EOSC 114 – The Catastrophic Earth, Natural Disasters

25th November 2024

IMPACTS 2

Mass Extinctions

Dr Mitch D'Arcy

THE UNIVERSITY OF BRITISH COLUMBIA

Pangaea, about 250 million years ago – the crime scene for today's class

EOSC 114 – The Catastrophic Earth, Natural Disasters

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IMPACTS MINI-MODULE

1. Biostratigraphy and Geological Time
2. Mass Extinctions
3. Impacts and the Extinction of the Dinosaurs
4. Impacts and Humans: Frequency and Mitigation

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IMPACTS 2

Mass Extinctions

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LEARNING GOALS

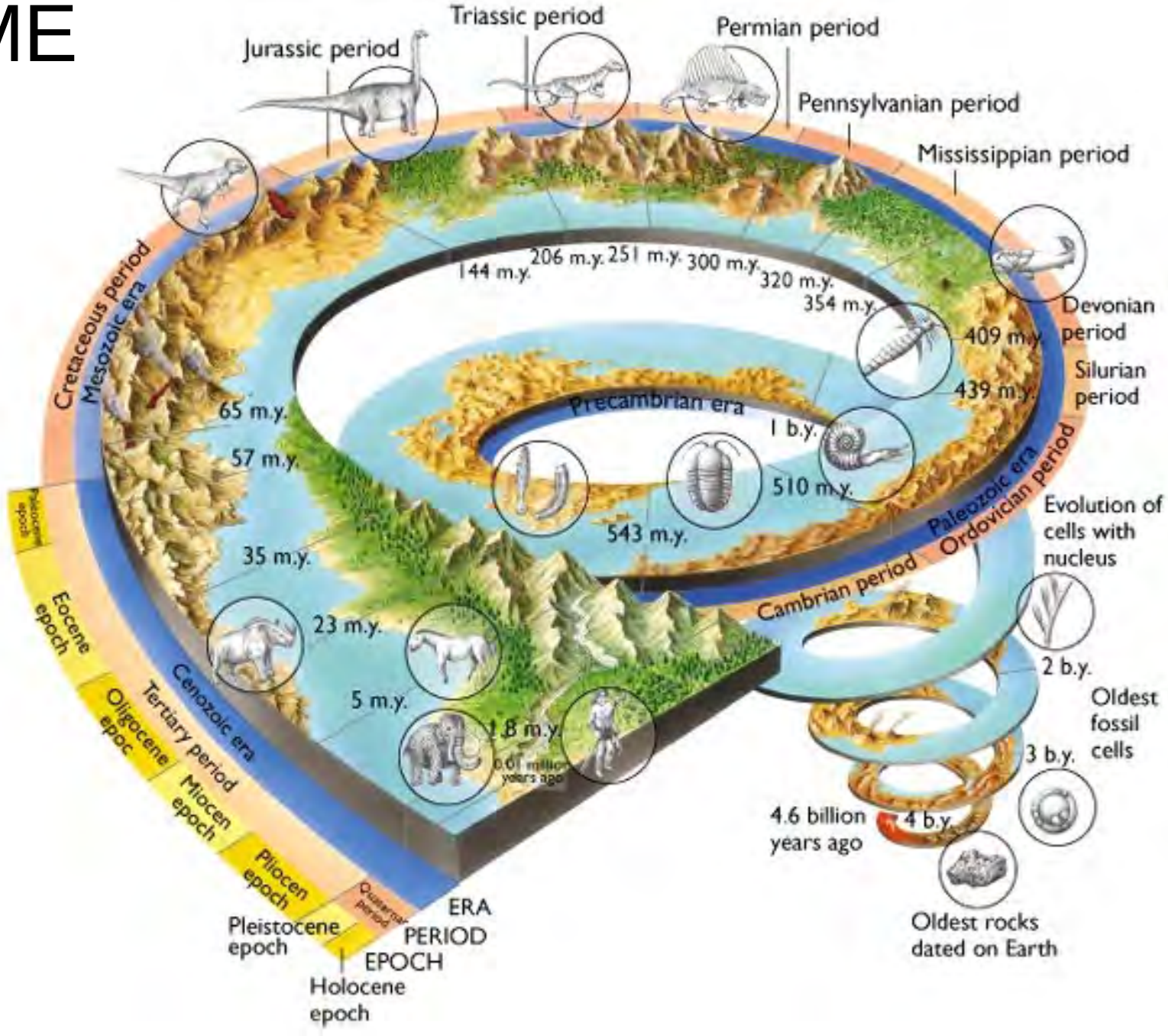
1. Define the characteristics of a mass extinction
2. List the 'Big 5' mass extinction events and their order through time
3. Distinguish between broad extinction-producing phenomena
4. Describe the significance and magnitude of the End-Permian (also known as Permo-Triassic, P/T) event
5. List the causes and effects of the End-Permian mass extinction
6. Describe the significance and magnitude of the End-Triassic event
7. List the causes and effects of the End-Triassic event
8. Appreciate that open questions remain about mass extinctions and Earth's geological history, and that we do not yet have all the answers

GEOLOGICAL TIME

How have we built our understanding of Earth's geological history?

- Understanding the Earth as a system
- Steno's laws of stratigraphy
- Biostratigraphy
- Correlation
- (and radiometric dating)

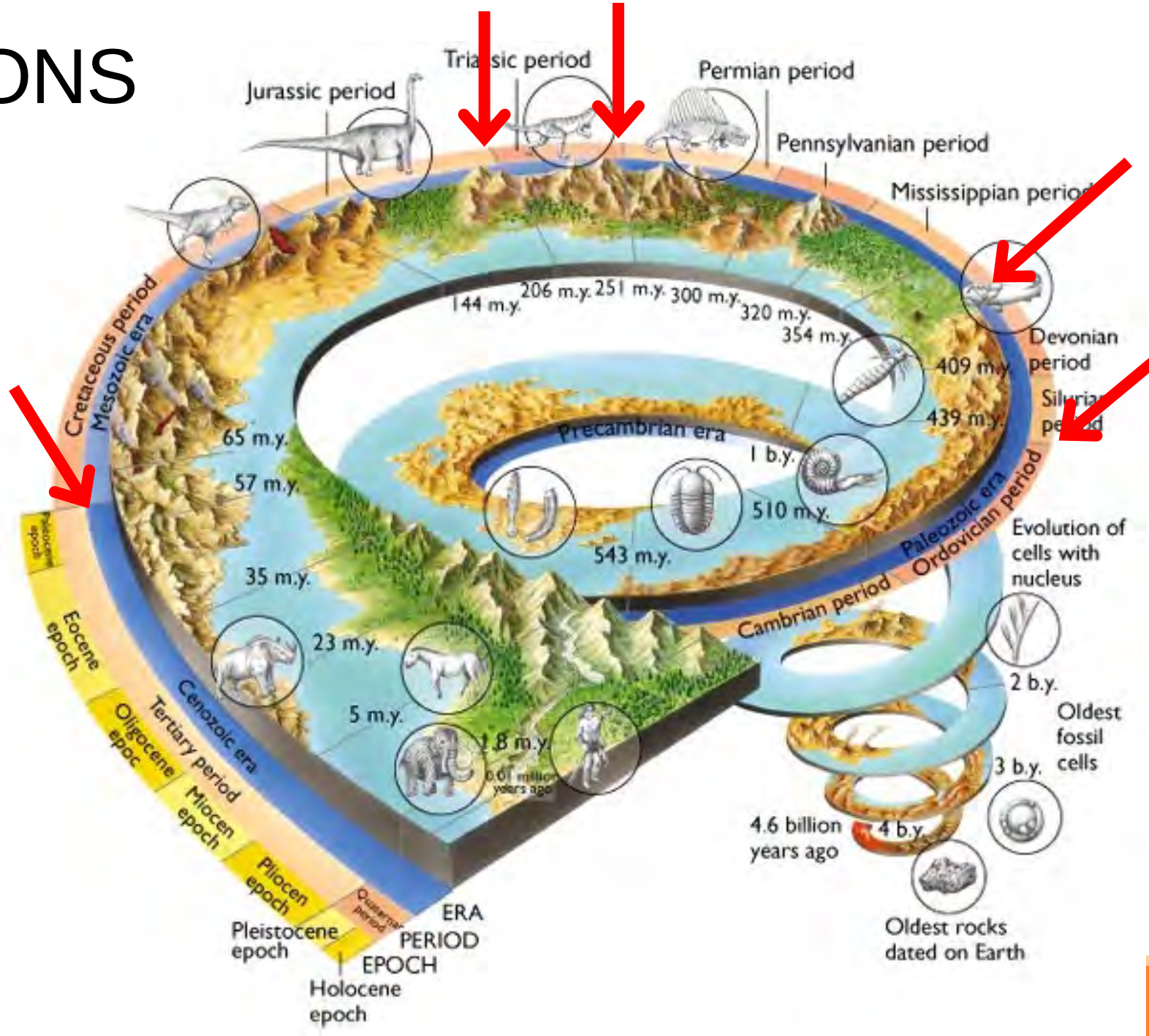
We learned that the Earth has experienced major changes through time.



MASS EXTINCTIONS

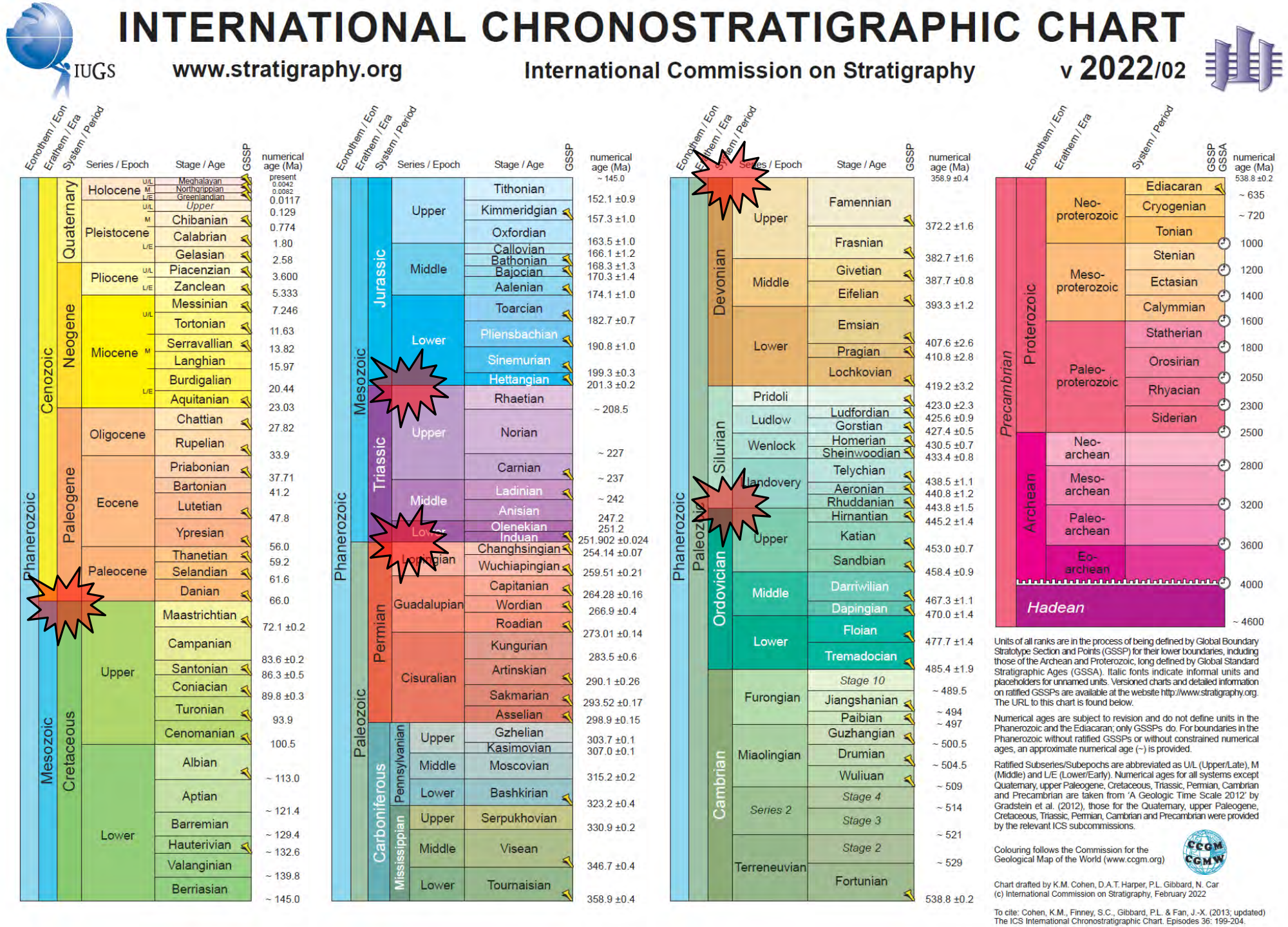
There have been five major extinction events:

