COUNTDOWN TO MASS EXTINCTION?

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The Museum Ladin presents this exhibition on the greatest mass extinction in Earth's history and the current climate crisis.

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0 INTRODUCTION

The Museum Ladin presents this exhibition on the greatest mass extinction in Earth's history and the current climate crisis. It strikingly highlights the parallels between the climate catastrophe triggered by massive volcanic eruptions in Siberia about 252 million years ago and today's climate change. Today, our activities release more CO_2 annually than those Siberian volcanoes at their peak annual emissions. The exhibition vividly demonstrates how that mass extinction occurred through fossils from the Bellerophon and Werfen Formations, drawing direct comparisons to the urgent climate crisis of our times.

WHAT IS A MASS EXTINCTION?

2 Jack Sepkoski (left) and his colleague David Raup (right)

Jack Sepkoski (1948-1999), a renowned paleontologist at the University of Chicago, Illinois, was the first to define mass extinction in 1986.

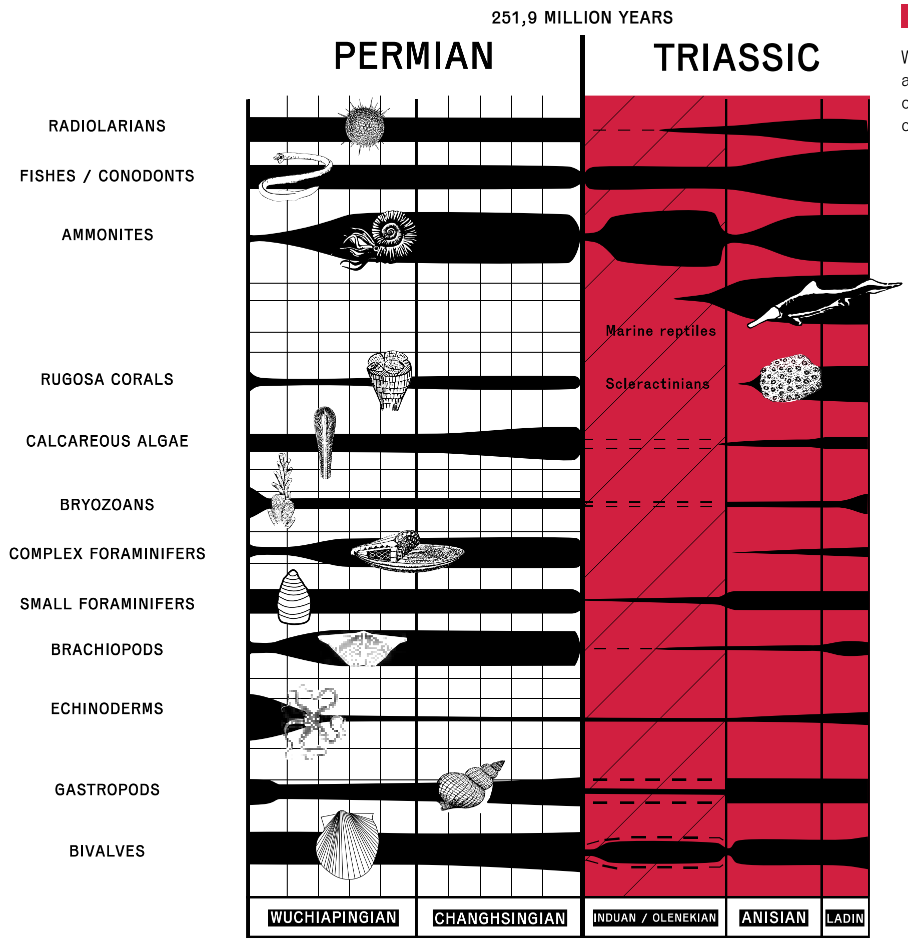
A MASS EXTINCTION MUST MEET THE FOLLOWING CRITERIA 1

1. There must be a significant increase in the rate of extinction
2. More than one widespread higher taxon must be affected, including at least genera, families, or classes of organisms (for example, ammonites, dinosaurs).
3. There must be terminations of evolutionary lineages.
4. There must be a temporary decrease in existing diversity.
5. And this during a relatively short geological period.

JACK SEPKOSKI 2 and his colleague David Raup identified five major mass extinctions, which they classified as the “Big five”. In addition, Sepkoski compiled extensive worldwide datasets of marine animal families and genera. Through the evaluation of this information, he was able to determine three successive ‘Evolutionary Faunas’ that represented the predominant groups. 3

THE NATURAL BACKGROUND EXTINCTION RATE

Estimates suggest that about 10% of species go extinct every million years, 30% every ten million years, and 65% every hundred million years. Extinction is thus a natural part of evolution, requiring a balance between the loss and the emergence of new species. In a mass extinction, however, at least 75% of species disappear in less than a million years, which is a short period by geological standards.



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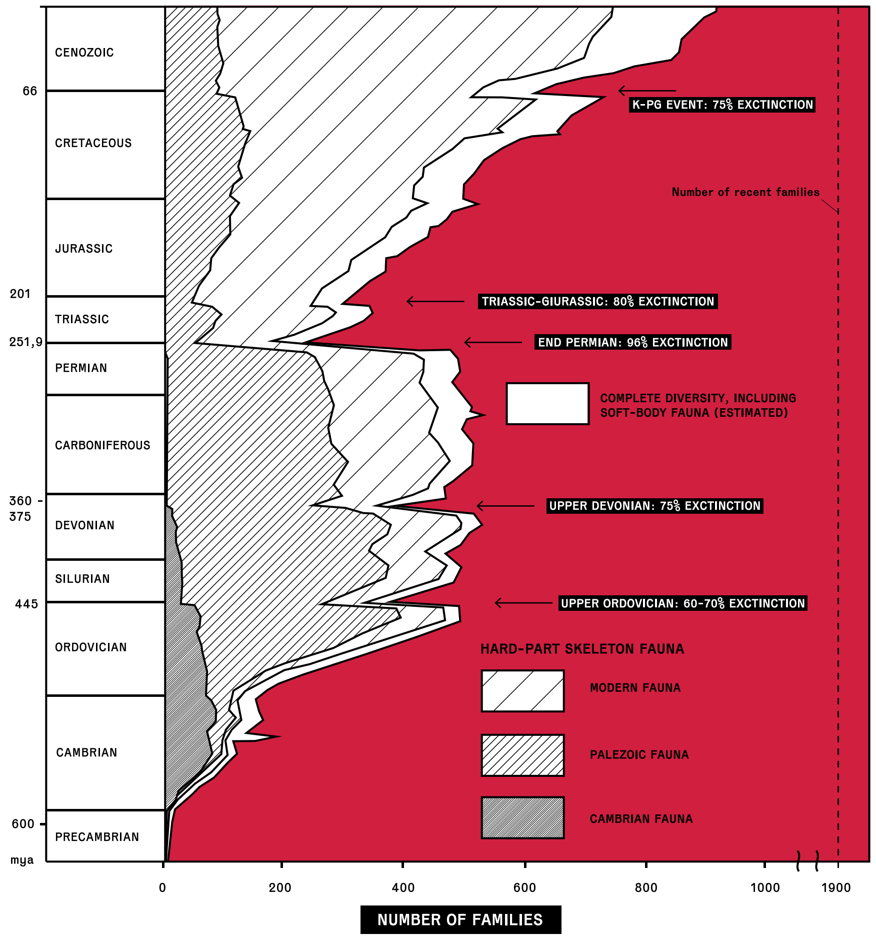
With an extinction rate of up to 96% for marine organisms and around 70% for terrestrial vertebrates, the mass extinction that occurred at the end of the Permian represents the greatest catastrophe in Earth's history.



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Sepkoski's diversity chart, 1984

1 THE WORLD BEFORE THE MASS EXTINCTION

Have you ever wondered what the world looked like when all continents were connected into a single supercontinent? Discover the upper Permian period, 254-252 million years ago, when the Dolomite area was near the equator and covered by the Tethys Ocean.

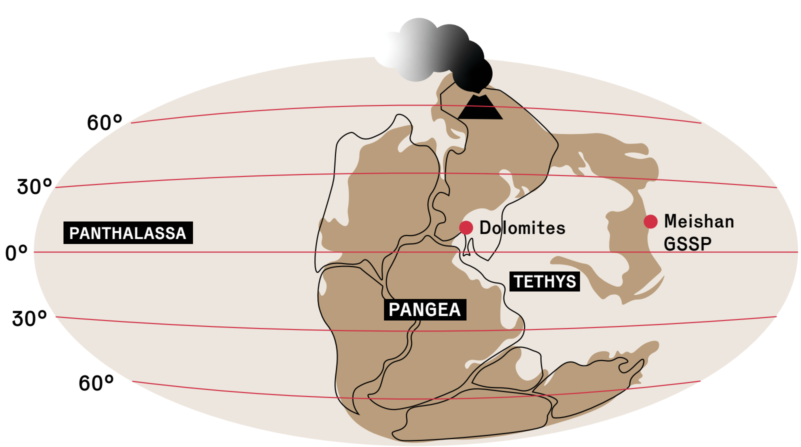
THE PERMIAN 1

2 Roderick Murchison

The Permian is a segment of Earth's history that began about 298.9 million years ago and ended about 251.9 million years ago.
2 The Scottish geologist **Sir Roderick Murchison** named the Permian period after the city of "Perm" at the foot of the Ural Mountains in 1841.

THE WORLD AT THE END OF THE PERMIAN

3 4 At the time of the supercontinent Pangea, when all continents were united, the future Dolomite region was located near the equator, around the 15-20th latitude. This corresponds to the current location of countries like Oman, Yemen, and Niger. The area was covered by a shallow, warm tropical sea, the Tethys Ocean. In this sea, the beds of the Bellerophon Formation were deposited. Since that time, the area has shifted about 3500 km northward.



3 Reconstruction of Pangea and Tethys at the end of the Permian 252 million years ago

4

Terrestrial environment at the Bletterbach during the Upper Permian

ERA	DATE	PERIOD
CENOZOIC	2,6	QUATERNARY
	23,3	NEOGENE
	66	PALAEOGENE
MESOZOIC	145	CRETACEOUS
	201,4	JURASSIC
	251,9	TRIASSIC
PALAEOZOIC	298,9	**PERMIAN**
	358,9	CARBONIFEROUS
	419,2	DEVONIAN
	443,8	SILURIAN
	485,4	ORDOVICIAN
	538,8	CAMBRIAN
		PRECAMBRIAN

1

The Permian period

5

Bellerophon Formation, Seceda, Ortisei

THE BELLEROPHON FORMATION

5 The Bellerophon Formation comprises rock layers from the late Permian (about 254-252 million years ago), deposited in shallow marine areas. Its fossils display the diverse marine communities just before the mass extinction at the end of the Permian.

2 THE MARINE ECOSYSTEM OF THE LATE PERMIAN PERIOD

DIVERSITY AND ADAPTATION

The Bellerophon Formation testifies to a remarkable diversity of marine organisms shortly before the largest mass extinction in Earth's history. Explore the different marine habitats - from stress-plagued coastal areas to more stable shallow water areas, which were rich in nautiloids, bivalves, and other marine organisms.

LIFE BEFORE THE CATASTROPHE

THE GREAT BIODIVERSITY

Biodiversity, the variety of life, includes genetic, species, and ecosystem diversity. It is crucial for the resilience of ecosystems, especially in times of crisis. A high species diversity in an area increases stability, as the loss of one species can be compensated by others. This helps ecosystems to better withstand disturbances such as climate change. However, a lack of species diversity can increase the risk of rapid ecosystem collapse.

THE SEA OF THE BELLEROPHON FORMATION WAS DIVIDED INTO TWO DIFFERENT HABITATS

- A stressed shallow, nearshore area with unstable ecosystems, subject to rapid changes, such as fluctuating sea levels, changing salinity, high temperatures, low oxygen levels, and high sediment influx from rivers. Only a few resilient species survived here.
- A more stable marine habitat with a diverse fauna of nautiloids, bivalves, some brachiopods, calcareous algae, foraminifera, ostracods, and numerous *Bellerophon*.

