GEOPARK RIES
Europe's Giant Meteorite Crater

Windows into the Earth

with excursion tips

Adventure Geotopes

Nature Trail

www.geopark-ries.de

INFO APP

How it works

1. Please scan the QR code on the GPS sign or under Fact Sheet of the respective geotope in this brochure.
2. To use offline, download the app.
3. Then start the app. You will get information about the location. Choose to read or listen.
4. Geofencing: If the location services of your smartphone are activated, it will notify you when you have reached the next landmark.
5. You can find further user instructions under Help in the app.

Scan the QR code or enter **app.geopark-ries.de** into the browser to get to the app homepage and select the geotope.

Welcome!

Stefan Rößle, Chief Administrative Officer, District of Donau-Ries
Chairperson, Geopark Ries e.V.

»An impact event has developed into an impactful experience. I thank the Geopark management and the network of engaged organizations and individuals for their terrific cooperation.«

Gisela Pösges
Geologist, Geopark Ries e.V.

»Here in the Nördlinger Ries, where heaven and Earth so vehemently met about 14.5 million years ago, you can experience – live and up-close – a very exciting chapter in the history of the Earth.«

GEOPARK RIES
Europe's Giant Meteorite Crater

Prof. Dr. Richard Höfling
GeoZentrum Nordbayern der Universität Erlangen-Nürnberg

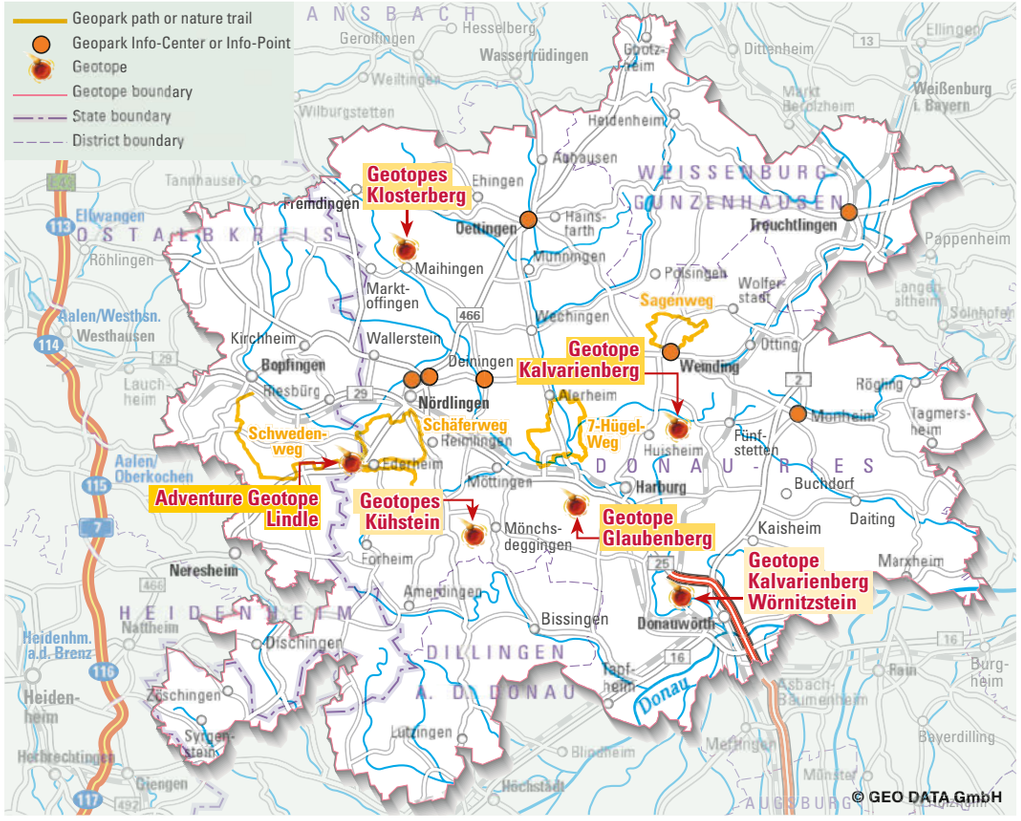
»For three decades now, I have been fascinated by the Nördlinger Ries – especially by the range of geoscience fields that can be studied here. For me – an avowed geological “RIES-ling” – the Geopark region has long been a fixed component of my research projects. With my working group, all Adventure Geotopes have been freshly reworked. The Ries is attractive as an outside-the-lab-and-lecture-hall learning environment for students«

Heike Burkhardt
Director, Geopark Ries e. V.
Graduate degree in biology

»The National Geopark Ries is certainly one of the most fascinating areas of Germany. It all began with the impact of a stone asteroid about 14.5 million years ago. We are pleased that – with six Adventure Geotopes – we can now open “Windows into the Earth.”«

OVERVIEW MAP

The National Geopark Ries with Adventure Geotopes, hiking trails, Info-Centers and Info-Points



This map of the Geopark Ries e.V. shows the outline of the Geopark and the locations of its six geotopes and four hiking trails. As "Windows into the Earth" the geotopes are attractive destinations for active and informative excursions.

GOOD TO KNOW

Crater diameter: ca. 25 km
Height of crater rim: up to 150 meters
Area of Geopark: ca. 1.750 km²
Approx. 160 mapped geotopes
Five of the 100 best geotopes in Bavaria
Six geotopes with nature trails

CONTENT

Windows into the Earth

Good to know

THE NATIONAL GEOPARK RIES

A success story

The Ries Crater is one of the best preserved and researched impact craters on Earth – and so a first-class geological feature. It has a magnetic effect – and not just on geologists. A large and consistently growing number of geo-tourists, school groups, interested lay persons, hikers and bikers from all over the world make their way to the Ries in search of traces of the cosmic catastrophe. The asteroid impact that occurred approximately 14.5 million years ago had a fundamental and definitive influence on the landscape and qualities of the geological underground that is still discernable today. Through the National Geopark Ries, these geological and geomorphological processes and their far-reaching consequences become visible and vivid.

As “Windows into the Earth,” numerous geotopes offer insights in the development of the Ries landscape. At many locations, visitors can trace the influences of the geological formations on the composition of soil and habitats, for example, on the dry grasslands of the crater rim.

GEOPARK RIES ONLINE AND ON SITE

With the comprehensive interactive map on Geopark Ries’ homepage (www.geopark-ries.de), visitors can become acquainted with the region online and plan their vacation or excursion. A dense network of marked biking and hiking trails crisscrosses the region – always close to geological and cultural heritage sites.

Certified Geopark Ries Guides, as well as the Ries Crater Museum in Nördlingen, offer thematic and even individually designed tours.

GEOPARKS – A WORLDWIDE TREND

The protection of unique biotopes has been common in Germany for some time now, and often a geotope is also included. Yet geological features and their protection have increasingly experienced stand-alone appreciation only since the end of the 1990s. Worldwide, the designation of geoparks has been gaining ground since 2001; around the new millennium UNESCO even initiated a “Global Geopark Network.”
In Germany there are currently 16 National Geoparks certified by the GeoUnion Alfred-Wegener Foundation. Geoparks are regions with unique geology and contain geological sights of interest (geotopes) of special scientific significance, rareness or beauty. Geotopes may also include archeological, ecological, historical or cultural attractions. The goal is to impart to the visitor, knowledge about the formation of the Earth, the geological processes involved and the influence of geological and geomorphological processes on habitats. National Geoparks sensitize the public to the uniqueness of the Earth and serve a declared objective of UNESCO: the preservation of the creation.

Geotopes show: how and why dry grasslands developed at these locations, how this biotope is utilized and maintained by migratory sheep grazing, which factors were advantageous for early settlers who resided in the crater basin as early as the Stone Ages, why even today the Ries Crater is one of the "breadbaskets" of Bavaria.

Beside the geological heritage sites, the Geopark Ries also presents the rich settlement history and cultural qualities of the region. The Geopark focuses the attention of residents and guests on environmental features and natural and cultural treasures and, in this way, encourages respectful interaction with the unique heritage.

In 2006 the Geopark Ries was certified as the first National Geopark in Bavaria. One of the Geopark Ries' most important functions is to develop the geological heritage for residents and tourists. This also includes the advancement of science and scientific cooperation as well as environmental education.

FROM SEABED
to crater basin

Tidal flats at the foot of the Alps
Around 170 million years ago, advancing from the northwest, the Jurassic Sea flooded the Vindelician land mass, highlands that existed in today's southern Germany during the Triassic (250-200 million years ago). The coastline ran about where Munich is located today. The area of today's Ries was a seabed of shallow mudflats that were strongly affected by tides. Later, the continental plate rose, and north of the Alps a seabed with no outlet emerged and increasingly silted up. During the early Cenozoic (66-23 million years ago) and start of the middle Cenozoic (23-5.3 million years ago), the climate was sufficiently warmer so that palms grew in Central Europe and tree-dwelling primates were widespread in southern Germany (65-20 million years ago). The region of today's Ries experienced a subtropical climate during which it was populated by animals that died out long ago, such as the weasel-like **Trochotherium**, primeval horses, various rhinoceros species and crocodiles.

Trochotherium

Starting over – a cosmic bomb destroys life
In just a few seconds, the impact of the asteroid fundamentally changed the region that became the Ries Crater. Ejected rock debris covered the impact area over a wide radius. Shock waves swept over a broad part of Central Europe and propelled an infernal heat that burned forests as well as remaining vegetation. All life was extinguished within a large radius of the crater. After the crater was formed and the cloud of vaporized and molten rock collapsed, today's Ries was a huge, lifeless debris field.

EXCURSION TIP

The Jurassic Sea dominated the landscape well before the Ries event and has left behind visible traces. Near Dischingen, about 25 kilometers south of Nördlingen, there are a few partially-rounded blocks of massive limestone that are construed as the remains of a boulder-strewn beach. In the Geotope Glaubenberg (page 34) there is a red-colored sandstone block of brown Jurassic. The red iron oxide was incorporated in the sandstone by microbes on the former seabed.

The Jura Museum Eichstätt on the Willibaldsburg ridge over the Altmühl is a natural history museum in one of the prettiest settings in Germany:

Jura Museum Eichstätt – "Into the Jurassic Sea with the Museum time machine"
Willibaldsburg, 85072 Eichstätt
Telephone +49 8421 2956
www.jura-muesum.de