- End Cretaceous (66 Ma)
- End Triassic (201 Ma)
- End Permian (251 Ma)
- Late Devonian (360 Ma)
- Late Ordovician (450 Ma)



There have been five major extinction events:

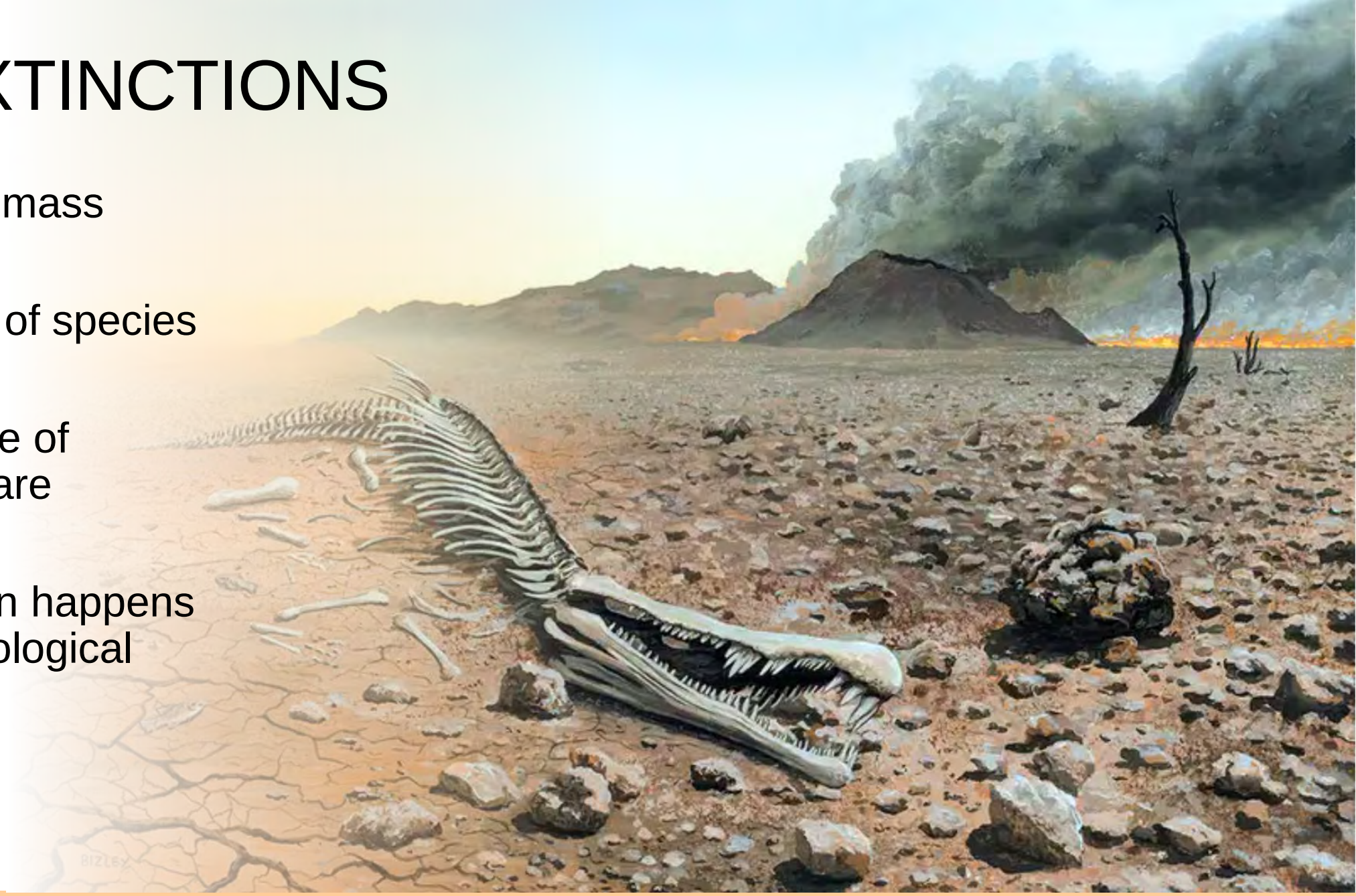
- End Cretaceous (66 Ma)
- End Triassic (200 Ma)
- End Permian (250 Ma)
- Late Devonian (360 Ma)
- Late Ordovician (450 Ma)



MASS EXTINCTIONS

What defines a mass extinction?

- At least 30% of species are extinct
- A broad range of ecosystems are affected
- The extinction happens quickly in geological timescales

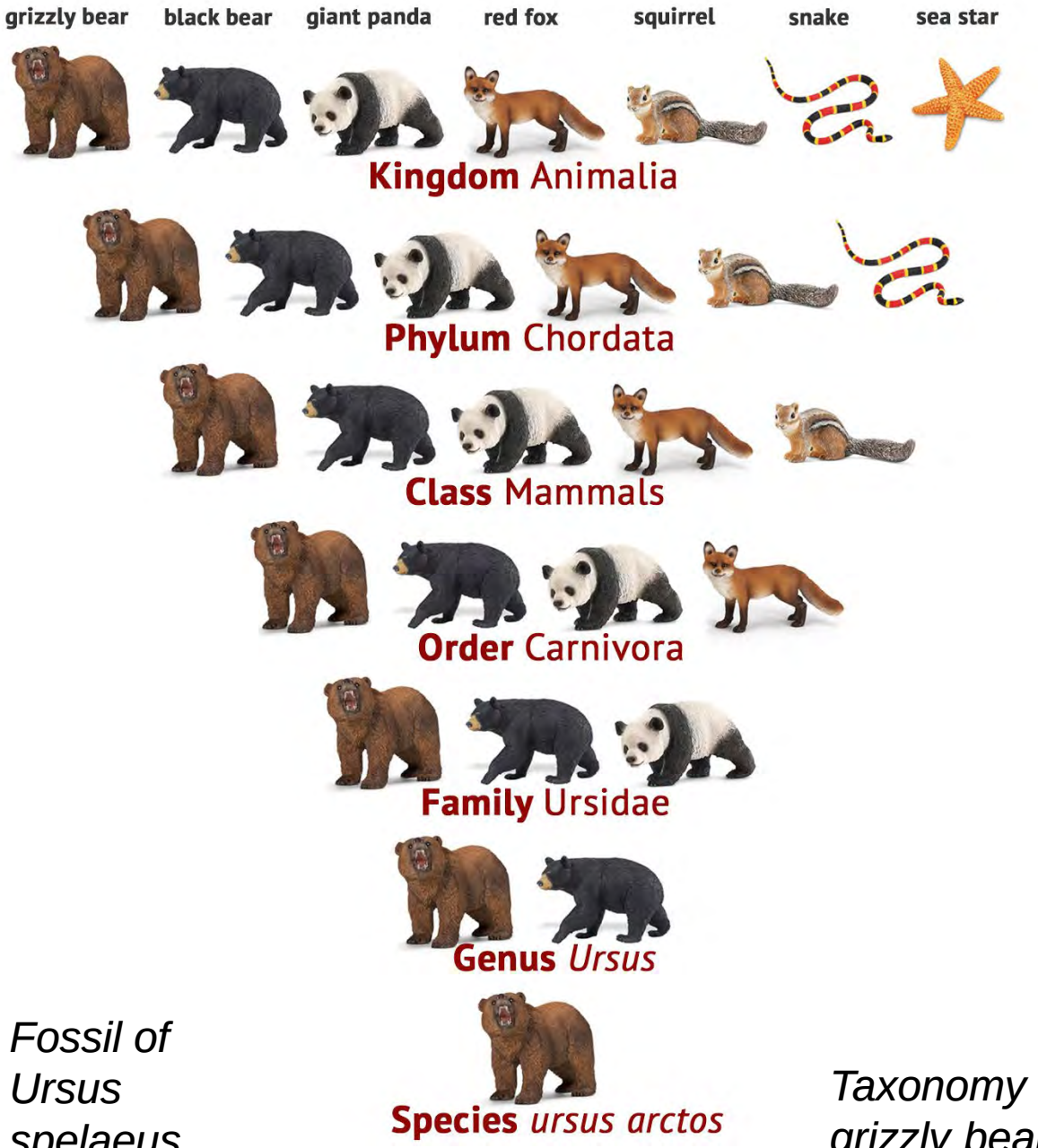


TAXONOMY

A species is a group of living organisms that are capable of viable interbreeding.

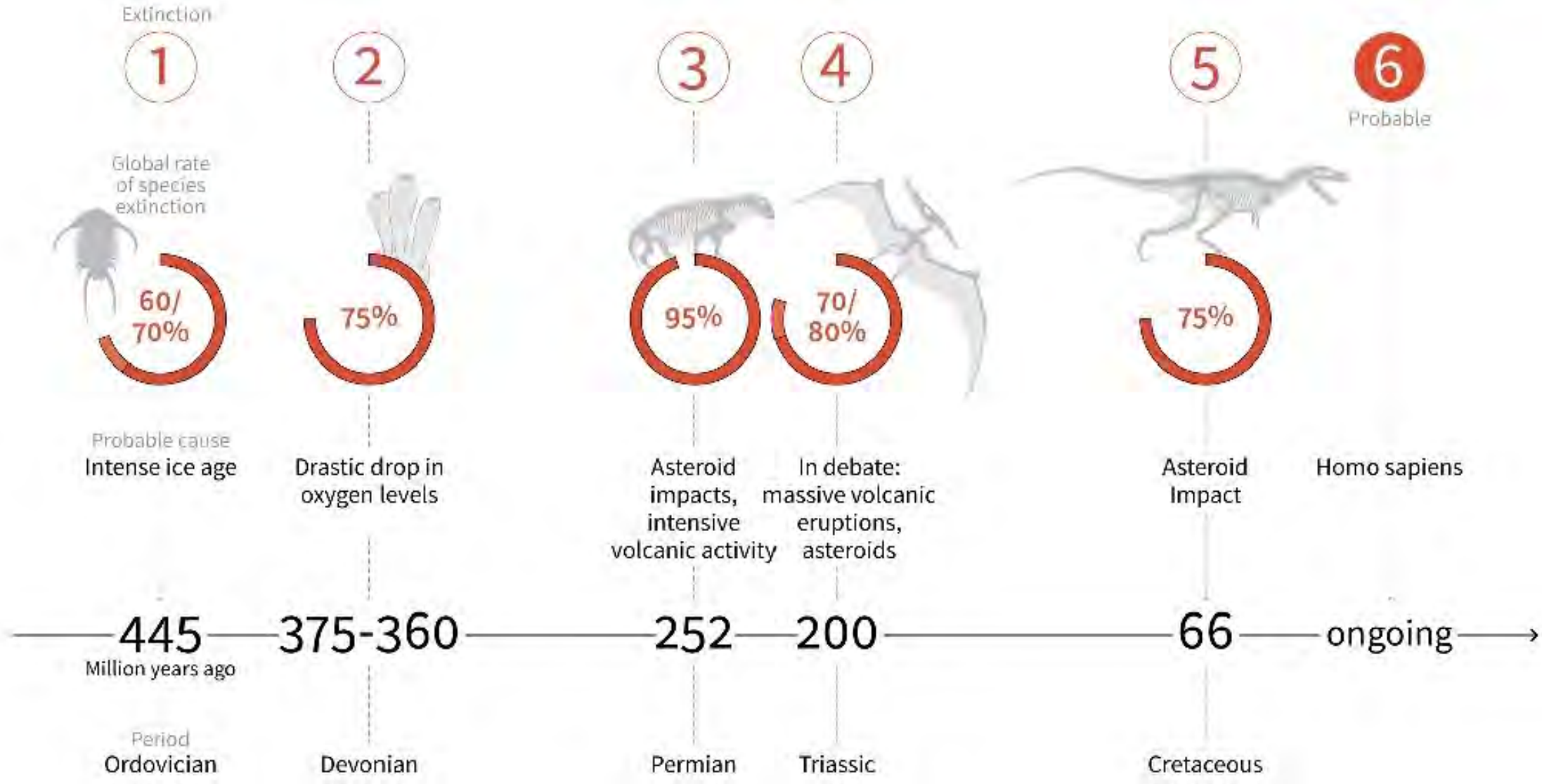
For extinct organisms preserved as fossils, we use their physical characteristics to identify species.

Fossil of Ursus spelaeus



Taxonomy of the grizzly bear

THE BIG FIVE MASS EXTINCTIONS



CAUSES OF MASS EXTINCTIONS

1. **Biological Causes**

- Competition
- Predation
- Pathogens
- Biological effects on the rest of the Earth system
  - E.g., mosses might have caused the Late Ordovician glaciation: Weathering the continents caused atmospheric CO_2 to drop by 22x, and the first soils washed into the oceans caused algal blooms and anoxia.

