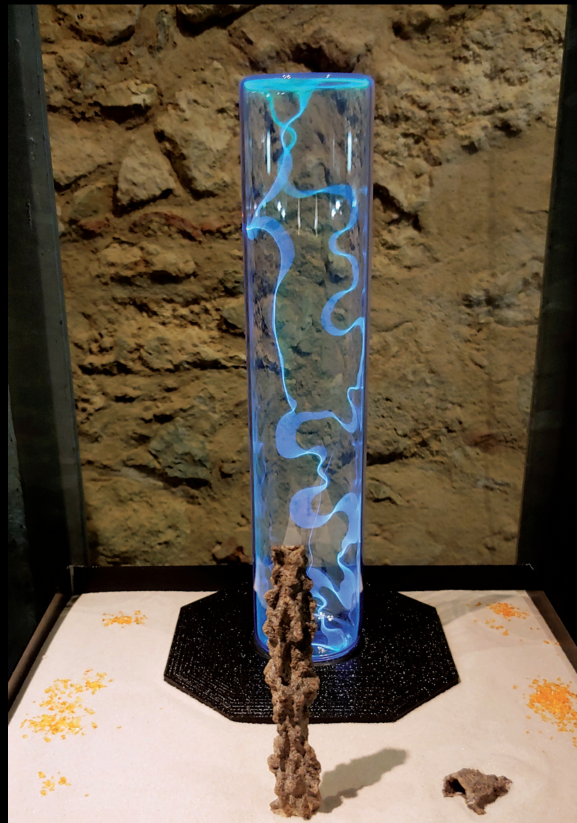
Lightning in a simulated primordial atmosphere played a central role in a groundbreaking experiment that greatly influenced research into the origin of life. It succeeded in producing important molecular building blocks of life. Decades later, however, researchers recreating the experiment made a completely surprising discovery: a mineral turned out to be very important for the production. But it was never added to the experiment. How can this be explained?

Background

The formation of complex molecules from simpler building blocks requires energy. Lightning discharges are one way of supplying this energy. In the Miller-Urey experiment, lightning is generated in a glass flask in a simulated urate atmosphere to test whether important building blocks of life are formed as a result. A precipitate is formed in the glass flask, in which components of proteins and DNA can actually be found. However, when an attempt was made to recreate the experiment using a Teflon flask instead of glass, the yield was extremely low and some molecules were not found at all.10 The surface of the silicate glass flask in the original experiment therefore played a very important role, which no one had noticed until then.

What does this mean for the origin of life?

Silicate glass can form in many ways under early Earth conditions. This also includes volcanic glass in ash clouds. Lightning is common in such clouds. The current findings from this experiment show that the path to the formation of molecular building blocks of life through lightning discharges in the early atmosphere leads via mineral silicate particles in the clouds.



What does the exhibit show?

A plasma tube is set up in the display case. In its glass bulb, lightning discharges are simulated in an oxygen-free atmosphere like that of the primeval earth. In front of the plasma tube is a fossil lightning bolt. Such formations are known as fulgurites. They are formed when lightning strikes a sandy soil and the high heat in the plasma channel melts the grains of sand into elongated shapes.