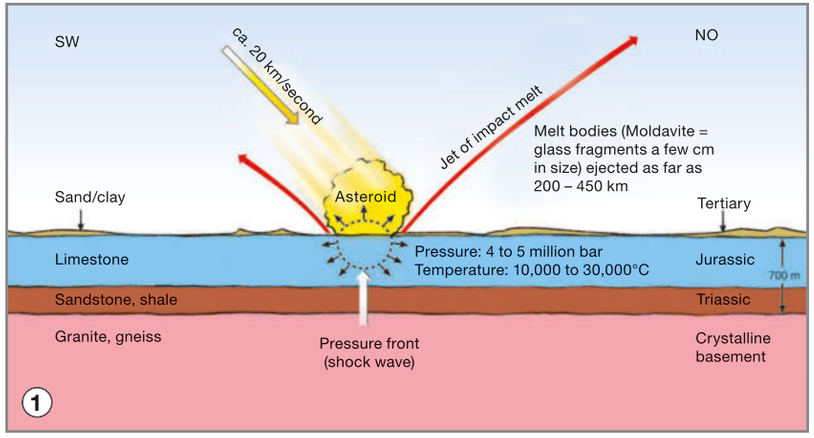
Good to know

THE RIES EVENT

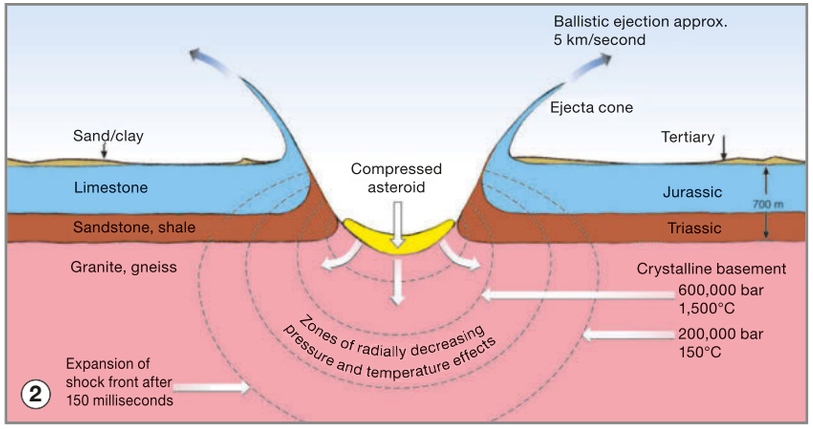
A cosmic catastrophe

A celestial body races toward the Earth

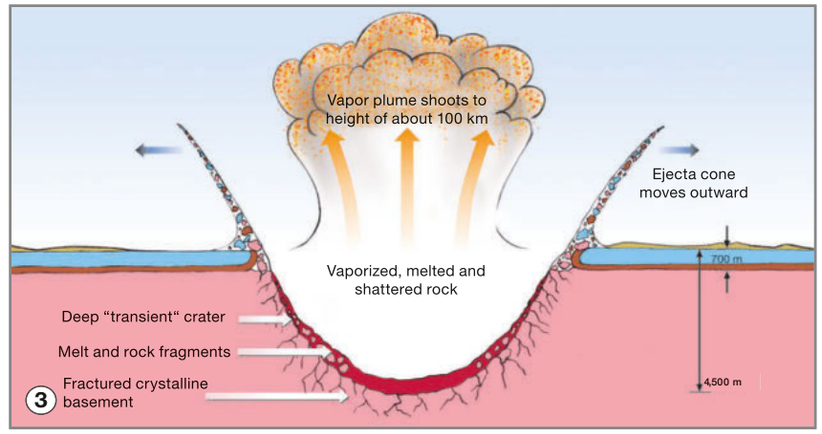
As we know it today, the history of the Ries begins on a day almost 14.5 million years ago with a cosmic catastrophe. An asteroid with a diameter of about 1,000 meters is on a collision course with the Earth. With a speed of about 20 km/sec (ca. 72,000 km/hr), it races through the Earth's atmosphere in just a few seconds. Even before the impact, the air between the extraterrestrial body and the impact site is so compressed and heated, that material from the Earth's surface and the asteroid melt and are hurled far up into the atmosphere. While still in flight, some molten rock solidifies into glass; these so-called tektites have been found up to 450 kilometers away in Bohemia, Moravia and Lusatia. The tektites created by the Ries impact are called Moldavites.



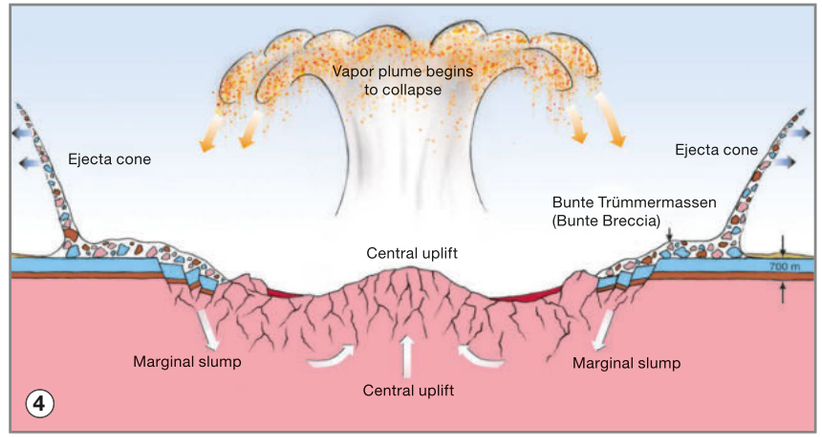
1 ***10 milliseconds after impact***



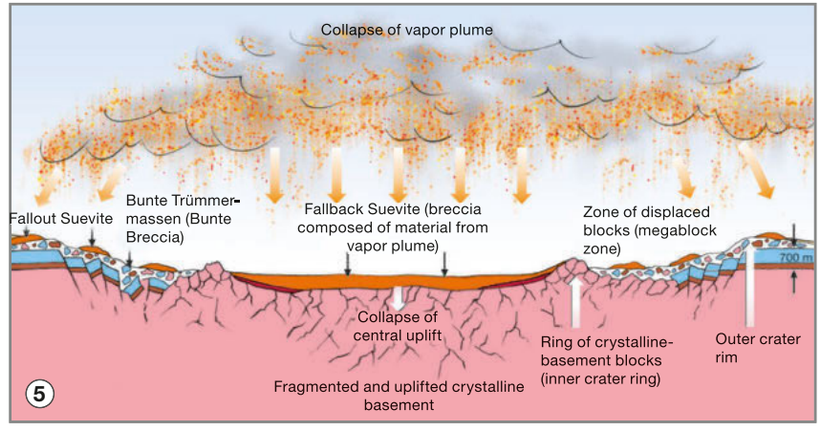
2 ***Start of crater formation after 60 milliseconds***



3 ***Formation of deep "transient" crater after about 10 seconds***



4 ***Collapse of "transient" crater and deposit of ejected rock masses after 1 minute***



5 ***End of crater formation and deposit of Suevite after 10 minutes***

Graphic: D. Stöffler, T. Kenkmann, W. U. Reimold, K. Wünnemann

Brighter than the sun

The impact of the asteroid on the Earth releases an unimaginable amount of energy – equivalent to the explosive strength of the simultaneous firing of hundreds of thousands of Hiroshima-size atomic bombs or several gigatons of TNT. The apparent brightness of the explosion on the Earth surpasses by far that of the sun. Even in the first seconds the cosmic bullet penetrates approximately 1,000 meters into the Earth's crust. The entire celestial body vaporizes; the rock in the impact crater melts, vaporizes and rises in a glowing cloud over the crater. A violent shock wave drives the infernal heat outwards. The shock wave travels at the speed of sound around the entire Earth. Even at a distance of 500 kilometers, it can be clearly felt with a wind speed of Beaufort force six (39-49 km per hour). After 17 seconds the shock wave reaches the opposite side of the Earth at a distance of 20,000 kilometers. Even there, the thunderclap can be faintly heard at a volume of about 40 decibels (equivalent to low-voiced conversation).

Trümmermassen and glowing cloud of rock

The transient crater formed by the impact has a depth of about 4.5 kilometers and a diameter of 12 kilometers.

Fragments and large blocks of rock masses from various layers are thrown out of the crater or slide inwards from the crater rim. The surrounding landscape within a radius up to 50 kilometers is covered by a thick layer of *Bunte Trümmermassen* (rock debris) up to 100 meters deep. The crystalline basement rock vaporized by the impact rises in an eruption column up to 100 kilometers into the atmosphere and carries with it pulverized and fractured rock of various stratigraphic layers.

CHICXULUB CRATER

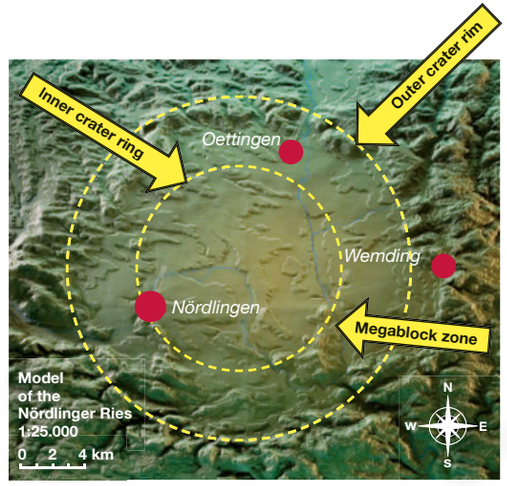
Besides the Ries Crater, the Chicxulub Crater of the Yucatán Peninsula in Mexico is one of the best known impact craters on Earth. It may have contributed to the extinction of the dinosaurs.

GERMANY

Ries Crater, Bavarian Swabia	
Age	ca. 14.5 million years
Ø Impactor	ca. 1 km
Explosive effect	Several 100,000 Hiroshima-type atomic bombs
Ø Crater	ca. 25 km

MEXICO

Chicxulub Crater, Yucatán Peninsula	
Age	ca. 65 million years
Ø Impactor	ca. 10 km
Explosive effect	100 million Hiroshima-type atomic bombs
Ø Crater	ca. 200 km



On the steep crater walls, large blocks of rock break off and slide into the center. The diameter quickly expands to approximately 25 km. At the same time, the impact-compressed crystalline basement rebounds to form a central uplift with an inner ring. Combined with the sliding blocks, the crater floor is raised to a depth of around 500 meters.

Just minutes after the impact, the glowing cloud collapses and settles as an ejecta blanket (of debris, molten rock, etc.) over the devastated landscape. The rock that results from it is called Suevite, and it forms a circa 300-meter-thick layer in the crater. The asteroid has completely extinguished all life within approximately 100 kilometers of the impact site. The effects on the water network of the Ries landscape at that time are also significant: the courses of the primordial rivers Main, Altmühl and Wörnitz are dammed; a large lake forms in the northeast of the Ries Crater.

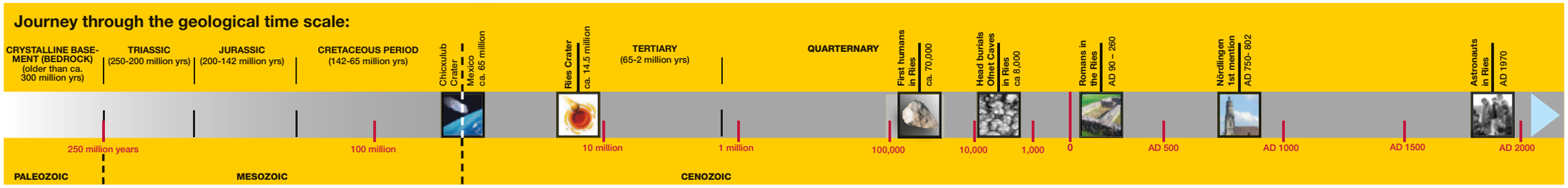
The crater fills up

A nutrient-rich lake forms in the closed-drainage crater. The warm climate leads to strong evaporation, which increases the salinity. More or less comparable to present-day salt and soda lakes in dry areas, this body of water could not support many forms of life. The variety of living creatures was therefore limited – yet the number of individuals that populated the lake was large. Green algae, cyanobacteria, brackish-water snails and ostracods populated the body of water. Only after 2 million years, with increasing sedimentation, did the Ries Lake become life sustaining. It was settled by numerous small mammals (bats, species of hares and hamsters) and birds (pelicans, **flamingos**, parrots).

EXCURSION TIP

One of Bavaria's 100 best geotopes is in Hainsfarth. Here fossilized small animals like ostracods and the worldwide unique structures of reef-building green algae vouch for the long-ago Ries Lake. Equally impressive is the Wallerstein Cliff, where stromatolites were formed by cyanobacteria. The view from the top is phenomenal.

Journey through the geological time scale:



Good to know

SUEVITE

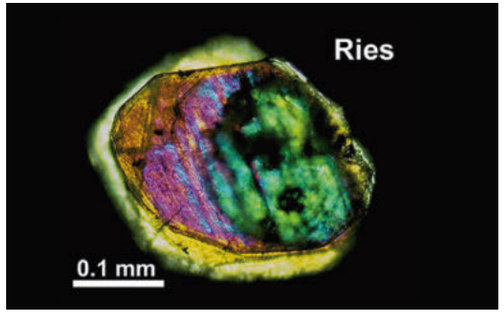
Schwabenstein

What is Suevite?
Suevite, or *Schwabenstein* (“Swabian stone” from the Latin *Suevia* = Swabia) is a typical impact rock.
The effects of an asteroid impact go deep underground – resulting in pressures of several million bar and temperatures up to tens of thousands of degrees. The cosmic bomb explodes and completely vaporizes. During these events, huge amounts of rock from the crystalline basement are melted or vaporized and flung into the stratosphere as a glowing, mushroom-shaped cloud. The cloud eventually collapses, and the debris thrown out of the crater is then deposited over the landscape destroyed by the impact. The layer formed by the Ries event is up to 300 meters thick in the crater basin. As the melt cools down, a rock with glass inclusions is formed – Suevite.

