LIFE'S STRUGGLE TO SURVIVE

John Baez

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But what fraction of Earth-like planets have civilizations we might detect?

I won't try to answer that. I'll just talk about some obstacles life on *our* planet had to overcome to reach the point where other civilizations might detect *us*.

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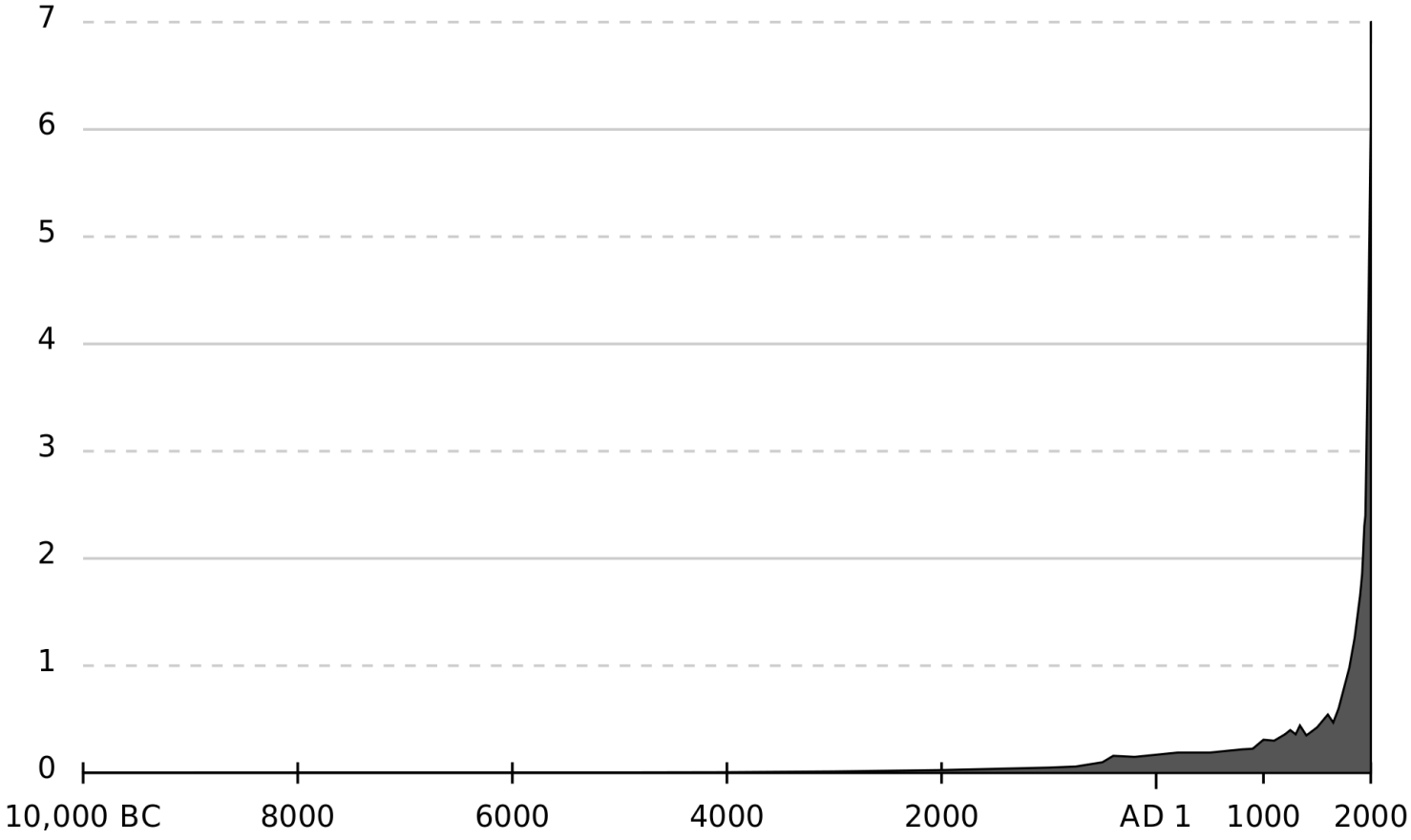
And we're not there yet. We haven't yet made a major effort to broadcast information to other planets. Our civilization *could, in principle* collapse before we ever do that!

After all, we have left the Holocene and entered a new epoch: the Anthropocene, when the biosphere is rapidly changing due to human activities.