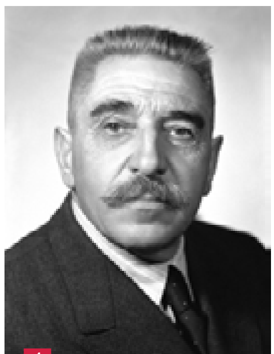
THE MARINE ECOSYSTEM DURING THE UPPER PERMIAN WAS DIVIDED INTO THREE TROPHIC LEVELS

- **Primary producers and detritus:** this includes, for example, the calcareous algae, which produced biomass from inorganic substances through photosynthesis. Detritus refers to dead organic matter or debris produced by living organisms.
- **Herbivores or primary consumers:** this included various species of marine invertebrates (e.g., bivalves, gastropods, brachiopods) that fed on the primary producers.
- **Carnivores or secondary consumers:** nautiloids and larger predators as sharks that fed on the primary consumers.

1 Guido Stache

2 Maria Matilda Ogilvie Gordon

3 Giovanni Merla



4 Michele Gortani

WHO WERE THE PIONEERS IN THE STUDY OF THE FOSSILS FROM BELLEROPHON FORMATION?

1 **Guido Stache** (1833-1921) was an Austrian geologist and paleontologist, known for his significant contributions to the study of the Bellerophon Formation in the Dolomites, which he published in *“Beiträge zur Fauna der Bellerophonkalke Südtirols” (Contributions to the Fauna of the Bellerophon Limestone of South Tyrol)* in 1877 and 1878.

2 **Maria Matilda Ogilvie Gordon** (1864-1939), was a Scottish geologist known for her research in the Dolomites. Her research also covered the fauna of the Bellerophon Formation. Her notable work *“Das Grödener-, Fassa- und Enneberggebiet in den Südtiroler Dolomiten” (The Gröden, Fassa, and Enneberg area in the South Tyrolean Dolomites)* was published in 1927.

3 **Giovanni Merla** (1906-1984) was an Italian geologist, paleontologist, and writer. He studied the fossil collection of Giorgio Caneva and published it in his 1930 work titled *“La fauna del Calcare a Bellerophon della Regione Dolomitica” (The Fauna of the Bellerophon Limestone of the Dolomite Region)*.

4 **Michele Gortani** (1883-1966) was an Italian geologist, entomologist, and politician who was particularly interested in the Carnic Alps. He published his research on the fauna of the Bellerophon Formation in his work: *“La fauna degli Strati a Bellerophon della Carnia” (The Fauna of the Bellerophon Strata of Carnia)* in 1906.

THE CALCAREOUS ALGAE

1 Calcareous algae, marine plants, produced a calcareous skeleton (calcium carbonate) and were important primary producers during the upper Permian. Their calcification significantly contributed to sediment formation.

BELLEROPHON

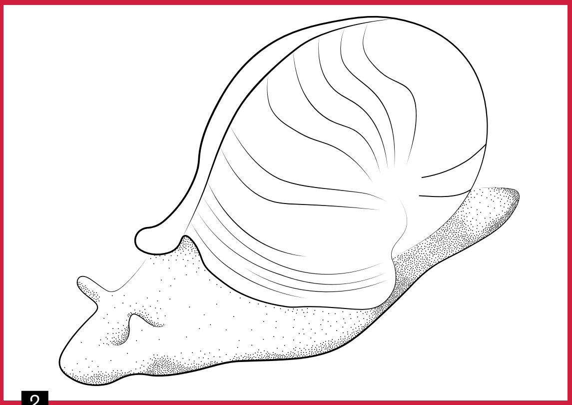
2 *Bellerophon* was a marine gastropod with a flat spiral shell, unlike most other snails, which have a tower-like spiral shell. It had a notch in the opening and a keel along the surface. It is often found as a steinkern because the shell has dissolved. As a herbivorous, it likely fed on algae mats and gave the Bellerophon Formation its name.

THE BIVALVES

3 4 Bivalves, also known as clams, breathe through gills, which they also use to filter plankton or organic residues from the water for nutrition. While some are firmly attached to the seabed, others lie or move freely and can even swim actively over short distances.
In 2023, Herwig Prinoth and Renato Posenato published an extensive study on the bivalves of the Bellerophon Formation. In this study, they described 26 species, including 10 new species, 3 new genera, and one new family that were previously unknown to science. These newly discovered species are designated with the abbreviation "sp. nov." (species nova)

1

Recent calcareous algae



2

Bellerophon

3

Acharax frenademezi sp. nov., Bellerophon Formation, 252.000.000 years

4

Acharax clarificata, New Zeland (recent)

THE BRACHIOPODS

5 Brachiopods are a group of invertebrates with a two-part shell that is dorsal and ventral. They are not related to bivalves.
They only live in the sea and are sessile filter feeders, meaning they are anchored in one place and feed on plankton filtered from the water. They are often attached to the bottom with a stalk.
They have a lophophore, a feeding organ with cilia that surrounds the mouth and also serves for breathing. Until the end of the Permian, they were the most diverse and significant animal group in marine ecosystems.
They are divided into two groups: Articulata and Inarticulata.

THE ARTICULATA

They have a shell with a hinge and several muscles to open and close it. Inside the lophophore is the brachidium, a support organ made of calcium carbonate that forms a double spiral or just a loop shape.

THE INARTICULATA: THE LINGULIDS

6 The shell is composed of chitin, proteins, and calcium phosphate. The valves are almost equal in size and are not attached to each other, nor do they have a brachidium inside. Lingulids still live today in shallow marine environments, burrowing into the sea floor. They prefer soft mud or sand and can tolerate low oxygen levels and fluctuations in salinity.

DIFFERENCE BETWEEN BIVALVES AND BRACHIOPODS

- Have a right and a left valve / Have a top and a bottom valve
- Shell made of aragonite and some of calcite / Shell made of calcite
- Muscles close the shell / Muscles close and open the shell
- Gills for feeding and respiration / Lophophor for feeding and respiration

5

Lophophor of brachiopod (recent)

6

Lingula anatina, Stradbroke Island, Australia

THE NAUTILOIDS

7 They belong to the cephalopods, which include organisms such as cuttlefish, squids, and octopuses. All nautiloids, except for the genera *Nautilus* and *Allonautilus*, are extinct. Their shells are divided into chambers connected by a siphon, and they move by expelling water from a funnel. The modern *Nautilus* primarily feeds on dead crustaceans, fish, and other marine organisms, a feeding behavior presumably common to the nautiloids of the Bellerophon Formation as well.

SEA URCHINS (ECHINOIDEA)

8 They were widespread during the Permian period and exhibited a variety of species. These echinoderms had a spherical internal skeleton that displayed radial symmetry and was organized into five equal sectors. The sea urchins used a complex chewing apparatus, Aristotle's lantern, to grind their food, which mainly consisted of algae and organic remains. Their spines served as an effective protection mechanism against starfish and fish.

THE STARFISH (ASTEROIDEA)

9 They are distinguished by their characteristic star-shaped morphology, which typically consists of five arms. These marine organisms live on the sea floor and feed on algae, bivalves, gastropods, and other small marine creatures.

7

Nautilus pompilus

8

Sea urchins (Echinoidea)

9

The starfish (Asteroidea)

ARCHAEOLEPIDOTUS LEONARDII

10 The only completely preserved fish from the Bellerophon Formation had only tiny teeth and was likely an omnivore that fed on small insect larvae, algae, and detritus. It is considered one of the oldest representatives of the group of Parasemionotids. The presence of this fish group both in the late Permian and the early Triassic suggests evolutionary adaptations that may have favored their survival during the mass extinction.

10

Archaeolepidotus leonardi
(copy, original in the Museum Gherdëina)

TRACE FOSSILS

Fossilized traces of life provide insights into the behavior and environmental conditions of past organisms, including movement patterns, resting traces, feeding traces, nesting traces, and fecal imprints.

FORAMINIFERS

Benthic foraminifera, living on the seabed, were single-celled animals with a microscopic calcium carbonate shell. They fed on detritus (decaying organic matter), algae and small animals. They also served as a food source for a variety of marine organisms. Foraminifera still exist today.

MICROCONCHIDS

Microconchids were fossilised tube worms that lived in the sea and formed a spiral calcite tube a few millimetres long. The genus *Microconchus*, formerly called *Spirorbis*, was a filter-feeding organism that lived attached to the surface of other organisms.

11

Recent ostracod

OSTRACODS

11 Ostracods were microscopic crustaceans that possessed a two-valved shell. These completely enclosed the animal and between them protruded the ostracod limbs, which could be retracted in case of danger. They were between 0.5 and 2 mm long. Ostracods still exist today.

EQUILIBRIUM

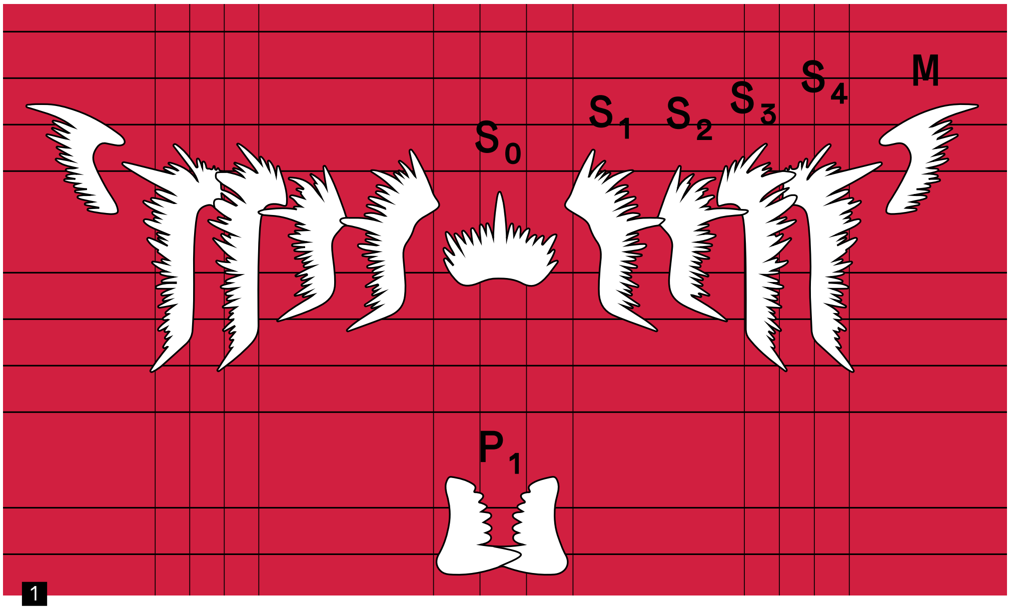
This video provides a fascinating insight into life on Earth before the mass extinction at the end of the Permian period. Created with artificial intelligence, it conveys the atmosphere of an intact ecosystem before the catastrophe. It is not an exact scientific reconstruction but captures the mood and great diversity of life of that time.

3 THE END PERMIAN MASS EXTINCTION

CAUSES, PROGRESSION, AND CONSEQUENCES

The eruption of the Siberian Traps marked the beginning of a dramatic global change. Did you know that the resulting release of carbon dioxide triggered an extreme greenhouse effect, raising the global temperature by about 10 degrees? This warming is considered one of the main causes of the end Permian mass extinction. But what other consequences did this catastrophic warming have? Explore how the resulting oxygen shortage, ocean acidification, and changes in marine chemistry affected marine life.

