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.

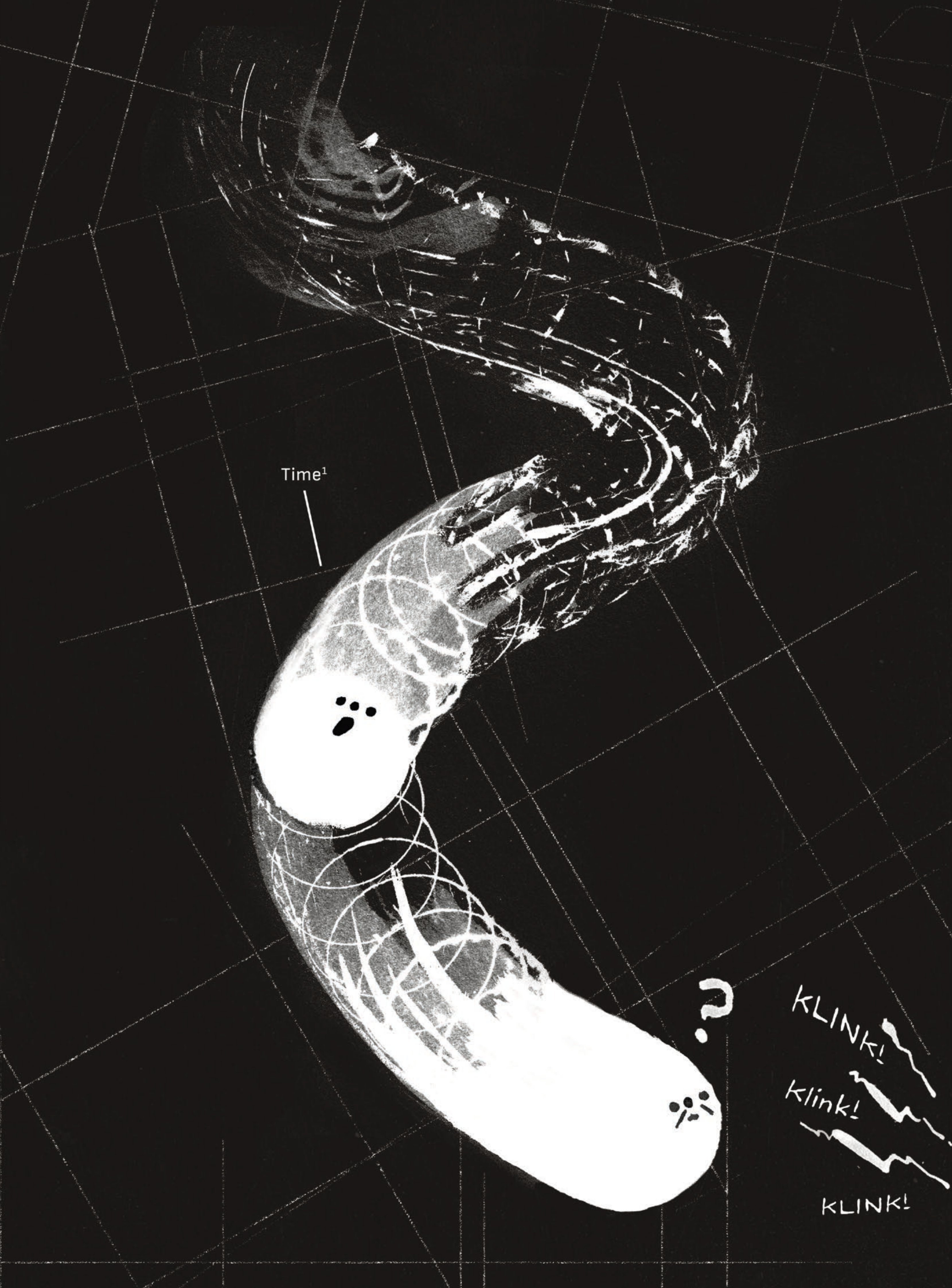
Now a new age is being established, the Anthropocene.
Who is doing this and why are they doing it? How are time periods defined and what distinguishes them from another? How can this process help us develop a deep understanding of the world we live in so that we can create a sustainable and just future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

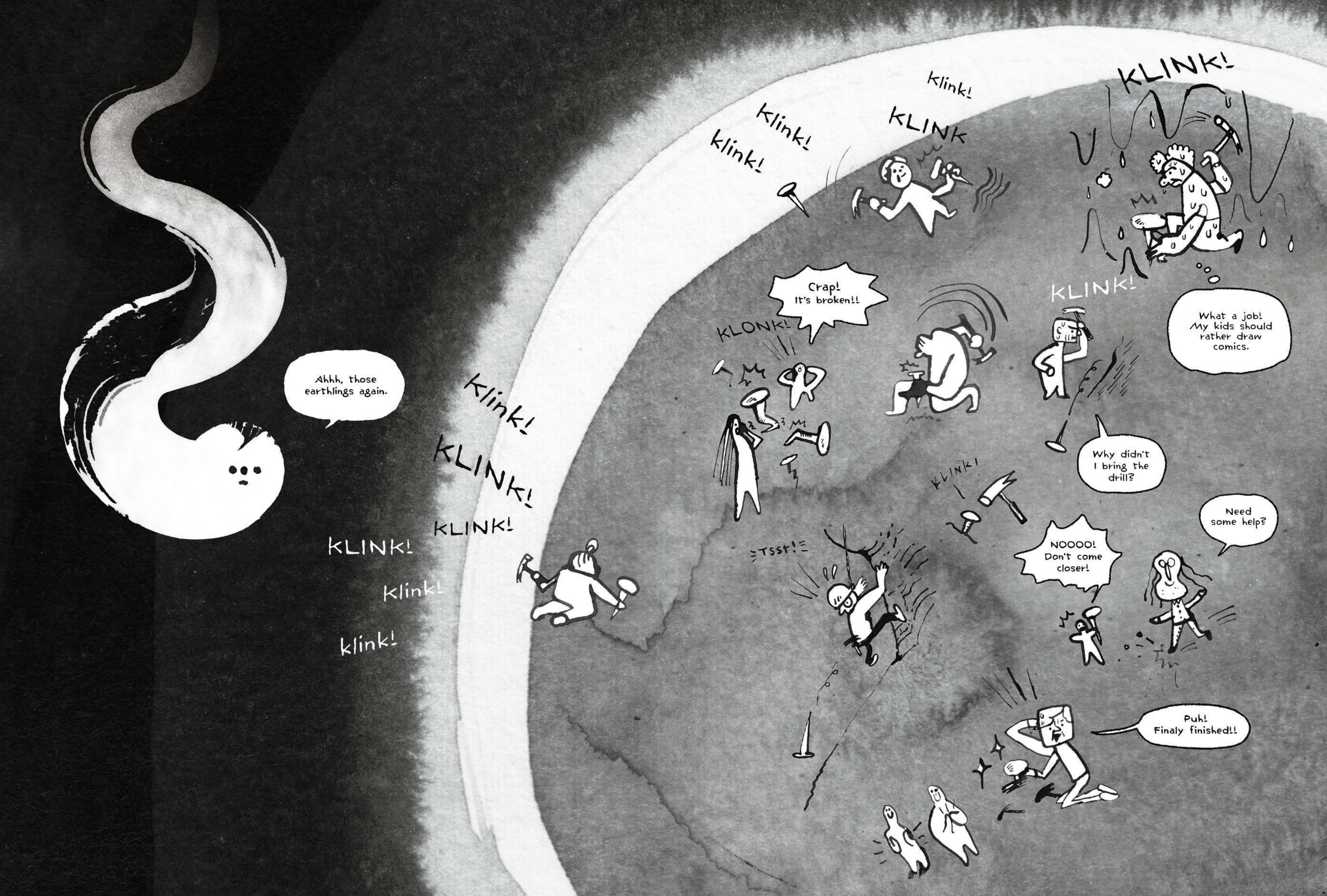
We will try to answer these question here, but there is one thing that can be said already: We can't change the past, but the future lies in our hands.

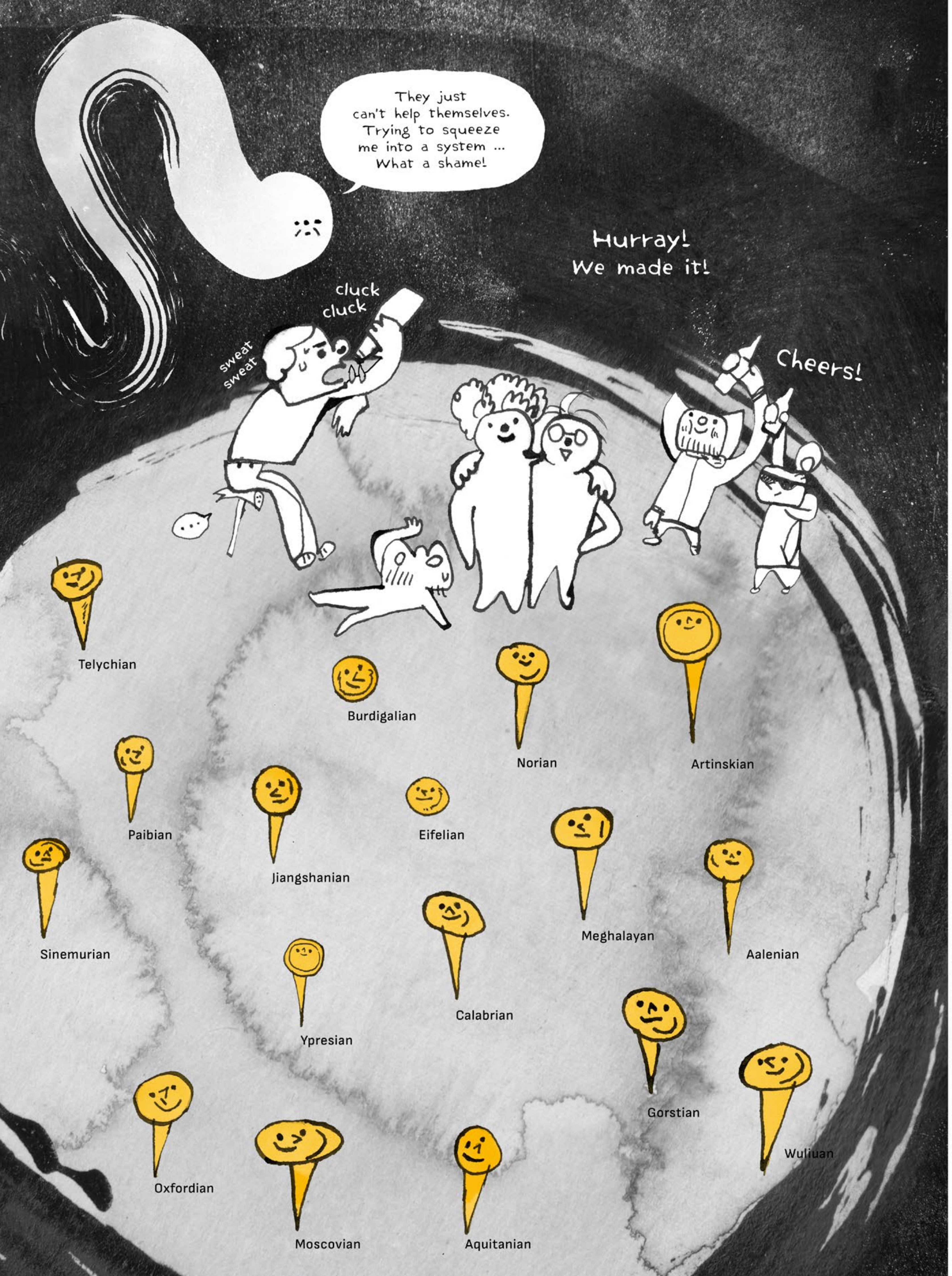
Alexandra Hamann and
Reinhold Leinfelder