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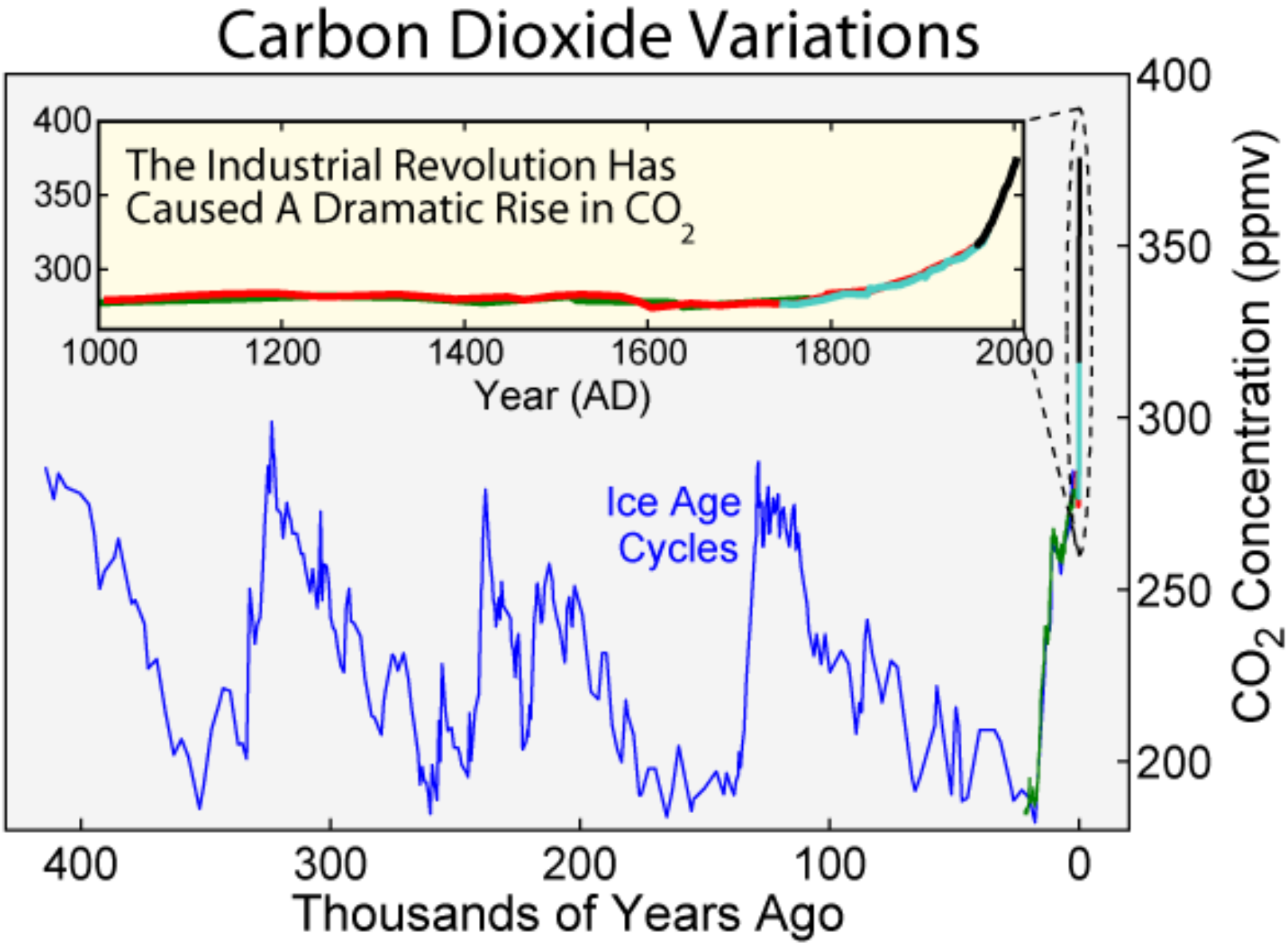
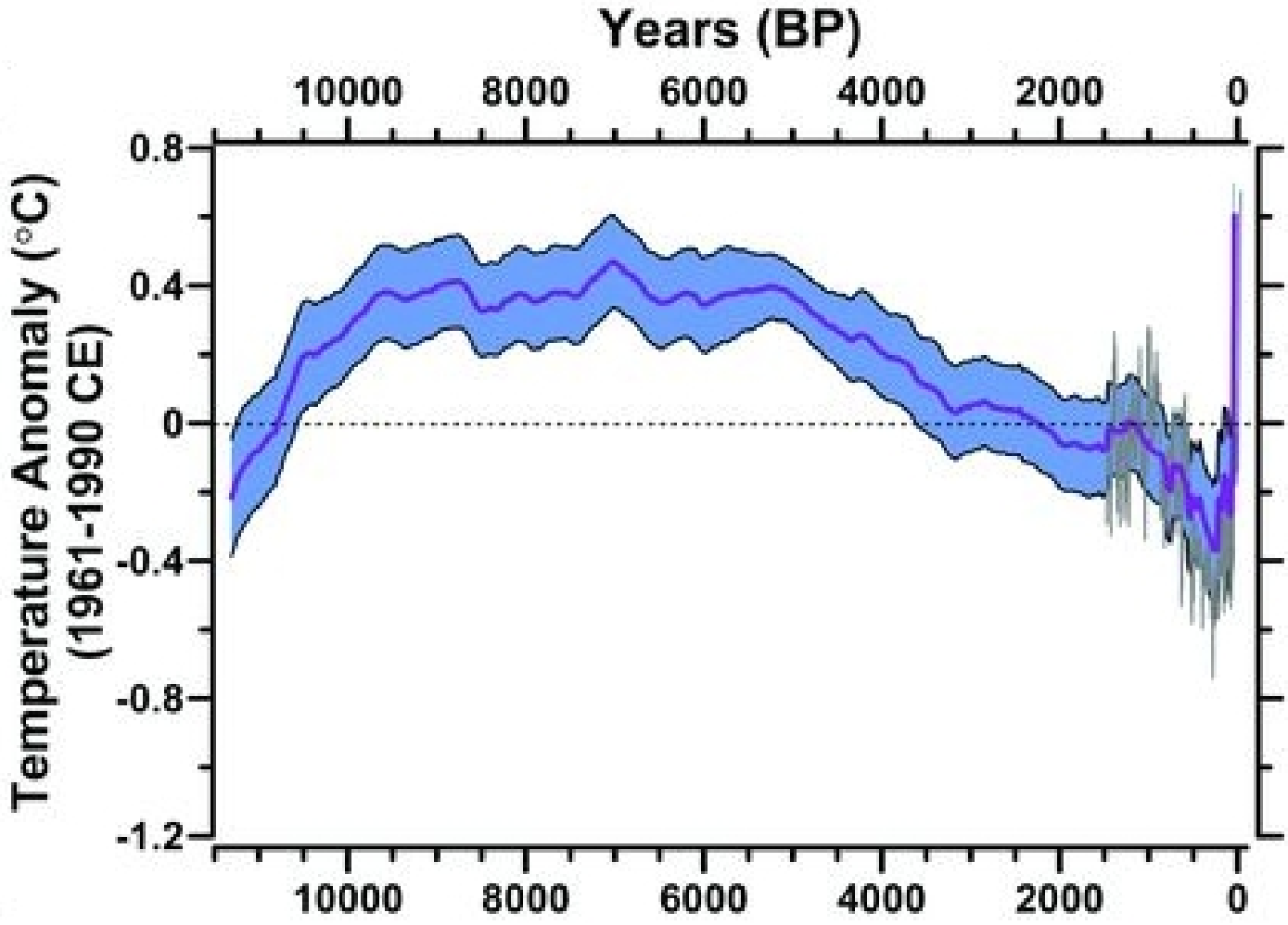