THE MASS EXTINCTION



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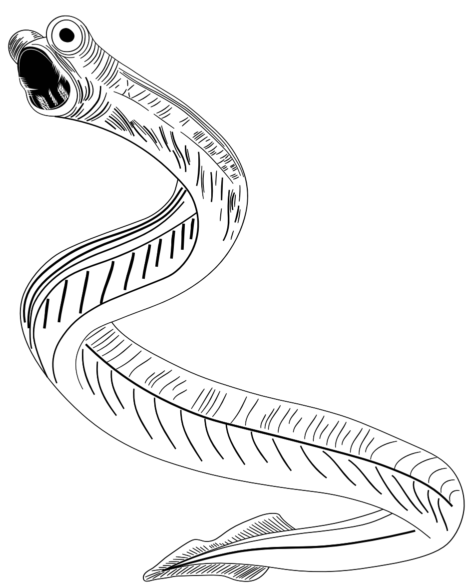
Hindeodus parvus, conodontal apparatus



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Hindeodus parvus

The duration of the different phases of the mass extinction is still not definitively clarified. It began 251.939 ± 0.031 million years ago and lasted, according to various studies, a total of between 60,000 and 30,000 years. However, the first and most devastating phase of extinction likely lasted only a few hundred or thousand years.

THE CONODONTS

1 2 3 They are considered to be primitive vertebrates and have tooth-like hard parts in the head region, which together form the so-called conodont apparatus. These tooth-like structures, the conodont elements, are usually 0.1 to 2 mm in size, consist of hard fluorapatite, and can be extracted from the rock using acetic acid. The conodont species *Hindeodus parvus* is particularly important, as the first appearance of its conodont elements in the stratigraphic beds marks the beginning of the Triassic period.

THE STRATOTYPE FOR THE PERMIAN-TRIASSIC BOUNDARY IN MEISHAN

The stratotype of the Permian-Triassic boundary, located in Meishan, Zhejiang, China 4 5, was determined in 2001 as the global reference point (GSSP) that marks the exact boundary between the Permian and Triassic geological periods. This point was identified by the first appearance of the conodont species *Hindeodus parvus* in bed 27c 6. This point serves as a global standard to compare geological beds from this time period and determine their relative chronological sequence.
On the other hand, the parastratotype for the Permian-Triassic boundary 7 in the western Tethys is the Bulla/Pufels section, the outcrop at the Geotrail of Bulla/Pufels. Here, *Hindeodus parvus* occurs approximately 130 cm above the boundary between the Bellerophon Formation (Bulla Member) and the Werfen Formation (Tesero Member) and marks the beginning of the Triassic.

3

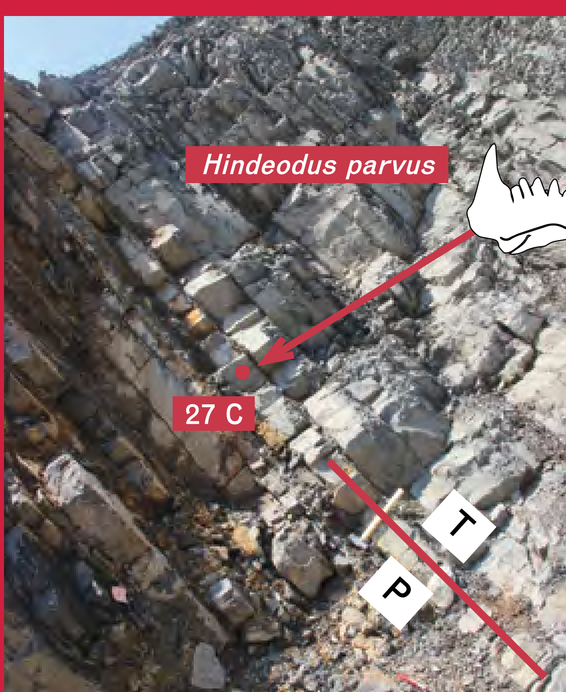
Monument to Meishan of *Hindeodus parvus*

4

Meishan, Zhejiang, China

5

Meishan Geopark, Zhejiang, China



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The Permian-Triassic boundary stratotype, Meishan, Zhejiang, China

7

Parastratotype of the Permian (P) – Triassic (T) Boundary of Bulla

1

Map showing the position of the Siberian Traps compared to the extent of the USA

Siberian trap

THE SIBERIAN VOLCANISM

The Siberian Traps are an extensive flood basalt in Siberia 1 2, that formed around 252 million years ago at the Permian-Triassic boundary. This volcanic eruption, one of the largest in Earth's history, lasted about 1 million years and created a present-day area of about 2 million square kilometers, while the original area was approximately 5 million square kilometers. The thickness of the Siberian Traps reaches more than 3000 meters in some regions, and the total amount of basalt lava emitted is about 4 million cubic kilometers.

2

Volcano

SIBERIAN TRAPS VOLCANISM

3 The Siberian Traps volcanism was triggered by a mantle plume, a column of very hot rock that rises from the Earth's mantle. At the Earth's surface, these plumes formed hotspots, where magma was pushed through the crust to form volcanoes that typically spewed basaltic lava, similar to that of the Hawaiian island chain.

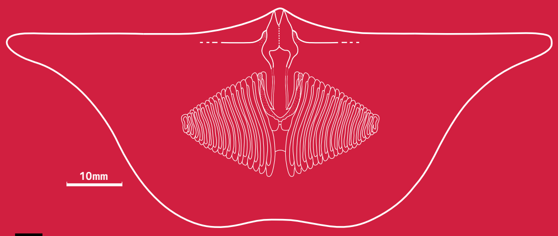
THE LAST BRACHIOPODS: *OMBONIA* AND *ORTHOTETINA* BEDS

After the first extinction phase, there was a final resurgence of the brachiopods. In a bed only up to 20 cm thick within the Tesero Member, brachiopods are found in abundance, particularly *Ombonia* and *Orthotetina*. In the subsequent beds of the Tesero Member, the fossils become increasingly rare and smaller until they are only tiny. These beds document the second extinction phase, during which the last brachiopods, calcareous algae, and foraminifers were wiped out.

BRACHIOPOD SHELLS SERVE AS RECORDS OF THE CLIMATIC CONDITIONS OF THEIR ERA

4 The paleoclimate is reconstructed through geochemical analyses of stable isotopes, providing insights into:

- Greenhouse gas levels in the water and atmosphere – carbon isotopes ^{12}C and ^{13}C indicate a swift increase in greenhouse gases (e.g., CO_2 and CH_4), triggered by the volcanic eruptions in Siberia.
- Paleotemperatures – oxygen isotopes ^{16}O and ^{18}O reveal a sudden rise in marine water temperatures, exceeding 40°C.
- Acidification levels – boron isotopes ^{11}B and ^{10}B demonstrate a drop in the pH of marine water from 8.1 to 7.4.
- Fossil ages – strontium isotopes ^{87}Sr and ^{86}Sr allow for the dating of the oldest known Comelicania from the Bulla Member to 252.311 million years ago.



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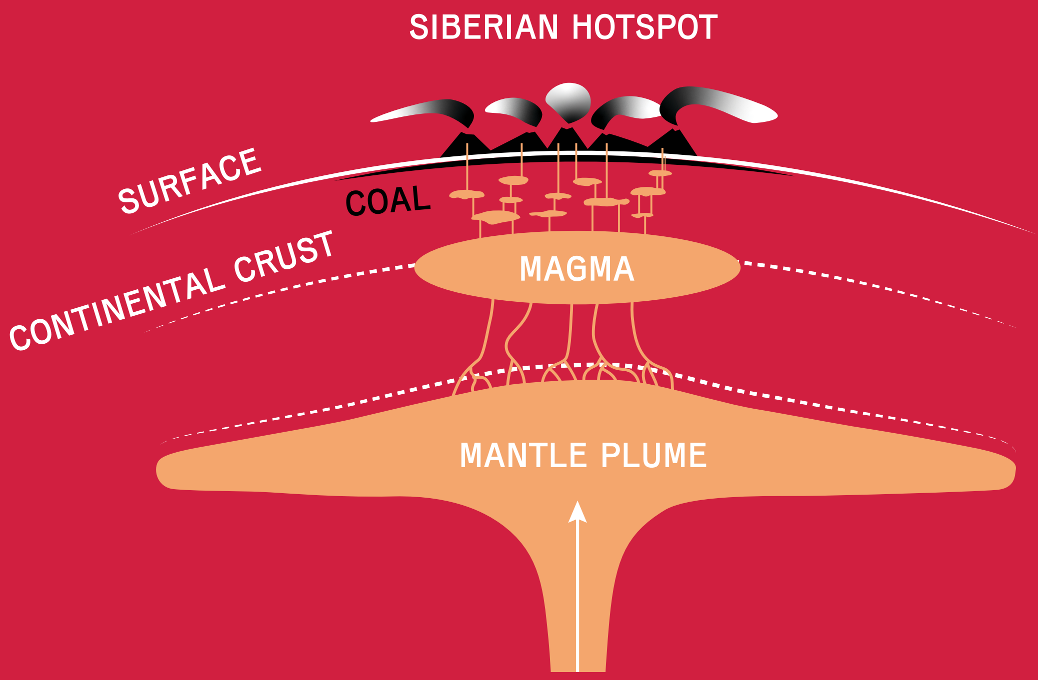
Comelicania sp., Bellerophon Formation



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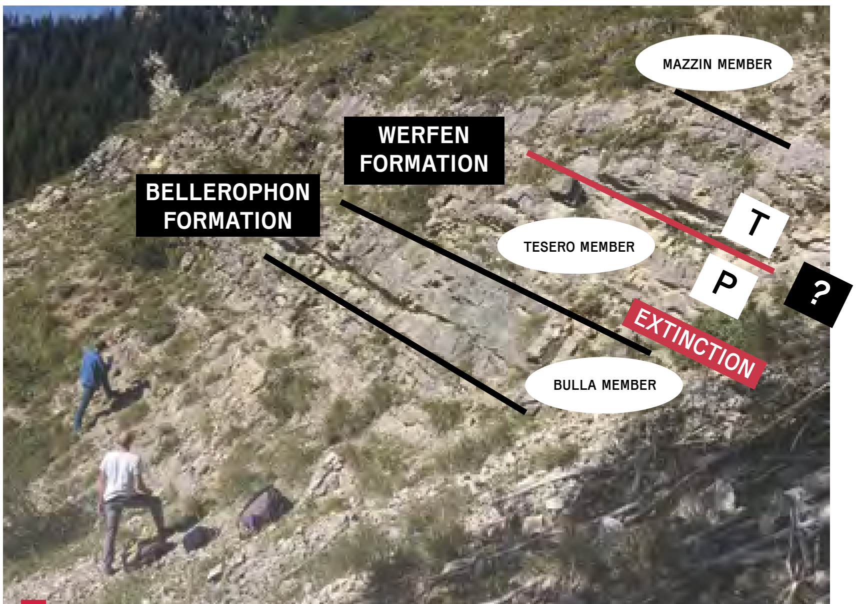
Siberian Trap volcanism

THE FIRST EXTINCTION PHASE



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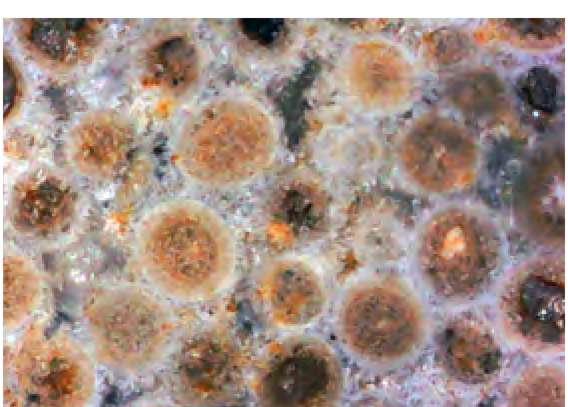
Permian (P) – Triassic (T) boundary of Seres

EXTINCTION AT UNCONFORMITY U2 AT BULLA

The top 1.5 meters of the Bellerophon Formation consist of black limestone and are referred to as the Bulla Member. At the transition between the Bulla Member and the Tesero Member, there was a very short sea level drop during which no beds were deposited. During this brief stratigraphic gap, known as *Unconformity 2*, which lasted at most a few thousand years and occurs throughout the Dolomites, the first and most catastrophic phase of mass extinction took place. In Bulla/Pufels, one can see a bed full of fossils before the mass extinction, and in the subsequent bed, almost all ostracods and a large part of the foraminifers and calcareous algae died.