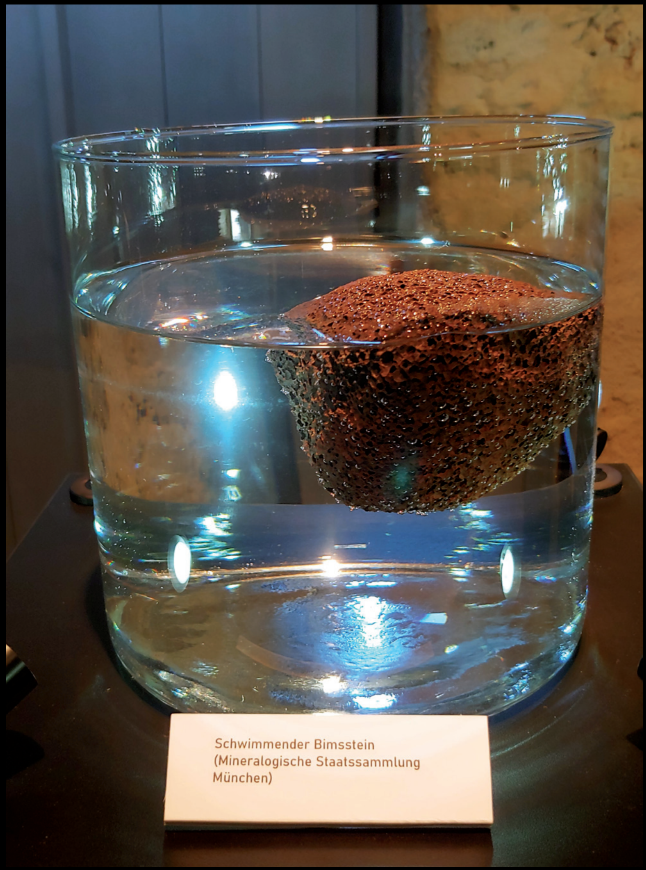
Vesicle film

Lipids are among the building blocks of life. One of their functions is to build the cell envelope. Due to their surface energy, rocks help the lipids to organize themselves into cell-like vesicles (protocells) and even absorb DNA, as can be seen in the film. It was created in the working group of Prof. Irep Gözen, University of Oslo, using a laser microscope.

Issua gneiss

Issua gneiss is one of the oldest rocks on earth
Location: north of Nuuk, Greenland
Age: 3.8 billion years
(Collection: Rudolf Dorstewitz)

Origin on the land surface



Four billion years ago, the Earth had a completely different appearance: there were no continents as land masses, as geological findings suggest. A global ocean must therefore have covered the earth. Nevertheless, the origin of life on land is often discussed. Why?

Background

Molecular building blocks of life cannot combine in free water to form DNA or proteins. Water inhibits this process. Numerous assumptions about the origin of life are therefore based on environments in which water is repeatedly removed by the repeated drying out of solutions. However, desiccation requires direct contact with the atmosphere. This requires a solid surface. Despite a global ocean, this is possible in various ways: on the one hand, floating stone fields can form as a result of eruptions of underwater volcanoes with gas-rich magma. They consist of pumice, which is so light due to its many air-filled pores that it floats on water. Volcanoes can also become so large that they occasionally break through the surface of the water. In this way, they form land masses with hot springs through chains of islands.

What does this mean for the origin of life?

There are numerous hypotheses and laboratory experiments that are based on desiccation cycles. They refer to geological environments such as floating pumice8 or hot springs9 that allow such cycles on mineral surfaces. Under these conditions, simple molecules can combine to form proteins or RNA, but can also form fatty acid vesicles similar to biological cell walls.

What does the exhibit show?

On display is a pumice stone floating on water. Such stones can form so-called "pumice rafts" after submarine volcanic eruptions - extensive stone fields that float on the sea. Evidence of such fields is known from the Earth's early history. As a kind of "land surface", they could have created favorable conditions for the emergence of life.

Origin through meteorites

Life arose on Earth surprisingly quickly. The oldest evidence comes from a time when the still cooling Earth was just reaching life-friendly conditions. Is the origin of life relatively simple or are at least the building blocks of life already formed in space? The study of meteorites brings surprising things to light.

Background

Meteorites are fragments of other celestial bodies from the solar system that have landed on Earth. Asteroids are their main source. When asteroids collide, chunks of rock and dust that have been knocked out can end up on their own orbits around the sun and eventually crash into the Earth. Some meteorites have characteristics that indicate liquid water in the original asteroid. Heat, mainly generated by radioactive radiation in the core of larger asteroids, can melt ice in the overlying crustal rock. Chemical energy from the contact of the rock with the liquid water can create conditions that set chemical evolution in motion.

What does this mean for the origin of life?

Some carbon-rich meteorites contain organic molecules that are the result of astonishingly advanced chemical evolution.[11] These include molecular building blocks of DNA, proteins and cell membranes. As these molecules survive the hot phase when the meteorites enter the Earth‘s atmosphere, it is possible that complex biomolecules could have reached the Earth from space in the early days of the Earth and served as building blocks for the emergence of life.