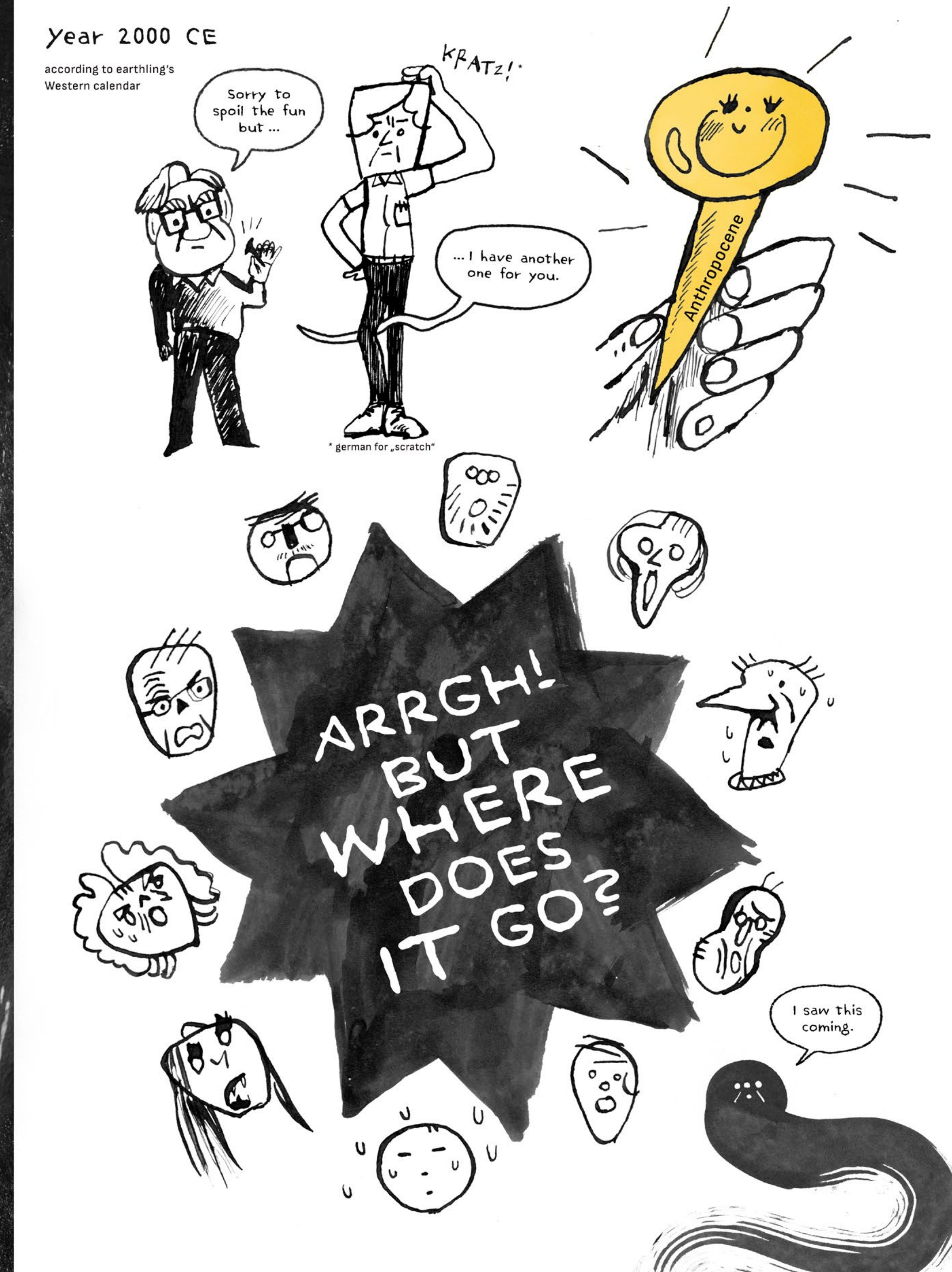
The content of this science graphic novel is largely based on University course lectures and research on the Anthropocene by Reinhold Leinfelder at Freie Universität Berlin and his membership work within the Anthropocene Working Group.

PREFACE

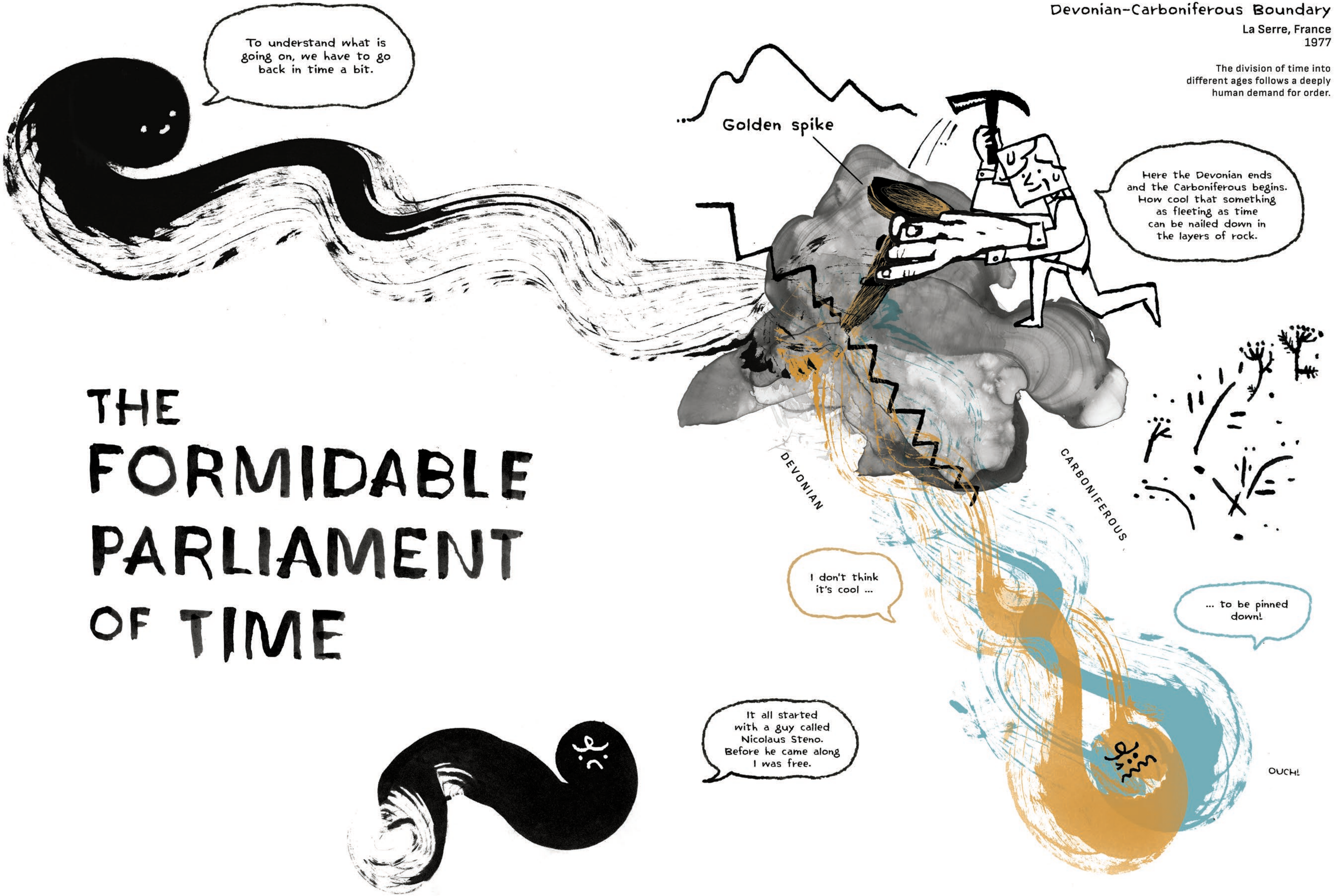



Ahhh, those earthlings again.
klink!
KLINK!
KLINK!
KLINK!
klink!
klink!
klink!
klink!
klink!
KLINK
KLINK!
Crap! It's broken!!
KLONK!
KLINK!
What a job! My kids should rather draw comics.
Why didn't I bring the drill?
KLINK!
Need some help?
NOOOO! Don't come closer!
TSST!
Puh! Finaly finished!!


They just can't help themselves. Trying to squeeze me into a system ... What a shame!
Hurray! We made it!
cluck cluck
sweat sweat
Cheers!
Telychian
Burdigalian
Norian
Artinskian
Paibian
Eifelian
Jiangshanian
Sinemurian
Meghalayan
Aalenian
Calabrian
Ypresian
Gorstian
Wuliuan
Oxfordian
Moscovian
Aquitanian


Year 2000 CE
according to earthling's Western calendar
Sorry to spoil the fun but ...
KRATZ!*
... I have another one for you.
Anthropocene
* german for „scratch"
ARRGH! BUT WHERE DOES IT GO?
I saw this coming.

THE FORMIDABLE PARLIAMENT OF TIME



Tuscany
1667 AD*

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

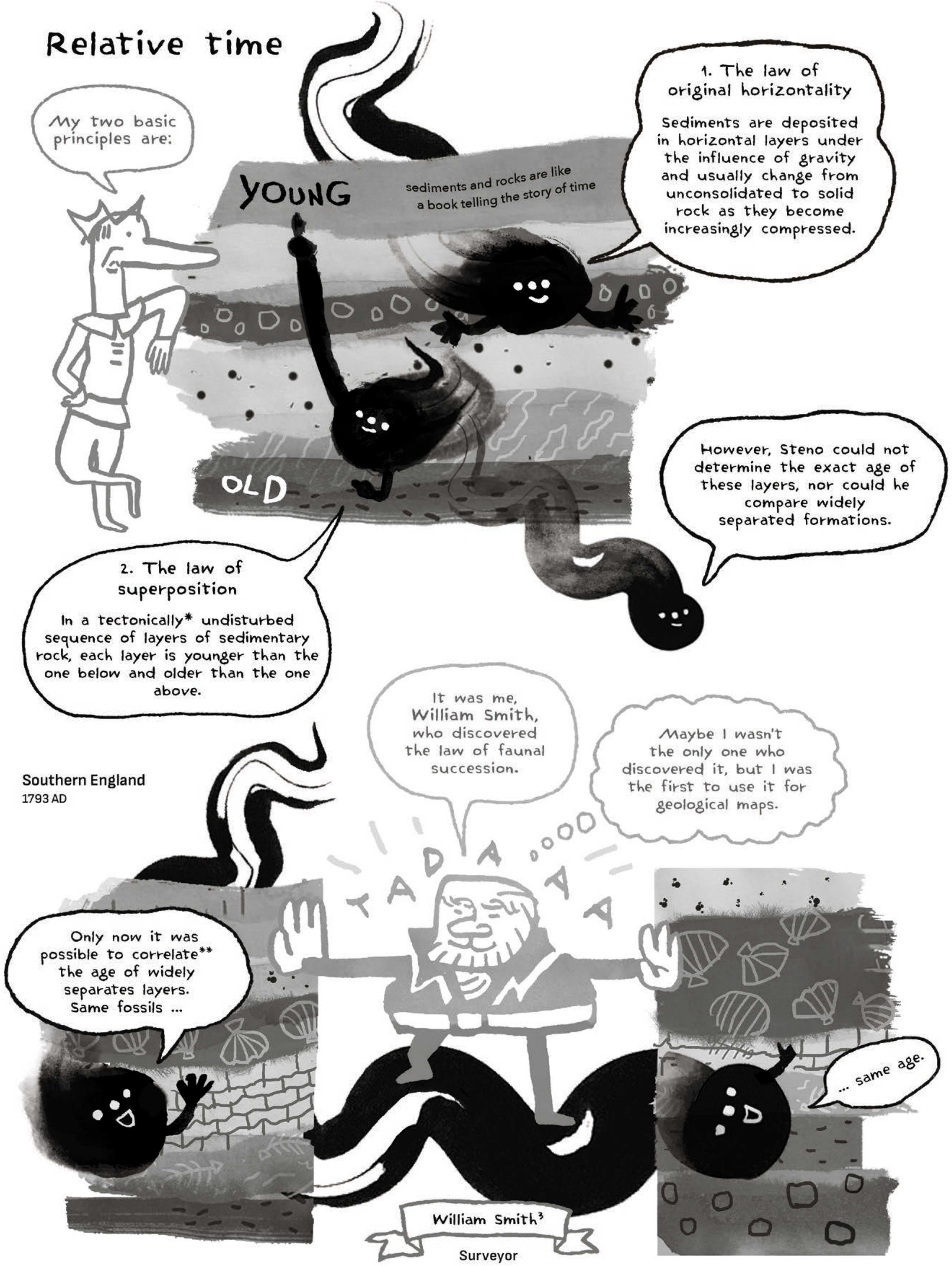
* AD: Anno Domini (after Christ was born)
* BC: before Christ