2

Oolite of Tesero

THE OOLITE OF TESERO

HOW ARE OOLITES FORMED?

2 In warm, calcium-saturated seawater, sand grains on the sea floor start to form a layer of limestone around themselves, similar to how an oyster forms a pearl. Gradually, as the waves roll the grain back and forth, the limestone layer continues to grow until the grain becomes too heavy and sinks to the sea floor. There, many of these “pearls” accumulate and form a bed. Over time, this bed solidifies into the rock we know as oolite. The oolites that were deposited during the mass extinction were first studied in Tesero in the Fiemme Valley and are therefore referred to as the Tesero Member, which forms the base of the Werfen Formation. During the mass extinction, oolites were widespread along almost all coasts of the Tethys and are therefore called “Disaster Oolites.”

THE PHASES OF MASS EXTINCTION

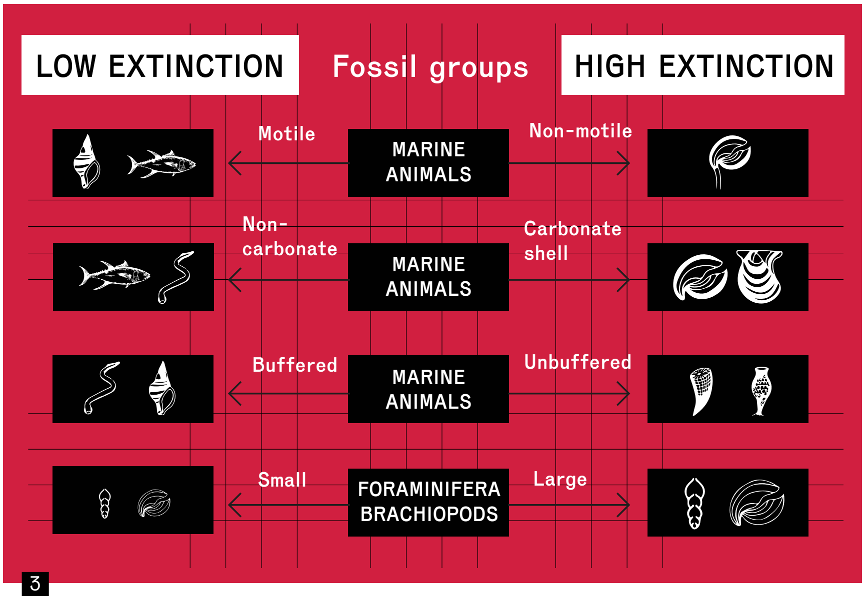
There are two main phases of extinction at the end of the Permian, determined by different factors:

1. **Primary Phase:** in this phase, the physiology, i.e., the physical characteristics and functions of the species, is crucial for their survival. If a species was not well adapted to the rapidly changing environmental influences, it became extinct in this phase.
2. **Secondary Phase:** in this phase, the relationships between the species and their environment, i.e., the ecological interactions, are decisive. If a species was dependent on another species that had become extinct in the primary phase, then it became extinct in the secondary phase.

WHICH ORGANISMS WENT EXTINCT AND WHICH SURVIVED?

3 4 SELECTIVITY OF THE MASS EXTINCTION AT THE END OF THE PERMIAN PERIOD

- Organisms anchored to the sea floor and with limited mobility were much more affected by the mass extinction than those that were mobile.
- Species with phosphatic shells, like linguliform brachiopods, were significantly more likely to survive the mass extinction than those with calcareous skeletons (aragonite or calcite).
- Marine organisms that could maintain stable acidity levels in their bodies survived, even as the surrounding water became increasingly acidic due to more carbon dioxide (CO_2).
- The microfauna (ostracods, foraminifera, larvae of invertebrates) was heavily decimated. Among the remaining life forms, larger species were much more affected than smaller ones (e.g., snails).
- Brachiopods were adapted to the open sea with stable living conditions, while bivalves primarily lived in stressed coastal areas. Bivalves were already adapted to the extreme conditions before the mass extinction that nearly completely wiped out the less resistant brachiopods during the extinction. In accordance with the adage, what doesn't kill me makes me stronger.
- Marine organisms that had a wide geographical distribution, could cope in a broad spectrum of different habitats, had a high number of individuals, and featured several species per genus survived the mass extinction better than others.



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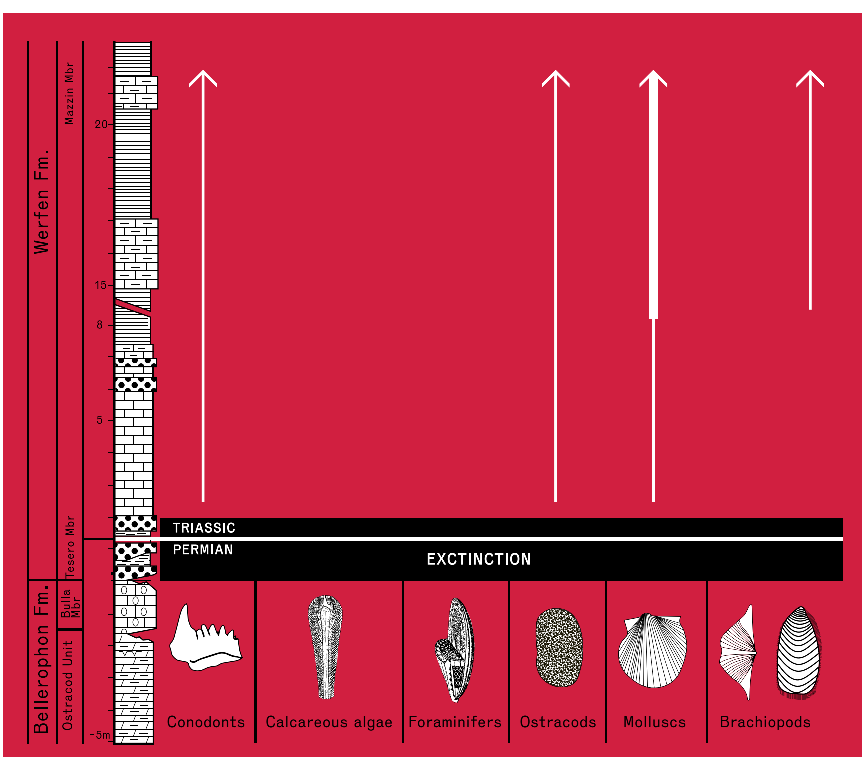
Selectivity of the late Permian mass extinction

VOLCANISM AND CLIMATE CATASTROPHE

5 It is estimated that during the mass extinction at the end of the Permian period, the massive volcanic eruptions in Siberia released at least 3000 GT (gigatonnes) of CO_2 over an estimated period of about 1 million years. 1 gigatonne = 1,000,000,000 tons. This certainly led to an extreme greenhouse effect, acting like a warm blanket around the Earth and causing sea temperatures to rise to over 40°C (104°F). The trigger for the mass extinction was the volcanism in Siberia. But that was just the trigger, as the organisms in the Tethys Ocean were not killed by contact with the lava. The volcanism and the dramatic CO_2 emissions it caused set off a whole cascade of killing mechanisms that then nearly completely wiped out life on Earth.

WHAT WERE THE KILLING MECHANISMS?

- The sea water, heated to up to 45°C, likely killed most organisms.
- Some marine zones experienced a lack of oxygen. Warm water can hold much less oxygen than cold water. Moreover, ocean circulation slowed down, and sea water was no longer mixed, hardly any oxygen reached deeper marine layers.
- In some marine zones, CO_2 poisoning (hypercapnia) could occur. The consequences for marine organisms include breathing difficulties, altered blood chemistry, and changes in behavior.
- Some regions experienced ocean acidification. When there's more CO_2 in the air, the oceans soak it up, leading to changes in the water that can harm sea life. This process doesn't make the water sour like lemon juice, but it does make it less friendly for creatures that need to build their shells or skeletons, such as clams and corals. They find it harder to obtain the materials they need to construct their shells, which can upset the balance of life under the sea.



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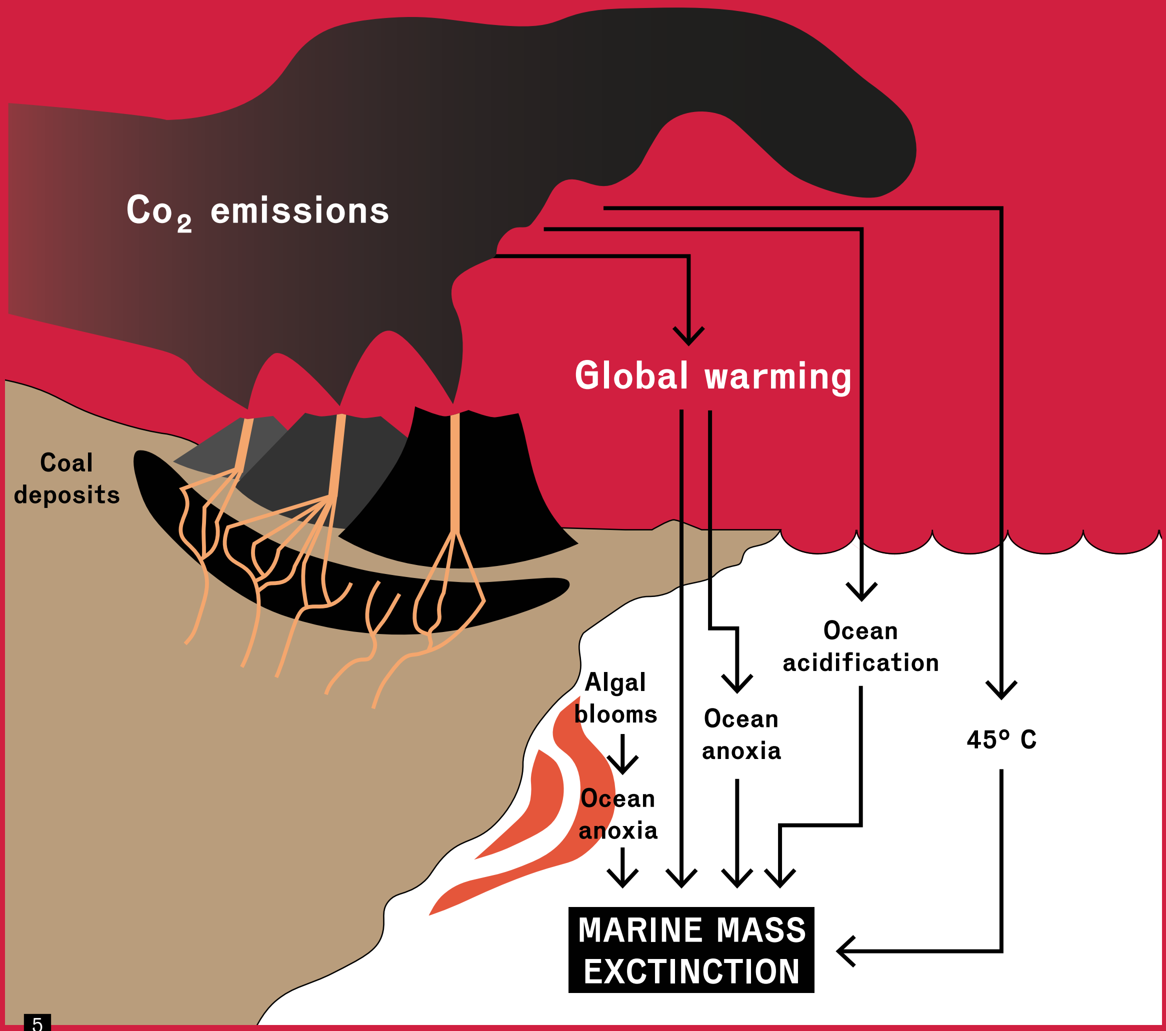
Mass extinction at the Bulla / Pufels section



Siberian volcanism and climate catastrophe
When magma penetrated the gigantic Siberian coal deposits and other organic deposits, igniting them, huge amounts of CO_2 and methane were released. This led to a super greenhouse effect that triggered mass extinction.