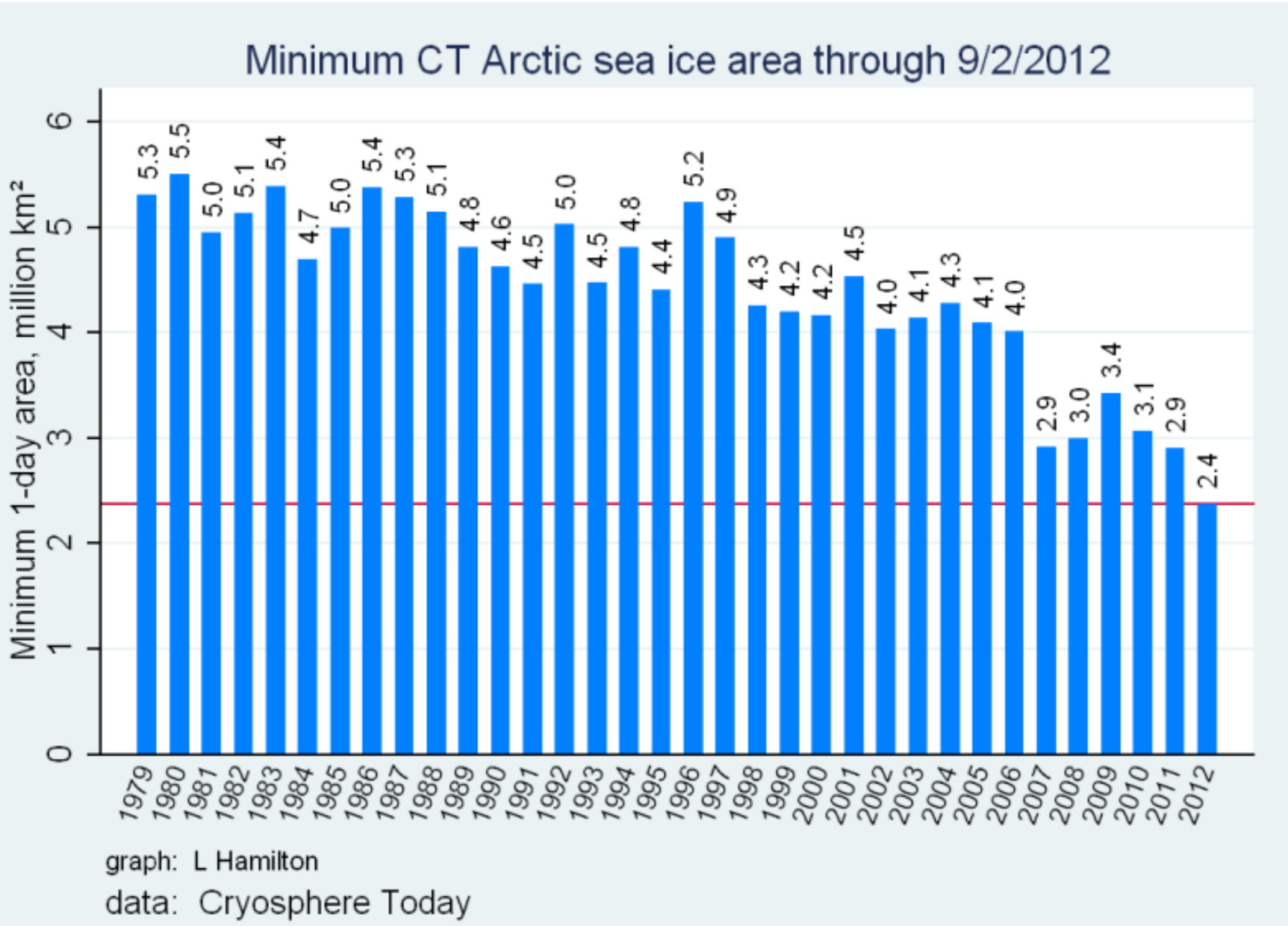
- Thanks to us, nitrogen and phosphorus in oceans have created about 400 dead zones, from 1 to 70,000 km^2 in area.