Universal scholar and Catholic priest
1638 – 1686

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

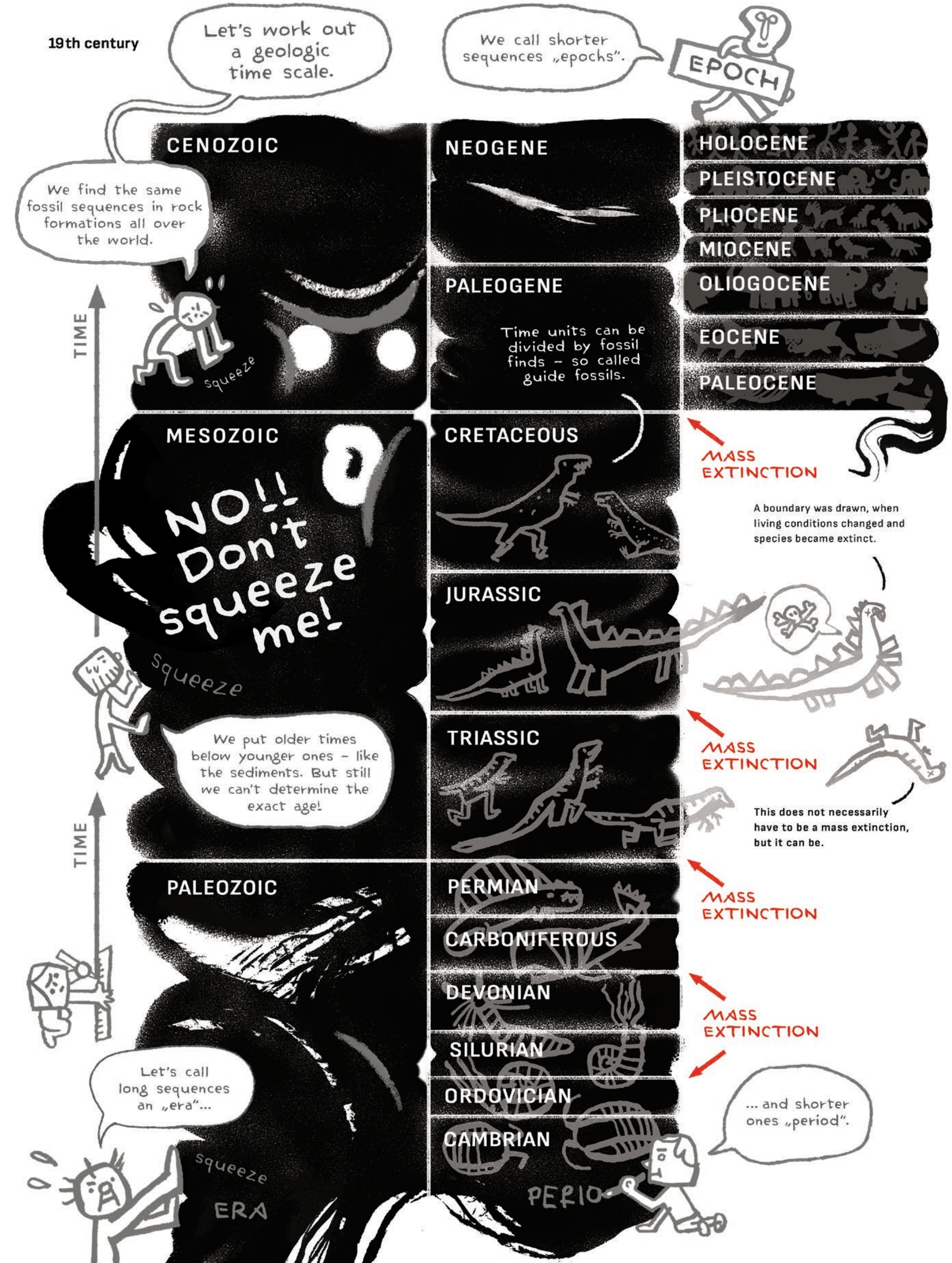
** ***Appeninnes:*** moiuntain range in Italy

Relative time

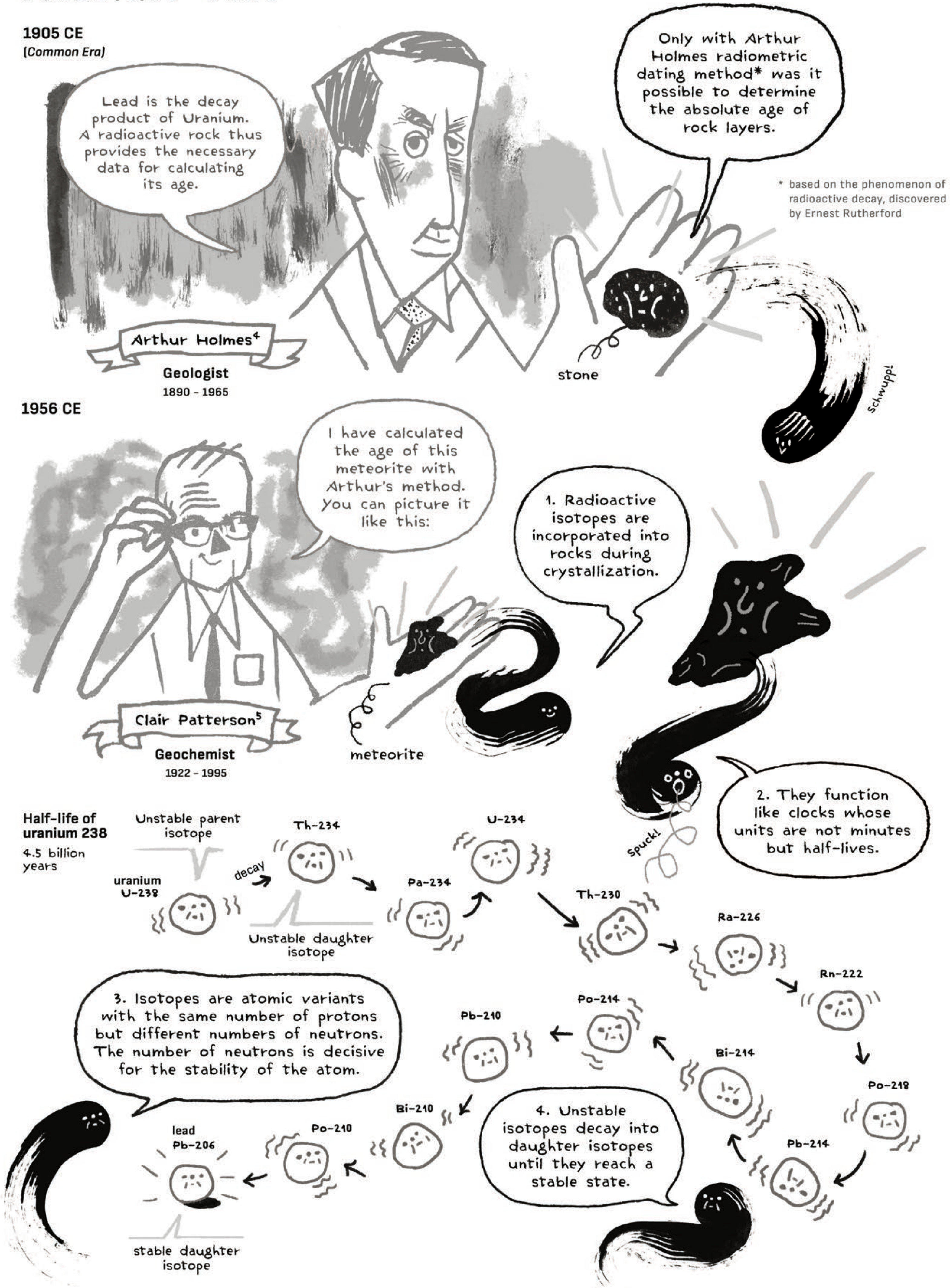


* In geology, *tectonics* describes the structure and large-scale movement of the Earth's crust.

** *correlate*: In geology, the term correlation refers to the methods by which the age relationship between various strata of Earth's crust is established.