Generally, biological causes lead to extinctions, but not MASS extinctions

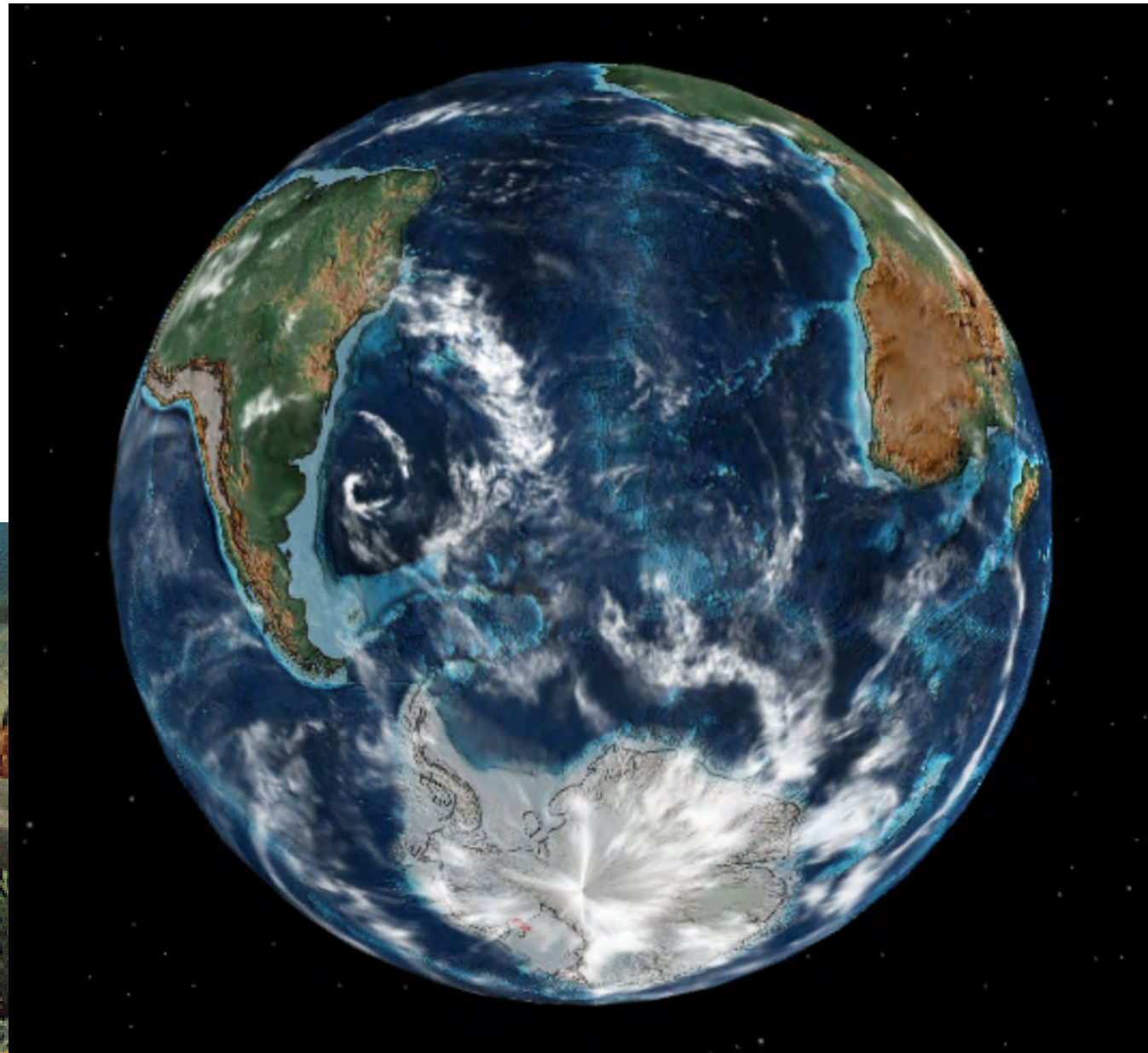
CAUSES OF MASS EXTINCTIONS

Today

2. Plate Tectonics

Plate tectonics can cause changes in climate and sea level.

Example: The Late Ordovician glaciation was probably promoted by Gondwana moving to the South Pole.



CAUSES OF MASS EXTINCTIONS

445 Ma

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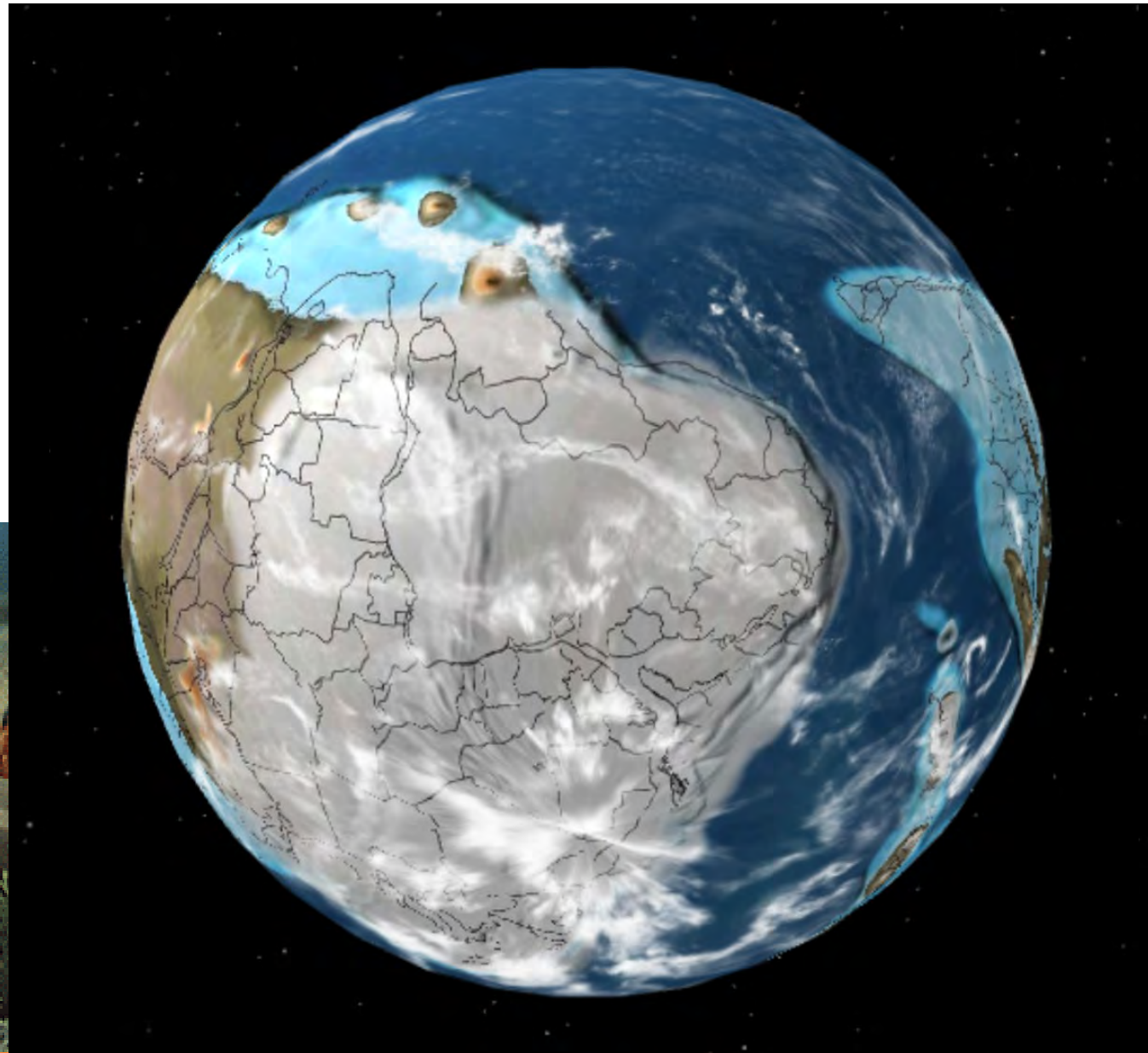
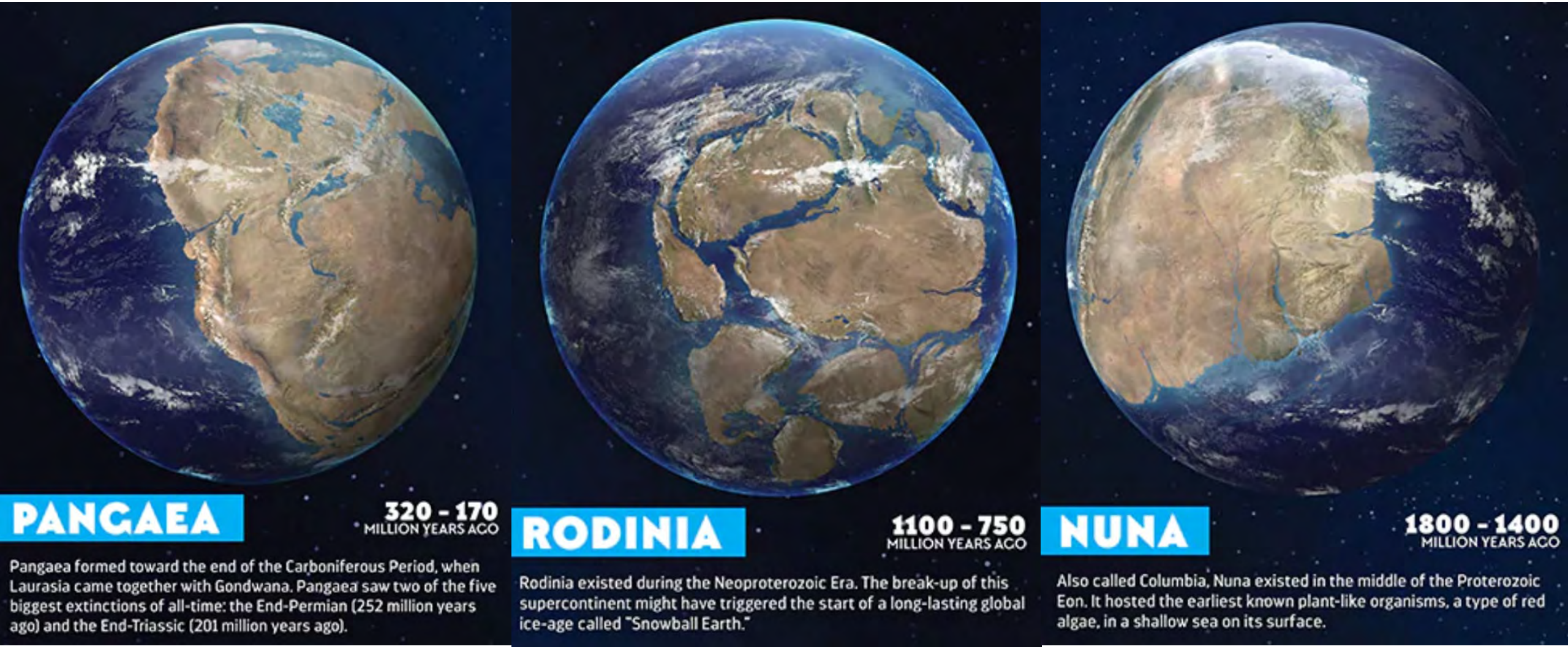


