

The background is a complex, abstract composition. It features a network of thin, grey lines forming a grid or web-like structure. Overlaid on this are various organic and geometric shapes. Large, vibrant brushstrokes in shades of pink, yellow, blue, and purple sweep across the scene. There are also several dark, charcoal-colored circular and oval shapes, some with white highlights, suggesting spheres or planets. In the lower right, a small, white, cartoonish character with a smiling face and yellow starburst accents is visible. The overall aesthetic is dynamic and layered, combining scientific or technical motifs with expressive, artistic elements.

# TAMING TIME

A GOLDEN SPIKE  
FOR THE ANTHROPOCENE

ALEXANDRA HAMANN  
REINHOLD LEINFELDER  
MAKI SHIMIZU



# What is time?

What may come to mind is the time of day, the calendar, or our lifetimes. In physics, time is a dimension which – bound to space – sometimes moves fast, sometimes slow, but always in the same direction, from the past into the future. In our own perception, too, there are hours that fly by and minutes that seem endless.

There are moments when we think that time stands still and everything happens simultaneously. In her book „Timefulness“, Marcia Bjornerud describes a moment when she stood alone in a place that showed no signs of time. It seems like time needs to be visible in one way or another. But at the same time, she was standing on a piece of land with a long history behind it, from the formation of the Earth 4.5 billion years ago to the time she was there. Below her millions of years, above her an even older universe – perceivable in one single moment.

Most of us aren't aware of our own connection to the long processes of Earth's history. We can barely picture our own lifetime and that of one or two generations before and after us.

Meanwhile, we are using resources that reach deep into Earth history and in doing so we are changing the Earth system far into the future. Terms like „Deep Time“ and „The Long Now“ are more foreign to us than the space that surrounds us. We all know the seven

continents, but have no idea which time epochs our Earth has passed through.

Now a new age is being established, the Anthropocene.

Who is doing this and why are they doing it? How are time periods defined and what distinguishes them from another? How can this process help us develop a deep understanding of the world we live in so that we can create a sustainable and just future – for ourselves, for our children and grandchildren, and for all generations that will come after us?

We will try to answer these questions here, but there is one thing that can be said already: We can't change the past, but the future lies in our hands.

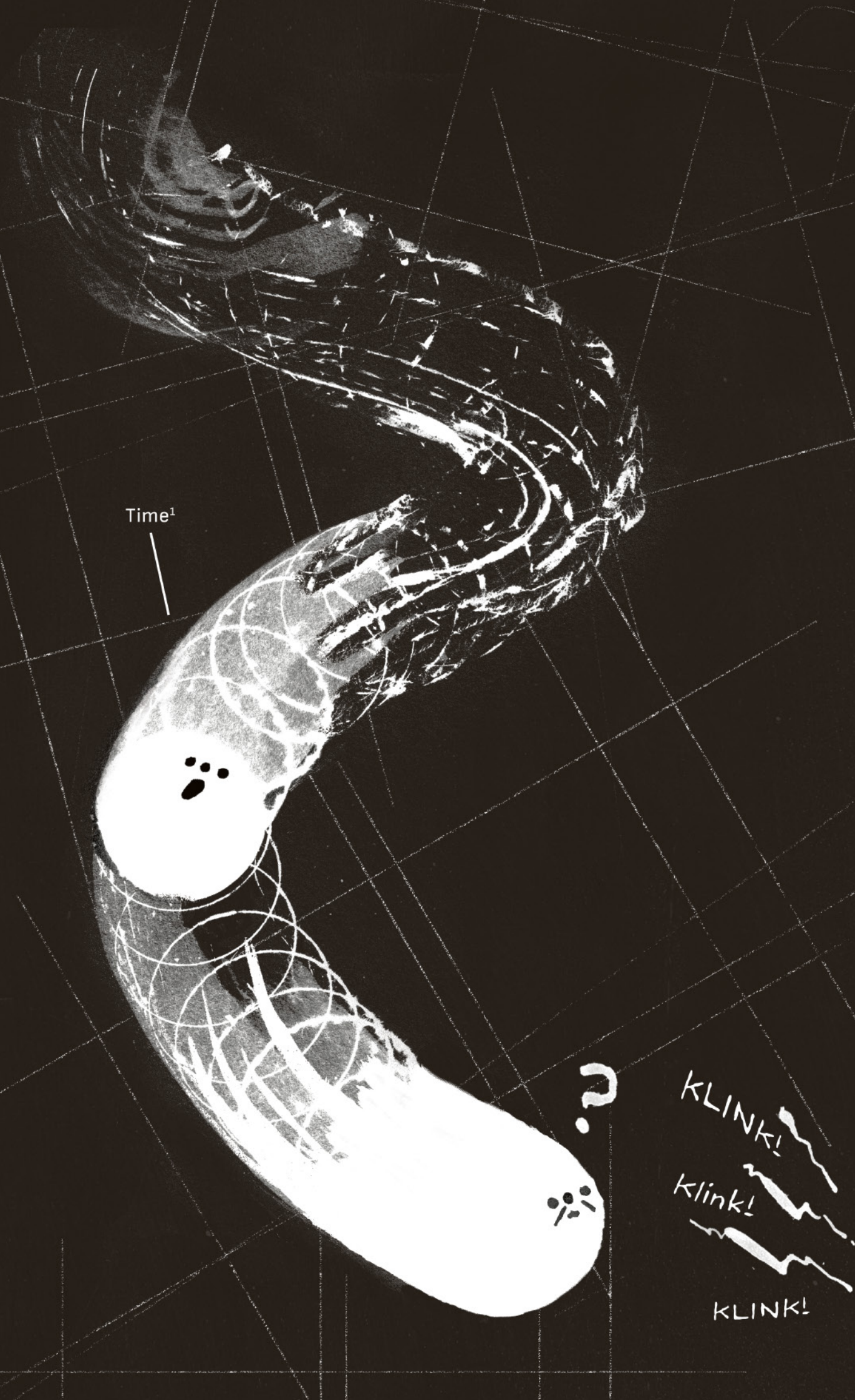
Alexandra Hamann and  
Reinhold Leinfelder



The content of this science graphic novel is largely based on University course lectures and research on the Anthropocene by Reinhold Leinfelder at Freie Universität Berlin and his membership work within the Anthropocene Working Group.



# PREFACE







Ahhh, those earthlings again.

KLINK!

klink!

klink!

klink!

KLINK!

KLINK!



klink!

klink!

klink!

KLINK



Crap!  
It's broken!!

KLONK!



KLINK!



What a job!  
My kids should  
rather draw  
comics.

Why didn't  
I bring the  
drill?



NOOOO!  
Don't come  
closer!

Need  
some help?

Tsst!



Puh!  
Finally finished!!



KLINK!





Year 2000 CE

according to earthling's Western calendar





The division of time into different ages follows a deeply human demand for order.

To understand what is going on, we have to go back in time a bit.

Golden spike

Here the Devonian ends and the Carboniferous begins. How cool that something as fleeting as time can be nailed down in the layers of rock.

# THE FORMIDABLE PARLIAMENT OF TIME

I don't think it's cool ...

... to be pinned down!

It all started with a guy called Nicolaus Steno. Before he came along I was free.

OUCH!





(At that time it was believed that the Earth was created by God in 3761 BC\* in 7 days.)

\* AD: Anno Domini (after Christ was born)  
\* BC: before Christ

Beautiful is what we see.  
More beautiful is what we know.  
Most beautiful by far is what we don't.



Nicolaus Steno<sup>2</sup>

Universal scholar  
and Catholic priest  
1638 - 1686

I am the founder  
of modern  
stratigraphy\*.



He took a closer  
look at the Appennines\*\*  
and worked out two  
important principles.

Wilhelm von Humboldt  
called him the "father of  
geology". By the way,  
Steno was beatified by  
Pope John Paul II  
in 1988.

\* *Stratigraphy*: subfield of geology with the aim of defining a temporal and spatial order of the rock layers (strata = layer).

\*\* *Appennines*: mountain range in Italy



# Relative time

My two basic principles are:

**1. The law of original horizontality**  
Sediments are deposited in horizontal layers under the influence of gravity and usually change from unconsolidated to solid rock as they become increasingly compressed.

sediments and rocks are like a book telling the story of time

**YOUNG**

**OLD**

However, Steno could not determine the exact age of these layers, nor could he compare widely separated formations.

**2. The law of superposition**  
In a tectonically\* undisturbed sequence of layers of sedimentary rock, each layer is younger than the one below and older than the one above.

It was me, William Smith, who discovered the law of faunal succession.

Maybe I wasn't the only one who discovered it, but I was the first to use it for geological maps.

Southern England 1793 AD

Only now it was possible to correlate\*\* the age of widely separated layers. Same fossils ...

... same age.

**William Smith<sup>3</sup>**  
Surveyor  
1769 - 1839

\* In geology, tectonics describes the structure and large-scale movement of the Earth's crust. \*\* correlate: In geology, the term correlation refers to the methods by which the age relationship between various strata of Earth's crust is established.

19th century

Let's work out a geologic time scale.

We find the same fossil sequences in rock formations all over the world.

TIME ↑

**CENOZOIC**

Let's call long sequences an „era“...

squeeze

**NEOGENE**

We call shorter sequences „epochs“.

**HOLOCENE**

**PLEISTOCENE**

**PLIOCENE**

**MIOCENE**

**OLIOGOCENE**

**EOCENE**

**PALEOCENE**

Time units can be divided by fossil finds - so called guide fossils.

**CRETACEOUS**

**JURASSIC**

**TRIASSIC**

**PERMIAN**

**CARBONIFEROUS**

**DEVONIAN**

**SILURIAN**

**ORDOVICIAN**

**CAMBRIAN**

**PERIO.**

squeeze

**ERA**

**PERIOD**

← **MASS EXTINCTION**

A boundary was drawn, when living conditions changed and species became extinct.

← **MASS EXTINCTION**

This does not necessarily have to be a mass extinction, but it can be.

← **MASS EXTINCTION**

← **MASS EXTINCTION**

← **MASS EXTINCTION**

... and shorter ones „period“.



# Absolute time

1905 CE  
(Common Era)

Lead is the decay product of Uranium. A radioactive rock thus provides the necessary data for calculating its age.



Only with Arthur Holmes radiometric dating method\* was it possible to determine the absolute age of rock layers.

\* based on the phenomenon of radioactive decay, discovered by Ernest Rutherford

**Arthur Holmes<sup>4</sup>**  
Geologist  
1890 - 1965



1956 CE

I have calculated the age of this meteorite with Arthur's method. You can picture it like this:

1. Radioactive isotopes are incorporated into rocks during crystallization.

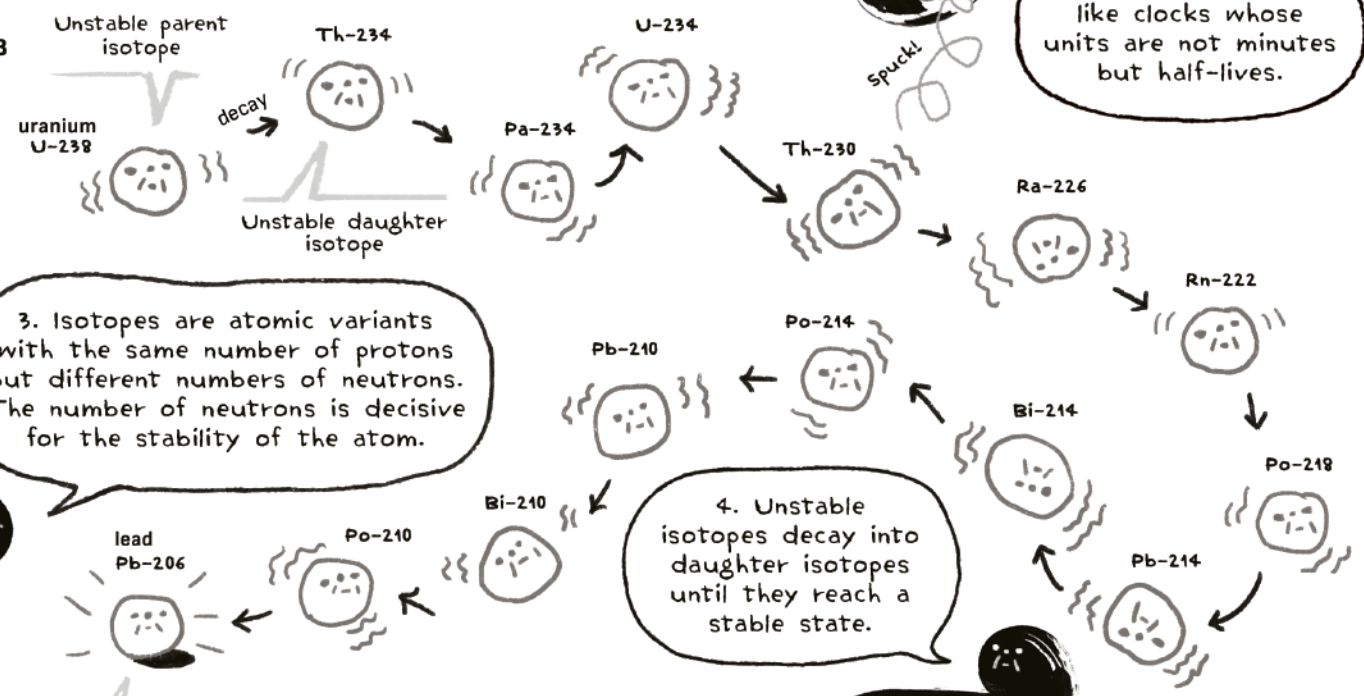


**Clair Patterson<sup>5</sup>**  
Geochemist  
1922 - 1995



2. They function like clocks whose units are not minutes but half-lives.

Half-life of uranium 238  
4.5 billion years



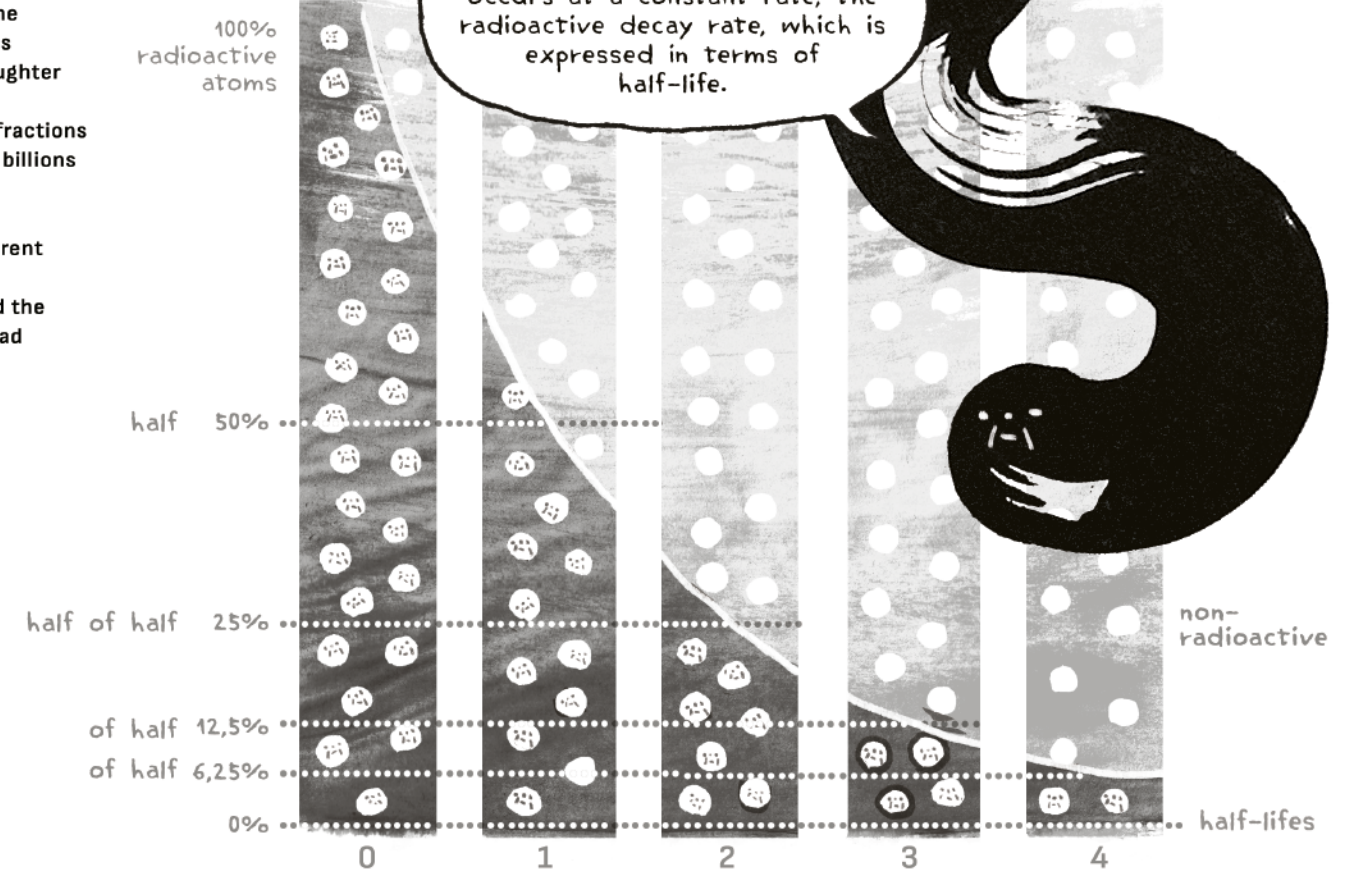
3. Isotopes are atomic variants with the same number of protons but different numbers of neutrons. The number of neutrons is decisive for the stability of the atom.

4. Unstable isotopes decay into daughter isotopes until they reach a stable state.

# Radioactive decay law

The half-life indicates when half of the parent isotopes decayed to daughter isotopes. It varies from fractions of a second to billions of years.

There are different decay series. Patterson used the uranium-to-lead decay series.



The transition from parent isotope to daughter isotope occurs at a constant rate, the radioactive decay rate, which is expressed in terms of half-life.

Meteorites are fragments of matter from our solar system that must have formed at the same time as the Earth. However, they are not subject to the constant change of the Earth's rock cycle, which means the age of the Earth can be determined from the meteorites' age.

Clair says I am 4.55 billion years old (+/- 70 million).

Now people could tell the age of Earth was about 4.55 billion years and it wasn't created by God only 6,000 years ago!



And to save the best for last, thanks to my research the industrial use of lead has been banned.\*

\* 1986 marked the beginning of the end of leaded gasoline, which disappeared from all filling stations in the US on 31 December 1995 (blood lead levels of Americans decreased by 80%)



There was no stopping the stratigraphers now. The history of the planet had been nailed down.

We are the International Commission on Stratigraphy, the formidable Parliament of Time\*.

The Phanerozoic begins here. I'm marking it with a Golden Spike<sup>6</sup> at the type section. A real nail was hammered in at a type location, a so-called Global Stratotype Section and Point or GSSP<sup>7</sup>.

Let's call this time section the Proterozoic and give it a nice pinkish red.

Since we now know how old the planet is we need a whole new section here.

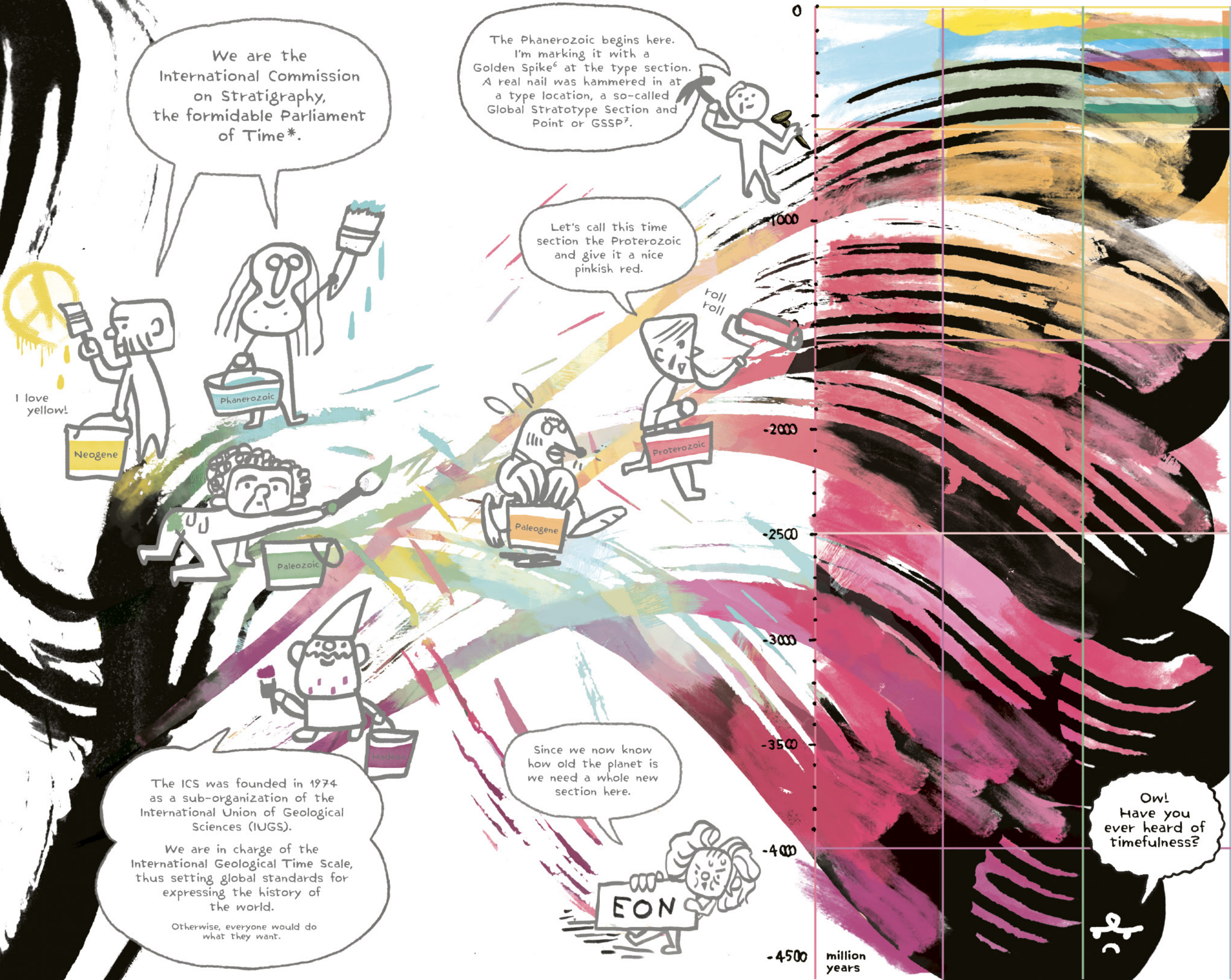
The ICS was founded in 1974 as a sub-organization of the International Union of Geological Sciences (IUGS).

We are in charge of the International Geological Time Scale, thus setting global standards for expressing the history of the world.

Otherwise, everyone would do what they want.

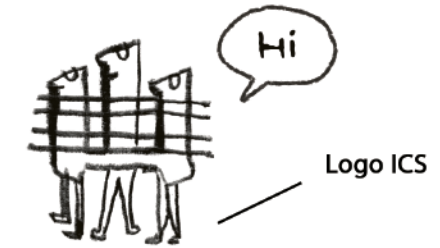
Even in 1974 only men!

Ow! Have you ever heard of timefulness?



\* that's what Marcia Bjornerud called the ICS in her book 'Timefulness'





This is what our time scale looks like today.



David A. T. Harper  
Earth Sciences  
Durham University  
UK

Isn't it beautiful?!



Kim Cohen  
Graphics Officer  
Utrecht University  
Netherlands

Eonothem / Eon	Era	System / Period	Series / Epoch	Stage / Age	GSSP	numerical age (Ma)	
Phanerozoic	Cenozoic	Quaternary	Holocene	Meghalayan	present	0.0042	
				Northgrippian	0.0082		
				Greenlandian	0.0117		
			Pleistocene	Upper	0.129		
				Chibanian	0.774		
			Pliocene	Calabrian	1.80		
				Gelasian	2.58		
				Piacenzian	3.600		
			Paleogene	Neogene	Miocene	Zanclean	5.333
						Messinian	7.246
	Tortonian	11.63					
	Serravallian	13.82					
	Langhian	15.98					
	Oligocene	Burdigalian		20.44			
		Aquitanian		23.03			
		Chatian		27.82			
		Rupelian		33.9			
		Priabonian		37.71			
	Paleocene	Eocene	Bartonian	41.2			
			Lutetian	47.8			
		Ypresian	56.0				
		Thanetian	59.2				
		Selandian	61.6				
	Mesozoic	Cretaceous	Upper	Danian	66.0		
				Maastrichtian	72.1 ± 0.2		
Campanian				83.6 ± 0.2			
Santonian				86.3 ± 0.5			
Coniacian				89.8 ± 0.3			
Lower			Turonian	93.9			
			Cenomanian	100.5			
			Albian	~ 113.0			
			Aptian	~ 121.4			
			Barremian	125.77			
Paleozoic	Carboniferous	Upper	Hauterivian	~ 132.6			
			Valanginian	~ 139.8			
		Lower	Berriasian	~ 145.0			

Es gekht.