Antarctic ice cores and other data — Global Warming Art



Reconstruction of temperature from 73 different records — Marcott *et al.*


Minimum CT Arctic sea ice area through 9/2/2012
Minimum 1-day area, million km²
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5
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graph: L Hamilton
data: Cryosphere Today

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How bad will things get? It seems extremely unlikely to me that life on Earth or even our species will go extinct. But the Anthropocene *could* knock down our highly technological civilization.

For example, Sherwood and Huber argue that:

> *Any exceedence of 35 °C for extended periods should induce hyperthermia in humans and other mammals, as dissipation of metabolic heat becomes impossible. While this never happens now, it would begin to occur with global-mean warming of about 7 °C, calling the habitability of some regions into question. With 11–12 °C warming, such regions would spread to encompass the majority of the human population as currently distributed. Eventual warmings of 12 °C are possible from fossil fuel burning.*

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Could we ever let things get that bad? We might if we got stuck in an 'intergenerational arms race', with each generation saying it urgently needs to burn fossil fuels because the situation is so desperate.

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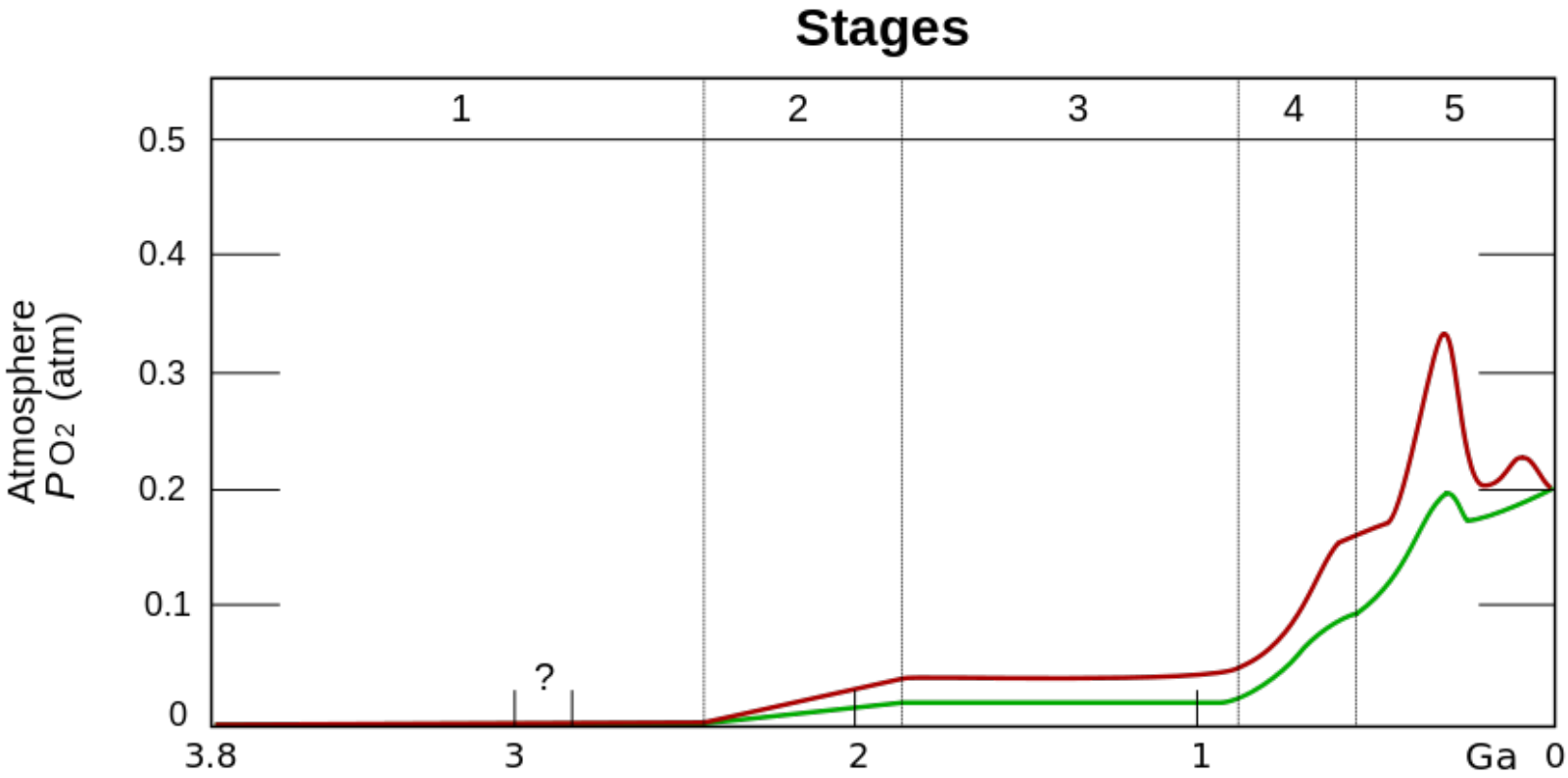
Sometime between 3.5 and 2.6 billion years ago, the first photosynthesizing organisms started dumping a deadly gas into the atmosphere: *oxygen!*

Banded iron formation, 2.1 billion years old.

Oxygen, poisonous to all life at the time, was first absorbed by dissolved iron and organic matter—but eventually there was too much. Concentrations shot up... and most life on Earth may have died! This was the Oxygen Catastrophe:



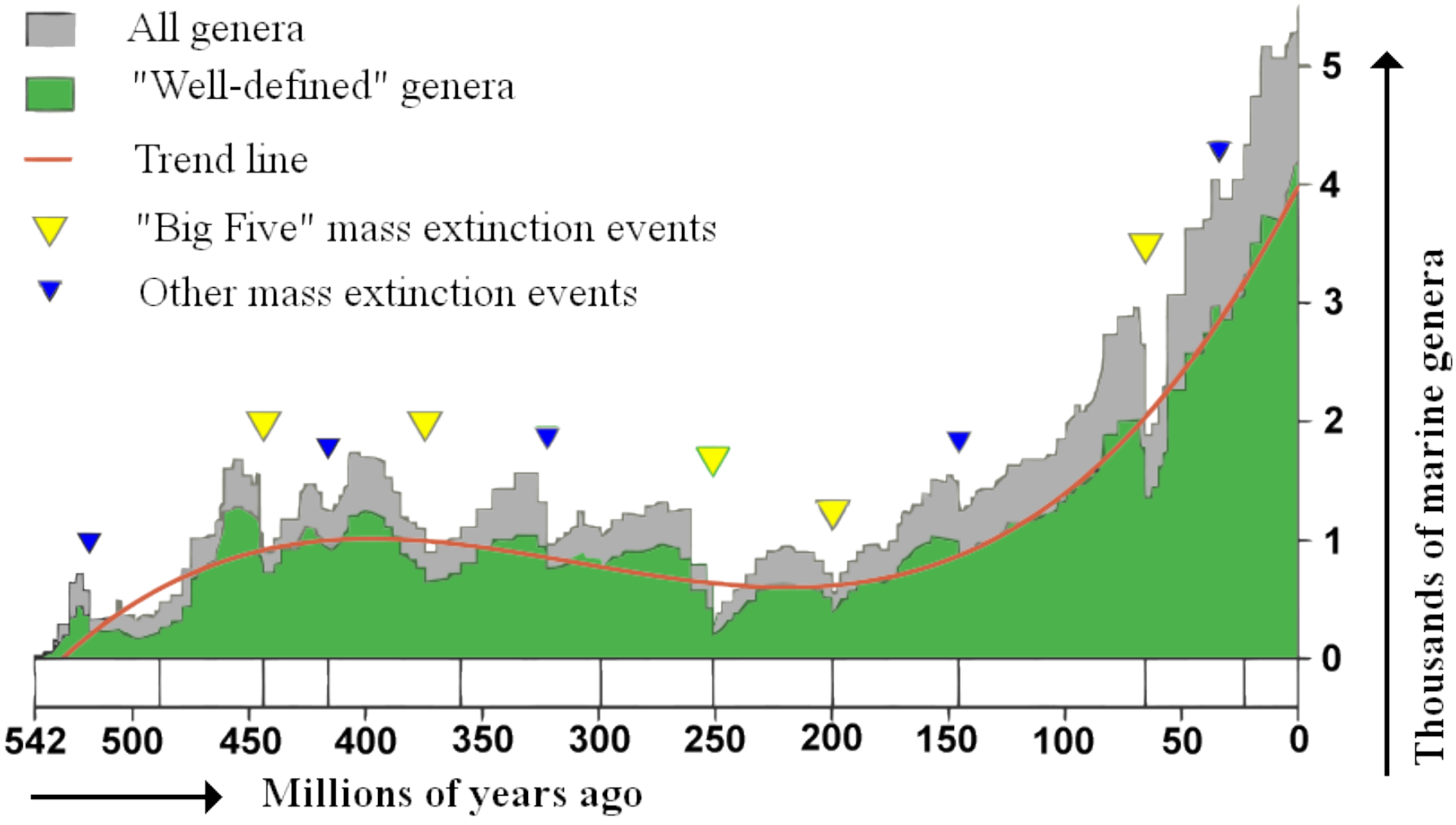
Luckily this happened slowly enough that evolution saved the day!