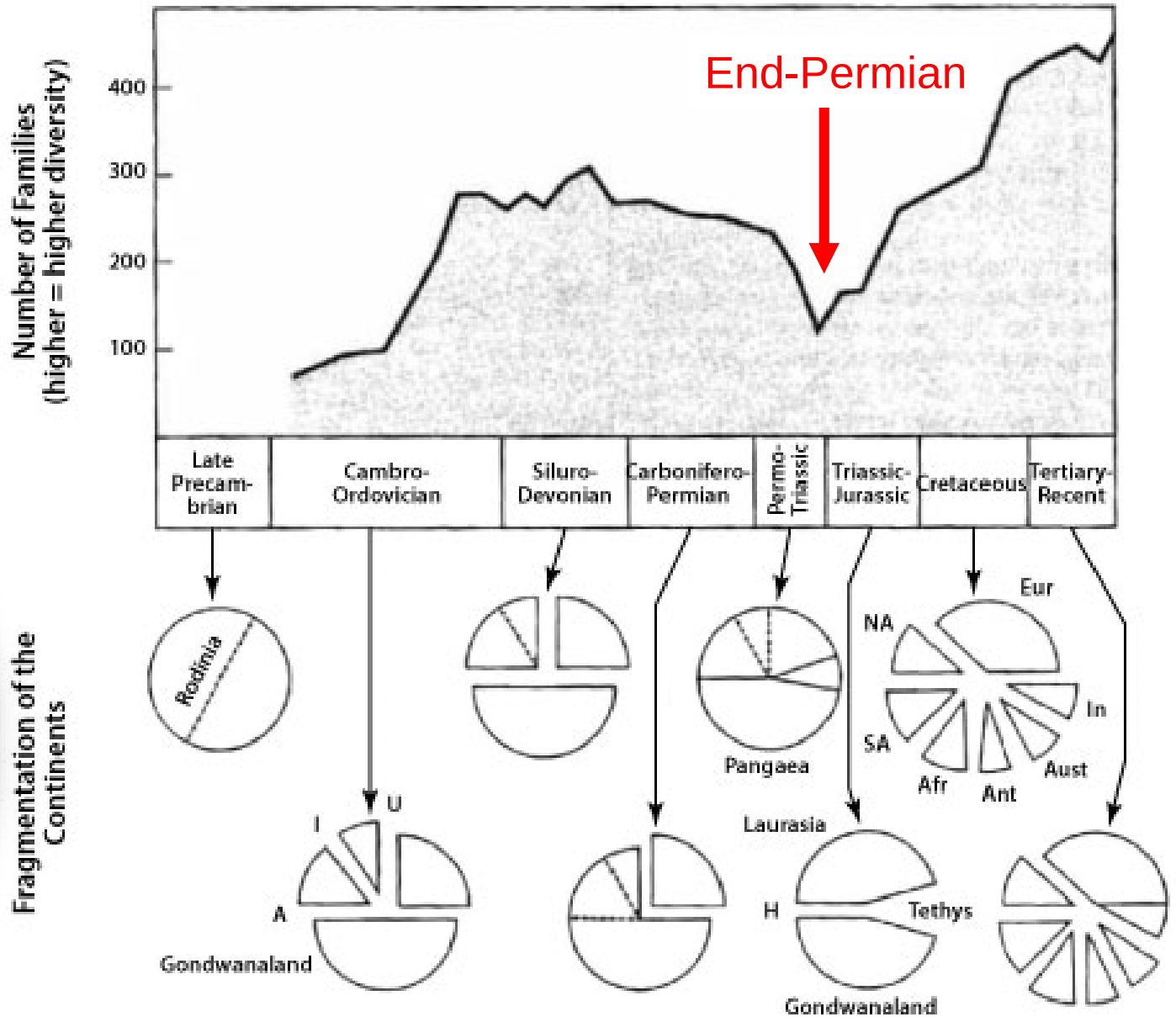
SUPERCONTINENTS



SUPERCONTINENTS

Biodiversity decreases when supercontinents form – on land and in the oceans.

Pangaea
250 Ma



CAUSES OF MASS EXTINCTIONS

3. Climate Change

In the geological past, sudden climate changes were typically caused by volcanism, especially flood basalts.

Long-term shifts between icehouse-greenhouse climate states have also been influenced by volcanism and tectonics.

The eruption of Hunga Tonga–Hunga Ha'apai in January 2022

CAUSES OF MASS EXTINCTIONS

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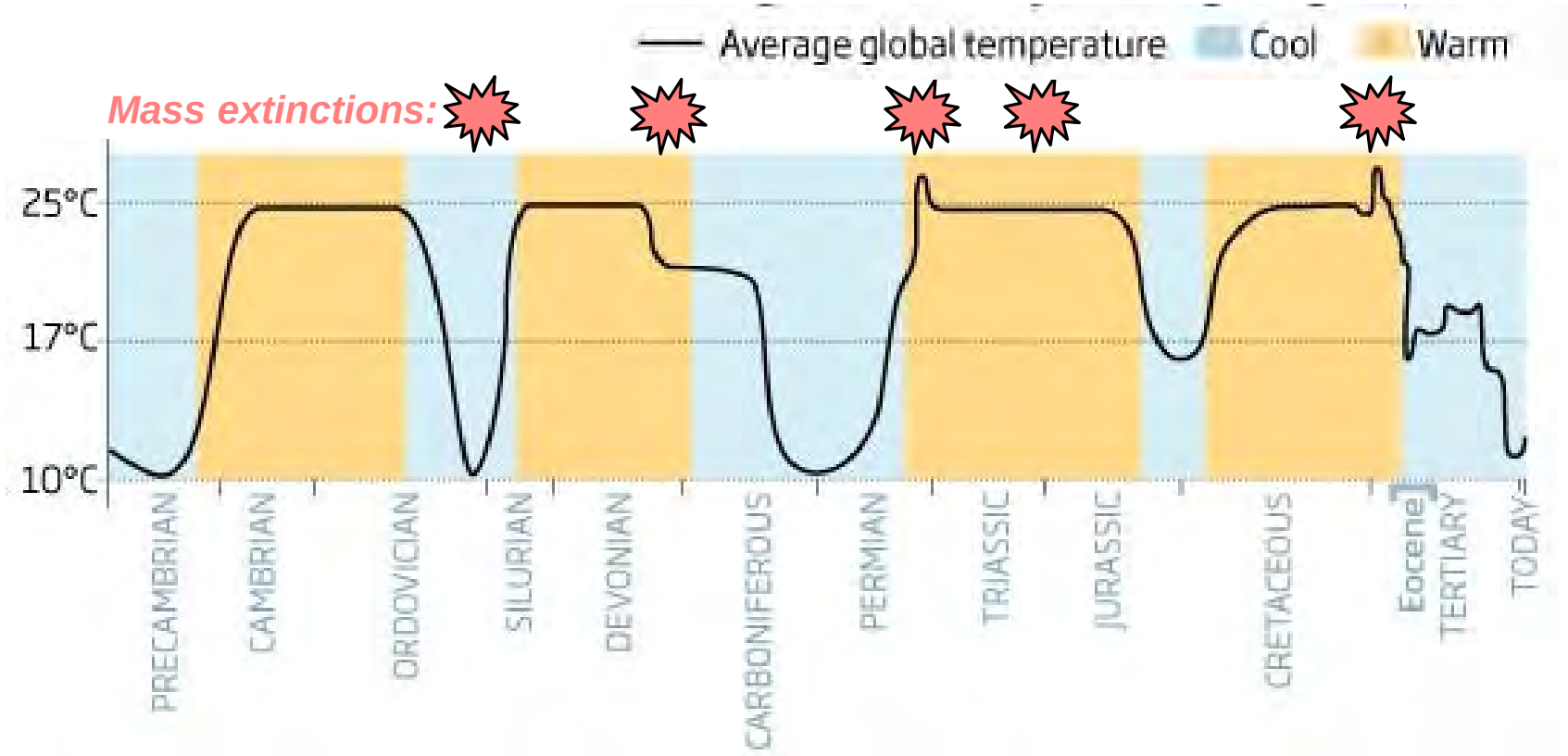

Icehouse climate = Ice present at the poles
Greenhouse climate = No ice present at the poles

CAUSES OF MASS EXTINCTIONS

4. Extraterrestrial Events

- Asteroid impacts
  - E.g., end-Cretaceous mass extinction
- Gamma radiation bursts
  - E.g., perhaps the end-Ordovician mass extinction?

CAUSES OF MASS EXTINCTIONS

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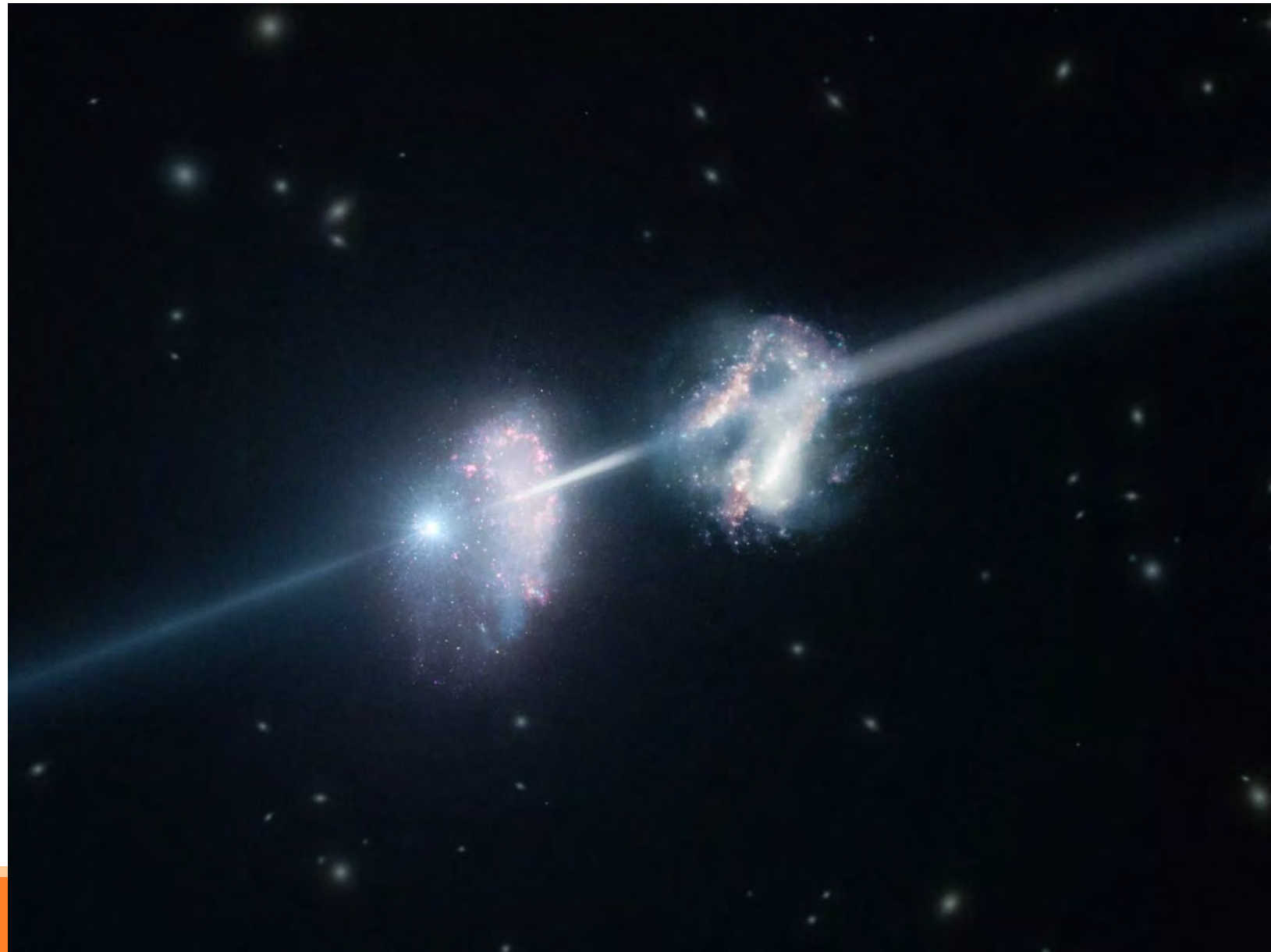


CAUSES OF MASS EXTINCTIONS

Mass extinctions are probably caused by a **combination of factors**.

Late Ordovician (450 Ma)	Late Devonian (360 Ma)	End Permian (251 Ma)	End Triassic (201 Ma)	End Cretaceous (66 Ma)
Glaciation of Gondwana	Rapid climate and sea level changes	Volcanism	Volcanism	Impact(s)
Configuration of tectonic plates	Impact?	Massive climate change	Climate change	Volcanism
Evolution of moss	Volcanic eruptions?	Pangea supercontinent	Impact?	Sea level fall
Gamma radiation burst?	Nearby supernova?	Impact?		

All of these causes disrupt the Earth system, and therefore the biosphere.