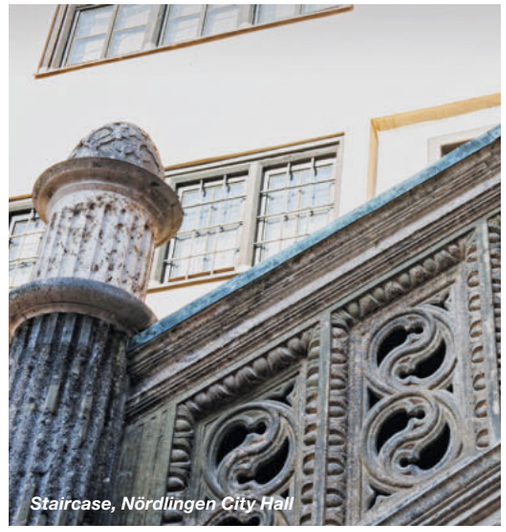
A rock writes scientific history
Even though individual academics brought up the theory of an impact occurrence again and again – until the mid-20th century, the prevailing schools of thought interpreted the Ries Crater as the remains of an extinct volcano. Accordingly, the Suevite in the Ries Crater was considered to be rock of volcanic origin – as shown by the historical designations of *Feuerduftstein* or volcanic tuff. It was only the analyses of Eugene Shoemaker and Edward Chao, both from the U.S.A., who “set the ball (or stone, in this case) rolling.” In the 1960s, they used specialized X-ray techniques to analyze samples of Suevite from the Ries and discovered in them high-pressure modifications of quartz (coesite and stishovite) that could not be formed by the current temperatures and pressures of terrestrial geological processes. This discovery was the decisive impetus for a turnaround to impact theory – in a short time, additional rock analyses and sample borings produced further evidence for the impact occurrence.


Daniel, Nördlingen


Suevite on top of Bunte Breccia: Shocked and partly melted plutonic rock covered the ruined landscape in a layer up to 300 meters thick.



Suevite contains diamonds, among other high-pressure minerals resulting from the impact, but the diamonds are tiny and of no commercial value.


Staircase, Nördlingen City Hall

Stone on stone—Suevite as building material
Suevite is a medium-hard, easy-to-work stone. It has been used in architecture in the Ries since Roman times and especially in the Middle Ages. In Nördlingen, numerous structures erected using Suevite can be visited, including **Baldinger Tor (Gate), City Hall and, the most prominent building, St. George’s Church**. The building material was extracted from quarries in the surrounding area, some of which remain open but not operating. In the quarry Altenbürg, Suevite is found between layers of Upper-Jurassic limestones; in the quarry Aumühle, Suevite can be seen in contact with Bunte Breccia.

In the 18th century, Suevite was discovered to be a suitable binding agent for mortar and cement. The crushed Suevite – also called trass – demonstrates high elasticity, lower susceptibility to cracking and water permeability and high stability against moisture and atmospheric pollutants. Therefore, it is exceptionally well-suited for water-related structures. Today Suevite is found as a building material mainly in restoration mortars in old-building renovations, in the restoration of structures protected as historic monuments and as grout used in tile and natural surfaces.

EXCURSION TIP

Altenbürg, quarry on Shepherd‘s Way
Location: ca. 1.5 km south of Utzmemmingen
Directions: from Nördlingen on the B 466 towards Utzmemmingen, to the guesthouse Alte Bürg, the quarry is ca. 100 m north of the guesthouse
Parking: at the guesthouse

Quarry Aumühle
Location: 2.5 km northeast of Oettingen
Directions: through Oettingen following the B 466 towards Westheim, ca. 2.5 km past Oettingen turn onto a farm road
Parking: on the farm road

Before visiting the Aumühle quarry, it is necessary to obtain permission from Märker Zement in Harburg (phone: +49 9080 8211).


The Aumühle quarry is one of Bavaria’s 100 best geotopes.

Good to know

MOON LANDING IN THE RIES

Summer visitors on an outer-space mission

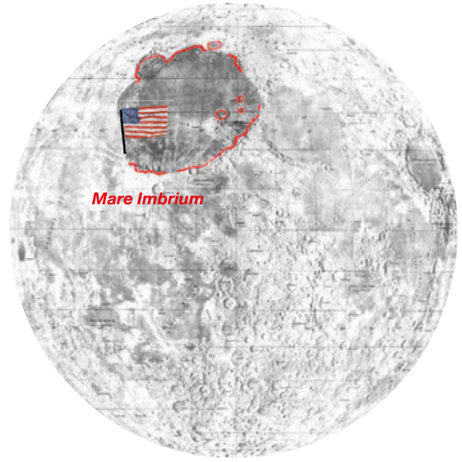
It is the beginning of August 1970 when the astronauts stand on the floor of the crater basin for the very first time. Although the delightful and densely populated Ries Crater does not really look like a lunar landscape, this is where the space travelers will prepare themselves for the Apollo-14 mission. Field training here will acquaint them with geological aspects of the Moon – the Ries Crater serves as a sort of geological simulator for the impact craters of the Moon.

At first the visit does not resemble work at all, decides the *Augsburger Allgemeine* newspaper at that time. The crew members sent by NASA look more like "summer tourists from Texas." Commander **Alan B. Shepard** confirms the impression: "I would much prefer to come to Old Germany as a tourist." But the young men face a tough program: In three days they are supposed to visit 13 quarries. "These boys really have to work hard to accomplish their tasks in a few days," says a NASA spokesperson, as reported by the paper.

On left: Alan B. Shepard

Landing on the edge of the "Sea of Rains"
The meteorite crater Fra Mauro was the intended landing site for the 1971 Moon mission – Apollo 14 would be the United States' third successful Moon landing. Fra Mauro has a diameter of 80 kilometers and is located on the southern edge of the huge **Mare Imbrium ("Sea of Rains")** basin that was itself formed by the impact of an asteroid. In order to be able to recognize and study typical impact-affected rock and tectonic features on site, the Apollo-14 crew is familiarized with the special features of the comparable Ries geology by geologists from NASA and the University of Tübingen.

Stations include the quarry Siegling (see also page 24 "Adventure Geotope Lindle"), where the space travelers study the geologically reversed succession of rock strata (inverse bedding); a Suevite quarry near Otting, where they familiarize themselves with the outward appearances of typical impact rock (see also page 14 "Suevite – *Schwabenstein*"); and the quarry Langenmühle near Maihingen (see also "Geotope Klosterberg" on page 38), where they become acquainted with modifications in the mineralogy of plutonic rock – for example, the formation of high-pressure minerals.



Compared to most terrestrial impact craters, the Ries Crater is especially well preserved and considered one of the best studied craters of the Earth. As a consequence, geologists and impact researchers from all over the world come to the Ries to conduct research. The City of Nördlingen operates ZERIN, the Center for Ries Crater and Impact Research, located next to the **Ries Crater Museum**. Important geoscientific objects and core samples from the Nördlinger Ries are archived in ZERIN and made available to the research community worldwide for scientific work. Scientific findings from research work in the Nördlingen Ries Crater Museum are comprehensibly prepared and made accessible to the general public.

The Ries: a planetary learning site
Research studies of impact events on the Earth and on the Moon are mutually beneficial. During the Late Heavy Bombardment (LHB, or lunar cataclysm) around 4 billion years ago, both the Earth and the Moon were frequently hit by meteorites, asteroids and other remnants of planet formation. In contrast to on Earth, where smaller cosmic projectiles burn up in the atmosphere and the effects of impacts are worn away by erosion or covered by sediment, the Moon has no atmosphere as a protective shield, so erosion is practically nonexistent. The Moon is therefore a sort of geological time capsule; its surface is dotted with well-preserved impact craters of every size.

The Apollo-14 mission confirmed that the geological structures of the debris fields in the Fra Mauro crater, to a large extent, are consistent with those of the Ries Crater. In addition, the terrestrial impact rock Suevite exhibits strong similarity to the impact rock in the Moon craters. NASA continued its research in the Ries; layers of rock were further analyzed in exploratory drillings. And Mars researchers have recently become intensely interested in the Ries. The Ries is and remains a planetary learning site.

EXCURSION TIP

Ries Crater Museum
Eugene-Shoemaker-Platz 1
86720 Nördlingen, phone: +49 9081 84710
www.rieskratermuseum.de
www.freunde-des-rieskratermuseums.de

In recognition of the importance of the Ries Crater in preparation for the Moon mission, NASA presented a Moon rock to the City of Nördlingen. It is exhibited in the Ries Crater Museum.

Good to know

HAND AXES AND NESTS OF SKULLS

Why man settled the Ries

① *The Ries is considered a treasure trove of pre- and early history*

As long ago as the Stone Ages, early settlers found especially favorable conditions in the Ries. Above all, the dynamic topography of the landscape and its consequences for the soil, microclimate and vegetation appear to be important factors in the decision to settle on the hills in the crater and on the heights.

Workshops and hunting stations

Apparently, the southeast region of the crater was especially attractive; the majority of Stone-Age finds come from the area around Harburg and the southern Ries. In fact, the oldest artifact was found near Harburg: a hand axe about 130,000 years old – the oldest artifact in Swabia to date. Intensive site visits have also yielded evidence of the presence of Paleolithic humans near Holzkirchen, Wechingen and Schwörsheim. They constructed open-air camps in which to rest while hunting for large animals. Remains from a mammoth were found in the sand dunes near Gosheim.

Thousands of artifacts from the Middle Paleolithic have been found at about 50 sites in the Ries and its immediate vicinity. In addition to lithic flakes and hand axes, excavations revealed the remnants of a complete Stone-Age workshop including toothed devices, points and scrapers. Robert Rudolf Schmidt, an archeologist from Tübingen, made an exceptional find while working at the Ofnet Caves south of Nördlingen. At his direction, a collapsed rock wall was removed. When he examined the layer underneath, he discovered a spectacular find from the Middle Paleolithic: **33 human skulls**.

② *The skulls were found carefully arranged in the head burial in the Ofnet Caves. Due to its resemblance to a clutch of eggs, it is also called a nest of skulls.*

Elaborate head burial

The skulls were found arranged in two small groups, the faces turned toward the west. Evidently the people of the Middle-Paleolithic period attached great importance to the ritual of head burial: the carefully arranged heads were colored with ochre and embellished with over 200 pierced deer grandel (canine teeth) and more than 4,000 pierced snail shells.

The first farming settlers from the New Stone Age (Neolithic) also found good conditions here.

Celtic site on the Ipf hill

Celtic hilltop fort on the Ipf plateau

The Ries had one of the most important small-scale concentrations of settlements of early farmers in the German region. The locations of archeological finds indicate that Neolithic settlers also preferred the southern Ries basin. That was probably due to soil conditions there: wind from the southwest had blown loess that then accumulated on the leeward side of the crater rim. Almost all Neolithic finds are located in close proximity to the fertile loess soil. The few loess areas in the northern Ries were settled about four centuries later – presumably in the context of a growing demand for space. Around the end of the New Stone Age, early farmers also settled the sandy areas of the eastern Ries.

Grain has been cultivated in the Ries since the 6th century B.C.; root crops and forage plants came later. Still today, the fertile soil of the crater basin and the favorable climate – both indirect results of the impact event – provide good returns. Consequently, the region has been known up to current times as one of "breadbaskets" of Bavaria.

EXCURSION TIP

Celtic hilltop fort on the Ipf hill
The settlement of a Celtic noble of wide-ranging importance was on the Ipf north of Bopfingen. The isolated height was formed by erosion—its geological origins are not due to the Ries event.

Villa rustica (near Nördlingen, Holheim)
During the *Limes Germanicus* period, the Romans established agricultural estates on the fertile crater basin to provide supplies for legions at the border. The name "Ries" comes from the Latin name "Raetia."