As oxygen entered the atmosphere, *methane* — a powerful greenhouse gas — was eliminated. This may have caused the most severe ice age in history: the Huronian glaciation, which lasted from 2.4 to 2.1 billion years ago.

Much later, between 800 and 625 million years ago, a series of Snowball Earth events put a lot of the Earth under ice. The cause is unclear: there may have been a climate instability where in the hot phase there was 350 times as much CO_2 in the air as now!

Around 540 million years ago, the first *multicellular life* arose.

Since then, there have 5 really big mass extinctions:



Rohde and Muller, "Cycles in fossil diversity"

Here are the ‘Big Five’:

1. The Ordovician-Silurian Extinction, 440–450 million years ago. 57% of marine genera went extinct.

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What caused it? One theory is that as the continent Gondwana drifted over the South Pole, there was a phase of global cooling, and so much glaciation took place that sea levels were drastically lowered.

2. The Late Devonian Extinction, 375 million years ago. 50% of marine genera went extinct.

The extinction seems to have only affected marine life — but 70% of marine species went extinct! Reef-building organisms were almost completely wiped out. Coral reefs returned only with the development of modern corals in the Mesozoic.

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Since warm water species were the most severely affected, many scientists suspect another bout of global cooling. There were also shortages of oxygen in ocean bottom waters. It seems this extinction was not a sudden event. Indeed, there were several 'pulses' of extinction, over a period lasting up to 25 million years!