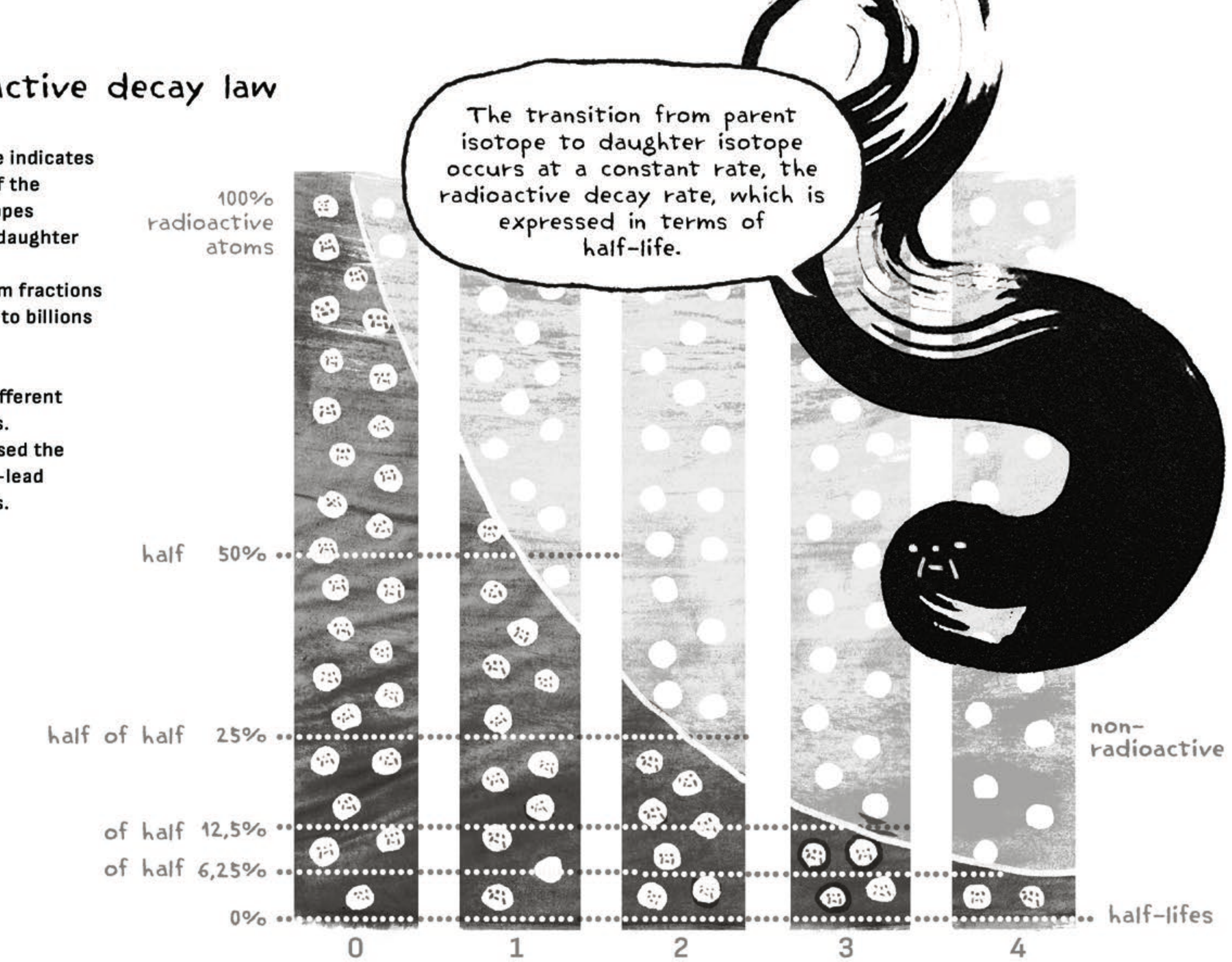
Absolute time

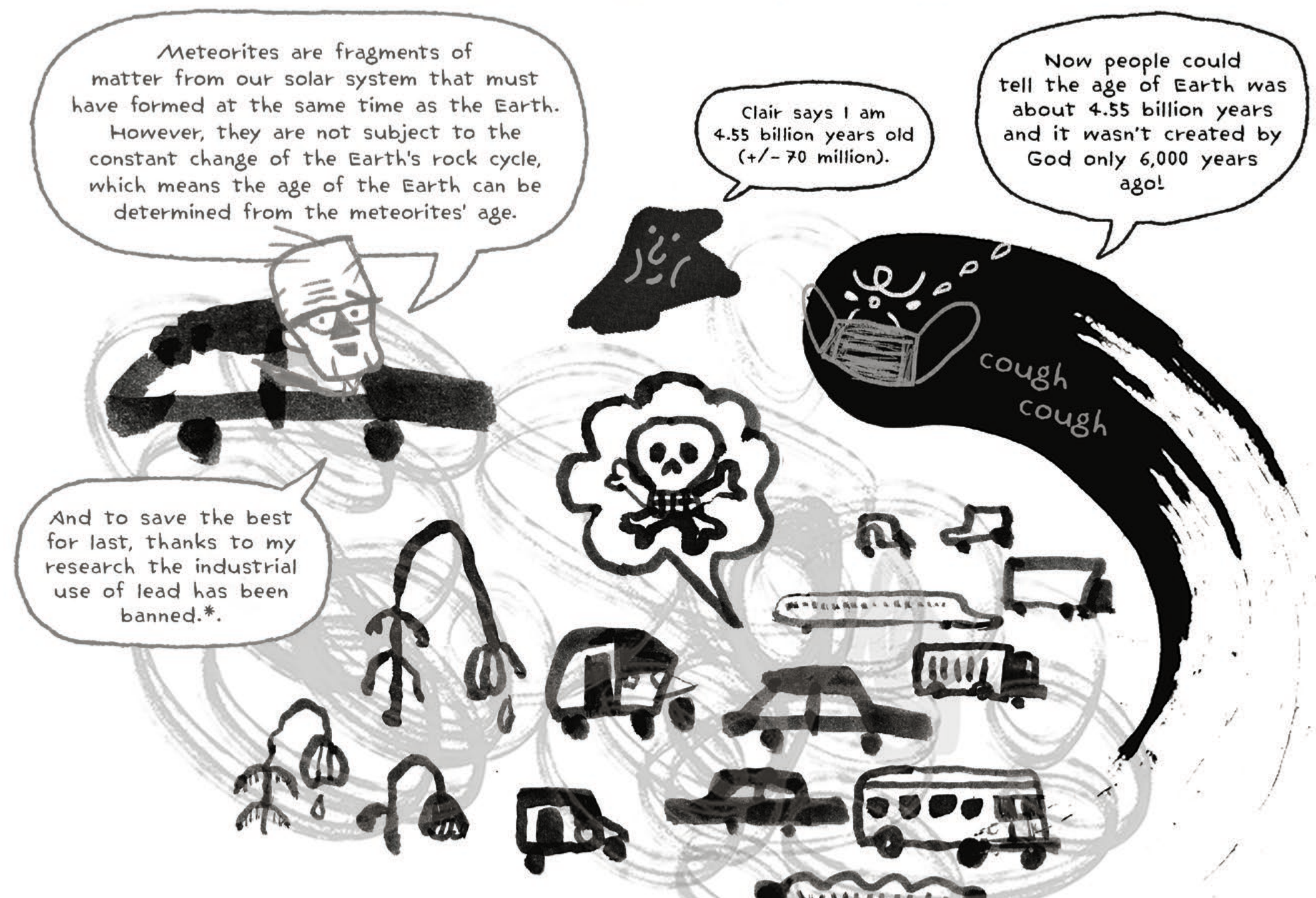


Radioactive decay law

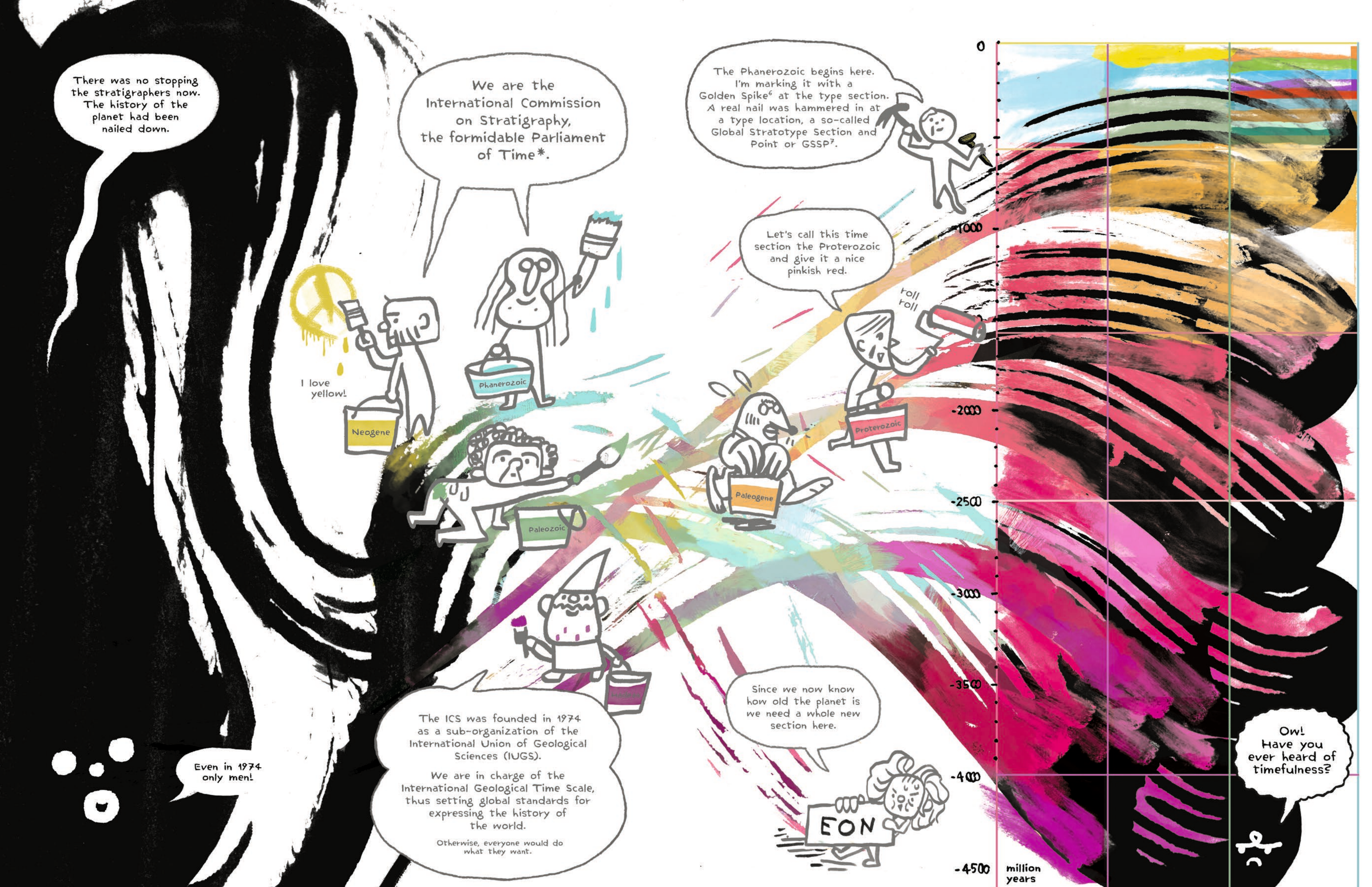
The half-life indicates when half of the parent isotopes decayed to daughter isotopes.
It varies from fractions of a second to billions of years.

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





*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%)

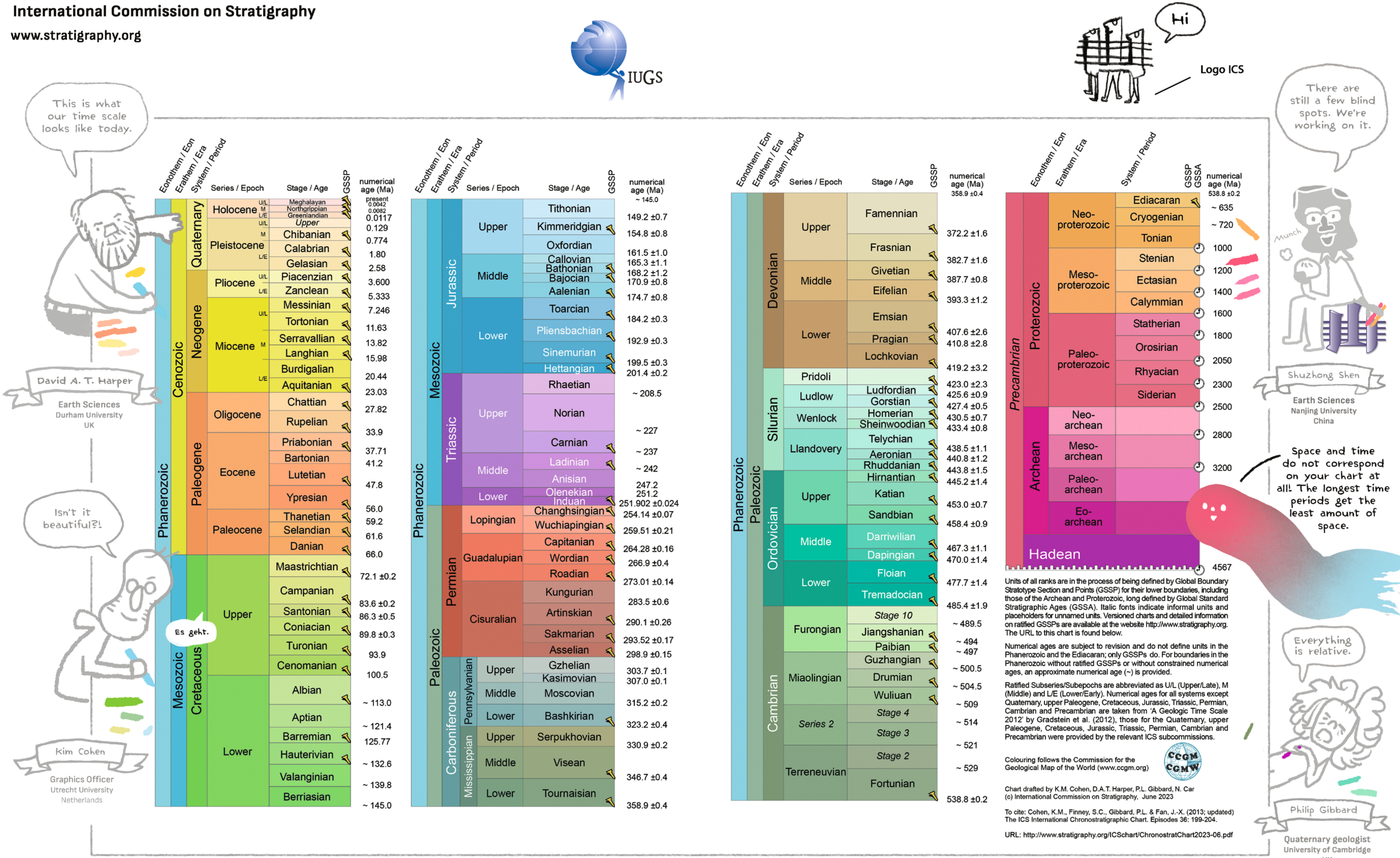


* that's what Marcia Bjornerud called the ICS in her book „Timefullness"

INTERNATIONAL CHRONO STRATIGRAPHIC CHART[8] v2023/06

International Commission on Stratigraphy

www.stratigraphy.org



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.

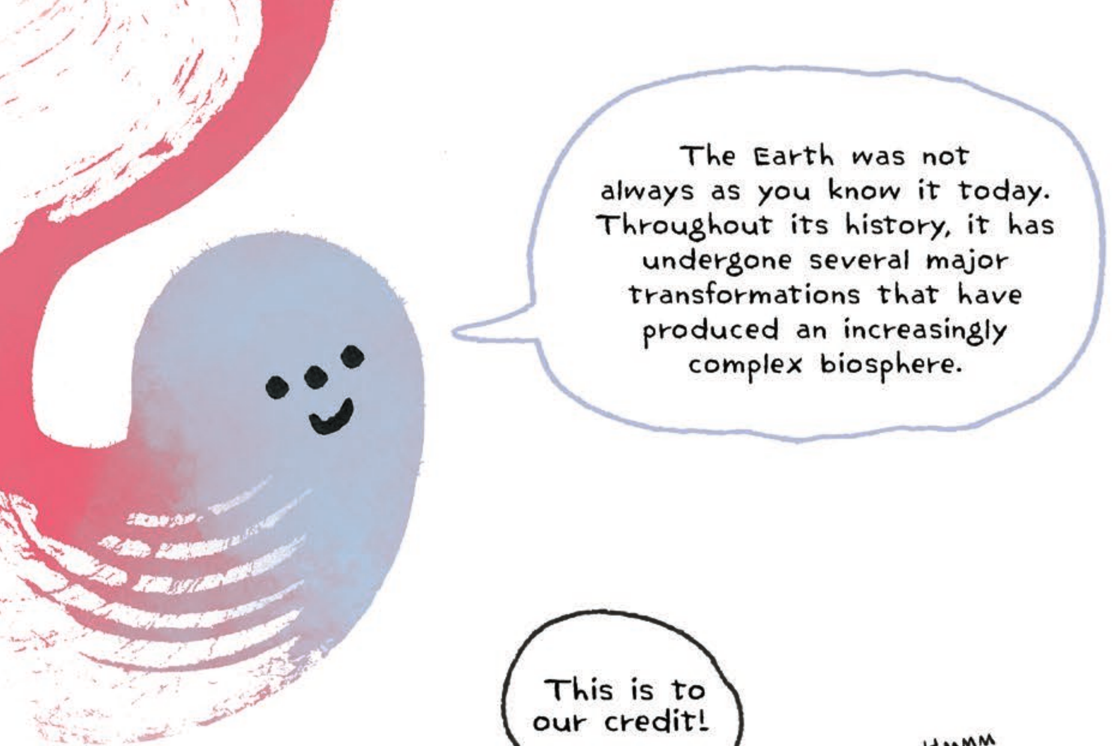
Ratified Subseries/Subepochs are abbreviated as U/L (Upper/Late), M (Middle) and L/E (Lower/Early). Numerical ages for all systems except Quaternary, upper Paleogene, Cretaceous, Jurassic, Triassic, Permian, Cambrian and Precambrian are taken from 'A Geologic Time Scale 2012' by Gradstein et al. (2012),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