What does the exhibit show?

On display are pieces of the meteorite “Almahata Sitta”. It is a carbonaceous chondrite in which molecular building blocks of DNA and proteins have been detected.[11] A picture of a micrometeorite can be seen in the background. Micrometeorites are cosmic dust particles that can also carry complex organic molecules. An estimated 100 tons per day reach the earth‘s surface.

Origin in the deep sea

If life originated in the sea, then presumably not in open water. Because without a defined reaction space that brings together the molecular building blocks of life and keeps them together, the emergence of life is almost inconceivable. But the deep sea has a few surprises in store.

Background

A few decades ago, completely unexpectedly, bizarre mineral formations were found in the deep sea, rising out of the ground as hot, smoking chimneys.
Although no sunlight penetrates this depth of the sea, these vents are teeming with life.

What does this mean for the origin of life?

Research into the geology and properties of deep-sea vents has shown that they have a highly porous structure. The tiny pores represent reaction vessels that are largely separated from the open sea. A simulation of such vents in laboratory experiments showed that complex organic compounds can form and concentrate in the pores. The thermal energy required for such processes in the deep sea comes from the earth's interior, while the chemical energy required is produced when the crustal rock reacts with the seawater under high pressure.

What does the exhibit show?

The exhibit shows a hydrothermal vent made of hydrous iron hydroxide minerals. It was grown at the Ludwig Maximilian University of Munich in the laboratory of Prof. Bill Orsi's research group. Such vents are used to study the origin of life in the deep sea. Cultivation and preparation for the exhibition: Vanessa Helmbrecht.

Origin in the deep biosphere

Did life on Earth perhaps not originate in the sea, but in the Earth's crust?

The background

Even today, life can still be found in the earth's crust at depths of well over 1000 meters. Single-celled organisms use tiny water-filled crevices and cracks in rocks to generate energy from chemical reactions in rocks. They do not need sunlight to do this.

Four billion years ago, cracks must have formed deep into the rock crust. This is because the moon and earth were much closer to each other and the moon orbited the earth in a much shorter time than it does today.The Earth also rotated much faster back then.
Tidal forces were therefore enormously strong and acted in shorter cycles, so that the Earth's crust periodically deformed very significantly. In addition, asteroid impacts were much more frequent than today. All this must have led to a deep disruption of the Earth's crust.

What does this mean for the origin of life?

Water and CO_2 under high pressure filled faults and fine cracks in the shattered crust.Various forms of energy were available in these cracks:In addition to chemical energy from the reaction of water with rock and heat from asteroid impacts and tidal friction, electrical energy could also be generated via the periodic deformation of piezoelectric minerals.
The cracks widened and narrowed periodically in the cycle of extreme tides. As tiny, slowly pulsating reaction spaces, they could have triggered chemical evolution and ultimately the emergence of life.[1]

What does the exhibit show?

On display is a sample of rock from the Earth's crust from a depth of more than 1000 m, which was brought to the surface from the Ries crater through a borehole. The rock was broken up by the asteroid impact and has re-bonded. It contains microscopically small cracks, similar to those discussed as the site for the origin of life in the early days of the Earth.[2]

Mineralisation is caused

Life on Earth is accompanied by a mineral diversity that is not yet known on other celestial bodies in the solar system. How are the two connected?

Background

Life has been changing its geological and atmospheric environment since its origin. This drives both the biological evolution and mineral development of the Earth. Around 2.5 billion years ago, for example, the atmosphere and oceans were enriched with oxygen from photosynthesis. However, oxygen is actually toxic to organisms. Life therefore had to adapt to the increase in oxygen through evolution. This eventually led to multicellularity and ultimately to us.

What does this mean for rocks?