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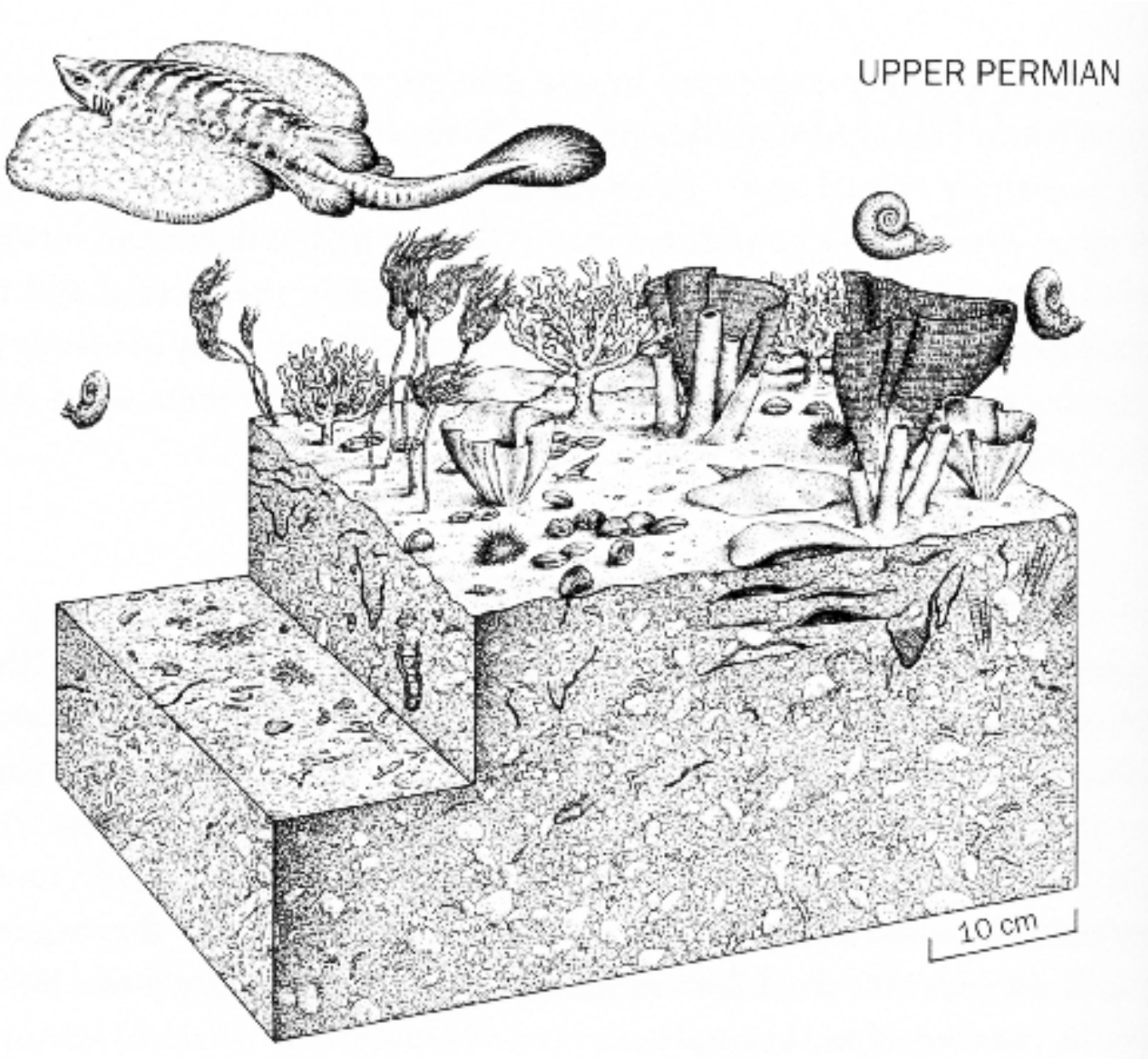
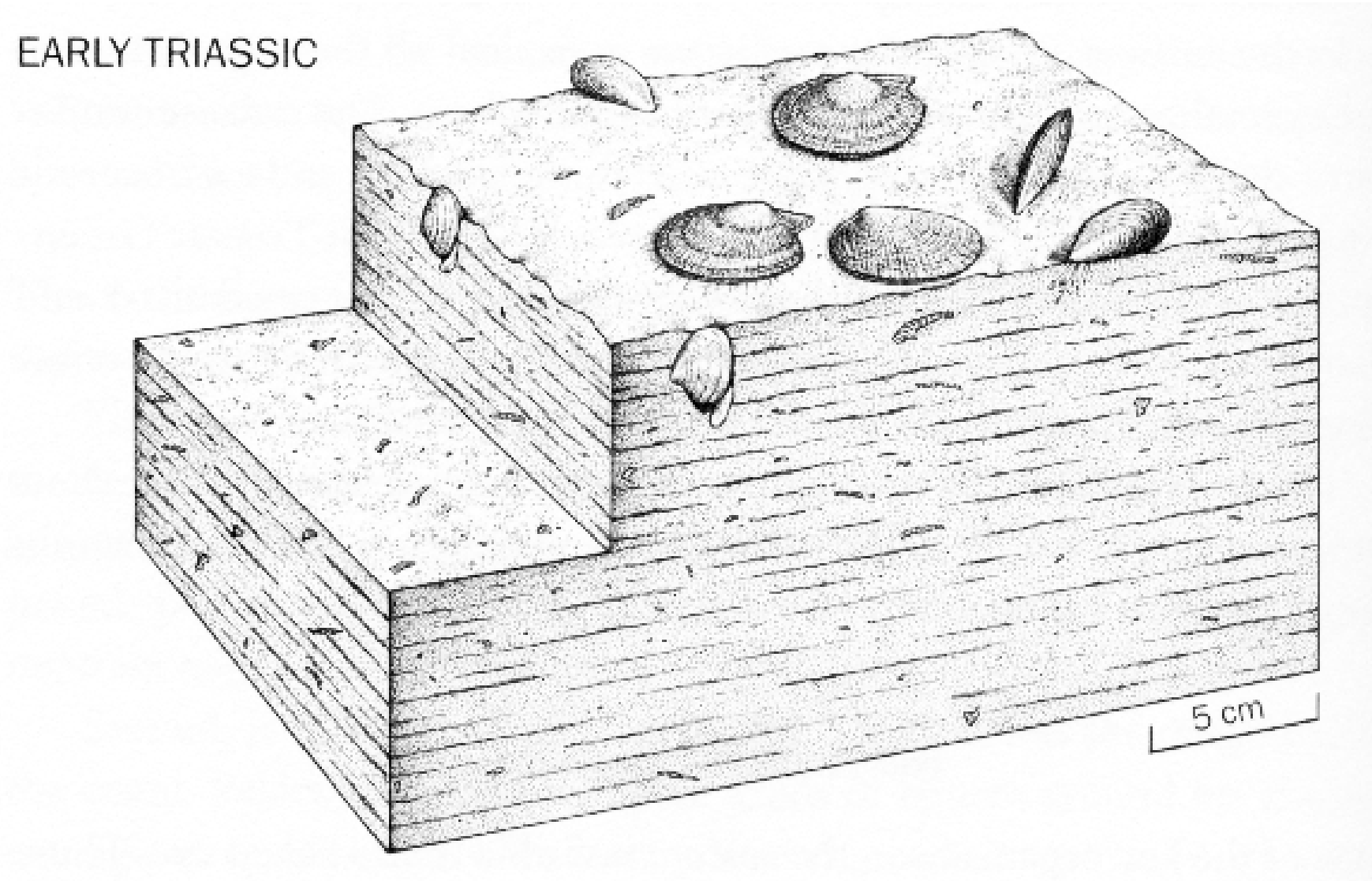
Before this extinction, seabeds near China looked something like this...



From Michael Benton, *When Life Nearly Died: The Greatest Mass Extinction of All Time*

Afterwards, they looked like this:



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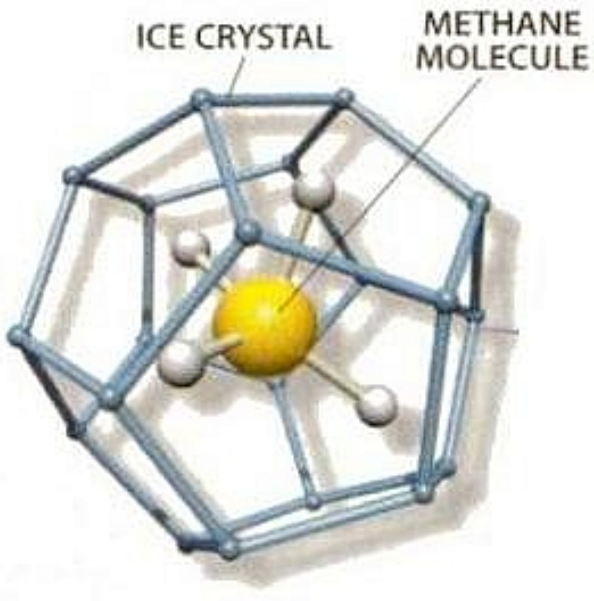
There was a lot of carbon in the atmosphere — maybe caused by a massive release of methane from clathrates under the ocean.