END-PERMIAN MASS EXTINCTION

Occurred at 251 Ma

Also known as “the Great Dying”

Wiped out 90-96% of species

The closest Earth has come to life failing completely

The earliest palaeontologists thought life might have ended and restarted

END-PERMIAN MASS EXTINCTION

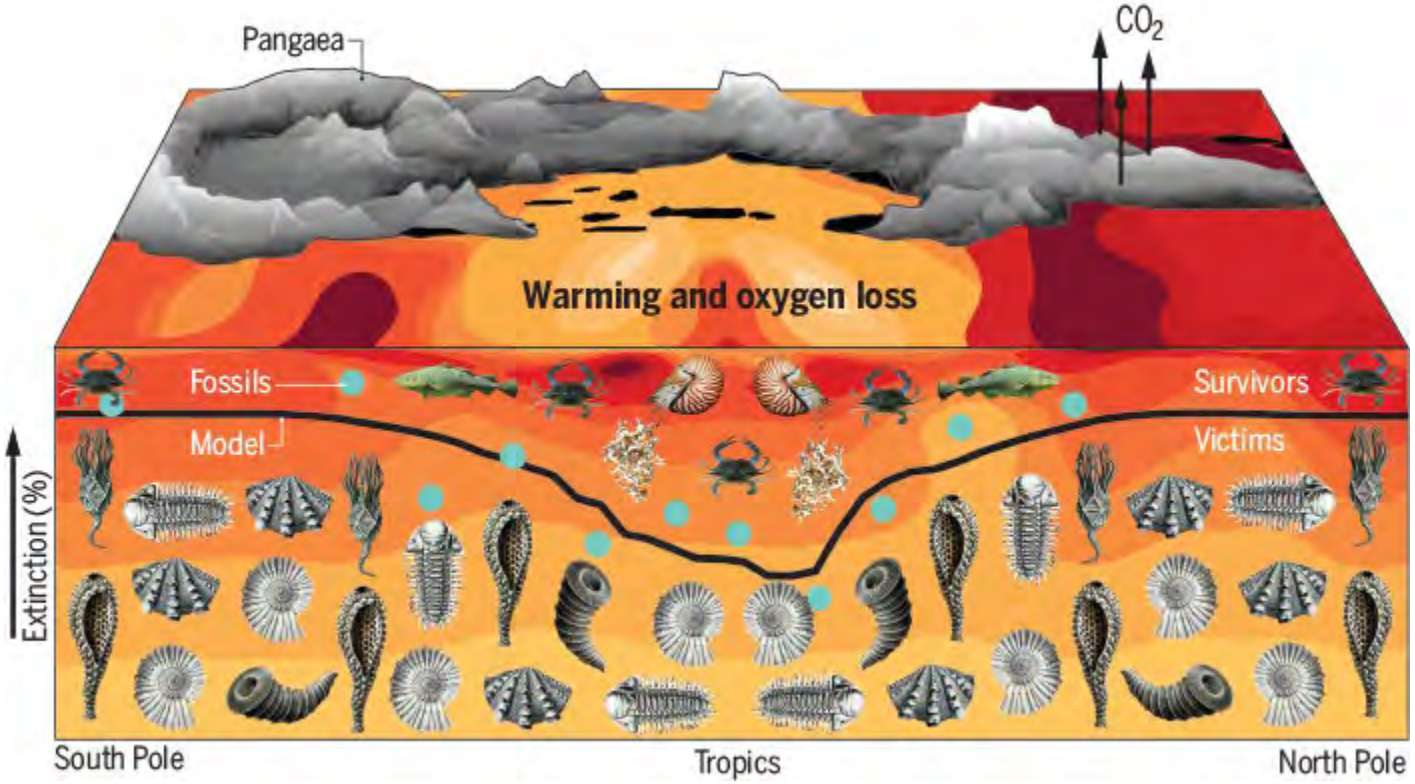
The Permian world had a massive supercontinent called **Pangaea**.

Pangea was huge and dry, causing the Carboniferous Rainforest Collapse ~300 Myr ago.

By 290 Ma, most forests were replaced by vast deserts and an ice cap in the southern hemisphere **– arid wastelands.**

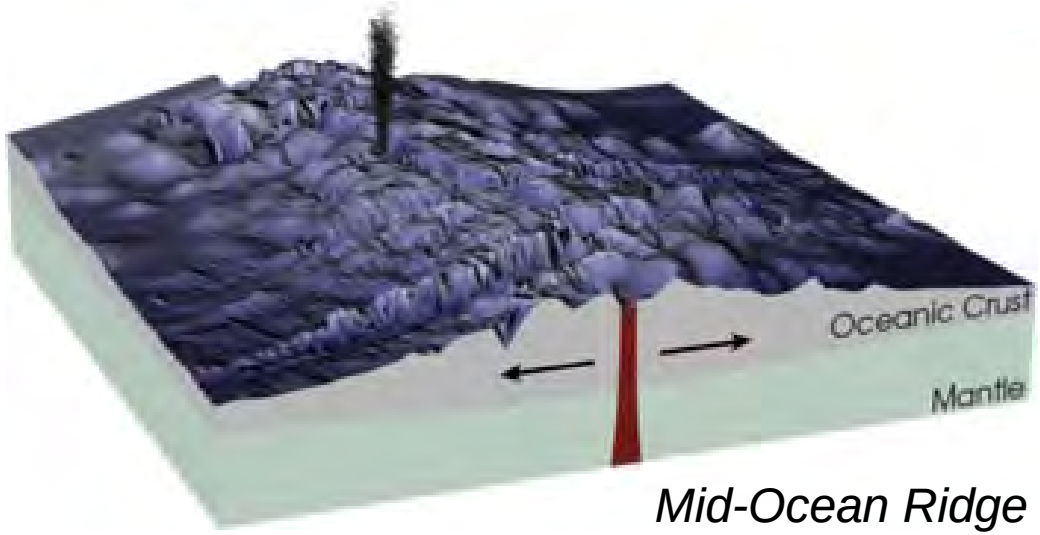
There were **fewer ecological niches** on land, and **fewer continental shelves** in the oceans.

END-PERMIAN MASS EXTINCTION



- **Ocean stagnation**

Polar waters were unable to sink, and ocean circulation was weakened – resulting in **anoxia** (a lack of oxygen).

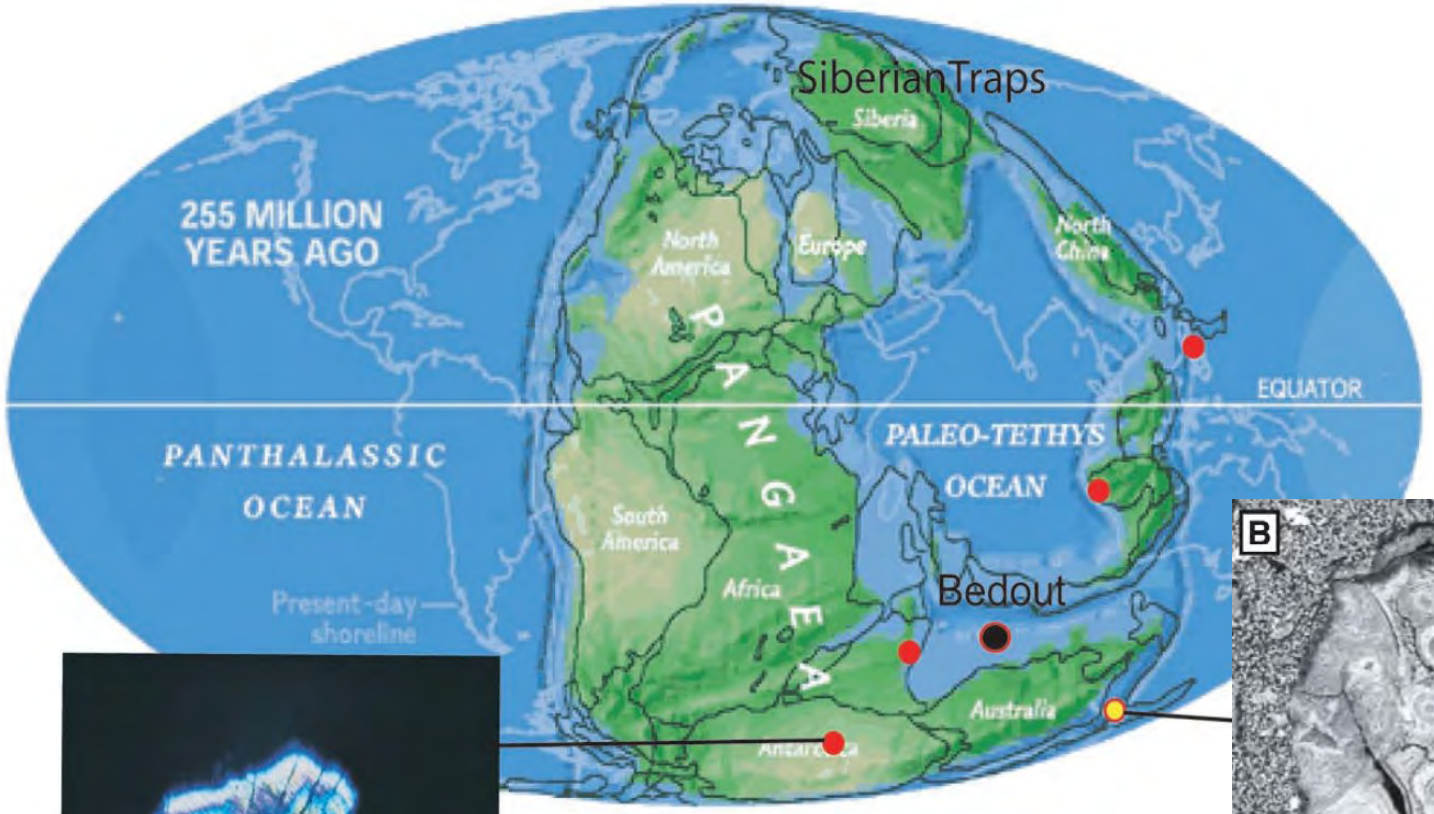


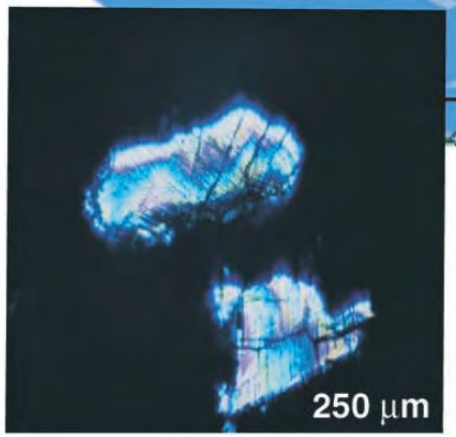
Mid-Ocean Ridge (spreading center)

- **Sea level fall**

Due to plate tectonics (mid-ocean ridge activity) slowing in the Permian.

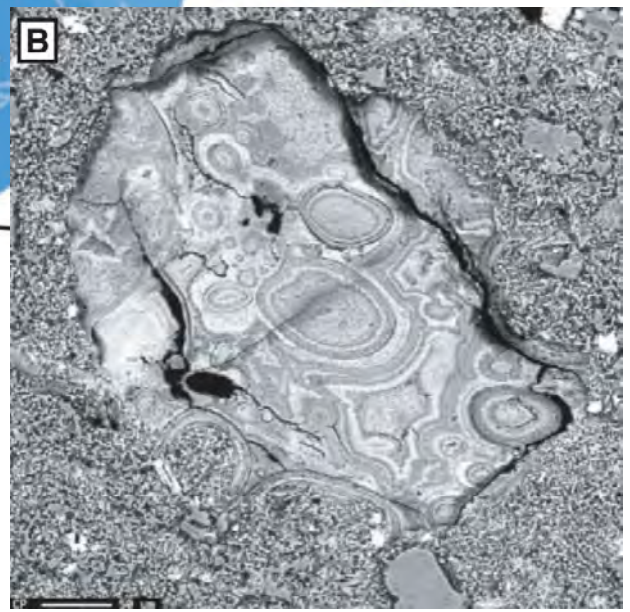
END-PERMIAN MASS EXTINCTION





Red sites: possible extraterrestrial fullerenes

Shock-melted quartz crystals



At the same time, an **impact** *might* have happened at the Bedout site.

Potential impact breccia, shock-melted quartz, and extraterrestrial fullerenes (found in asteroids).

Only a single plagioclase crystal could be dated, but it gave an age of 250.1 ± 4.5 Ma.

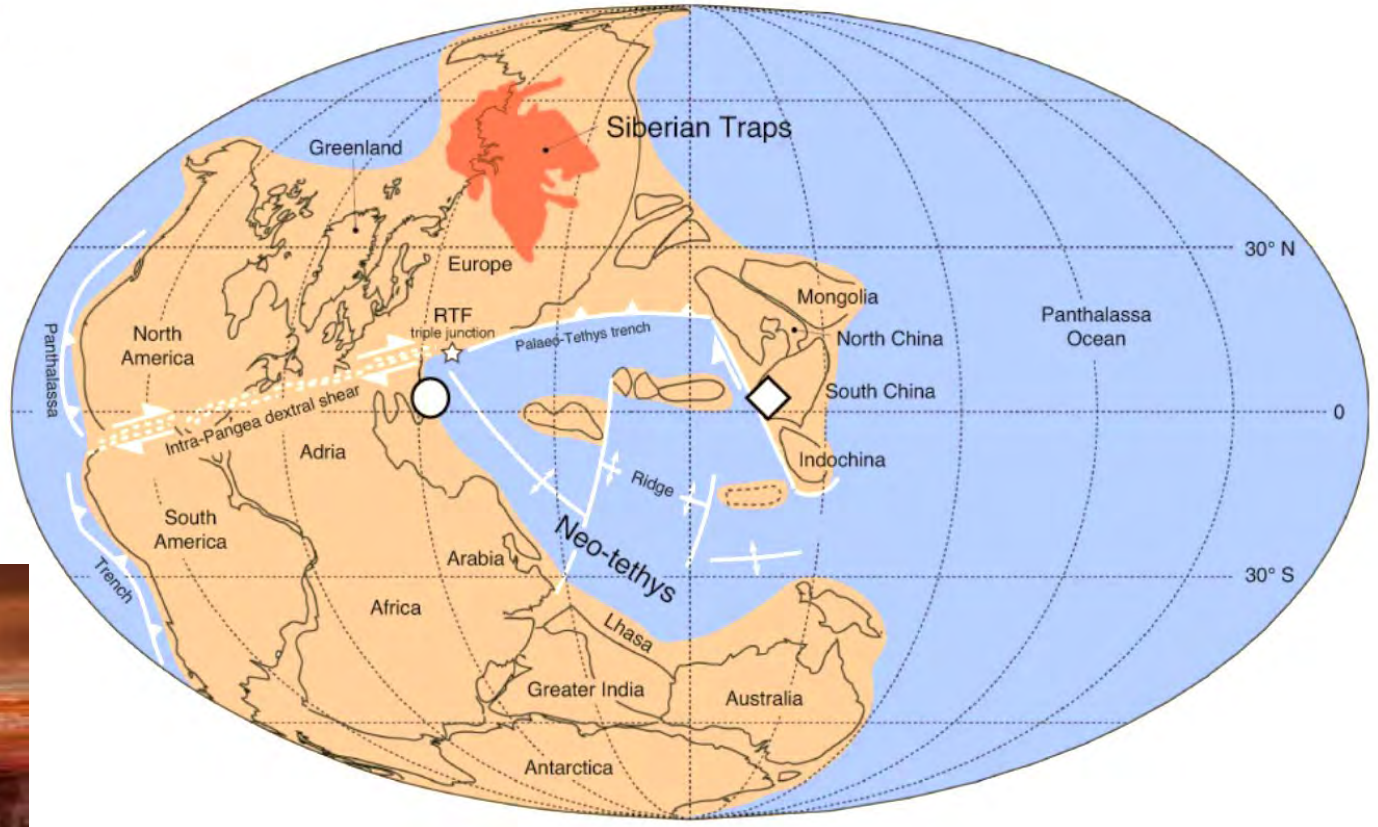
An impact is not yet confirmed.