① **130,000-year-old hand axe**
Archeological Museum, Donauwörth
Reichsstraße 34, 86609 Donauwörth
Phone: +49 906 789170

② *Ofnet Caves*

③ **Villa rustica** – *site of a Roman agricultural estate*

Good to know

THREATENED HABITATS

Dry-grasslands biotopes

Dry grasslands and heath landscapes are a refuge for many species. The Ries has space for these rare biotopes, but their preservation is not always easy.

A habitat made by human hands

Dry (or calcareous) grasslands are found in areas that were originally forested but used by the local population as pasture; they are referred to as herding forests. By nibbling on young trees and shrubs, pasture animals, especially sheep and goats, push the forest back. Clearings and semi-open areas appear until eventually dry grasslands remain.

Dry-grassland biotopes are always on nutrient-poor soil; they provide habitat for a multitude of plants and animal species that thrive in a specialized nutrient-poor and mostly dry location. In spite of the sometimes barren-looking landscape, dry grasslands are among the most species-rich biotopes in Central Europe. They are refuges for numerous endangered species, including many on the Red List of Threatened Species.

Dry grassland on the crater rim – a typical Ries landscape

While the deep, nutrient-rich soil in the crater basin has often been chemically altered by fertilization and agriculture, the geology of the soil on the heights of the crater rim has not changed. The special characteristics of the soil-forming bedrock – including blocks of basement and various sedimentary layers – considerably affect the vegetation. The heavily fragmented rock of the megablock zone is very often permeable to water; dry locations form on warm, sun-exposed slopes.

With about 620 hectares of dry grassland, the District of Donau-Ries is one of the most important “dry-grassland districts” in Bavaria. Located at the intersection of the Franconian and Swabian Alb, today’s heath landscapes serve a bridging function – a sort of corridor between biotopes. In addition, in this region, it is possible to find western-Mediterranean as well as eastern-continental and Alpine species side by side. The area is therefore considered a “hotspot” of biological diversity.

Carthusian pink *(Dianthus carthusianorum)*

Sheep: four-legged landscape conservationists

The heath landscape of the Ries is grazed by eleven large flocks of sheep. Migratory sheep-herding is a form of extensive pasture farming that has been practiced here for centuries. Regular grazing is the only way to avoid the dry-grassland areas becoming overgrown and reverting back to forests.

Nevertheless, socio-economic conditions are not favorable for this economic system – many of the traditional sheep farms have difficulty continuing their operations. At the same time, their use of the land is in competition with intensifying cultivation. Fertilization, reforestation, insufficient interconnections and lack of maintenance threaten this unique habitat.

The Heide Allianz – united for biodiversity

It is of utmost importance that the grazing animals are not penned up on the dry grasslands overnight. Excessive fertilization can have a long-lasting and adverse effect on the composition of the plant community.

Heide-Allianz DONAU-RIES

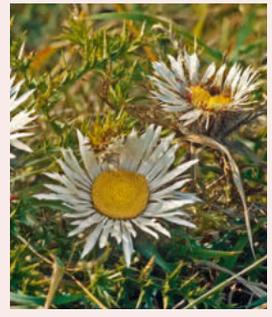
The Heide Allianz was established to preserve the valuable biotopes in the District of Donau-Ries, and it is a joint effort of nature protection associations and the District with its seat in Donauwörth. Its function is to secure areas for pens as well as for livestock trails, to maintain heath areas and to improve the marketing of shepherds’ products such as wool and lamb.

What is blooming there...?

Many wild herbs and medicinal plants thrive in dry grasslands. The flora of the alkaline soil of calcareous grasslands is especially rich in flowering plants; in contrast, sandy dry grasslands are acidic and the vegetation often distinctly resembles heath.

Typical representatives of dry-grassland flora are, for example, pasque flower *(Pulsatilla vulgaris)*, broad-leaved thyme *(Thymus pulegioides)*, common rock-rose *(Helianthemum nummularium)*, **Carthusian pink *(Dianthus carthusianorum)*** and **stemless carline thistle *(Carlina acaulis)***.

Calcareous grasslands’ warm meadows and abundant flowers are suitable habitats for numerous butterflies and grasshoppers, including rare species such as the hermit (a butterfly still existing only on the Ostalb), Chapman’s blue butterfly, lesser mottled grasshopper and grey bush cricket. The sand lizard *(Lacerta agilis)* uses sun-exposed slopes to warm up and to hunt. The semi-open landscape and transitional areas between dry grasslands and other biotopes are also ideal for many species of birds. For example, the red-backed shrike hunts on the borders between grazing areas and hedgerow country.



Stemless carline thistle *(Carlina acaulis)*

Ries panorama

THE AFTERMATH

How the landscape of today's Geopark was formed

At the end of the last Ice Age, tundra devoid of forest had developed in the Ries. The steppe-like landscape slowly evolved into a low birch forest. Additional thousands of years elapsed before a forest of oak and hornbeams developed that would represent the foundation for the forest now typical in the region. The area's deciduous forests are especially diverse and species-rich. Warmth and light have the greatest effect on the flora of the beech forest in the spring due to the lack of foliage.

Over the course of millions of years, the appearance of the Ries basin today developed from sedimentation in the Ries Lake, subsequent erosion of soil and rock by wind and water as well as deposits of loess and sand during the last Ice Age. The crater basin turned into an almost unwooded landscape, in which rivers and streams and their accompanying wetlands alternate with agricultural fields. In many places on the edge of the basin and on the crater rim, this landscape turns into dry grasslands. Widespread floodplains and wetlands provide the nutritional basis for the northern lapwing, Eurasian curlew, common snipe and white stork.

White stork family on church roof in Rudelstetten

ADVENTURE GEOTOPES

Geological processes have shaped the Earth throughout its 4.5-billion-year existence and constantly transform it further. The surface of our Earth and its forms and outcrops are a mirror into these processes. At some places on the Earth's surface, geological features emerge that eloquently relate the history of the Earth, reveal rare geological phenomena or simply are of particular beauty.

Sites like these – whether they are manmade outcrops like quarries or natural landscape features like caves, rock faces or steep cliffs – are called geotopes (Greek: *gé* = Earth, *topos* = place). Geotopes are geological landmarks, represent a landscape and make the formation history visible. That is why they are called "Windows into the Earth."

THESE SIGNS GUIDE AND INFORM YOU

Street signs
point the way to geotopes

Safety instructions
explain conduct on-site

Trail signs
regularly mark the route of Geopark nature trails

Info signs
along trails point to side trips or highlight **vantage points and outlooks**

Info panels
explain interesting facts

The geotopes described here were developed by the Geopark Ries between 2011 and 2014. Nature trails were created around particular "Windows into the Earth" in order to present the visitor with the most comprehensive picture possible of the impact event and its consequences and to facilitate a more profound experience of nature and the ecological relationships. Seating at "special" places invites lingering.

Landscape maintenance: By grazing, Valais Blackneck goats control vegetation in the quarry and on rock walls.

FACT SHEET

The first stop along the nature trail in the Adventure Geotope Lindle is the former Arlt-company quarry. A series of geological features are impressively apparent on the large, exposed rock wall. Here it can be seen how different types of rock, due to their qualities, were shattered by the shock wave and with what violence the shock wave traveled through the rock.
Along the trail, 13 info panels explain the features of the geotope and biotope. Seven vantage points look out into the Ries, over Nördlingen and to the crater rim. Seating invites lingering and picnicking at an outstanding view over Nördlingen and a large part of the crater. The path leads past two platforms (6,7) on gravel but is mostly natural. The path rises slightly uphill at one point, so it is not suitable for strollers or wheelchairs.

Starting point:
86720 Nördlingen, village of Holheim,
Am Lindle 1, Geotope parking
E: 4387287.01 N: 5410355.31
48.82042 10.46373

Geopark Nature Trail
Long circular path: ca. 3.3 km
Short circular path: ca. 1.8 km

Walking time: 1 – 2 hrs

Scan the QR code for audio guide and information to read.

ADVENTURE GEOTOPE LINDLE

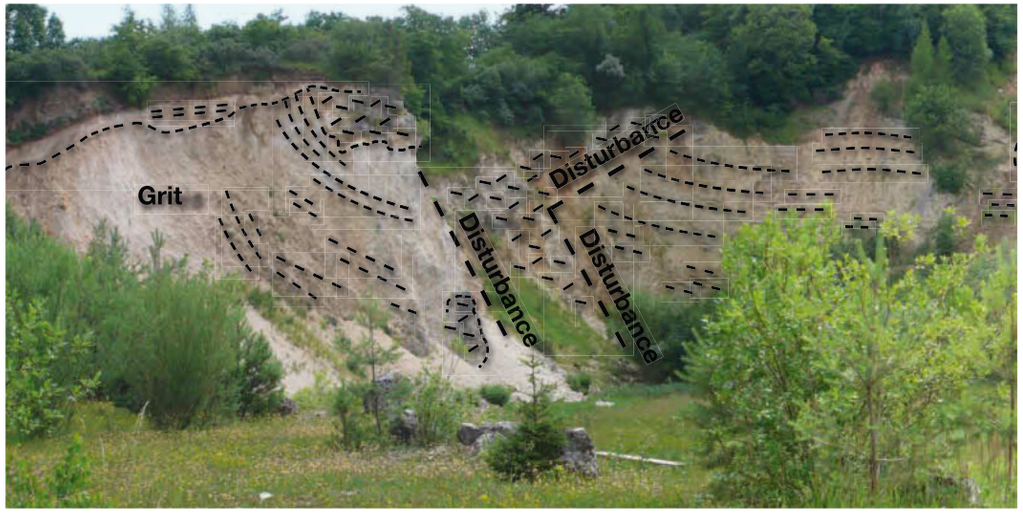
Searching for traces in the rock debris

The impact of the asteroid first formed a primary crater about 4.5 km deep with a diameter of about 12 kilometers (pages 10-11 & 13). In the seconds immediately following impact, huge blocks slid down the steep sides of the crater rim into the crater below. The crater thus spread further outwards until it reached a diameter of about 25 kilometers.

- 1-13 = *Location of info panels*
- = *Vantage point*
- = *Geological feature*
- = *Landscape feature*
- = *Archeological and cultural history site, ground monument*
- 6 = *Tower*
- 7 = *Platform with panorama photo*
- = *Geopark Nature Trail, large loop*
- = *Geopark Nature Trail, short loop*
- = *Seating*
- = *Quarry*
- P = *Geotope parking*

EXCURSION TIP

The Adventure Geotope Lindle is just about 5 km south of Nördlingen. The picturesque, well-preserved Old Town is full of lovingly renovated, splendid houses from the Middle Ages and Renaissance. Especially impressive: the completely preserved city wall from 1327 with five gates, 16 towers and one bastion. The parapet is also preserved, so it is possible to walk on the wall entirely around the Old Town. The symbol of Nördlingen is called Daniel, the 90-meter-high bell tower of St. George's Church. Climbing the steps to the top of Daniel is rewarded with a breathtaking view over the town and the Ries.



The blocks that slid into the crater but not far from their original position are called parautochthonous blocks. The area just inside the outer crater rim has an abundance of these blocks and is therefore called the megablock zone (see graphic page 13). Located within the megablock zone, Geotope Lindle allows a glimpse into the structure of such a mega-block. The rock of the former Arlt quarry primarily consists of Upper-Jurassic (Malmian) limestone – and includes thickly stratified limestone blocks of individual slabs built up into layers, interlocked with massive, homogenously-formed limestone.