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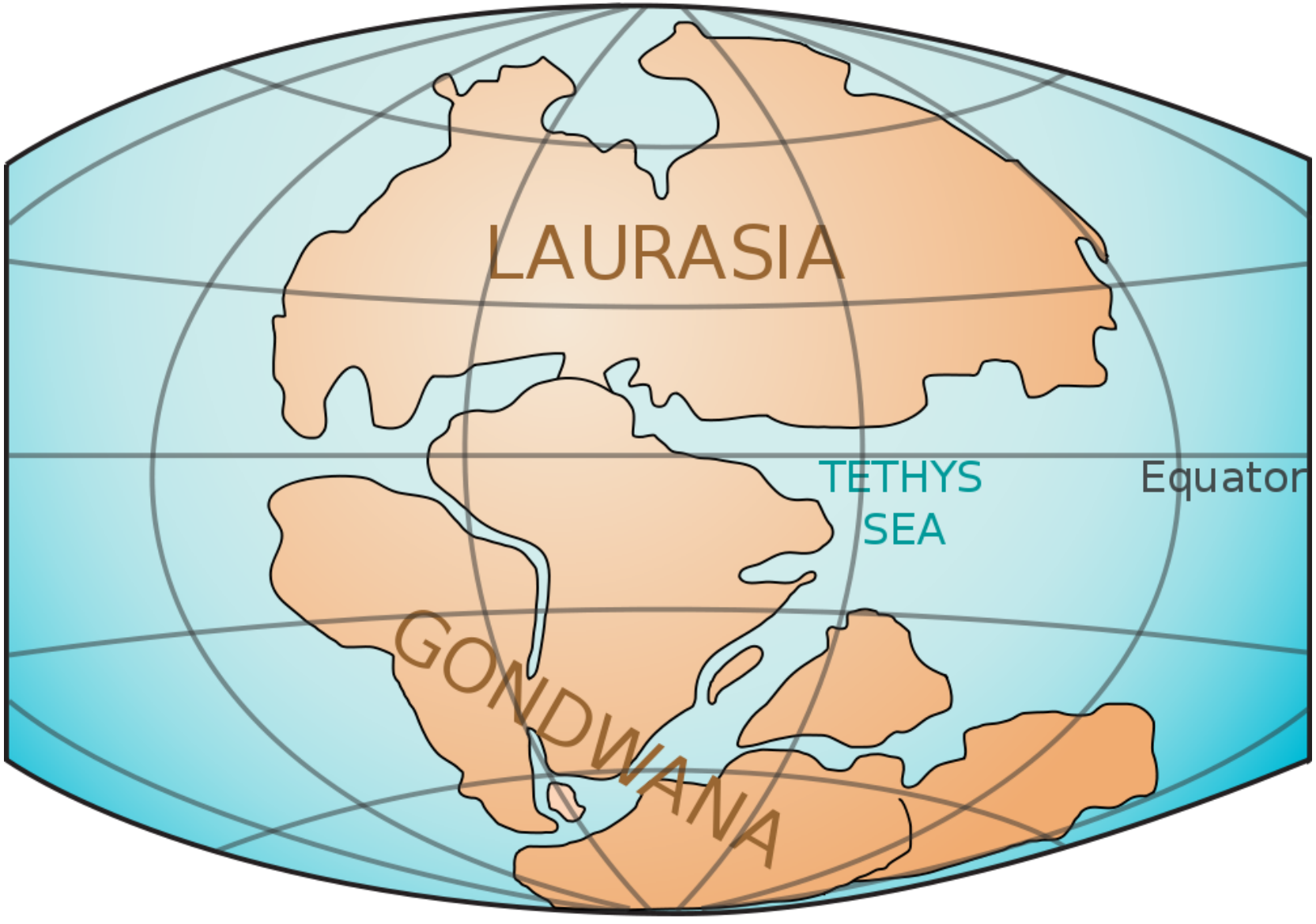
Yet again, the cause is unclear! But about this time, the supercontinent Pangaea began splitting into Laurasia and Gondwana, with massive floods of lava in the Central Atlantic Magmatic Province — perhaps one of the largest igneous events in the Earth's history.



TRIASSIC
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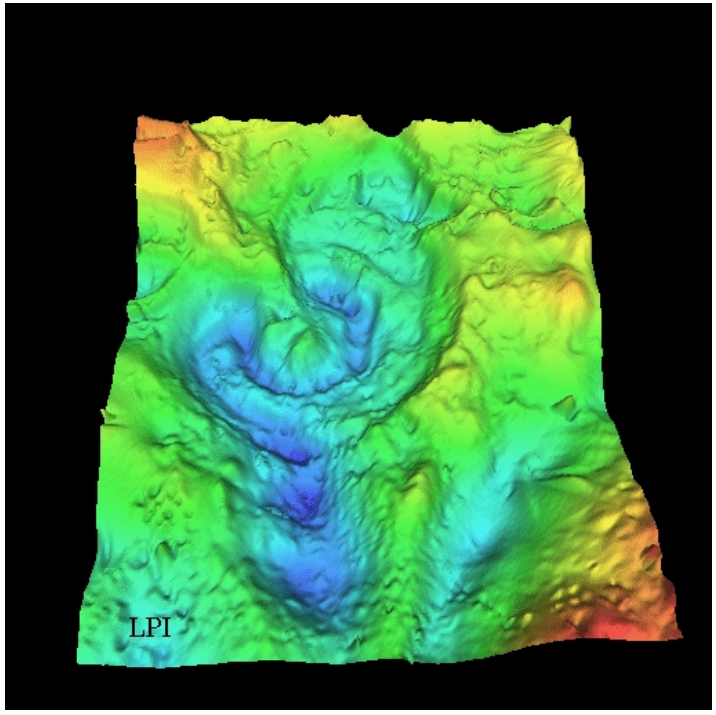
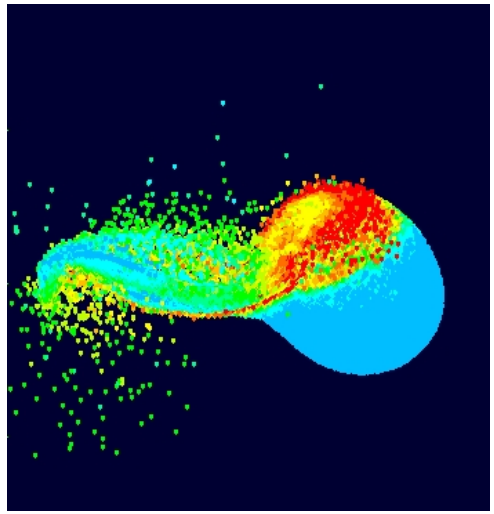
This is the famous one that killed off the dinosaurs. It's probably due to the asteroid that hit Chicxulub. This was 10 kilometers across and delivered an energy of 100 teratons of TNT: 2 million times the largest manmade bomb, the 57-megaton Tsar Bomba.