EXTINCTION

This video showcases the impressive volcanic activities of the Siberian Traps. Created using artificial intelligence, it captures the power and dynamics of these events. The video is not an exact scientific representation but illustrates the imposing atmosphere of the volcanism of that time.

4 AFTER THE MASS EXTINCTION

After the end Permian mass extinction, cyanobacteria temporarily dominated the oceans. What allowed these microorganisms to spread so effectively? In the Werfen Formation, the presence of the bivalve *Claraia* shows a remarkable adaptation to the extreme conditions of the early Triassic. How did *Claraia* and other marine organisms adapt to the challenges of oxygen-poor and extreme warm seas?

THE TRIASSIC PERIOD

1

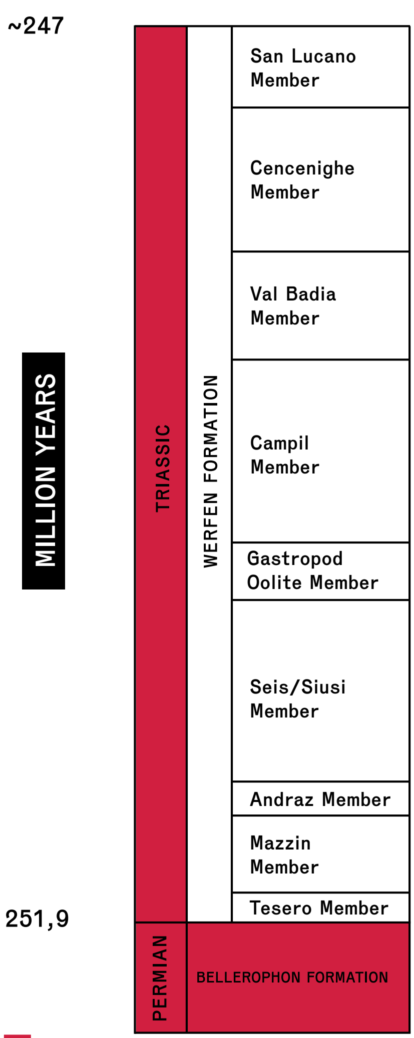
Friedrich August von Alberti

The Triassic is a geological period spanning from 251.9 to 201.3 million years ago. Introduced in 1834 by **Friedrich August von Alberti**, 1, it is named after the three distinct rock formations - *Keuper, Muschelkalk,* and *Buntsandstein* - characteristic of this time frame in Europe.

THE WERFEN FORMATION

After the mass extinction, the Werfen Formation 2 (about 251,9-247 million years) formed, which is up to 400 meters thick and consists of marls and claystones. It is divided into nine stratigraphic members, some of which may be partially missing due to erosion:

- **Tesero Member:** consists of thinly bedded oolites and reaches up to 6 meters in thickness.
- **Mazzin Member** 3: 50 meters thick marls with limestone banks and shell beds.
- **Andraz Member:** up to 15 meters thick and brightly colored claystones.
- **Seis Member** 4: 40 meters of gray and yellowish-gray limestones, marly limestones, or lime marls.
- **Gastropod Oolith Member:** reddish beds, which can be up to 50 meters thick and consist of tiny gastropod shells.
- **Campil Member:** up to 80 meters thick, mostly reddish marls and claystones. They include numerous sediment structures.
- **Val Badia Member:** these calcareous to marly sediments become up to 50 meters thick.
- **Cencenighe Member:** is partially silty with dolomites, dolomitic limestones, and calcarenites found.
- **San Lucano Member:** is partially evaporitic.



2

Werfen Formation

THE TEMPERATURES REMAIN HIGH

For nearly 5 million years after the catastrophe, temperatures remained high, caused by recurring volcanism in Siberia or other not yet fully understood processes. The rock weathering, which binds CO_2, was ineffective due to dryness, reducing erosion and thus the limestone production in the sea, leading to the formation of clay deposits and marls. There were no more calcareous algae that could produce sufficient limestone in the sea, resulting in the predominant formation of clay deposits and marls.
A lot of mud was washed into the sea or formed directly on the seabed through a process known as “inverse weathering”, which even releases CO_2.

3

Mazzin Member, Geotrail Bulla, Val Gardena

4

Siusi Member, Siusi

CYANOBACTERIA TEMPORARILY TAKEOVER THE WORLD

5 6 With the calcareous algae almost extinct, cyanobacteria became the dominant primary producers in the sea, as they could live in nutrient-poor soils, perform photosynthesis, and fix nitrogen, making it available to other organisms. They formed microbial mats and stromatolites (piles of very thin, stacked limestone layers) that were found worldwide, including in the Tesero Member. However, due to the toxins produced by some species, they were a food source for only a few animals, likely delaying the recovery of marine life.

?UNIONITES, A SUVIVOR

Two clam species are found throughout the Werfen Formation everywhere and very frequently: *?Unionites canalensis* and *?Unionites fassaensis*.
The question mark before the name indicates uncertainty about whether the species actually belongs to the genus *Unionites*.

5

Stromatolites, Tesero Member, Tesero

6

Recent stromatoliti, Shark Bay, Australia

5 LIFE RETURNS EXTREMELY SLOWLY

After the mass extinction, the few surviving species filled the empty ecological niches, leading to a slow increase in biodiversity. But what further steps were necessary to move from this initial expansion to a diversified and adapted variety of life? Only 15 million years later, in the Cassian Formation, signs of a continuing, yet incomplete recovery can be seen.

AND THEN CAME *CLARAIA*

1 Alexander Bittner

WHY *CLARAIA*?

Franz Clara, a priest from Badia in Val Badia, was an avid fossil collector. In 1843, the German geologist Hermann Friedrich Emmrich and Franz Clara met on the Seiser Alm. Clara made his exceptional fossil collection available to Emmrich. As a sign of deep gratitude, Emmrich named a newly discovered bivalve species from Bulla/Pufels after Clara - *Posidonomya clarae*. In 1901, Bittner described the new genus *Claraia*, which he also named in honor of the discoverer, after which the mussel was given the name *Claraia clarae*.

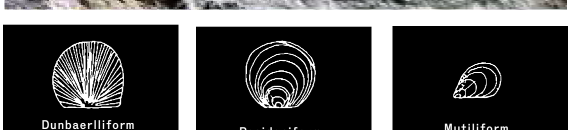
CLARAIA WAS VERY RESILIENT

After the End-Permian Mass Extinction, *Claraia* spread worldwide and diversified. It had a high reproduction rate and could live in low-oxygen conditions, indicating a high adaptability to stressed habitats. Their planktonic larval phase could have facilitated dispersion over long distances, similar to modern invasive species that quickly adapt to new environments.

ALEXANDER BITTNER 1 (1850-1902), Austrian geologist and paleontologist, was renowned for his research on bivalves of the Alpine Triassic period and was the first to describe the mussel genera *Eumorphotis* and *Claraia*.

"PAPER PECTEN"

2 *Claraia* and *Eumorphotis* belong to the group of "Paper Pecten" (paper scallops). These flat mussels, with large surface area and low volume, lived on soft seabeds and in oxygen-poor conditions. *Dunbarella, Posidonia* and *Mytilus* are also part of this group. *Claraia*, in particular, combines all the characteristics of these bivalve shells, making it the "Paper Pecten" par excellence.



2 Perfect "Paper Pecten", *Claraia clarae*

TIROLITES CASSIANUS

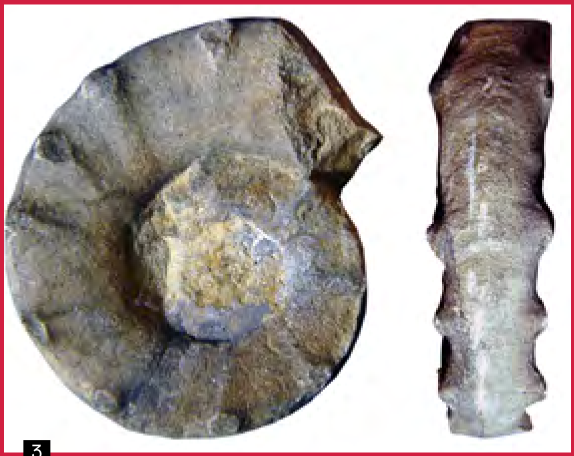
3 Ammonoids, marine cephalopods and relatives of today's *Nautilus*, are known for their spiral shells. Their reappearance in the Val Badia Member of the Werfen Formation after the near-total extinction at the end of the Permian marks a gradual recovery of marine ecosystems. The german paleontologist Friedrich August von Quenstedt first described this species in 1845 as *Ceratodus cassianus*, even though he knew it originated from the Werfen Formation and was not found in St. Kassian. The final assignment to the genus *Tirolites* was made in 1882 by Edmund von Mojsisovics.

THE BRITTLE STARS

4 5 In the Campil Member of the Werfen Formation, brittle stars reappeared after the mass extinction. The traces they left in the fine sediment, known as *Asteriacites lumbricalis*, show how these organisms moved and interacted with the marine environment.

THE LINGULIDS

6 Lingulids are the only brachiopods of the Bellerophon Formation that survived the mass extinction.



3

Tirolites cassianus

4

Campil Member of Werfen Formation

5

Ophiura albida (recent)

6

Lingula anatina, Philippines (recent)

WHEN DID LIFE RECOVER?

1

Cassian Formation, Störes (Val Badia)

The paleontologist Michael Hautmann investigated how life develops after mass extinctions and identified three recovery phases:

- **Immediately after the extinction:** with low competition among the few surviving species, biodiversity increases. The remaining species occupy many different habitats (e.g. *Claraia, Unionites*), leading to very similar ecosystems.
- **Competitive phase:** competition between species leads to specialization in certain habitats. Diversity within a habitat stagnates, while communities of different ecosystems become more differentiated.
- **Adaptation phase:** species develop specific traits to better adapt to their respective environments, resulting in a renewed increase in diversity.

INCOMPLETE RECOVERY: ECOLOGICAL ECHO IN THE CASSIAN FORMATION

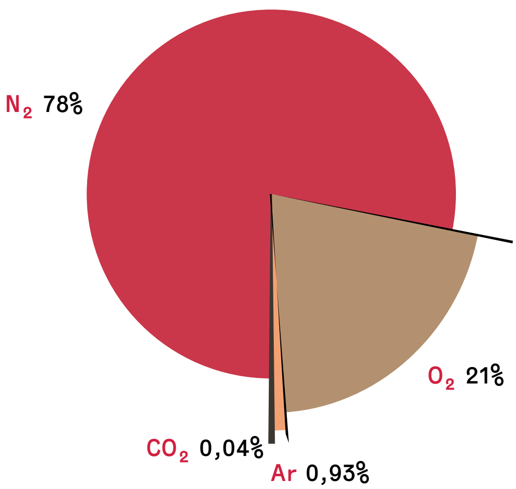
1 The Cassian Formation (approximately 237-232 million years ago), which was deposited about 15-20 million years after the end Permian mass extinction, indicates that marine life at that time was just transitioning to the second phase and had not yet fully recovered. Despite a great diversity of over 1000 documented invertebrate species, primarily mollusks, the dwarfism of these species indicates ongoing ecological stress conditions.