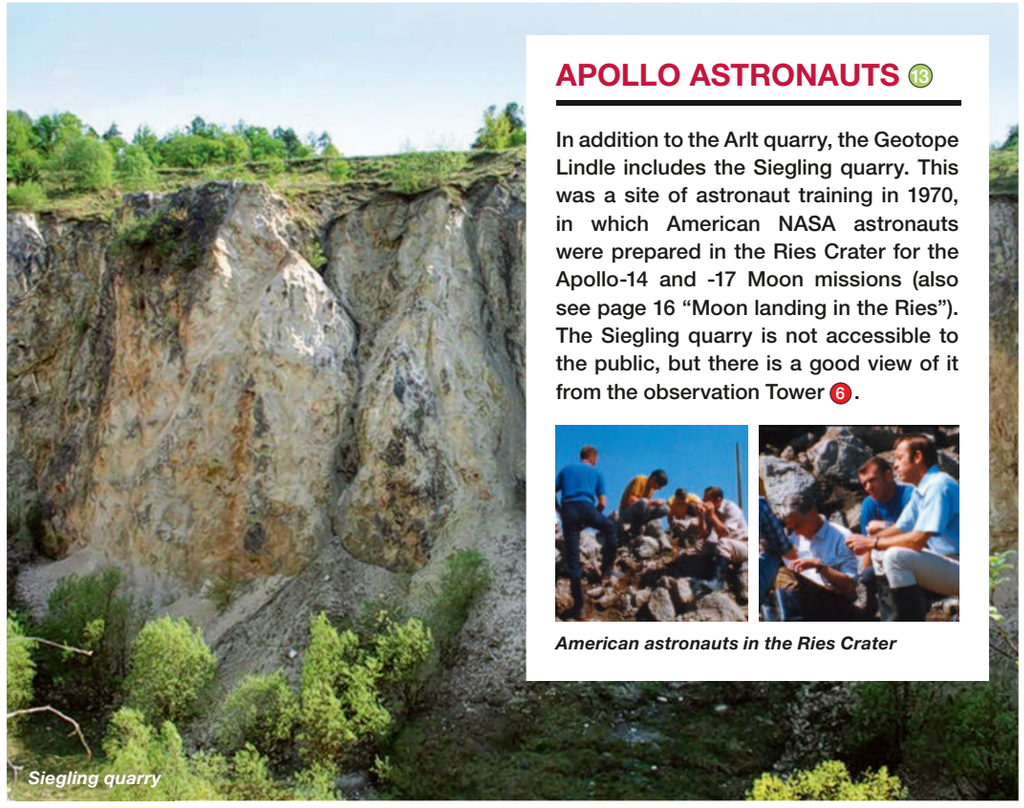
Seating with view of Nördlingen

The juxtaposition of these two types of limestone is especially observable on the exposure wall (info panels 6, 7). It is apparent that in most places the massive limestone was completely smashed into grit by the shock wave of the Ries event, while the thickly bedded limestone blocks were clearly less shattered. There is a simple explanation for this: in the bedded (that is, layered) rock, some of the energy of the shock wave was discharged along the joints between the individual layers. The rock layers did not remain completely intact, however, but were shattered into angular, small-size chunks (brecciation).

The inverse stratification typical for the Ries can also be observed in the Geotope Lindle: at the very top of the break-off edge of the exposure, the remains of the geologically older *Bunte Trümmermassen* (rock debris) are deposited in pockets, where it has endured more than 14 million years of erosion (more about typical Ries tectonics in “Geotope Kalvarienberg” page 30).

FEUERSTEIN 3

Over 125 million years ago, siliceous (glass) sponges lived on the floor of the Jurassic Sea here (see Geotope Kühstein). During the sedimentation process, they were trapped in limestone. These sponges contained silicic acid that was displaced in limestone through lime solution and collected by the inclusions. When rock was formed so were these nodules of flint – also known as *Feuerstein* (firestone). Due to its sharp cutting edge, this stone was used as raw material for hand axes and other Stone-Age tools. Visitors may try it themselves: Tapping is allowed only on the boulders placed for that purpose – it is very likely *Feuerstein* will be found.



Siegling quarry

APOLLO ASTRONAUTS 13

In addition to the Arlt quarry, the Geotope Lindle includes the Siegling quarry. This was a site of astronaut training in 1970, in which American NASA astronauts were prepared in the Ries Crater for the Apollo-14 and -17 Moon missions (also see page 16 “Moon landing in the Ries”). The Siegling quarry is not accessible to the public, but there is a good view of it from the observation Tower 6.

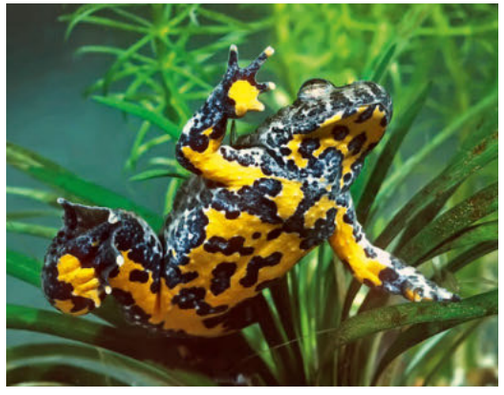
American astronauts in the Ries Crater

SUEVITE

The quarry Altenbürg is located along the Shepherd's Way trail about 2 km from the Adventure Geotope Lindle. The Ries rock Suevite was excavated here. This is probably where the building material for St. George's Church with the 90-meter-high tower Daniel was obtained (see also page 14 "Suevite – *Schwabenstein*"). A visit to the quarry is possible whenever the on-site restaurant is open (request the key there).

BIOTOPE

Typical for the megablock zone of the Ries Crater, soil properties change frequently and abruptly in Geotope Lindle. This is due to the diverse blocks and rock debris that were whirled together during the Ries event and came to rest on the surface in a chaotic dispersion.
Mainly dry biotopes form over limestone because of its high water permeability. But where *Bunte Breccia* containing clays occur, the ground is impermeable. Shallow bodies of water arise, fed only by rain, that can again completely dry out. These ponds are spawning waters and habitat for numerous animal species including toads, lizards, various insects and water snails.



Yellow-bellied toads* (Bombina variegata) *find an ideal environment in the ponds and are adapted to the extreme conditions (alternating from moist to dry).

EXCURSION TIP

The Shepherd's Way offers a longer hike near the Adventure Geotope Lindle and follows a traditional trail for migratory shepherds (length of trail: ca. 18 km; walking time: 5.5-6 hours). The trail begins and ends at the parking area of the Marienhöhe swimming pool in Nördlingen. The trail leads past geological and archeological sites that are explained in six informative panels.

In close proximity to Geotope Lindle, the Riegelberg hill is composed of limestone. Over millions of years, carbon dioxide in water permeating rock can partially dissolve limestone and lead to the formation of caves (karstification). The Ofnet Caves bear witness to this even today.

Archeological excavations in the caves have revealed numerous Stone-Age finds. Above all, the Ofnet Caves owe their prominence to Robert Rudolf Schmidt's 1907 discovery: The researcher from Tübingen uncovered two nests of skulls (see also page 18 "Hand axes and nests of skulls").

Ofnet Caves

FACT SHEET

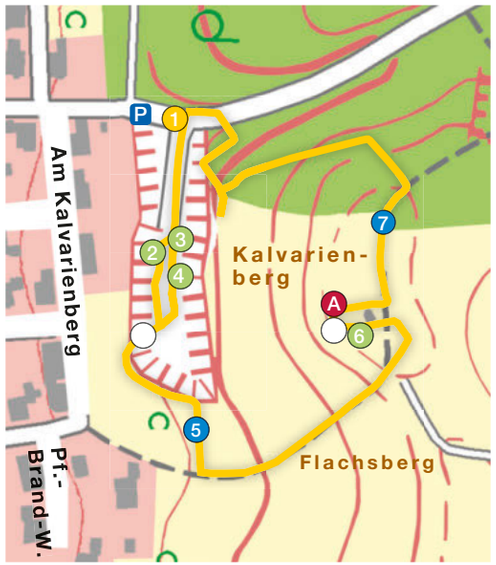
In Gosheim's Geotope Kalvarienberg, the exposures of the non-operating limestone quarry demonstrate the force and energy of the shock wave released by the Ries event. The nature trail leads over gravel and meadow paths through the publicly accessible quarry and then over the Kalvarienberg (Calvary Hill), along a 19th-century Stations of the Cross and past a chapel before returning to the starting point. Two seating areas invite lingering over a picnic or snack. The path climbs some stairs and is not suitable for strollers or wheelchairs.

Starting point:
86685 Huisheim-Gosheim,
Grüner Weg 16, Geotope parking
E: 4406429.39 N: 5411317.55
48.8322 10.72413

Geopark Nature Trail: ca. 1.0 km

Walking time: ca. 30 min

Scan the QR code for audio guide and information to read.



1-7 = *Location of info panels*
A = *Outlook with panorama photo*
= *Geological feature*
= *Landscape feature*
= *Geopark Nature Trail*
= *Seating*
= *Quarry*
P = *Geotope parking*

GEOTOPE KALVARIENBERG

A cosmic bomb moves mountains

Geotope Kalvarienberg is situated directly on the eastern crater rim in the megablock zone (graphic page 13). Here, despite their mass, huge blocks were moved over a wide stretch toward the east by the force of the shock wave produced by the Ries event – today their corresponding bedrock lies several kilometers west of the Geotope. Due to the braking effect of the accelerated blocks, the layers were partially buckled and pleated – wrinkles or creases like these are visible in several places in the quarry.

Such processes are only conceivable bearing in mind the energy that was released by the impact of the asteroid: Conservatively estimated, the explosion can be compared to hundreds of thousands Hiroshima-type atomic bombs. New experiments and calculations of the mechanics of the impact event have shown, even a megablock the size of the Kalvarienberg can be hurled through the air on a flat

KALVARIENBERG

Kalvarienberg (Calvary Hill) is also a destination for Stations of the Cross that start in Gosheim and lead to the summit. There, between rock faces and dry grasslands, stand a cross and a chapel. Every year on Good Friday, a procession of the faithful makes its way to the cross.

Chapel of the Sacred Heart

RIES BELEMNITES 4

“Ries belemnites” are a special feature of the limestone at the crater edge. These are fossilized skeletal remains of a small relative of the squid family. The shock wave of the Ries event fragmented the fossils into small slices that were subsequently re-attached to each other by the lime solution circulating in the rock. The resulting fossils – re-assembled offset slices – are typical for the Ries – and remarkable. With luck, a visitor to Geotope Kalvarienberg can see such a fossil.

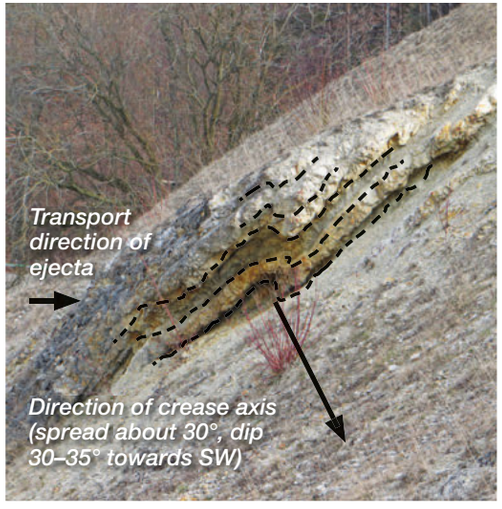
Various “Ries belemnites“ (Hibolithes sp.), a unique preserved shape

trajectory (ballistic transport) by pressures of nearly 10 gigapascals (about 100,000 atm) – surrounded by a thick cloud of debris.

Other megablocks were pushed over the ground in rolling-sliding movements – comparable to the processes by which glaciers move, just at higher speed. That left traces: the surfaces of some rock blocks display powerfully abraded areas on several sides, brightly polished or surrounded by contrasting mixed clays from various rock layers, whose streaky structure suggest a rolling motion. The clays could have played a lubricating role in rotational movement.

The Gosheim block is fairly rich in fossils; occasionally the fossils are even well preserved despite the shock wave. Fortunately the fossils include small ammonites, important as index fossils to determine the relative geological age. An analysis of these index fossils has verified that, in the exposed block in the quarry, older rock layers are situated on top of younger ones – in geology it is called an inverted deposit or inverse stratigraphy.
This sequence of rock layers, in opposition to the geological age, occurred when the uppermost rock layer sunk into the developing crater while, at the same time, being covered with *Bunte Breccia* that was ejected from deeper layers by the force of the impact. The deepest and oldest layer, the crystalline basement, rose as a glowing mushroom-shaped cloud over the crater that then dropped a layer of Suevite on top of everything else (see also page 14 “Suevite – *Schwabenstein*”).