Dissolved iron compounds in particular are precipitated or transformed by the reaction with oxygen from photosynthesis and rocks are formed from iron oxides. The precipitation and crystallization of other minerals is also determined by the conditions in the environment, such as the carbon dioxide content of the water. If living organisms are nearby, they change this content through their metabolism. For example, colonies of bacteria, algae, mosses or roots in their immediate vicinity extract dissolved carbon dioxide from the water. This causes lime to precipitate around the organisms, resulting in the formation of calcareous tufa. The oldest evidence of life on earth includes calcium deposits on bacterial mats. These so-called stromatolites date from around 3.5 billion years ago.[13] They were formed by such precipitation processes.

What does the exhibit show?

On display is lime tuff that was recovered in Nördlingen in 2024. Relatively close to its source, the karst water of the Eger contains a lot of dissolved lime. This is precipitated on the banks by tree roots, mosses and algae carpets - resulting in calcareous tufa.

Mineralization is organised

In some rocks, mineral formations can be found in a wide variety of shapes that could not possibly be created by normal crystal growth. This is because their shapes and compositions are far removed from any strict order. On the other hand, they are not chaotic either, as they occur in exact copies of each other. How is this possible?

Background

The cells of many life forms can trigger mineral formation with the help of proteins and organize the resulting minerals in the process. During biologically controlled mineralization, cells control the formation of crystallization nuclei, the growth dynamics and the appearance of the mineral compound. So-called nanocomposites can also be formed, i.e. structures consisting of a mineral component of nanoparticles, which ensures high compressive strength, and an organic component of proteins, which increases the tensile strength. Such nanocomposites are, for example, the shells of snails or the bones of vertebrates.

What does this mean for rocks?

Lime, silica and apatite in particular play a major role in controlled biomineralization. If such organisms die, their mineral remains can be deposited in such large quantities as sediment that they become rock-forming after compaction. Rocks such as chalk, reef limestones (e.g. White Jurassic of the Swabian and Franconian Alb, Limestone Alps), radiolarite or flint are formed in this way.

What does this exhibit show?

The stone on display is made of nummulite limestone. It comes from a quarry near Bad Heilbrunn (geotope number: 173A003) and was once quarried there as "Enzenau marble" for use as building stone.14 The stone consists almost entirely of the shells of large foraminifera - single-celled organisms that were deposited in a shelf sea around 45 million years ago. A thin section of this rock can be seen as a projection.

Rock is utilized

There are individual stones in sedimentary deposits that do not actually belong there due to their size, shape and texture. But they have none of the characteristics of meteorites that would normally be considered foreign bodies. How did these stones get there and what formed them?

Background

Some animal species take stones into their stomachs. Herbivorous birds use them to crush food by rubbing the stones. Crocodiles, on the other hand, use stones as ballast to control their buoyancy in the water.

What does this mean for rocks?

This way of using stones leaves characteristic marks. Although gastroliths are rounded like pebbles, there are features that distinguish them from pebbles. These include microscopic grooves caused by the action of stomach acid and a strong polish, which is particularly evident on elevations (the reverse of pebbles) and makes them look similar to a used bar of soap. Such stones are called gastroliths. They are transported by the migration of the animals that use them to areas where they do not actually occur geologically. This can also be used to deduce the long migrations of dinosaurs from the Jurassic period.[15]

What does the exhibit show?

Two stones are on display. Their characteristics indicate that they are gastroliths. It is assumed that they were polished in the stomachs of herbivorous dinosaurs such as Tenontosaurus. The gastroliths are between 140-100 million years old and come from the Cloverly Formation[16] in Montana, USA.

Rock is worked

If you find a hand axe in the terrain, it stands out among the other stones. Something about its shape is not recognizable as natural. But what is it?

Background

There are animal species such as corvids that not only use natural materials as tools in their found form, but also use them to make tools/work them for their intended use.[17]
Humans are also able to work with stone thanks to their mental and manual skills. The processing of stones into hand axes can be traced back up to 2 million years.[18] The processing requires an ideal idea of the form that follows the intended purpose.

What does this mean for rocks?

Through processing, natural stones can be transformed from a chaotic to an orderly form that fulfills a specific function for the owner or society. With the functional order, the stone is brought into the border area between order and chaos, in which life is located without it being life itself.

What does the exhibit show?