Eonothem / Eon	Era	System / Period	Series / Epoch	Stage / Age	GSSP	numerical age (Ma)
Phanerozoic	Mesozoic	Jurassic	Upper	Tithonian	149.2 ± 0.7	
				Kimmeridgian	154.8 ± 0.8	
				Oxfordian	161.5 ± 1.0	
			Middle	Callovian	165.3 ± 1.1	
				Bathonian	168.2 ± 1.2	
				Bajocian	170.9 ± 0.8	
			Lower	Aalenian	174.7 ± 0.8	
				Toarcian	184.2 ± 0.3	
				Pliensbachian	192.9 ± 0.3	
				Sinemurian	199.5 ± 0.3	
	Hettangian	201.4 ± 0.2				
	Triassic	Upper	Rhaetian	~ 208.5		
			Norian	~ 227		
			Carnian	~ 237		
			Ladinian	~ 242		
			Anisian	247.2		
		Middle	Olenekian	251.2		
			Induan	251.902 ± 0.024		
			Changhsingian	254.14 ± 0.07		
			Wuchiapingian	259.51 ± 0.21		
			Capitanian	264.28 ± 0.16		
	Lower	Roadian	266.9 ± 0.4			
		Kungurian	273.01 ± 0.14			
		Artinskian	283.5 ± 0.6			
		Sakmarian	290.1 ± 0.26			
Asselian		293.52 ± 0.17				
Paleozoic	Permian	Guadalupian	Asselian	298.9 ± 0.15		
			Artinskian	299.52 ± 0.17		
		Lopingian	Sakmarian	293.52 ± 0.17		
			Wuchiapingian	259.51 ± 0.21		
			Changhsingian	254.14 ± 0.07		
	Carboniferous	Upper	Changhsingian	251.902 ± 0.024		
			Wuchiapingian	254.14 ± 0.07		
		Lower	Wuchiapingian	259.51 ± 0.21		
			Capitanian	264.28 ± 0.16		
			Roadian	266.9 ± 0.4		

Es gekht.

Eonothem / Eon	Era	System / Period	Series / Epoch	Stage / Age	GSSP	numerical age (Ma)
Phanerozoic	Paleozoic	Devonian	Upper	Famennian	372.2 ± 1.6	
				Frasnian	382.7 ± 1.6	
				Givetian	387.7 ± 0.8	
			Middle	Eifelian	393.3 ± 1.2	
				Emsian	407.6 ± 2.6	
				Pragian	410.8 ± 2.8	
				Lochkovian	419.2 ± 3.2	
			Lower	Pridoli	423.0 ± 2.3	
				Ludlow	425.6 ± 0.9	
				Wenlock	427.4 ± 0.5	
	Sheinwoodian	430.5 ± 0.7				
	Llandovery	433.4 ± 0.8				
	Silurian	Upper	Telychian	438.5 ± 1.1		
			Aeronian	440.8 ± 1.2		
			Rhuddanian	443.8 ± 1.5		
			Hirnantian	445.2 ± 1.4		
			Katian	445.2 ± 1.4		
		Lower	Sandbian	453.0 ± 0.7		
			Darriwilian	458.4 ± 0.9		
			Dapingian	467.3 ± 1.1		
			Floian	470.0 ± 1.4		
			Tremadocian	477.7 ± 1.4		
	Cambrian	Series 1	Stage 10	485.4 ± 1.9		
			Furongian	~ 489.5		
			Jiangshanian	~ 494		
Paibian			~ 497			
Guzhangian			~ 500.5			
Series 2		Miaolingian	~ 504.5			
		Drumian	~ 509			
		Wuliuan	~ 509			
		Stage 4	~ 514			
		Stage 3	~ 521			
Terreneuvian	Stage 2	Stage 2	~ 529			
		Fortunian	538.8 ± 0.2			

Es gekht.

Eonothem / Eon	Era	System / Period	Series / Epoch	Stage / Age	GSSP	GSSA	numerical age (Ma)
Precambrian	Proterozoic	Eoarchean	Hadean	Ediacaran	538.8 ± 0.2		
				Cryogenian	~ 635		
				Tonian	~ 720		
		Meso-proterozoic	Stenian	1000			
			Ectasian	1200			
			Calymmian	1400			
			Statherian	1600			
		Paleo-proterozoic	Orosirian	1800			
			Rhyacian	2050			
		Archean	Siderian	2300			
	Neo-archean		2500				
	Meso-archean		2800				
	Paleo-archean		3200				
	Eo-archean		4567				

Es gekht.

There are still a few blind spots. We're working on it.



Shuzhong Shen  
Earth Sciences  
Nanjing University  
China

Space and time do not correspond on your chart at all! The longest time periods get the least amount of space.

Everything is relative.



Philip Gibbard  
Quaternary geologist  
University of Cambridge  
UK

Units of all ranks are in the process of being defined by Global Boundary Stratotype Section and Points (GSSP) for their lower boundaries, including those of the Archean and Proterozoic, long defined by Global Standard Stratigraphic Ages (GSSA). Italic fonts indicate informal units and placeholders for unnamed units. Versioned charts and detailed information on ratified GSSPs are available at the website <http://www.stratigraphy.org>. The URL to this chart is found below.

Numerical ages are subject to revision and do not define units in the Phanerozoic and the Ediacaran; only GSSPs do. For boundaries in the Phanerozoic without ratified GSSPs or without constrained numerical ages, an approximate numerical age (~) is provided.

Ratified Subseries/Subepochs are abbreviated as U/L (Upper/Late), M (Middle) and L/E (Lower/Early). Numerical ages for all systems except Quaternary, upper Paleogene, Cretaceous, Jurassic, Triassic, Permian, Cambrian and Precambrian are taken from 'A Geologic Time Scale 2012' by Gradstein et al. (2012), those for the Quaternary, upper Paleogene, Cretaceous, Jurassic, Triassic, Permian, Cambrian and Precambrian were provided by the relevant ICS subcommissions.

Colouring follows the Commission for the Geological Map of the World (www.ccgmm.org)

Chart drafted by K.M. Cohen, D.A.T. Harper, P.L. Gibbard, N. Car (c) International Commission on Stratigraphy, June 2023

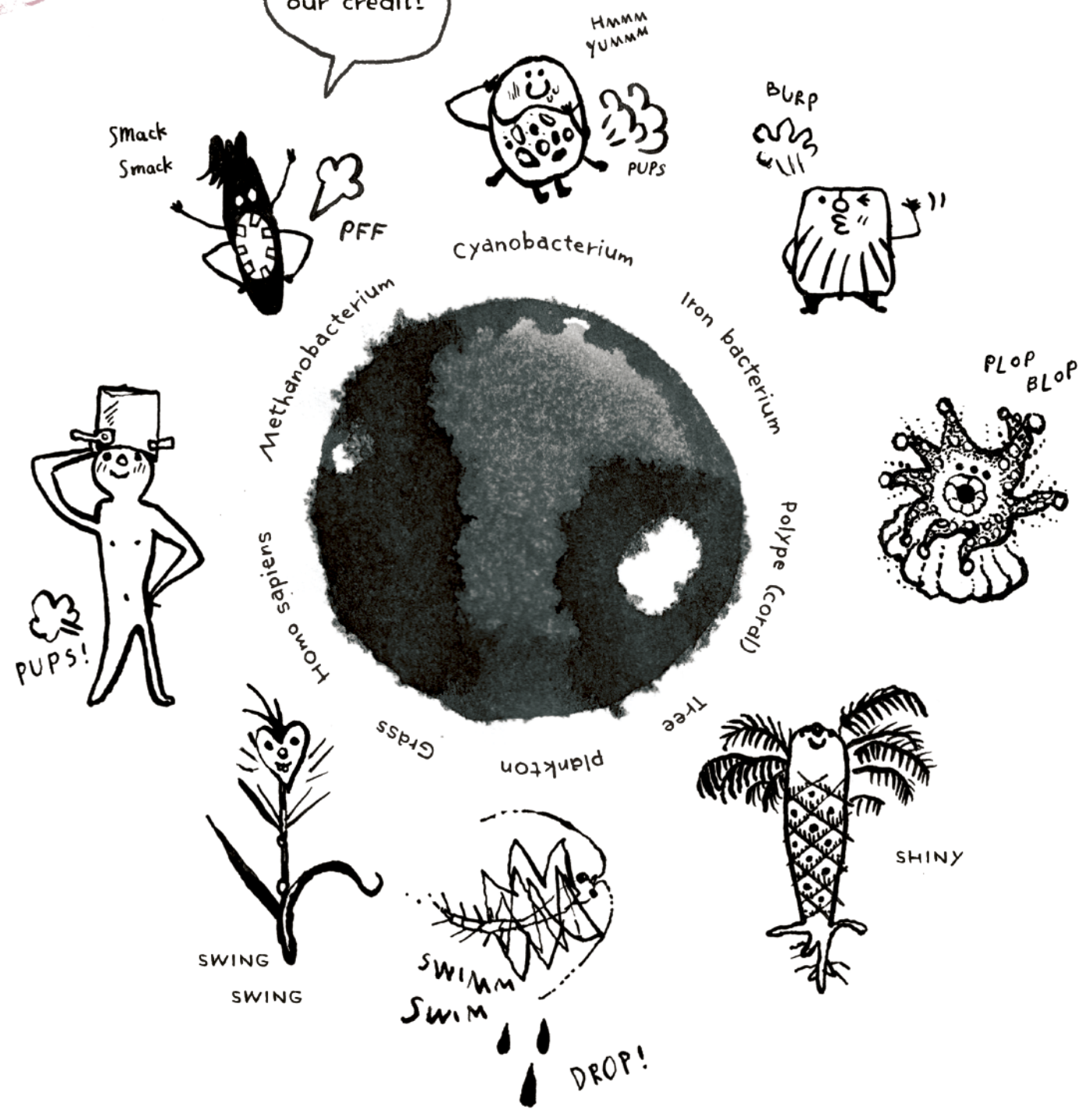
To cite: Cohen, K.M., Finney, S.C., Gibbard, P.L. & Fan, J.-X. (2013; updated) The ICS International Chronostratigraphic Chart. Episodes 36: 199-204.

URL: <http://www.stratigraphy.org/ICSchart/ChronostratChart2023-06.pdf>



The Earth was not always as you know it today. Throughout its history, it has undergone several major transformations that have produced an increasingly complex biosphere.

This is to our credit!



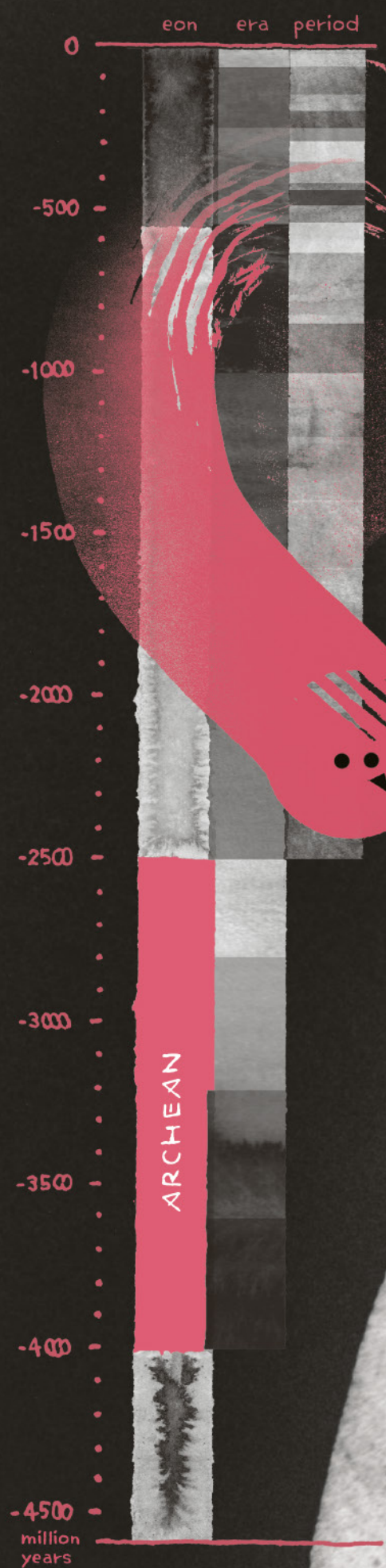
Please meet the...

# EARTH SYSTEM CHANGER

Hmm... not sure if I like my new look...





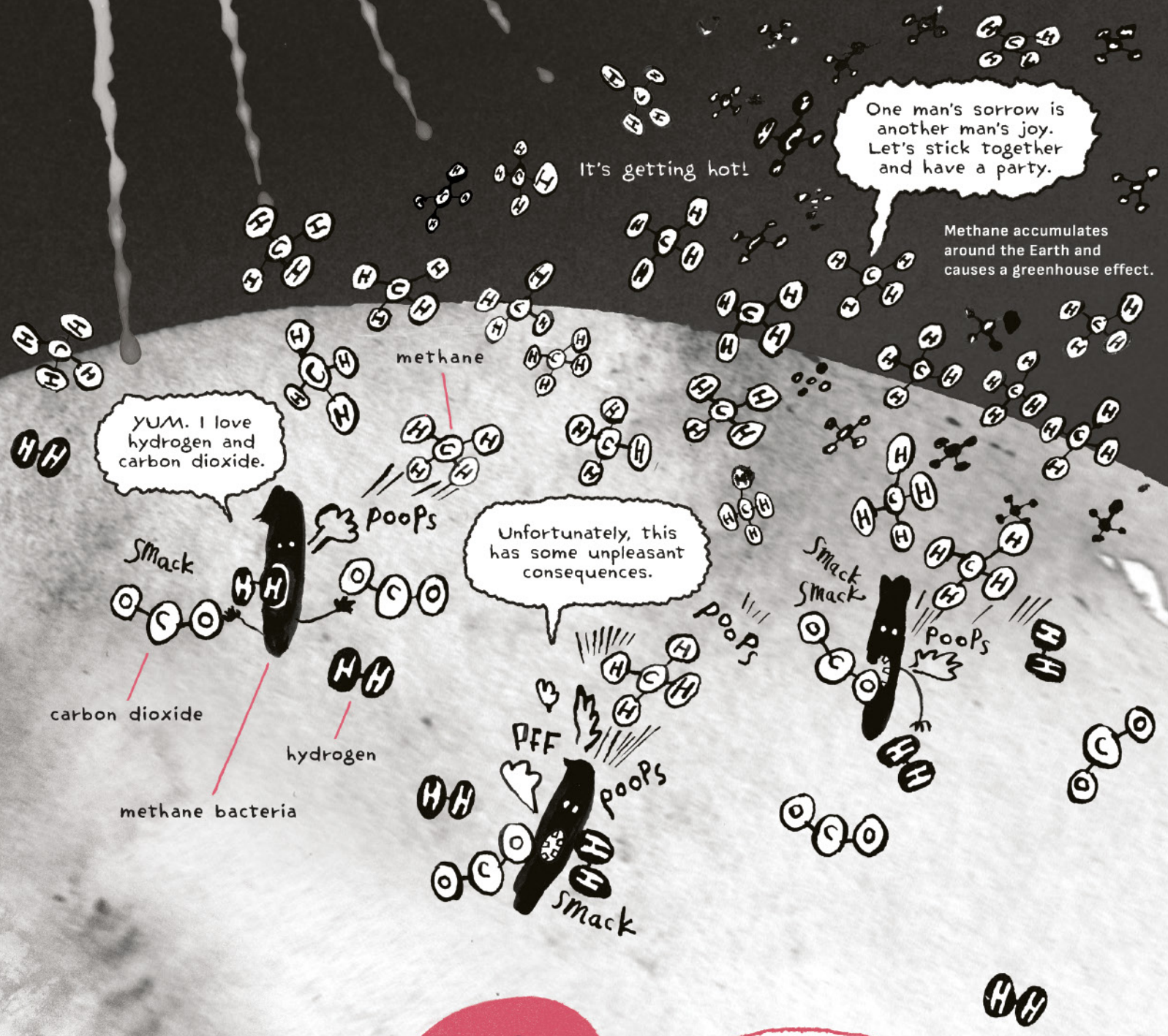


Let's look back to the **ARCHEAN**, about 4 billion years ago, ...

... starring the methane bacterium!

The Archean was a very long interval of time when the Earth's crust was turning into rock. There was a lot of molecular hydrogen, to which the many active volcanoes added carbon dioxide. A perfect environment for our methane bacteria.

Solar rays only 70% radiant power compared to today.  
That means it's freezing cold!

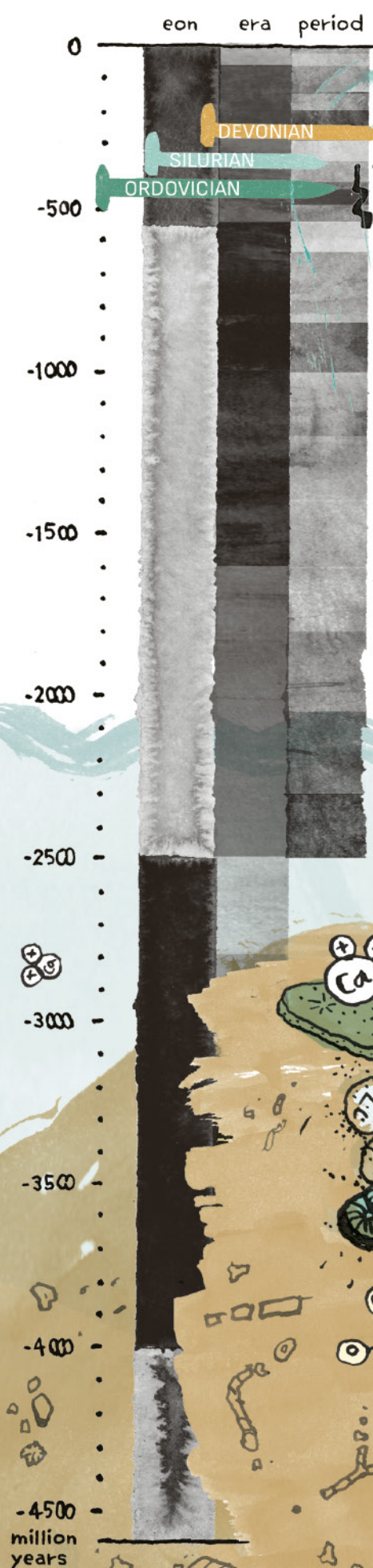


Inadvertently, they have built up an atmosphere that protects the Earth from the cold of space.









A mere two billion years later, about 450 million years ago, the era of the coral reefs began - and with it that of the polyps\*.



Calcifying organisms formed the fossil-rich organic limestone, which will later provide earthlings with cement, the most important component of concrete.

My tenants not only help me to produce calcium carbonate to build up a skeleton, but also feed me the most delicious molecules.

And best off all, I get rid of my shit!

We're totally codependent.

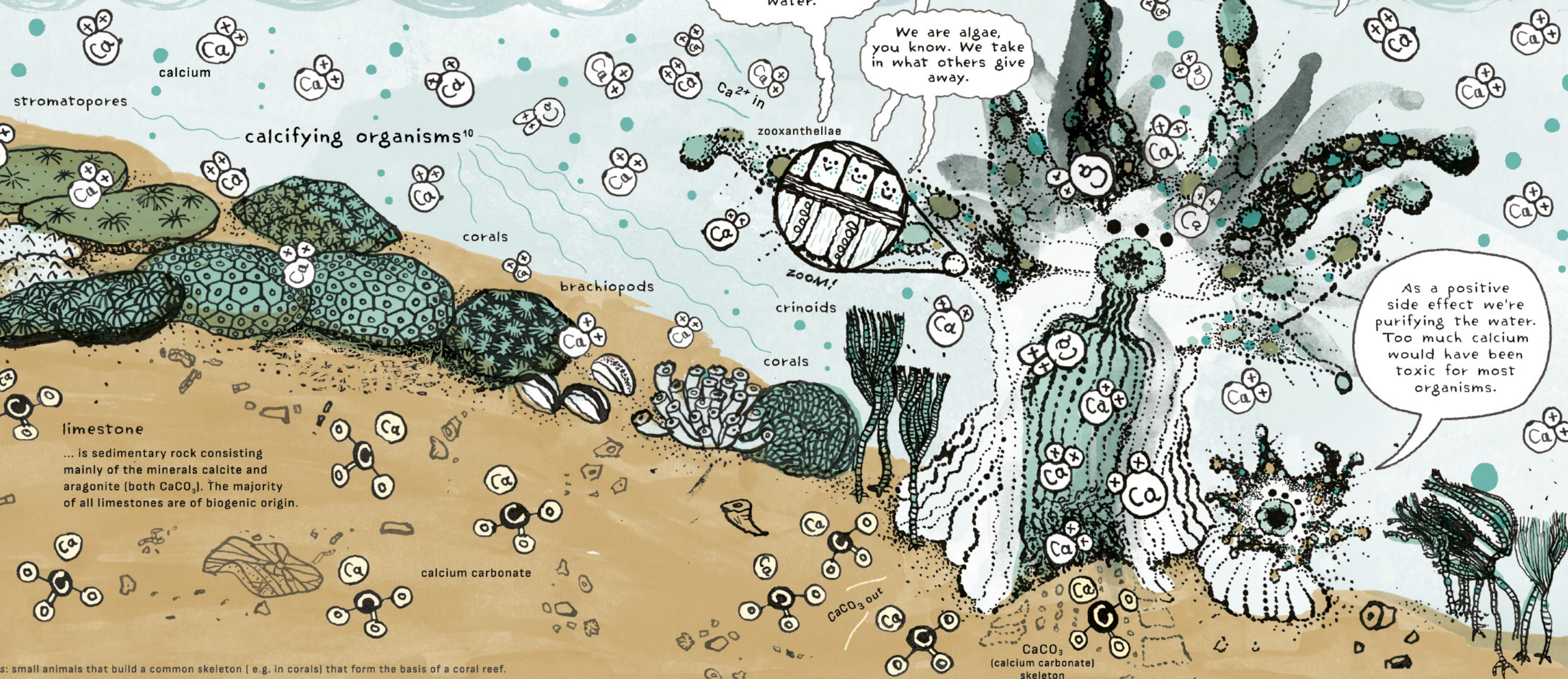
Successful symbiosis  
Enlargement of polyp

We support our landlord with calcification by absorbing the calcium from the water.

Aaaaand we trade sugar and proteins for housing and excretions.

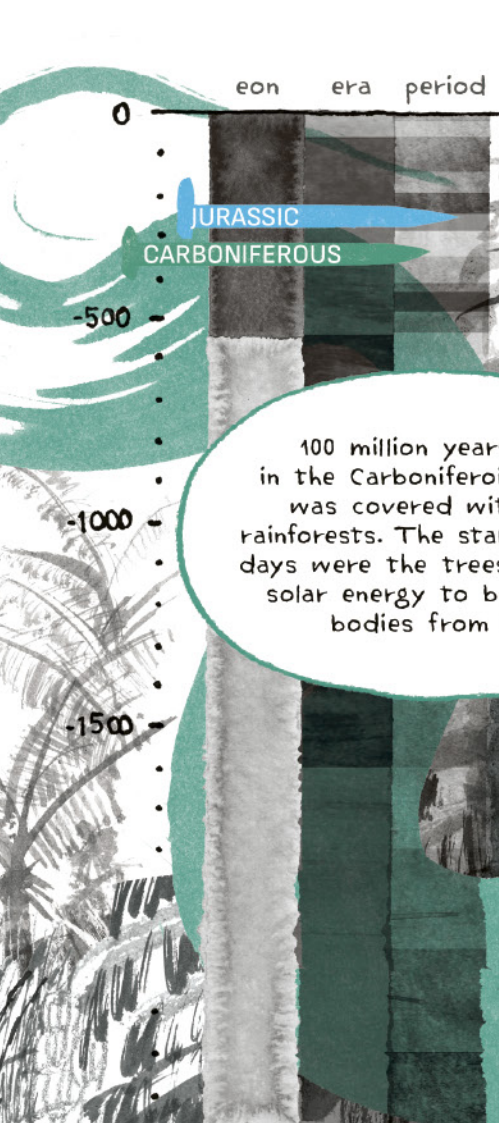
We are algae, you know. We take in what others give away.

As a positive side effect we're purifying the water. Too much calcium would have been toxic for most organisms.



\* Polyps: small animals that build a common skeleton (e.g. in corals) that form the basis of a coral reef.





Calamites: huge horsetails

100 million years later, in the Carboniferous, Earth was covered with huge rainforests. The stars of these days were the trees. They use solar energy to build their bodies from CO<sub>2</sub>.

We take over all of the land and start the first large-scale producer-consumer-interaction<sup>11</sup> outside the oceans.

Solar energy and CO<sub>2</sub> in

and O<sub>2</sub> out

Scale tree: *Lepidodendron*

Huge amounts of solar energy have been stored in these forests. Earthlings will later mine it in the form of hard coal and bring about another change in Earth Systems.

To do so, we use up so much CO<sub>2</sub> that we will trigger an ice age. Hehehehe

Fern like tree: *Pecopteris cyathea*



Mayflies like *Palaeodictyopteroidea* grow up to 50 cm

*Sigillaria*

*Cordaites Borassifolia*

All living organisms are made of carbon compounds. We just use other energy sources, as you will see later.

Dragonflies like *Meganeuropsis* are huge too.

Amphibians like *Ichthyostega* leave the oceans and start living on land, but still lay their eggs in the water.

Ewww, water... how disgusting.

Lots of CO<sub>2</sub> in the atmosphere helped an insane amount of vegetation to grow. As the forests died, the 'carbon' was buried as coal and the 'dioxide' released made the air oxygen-rich, allowing animals like dragonflies and the 3m-long centipede *Arthropleura* to grow to immense sizes.

*Odontopteris*

First reptiles of the genus *Hylonomus* get totally independent from water.

A little later, some 200 million years ago, another source of energy has formed: crude oil\*. Its energy was stored in microorganisms called plankton.

\* The European deposits are from the Jurassic and Cretaceous periods.



solar energy

We float in the water. Some of us are plants ...

... and some are animals.

When we die our bodies sink to the bottom of the sea.

Crude oil becomes the lifeblood of earthlings' mobile system.

Dead plankton sinks to the ground and forms digested sludge, broken down by bacteria. Muddy sediment layers are deposited on top. The complete exclusion of oxygen prevents the decomposition of the organic material. With the help of pressure and heat, the hydrocarbon components of petroleum are formed.

oxygen rich water

oxygen poor water

CHOMP MUNCH

PUPS!





Last, but not least, at the end of the Cretaceous and the beginning of the Paleogene, about 70 million years ago, grass appears.

About 12 thousand years ago, with the beginning of the Holocene, Homo sapiens began to settle down and started their career as Earth System changer.