Inverse stratigraphy is otherwise found only in fold mountains. In the megablock zone around the Ries Crater, though, it is pervasive – therefore Ries researchers designate this geological feature also as “Ries tectonic.”



Creases in Upper-Jurassic limestone, a result of the braking effect of the block; the creases spread toward the southwest.

EXCURSION TIP

Geopark Info-Point
A Geopark Ries Info-Point is conveniently located in Wemding. In addition to informative panels explaining themes of the Geopark, numerous local topics are also elaborated. The subjects range from scientific analysis of Suevite from the Otting quarry, to the life and works of botanist Leonhart Fuchs, to the second largest Marian pilgrimage site in Bavaria, Maria Brünnlein.

DRY GRASSLANDS 5

Surrounding Geotope Kalvarienberg are stretches of the sunny grazing land, interfused with hedges, so typical for the Ries landscape on the edges of the crater. Such semi-open dry-grassland biotopes offer ideal conditions for the red-backed shrike *(Lanius collurio)*. Birds of the shrike family build their nests in thorny hedgerows and sit on the edges of open areas to hunt large insects such as dragonflies and beetles and even small mammals like mice.
Above all, the red-backed shrike is well-known for his remarkable behavior of skewering his prey on thorns – a method of food storage. His German name, *Neuntöter* (nine-killer), derives from an erroneous folk belief that he will spear nine prey animals before he eats. The migratory bird overwinters in southern Africa.

***Red-backed shrike* (Lanius collurio)**

FACT SHEET

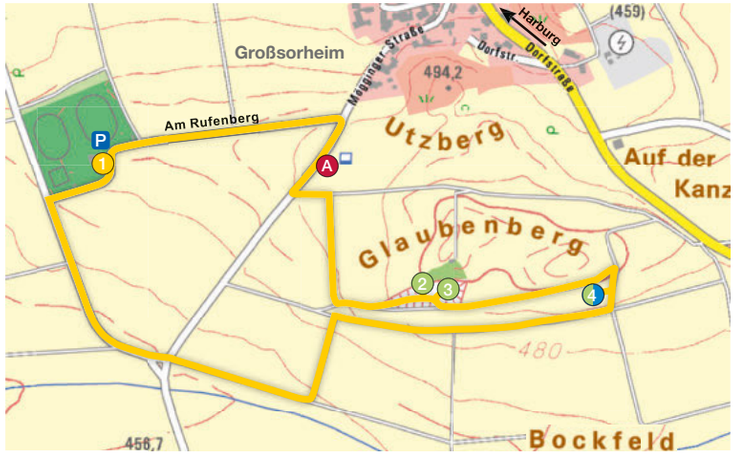
The nature trail through Geotope Glaubenberg follows gravel and meadow paths as well as a short street segment to a quarry south of the Harburg community of Großsorheim. The rock layers of the exposed face show chaotic stratification – here the natural order was completely confused in the course of the Ries event. Four info panels clarify the geology and natural history of the Geotope, and a panorama photo explains the magnificent view over the gently rolling countryside.

Starting point:
86655 Harburg, village of Großsorheim,
Am Rufenberg
Parking at sports field
E: 4399666.67 N: 5406490.99
48.7879 10.6331

Geopark Nature Trail: ca. 2.7 km

Walking time: ca. 1 – 1.5 h

Scan the QR code for audio guide and information to read.



1-4 = *Location of info panels*
3 = *with sediment-transfer preparation*
A = *Outlook with panorama photo*
= *Geological feature*
= *Landscape feature*
= *Geopark Nature Trail*
= *Quarry*
P = *Parking at sports field*

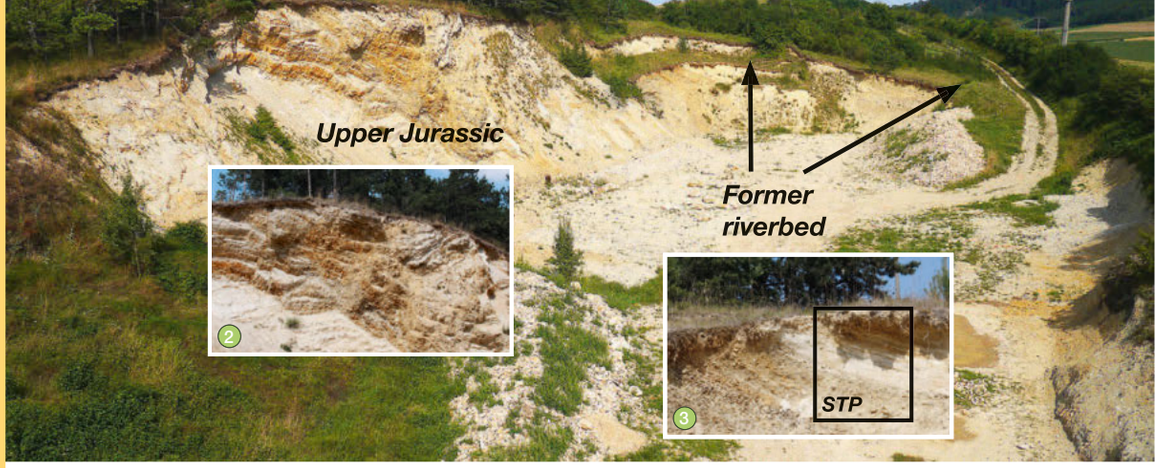
GEOTOPE GLAUBENBERG

A geological puzzle

Geotope Glaubenberg is located on a section of hilly landscape, about four kilometers wide, southeast of the outer crater rim in the so-called megablock zone (see graphic page 13). The elevations are composed largely of displaced blocks—massive rock debris that came to rest here after being hurled through the air or pushed across the surface by the shock wave of the asteroid impact.
The geological detail map (info panel 2) reveals the chaos caused here by the impact. In the area surrounding Geotope Glaubenberg, blocks of crystalline basement rock that are over 250 million years old are situated beside geologically younger Triassic and Jurassic blocks in a chaotic mosaic on the surface – an impressive witness to the way deeper and more shallow lying rock layers were churned pell-mell during the impact event.
The Geotope Glaubenberg Nature Trail leads to an inoperative quarry in which the town of Harburg had formerly excavated roadway material. The outcrop is composed of Upper-Jurassic limestone; fossil finds (ammonites, belemnites and sea urchins) verify an age of about 150 million years. The rock exposed in the quarry is structured predominantly from overlying, interconnected layers. Geologists call it bedded or stratified block.
Tracking the demarcation lines that distinguish these different rock layers, it is apparent that, within individual parts of blocks, they run in different directions, some only slightly diverging, others almost perpendicular to each other. The chaotic position of the blocks is recognizable in this line structure – the natural order is considerably disrupted. Even geologists can barely reconstruct the original positions and common origins of individual blocks – a geological puzzle still waiting for its solution.

Former riverbed 3

East (to the right) of the main face are layers of rubble, sand and crumbly sandstone. These are the deposits of the course of a river, probably a tributary of the ancient Wörnitz. The sediments also contain limestone from the Ries Lake that formed in the crater after the asteroid impact (see also page 9 “From seabed to crater basin”). The river must have come into existence after the Ries event.



Sediment-transfer preparation (STP)
Looking closely at the sediment, it is possible to recognize the sequence of different layers. The basis – that is, the undermost layer – is interspersed with coarse rubble. At first the river must have had a strong current, in order to carry along fragments of this size. In the middle layers, the deposits alternate between coarse- and fine-grained sediment. This is a clear indication of an abrupt change in the speed of the current. A possible explanation is short-term climate fluctuations, as often occurred during the Ice Age. During the brief warm periods, the tundra-like permafrost soil thawed for a few weeks and allowed rivers to swell to torrential flows. In the upper section of the sediment layer, fine-grain sand predominates; therefore the current was for the most part slow, before the river eventually ran dry. The rock sequence is illustrated and explained by the sediment-transfer preparation (STP) produced directly from this Geotope rock wall.

Deformed Upper-Jurassic block (front left) (2). The stratified Upper-Jurassic block Glaubenberg, a complicated block mosaic. In background, right-hand side, Ice-Age river bed. (3) Profile detail of Glaubenberg's Pleistocene (Ice-Age) fluvial deposits with interpretations of each dominant flow dynamic on the basis of the rubble and, respectively, gravelly sand portions; inclined layers due to more recent slides. (STP) Sampling point of sediment-transfer preparation.

EXCURSION TIP

The Ries is a land of fortresses and castles. Especially well preserved and certainly worthwhile to visit, Harburg Castle sits enthroned above the town of the same name. The extensive medieval complex – with archways, and other structures, of Suevite – was first mentioned in a document in the year 1150. A walk along the battlements is like immersion in the Middle Ages – peeking out through embrasures, passing jail cells, gates and towers. Tours are regularly scheduled.

Harburg Castle is the largest and best-preserved medieval fortress in the Geopark Ries.

SPECIAL GEOLOGICAL AND LANDSCAPE FEATURES

The displaced sandstone blocks were moved a long distance during the impact event. In spite of the strong shock wave, the sandstone surprisingly retained its original layers. The shock wave, however, loosened the formerly firm sandstone to predominantly fine-grained sand.

An additional exposure in the easternmost point of the nature trail offers a glimpse into the period before the Ries event. About 170 million years ago, today's Ries was flooded by a sea advancing into the region from the northwest. The coastline of this sea had already reached the vicinity of today's Munich. The Middle-Jurassic, reddish, sandstone blocks were formerly part of the bed of a sea strip that – similar to the Wattenmeer – was strongly affected by tides.

The rivers that flowed into the sea here brought with them a large amount of ferrous rubble. The shallow sea bed was extensively inhabited by microbes (biofilms), including specialized bacteria that through their metabolic activity turned iron into iron (III) hydroxide (the mineral goethite) and thus enriched the seabed where eventually rock layers formed out of the sediment.

Doggererze (a type of iron ore; Dogger is an earlier name for Middle Jurassic) demonstrates an iron content of up to 40%. Since the start of the 16th century and into the period of the Second World War, _Doggererze_ was mined in the Ries and distant surroundings to the Swabian and Franconian Alb as well as in Lothringen for iron production.

In Geotope Glaubenberg, alkaline soil over limestone alternates with acidic soil over Middle-Jurassic sandstone – as a result, an abrupt change in vegetation at the edges of different blocks is often noticeable. Typical representatives that grow on the acidic ground of sandstone blocks are the colonial bent, thyme-leafed sandwort, field wormwood, red bartsia, carline thistle and greater musk-mallow.

On the walls of the sandstone blocks, the sandy soil provides ideal living conditions for other inhabitants: Mining bees (genus _Andrena_) and solitary-living bees of the genus _Anthophora_ dig their nests in the soil here. The burrows for living and breeding can reach up to 65-cm deep in the loose, sandy subsoil.

FACT SHEET

The outcrops in Klosterberg permit a glimpse into the deep geological underground of the region. Here, on the northwest edge of the primary crater, rocks of the crystalline basement are exposed. The nature trail leads through the lovely landscape of Mauchtal (valley of the millstream Mauch) to two former crystalline quarries, Langenmühle I and II, and further to the Hahnberg quarry where a Ries-Lake-period algae reef is exposed. Seven info panels explain the geological, biological and historical features of the Geotopes, and a panorama photo elucidates the view of the crater landscape.

Starting point:
86747 Maihingen, Klosterhof 8,
Parking at Museum KulturLandRies
E: 3609334.530 N: 5422349.884
48.928867 10.491084

Geopark Nature Trail: ca. 2.6 km

Walking time: ca. 2 hrs

Scan the QR code for audio guide and information to read.