Poreda et al. 2004

END-PERMIAN MASS EXTINCTION

The **Siberian Traps** erupted at ~250 Ma. This was a ‘Large Igneous Province’ in Siberia.

2-3 million km^3 of basalt lava erupted, releasing huge amounts of carbon dioxide and methane.



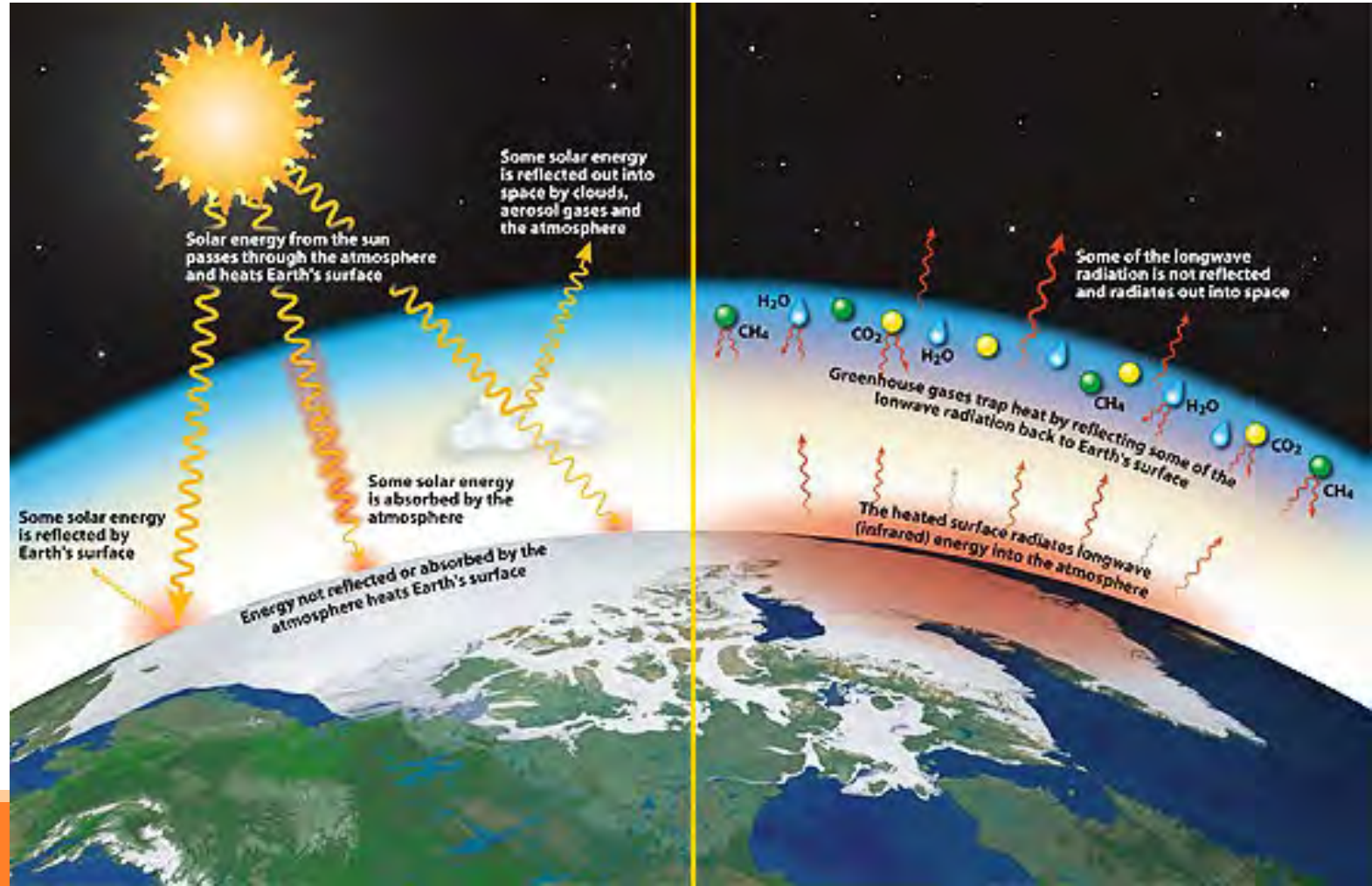
The eruption **set fire to the largest coal, oil, and gas deposits on Earth** at the time.

END-PERMIAN MASS EXTINCTION

Massive amounts of **greenhouse gases** were released into the atmosphere and **global temperatures <u>soared</u>**. **Climate change** was one of the biggest contributors to the End-Permian extinction.

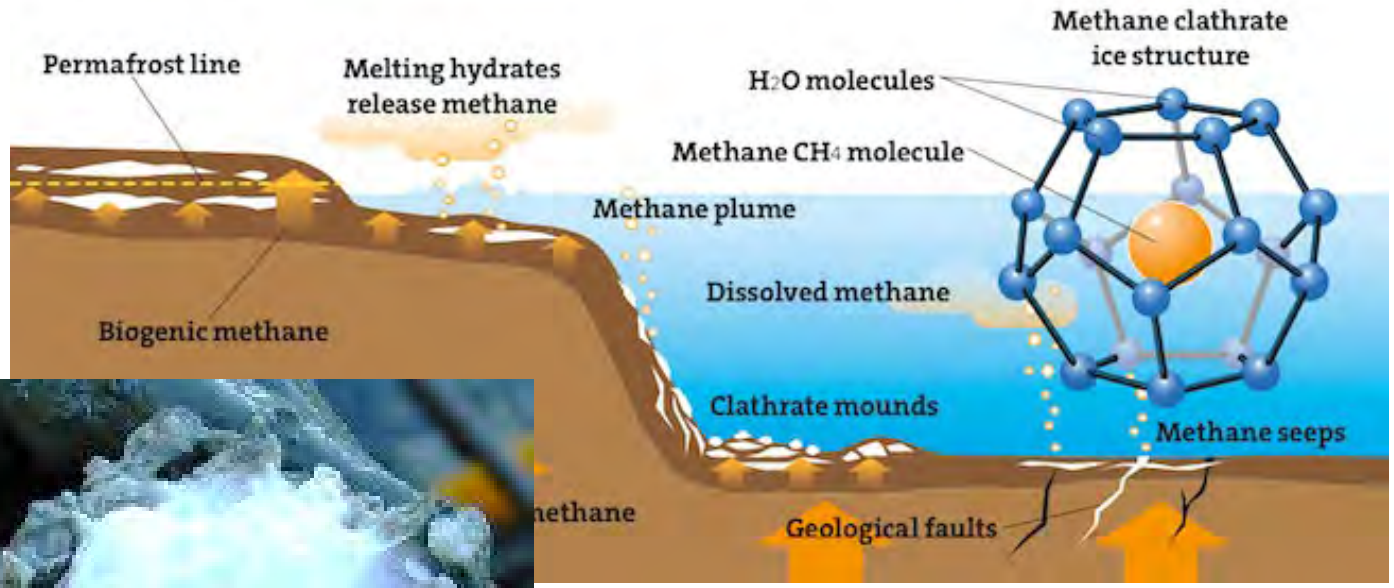
Greenhouse gases act like a warming blanket in the Earth's atmosphere.

They absorb radiation and emit some of it back down to the Earth's surface.



END-PERMIAN MASS EXTINCTION

Massive amounts of **greenhouse gases** were released into the atmosphere and **global temperatures soared**. **Climate change** was one of the biggest contributors to the End-Permian extinction.



Then, methane clathrates melted.

Clathrate: Solid crystal structure containing methane (CH_4) from the decay of organic material, common in deep-ocean sediments.

Ocean warms ➔ melts clathrates ➔ releases CH_4

Methane is an even stronger greenhouse gas than CO_2

END-PERMIAN MASS EXTINCTION

Massive amounts of **greenhouse gases** were released into the atmosphere and **global temperatures soared**. **Climate change** was one of the biggest contributors to the End-Permian extinction.

If you existed at the end of the Permian, would you rather live…

In the ocean

Trilobites

On the land

Gorgonopsids

END-PERMIAN MASS EXTINCTION

Massive amounts of **greenhouse gases** were released into the atmosphere and **global temperatures soared**. **Climate change** was one of the biggest contributors to the End-Permian extinction.

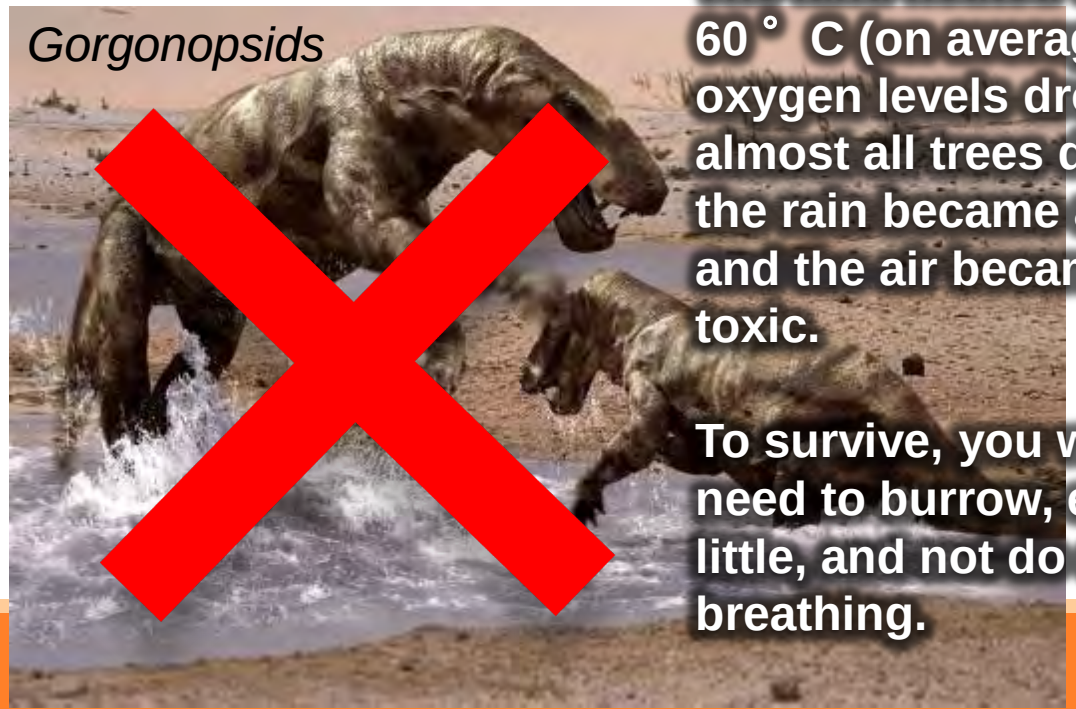
If you existed at the end of the Permian, would you rather live…

In the ocean

The oceans heated to ~40 ° C (on average!) and became acidic and anoxic.

Global reef systems and most ecosystems collapsed

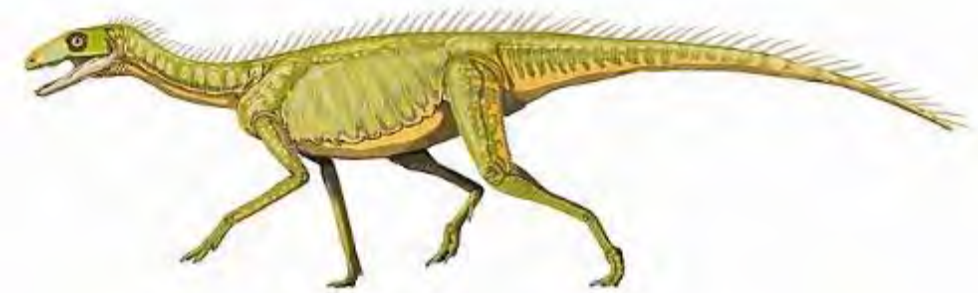
On the land



The land heated to 50 - 60 ° C (on average!), oxygen levels dropped, almost all trees died, the rain became acidic and the air became toxic.