At the beginning of the Holocene there was about 280 ppm CO<sub>2</sub> in the atmosphere that created a nice and stable greenhouse. Since the planet just went through an iceage it got a little bit warmer, which meant perfect conditions for settling down.

Since grasslands started spreading in the late Oligocene, we have left the forests and changed our eating habits. Instead of leaves, we now eat grass.

Thank goodness, we can finally rely on a stable climate. Let's cultivate grain\* and domesticate grass-eating animals.

Animals are useful in two ways: They help with the hard work in the fields and you can eat them!

\* First emmer and einkorn, later maize, wheat, rice and rye. They all have one thing in common: they're grass!

You didn't think a random plant like me could be such a hot shot, did you?

Climate is cooling. Perfect for grass. It's growing all over. That's why I developed from a mere 30 cm ...

... to a 150 cm tall horse.

We store food over the winter and can live in colder areas now.

To be eaten up is no problem for me! I can recover very quickly and regrow from here ...

... or here ...

... or here.

*Eohippus* lived in the Eocene 56 Million years ago.

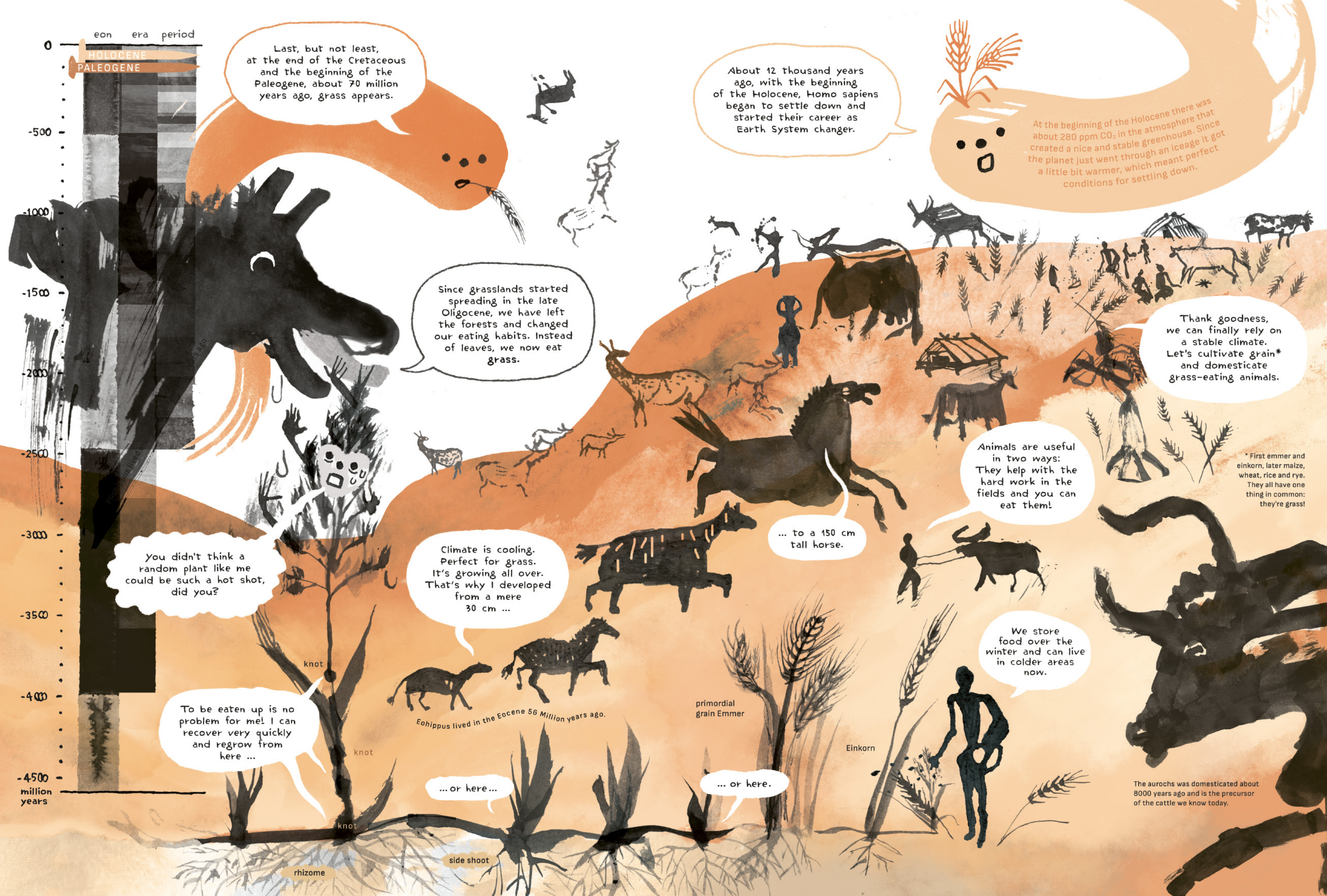
primordial grain Emmer

Einkorn

The aurochs was domesticated about 8000 years ago and is the precursor of the cattle we know today.

rhizome

side shoot





Today's complex ecosystems<sup>12</sup> were built in an interplay between inanimate and animate matter. All ecosystems together form the **biosphere**<sup>13</sup>.



Life is a constant flow of production, consumption and adaptation. It takes a lot of energy to keep it going. Luckily, I can get free energy from the sun and store it in my plants.

I feed on everything!

Without the influence of humans, I am in a dynamic equilibrium. I can react to environmental changes and adapt, if necessary. Furthermore, I continue to develop evolutionarily. That takes a lot of time!





In the history of Earth there have always been major upheavals that marked a new time interval.

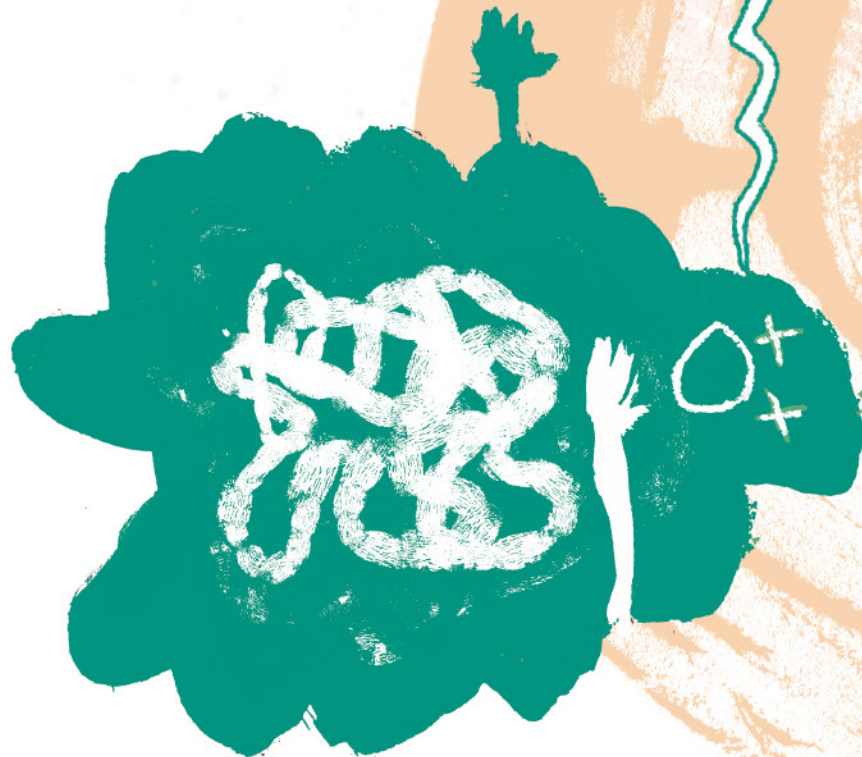
One is happening right now!

At present, earthlings are refashioning the relationship between consumption and production – with heavy consequences ...



Hold on, TIME!

These changes are way too fast. I can't adapt anymore.



Oh NO!



**WHAT  
HAVE WE  
DONE?**

I'm sorry.  
I can't stand still!





I tell you what you've done ...

Let's have a look back into the Pleistocene, two and a half million years before present, when humans started to use stone tools.

You folks migrated all over the place.

From about 70,000 - 50,000 years ago you modernised your cultural practices.

About 11,700 years ago you started forest clearing and agriculture.

But after 300 years of industrialisation ...

... and, more recently, 70 years of accelerated population growth ...

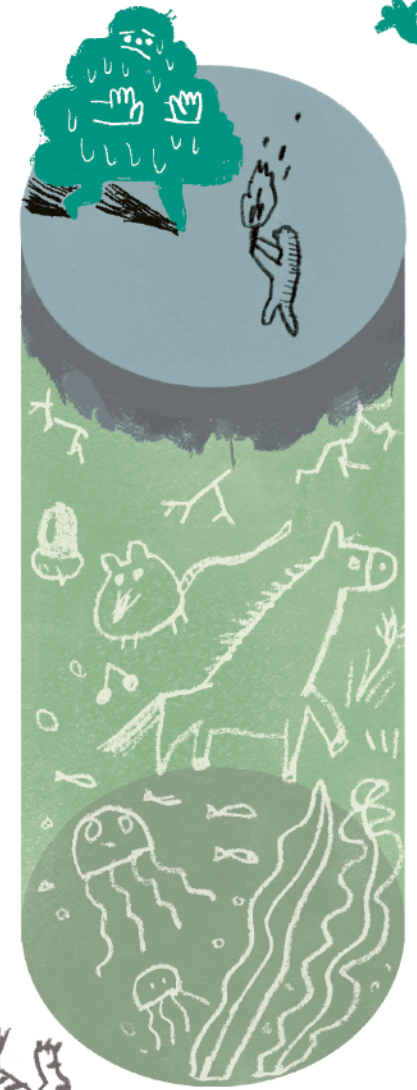
Human intervention in the biosphere remained without major effects for a long time.

No single species dominated my production and consumption circle ...

... before ...

... Homo sapiens settled down. I was strong back then and adapted to the changes.

... you overdid it. I can't take it anymore. I'm experiencing the sixth mass extinction event right now!



Global population of humans  
1970: 3,682,000  
2022: 8,000,000

Population size of most other species is declining

All birds on earth:  
- 70% livestock  
- 30% wild birds

All mammals on land:  
- 98% humans and livestock  
- 2% wild mammals

- 34-45% of fish are overfished to the point of collapse

- 40-60% are maximally fished











Marcia Bjornerud

Professor of Geology  
and Environmental Studies  
Lawrence University  
USA

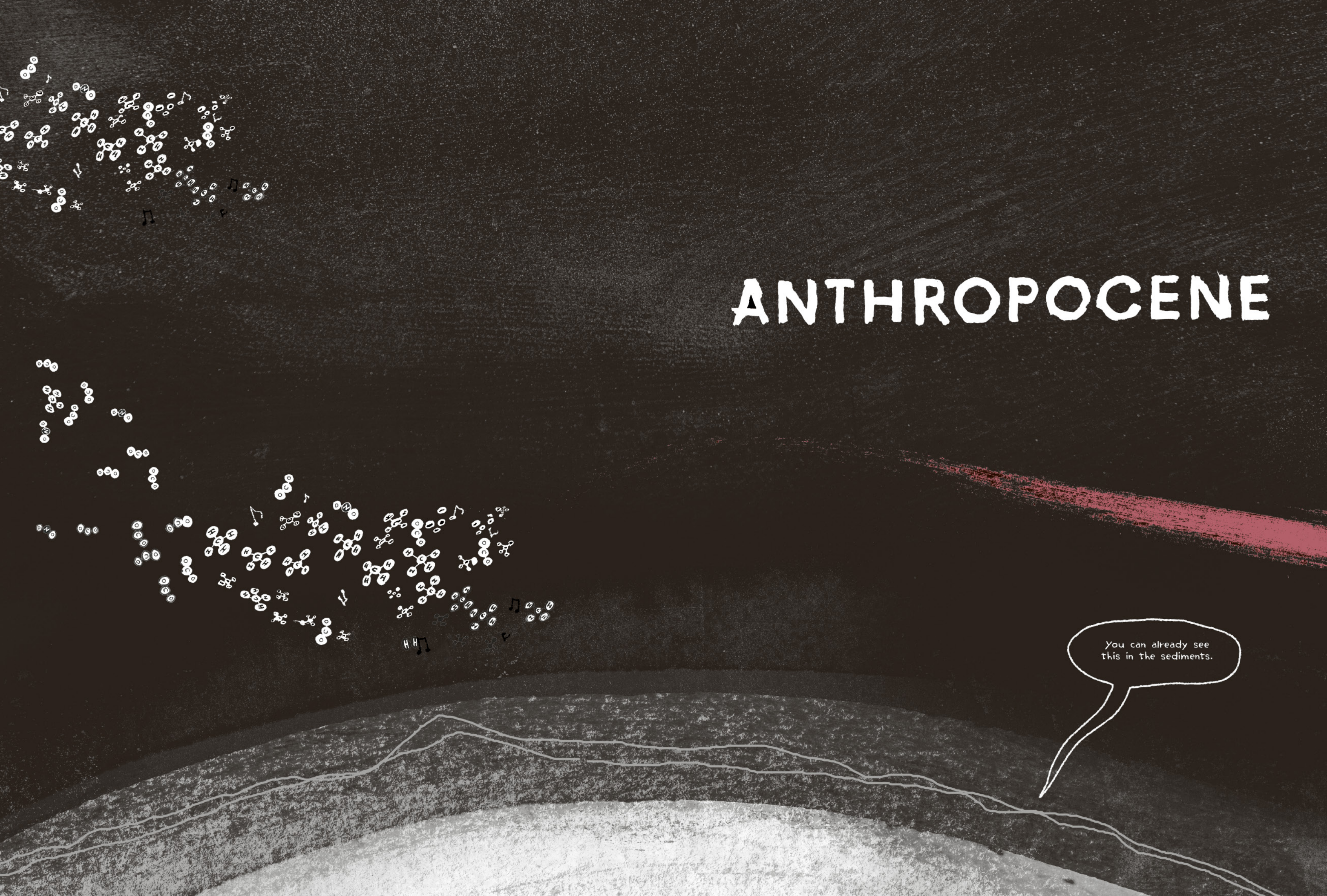
Not only have we  
consumed all the available  
space, but also the work  
of Time.





# ANTHROPOCENE

You can already see this in the sediments.





That is why at a meeting of the IGBP\* in 2000 a guy named Paul Crutzen proposed a new geological era ...

Everyone agrees that humans have become one of the most important factors influencing atmospheric, biological, and geological processes.

In 2002, Paul argued for the introduction of a new epoch in an article published in Nature\* ...

\*IGBP: International Geosphere Biosphere Programme, founded in 1986 with the aim of understanding the interactive physical, chemical and biological processes that regulate the Earth system and analyzing the interrelationships of their natural and anthropogenic changes.

International Geosphere Biosphere Program

We no longer live in the Holocene, we live in the ...

**ANTHROPOCENE\*!**

Paul Crutzen<sup>16</sup>

Meteorologist and atmospheric chemist  
Recipient of the Nobel Prize in Chemistry  
1933-2021

Really rolls off the tongue, huh?

Whoops! I'm losing my color.

\*Anthropocene: Literally translates to the man-made new; The Earth age of Man

It seems appropriate to assign the term 'Anthropocene' to the present, in many ways human-dominated, geological epoch, supplementing the Holocene — the warm period of the past 10-12 millennia.

For the past three centuries, the effects of humans on the global environment have escalated. Because of these anthropogenic emissions of carbon dioxide, global climate may depart significantly from natural behaviour for many millennia to come.

\*Nature: important scientific journal, Macmillan Publishers Ltd. (Great Britain)



During the past three centuries, the human population has increased tenfold to more than 6 billion and is expected to reach 10 billion in this century.

That was in 2002, today there are 8 billion earthlings.

WOW! This really calls for a new epoch!

About 30-50% of the planet's land surface is exploited by humans.

Recent estimates suggest as much as 95% of the ice free landscape is influenced by humans in some way.

Tropical rainforests disappear at a fast pace, releasing carbon dioxide and strongly increasing species extinction.

Dam building and river diversion have become commonplace.

Methane producing cattle population has risen to 1.4 billion.

More than half of all accessible fresh water is used by humankind.

Fisheries remove more than 25% of the primary production in upwelling ocean regions and 35% in the temperate continental shelf.

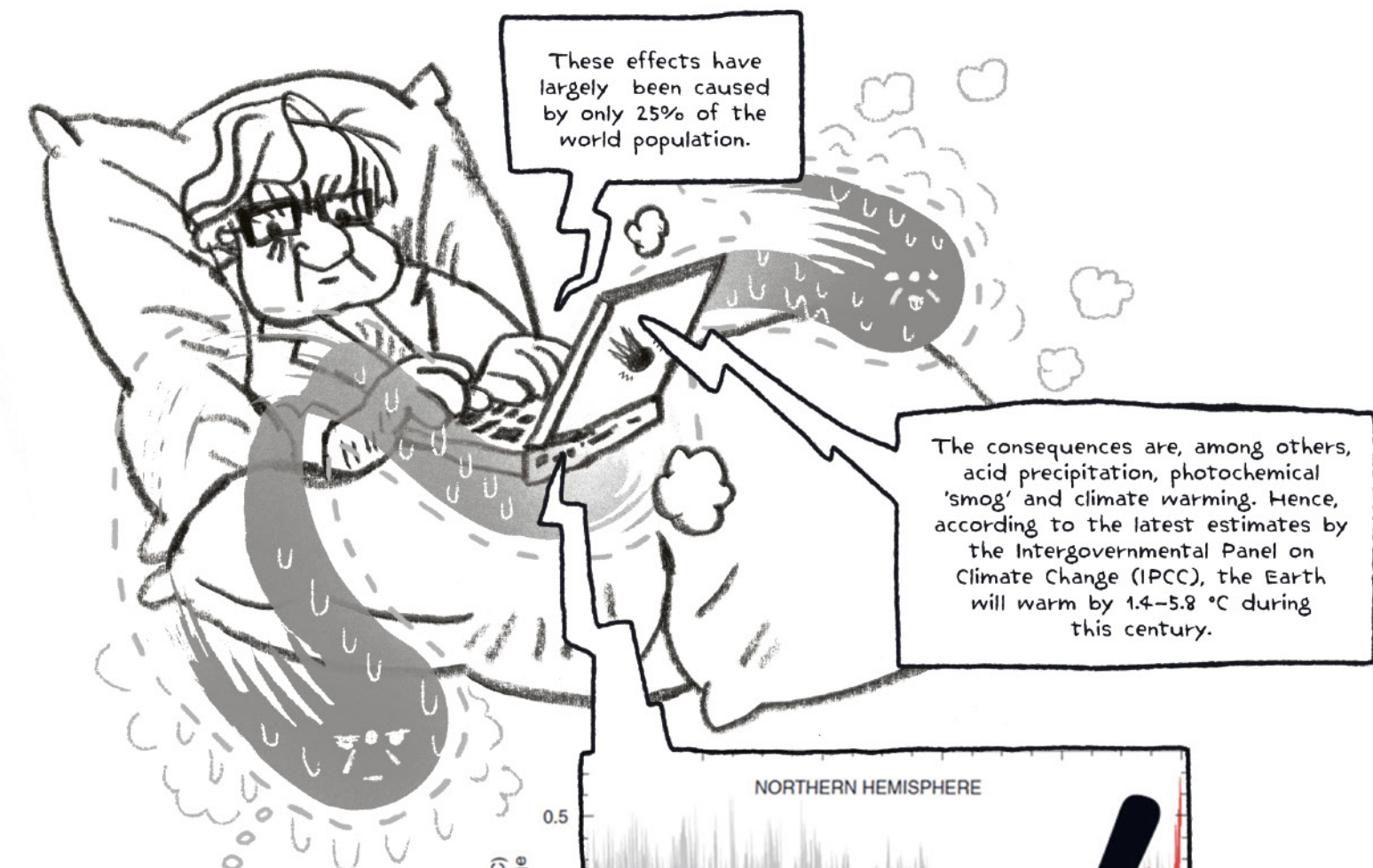
Energy use has grown 16-fold during the twentieth century, causing 160 million tonnes of atmospheric sulphur dioxide emissions per year, more than twice the sum of its natural emissions.

Nitric oxide production by the burning of fossil fuel and biomass overrides natural emissions.

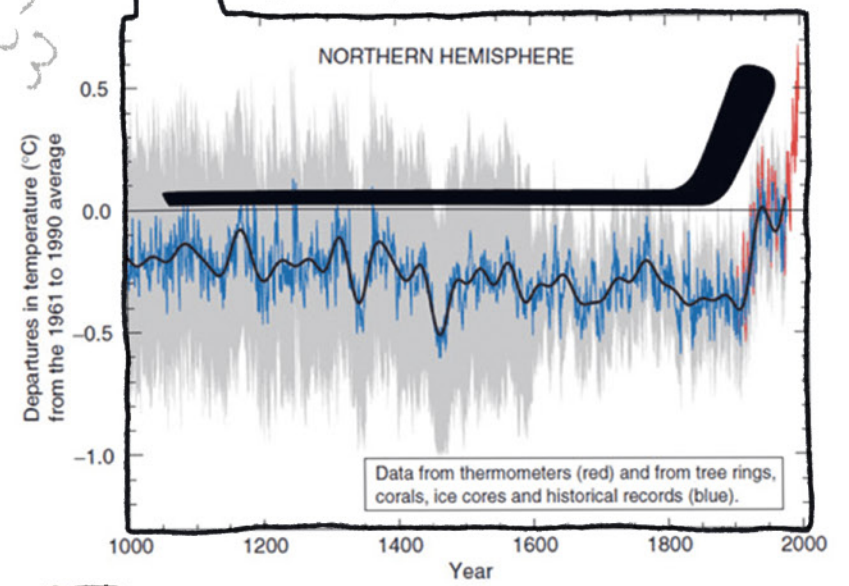
Fossil-fuel burning and agriculture have caused substantial increases in the concentrations of 'greenhouse' gases - carbon dioxide by 30% and methane by more than 100% - reaching their highest levels over the past 400 millennia, with more to follow.

As of July 2022 worldwide over 35% of commercially exploited fish stocks are considered overfished and 60% as maximally exploited.

More nitrogen fertilizer is applied in agriculture than is fixed naturally in all terrestrial ecosystems.



Today we are already dealing with a global warming of 1.2 degrees.



A daunting task...

... lies ahead for scientists and engineers to guide society...

... towards environmentally sustainable management during the era of the Anthropocene.





The term „Anthropocene“ spread like wildfire.

Other disciplines have also happily taken up the new Earth age ...

ANTHROPOCENE!

science

ANTHROPOCENE!

humanities politics arts archaeology sociology

... so that in 2008 the Stratigraphic Commission of the Geological Society in London has made the following considerations:

Everyone is talking about the Anthropocene. One should examine whether a formalization of the Anthropocene as a new epoch makes sense.

In 2009, the SQS<sup>17</sup>, a subcommittee of the ICS responsible for the Quaternary\*, stated:

Humans can indeed significantly affect not only the Earth system parameters but, as a consequence of this, also the course of Earth's geological evolution!

That is why we are commissioning a subgroup to investigate whether a new geologic epoch should replace the Holocene.

That's how the Anthropocene Working Group<sup>18</sup> was founded.

TADAAAAA!!

AWG

\*Quaternary: a unit of time within the Cenozoic Era, beginning 2,588,000 years ago and continuing to the present day

In 2019, Jan, at that time chair of the AWG, announced:

We will develop a proposal to formalize the Anthropocene based on our recommendations from 2016:

It is being considered at series or epoch level – and so its base or beginning would terminate the Holocene series (or epoch) as well as the Meghalayan stage (or age).

Jan Zalasiewicz  
Geologist, Palaeontologist, and Stratigrapher

Which color??

System / Period	Series / Epoch	Subseries / Subepoch	Stage / Age	GSSP
Quaternary	Anthropocene		Stage 8	mid-20th century
	Holocene	Upper / Late	Meghalayan	4250 yr b2k
		Middle	Northgrippian	8236 yr b2k
Pleistocene	Lower / Early	Greenlandian	11,700 yr b2k*	
	Upper / Late	Stage 4	-129 ka	
	Middle	Chibanian	0.774 Ma	
	Lower / Early	Calabrian	1.80 Ma	
		Gelasian	2.58 Ma	

We'd put the spike here.

The Anthropocene will be defined by the standard means for a unit of the Geological Time Scale, via a GSSP, colloquially known as a 'golden spike'.

Its beginning would be optimally placed in the mid-20th century ...

Why that? Paul suggested another time for the beginning!.

I'll tell you more about it in a bit. Let's check out the members of the AWG first.

\*b2k: before the year 2000 AD



The working group members are a multidisciplinary – but not very diverse! – crowd of scientists.