1-7 = *Location of info panels*
A = *Vantage point with panorama photo*
= *Geological feature*
= *Landscape feature*
= *Archaeological and cultural history site, ground monument*
= *Geopark Nature Trail*
= *Seating*
= *Quarry*
P = *Parking, Museum KulturLandRies*
= *Parking, Geotope*

GEOTOPES KLOSTERBERG

Geological dispatches from the depths

In the Paleozoic – over 300 million years ago – the continental plates of the two largest land masses at the time, Laurasia (or Euramerica, northern) and Gondwana (southern) collided. This collision caused the so-called Variscan, a mountain-building event. These mountains (of crystalline basement) appear today in Central Europe, for example, in numerous low-mountain ranges including the Vosges, Black Forest, Harz and also Ore Mountains. In many places – as around the Ries – the crystalline basement was subsequently covered by layers of sediment and rested hundreds of meters below the surface.

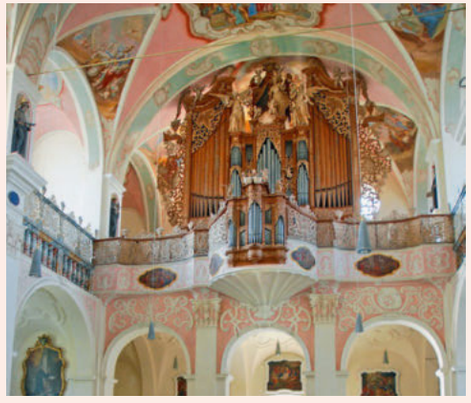
However, in the Geotopes Klosterberg – on the edge of the primary crater – the crystalline basement appears on the surface. Why? During impact, the Ries asteroid penetrated the sedimentary layers and at

first created a 4.5-km-deep crater that reached the crystalline basement (pages 10-11). The vaporization and ejection of rock led to a release of pressure – and the compressed basement of the basin floor rebounded. Subsurface material was pushed upwards hundreds of meters, sometimes at an angle, and so arrived on the surface. This phenomenon, unique for the region, can be explored in the former crystalline quarries, Langenmühle I and II, of the Geotopes Klosterberg.

Among the plutonic rock to be found in the Ries are **granite and gneiss**. Granite is igneous rock formed by the crystallization of melt. Gneiss is designated a metamorphic rock, formed under high pressures and temperatures during mountain building. For geologists, the blocks transported to the surface during the Ries event are very interesting dispatches from underground; they deliver clues, as to which rock exists at which depth, and allow comparison to the near-surface exposures of the places where the Variscan highlands appear. The Geotopes outside Maihingen also are of interest to space exploration. This is where the Apollo-14 and -17 astronauts who prepared for their missions in the Ries studied the mineralogical changes to crystalline basement caused by the Ries event (see also page 16 “Moon landing in the Ries”).

EXCURSION TIP

Convent in Maihingen &
Museum KulturLand Ries
Combine a walk on the Geopark Nature Trail with a visit to the convent in Maihingen. Construction of the convent began in 1437. Originally built of tuff and brick, the complex was significantly enlarged by the Brigittine order of Augustinian nuns. Besides the convent church Maria Immaculata (cornerstone ceremony 1712), the former mill, brew house and farm buildings exist today. Housed in the former convent’s commercial buildings, the Museum KulturLandRies impressively documents rural life in Ries.



The historic Baroque organ, (constructed 1734-37, restored 1988-90) with its preserved meantone temperament, is a special attraction.

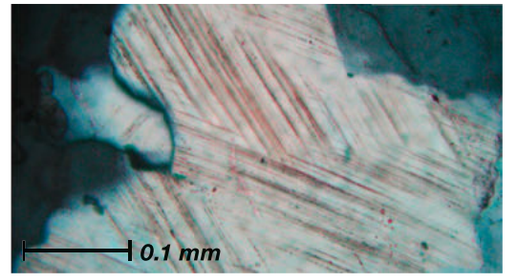
HIGH-PRESSURE MINERALS: EVIDENCE 5, HUNT FOR ORE 1

Rock-solid evidence
Ever since American underground nuclear-weapon experiments in Nevada in the 1950s, it is known that sudden pressure load affects mineralogy. On the basis of these findings, the renowned impact researcher Eugene Shoemaker examined thin sections of crystalline rocks from the Ries for corresponding deformation structures and the accompanying new mineral formations.
He found, among others, the high-pressure minerals coesite and stishovite, melted glass and so-called diaplectic glasses of quartz and feldspars as well as characteristic lamellae and fractures in the thin sections – all properties of rock that clearly point to an asteroid impact. Just like that Shoemaker could definitively prove in 1960 that the Ries was an impact crater. The interpretation of the Ries as a crater of volcanic origins was shelved.

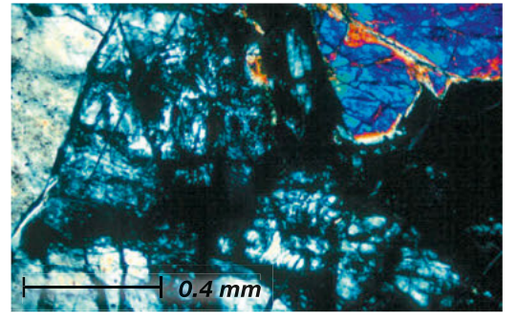
Mining for biodiversity
Crystalline rock, like that in the Geotopes near Maihingen, frequently also contains metallic ores such as gold and silver. Early on, that aroused interest in the Ries. In the 1670s, Prince of Oettingen-Wallerstein had exploratory shafts dug; quarries and exposed slopes were eagerly prospected. But according to historical sources, the activities ended in 1684 after even diviners were unsuccessful. As known today, the special features of Ries geology are due to greatly brecciated rock masses – in which no continuous, commercially-workable veins of ore are to be found. Dreams of gold and silver were dashed.
The tunnels created during the search for ore later served the convent and breweries in Maihingen and Marktoffingen as storage for beer and foodstuff. Today the tunnels and shafts provide suitable winter quarters for numerous species of bats. For example, documented here are the greater mouse-eared bat and the brown long-eared bat. In summer the Mauchtal, with its mosaic of diverse and near-natural habitats, provides a superbly suitable hunting ground for the bats. In this way, the exploratory tunnels make an important contribution to species conservation today.

Various types of bats hibernate in rock cellars.

Thin-section microscopy/electron microscopy of relevant minerals affected by a shock wave



Quartz with planar elements (shocked)



Plagioclase, planar deformation features (shocked, Moon)

FACT SHEET

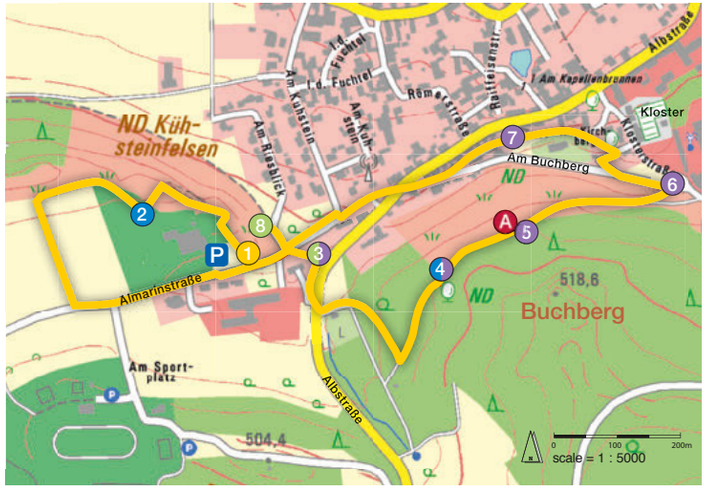
The Geotopes Kühstein are located directly on the edge of the village of Mönchsdeggingen. Here, on the southern rim of the crater, two quarries offer a look into the geological past of the region: a 160-million-year-old belt of reefs and the remains of a delta of the Ries Lake. On the 2.7-km nature trail, eight info panels explain the phenomenon of the Geotopes and the biological as well as historical significance. The top of the Buchberg hill provides a spectacular view of the Ries, its inner ring and outer rim.

Starting point:
86751 Mönchsdeggingen, Almarinstraße
E: 4395371.34 N: 5404854.86
48.772507 10.575113

Geopark Nature Trail: ca. 2.7 km

Walking time: ca. 1-1.5 hrs

Scan the QR code for audio guide and information to read.



- 1-8 = *Location of info panels*
- A = *Vantage point with panorama photo*
- = *Geological feature*
- = *Landscape feature*
- = *Archaeological and cultural history site, ground monument*
- = *Geopark path, Geopark Nature Trail*
- = *Seating*
- = *Quarry*
- P = *Geotope parking*

GEOTOPES KÜHSTEIN

Reefs in the Ries

The mid-Upper-Jurassic period, about 160 million years ago, was the great age of reefs. Worldwide, an enormous variety of reef-building organisms abounded – not just corals, algae and microbes, but also calcareous and siliceous (glass) sponges. In deeper water regions siliceous sponges created some large hilly structures (so-called mounds). The outcrop on the Kühstein cliff 8 opens a window into this geological period; here relicts of a former sponge-reef appear.

The Kühstein-hill, Upper-Jurassic limestone block with the exposed areas was greatly mechanically stressed when it and its neighboring block slid into the crater during crater formation. Nonetheless, the upper section of the outcrop is especially well preserved.

The section of the reef visible on the Kühstein cliff belongs to the so-called Ries-Wiesent reef-tract that traversed the region of the Franconian Alb in the Jurassic Sea. It was part of a gigantic, interconnected belt of sponge reefs that stretched over 7,000 kilometers from the Caucasus across Romania,

Presumed expanse of the over 7,000-km-long Upper-Jurassic siliceous-sponge reef belt

Small hill-shaped reefs (mounds) of living siliceous sponges, ca. 200-meters deep, off Canada's western coast.

Poland, Germany, France, Spain and Portugal to New Zealand and even Oklahoma – an impressive witness to the importance of sponge organisms to reef building at that time.

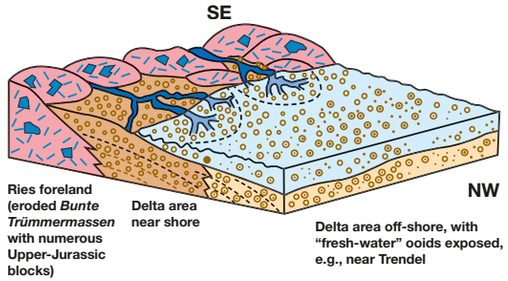
Never again in the Earth's history have siliceous sponges attained this significance. For a long time, researchers questioned whether still-living sponge reefs existed. Only in 1987 did they discover, in 200-meter-deep water off the western Canadian coast, a similar hill-shaped reef formed by sponges – a real surprise.

The Mönchsdeggingen quarry offers another geological highlight near the former community sheep farm 3. Close observation of the rock layers reveals how coarser and finer rubble alternates. Also called clastic rock, these fragments – according to layer – exhibit completely different forms and degrees of rounding. Coarse and fine rubble is partially separated into layers, but there are also banks with fully mixed components.

This outcrop exposes sediment of a former river delta. Here a tributary emptied into the lake in the crater. The sequence of layers in the rock profile illustrates the climatic circumstances around the time of the Ries event. Characterized by increasing seasonal precipitation, the inflow amounts and water levels of the Ries Lake were evidently subject to strong fluctuations at times. The deposits and degree of cementation in the sediments changed with the strength of the current – which explains the sequence of the various layers. The profile of the river delta also reveals something about climate fluctuations on a small scale; the alternating rock sequences can be interpreted indirectly as a climate archive.

EXCURSION TIP

After a sunny hike in the Geotope, tired feet can rejuvenate in the Kneipp "bath." To reach the facility, leave Mönchsdeggingen and travel towards Merzingen – it is located ca. 200 meters on the right-hand side. There is a round foot bath and an arm basin as well as a small, wet biotope.



Block-diagram reconstruction: presumed situation on shoreline of Ries Lake during period of the filling of the river delta at Mönchsdeggingen from the southeast (SE) to the northwest (NW). Possible shore vegetation not included.