The display case contains one of the oldest archaeological artifacts from the Nördlingen Ries: a hand axe that is estimated to be 70,000 to 80,000 years old. Based on its size and processing characteristics, it is attributed to the Micoquian culture of the Neanderthals. It was found in the "Straßäcker" field (field no. 166) near Großsorheim by Franz Krippner (Nördlingen).
The hand axe was made by working Jura chert. The feel of the artifact and the traces of processing and wear indicate that it was made as a tool for a rather small hand and was wielded with the right hand.

Rock is processed

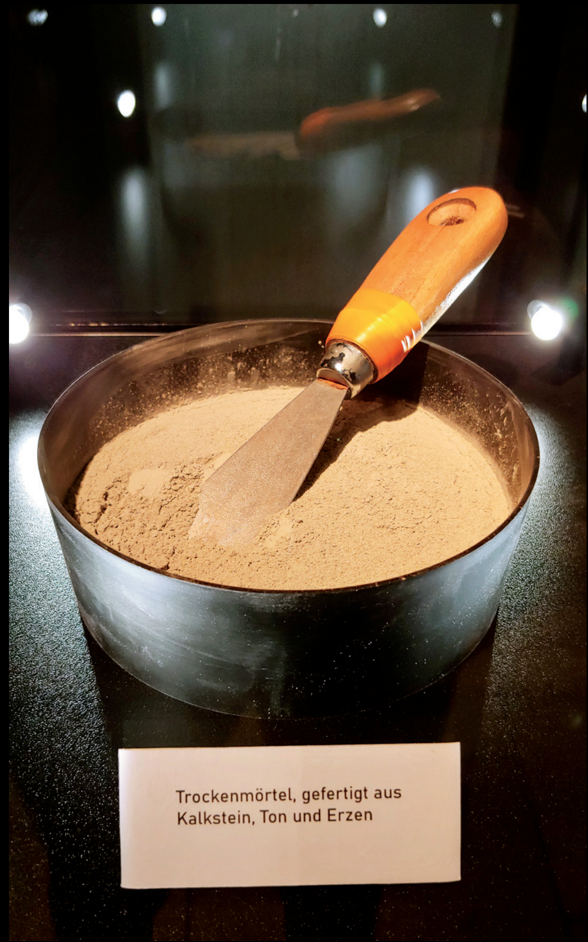
Lime has been burned for almost 10,000 years. However, the aim is not to generate energy, as is the case when burning wood. On the contrary, burning lime consumes a lot of energy. But what purpose does it serve?

Background

In contrast to the processing of limestone by cutting, hewing, grinding or polishing, it is transformed into a product (cement) during processing. Mixed with water, cement acts as a binding agent between the grains of rock and finally hardens to form a solid mixture: Mortar or concrete. The burning of lime is an important preliminary stage and utilizes a decisive phenomenon: during burning, lime transforms into a new phase by releasing carbon dioxide. This can be stored and transported as a powder. However, as soon as water is added, a further transformation takes place and the overall mixture becomes hard. If clay, sand and ores are added to the lime and this mixture is ground and fired, the result is Portland cement, which is very important in the construction industry.

What does this mean for rocks?

The processing of lime, clay, sand and ores means that these rocks are transformed into a completely new rock material. A quasi-liquid stone is formed with mortar and concrete at room temperature, which can be poured into any shape until it hardens. If reinforcing steel is added to the mixture, the result is a composite material that has a high compressive strength due to the concrete and a high tensile strength due to the steel. This is similar to the nanocomposites created by biomineralization.



What does the exhibit show?

On display is a bowl filled with dry mortar. Various rocks, including limestone, clay and ores, were transformed into this product during processing.

What is the difference?

What would Mars look like if there was life there? The image of a forested landscape in Tasmania, which coincidentally resembles a cratered landscape on Mars, gives us an idea. However, if we look behind the scenes of the visible impression, we come across a very important question: What exactly is it that we do not see in the picture of Mars? What is life?