**An Zhisheng**  
Geologist  
Earth system science  
Chinese Academy of Sciences



**Anthony Barnosky**  
Geologist, Ecologist  
Stanford University



**Alejandro Cearreta**  
Geologist, Micropaleontologist  
Universidade del País Vasco



**John McNeill**  
Historian  
Environmental History  
Georgetown University



**Eric Odada**  
Geologist  
University of Nairobi



**Naomi Oreskes**  
Historian of Science  
Harvard University



**Clément Poirier**  
Affiliated Researcher  
LMCC  
Université de Caen



**Andy Cundy**  
Geologist  
Environmental Radiochemistry  
University of Southampton



**Matt Edgeworth\***  
Archaeologist  
Ancient History  
University of Leicester



**Erle Ellis\***  
Geographer  
Environmental Systems  
University of Maryland



**Ian Fairchild**  
Geographer  
Earth and Environmental Systems  
University of Birmingham



**Dan Richter**  
Ecologist  
Soils and Forest Ecology  
Duke University



**Neil Rose**  
Geographer  
Palaeolimnology  
London University College



**Yoshiki Saito**  
Quaternary Geologist  
Marine & Coastal Sedimentology  
Shimane University



**William Skotyk**  
Geochemist  
Agriculture and the Environment  
University of Alberta



**Barbara Fialkiewicz-Koziel**  
Geographer  
Adam Mickiewicz University



**Agnieszka Gatuszka**  
Geologist  
Uniwersytetu Jana Kochanowskiego



**Philip Gibbard\***  
Quaternary Geologist  
University of Cambridge



**Jacques Grinevald**  
Philosopher, Epistemologist,  
Historian  
Fellow Geological Society of London



**Will Steffen\***  
Emeritus Professor  
Earth System Science  
Australian National University



**Colin Summerhayes**  
Oceanographer, Geochemist  
Emeritus Associate  
University of Cambridge



**Jaia Syvitski**  
Oceanographer, Geologist  
Professor Emeritus  
University of Colorado



**Simon Turner**  
Geographer  
University College London



**Peter Haff\*\***  
Geologist  
Technological Systems  
Duke University



**Irka Hajdas**  
Geochronologist  
Radiocarbon Dating  
ETH Zürich



**Han Yong Ming**  
Geochemist  
Earth Environment  
Chinese Academy of Sciences



**Martin J. Head**  
Stratigrapher,  
Marine Palynologist  
Brock University



**Davon Vidas**  
Research Professor  
Director of the Law of the Sea Prog.  
Fridtjof Nansen Institute



**Michael Wagreich**  
Geologist  
University of Vienna



**Colin Waters**  
Geologist  
Honorary Professor  
University of Leicester



**Mark Williams**  
Palaeobiologist  
University of Leicester



**Juliana Assunção Ivar do Sul**  
Oceanologist  
Univ. Federal de Pernambuco



**Catherine Jeandel**  
Geochemical Oceanographer  
Fellow of the American  
Geophysical Union



**Reinhold Leinfelder**  
Geobiologist, Palaeontologist  
Freie Universität Berlin



**Francine McCarthy**  
Geologist  
Earth Sciences  
Brock University



**Scott Wing**  
Geologist  
Curator of Paleobotany  
Smithsonian Nat. Museum of Nat. History



**Jan Zalasiewicz**  
Geologist, Palaeobiologist  
University of Leicester



**Jens Zinke**  
Marine Geologist  
University of Leicester

... and of course Paul Crutzen until he died in 2021.

\*members of the AWG until summer 2023

\*\*Peter Haff sadly died in Feb 3, 2024

\*Will Steffen sadly died January 29, 2023



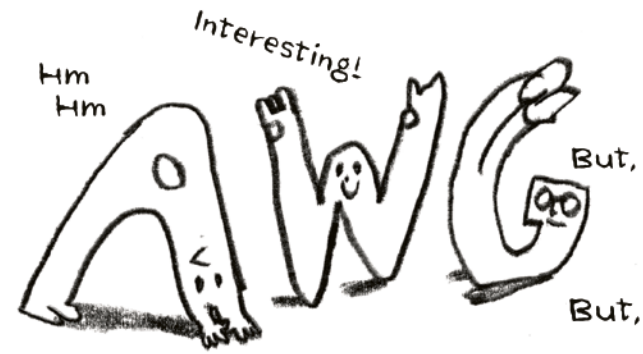


Back to the question about the beginning of the Anthropocene ...

Since Paul first brought up the topic, there have been several proposals until the AWG came up with a suggestion.



Why do you always make it so complicated?



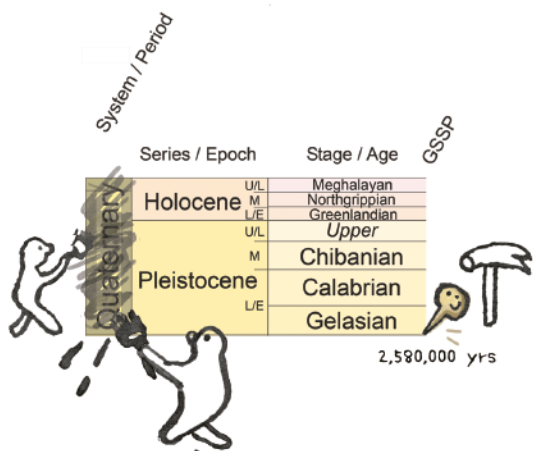
1. The Anthropocene should replace the entire Quaternary

2. The Anthropocene begins in the late Pleistocene

3. The Anthropocene begins with the Neolithic Revolution

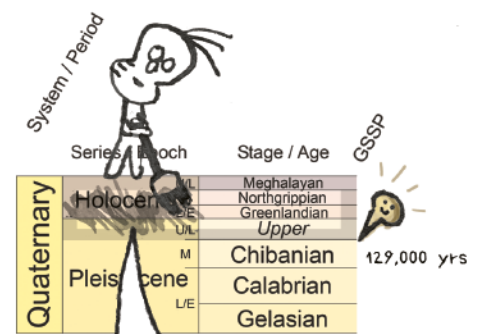
4. The Anthropocene starts with the Industrial Revolution

5. ... we'd place the lower limit of the Anthropocene around 1950.



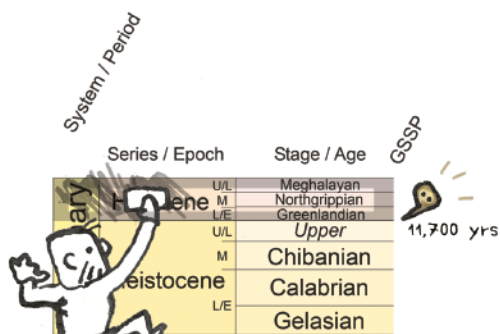
The Anthropocene begins with the appearance of modern humans.

Sorry, but humans were - just like all other living beings - a biological factor. This alone is not a new quality.



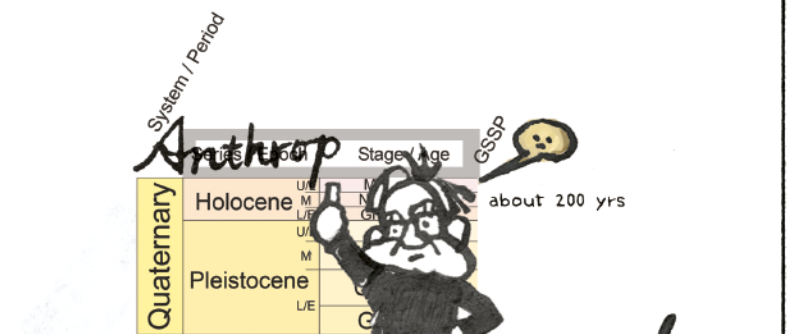
Human activity might have caused the extinction of large mammals in the last ice age.

Yeah, they MIGHT have ... but "might" isn't enough.



Human impact on the biosphere increased because of land use and deforestation.

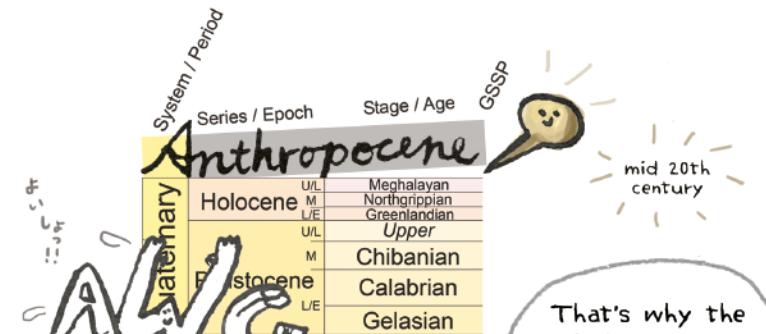
Right, but as I said before, at that time I was still strong. Humans bothered me only regionally.



With the industrialization, the exploitation of fossil energy sources and the utilization of Earth system services took on a whole new dimension.



Thus, the Anthropocene terminates the Holocene series / epoch as well as Meghalayan stage / age.



In any case, industrialization has left serious traces in the chronostratigraphic layers, but there are some strong regional variations.



Techno is a global player now!

Will will tell us why.





# The Great Acceleration<sup>19</sup>

Just have a look at these facts here, which we published in 2015. They speak for themselves.



**Will Steffen**  
Climate researcher and earth system scientist

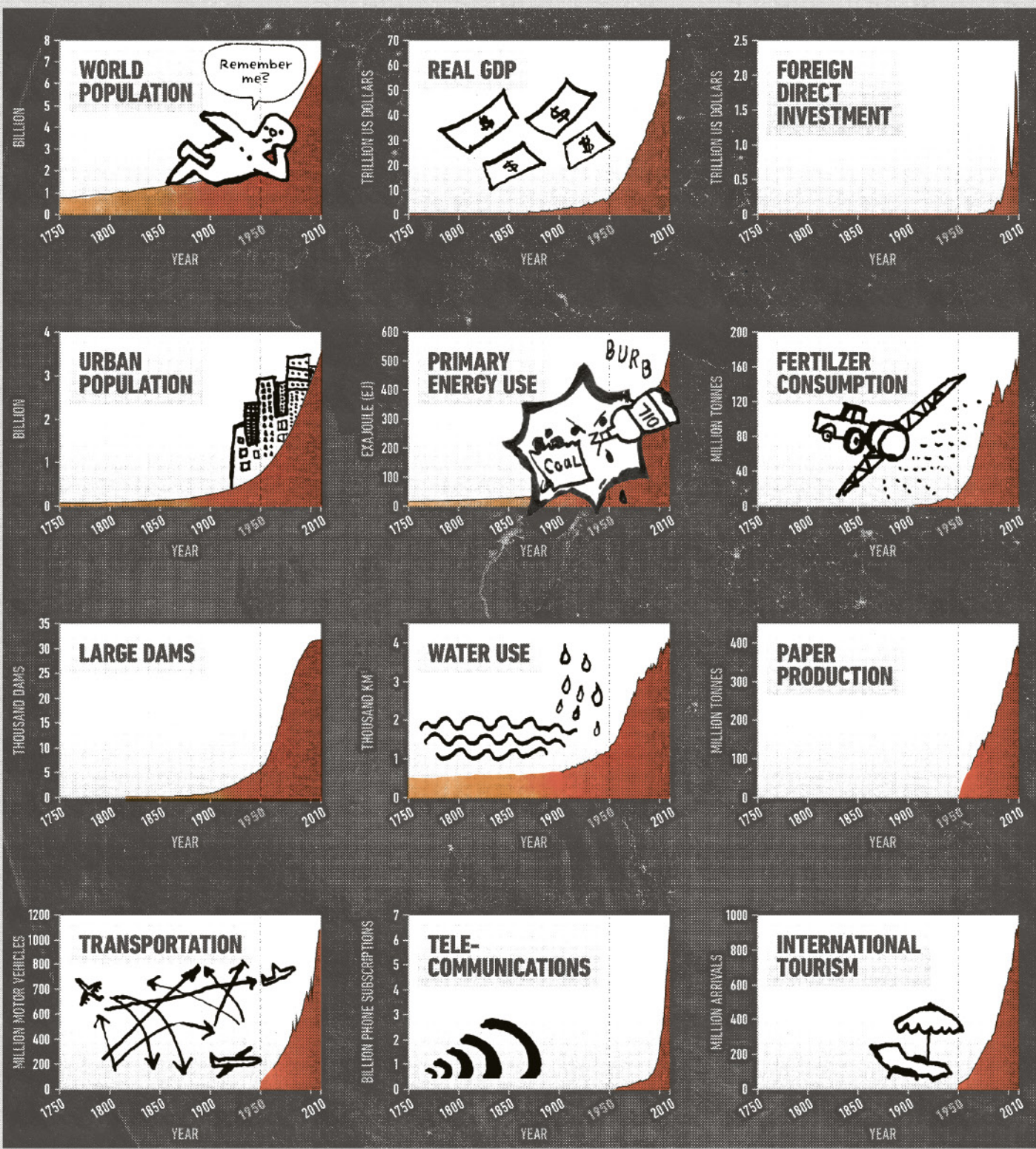
The human imprint influences all components of the global environment - oceans, coastal zones, atmosphere, and land.

We are not only a dominant Earth system factor but also a geological factor, that's for sure!

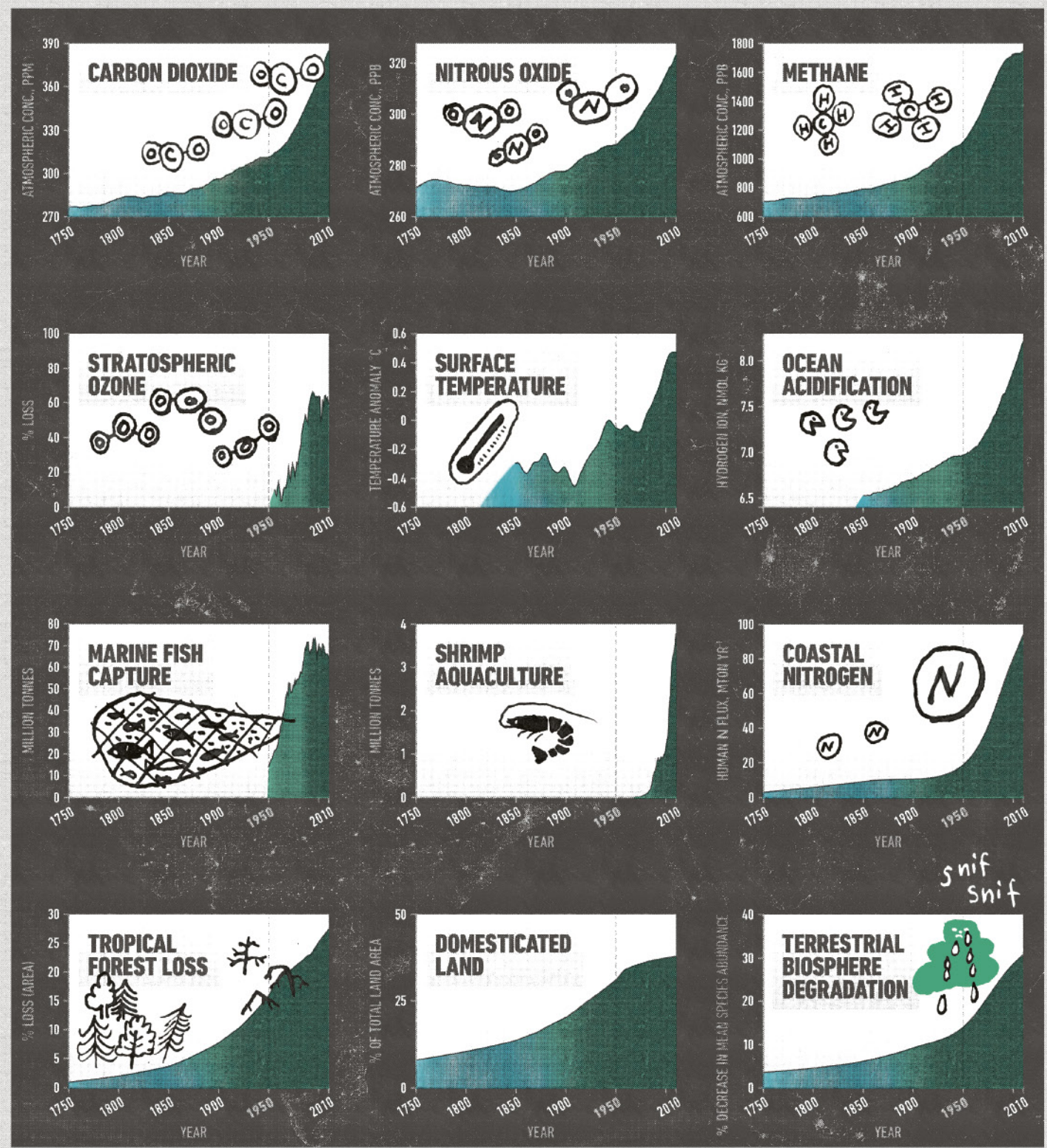
Looking at this, I definitely agree: the Anthropocene should start with the beginning of the Great Acceleration.



## SOCIO-ECONOMIC TRENDS



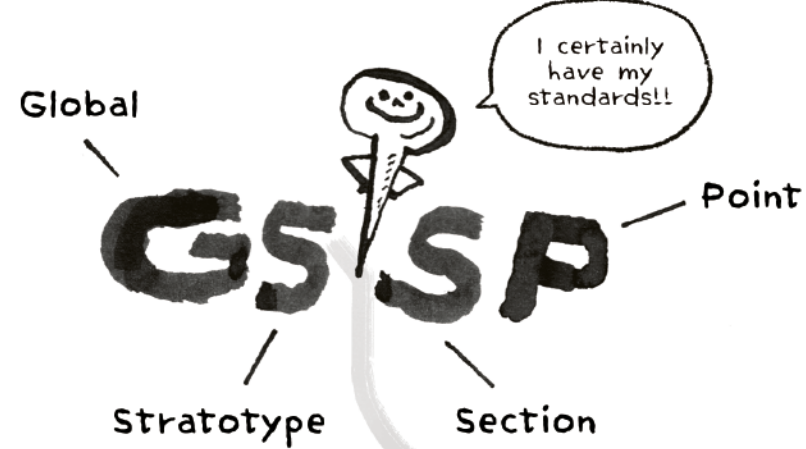
## EARTH SYSTEM TRENDS



Graphic adapted from Steffen et al, Global Change and the Earth System, 2004, Design: Globaia



Besides time, there are a few more requirements for the formalization of a chronostratigraphic unit ...



Last, but not least, we need to identify specific physical properties in the sediment layers that reflect anthropogenic impacts on the Earth system.

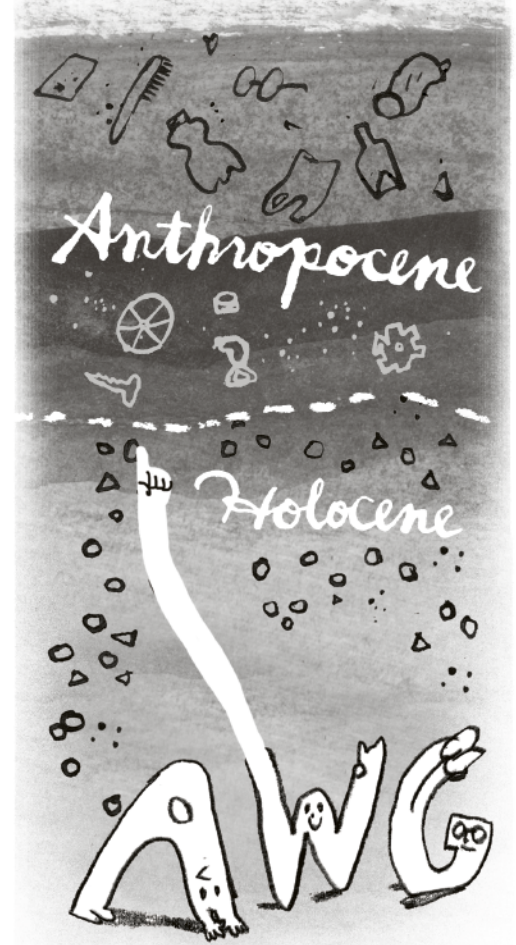


### 1. Point

First of all, we need a place on Earth where we can nail down the Anthropocene in the sediments.



### 2. Stratotype Section



The strata must represent a complete time record, with no gaps or disturbances in the Holocene-Anthropocene transition.

### 3. Reference



The sedimentary deposits must be preserved (for example as a drill core) for the future, and the site should be sufficiently accessible for reference.



### 4. primary and secondary markers

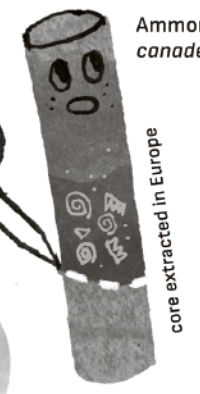
These properties are divided into so called primary and secondary markers.



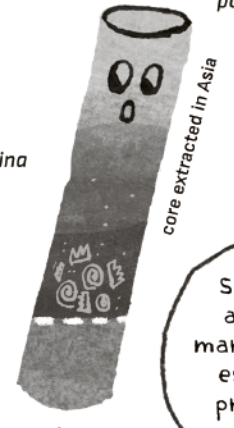
- magnetic polarity chrons
- microfossils
- Conodonts
- Milankovitch Cycles
- stable isotopes
- Brachiopods
- Agnostids
- Graptolites

Ideally, a primary marker is traceable globally in the stratigraphic settings.

Example of a primary marker:  
*Ammonite Daxatina canadensis* @

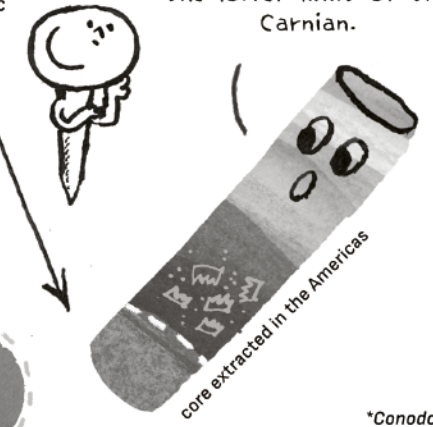


Example of a secondary marker:  
*Conodont Paragondolella polygnathiformis* m



Secondary markers assist the primary marker for correlation, especially when the primary marker can not be detected.

Sorry, I can only show the conodonts\*, but you can still determine the lower limit of the Carnian.



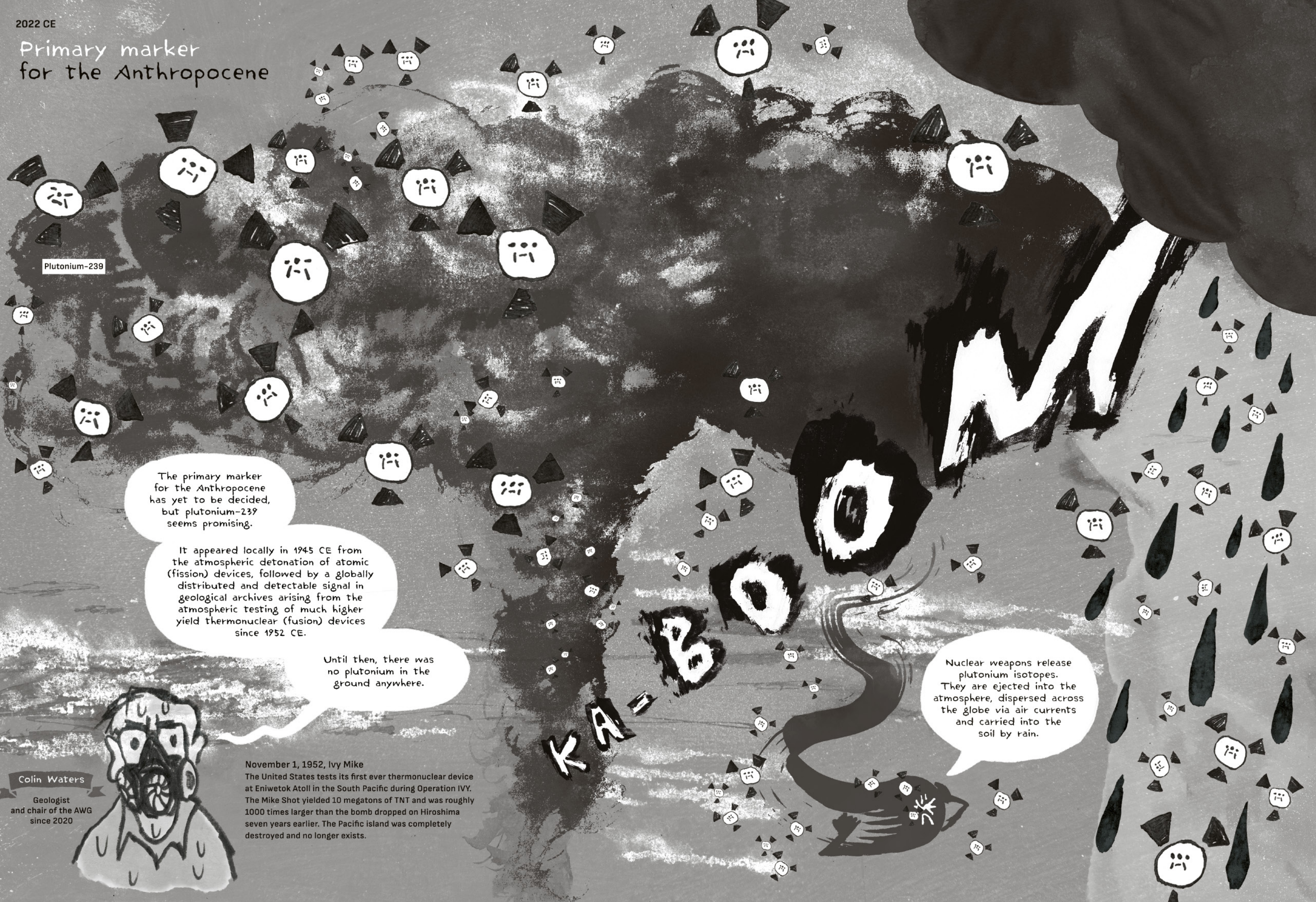
\*Conodont: Conodont elements are phosphatic tooth-like structures whose function is believed to be part of the feeding apparatus of an extinct early marine vertebrate.

That's one of the reasons why Colin suggested a geochemical signal as primary marker for the Anthropocene.

The stratigraphic markers<sup>20</sup> must persist long into the future.



# Primary marker for the Anthropocene



Plutonium-239

The primary marker for the Anthropocene has yet to be decided, but plutonium-239 seems promising.

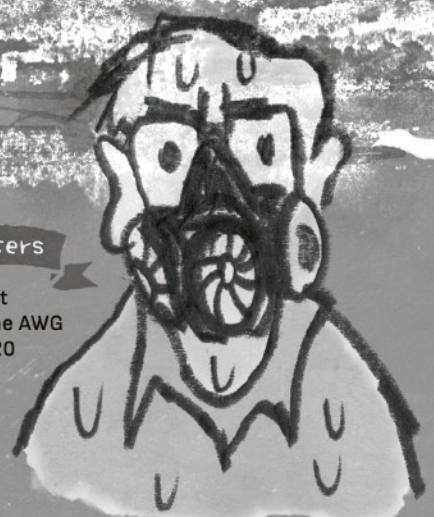
It appeared locally in 1945 CE from the atmospheric detonation of atomic (fission) devices, followed by a globally distributed and detectable signal in geological archives arising from the atmospheric testing of much higher yield thermonuclear (fusion) devices since 1952 CE.