To survive, you would need to burrow, eat very little, and not do a lot of breathing.

THE AFTERMATH: TRIASSIC

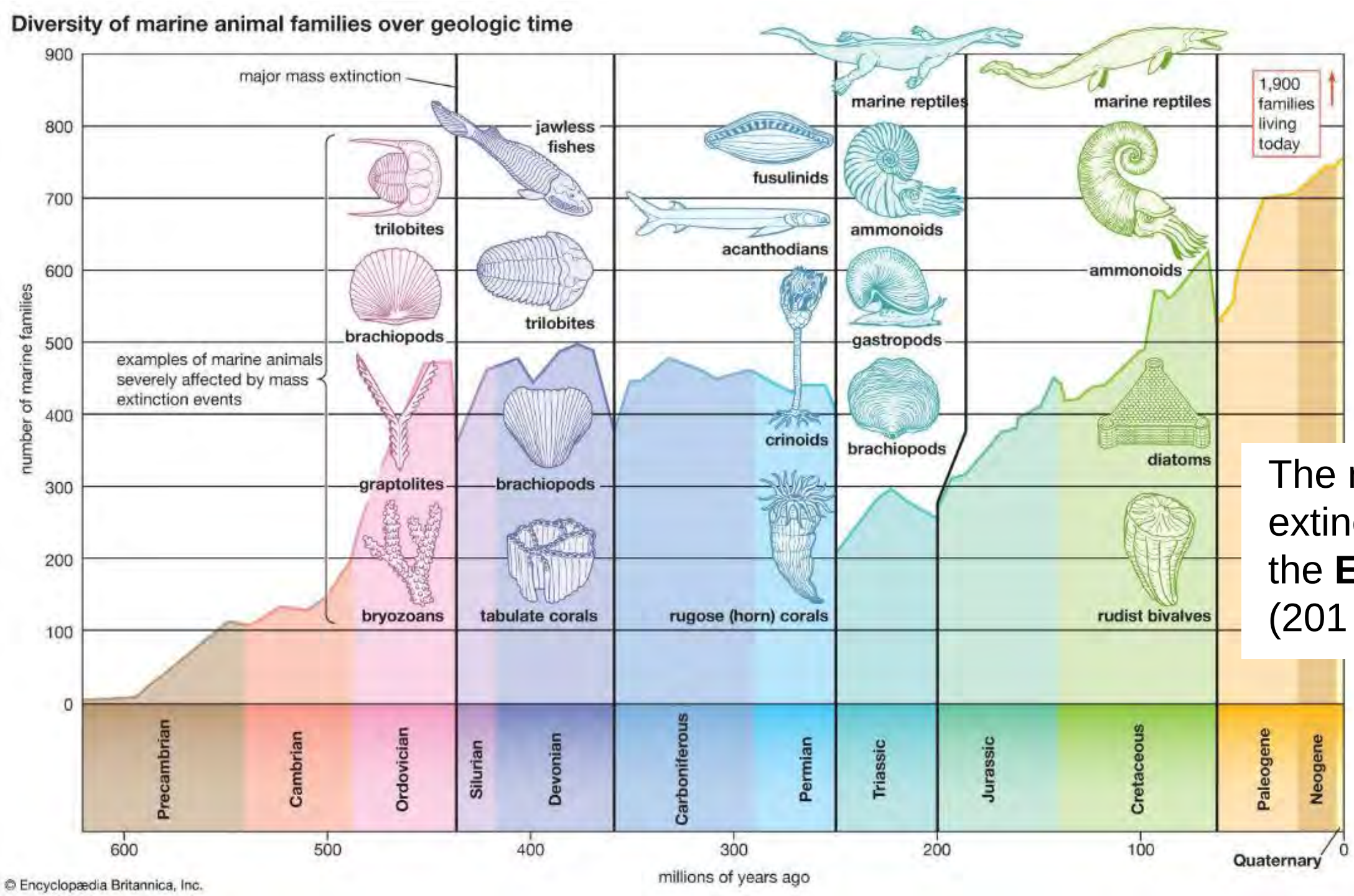


No coal is known anywhere on Earth until 243 Ma (the **Triassic Coal Gap**). It took until 230 Ma for plant diversity to recover to pre-extinction levels.

With 90-96% of all species extinct, there was a lot of **ecological space** (opportunities for the survivors to evolve and dominate available ecological niches).

Life evolved, and a new type of reptile appeared… the **dinosaurs**.

Nyasasaurus
Perhaps the earliest 'dinosaur' (debated) from ~240 Ma.

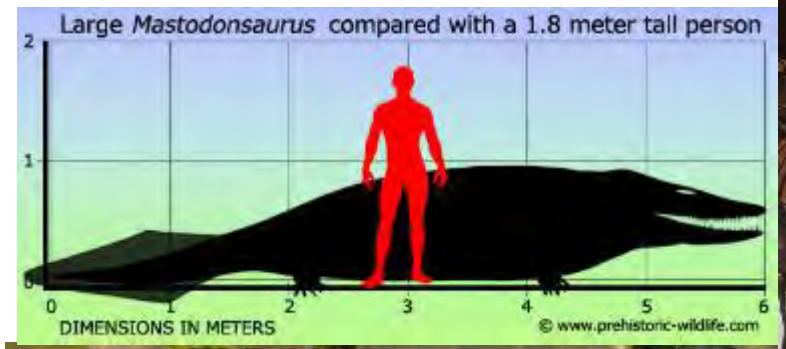


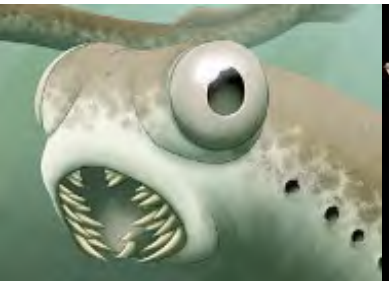
The next mass extinction was at the **End-Triassic** (201 Ma)

END-TRIASSIC MASS EXTINCTION

Occurred at 201 Ma. 70-80% of species extinct.

- More than half of animals: many large amphibians, reptiles, and synapsids (early mammals)
- Major extinction of plants (perhaps as high as 60%)
- Large decline in ammonites
- **Conodonts** extinct – Index Fossils from Cambrian to Triassic





Mastodonsaurus
A (large!) Triassic amphibian that went extinct

END-TRIASSIC MASS EXTINCTION (201 Ma)

What caused the End-Triassic mass extinction?

It’s still unclear…

END-TRIASSIC MASS EXTINCTION (201 Ma)

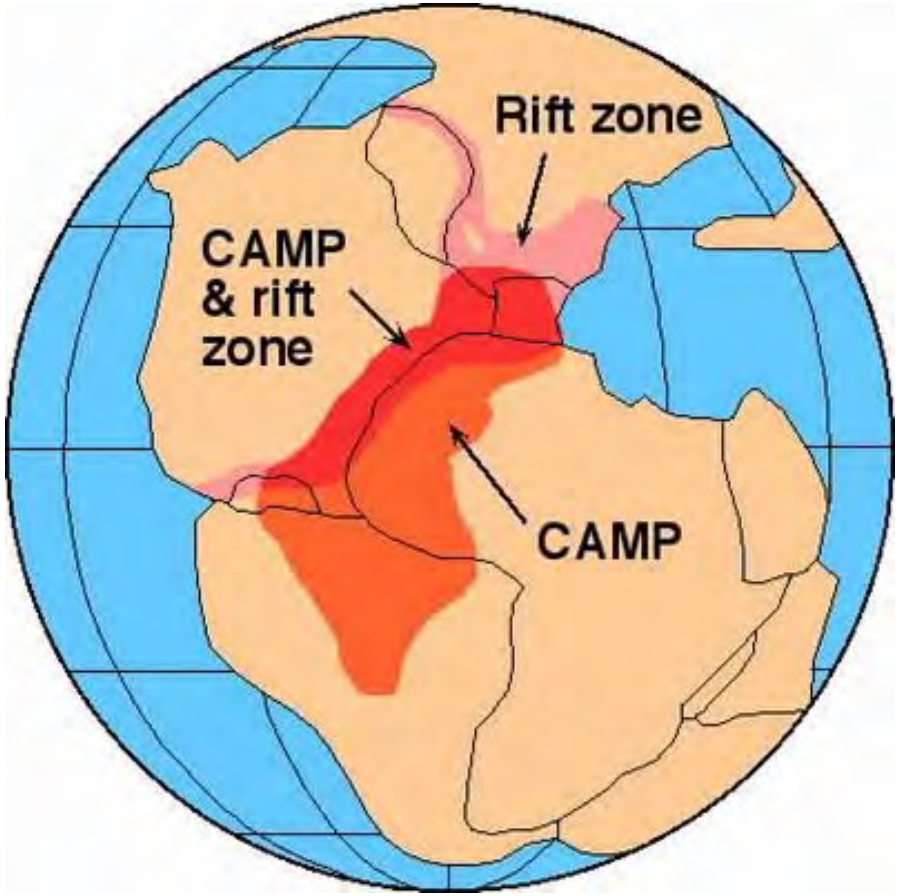
Attributed to the emplacement of the **Central Atlantic Magmatic Province (CAMP).**

3 million km^3 basalt erupted at 201.5 Ma, releasing large amounts of carbon dioxide (CO_2), but eruptions were also rich in sulphur dioxide (SO_2).

The oceans acidified, and carbonate deposition stopped globally at the Triassic-Jurassic boundary.

Atmospheric CO_2 approximately doubled, but SO_2 would have had a short-lived cooling effect.

So **volcanism** and **climate change** definitely played a role, but the details are not certain.

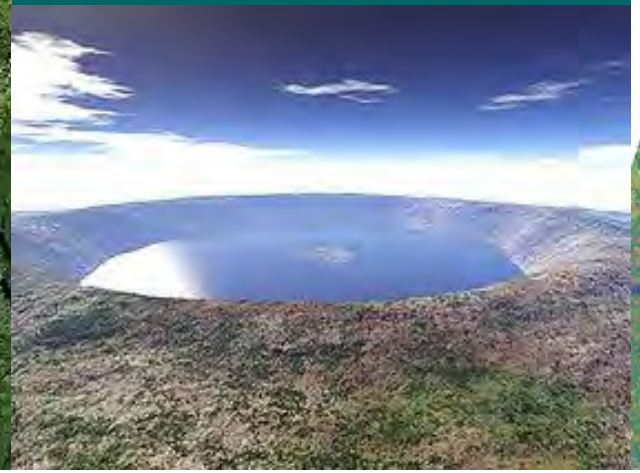


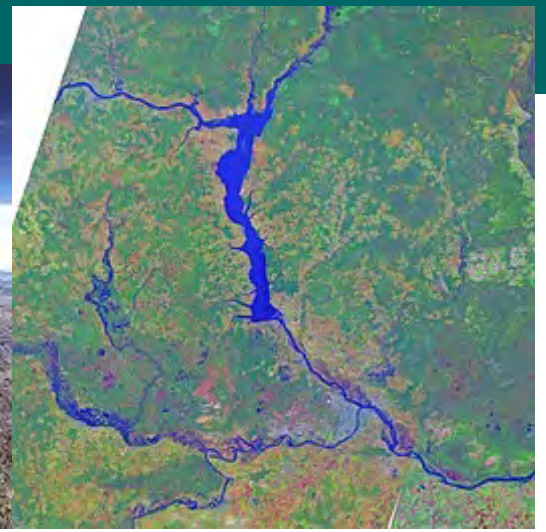
Central Atlantic Magmatic Province

END-TRIASSIC MASS EXTINCTION (201 Ma)

What about impacts?