6 INTRODUCTION TO WEATHER AND CLIMATE

How can the seemingly inconspicuous carbon dioxide have such a major impact on our global climate? Learn how this gas influences the weather and climate on Earth. What is the difference between the weather we experience daily and the climate that spans decades? Why is the current climate change a special challenge, and how does it differ from natural climate variations of the past?

THE COMPOSITION OF THE EARTH'S ATMOSPHERE

AND THE ROLE OF CO_2



1

The composition of the Earth's atmosphere

THE COMPOSITION OF THE EARTH'S ATMOSPHERE AND THE ROLE OF CO_2 1

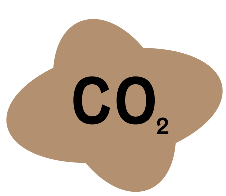
Nitrogen (N_2): 78,08%
Oxygen (O_2): 20,95%
Argon (Ar): 0,93%
Carbon dioxide (CO_2): 0,04%

WHAT IS CO_2?

Carbon dioxide (CO_2) is a chemical compound made of carbon and oxygen. It is a colourless, odourless, and non-flammable gas. The fizz in sparkling water comes from carbon dioxide (CO_2).

WHAT IS THE WEATHER?

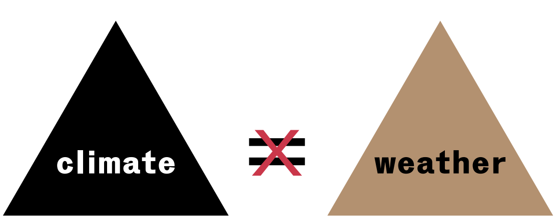
The conditions in the atmosphere that we actively feel and experience are known as weather phenomena (for example, temperature, precipitation, humidity, wind speed, and direction, etc.). These always refer to a short period of a few hours, days, or a few weeks and are specified for a particular place or region.



WHAT IS THE CLIMATE?

The term "climate" refers to the average of weather phenomena at a selected location, in a large region, or even on the entire globe over a period of at least 30 years. This timespan is defined as a climate normal period. Due to the large timeframe, the climate is a sluggish, more stable system. Changes do occur, but they proceed much more slowly, and the range of variation is also significantly smaller.

Climate skeptics often claim: *There has always been climate change, so why should the current one be a problem?*



WHAT DISTINGUISHES TODAY'S GLOBAL CLIMATE CHANGE FROM PREVIOUS CLIMATE FLUCTUATIONS?

Today's climate change is a global phenomenon that, unlike previous climate fluctuations, is not limited to local or regional areas. While the Little Ice Age (1350-1830 AD), the Medieval Warm Period (1050-1150 AD), and the Roman Warm Period (50-250 AD) mainly affected certain regions of the Earth and were triggered by a variety of natural factors, the current climate change is caused by human activities and affects the entire global climate system.

2

Speleologist with the core sample

3

Position of Conturines Cave, (2750 m)

DRILL CORE FROM CONTURINES CAVE

A 2.5-meter-long core sample 2, obtained with a diamond drill bit from the bottom of the cave, shows the structure of the cave sinter. The upper layers are about 400,000 years old, while the deeper layers could be over a million years old. This core sample documents calcite deposits from a time when the Conturines Cave 3 was at a much lower altitude. The climate was warmer and more humid back then, and rainwater deposited calcite layers in the cave. 4

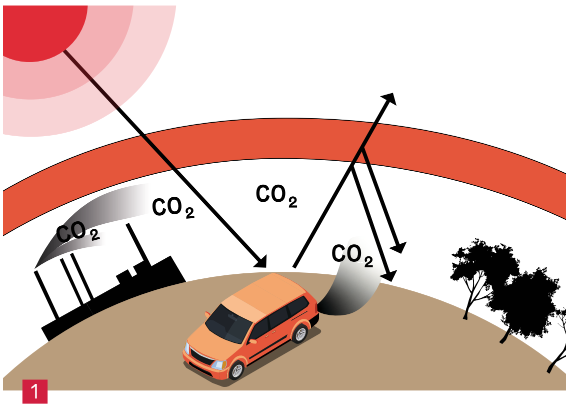
4

Stalagmite *Raiëta* inside Conturines Cave

7 THE ROLE OF CO_2 IN OUR CLIMATE SYSTEM

How does the greenhouse effect, particularly from CO_2, influence our Earth's atmosphere, and what are the thresholds where it becomes harmful? At the Mauna Loa Observatory, a CO_2 concentration of 426 ppm is measured. This concentration is not just a numerical value; it reflects the impacts of human activities that go beyond natural CO_2 cycles. Is this percentage truly insignificant, as some climate skeptics claim, or does it enhance the natural greenhouse effect to our detriment?

WHAT IS THE GREENHOUSE EFFECT?



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The greenhouse effect

1 The greenhouse effect is the impact of greenhouse gases, like CO_2, that retain heat radiation in the atmosphere, thereby increasing the temperature of the planet's surface.

THE GREENHOUSE EFFECT IS VITAL, ONLY TOO MUCH IS HARMFUL

Without the natural greenhouse effect, the heat from the sun would simply be reflected back into space, and the average temperatures on Earth would fall to about -18°C. In fact, thanks to this greenhouse effect, the global average temperature is about 15°C, creating a mild climate suitable for many forms of life. However, an enhanced greenhouse effect due to too many emissions leads to an increase in this average temperature, which in turn triggers extreme weather events and climate changes.
The CO_2 content of the atmosphere is measured in ppm = parts per million.

2

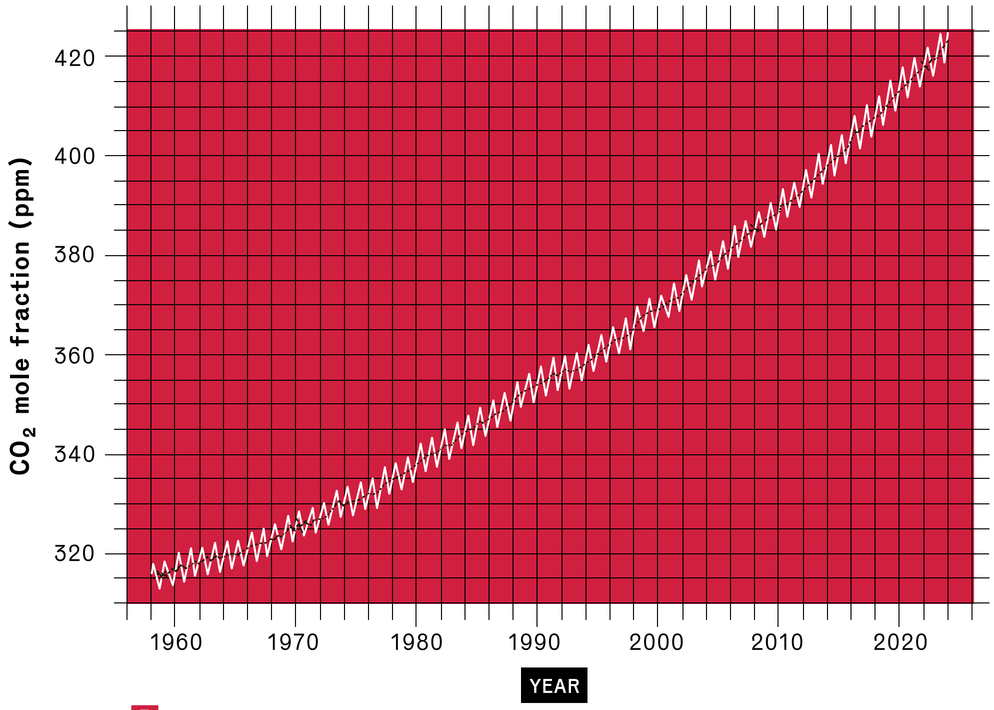
Mauna Loa Observatory, Hawaii

WHERE IS THE CO_2 CONTENT MEASURED?

At the Mauna Loa Observatory in Hawaii 2: here, the CO_2 concentration is measured at an altitude of 3400 meters. 3 4 Current CO_2 value, July 2024: 426 ppm *(co2.earth/daily-co2)*.

THE MISTAKE OF CLIMATE SCEPTICS

Although it is estimated that only 3% of global CO_2 emissions are directly attributable to human activities such as the burning of fossil fuels and deforestation, climate skeptics often argue that this seemingly small proportion cannot have a significant impact on the climate. However, this view overlooks the fact that even these 3% disrupt the natural CO_2 cycles, which are characterized by a balance process where CO_2 is normally absorbed through photosynthesis. Therefore, the additional CO_2 emissions caused by humans lead to an imbalance, increasing the atmospheric CO_2 concentration and thus having profound effects on the climate.



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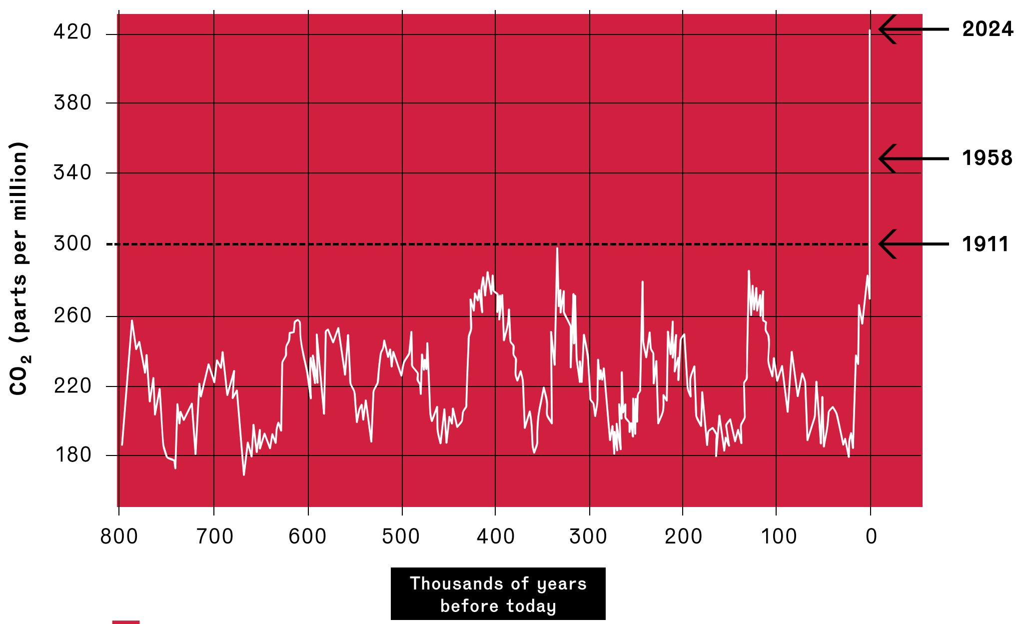
Increase in atmospheric CO_2 since 1960



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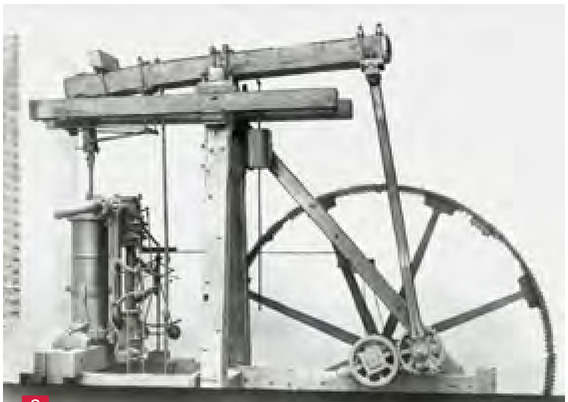
The concentration of CO_2 in the atmosphere over the last 800,000 years has never been as high as it is today (data from ice cores)

8 THE EVOLUTION OF CLIMATE CHANGE

FROM EARLY INDUSTRIALIZATION TO THE PRESENT

How did the Industrial Revolution change the environment and impact our atmosphere? Discover how the use of fossil fuels and new technologies transformed a nearly untouched world into a landscape shaped by human activity.
What adaptations did animals need to make to survive in a rapidly changing environment? And how have these developments had long-term effects on our current climate?