Until then, there was no plutonium in the ground anywhere.

Nuclear weapons release plutonium isotopes. They are ejected into the atmosphere, dispersed across the globe via air currents and carried into the soil by rain.

November 1, 1952, Ivy Mike  
 The United States tests its first ever thermonuclear device at Eniwetok Atoll in the South Pacific during Operation IVY. The Mike Shot yielded 10 megatons of TNT and was roughly 1000 times larger than the bomb dropped on Hiroshima seven years earlier. The Pacific island was completely destroyed and no longer exists.

Colin Waters  
 Geologist and chair of the AWG since 2020





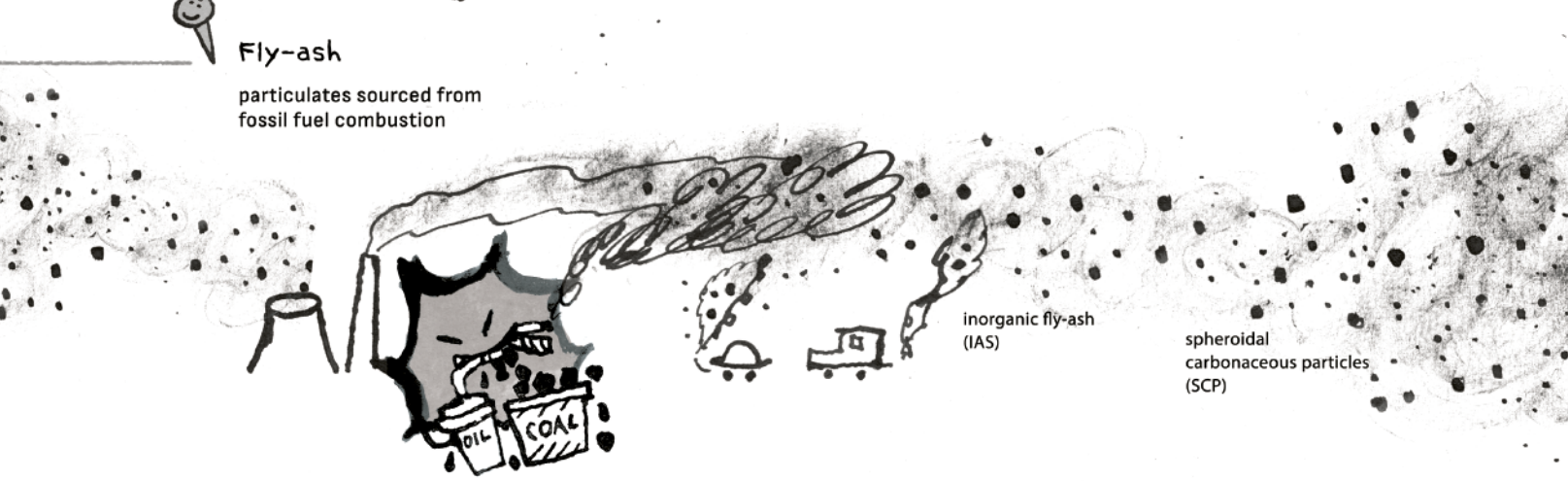
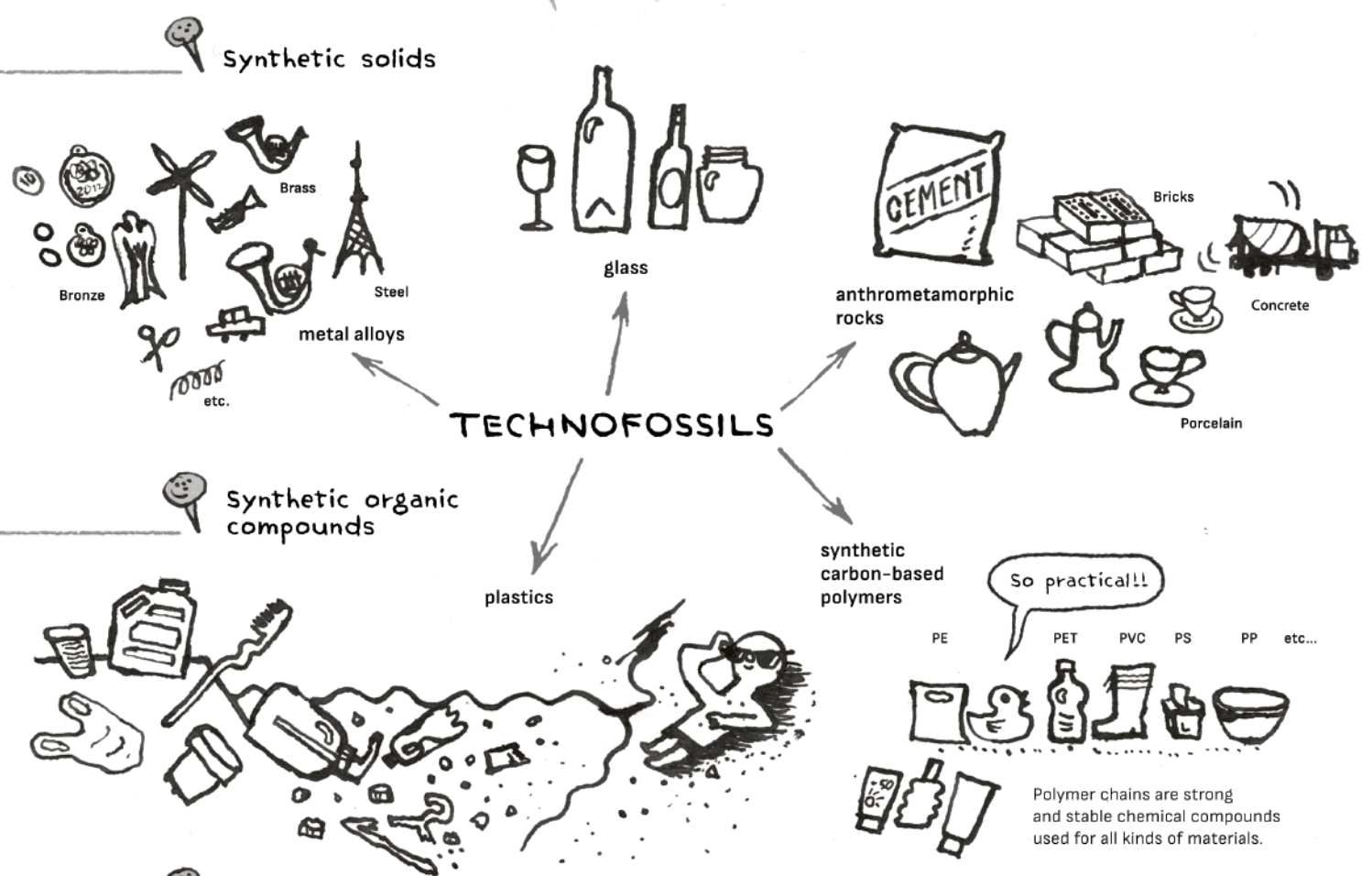
# Secondary markers for the Anthropocene

The proposed secondary markers are more closely associated with the drivers of the Anthropocene.

The aim for the GSSP candidates is to have many guiding criteria to support the primary marker for correlation.

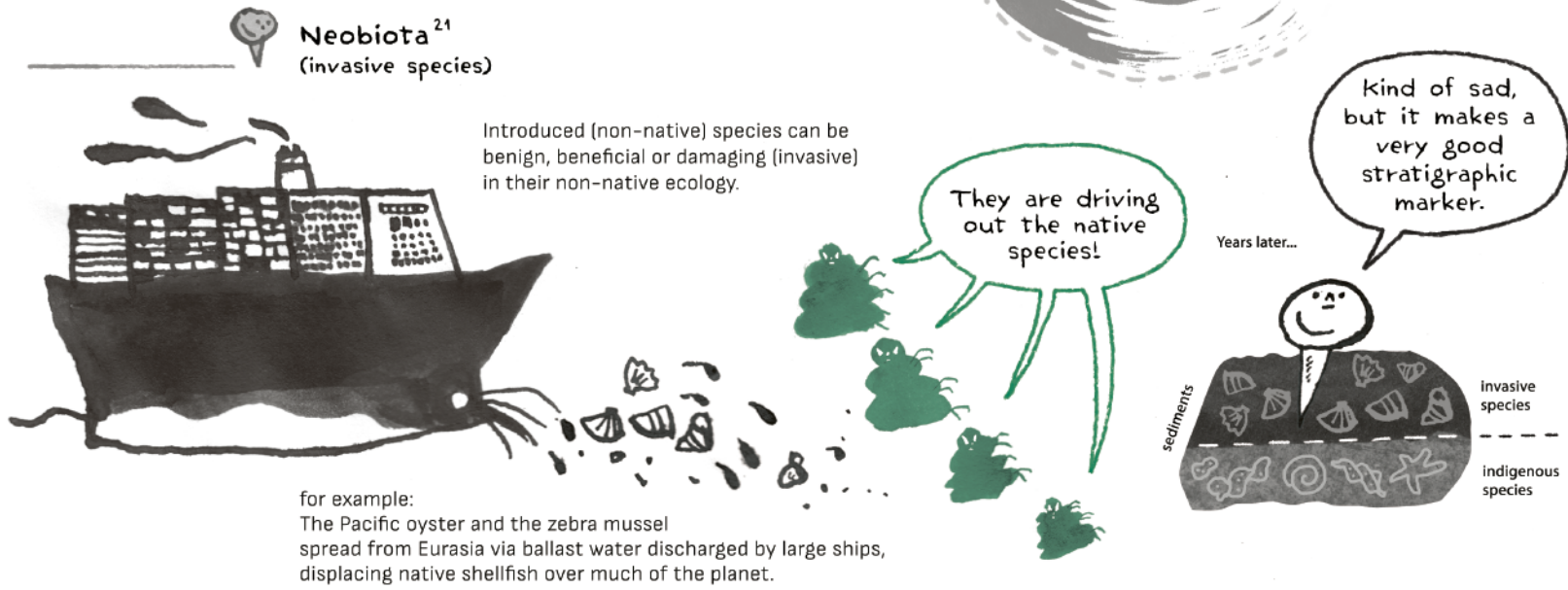
Unfortunately, there are a lot to choose from.

## Novel materials

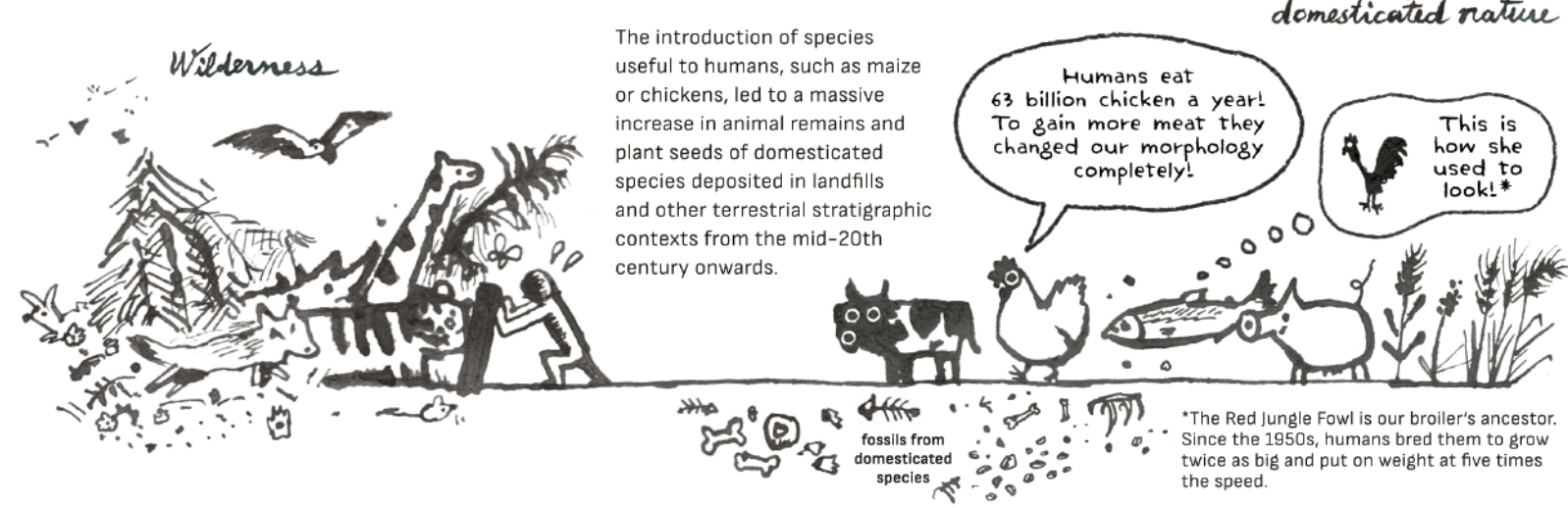


## Biotic markers

It's all a matter of timing.

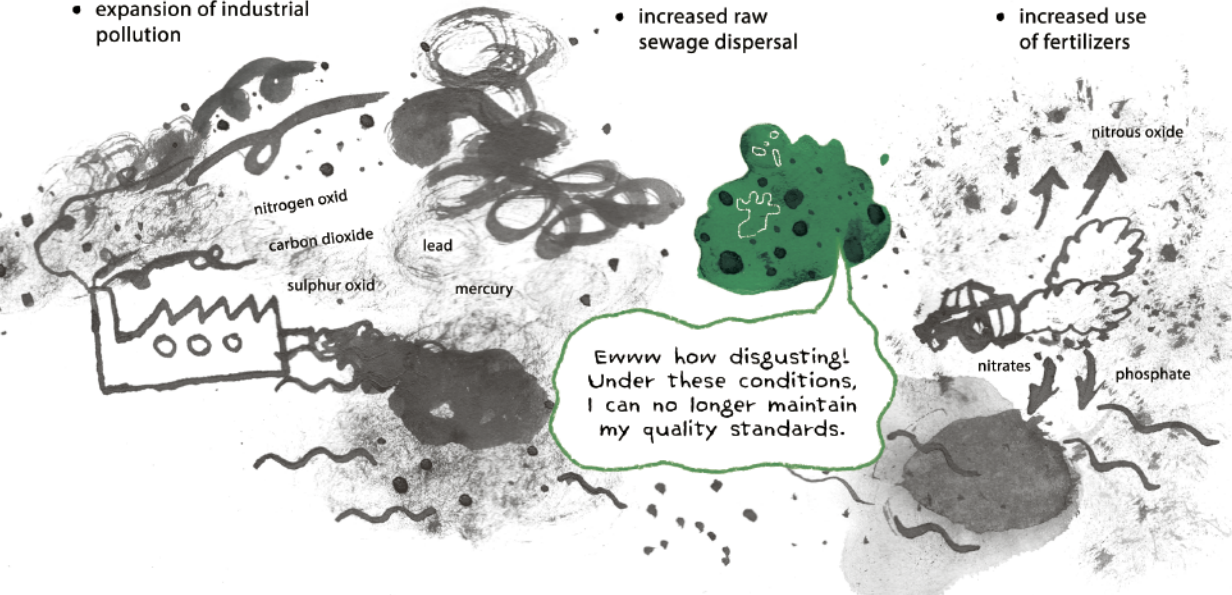


## Human-driven and neobiota-driven extinctions and local extirpations of species



## Ecological degradation through:

- expansion of industrial pollution
- increased raw sewage dispersal
- increased use of fertilizers







Additionally there are also...

## Geochemical markers

like:

### Oxygen and hydrogen isotopes

important climate change proxies

oxygen isotopes



light  
8 protons  
8 neutrons  
<sup>16</sup>O

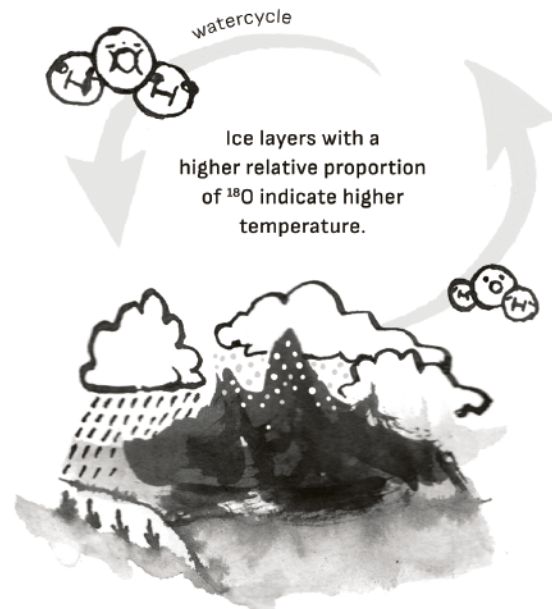
heavy  
8 protons  
10 neutrons  
<sup>18</sup>O

hydrogen isotopes



light  
1 proton  
<sup>1</sup>H (Protium)

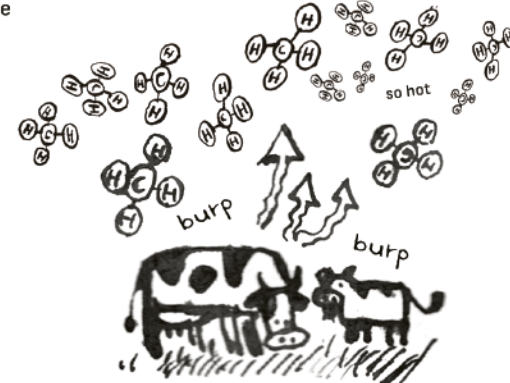
heavy  
1 proton  
1 neutron  
<sup>2</sup>H (Deuterium)



### Atmospheric CO<sub>2</sub>

from fossil fuels

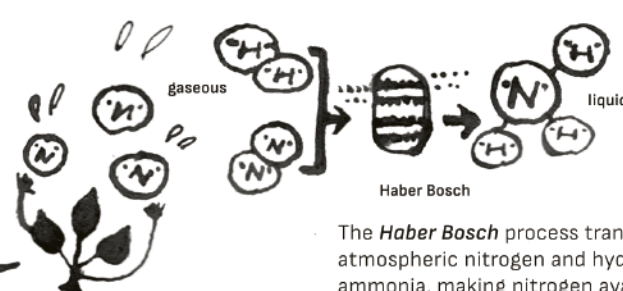
from agriculture



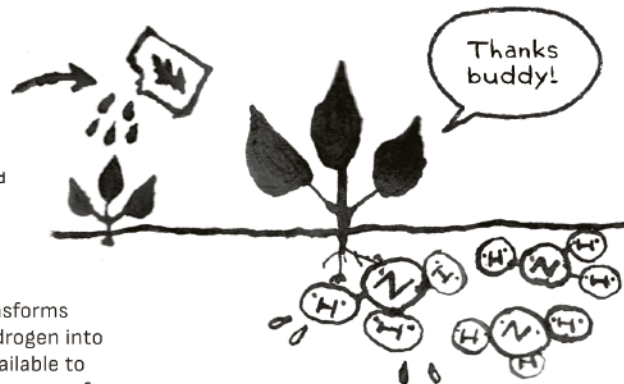
### Nitrate (NO<sub>3</sub><sup>-</sup>)

Concentrations went up mainly due to the production of fertilizers.

I can't pull the nitrogen out of the air.

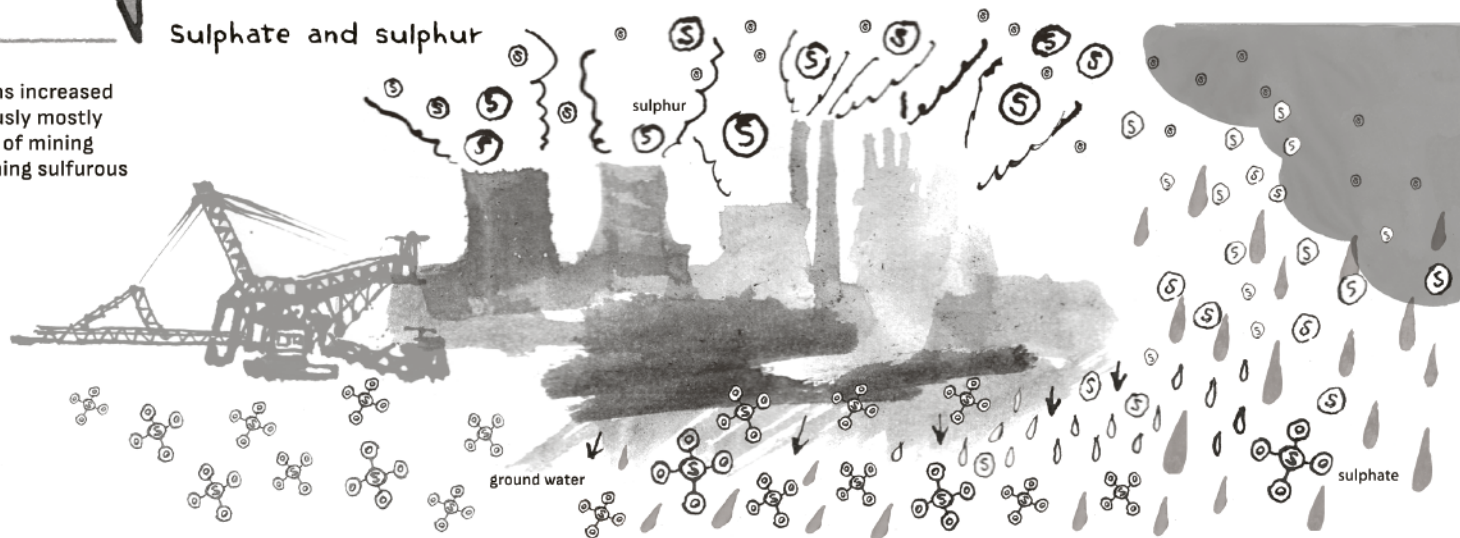


The **Haber Bosch** process transforms atmospheric nitrogen and hydrogen into ammonia, making nitrogen available to plants. The invention was a huge step for world nutrition.

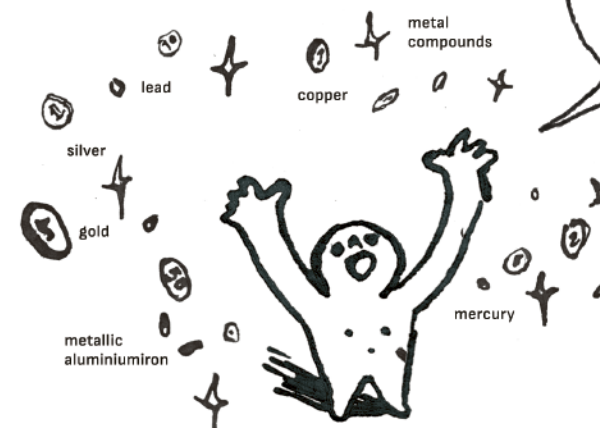


### Sulphate and sulphur

Emissions increased enormously mostly because of mining and burning sulfurous coal.



### Pure metals



We take them out of their host rocks and distribute them around the globe.

I'd say the most widespread and abrupt signal is the lead isotope ratio associated with the use of leaded petrol from the 1920s onwards.

Pb-206

### Organic compounds

like the insecticide DDT

Persistent organic pollutants (POPs), including organochlorine pesticide (OCP) signals such as DDT, aldrin and dieldrin and various polychlorinated biphenyls (PCBs) and brominated flame retardants, e.g. polybrominated diphenyl ethers, PBDEs.



### Anthropogenic radionuclides

Radionuclides that are absent or rare in nature, such as plutonium-239, americium-241, caesium-137, strontium-90 and plutonium-240, etc. released by 543 atmospheric nuclear weapons tests.



### Carbon-14 (<sup>14</sup>C)

Highly elevated carbon-14 levels in the atmosphere due to atmospheric nuclear weapons testing. Atmospheric tests were banned in 1963.

Hi, I am a radioactive isotope of carbon.

<sup>14</sup>C  
6 protons  
8 neutrons







Now that we know the requirements for the official launch of the Anthropocene, let's see which places have applied.

# THE CANDIDATES



FINALLY!



Nov 17 - 2022  
in the Gregorian calendar

5782  
in the Jewish calendar  
Reiwa 4  
in the Japanese calendar  
1441  
in the Islamic calendar  
2565  
in the Buddhist calendar  
5124 or 2079  
in some of the various Hindi calendars  
and many more...

Time is a complex matter  
for earthlings!

Based on many years of research,  
12 sites applied.

How exciting!



Maybe, but only after the competition.

Shall we go to an Onsen together?

Beppu Bay Japan

Sihailongwan Lake China

I have huge dead zones.

I have loads of chromium and nickel.

I'm out.

BASTA!!

LOVE wins!

Gotland Basin Baltic Sea

The Sudetes Poland

Wien Museum Austria

Ernesto Cave Italy

It's not so bad if I don't win. The main thing is that we have found each other!

Searsville Reservoir USA

I have real potential!

Francisco Estuary USA

Crawford Lake Canada

Wait till you really get to know me.

Flower Garden Bank Reef USA

No candidates from the global south? Is that because they have the least impact on the Earth system?