Manicouagan Reservoir, Quebec	Rochechouart impact structure, France	Puchezh-Katunki crater, Russia	… and others!
100 km wide, but too old – 214 Ma	Between 201-208 Ma, but too small – only 25 km	80 km wide but too young – 196 Ma	Saint Martin crater, Manitoba Obolon crater, Ukraine Red Wing Creek crater, North Dakota

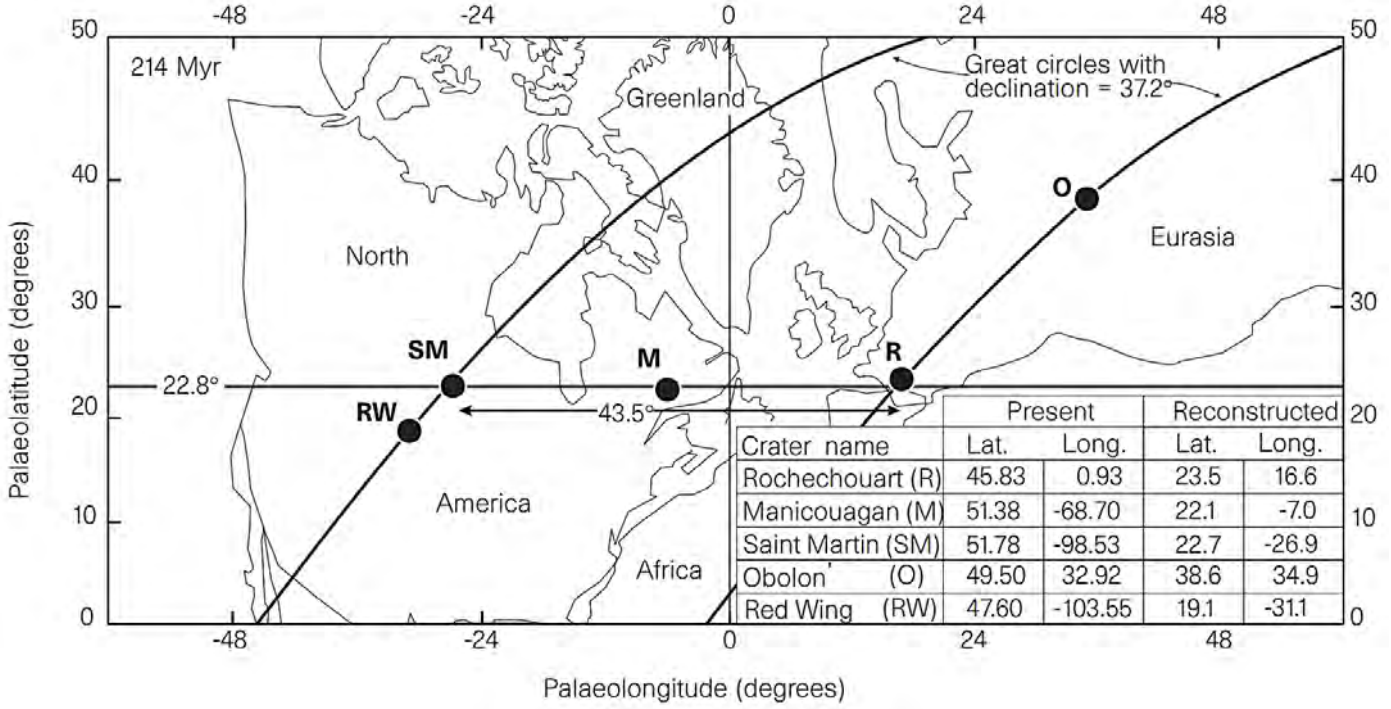




There were multiple impacts in the late Triassic / early Jurassic

END-TRIASSIC MASS EXTINCTION

What about impacts?



Crater name	Present Lat.	Present Long.	Reconstructed Lat.	Reconstructed Long.
Rochechouart (R)	45.83	0.93	23.5	16.6
Manicouagan (M)	51.38	-68.70	22.1	-7.0
Saint Martin (SM)	51.78	-98.53	22.7	-26.9
Obolon' (O)	49.50	32.92	38.6	34.9
Red Wing (RW)	47.60	-103.55	19.1	-31.1

In 1998, John Spray at the University of New Brunswick noticed a pattern…

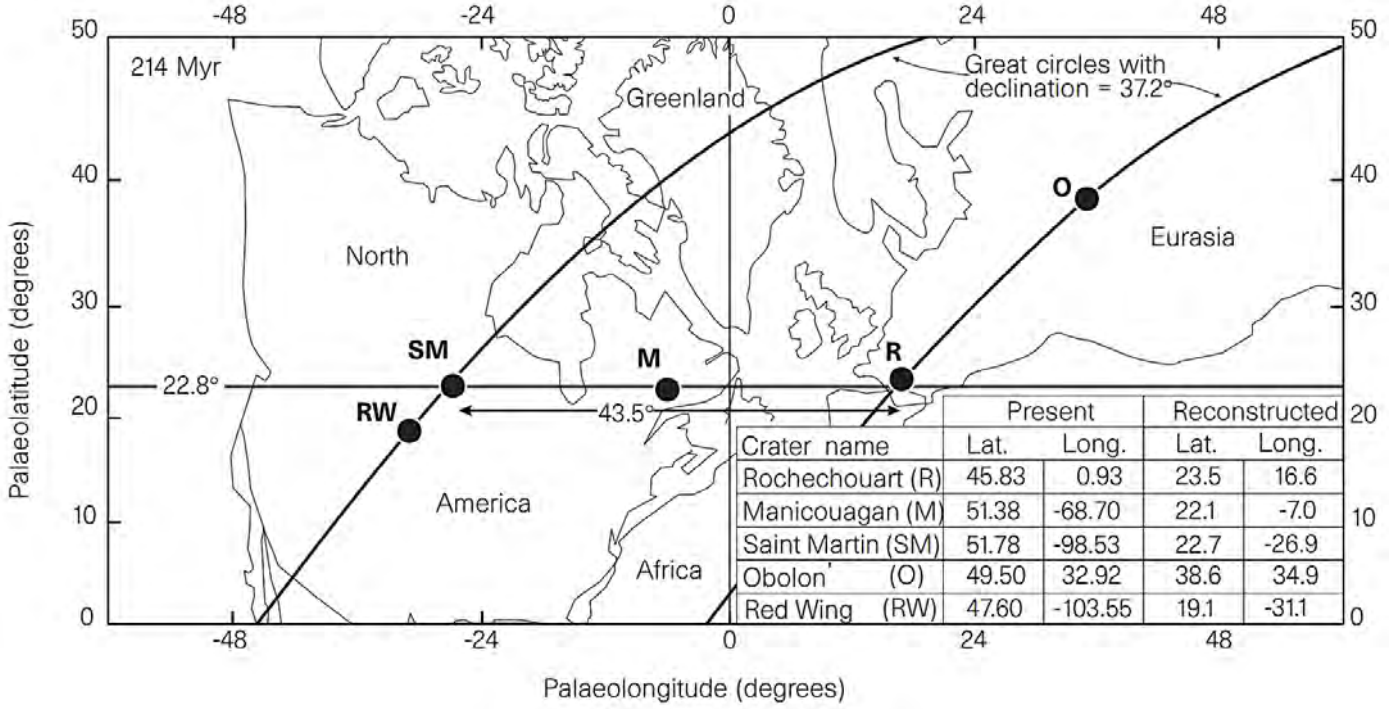
Comet Shoemaker–Levy 9 broke apart in 1992 and collided with Jupiter in 1994.

Image from Hubble space telescope.

END-TRIASSIC MASS EXTINCTION

The Geological Timescale has changed since 1998!

What about impacts?



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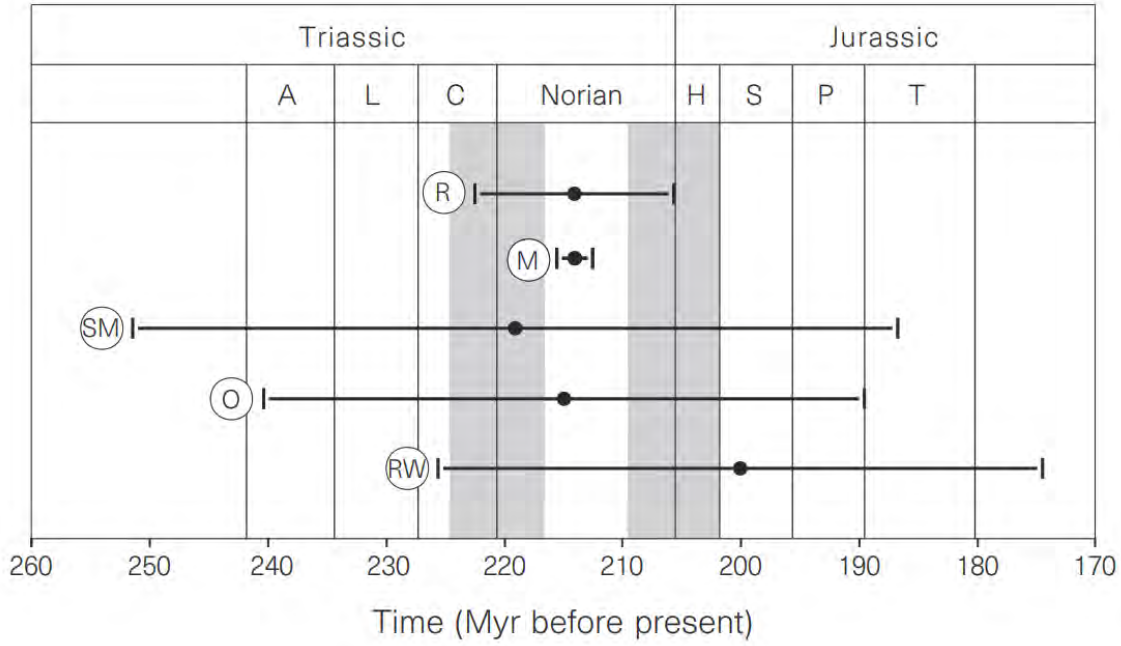


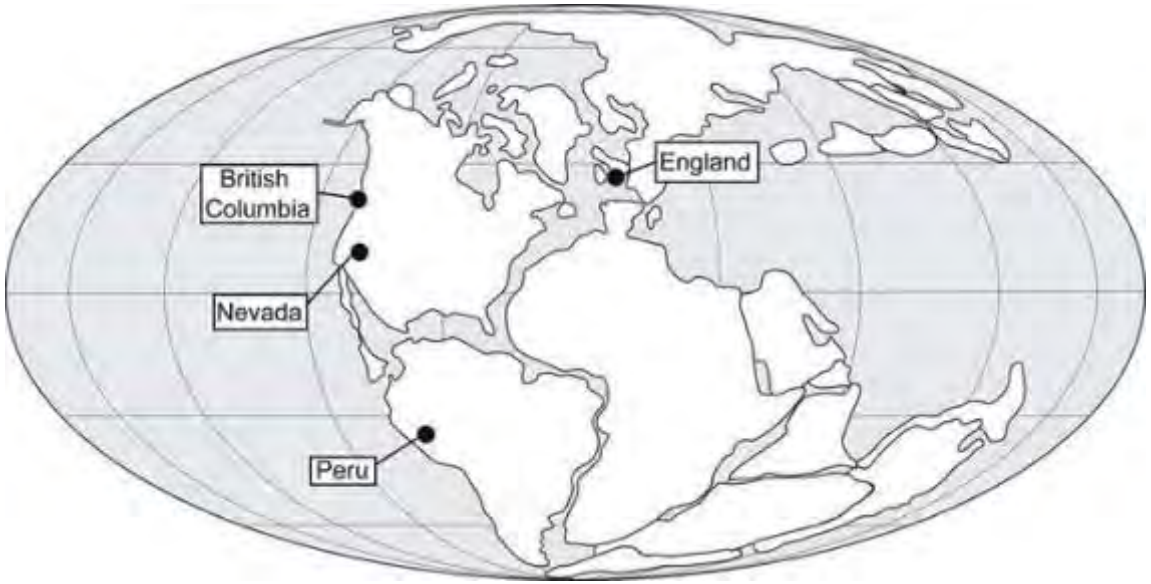
In 1998, John Spray at the University of New Brunswick noticed a pattern…

This remains an **unsolved question.**

END-TRIASSIC MASS EXTINCTION

British Columbia is one of the few places where the Triassic-Jurassic boundary is well preserved – you can touch it!

Geologists studying the Triassic-Jurassic contact on Haida Gwaii



These fossils are common in BC – what are they called?

END-TRIASSIC MASS EXTINCTION

The dinosaurs really took over after the End-Triassic mass extinction, as many competitor animals went extinct. The dinosaurs adapted to their **ecological niches** by **adaptive radiation**.

Aetosaurus
A heavily-armoured Triassic herbivore reptile

Stegosaurus
A heavily-armoured Jurassic herbivore dinosaur

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SUMMARY

1. Mass extinctions wipe out at least 30% of species across multiple ecosystems, relatively quickly compared to geological timescales
2. Mass extinctions can be caused by biological factors, plate tectonics, volcanism, climate change, and extraterrestrial events (e.g., impacts)
3. Usually, mass extinctions involve multiple causes
4. The End-Permian mass extinction (251 Ma) was the worst of the big five, with 90-96% of species going extinct. Lots of things went wrong at the same time!
5. Shortly after, the End-Triassic mass extinction happened (201 Ma)
6. It's not all bad… Mass extinctions create ecological niches and lead to adaptive radiation, e.g., the End-Permian and End-Triassic mass extinctions led to the rise of the dinosaurs.

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IMPACTS MINI-MODULE

1. Biostratigraphy and Geological Time ✓
2. Mass Extinctions ✓
3. Impacts and the Extinction of the Dinosaurs
4. Impacts and Humans: Frequency and Mitigation