Chart drafted by K.M. Cohen, D.A.T. Harper, P.L. Gibbard, N. Car

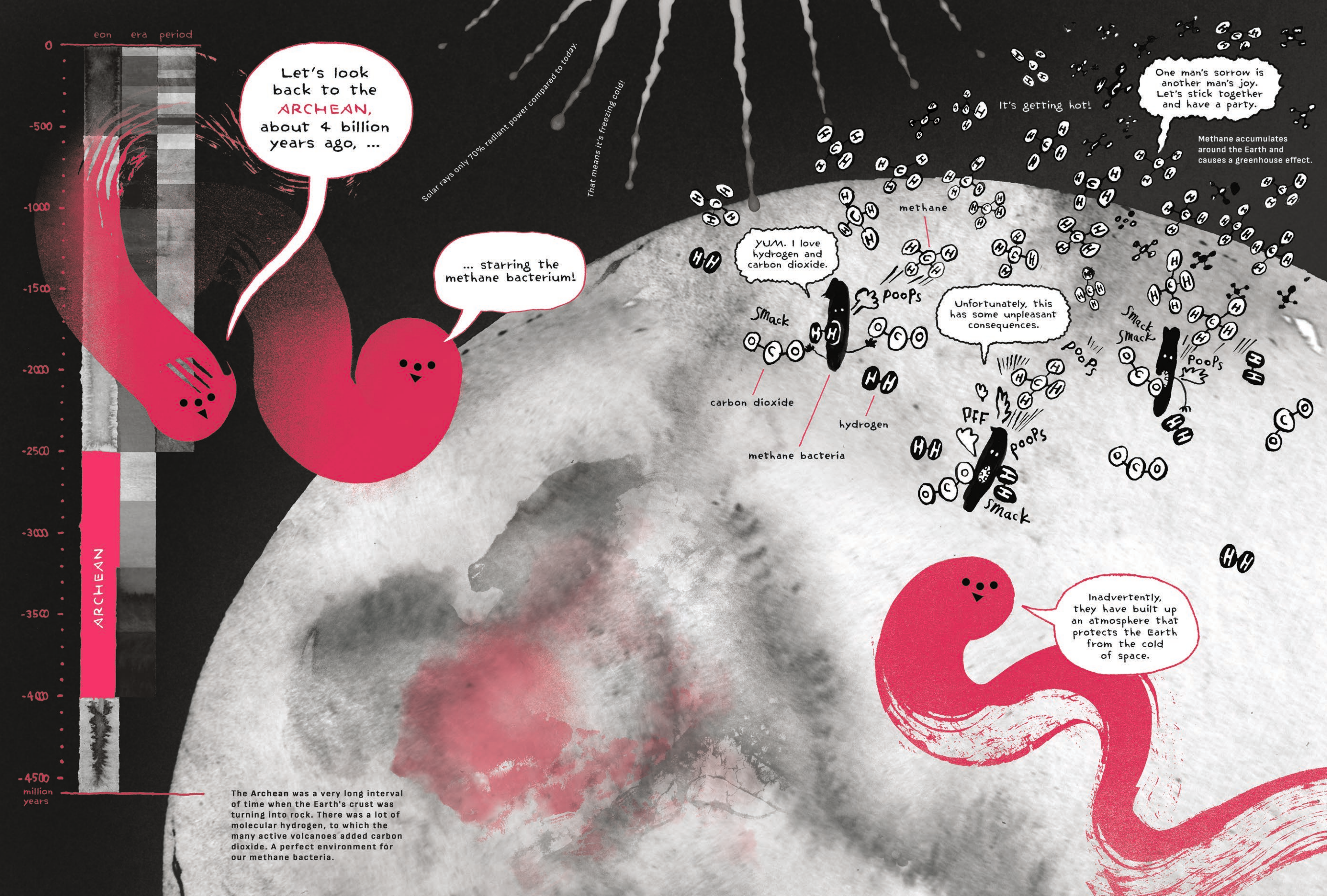
To cite: Cohen, K.M., Finney, S.C., Gibbard, P.L. & Fan, J.-X. (2013; updated) The ICS International Chronostratigraphic Chart. Episodes 36: 199-204.

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

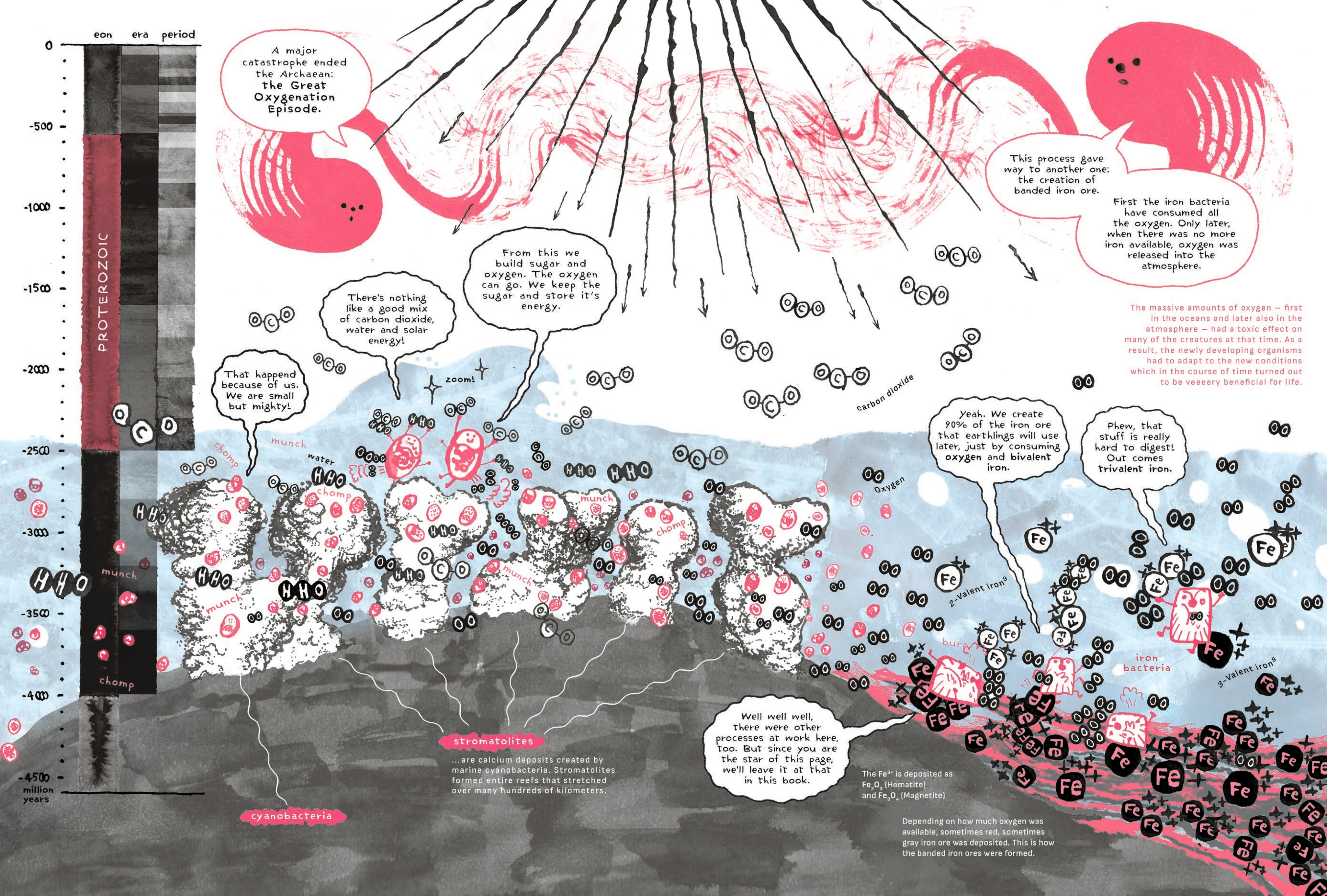


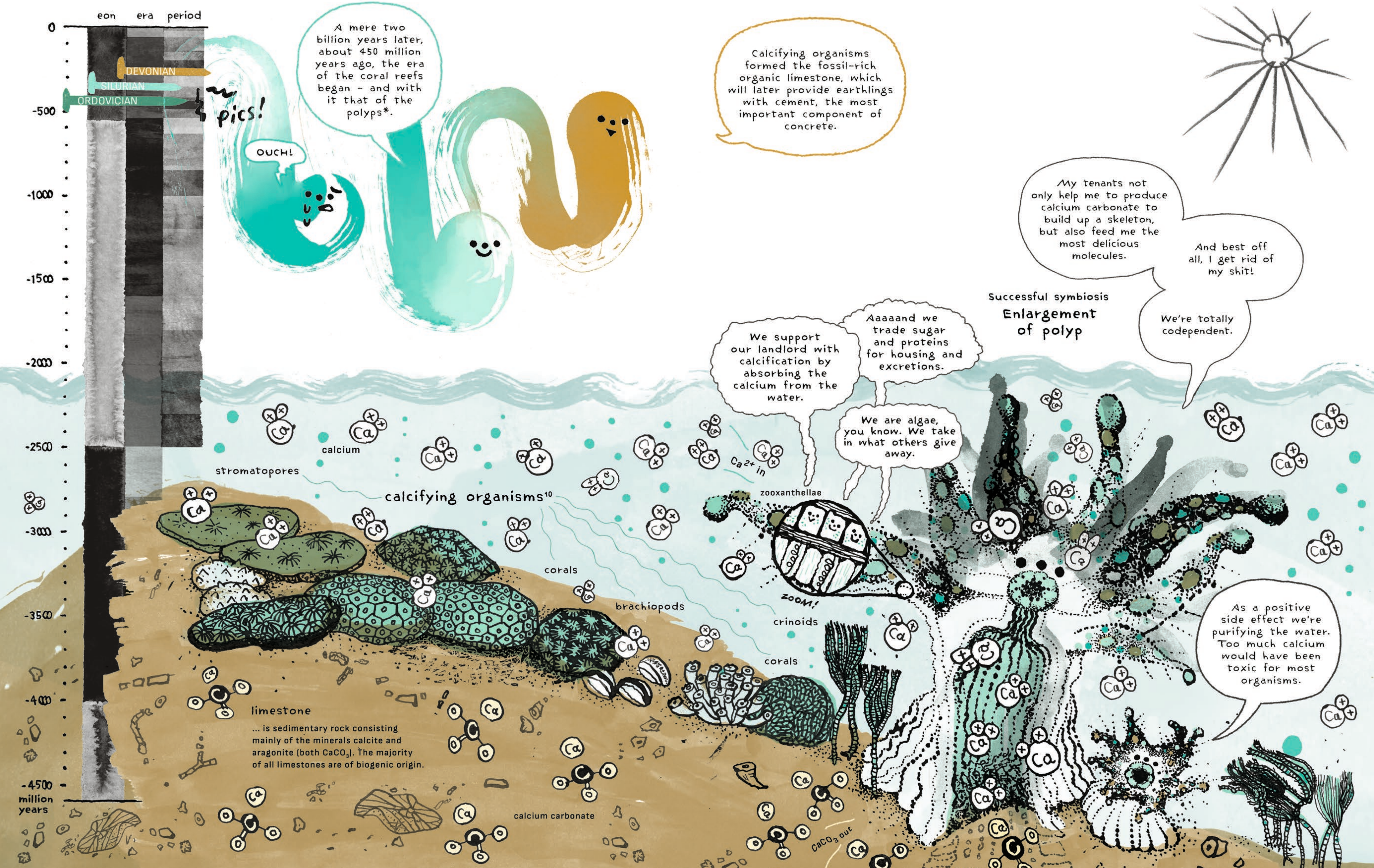
Please meet the...