Narcissist

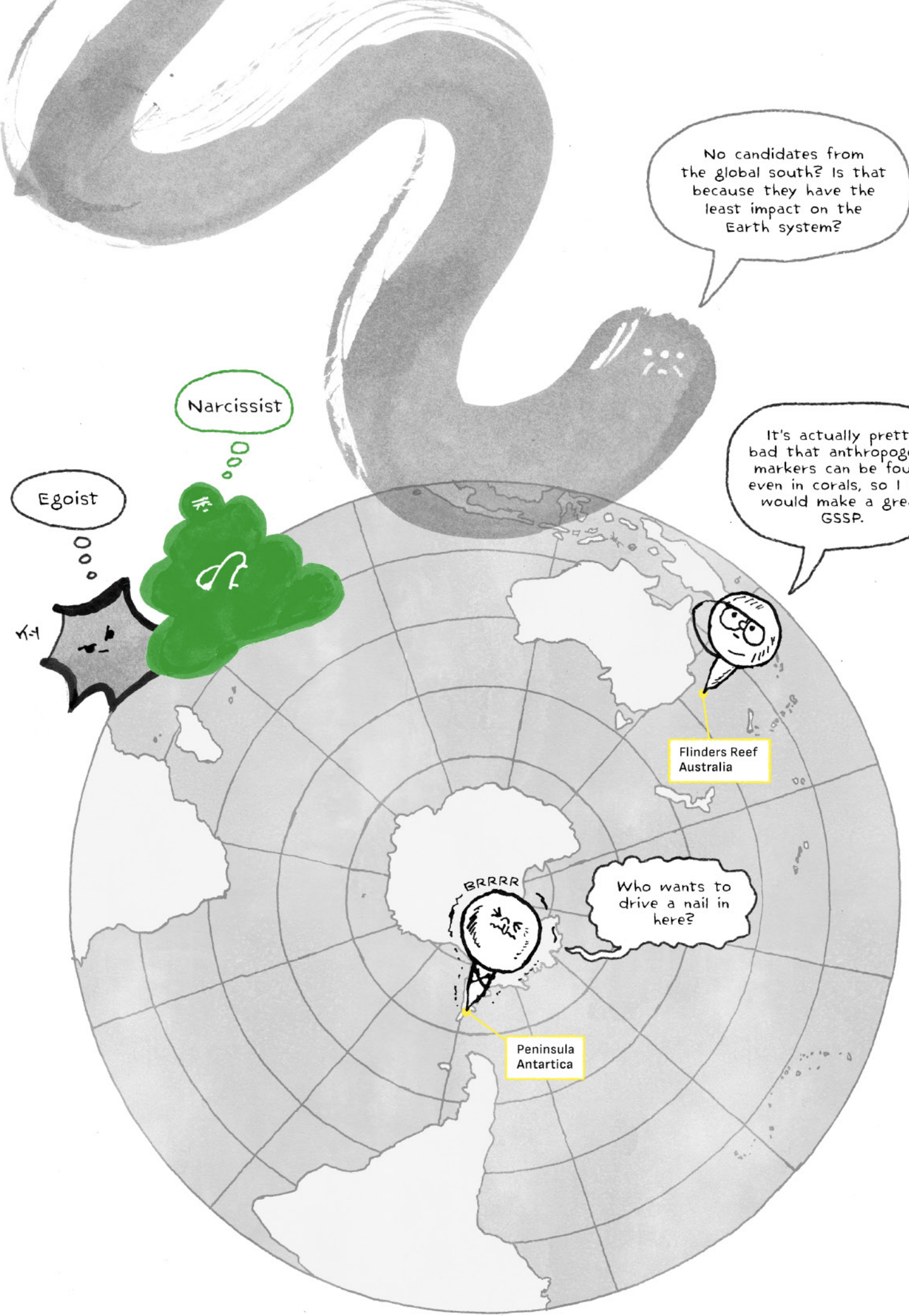
Egoist

It's actually pretty bad that anthropogenic markers can be found even in corals, so I too would make a great GSSP.

Flinders Reef Australia

Who wants to drive a nail in here?

Peninsula Antarctica





Cores were taken from most of the candidates. By far the longest core comes from Antarctica.

Two of the candidate sites are located in marine sediments.

Please note that we can only present some of the results of the investigations here!



We have three candidates from lake sites.

**Peninsula Antarctica**

name – Palmer  
length – 130 m  
time – 1617-2012

**Beppu Bay Japan**

name – BMC19 S1-4  
length – 94.2 cm  
time – 100 years

**East Gotland Basin Baltic Sea**

name – EMB201/7-4  
length – 45 cm  
time – 1840-2018

**Crawford Lake Canada**

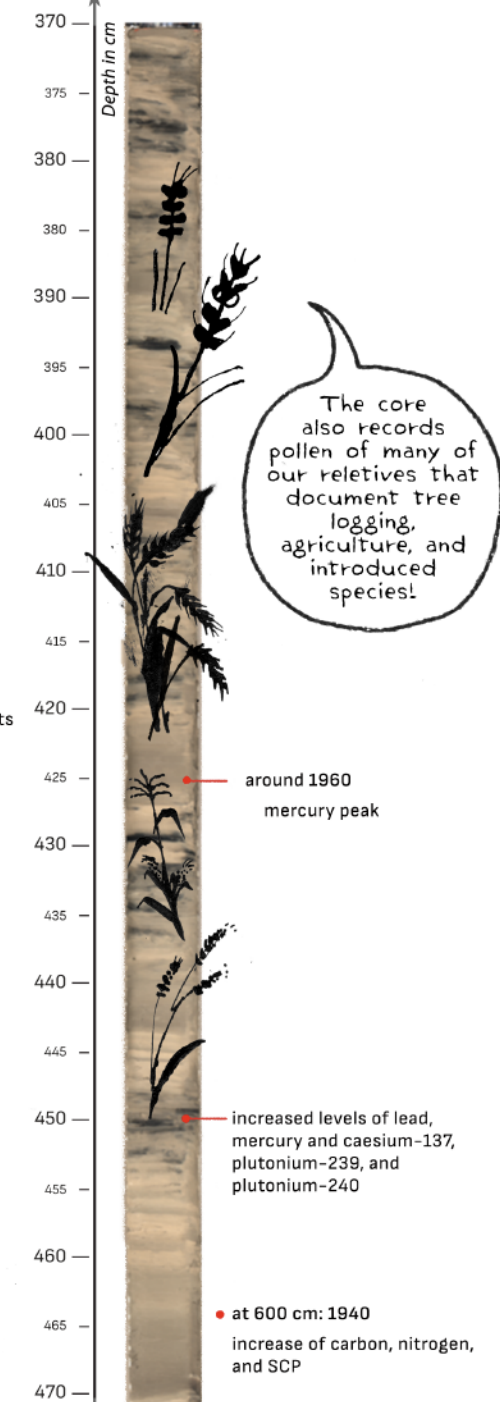
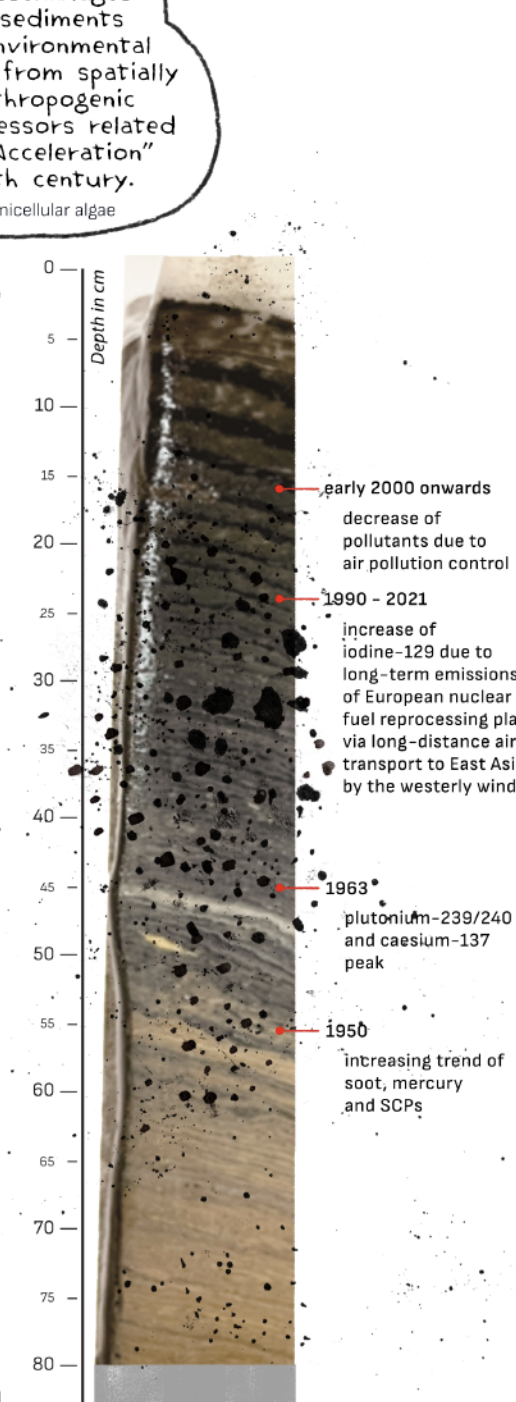
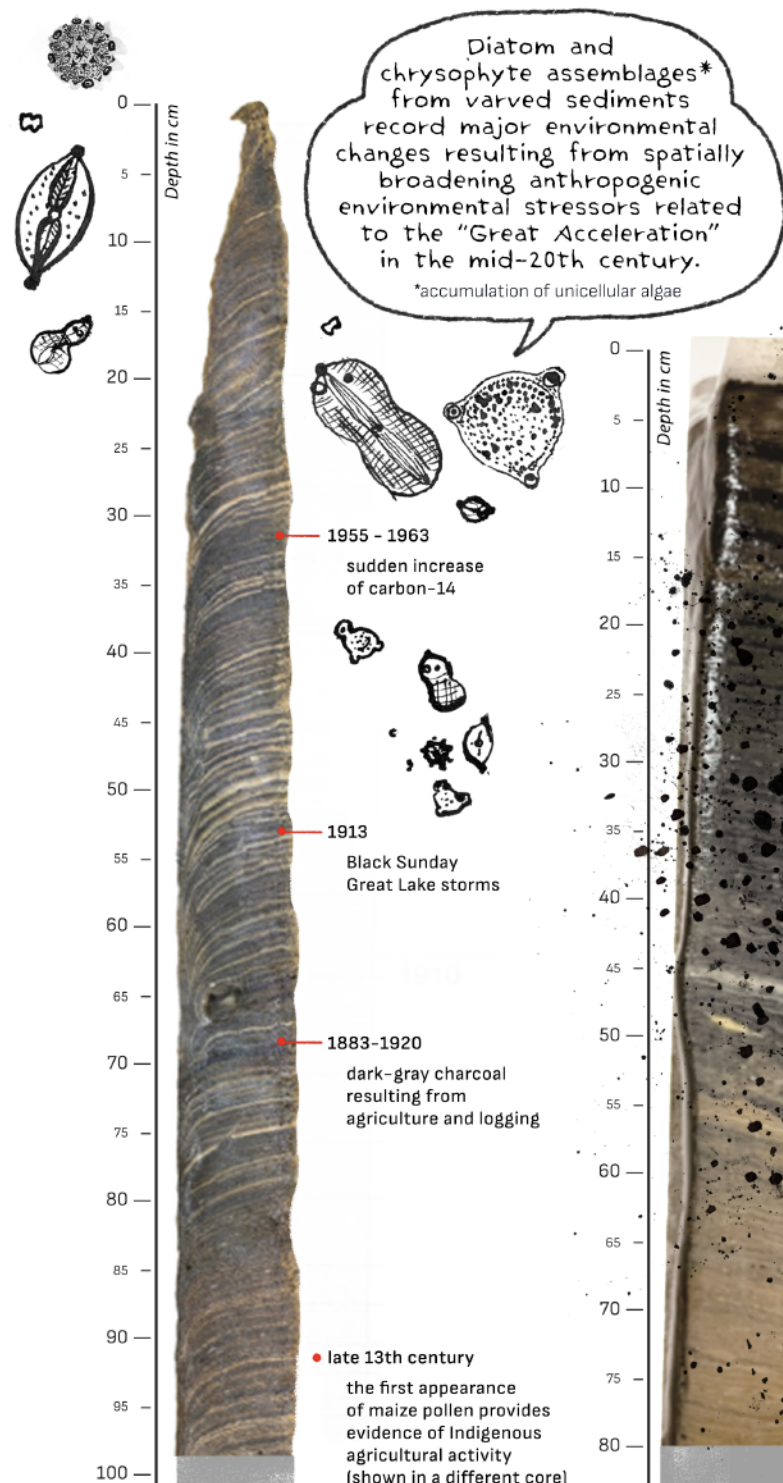
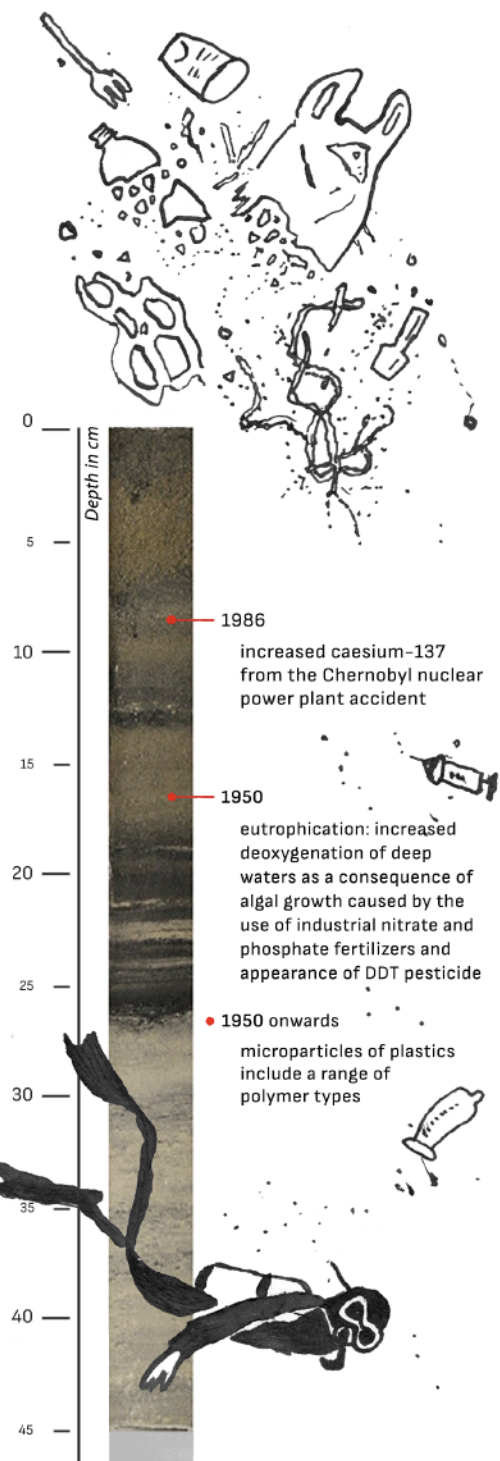
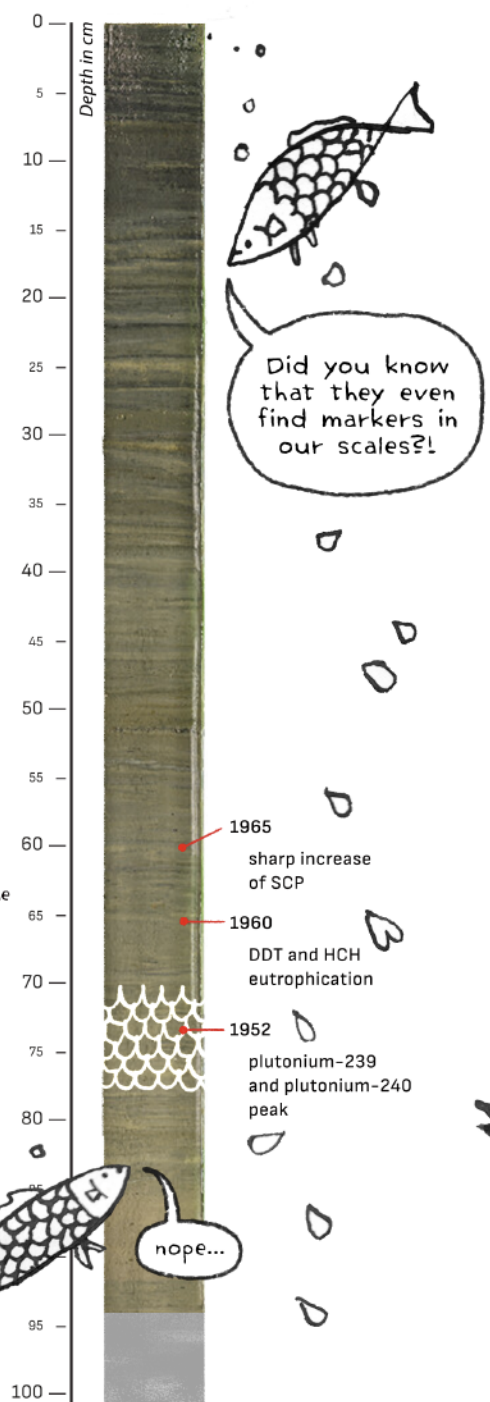
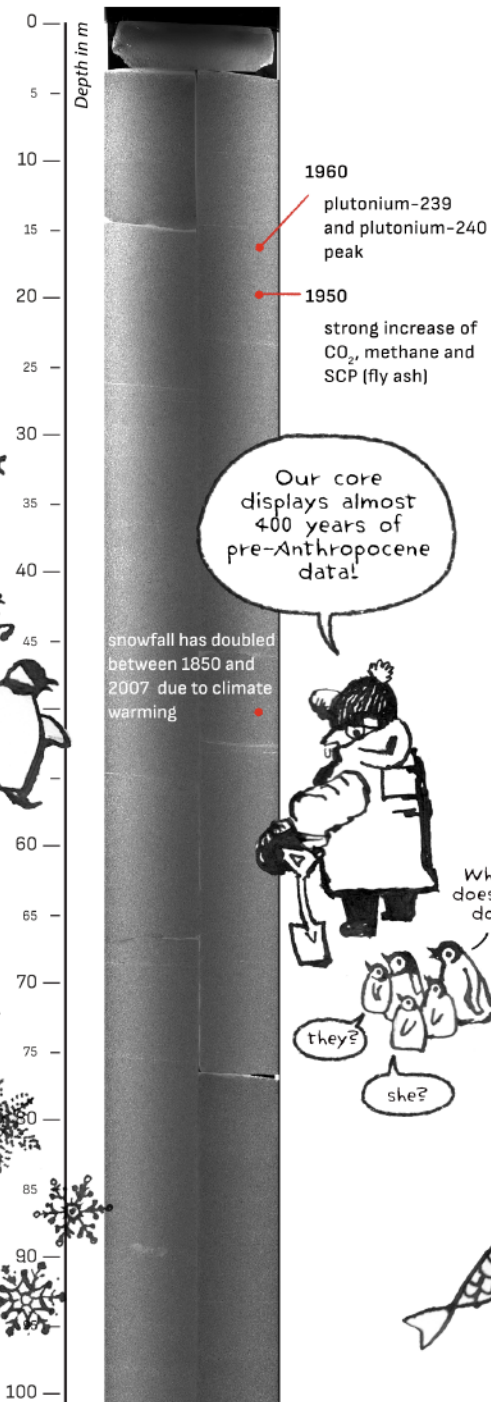
name – CRW19-2FT-B2  
length – 98 cm  
time – 1820-2019

**Sihailongwan Lake China**

name – SHLW-maar  
length – 80 cm  
time – 1920-2020

**Searsville Reservoir USA**

name – JRBP2018-VC01B  
length – 944.5 cm  
time – 1900-2018







One core is from a raised ombrotrophic peat bog.

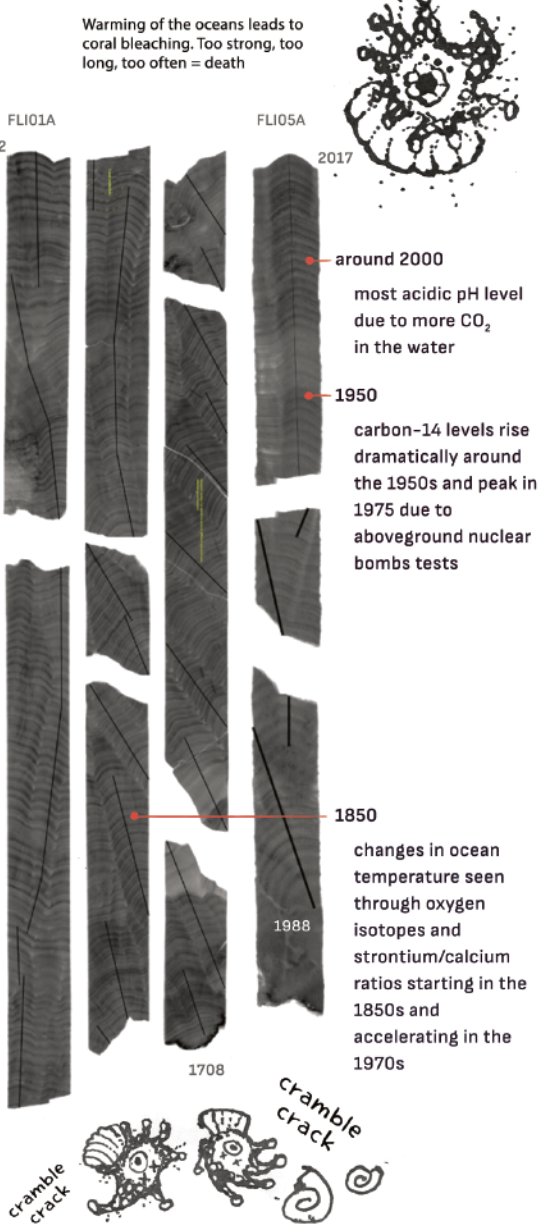
Three proposals have proven less favorable as the GSSP site:

The San Francisco Estuary core has one of the best historical records of neobiotic species, but because the age of the succession is relatively poorly constrained and the core stopped before reaching the key interval at the base of the Anthropocene, this site is also discounted as a GSSP.

### Flinders Reef Australia

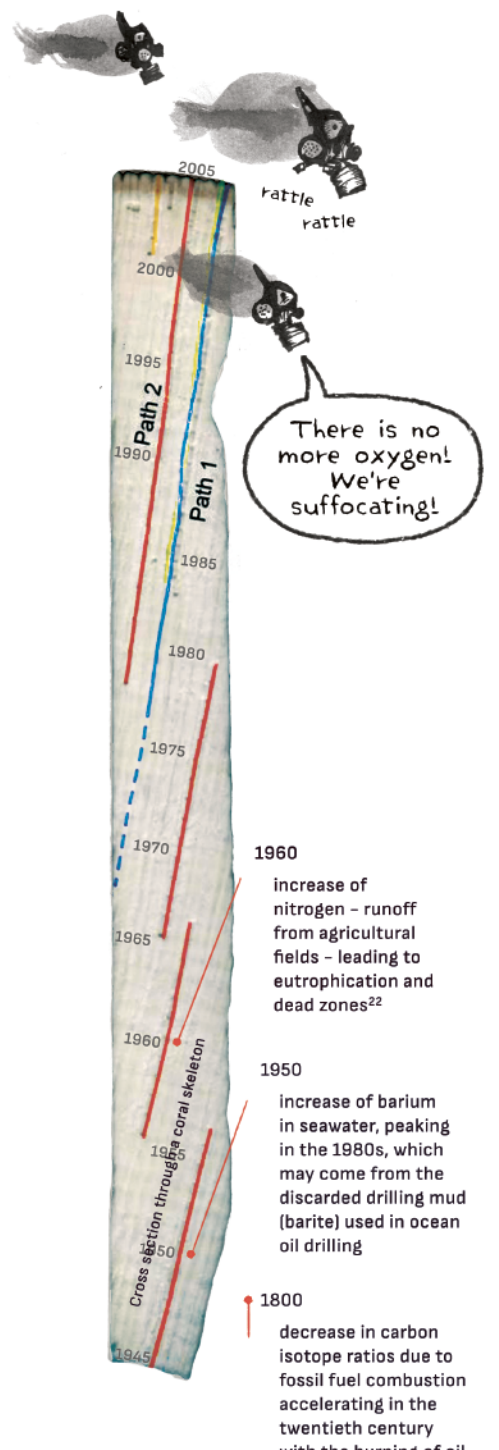
name – FLI01A and FLI05A  
length – 300 cm and 50 cm  
time – 1708-1992 / 1835-2017

Because of ocean acidification, all calcifying species have difficulty building their skeletons or shells.