HISTORY OF TODAY'S CLIMATE CHANGE



2

Watt & Boulton's steam engine, 1788

3

Crompton's spinning mule, 1779

THE TIME BEFORE THE INDUSTRIAL REVOLUTION (BEFORE 1760)

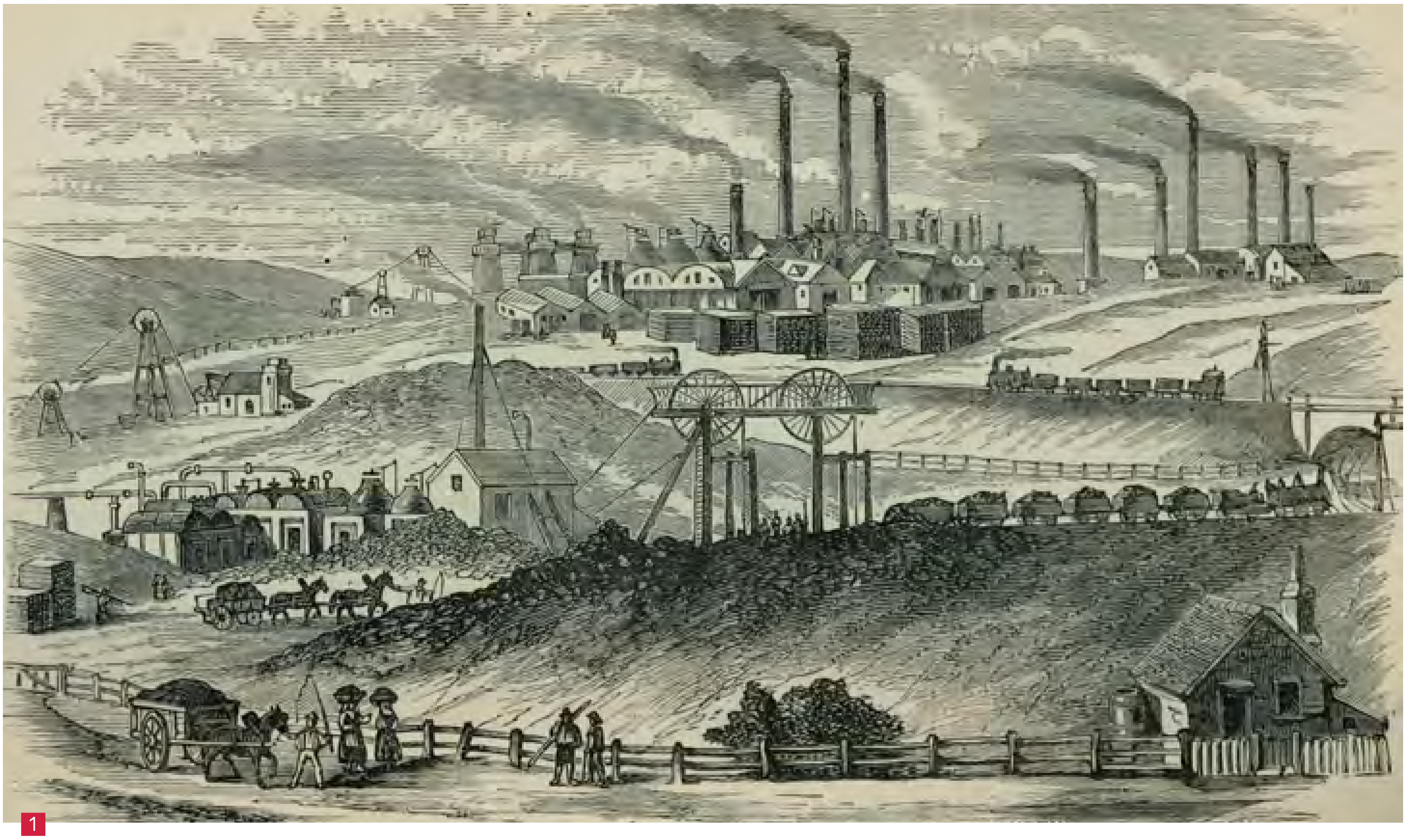
The environment was relatively untouched by industrial activities, and CO_2 emissions were low compared to later times. The global average temperature was probably about 13.7°C. The atmospheric CO_2 concentration was about 280 ppm. The world population grew slowly during this time.

THE INDUSTRIAL REVOLUTION (1760-1840)

1 The Industrial Revolution was triggered by the invention of numerous machines, such as James Watt's steam engine 2 (Scotland, 1769), the spinning machine 3 (England, 1764) and the mechanical loom (England, 1785). To operate these machines, vast amounts of fossil fuels were required. Initially, it was coal, then oil and natural gas were added.
The Industrial Revolution began in England and spread throughout Western Europe and the USA in the 19th century. During the Industrial Revolution, the consumption of fossil fuels increased significantly, leading to an increase in atmospheric CO_2 concentration to about 290 ppm. Researchers have found that climate change began around 1830 - with the start of the Industrial Revolution. By the year 1900, the population had already more than tripled to 1.6 billion. At that time, it was growing annually by 0.7 to 0.8%, corresponding to a doubling time of about 100 years.

AFTER THE INDUSTRIAL REVOLUTION (1840-PRESENT)

Since the Industrial Revolution, CO_2 emissions have been continuously increasing, especially in the 20th and 21st centuries. The atmospheric CO_2 concentration reached a level of 426 ppm by July 2024. The global average temperature has risen by about 1°C since the beginning of the Industrial Revolution, reaching around 14.8°C.
Today, according to the World Population Clock of the German Foundation for World Population, there are currently (as of July 2024) around 8.1 billion people living in the world. According to a UN forecast on the development of the world population, the number of Earth's inhabitants is expected to increase to 9.71 billion by 2050 and to 10.35 billion by 2100.



1

The Industrial Revolution

4

Peppered moths

IMPACTS ON THE PEPPERED MOTHS

4 Due to air pollution during the Industrial Revolution, the originally white peppered moths, which were hard to spot on the white bark of birch trees, mutated into a darker form. This change served to better camouflage them from birds on the now soot-covered tree barks.

HOW ARE CLIMATE DATA COLLECTED?

Modern climate data are captured by satellites and weather stations, which allow precise measurements of weather and atmosphere. Historical climate information, on the other hand, comes from natural sources such as ice cores and tree rings, which provide insight into past climate conditions. The age determination of these samples is carried out by methods such as radiocarbon dating.

THE EFFECTS OF CLIMATE CHANGE

1

Impact of climate change on extreme weather events

CO_2, THE INVISIBLE DANGER

Because we can neither see nor smell CO_2, we often do not realize how much of it we release into the air. Unlike trash, which can be seen and removed, CO_2 silently and secretly spreads in the atmosphere. This makes it difficult to identify the culprits of pollution because the consequences are not immediately visible.
Total CO_2 emissions worldwide for 2023 = 40 Gt (1 Gt = 1,000,000,000 tons), of which about 37 Gt are from the combustion of fossil fuels.
The amount of coal we consume in a year (8.5 billion tons for 2022) would be enough to fill a freight train that could stretch about once from the Earth to the Moon and back.

CONSEQUENCES OF CLIMATE CHANGE

1. **Effects of climate change on weather extremes** 1: Droughts, floods, and storms occur more frequently and intensely. For example, droughts have direct impacts on the food security of millions of people as they cause the destruction of crops and agricultural structures.
2. **Sea level rise:** in the 20th century, the sea level has already risen by 15 cm, about 1.5 mm per year. Now, the level is rising more than twice as fast, about 3.7 mm per year. This has significant impacts on coastal regions and can lead to flooding and land loss.
3. **Ocean acidification** occurs when CO_2 from the atmosphere is absorbed by the sea and combines with water to form carbonic acid, making the water more acidic. This change harms marine organisms such as corals and shellfish, as it impairs their ability to form calcium shells and skeletons, leading to a decline in biodiversity and disruptions in marine ecosystems.
4. **Impacts on biodiversity:** if animals and plants cannot adapt to new conditions, they will disappear, drastically reducing biodiversity. Climate change affects individual species, their communities, and habitats, directly impacting species' development and behaviour.

PARASITES SPREAD WITH CLIMATE CHANGE

Due to increasingly mild winters and higher summer temperatures, the overwintering and reproduction of the following parasites can be promoted:

- **The bark beetle** 2: have you ever wondered why innumerable trees have died within a short time in Gardena Valley, in the Badia Valley, and in many other Alpine valleys? The culprits are climate change and the bark beetle. This small insect eats its way into the bark of coniferous trees to feed and reproduce. As winters become milder due to climate change, more bark beetles now survive the cold.
- **The tiger mosquito** 3 is known to transmit various diseases such as dengue fever, chikungunya fever, and the Zika virus.
- **Ticks** 4 are known to transmit diseases such as Lyme disease and tick-borne encephalitis (TBE).
- **The deer ked** 5 is a parasite that primarily infests deer and other forest animals but can also infest humans and pets. It can transmit diseases like bartonellosis.

2

The bark beetle

3

The tiger mosquito

4

The tick

5

The deer ked

SOCIAL AND ECONOMIC IMPACTS

OF CLIMATE CHANGE

1 The Haunold, Sexten Dolomites

WHAT ARE THE SOCIAL AND ECONOMIC IMPACTS OF CLIMATE CHANGE?

1. **Migration:** climate change can lead to migration when people are forced to leave their homes due to environmental changes. For example, droughts and floods caused by climate change can destroy people's livelihoods, forcing them to migrate.
2. **Conflicts:** climate change can also lead to social and political conflicts. When resources such as water and food become scarce, this can lead to conflicts and instability.
3. **Economic impacts:** the costs of dealing with environmental disasters caused by climate change can be enormous. Moreover, the impacts of climate change on agriculture and other economic sectors can cause significant economic losses.

ROCKFALLS DUE TO CLIMATE CHANGE

Permafrost, permanently frozen ground below 0°C, is typically found in the Dolomites above 2,500 meters. Due to climate change, it's thawing more rapidly. Contrary to popular belief, ice doesn't act as a "glue" for soil and rocks. The real issue is the increase in temperatures, leading to frequent freeze-thaw cycles, particularly critical during heavy rainfall, thus increasing the risk of rockfalls and landslides.

1 **The Haunold, Sexten Dolomites:** a major rockfall occurred on the north side of the Haunold.

2 **Latemar, Torre di Pisa, Dolomites:** about 5000 cubic meters of Dolomite rock fell into the valley from the Torre di Pisa.

3 **Kleine Gaisl, Dolomites:** there was a major rockfall at Kleine Gaisl, attributed to the thawing of permafrost.

2

Latemar, Torre di Pisa, Dolomites

3

Kleine Gaisl, Dolomites

MEASURES AGAINST CLIMATE CHANGE 1

1

Heads of delegations to the 2015 United Nations Climate Change Conference (COP21)

THE 2015 UN CLIMATE CHANGE CONFERENCE AND THE PARIS CLIMATE AGREEMENT

- **Signatories:** The agreement was signed by nearly all countries in the world, including Italy.
- **Goals:** The main goal of the agreement is to limit global warming to well below 2°C, preferably to 1.5°C, above pre-industrial levels. It also aims to redirect global financial flows towards a low-carbon and climate-resilient development.
- **Funding:** Industrialized countries have committed to contributing 100 billion US dollars annually by 2025 to international financing for climate actions. However, public funds are not sufficient to implement this fundamental transformation. For this, all global financial flows, including private investments and foreign direct investments, must be aligned with these goals across all sectors of the economy and financial markets.

WHAT CAN EACH OF US DO?

1 **Reduce car traffic:** choosing public transport, cycling, or walking, when possible, can significantly lower the emission of greenhouse gases.