EARTH SYSTEM CHANGER

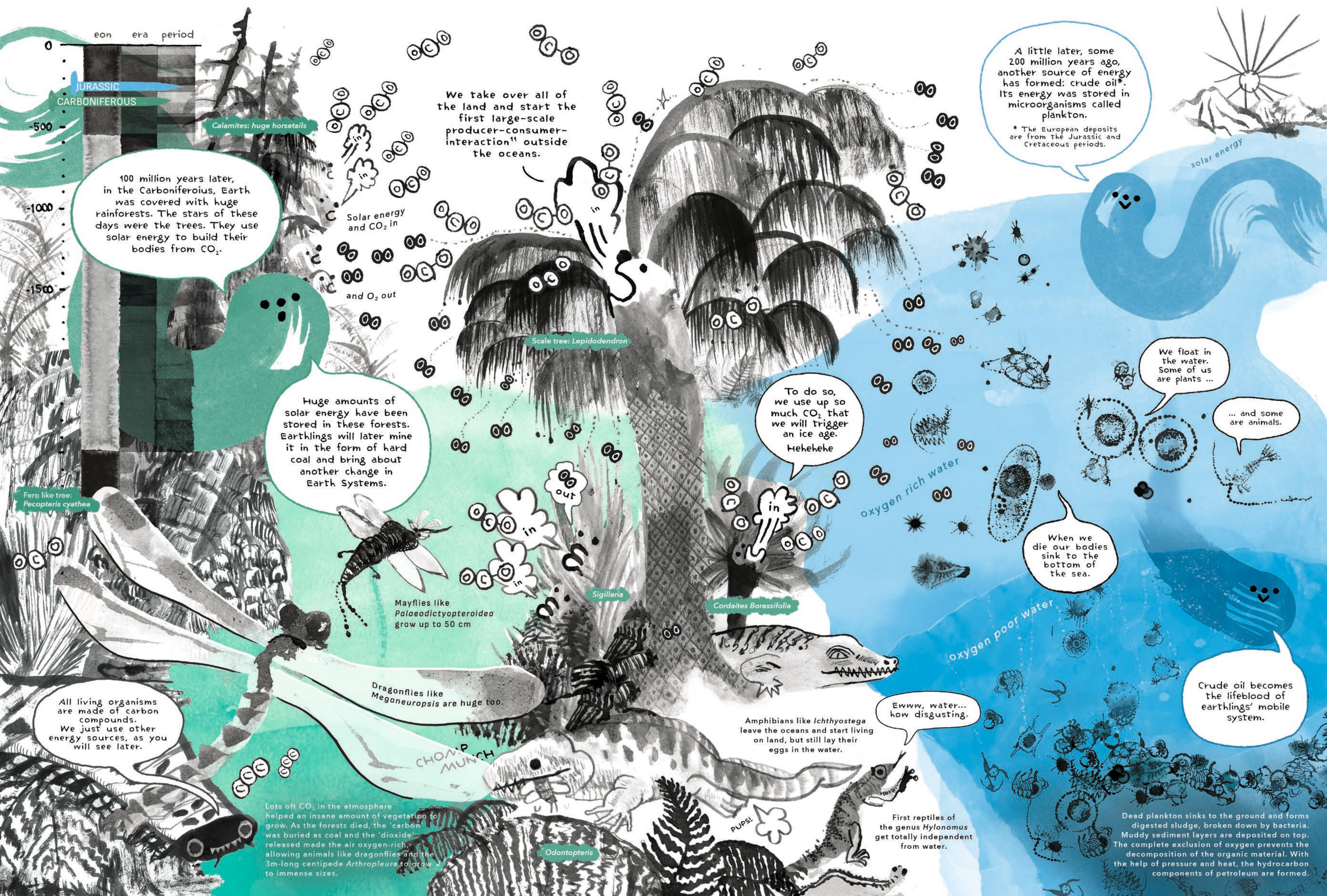


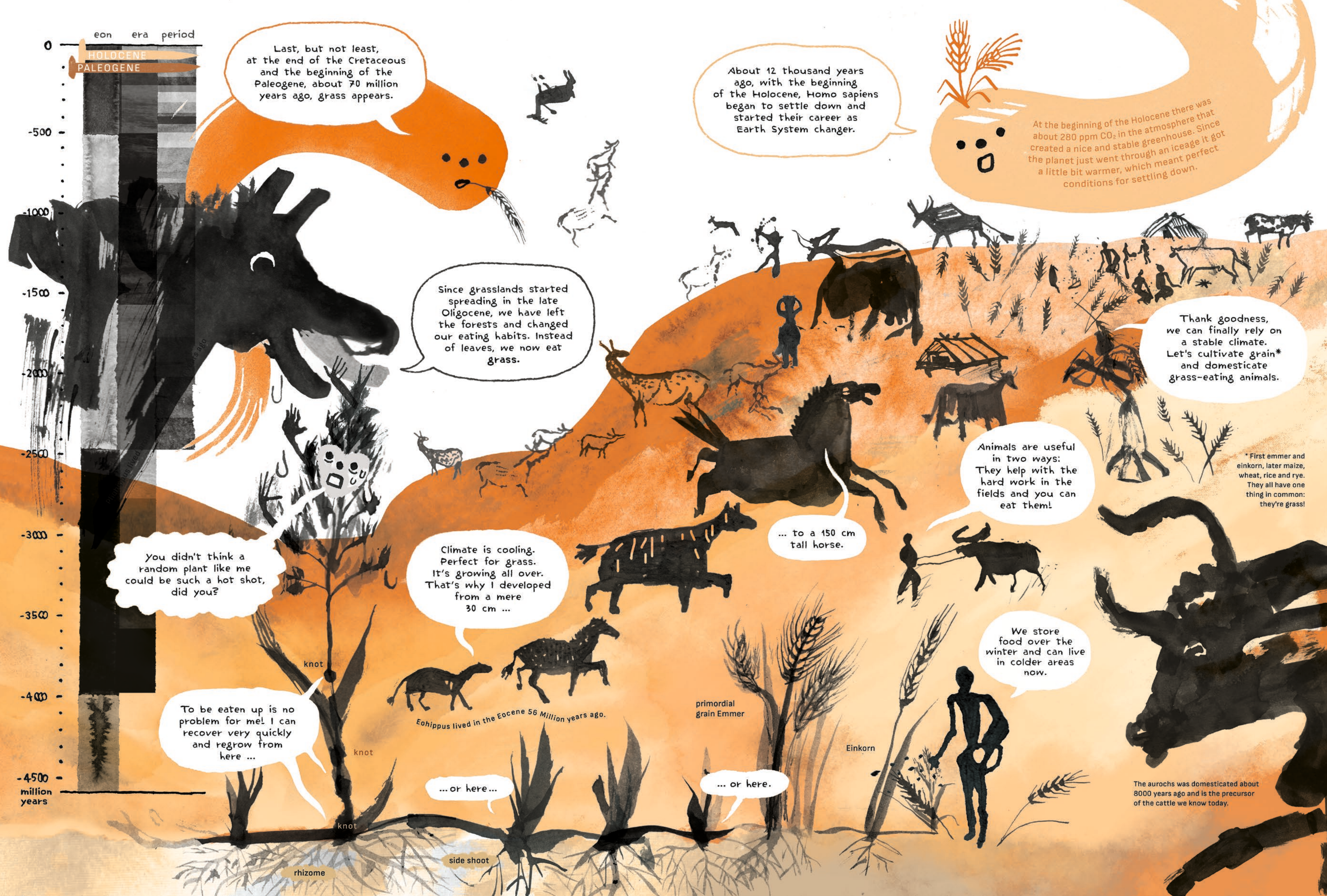
The Archean was a very long interval of time when the Earth's crust was turning into rock. There was a lot of molecular hydrogen, to which the many active volcanoes added carbon dioxide. A perfect environment for our methane bacteria.


eon era period
0
-500
-1000
-1500
-2000
-2500
-3000
-3500
-4000
-4500 million years
PROTEROZOIC
A major catastrophe ended the Archaean: **the Great Oxygenation Episode.**
This process gave way to another one: the creation of banded iron ore.
First the iron bacteria have consumed all the oxygen. Only later, when there was no more iron available, oxygen was released into the atmosphere.
The massive amounts of oxygen – first in the oceans and later also in the atmosphere – had a toxic effect on many of the creatures at that time. As a result, the newly developing organisms had to adapt to the new conditions which in the course of time turned out to be veeeery beneficial for life.
That happend because of us. We are small but mighty!
There's nothing like a good mix of carbon dioxide, water and solar energy!
From this we build sugar and oxygen. The oxygen can go. We keep the sugar and store it's energy.
zoom!
carbon dioxide
water
munch
chomp
Oxygen
Yeah. We create 90% of the iron ore that earthlings will use later, just by consuming **oxygen** and **bivalent iron.**
Phew, that stuff is really hard to digest! Out comes **trivalent iron.**
2-Valent iron[9]
3-Valent iron[9]
iron bacteria
burp
stromatolites
...are calcium deposits created by marine cyanobacteria. Stromatolites formed entire reefs that stretched over many hundreds of kilometers.
cyanobacteria
Well well well, there were other processes at work here, too. But since you are the star of this page, we'll leave it at that in this book.
The Fe^{3+} is deposited as Fe_2O_3 (Hematite) and Fe_3O_4 (Magnetite)
Depending on how much oxygen was available, sometimes red, sometimes gray iron ore was deposited. This is how the banded iron ores were formed.



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


eon era period
0
-500
-1000
-1500
JURASSIC
CARBONIFEROUS
Calamites: huge horsetails
100 million years later, in the Carboniferoius, Earth was covered with huge rainforests. The stars of these days were the trees. They use solar energy to build their bodies from CO_2.
Solar energy and CO_2 in
and O_2 out
in
We take over all of the land and start the first large-scale producer-consumer-interaction[11] outside the oceans.
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.
Fern like tree: Pecopteris cyathea
Mayflies like Palaeodictyopteroidea grow up to 50 cm
out
Sigillaria
Cordaites Borassifolia
To do so, we use up so much CO_2 that we will trigger an ice age. Hehehehe
Dragonflies like Meganeuropsis are huge too.
All living organisms are made of carbon compounds. We just use other energy sources, as you will see later.
CHOMP MUNCH
Amphibians like Ichthyostega leave the oceans and start living on land, but still lay their eggs in the water.
Ewww, water… how disgusting.
Lots oft CO_2 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
PUPS!
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.
oxygen rich water
When we die our bodies sink to the bottom of the sea.
oxygen poor water
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.