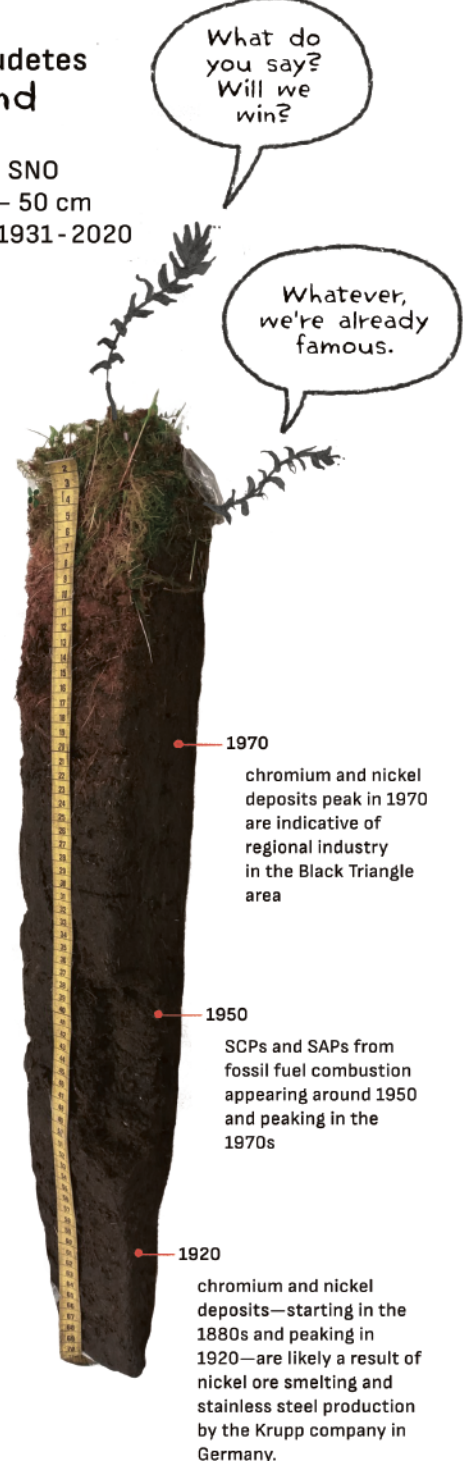
### West Flower Garden Bank Reef USA

name – OFWFGB3-1  
length – 174 cm  
time – 1752-2005



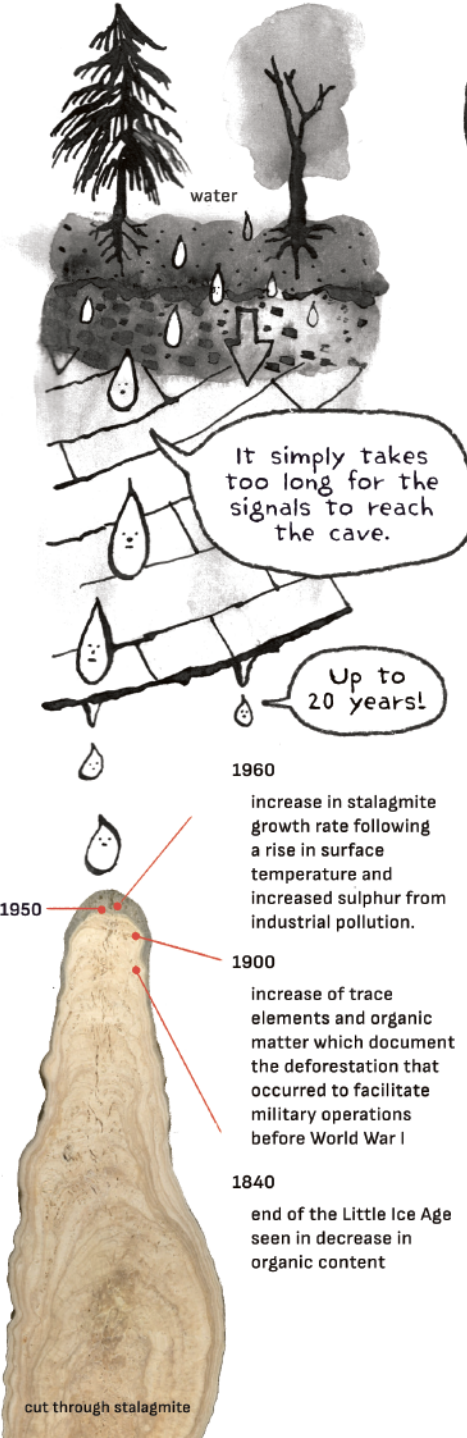
### The Sudetes Poland

name – SNO  
length – 50 cm  
time – 1931-2020



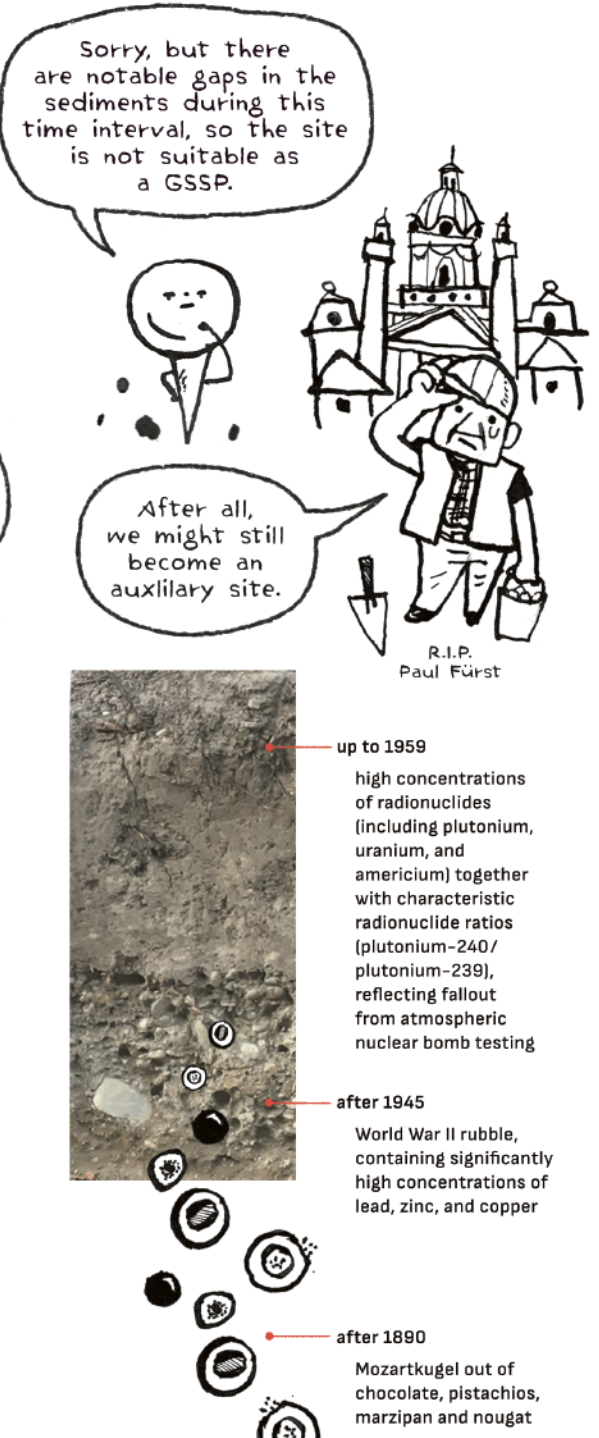
### Ernesto Cave Italy

name – ER77-78  
length – 45 cm  
time – last 5 mm from about 1950 - 2000



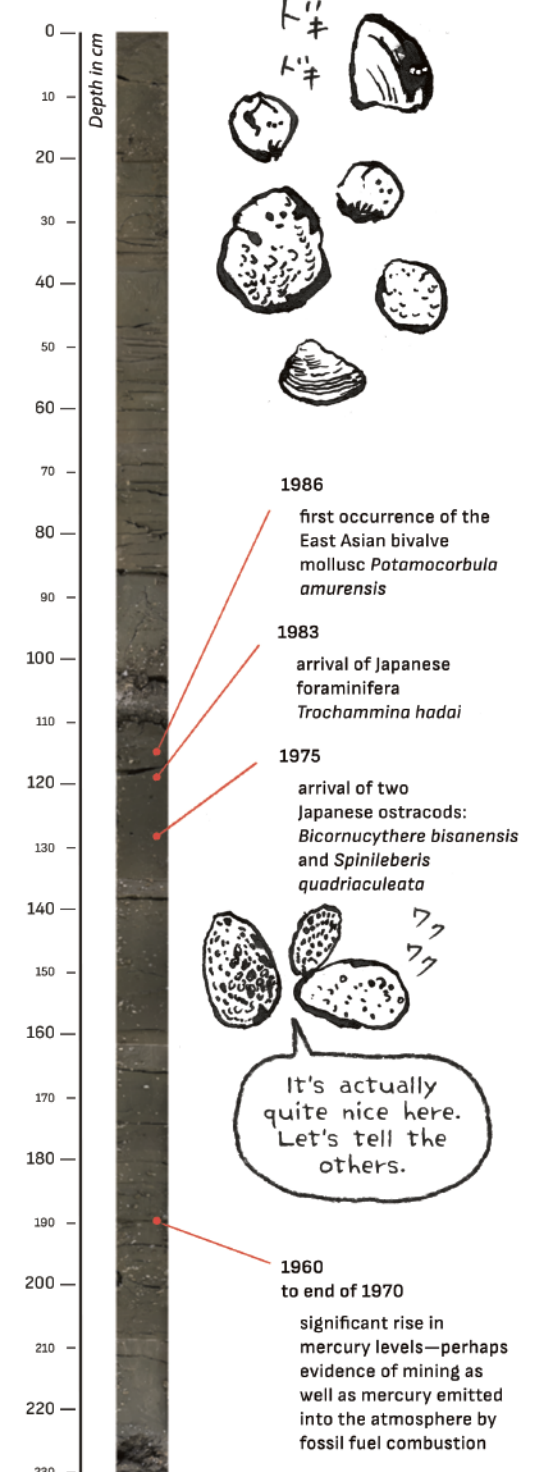
### Karlsplatz, Vienna Austria

name – 2019\_26  
samples of urban deposits  
time – near 200 years

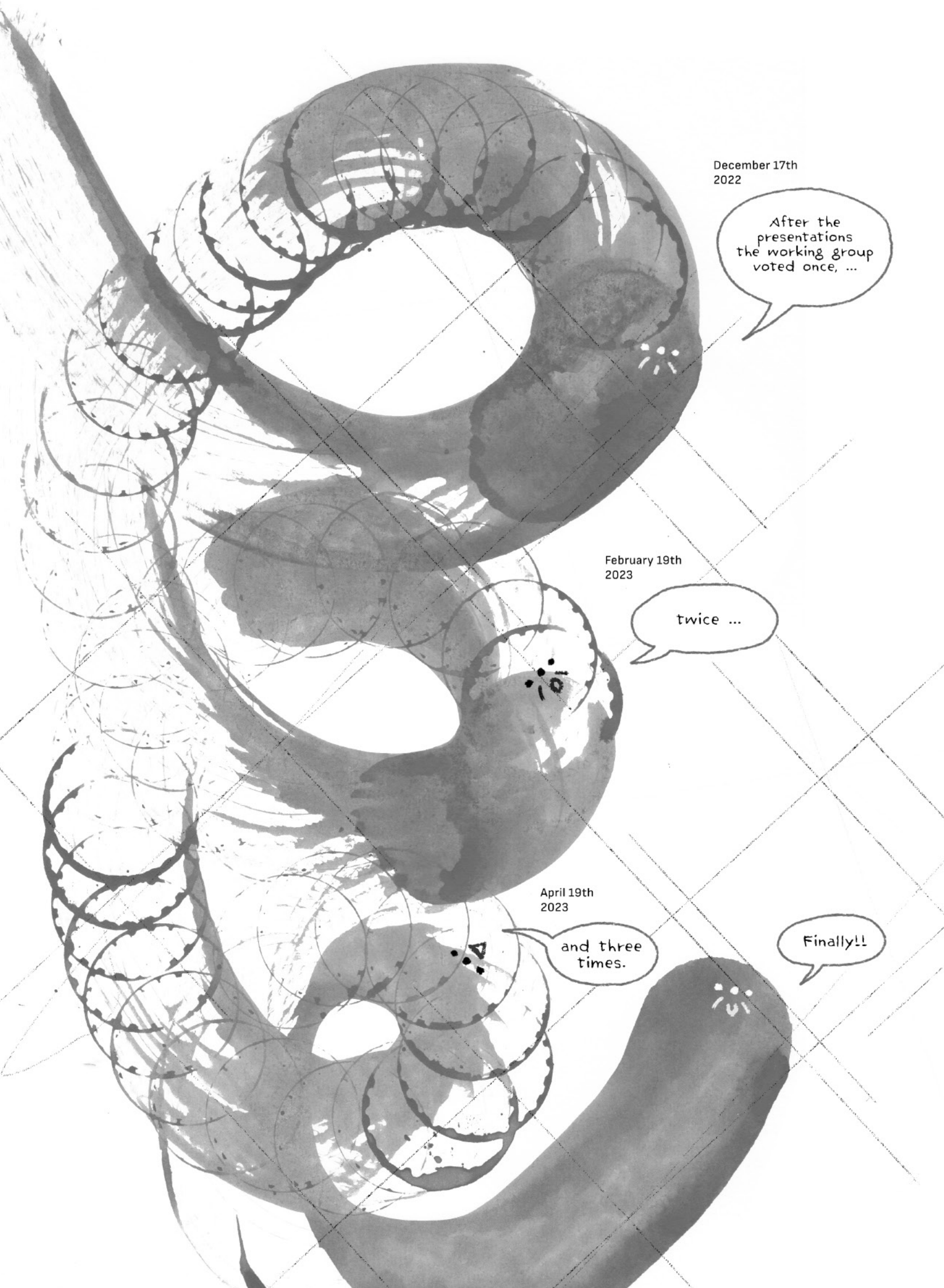


### San Francisco Estuary USA

name – 2019SFB-20A  
length – 230 cm  
time – 70 years







December 17th  
2022

After the presentations the working group voted once, ...

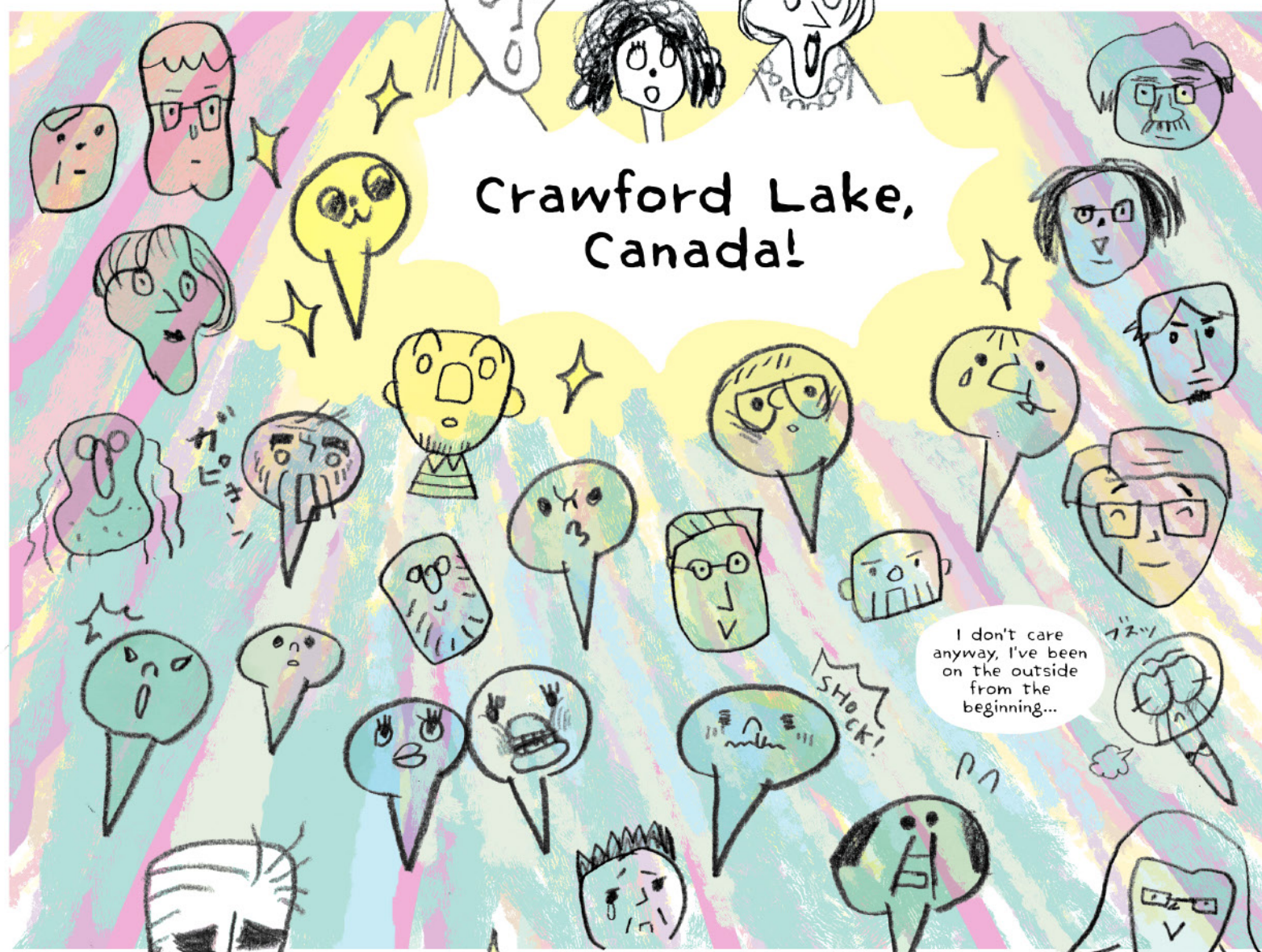
February 19th  
2023

twice ...

April 19th  
2023

and three times.

Finally!!



The proposal needs to be approved by the ICS and ratified by the Executive Committee of the IUGS. They will terminate the Holocene series / epoch and the Meghalayan stage / age respectively, and the Anthropocene will constitute a third series / epoch for the Quaternary System / Period (see page 28).





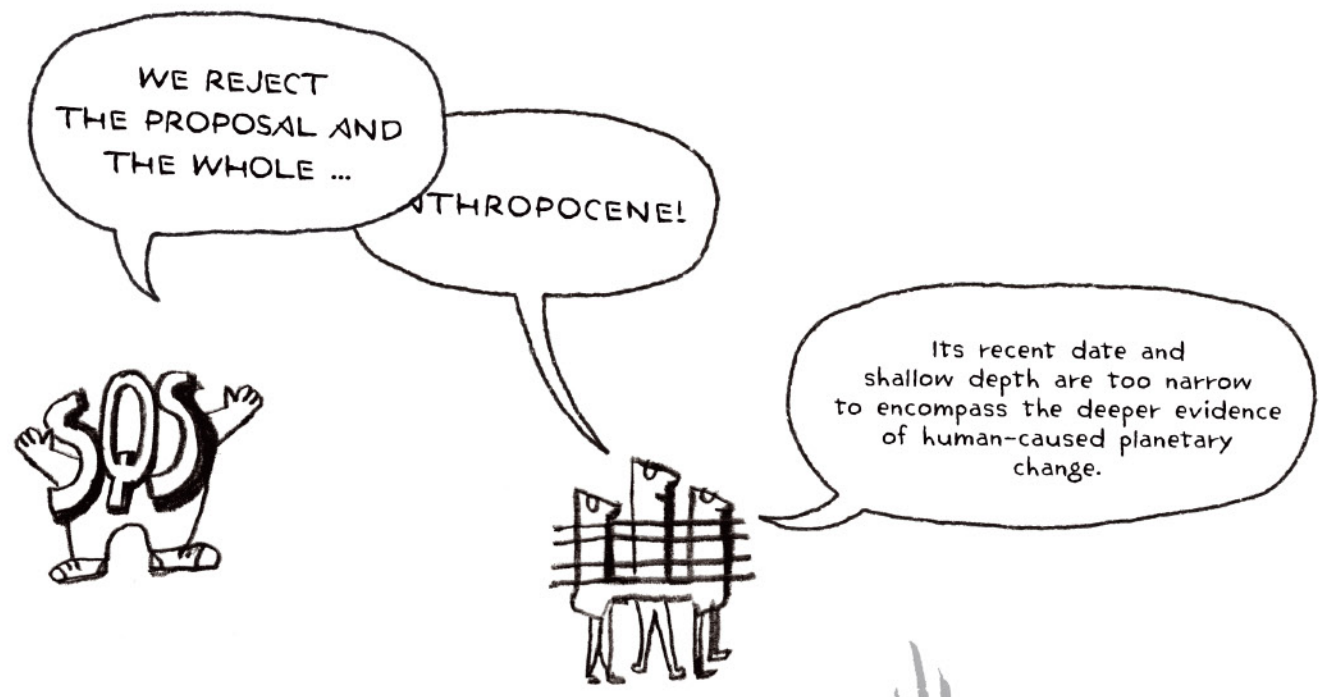
So, what do you think?

Well done!

What do you say, Will?

Paul!  
Good to see you again!





WHAT?!







## IMPRINT

scientific input	Reinhold Leinfelder Freie Universität Berlin, member of the Anthropocene Working Group (based on course lectures on Earth History, Reefs and the Anthropocene and on the scientific work of the Anthropocene Working Group)
concept and storyboard	Alexandra Hamann ( <a href="https://www.mintwissen.com">mintwissen.com</a> )
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graphic designer	Inês Gomes Ferreira
copy editing	Yoko Hamann
in collaboration with	Freie Universität Berlin
copyright	© Hamann, Leinfelder, Shimizu, 2023, 2024
licence	CC BY-NC-ND

Many thanks to

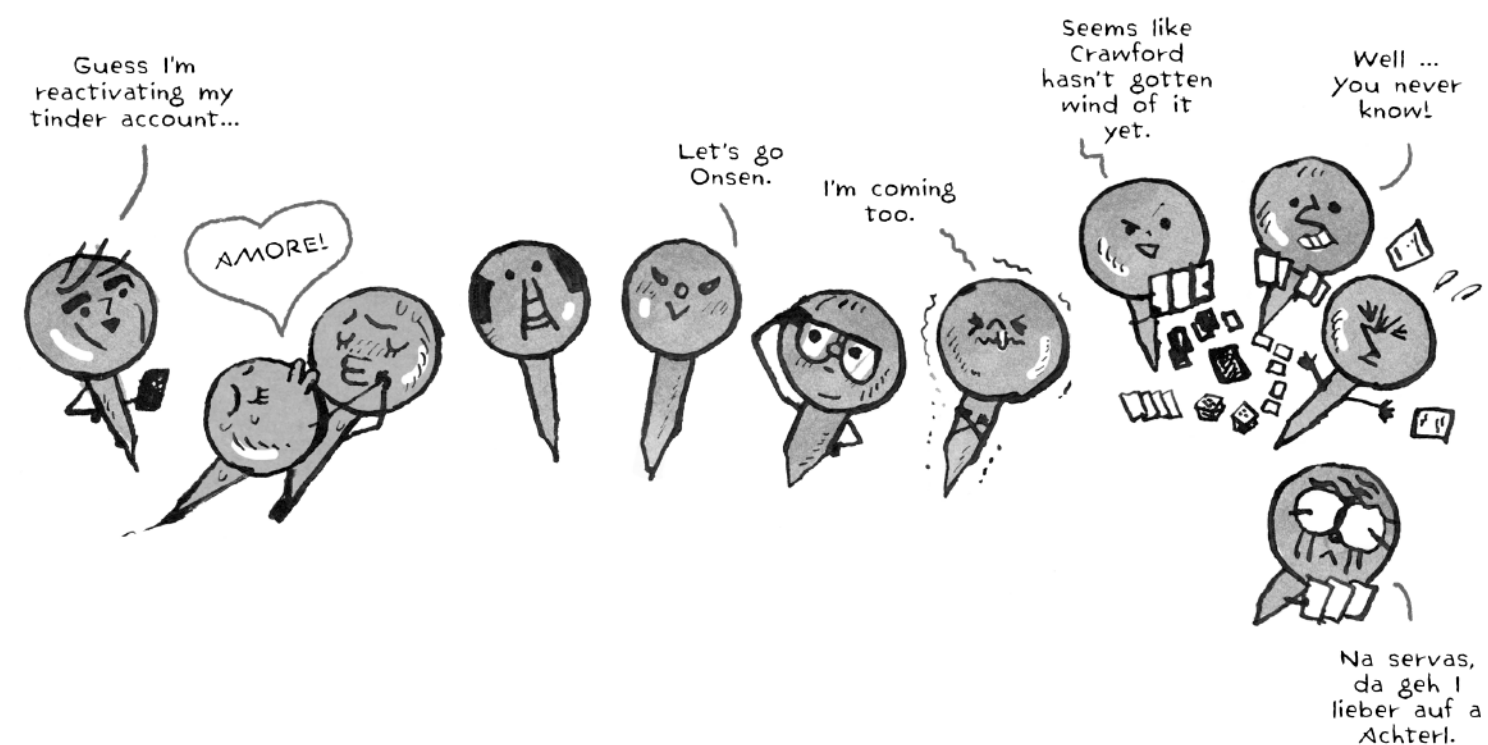
- Marcia Bjornerud (author of the wonderful book „Timefulness: How Thinking Like a Geologist Can Help Save the World“)
- Simon Turner (member of the AWG)
- Colin Waters (member of the AWG)
- Mark Williams (member of the AWG)
- Jan Zalasiewicz (member of the AWG)

Cite this work as:

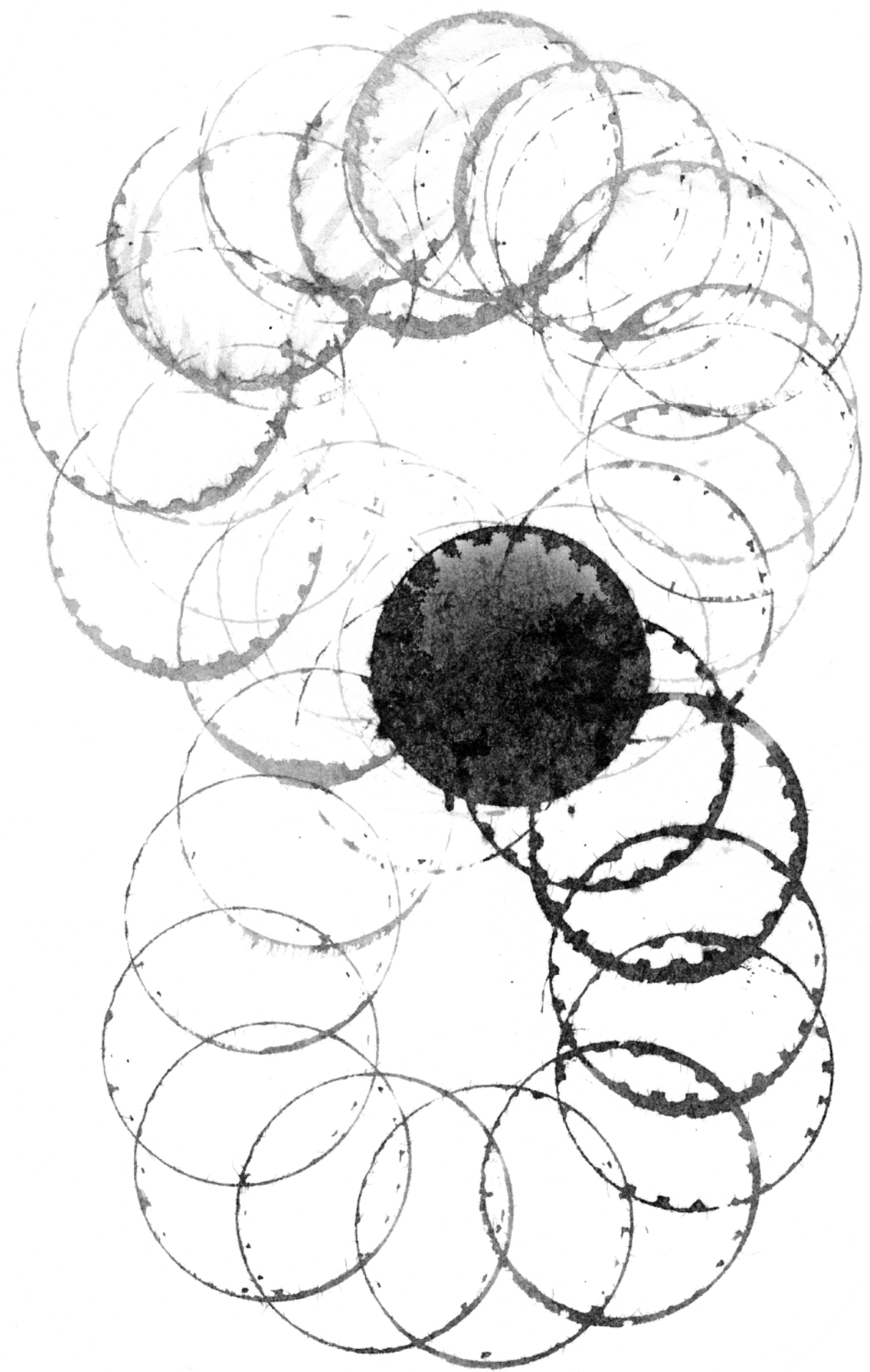
Hamann, Alexandra; Leinfelder, Reinhold; Shimizu, Maki (2024 (2nd ed.): Taming Time. A Golden Spike for the Anthropocene.- Refubium Open Access-Server, Freie Universität Berlin, <http://dx.doi.org/10.17169/refubium-40617.2>

Webpage of the Anthropocene Working Group (AWG) of the International Commission on Stratigraphy (ICS) until March 2024, now available as "Legacy site": <http://quaternary.stratigraphy.org/working-groups/anthropocene/>  
The new website of the AWG will be <http://anthropocene-working-group.org/> (under construction).