The asteroid that killed off the dinosaurs was nothing compared to planet that hit the Earth and formed the moon 4.53 billion years ago... according to the Giant Impact Hypothesis:



To make our Moon, Robin Canup simulated a collision with 'planet Theia', slightly bigger than Mars, moving slowly towards the Earth. 50 minutes after it hit it it looked like this: half the Earth's surface is red-hot.

After 5 hours, the iron core of Theia and most of the the debris comes crashing back down. The Earth's entire crust and outer mantle melts. A quarter of Theia has actually vaporized!

After a day, a ring of debris orbits the Earth. Within a century, it collects to form the Moon we know and love. Meanwhile, Theia's iron core sinks down to the center of the Earth!

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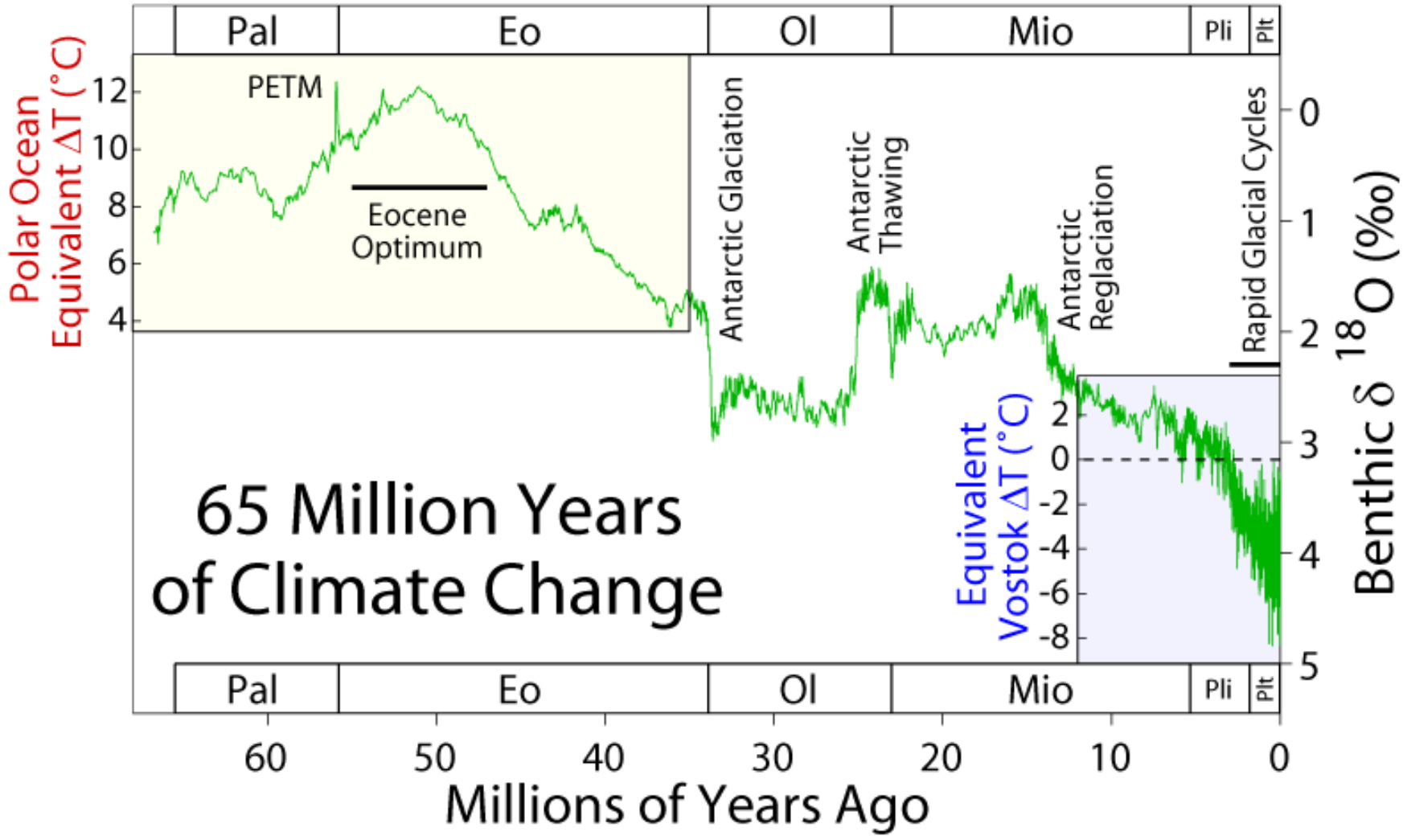
1. How stable is the Earth's climate? The 'clathrate gun hypothesis' says that methane locked in sea beds can escape, driving rapid global warming. These reserves contain 500-2500 billion tonnes of carbon — large compared to the 5000 contained in the rest of the biosphere! Methane is ~ 25 times as potent a greenhouse gas as carbon dioxide, for the first century.

The clathrate gun hypothesis could help explain the Paleocene -Eocene Thermal Maximum (PETM), when temperatures shot up 6° C in just 20,000 years and stayed hot for ∼200,000 years:



In the past century, temperatures have been rising ~ 40 times faster than in the PETM. Luckily, we're starting from a much colder temperature. Methane is already bubbling up from Arctic oceans at $\sim$ 12 million tonnes of carbon/year. This is tiny compared to the $\sim$ 10 billion tonnes/year from our carbon burning activities, but unsettling:

Methane bubbling up from the East Siberian Arctic Shelf — Natalia Shakhova

2. How does life respond to a tragedy of the commons / prisoner's dilemma situation?

If it happens slowly, life may evolve its way out.

If it happens fast, can intelligence figure a way out?