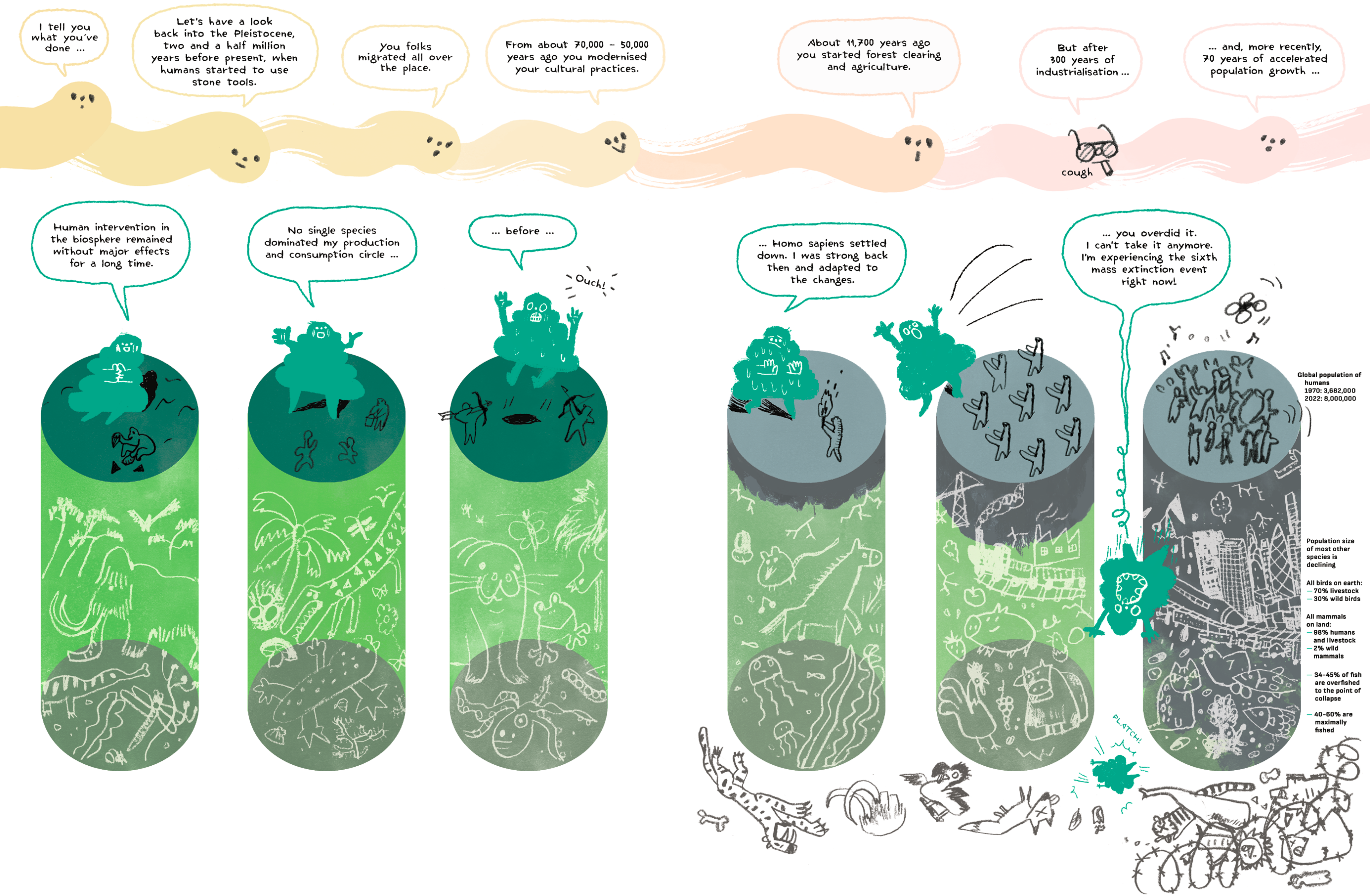


eon era period
0
HOLOCENE
PALEOGENE
-500
-1000
-1500
-2000
-2500
-3000
-3500
-4000
-4500 million years
Last, but not least, at the end of the Cretaceous and the beginning of the Paleogene, about 70 million years ago, grass appears.
Since grasslands started spreading in the late Oligocene, we have left the forests and changed our eating habits. Instead of leaves, we now eat grass.
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.
Eohippus lived in the Eocene 56 Million years ago.
To be eaten up is no problem for me! I can recover very quickly and regrow from here ...
... or here ...
... or here.
knot
knot
knot
rhizome
side shoot
primordial grain Emmer
Einkorn
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_2 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.
Thank goodness, we can finally rely on a stable climate. Let's cultivate grain* and domesticate grass-eating animals.
* First emmer and einkorn, later maize, wheat, rice and rye. They all have one thing in common: they're grass!
Animals are useful in two ways: They help with the hard work in the fields and you can eat them!
We store food over the winter and can live in colder areas now.
The aurochs was domesticated about 8000 years ago and is the precursor of the cattle we know today.


Today's complex ecosystems[12] were built in an interplay between inanimate and animate matter. All ecosystems together form the biosphere[13].


Life is a constant flow of production, consumption and adaption. 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!
SWEAT
SWEAT
energy lost by heat
BIOSPHERE
Quaternary consumers
feed on carnivores and herbivores
2
Tertiary consumers
feed on carnivores
20
Carnivores
Secondary consumers
feed on herbivores
200
Primary consumers
feed on plants
2,000
Herbivores
Primary producers of biomass[14]
live exclusively on inorganic substances
20,000
- 90%
- 90%
- 90%
- 90%
In short, one level feeds on the energy of the next and loses 90% of it at every step.
decomposers[11]
nutrients are made available again through biochemical decomposition
mineralic raw materials from rocks and soil, crushed and leached out by wheathering and erosion
water
energy stored by biomass in kcal/m²/yr
soils
(Pedosphere)
solar energy
rocks
(Lithosphere)

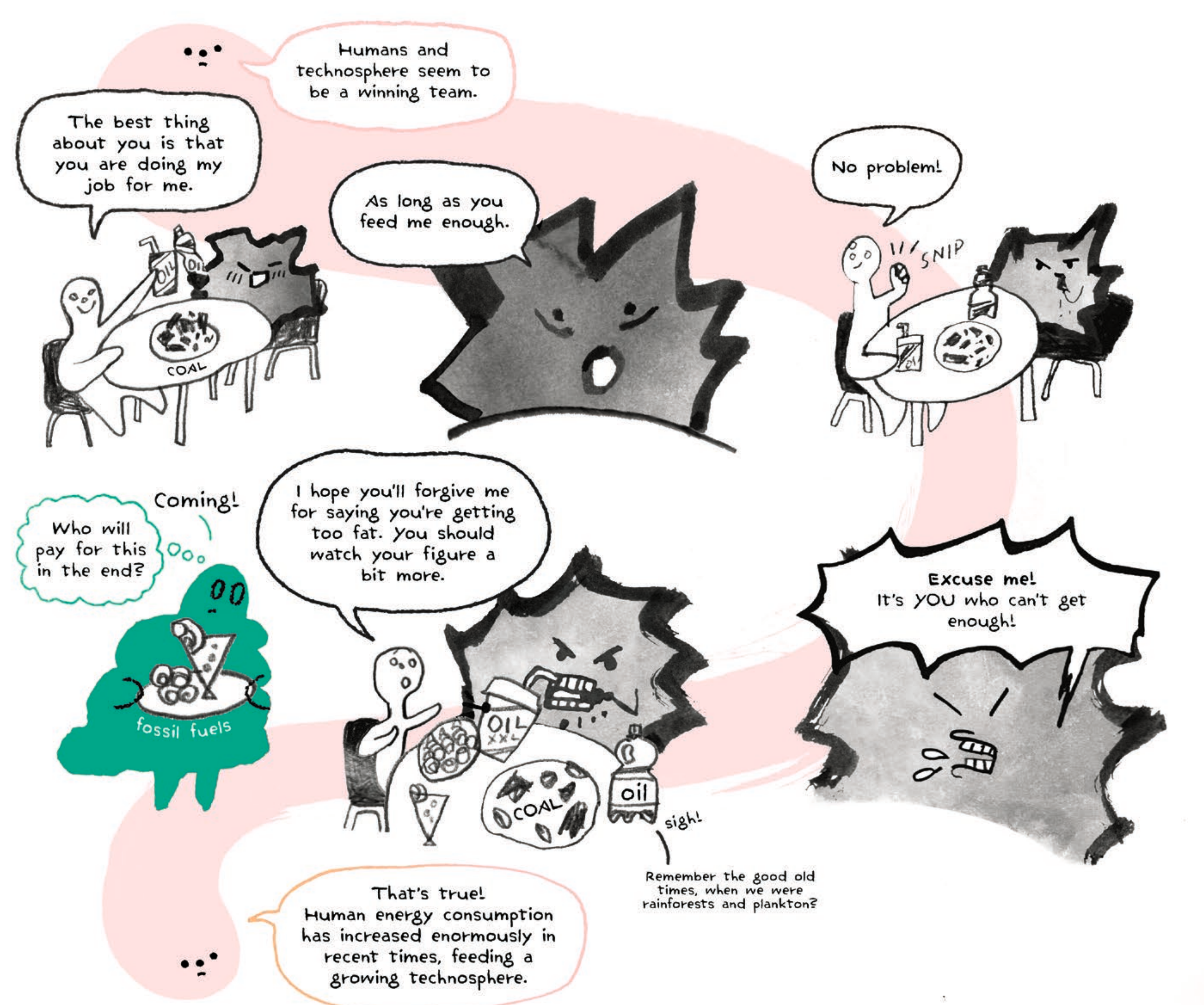

In the history of Earth there have always been major upheavals that marked a new time interval.
One is happening **right now!**
At present, earthlings are refashioning the relationship between consumption and production – with heavy consequences ...
Hold on, TIME!
These changes are way too fast. I can't 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 ...
cough
... 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 ...
Ouch!
... 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
PLATCH!

Sorry! We didn't mean to do this!
We just wanted to make life a little easier for ourselves.
I mean, you're not exactly squeamish yourself.
Hungry..!!
Grumel
That's why we tried to gain control...
... and be a little less dependent on you.
KLICK
KLACK
FOOD
BUY NOW
We have evolved from a natural being to a cultural one.
You used to tell me what to do ...
... now it's my turn!
Can I get something to eat, please?
Can I get some space and time, please?

Today, the total mass of the Earth's technosphere[15] outweihts the mass of the biosphere by far!
Trawled sea floor
2.25 Tt
Cropland
3.76 Tt
roar
Railways
0.02 Tt
Pasture
5.03 Tt
Urban areas
11.10 Tt
hunk
Rural housing
6.30 Tt
grrrrrrr
Reservoirs
0.20 Tt
grrrr
Plantation forests
0.27 Tt
Land use
and eroded soil
0.80 Tt
Rural roads
0.38 Tt
tremble
living biomass
2.27 Tt wet weight
Technosphere and its
waste products
30.11 Tt