BIOLOGY ON KÜHSTEIN 2

Among the rare animal species on the Kühstein hill is the smooth snake *(Coronella austriaca)* that is dependent on sunlit woods and dry grassland. Smooth snakes love dryness and warmth, so sun-exposed dry grasslands provide a biotope well-suited for them.
Smooth snakes often remain motionless and trust their camouflage. The snakes strangle larger prey by tightly coiling their bodies around their victims.

Although the smooth snake is strictly protected, again and again it is mistaken for the common European adder (also strictly protected) and killed as an allegedly dangerous poisonous snake. They are also threatened by the progressive destruction of their habitat.

In addition to protecting biotopes themselves, the prominent Kühstein cliffs are rimmed by species-rich dry grasslands with individual juniper trees and hedgerows. Biotope mapping has recorded 130 plant species in the area around Kühstein. Above all, the cliffs exhibit valuable rock-face vegetation, including basil thyme *(Acinos arvensis)* and the fern called wall-rue *(Asplenium ruta-muraria)*. The most well-known representative of rock-face vegetation is the white stonecrop *(Sedum album)*.

Although often mistaken for the common European adder, the smooth snake is not poisonous and is completely harmless to people.

The white stonecrop is a succulent plant with fleshy, water-storing leaves that has adapted to a hot, dry climate.

7 The "court linden" (or "court lime tree") in Mönchsdeggingen is estimated to be over 1,000 years old. During the Middle Ages, the village court or council would be held publicly under the tree. Moreover, the linden in Mönchsdeggingen was probably used as a "dance linden" with a podium for musicians and dancers.

ART IN THE WOODS 4

"Säulengang" by Elke Stadlmayr. The "Kunstwald" project concerns transience and will change itself over the years.

FACT SHEET

A 1.7-km-long nature trail leads through the Geotope Kalvarienberg in Wörnitzstein. The Geotope lies in the middle of a geological debris field – rock blocks flung by the meteorite impact landed here as *Bunte Trümmermassen*. In addition to illustrating how these ejected materials affected the transformation of the landscape, the four info panels describe settlement and natural history features.

Starting point:
86609 Donauwörth - Wörnitzstein,
Abt-Cölestin-Straße
E: 4406328.09 N: 5400073.57
48.731110 10.724976

Geopark Nature Trail: ca. 1.7 km

Walking time: ca. 1 hr

Scan the QR code for audio guide and information to read.

- 1-4 = ***Location of info panels***
- = ***Geological feature***
- = ***Landscape feature***
- = ***Archeological and cultural history site, ground monument***
- = ***Geopark Nature Trail***
- = ***Quarry***
- P = ***Parking***

GEOTOPE KALVARIENBERG DONAUWÖRTH - WÖRNITZSTEIN

In the midst of debris – the southern Ries foreland

The impact of the Ries meteorite devastated an area of hundreds of kilometers surrounding the crater. The Jura plateau was fractured into myriad fragments. Blocks of all sizes – including *Schollen* hundreds of meters in diameter – flew, rolled or slid in all directions from the crater. Masses of sediment – among them Jurassic and Triassic Keuper – were shattered into the tiniest particles. Mixed together, the smashed sediment and the hard block fragments became *Bunte Trümmermassen* (literally, colorful detritus), tiny scraps of which have been detected up to almost 200 km from the crater.

In the midst of this debris lies Geotope Kalvarienberg in Wörnitzstein. Here, a good 20 kilometers from the crater center, are blocks of considerable size. Further crater-outwards the size of the blocks decreases. After the Ries event, the *Trümmermassen* were affected by erosion and weathering – but to varying extents, depending on the hardness and composition of the debris. Strikingly etched, two displaced blocks protrude out of the landscape to this day: the Sendenberg and the Kalvarienberg. The hills of weathering-resistant detritus characterize the typical landscape in the Ries foreland.

Especially prominent, the Kalvarienberg rises from the landscape. Enthroned on the summit is the Kalvarienberg Chapel, erected in 1750 under Abbot Cölestin zu Kaisheim. The cliff of massive Upper-Jurassic limestone came to rest eight kilometers away from the crater rim after the impact. Despite being profoundly shattered by the shock wave, it offered a good building site – meanwhile most fissures have mended. From the top, there is a great view of the Ries foreland and the Wörnitz valley.

The displaced limestone block now called Sendenberg (2) also stands out strikingly over the landscape. The exposure shows bedded and massive rock sections, with respectively different degrees of disruption, that are interwoven together. In addition, the bedded portions are tilted relatively steeply, an indication of the turbulently acting forces during transport. The megablock must surely have been repeatedly rotated and also fragmented. For a long time, material for road construction was extracted from the block because of the extensive mechanical shattering.

The debris that landed in the Ries foreland also had a large effect on the course of the bodies of water at that time. Rivers were dammed and rerouted; due to the flows of the primordial Main and Altmühl, a large body of water (Rezat-Altmühl Lake) formed to the north of the crater; it can be geologically traced today.

Kalvarienberg ("Calvary Hill") Chapel

THE WÖRNITZ VALLEY (3)

With respect to nature protection, the Wörnitz valley is one of the most valuable in Bavaria, providing habitat for numerous species immediately threatened with extinction. One of the most prominent species is the white stork, who uses waterfront fields as feeding areas. Horsts are located in nearby Donauwörth and Harburg. The fields between Wörnitzstein and Ebermergen boast a diverse mosaic of wetland meadows, shrub swamps, large-sedge reeds and reed beds rich in sedges and rushes.

***Wörnitz with millstream:** Typical for the use of water power is splitting off into a millstream (waterway on left) and lower course. Water level is regulated by a low-head dam (in foreground).*

The water of the Wörnitz is somewhat burdened with an increased input of nutrients, but it is nonetheless the only body of water in Bavarian Swabia to have a so-called bream region – the species-richest fish region of a river of this lower reach. The main fish species is the common bream *(Abramis brama)*, but there are also white bream, common roach, wet catfish and the predatory fish zander, northern pike and perch. The presence of mussel species (thick-shelled river, painter's and swan) is indicative of especially good water quality.

Warinza – a river despite debris
The Wörnitz is a river with a long history. Even before the Ries event, the primordial Wörnitz ran close to its current course. Drilling and geophysical deep soundings have been able to demonstrate that it flowed through an 80-meter-deep, fjord-like, carved river valley with steep sides and eventually into the molasse basin to the south. This early Wörnitz valley was blocked by the debris ejected during the Ries event.

Following the Ries catastrophe, some time passed before the primordial Wörnitz, together with the early Eger, could once again reclaim the original course through today's crater region. In the period after the Ries event, the primordial Wörnitz washed away soft Ries-Lake sediment and contributed to the uncovering of the original crater form. In this way the river participated noticeably in the design of the Ries landscape familiar today.

EXCURSION TIP

For good sports: the Wörnitz bike path
The Wörnitz bike path follows the course of the Wörnitz from its source until it flows into the Danube, about 132 kilometers long in total. It meanders through wide meadow valleys, then across the Ries Crater, breaks through the crater-rim heights near Harburg and reaches the Danube in Donauwörth.
The bike path is about 100 kilometers long and presents a relatively low elevation profile. Along the route, there are landscapes and attractions to admire – and a regional cuisine to enjoy. Well-known spots like Schillingsfürst, Dinkelsbühl, Wassertrüdingen, Oettingen, Harburg and Donauwörth – to name just a few – invite lingering or an overnight stay.
www.woernitzradweg.de

GLOSSARY

Scientific terms

Beaufort
The Beaufort scale is the most widely used system to express wind speed. Beaufort Force 6 is equivalent to ca. 39-49 km/h.

Biofilm
Connected, layered communities of microorganisms that grow on firm ground such as marine sediment.

Breccia
(Italian *breccia*: loose gravel), part of *Bunte Trümmermassen*
Originally consolidated clastic rock with angular-cornered fragments; formed in various ways. The term *Bunte Breccia* refers exclusively to the foreland of the Nördlinger Ries; it describes debris resulting from the impact of the Ries meteorite – more or less loose, local, often very different compositions of *Trümmermassen*, formed by the intense, random mixing due to ballistic ejection and movement of materials, then deposited over the Ries foreland.

Diaplectic glass
In contrast to normal glass created by undercooling a melt, diaplectic glass is formed when the lattice of a crystal is destroyed by extreme force in the form of a shock wave.

Dry grasslands
Areas of grassland not suitable for agriculture, permeable soil, maintained by grazing; generally nutrient-poor soil, nevertheless distinctive for the great diversity of animal and plant species supported by the habitat.

Extraterrestrial
(Latin *extra*: outer; *terra:* Earth)
Heavenly bodies outside of the Earth and its atmosphere are designated as extraterrestrial.

Fluviatile sediment
(Latin *fluviatile*: of a river)
Reduced rock fragments carried by flowing waters.

Gneiss
Rock with parallel texture, formed by geological metamorphic processes that affect large areas, contains more than 20% feldspar.

Impact
Designates impact of a cosmic body (for example, meteoroid, asteroid or comet) on the surface of a usually larger body; it forms an impact crater.

Loess
Fine-grained sediment, not layers, contains calcium carbonate, generally yellow-brown color.

Massive limestone
Limestone without internal separation seams, "massive" appearance, predominantly the result of reef building by siliceous sponges or corals, often visible as hill-shaped rises in rock masses.

Megablock (zone)
Blocks of various compositions, with diameters from tens to hundreds of meters, rarely larger: characteristic for the peripheral areas of meteorite craters (so-called megablock zone), mostly slightly moved (parautochthonous).

Middle Jurassic
Soil type formed by deposits in the Jurassic Sea; ochre-brown to reddish color and fine-grain structure are characteristic. Formerly equated to Dogger or brown Jurassic.

Parautochthonous
Blocks pushed or slid minimal distances, retaining a certain connection to original root location (autochthonous). The outer Ries Crater rim is characterized by a megablock zone composed of blocks that slid (see graphic page 13). The Geotope Lindle highlights one of these megablocks.

***Schollen* (Blocks)**
Generally larger, more or less isolated blocks of rock, in the Ries area, resulting from the mechanical fragmentation of the surface by the impact of the meteorite.

Silicic nodules
Originate from former siliceous sponges that built small reef patches on the seabed; also known as flint.

Stratigraphic
Pertaining to the age determination of rock layers.

Trümmermassen
-> Breccia

Tuff
Volcanic rock.

Upper-Jurassic limestone
Light-colored limestone of the youngest series of the geological system Jurassic, widely distributed in Ries region, original rock unit affected by meteorite; appearing in both manifestations as massive and bedded limestone.

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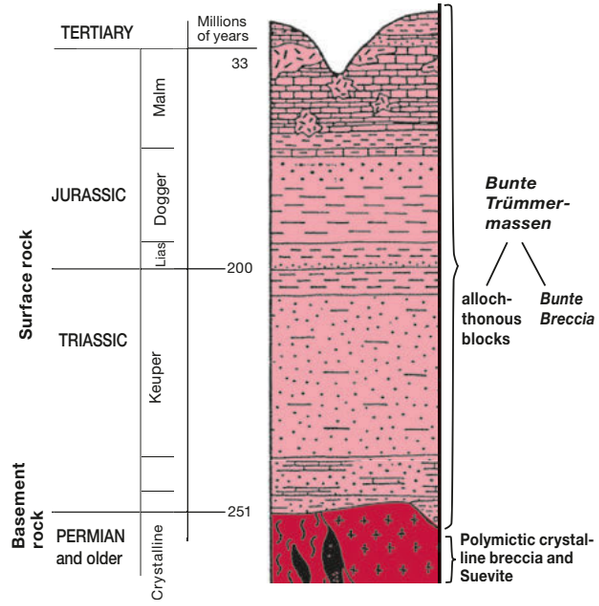
IMPACT ROCK OF THE RIES

Stratigraphy of starting material



Pre-impact geology

GEOPARK RIES

Europe's Giant Meteorite Crater

Location in southern Germany

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NATIONAL GEOPARK RIES

For additional information, visit our website at www.geopark-ries.de

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