For additional information see: <https://tamingtime.de>







# EPILOGUE



TECHNOS' PARADISE

R.I.P.  
❤️  
BIOSPHERE

Buy yourself  
mechanical  
bodies.



Thanks to  
you, we have  
finally become  
independent  
of nature.

We are  
married!

Then you don't  
need anymore  
O<sub>2</sub>, H<sub>2</sub>O,  
Vitamin C....

...  
and dependent  
on me.  
Heheheh!

Wir  
machen  
Kinder!



HUNGER!

!?

No Jobs!

No Money!

BIOS' PARADISE



knead

knead

Zzzzz

What a toxic  
couple!

What do you  
know about  
that?

I hope this doesn't  
turn into a toxic  
throuple!

EARTHLINGS' PARADISE



I LOVE  
YOU!  
Both!!

So do I.

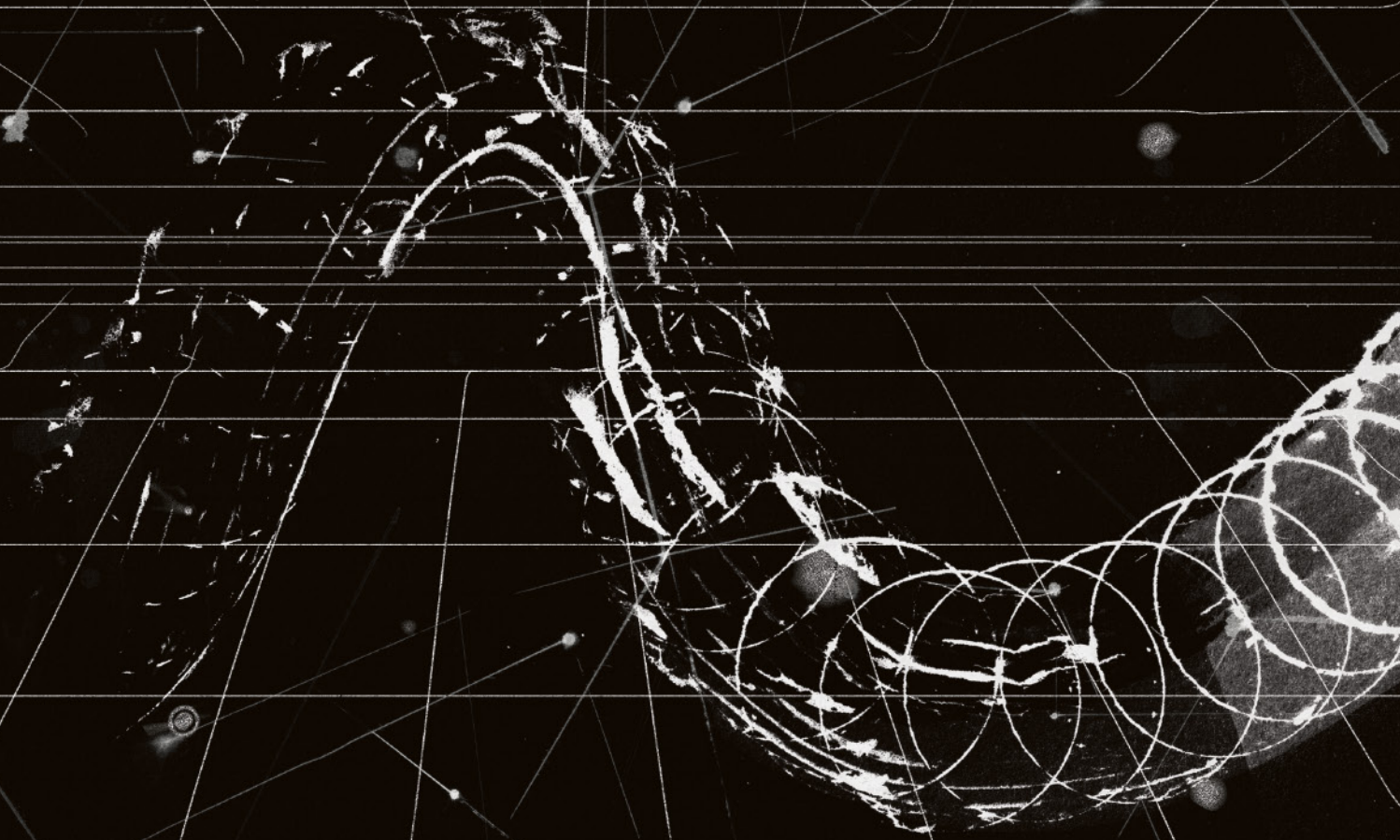
Sorry.  
I don't feel it  
yet ...





Time  
will tell...

La  
yeah, time!  
La La La





# Notes

We are aware of the fact that this science graphic novel uses a lot of scientific terms. We are also sure that our readership has a good digital literacy. Therefore we just list some notes, directly referring to note numbers in the novel. You will not find a full glossary, because term definitions can be easily found in the web. The following notes can also be a stimulus for further personal research.

To dive deeper into the subject, you will find a list of basic scientific literature, largely (but not only) publications of the Anthropocene Working Group, most of which are open access and/or deposited in researchgate.net.

If that still doesn't satisfy, you can get in touch on our blog <https://taming-time.blogspot.com>. We look forward to your comments or questions.

(1) time

In physics, time is one of the fundamental quantities. It runs steadily and inexorably in one direction, from the past into the future. The theory of relativity ties time closely to space to form a „spacetime“ that spans our universe in four equal dimensions, three spatial dimensions and time. Since time is coupled to space, it does not run at same speed, but relatively.

(adapted from Weltmaschine, 7.8.2023: [https://www.weltmaschine.de/physik/fundamentale\\_fragen/zeit](https://www.weltmaschine.de/physik/fundamentale_fragen/zeit)).

In philosophy, time describes a span between two events or the sequence of changes. It is characterised by change (therefore Plato defines it as a „moving image of eternity“) and irrevocability (one cannot go back to the past, except in fiction, or in historical reconstructions, including Earth history). (adapted from <https://www.philomag.de/lexikon/zeit>)

(2) Nicolaus Steno

Nicolaus Steno (1638 – 1686) was a Danish physician, anatomist and naturalist, and later a Catholic priest and bishop. In 1988 he was beatified by Pope John Paul II. With one of his writings Steno laid the foundations of modern geology. However, the work was explosive, because it challenged the previous biblical view of the Earth. for details see e.g. Deutschlandfunk Archiv, 7.8.2023: <https://www.deutschlandfunk.de/vor-350-jahren-druckerlaubnis-fuer-stenos-geologisches-100.html>)

(3) William Smith

William Smith (1769 – 1839) was an English geologist, credited with creating the first detailed, nationwide geological map. His colourful and sophisticated map was based on his astute observation that rock layers (strata) could be identified by the fossils they contain. He noticed that the layers always seemed to appear in the same order and realised it was possible to predict where specific types of rock could be found across the country.

Smith's map and ideas paved the way for a better understanding of geological time and laid the founding principles for geological surveys worldwide. His concept of using fossils to identify rocks is still very important today. (Natural History Museum London, <https://www.nhm.ac.uk/discover/first-geological-map-of-britain.html>)



#### (4) Arthur Holmes

Arthur Holmes (1890 – 1965) was an English geologist who made two important contributions to the development of geological ideas: the use of radioactive isotopes for dating minerals and the suggestion that convection currents in the mantle play an important role in continental drift. He held the chair of geology at Edinburgh University from 1943 until 1956. (Geological Society of Glasgow, 7.8.2023: <https://geologyglasgow.org.uk/arthur-holmes>)

#### (5) Clair Cameron Patterson

Clair Cameron Patterson (1922 – 1995) was an American geochemist whose pioneering work stretched across an unusual number of sub-disciplines, including archaeology, meteorology, oceanography, and environmental science. He is best known for his determination of the age of the Earth. That was possible only after he had spent some five years establishing methods for the separation and isotopic analysis of lead at microgram and sub-microgram levels. His techniques opened a new field in lead isotope geochemistry for terrestrial as well as for planetary studies. Whereas terrestrial lead isotope data had been based entirely on galena ore samples, isotopes could finally be measured on ordinary igneous rocks and sediments, greatly expanding the utility of the technique. (Clair Cameron Patterson, Biographical Memoir, Copyright 1998 National Academies Press Washington D.C.)

#### (6) GSSP

Global Boundary Stratotype Sections and Points (GSSPs) are reference points on stratigraphic sections of sedimentary rocks which define the lower boundaries of stages on the International Chronostratigraphic Chart. The Chart is issued by the International Commission on Stratigraphy ICS, the largest body of the International Union of Geological Sciences (sometimes also ironically called “the United Nations of the Geologists”). Since 1977, the ICS has maintained the international GSSP register. (for more see webpage of ICS: <https://stratigraphy.org/gssps/>).

The official guidelines of ICS specify that, to formalize a geological time period in the Earth’s history, a geological reference site must first be identified, described, and internationally agreed upon. These GSSPs are physically marked with a “Golden Spike” (see note 7) and have to be permanently accessible to researchers, either in the field or if defined in drillcores, in special scientific collections.

This is similar to the official process that takes place for defining new types of organisms in the field of biology. Here, a reference specimen of an organism – a ho-

lotype – is permanently preserved in a scientific collection and made available for all scientists. It is often stored together with its paratypes in order to demonstrate the variety of a species. In geology, this reference example is the GSSP. (Chronicle of a Catastrophe Foretold, FU Berlin, 14.8.23: <https://www.fu-berlin.de/en/featured-stories/campus/2023/anthropocene-crawford-lake/index.html>)

#### (7) Golden Spike

The term “Golden Spike” was borrowed from a specific chapter in railway history, namely the completion of the first transcontinental railroad across the United States. It was decided to complete the last link in the transcontinental railroad with a spike made of gold. After such a difficult construction process, the spike was a celebration of the railroad’s completion. The Golden Spike National Historic Park commemorates this event.

In geology, the lower boundaries of all ages defined with a GSSP are also marked with a Golden Spike. If the section site allows, a Golden Spike may be even hammered in the outcrop or – if the GSSP-Section is based on a drill core, is marked there with a small nail (see [stratigraphy.org](http://stratigraphy.org) for more)

#### (8) Chronostratigraphic chart of ICS

The chronostratigraphic chart is a table in which all geologically determined time-units of the Earth history are drawn, from the formation of the Earth about 4.5 billion years ago until today. This is important for all geologist, be them in China, Brasil, Germany or wherever, to understand the same of e.g. the Toarcian or the Anthropocene. If not, no exact interpretation of geological and biological processes having run at these time episodes would be possible. See also note on GSSP (6) The Chronostratigraphic Chart always shows two terms for each column, such as System/Period, Series/Epoch, Stage/Age. The first term relates to the sediment succession, the second term to the time interval.

The Chronostratigraphic Chart is issued by the ICS (International Commission on Stratigraphy) which is part of the IUGS (International Union of Geological Sciences). The ICS is the only body concerned with stratigraphy on a global scale for the whole geological column. Its most important major objective is the establishment of a standard, globally-applicable stratigraphical scale, which it seeks to achieve through the co-ordinated contributions of a network of Subcommissions and Working Groups with a specific, limited mandate. (see [stratigraphy.org](http://stratigraphy.org) for more)



#### (9) 2-valent iron, 3-valent iron

Chemical elements can give away electrons or take additional ones to achieve a full set of electrons (mostly 8) in their outer orbital electron shell to be in a more stable condition. Iron likes to give away electrons, hence is an electron donor. A 2-valent iron atom donated two electrons, a 3-valent iron three electrons. These electrons are used by other elements or compounds which are in need of additional electrons to fill up their outer orbital electron shell, such as oxygen or sulfur which are electron acceptors. Oxygen has a negative valency of 2, and is therefore very keen to receive 2 electrons to be more stable (which is also expressed as its high oxidation potential). The mineral  $\text{Fe}_2\text{O}_3$  has iron in its positive 3-valent form and oxygen in its preferred, hence negative 2-valent form ( $2\text{Fe}^{3+} + 3\text{O}^{2-}$ ). Owing to its red colour it is called hematite ("blood stone") when found as a natural mineral.  $\text{FeO}$  ( $\text{Fe}^{2+} + \text{O}^{2-}$ ) contains 2-valent iron and is not very stable, since its iron would prefer to donate another electron.

Rust is a corrosion product of iron caused by oxygen and water, and consists of a mixture of iron oxides and iron hydroxides with 2 and 3-valent iron.

#### (10) calcifying organisms

Biogenic calcification, the formation of calcium carbonate by living organisms, is performed by a wide range of marine invertebrate taxa, normally as an outer layer (an exoskeleton). Echinoderms (e.g. sea urchins, starfish, feather stars), squids, some sponges, and especially vertebrates have endoskeletons. The shells and skeletons produced by calcifying organisms do not only have vital functions for the physiology and ecology of their producers (such as stabilisation, protection, facilitating upwards growth), they also play a key role in biogeochemical cycling, e.g. as ballast for sinking particulate matter in calcareous plankton, transporting carbon and alkalinity to depth via the biological pump, or as an enormous carbon deposits within biogenic limestones produced by coral reefs and other organisms, such as lagoonal calcifying green algae, oysters etc.. (adapted from Geomar, 7.8.2023: <https://www.geomar.de/en/research/fb2/fb2-bi/research-topics/biogenic-calcification>)

#### (11) producer-consumer-interaction

Relationship between producers and consumers: a producer is an organism, such as a plant, that can harness the sun's energy to produce food through the chemical reaction known as photosynthesis. A consumer is one that consumes, or eats, this food. Several levels of consumers can be differentiated, especially primary (herbivores), secondary (herbivores, omnivores, carnivores), tertiary (omnivores, carni-

vores), and quaternary consumers (carnivores, incl. top predators), with secondary consumers eating up primary ones, etc. Of particular importance are also detritivores and decomposers. Detritivores, such as earth worms, wood lice or sea cucumbers ingest and digest dead organic matter whereas decomposers, such as fungi or certain bacteria directly absorb nutrients from organic substrates through external chemical and biological processes. Detritivores and especially decomposers are the key to the circular natural metabolism of the biosphere, with the energy for that being delivered by the sun and stored by the primary producers

#### (12) ecosystem

An ecosystem is a geographic area where plants, animals, and other organisms, as well as weather and landscapes, work together to form a bubble of life. (National Geographic Education, 7.8.2023: <https://education.nationalgeographic.org/resource/ecosystem/>)

#### (13) biosphere

The biosphere is the part of the Earth inhabited by living organisms, extending from deep root systems of trees to the life in ocean trenches, to coral reefs, rain forests and high mountain tops. It is closely interlocked and in constant interaction with other spheres of the Earth system such as the hydrosphere (water), the air (atmosphere), the soils (pedosphere) and also the Earth's crust (upper part of the lithosphere). Also see note 11, 12, 14

#### (14) biomass

Biomass quantifies the mass of living biological organisms in a given area or ecosystem at a given time. It is generally expressed as weight (g, kg, t etc), but it is important to see which biomass category is used: Living biomass is similar to wet biomass and includes the water content of organism or organic parts. Dry biomass is without water, and is more suited to compare different groups of organisms, since depending on type, their water content is quite different. If plants and animals are compared, the carbon based biomass may be used (sometimes also referred to as energetic biomass). C-biomass not only is suited for biomass comparisons between different groups of organisms, but since it does not take the rapidly degradable parts of the living organisms into account, it also is helpful in directly comparing the productivity of the biosphere and the technosphere (see 15), because the carbon content of living matter is the part that is conservable in Earth history, e.g. forming



coal, crude oil or natural gas.

Please note that biomass assessments use different methods, with slightly different results.

#### (15) technosphere

The technosphere includes the totality of human-produced technological infrastructures: machines, factories, computers, appliances, buildings, mobility and communication etc., as well of materials having to be used or removed for that. The term was introduced into General Systems Theory in the late 1960s by Canadian control engineer John H. Milsum (1925–2008). Milsum argued that the technosphere is distinct from other spheres of the Earth system, including the social sphere formed by all humans. (University of Vienna, 7.8.2023: <https://anthropocene.univie.ac.at/resources/technosphere/>), Later, geoscientist Peter Haff (Member of the AWG) saw technology as a geological phenomenon (Haff 2013). He also extended the definition of the technosphere by encompassing all the physical properties of a human-technological system that takes on a role equivalent to the biosphere or hydrosphere, hence including anthropogenically altered soils, sea-floors, and new plant or animal breeds. According to the AWG (Zalasiewicz et al. 2017, doi:10.1177/2053019616677743), the present weight of the technosphere is about 30 Teratons (which is a 3 with 13 zeros), from which today only 1,1 Teratons (1 Tt) is in use, the rest is in the environments. Wet (living) biomass of all organisms only amounts to 2,3 Tt (calculated as dry biomass would be 1,1 Tt, calculated as C-based biomass would be 0,5 Tt) (see Leinfelder 2022, also for other literature).

#### (16) Paul Crutzen

Paul Crutzen (1933 – 2021) was a Dutch meteorologist and atmospheric scientist. He was Director at the Max Planck Institute for Chemistry in Mainz, Germany, from 1980 to 2000 and received the Nobel Prize in Chemistry in 1995 for his research on the ozone hole. (Wikipedia, 8/7/2023)

Paul Crutzen coined the term „Anthropocene“: he intended it to describe the current era in which humans have become one of the most important factors in atmospheric, biological and geological processes on Earth, permanently reshaping the evolution of the planet. He was a member of the AWG until his death. Paul Crutzen himself said of the scientific and social debate that followed his proposal for the term Anthropocene: „I see the debate as an opportunity to come to a much-needed ecological reorientation.“ (Max-Planck-Gesellschaft, 7.8.2023: <https://www.mpg.de/trauer-um-paul-crutzen>)

#### (17) SQS

The Subcommission on Quaternary Stratigraphy (SQS) is a constituent body of the International Commission on Stratigraphy (ICS), dealing with the definition of the chronostratigraphic units of the Quaternary, which so far includes the epochs of the Pleistocene (the last glacials and interglacials) and the Holocene (postglacial), and which might now be followed by the Anthropocene. (See also note 8 on ICS)

#### (18) AWG

The Anthropocene Working Group is an interdisciplinary expert research group for investigation of the Anthropocene proposal. It was established in 2009 by the Subcommission on Quaternary Stratigraphy (SQS). Its major task is to advise the SQS/ICS as to the geological reality of a supposed Anthropocene and how to best define it following the standard rules of ICS (<https://www.anthropocene-curriculum.org/contributors/anthropocene-working-group>, see also <http://quaternary.stratigraphy.org/working-groups/anthropocene/>)

#### (19) The great acceleration

The Great Acceleration is a term used to describe the rapid and widespread increase in human activity and its impact on Earth's natural systems, which began around the mid-20th century. The Great Acceleration encompasses various social, economic, and environmental changes that have occurred on a global scale since the 1950s. (<https://globaia.org/acceleration>)

#### (20) stratigraphic marker

Stratigraphic markers are stratigraphically relevant “geosignals” such as stratigraphically significant fossils and other sediments with special characteristics of sediment succession that can be related to synchronous events, hence allowing “event stratigraphy”. They include seasonal sediment layers, e.g. in lakes, black shale layers (caused by deoxygenation collapse), storm layers (turbidites) and gravity flows (turbidites, often caused by major earthquakes, and ash layers from volcanic eruptions. Other markers can be provided by geochemical signals such as the Iridium layer caused by the asteroid impact at the Cretaceous–Paleogene boundary, or the radioactive fallout from atomic bomb testing in the Anthropocene. As to the Anthropocene, many other geosignals, such as the great array of “technofossils” (e.g. plastic, concrete, brick fragments, industrial spheroidal carbonate particles), geochemical signatures from agricultural and other products, but also occurrences of neobiota (see note 21) etc., add to the markers.



# Literature

Other proxies such as paleomagnetism signals, sequence stratigraphy (identifying characteristic, time-correlatable sequences of sea level change) etc. can be used as well.

Stratigraphic markers normally only allow the identification of “relative” age. Only in certain cases they are datable with absolute ages, mostly using decay process characteristics of unstable isotopes.

Clear markers not only facilitate the chronostratigraphic correlation but also permit the geological mapping.

In order to ensure its acceptance and use in the Earth sciences, a boundary strato-type should contain as many specific marker horizons or other attributes as possible favorable for long-distance correlation.

## (21) neobiota

Neobiota are animal or plant species that have been carried from their area of origin to other areas by intentional or unintentional human influence and do not naturally occur there. They are sometimes also called “invasive species”.

Human trade and transport play an important role in the introduction of neobiota. The discovery of the Americas in 1492 and the transcontinental trade that intensified enormously with it, was set as the „cut-off date“ for the introduction of neobiota (neozoa: „new animals“) and neophyta „new plants“.

## (22) Dead Zones

Dead zones are low-oxygen, hypoxic or anoxic, areas in the world’s oceans and lakes. Because most organisms need oxygen to live, few organisms can survive in hypoxic and anoxic conditions. Dead Zones can be seasonal, with summer heat stopping turnover of deeper waters, but also permanent (e.g. at the bottom of the Black Sea). Climate change towards warmer temperatures and overnutrification also leads to eutrophication and accelerates the spreading and persistency of Dead Zones both in the seas and in terrestrial lakes.

## Time, time chart, history of geology, stratigraphie, Earth history, Earth system changer

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- Johnson, C., Affolter, M.D., Inkenbrandt, P. & Mosher, C., *Absolute Dating*, Salt Lake Community College via OpenGeology, <https://geo.libretexts.org>
- Chronostratigraphic Chart: <https://stratigraphy.org/chart>
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## Neolithic, industrialization, technosphere, energy, biomass

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## IUGS/ICS refusal of the AWG Proposal

### Selection of media articles and other statements

- 5 March 2024: The New York Times, Are We in the 'Anthropocene,' the Human Age? Nope, Scientists Say. <https://www.nytimes.com/2024/03/05/climate/anthropocene-epoch-vote-rejected.html>
- 6 March 2024: Austria Presse Agentur & German Press Agency (APA/DPA), Rückschlag für „Anthropozän“ als neues Erdzeitalter. <https://science.apa.at/power-search/4568049296671746975>
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- 19 March 2024: Riffreporter, Nach Beschwerden über Unregelmäßigkeiten: Anthropozän-Vorstoß endgültig gescheitert, <https://www.riffreporter.de/de/artikel/streit-um-das-anthropozen-fuehrende-stratigraphen-lehnen-neue-erdepoche-endgultig-ab>
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- 18 April 2024: Smithsonian Magazine, What Myths About the Anthropocene Get Wrong ( Zalasiewicz, J., Wing, S. & The Anthropocene Working Group). [smithsonianmag.com/smithsonian-institution/what-myths-about-the-anthropocene-get-wrong-180984181/](https://smithsonianmag.com/smithsonian-institution/what-myths-about-the-anthropocene-get-wrong-180984181/)
- 8 May 2024: New Scientist, Why criticisms of the proposed Anthropocene epoch miss the point (Zalasiewicz J. & members of The Anthropocene Working). [newscientist.com/article/mg26234900-100-why-criticisms-of-the-proposed-anthropocene-epoch-miss-the-point/](https://www.newscientist.com/article/mg26234900-100-why-criticisms-of-the-proposed-anthropocene-epoch-miss-the-point/)
- 24 May 2024: Campus Leben, das Online-Magazin der Freien Universität Berlin: Hat das Anthropozän noch eine Chance? Geologie-Professor Reinhold Leinfelder im Gespräch über das Ausrufen eines neuen Erdzeitalters. <https://www.fu-berlin.de/campusleben/forschen/2024/240524-leinfelder-anthropozoen/index.html>
- Also see various blogpost articles in Der Anthropozäniker (Spektrum.de/Scilogs) by Reinhold Leinfelder on the case (partially with English versions) from 6 March onwards (also for additional media articles and other AWG statements): <https://scilogs.spektrum.de/der-anthropozoeniker/>

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