2 **Saving energy:** using household appliances with high energy efficiency, turning off lights when not needed, and limiting the use of air conditioning can help reduce energy consumption.

3 **Save, reuse, recycle:** waste reduction can have a significant impact on greenhouse gas emissions. This can include reducing the use of disposable plastic, reusing items whenever possible, and recycling materials such as paper, glass, and plastic.

4 **Sustainable diet:** reducing the consumption of meat and dairy products and choosing local and seasonal products can help reduce greenhouse gas emissions associated with agriculture.

5 **Supporting renewable energy:** choosing energy providers that use renewable sources, when possible, can contribute to reducing carbon emissions.

1

Reducing car traffic

2

Re-energising

3

Reduce, reuse, recycle

4

Sustainable nutrition

5

Supporting renewable energy

DATA FOR SOUTH TYROL

Since the 1960s, the annual average temperature in South Tyrol has risen by about 1.5 °C. The number of tropical nights, i.e., nights when the temperature does not fall below 20 °C, has increased.
This increase in average temperature leads to the melting of glaciers, which have shrunk by about a third between 1983 and 2006 (See photos of the Marmolada 1 2). The increase in temperatures also affects the snow cover that protects glaciers during the summer. Higher winter temperatures cause the snowfall limit to rise. A reduced presence of snow and its rapid melting limit its essential function as a natural water reservoir. Moreover, the distribution areas of many plant and animal species are shifting to higher elevations, and in lower areas, the spread of new species is observed.
There are two climate scenarios by 2100: a moderate scenario called RCP 4.5 expects a lower increase in average summer temperature of less than 2 °C if greenhouse gas emissions start to decline by 2040. In the worst-case scenario (RCP 8.5), if greenhouse gas emissions do not decrease, there will be a further increase in average summer temperature of about 5 °C.

SOUTH TYROL CLIMATE PLAN 2040

Key points of the Climate Plan 2040:

- **Reduction of CO_2 emissions:** By 2030, CO_2 emissions should be reduced by 55% compared to 2019, and by 70% by 2037.
- **Share of renewable energy:** The share of renewable energy should increase to 75% by 2030 and to 85% by 2037.
- **Holistic approach:** The climate plan covers all relevant areas of society, including energy, mobility, and agriculture.
- **Dynamic adjustment:** The plan will be evolutionarily adjusted to respond to new developments and challenges.

1

Ice withdrawal on the Marmolada, 1910-2021

2

Ice withdrawal on the Marmolada, 1984-2012

DESTRUCTION

This video impressively showcases the dramatic consequences of human environmental destruction in various regions of the world in time-lapse. The real footage highlights the rapid changes and the urgent need for environmental protection measures

9 COUNTDOWN TO MASS EXTINCTION?

Recent research indicates that humanity releases about 37 gigatonnes of CO_2 annually – a figure that far exceeds the historical emissions of 9.53 gigatonnes from Siberian volcanism at the end of the Permian. This massive increase in CO_2 threatens our ecosystems through global warming and ocean acidification.
A United Nations report warns that about one million animal and plant species are threatened with extinction. Many could disappear in the coming decades. The comparison of the current climate crisis with the mass extinction at the end of the Permian serves as a stark wake-up call: It is time to act to prevent the sixth mass extinction. We still have a choice, but for how much longer remains uncertain – the countdown to mass extinction has long begun.

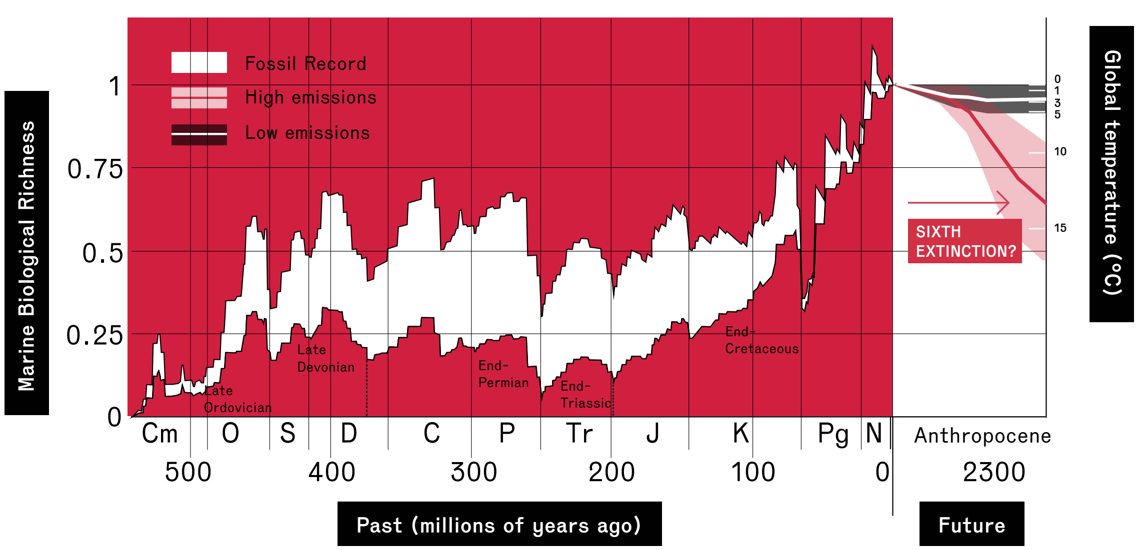
PREDICTIONS FOR THE FUTURE

PREDICTIONS FOR THE FUTURE OF OUR OCEANS

- The oceans are expected to warm by 4-5°C by the end of the 21st century.
- The average pH level of the oceans will decrease by 0.44 units.
- High temperatures will reduce the oxygen content of the oceans and alter nutrient cycles.
- If human emissions continue unabated, the oceans could experience widespread oxygen depletion over the course of the 21st century and beyond.

GRAPHIC FROM PENN & DEUTSCH, 2022 1

The scientists Justin L. Penn and Curtis Deutsch presented in their 2022 article published in *Science*, *“Avoiding ocean mass extinction from climate warming”* a graph that shows two scenarios: one predicting a minor biological crisis and another outlining a potential catastrophic mass extinction, depending on whether humanity reduces its CO_2 emissions or not. These scenarios emphasize the urgency of taking climate change seriously and preventing the worst impacts through globally coordinated efforts.



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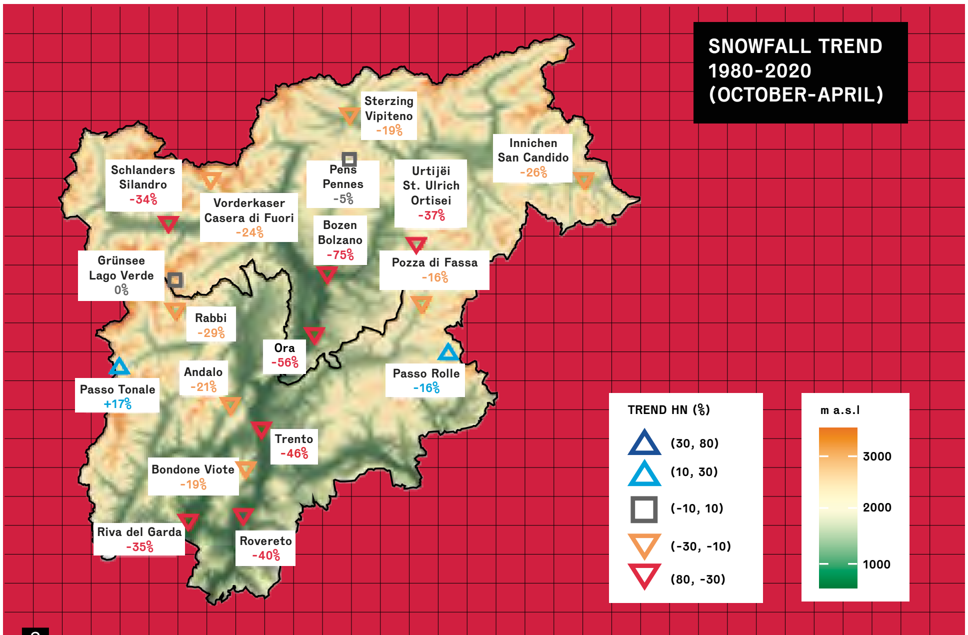
Penn & Deutsch’s graphic, 2022

CLIMATE CHANGE AND TOURISM

The end of winter tourism? What is the future of snowfall in winter? 2 3



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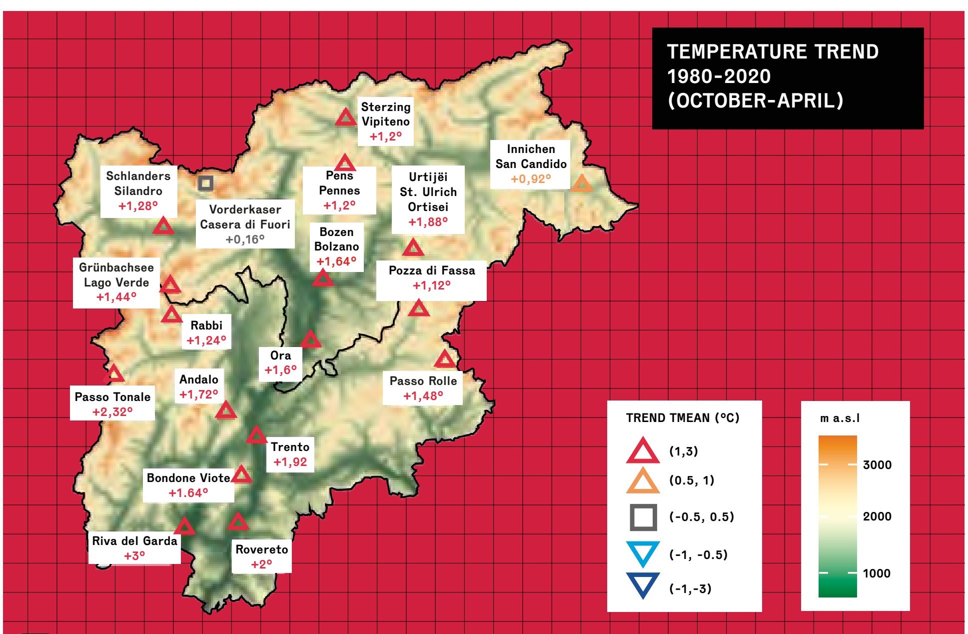
Snowfall trend in Trentino Alto Adige, 1980-2020 (October-April)



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Temperature trends in Trentino Alto Adige, 1980-2020 (October-April)

MICROPLASTIC

Microplastics in the ocean result from the breakdown of larger plastic waste and the introduction of small plastic particles. These tiny particles enter the food chain, are ingested by marine animals, and can have toxic effects. Microplastics pollute the seas worldwide and pose a serious threat to marine ecosystems.

IMAGE CREDITS

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Museum Ladin Ciastel de Tor, San Martin de Tor (BZ)
Direction Katharina Moling
Curator Herwig Prinoth

EXHIBITION DESIGN

Concept and design Studio Puls, Studio Nine
Technical team and lighting Elektro Eros
Carpentry Tistlaria Mamp
Print Rdk Visual Print
Translations in Ladin Werner Pescosta, Istitut Ladin Micurá de Rü

THANKS TO

Galleria Doris Ghetta & Judith Neunhäuserer, Renato Posenato (Univ. Ferrara), William Foster (Univ. Hamburg), Christoph Spötl (Univ. Innsbruck), Robbie Shone, Marc Zebisch (Eurac Research), Volkmar Mair (Amt für Geologie und Baustoffprüfung), Museum Gherdëina, Istitut Ladin Micurá de Rü, Peter Daldos (Geoparc Bletterbach), Davide Bonadonna, Sara Welponer, Giovanni Baccolo, Christian Casarotto (Muse), Giovanni Mortara e Stefano Perona del Comitato Glaciologico Italiano

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