Martian landscape. Photo: NASA / JPL / Cornell / Damia Bouic

Landscape in Tasmania. Photo: Felix Andrews (Floybix)

Background

If we approach the question via physics, the boundaries between geology and biology begin to dissolve. Crystals and living organisms then appear as just two extremes in the course of an accumulation of properties that have something to do with order, chaos, energy and information.

What can be seen on Mars?

The Martian landscape shows only rock - a chaotic mixture of small crystals whose inner structure is, however, highly ordered. So we see a juxtaposition of order and chaos. However, some images also show whirlwinds. These are so-called dissipative structures - ordered formations that only exist as long as energy is continuously supplied (here by updrafts). In the case of whirlwinds, chaotic turbulence briefly turns into orderly movement until it dissipates again. We thus see an oscillation between chaos and order.

What can't be seen on Mars?

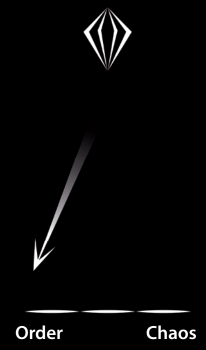
What the Martian landscape does not show are dissipative structures that regulate themselves and process information from the environment. In this way, they adapt to the border area to chaos without exceeding it. They remain there by means of a form of stability that is achieved by multiplying their elements. The earthly landscape shows exactly such structures: living beings.

Crystals, krill and chaos

The aquariums allow us to immerse ourselves in different worlds between order and chaos. Comparing these worlds paves the way to answering the question of what life actually is in contrast to rock. What do the individual aquariums show?

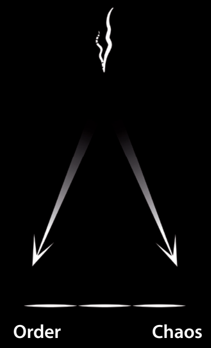
Crystal garden

The crystals on display are highly ordered structures. This means that the arrangement of the atoms that make them up follows a clear regularity. The aquarium therefore offers a glimpse into a world in which **order dominates.**



Chemical garden

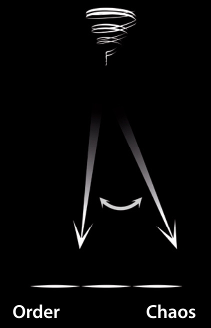
Bizarre structures of metal silicates grow in a water glass solution of metal salts. They are formed by microscopically small crystals with a high degree of internal order. However, the crystals combine with each other in such a way that largely disordered structures are formed, allowing us to look into a world where **order and chaos coexist.**



Crystals, krill and chaos

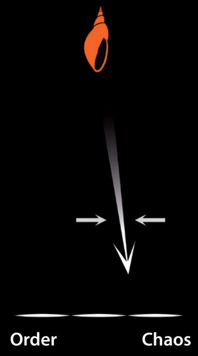
Vortex

A vortex is an ordered structure that only exists as long as energy and matter are constantly flowing through it. It is therefore a so-called dissipative system: not an object, but an organized state on the verge of chaos. In a vortex, chaotic turbulence briefly turns into orderly circular motion until it crosses the boundary to chaos again and dissolves. We thus see an **oscillation between order and chaos.**



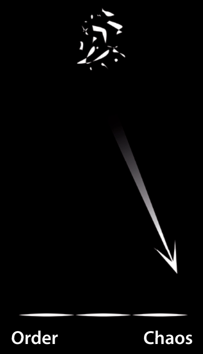
Living organisms

The organisms in the aquarium are also dissipative systems. In contrast to the vortex, however, they regulate themselves using information from the environment in order to remain in the flow of energy and matter. We thus see an adaptation to the **border area between order and chaos.**



Chaos

There is no connection between components, no regularity in the arrangement and no functions as elements of a system. The aquarium therefore shows a world of **chaos.**



ROCKY ROADS *to Life*

A special exhibition of the RiesKraterMuseum

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Photo Gastrolith:
Dr. Marcus Moser (Bayerische Staatssammlung für Paläontologie und Geologie)
Photo micrometeorite large:
Jon Larsen & Jan Braly Kihle
Photo micrometeorites small:
Thilo Hasse

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