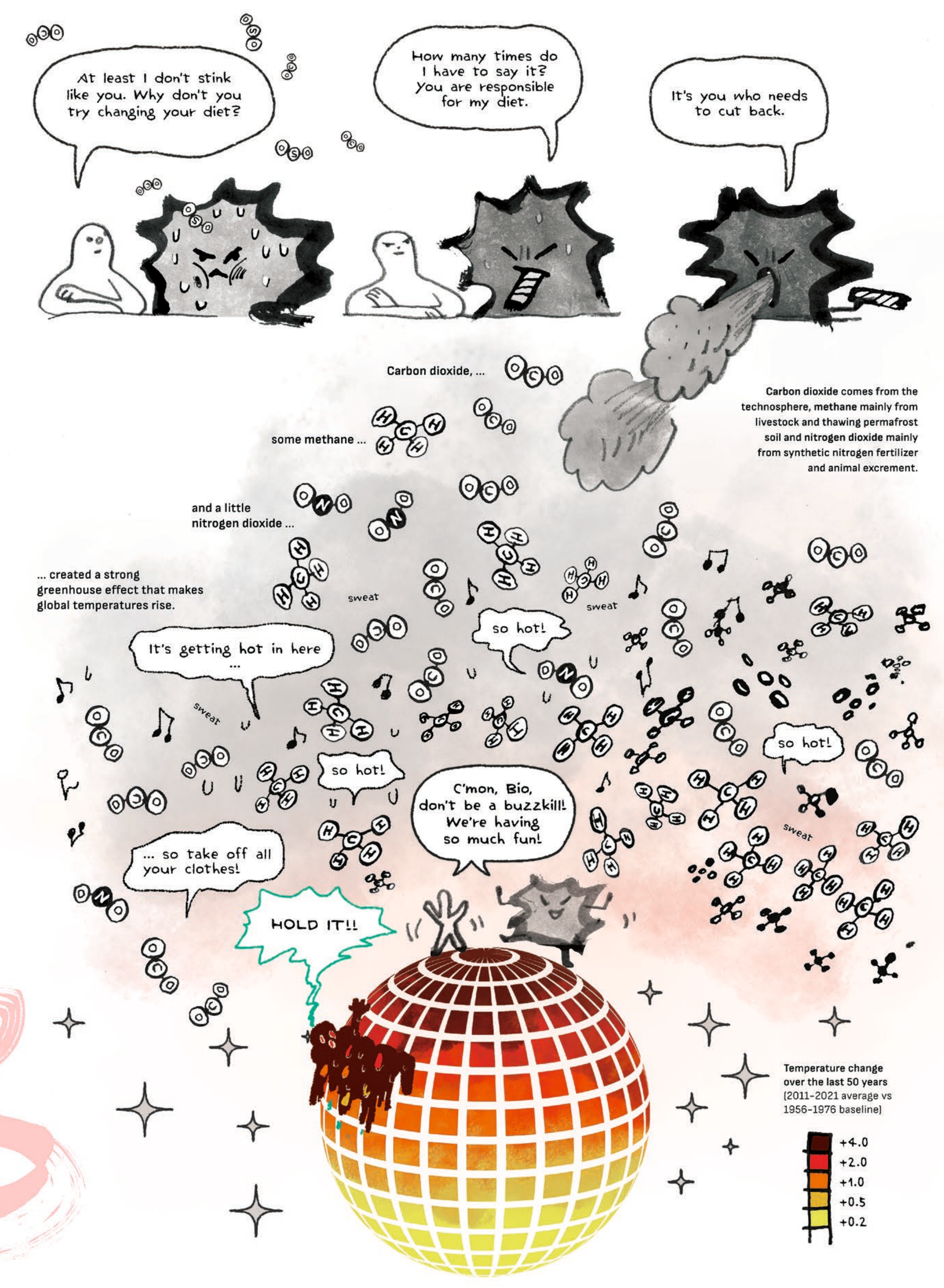


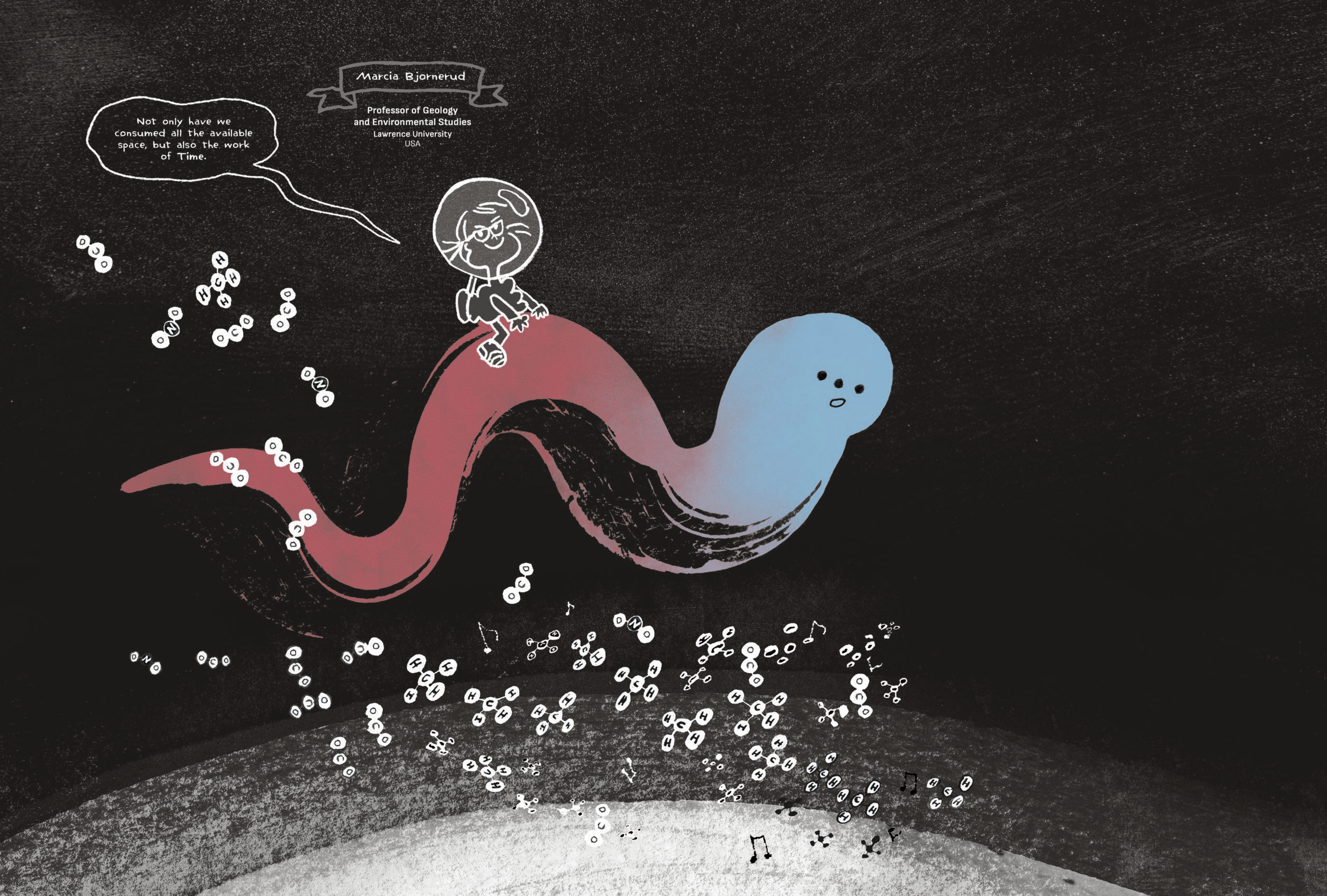
	Greenlandian Age 11,700 - 8,256	Northgrippian Age 8,256 - 4,270	Meghalayan Age 4,270 - 70	Pre-industrial Interval (informal) 350 - 170 (1630 - 1850)	Industrial Interval (informal) 170-70 (1850 - 1950)	Anthropocene (proposed epoch) 70 - Present (since 1950)
primary energy from	• human muscle • wood	• wood • animal muscle	• wood • muscle • coal in cities	• wood • muscle • whale oil • coal • streams	• coal • oil • hydroelectric	• coal • oil • gas • nuclear • renewables
energy consumption per capita (GJ/y)	6.2	7.1	8.3	18.4	27.2	61
total interval energy (Zetta Joule / ZJ)	0.12	0.34	14.2	2.9	4.9	22

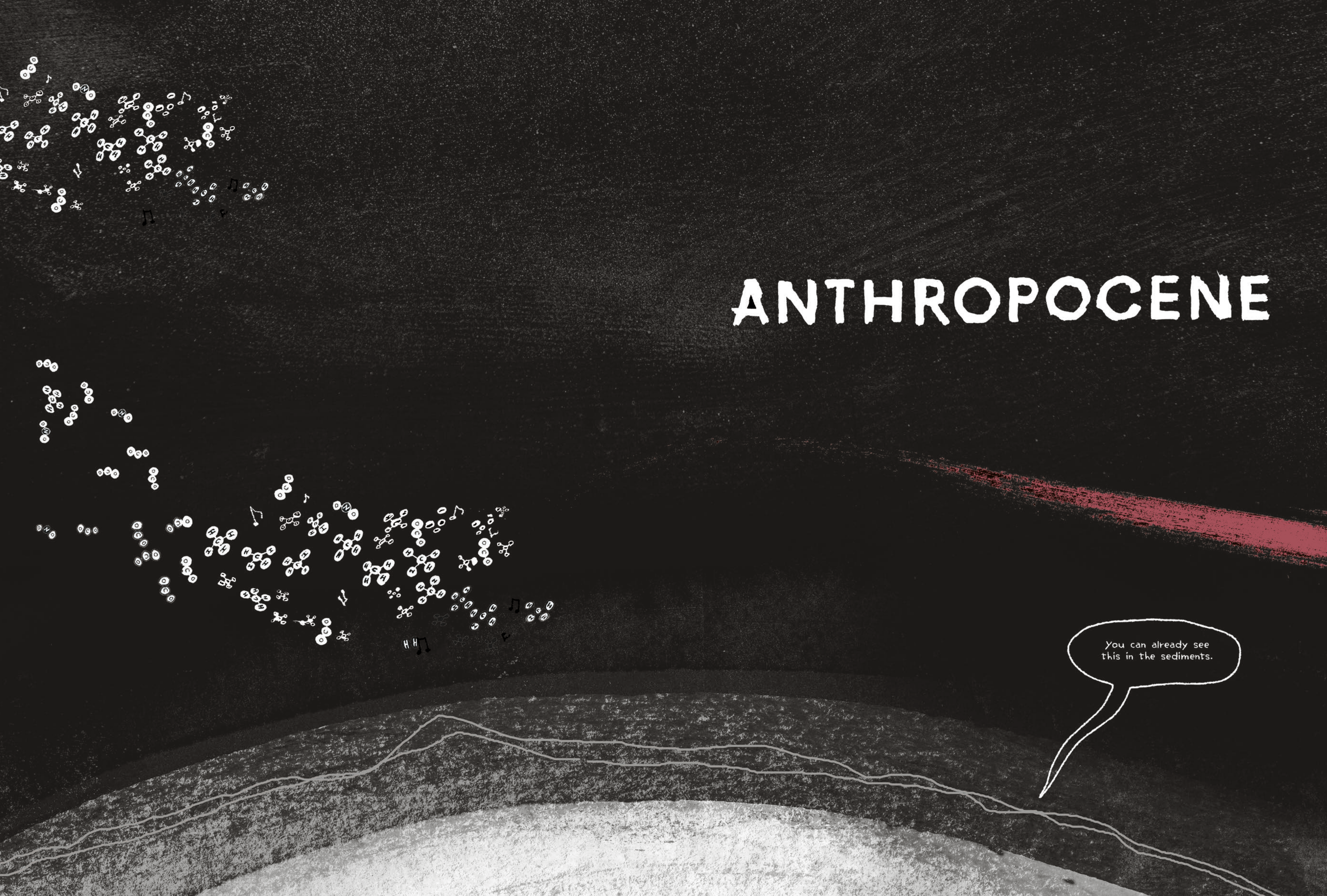
total Holocene: 14.6 ZJ

total Anthropocene: 22 ZJ

You used 1.5 times more energy in the last 70 years than in the whole Holocene!

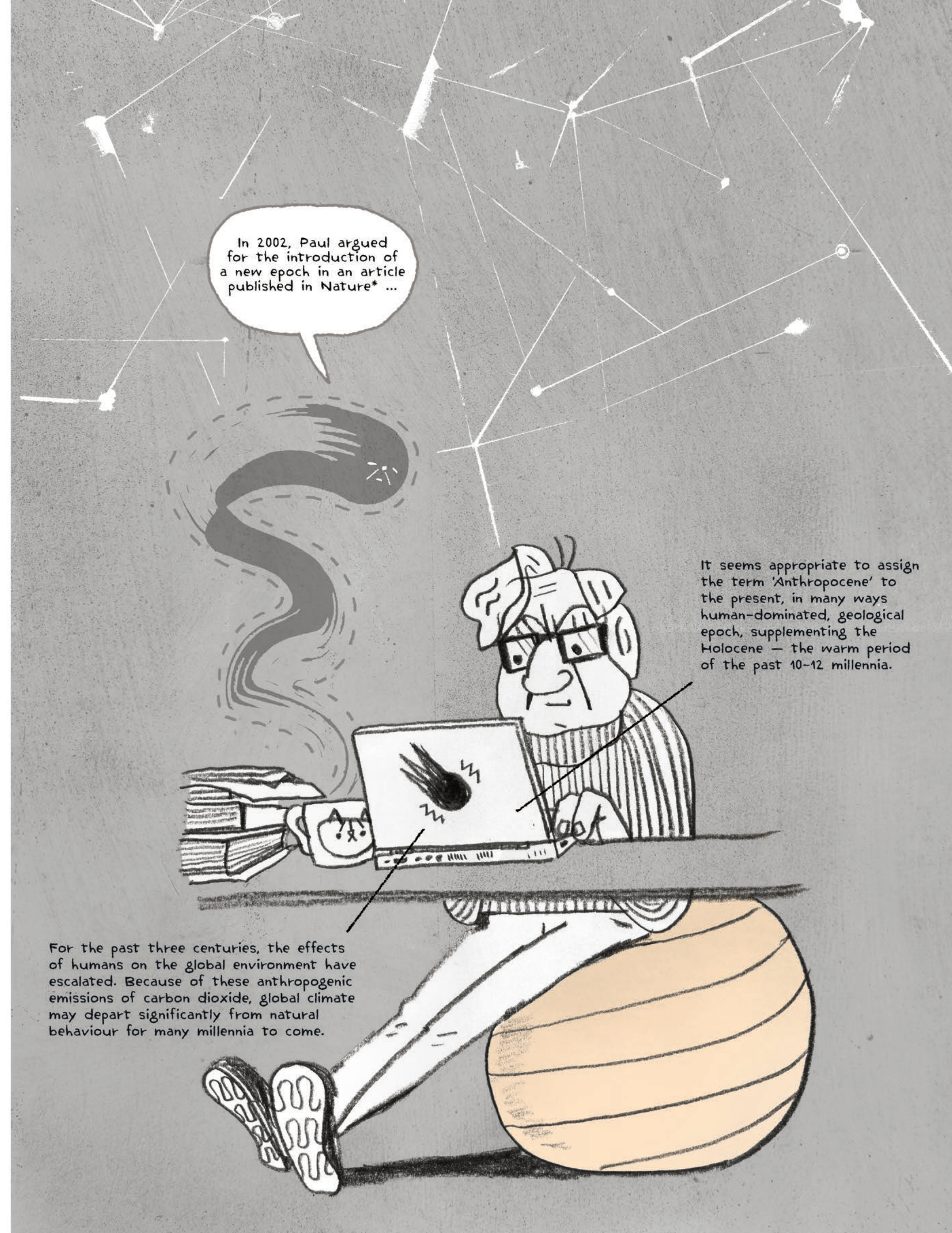



Marcia Bjornerud
Professor of Geology
and Environmental Studies
Lawrence University
USA
Not only have we consumed all the available space, but also the work of Time.

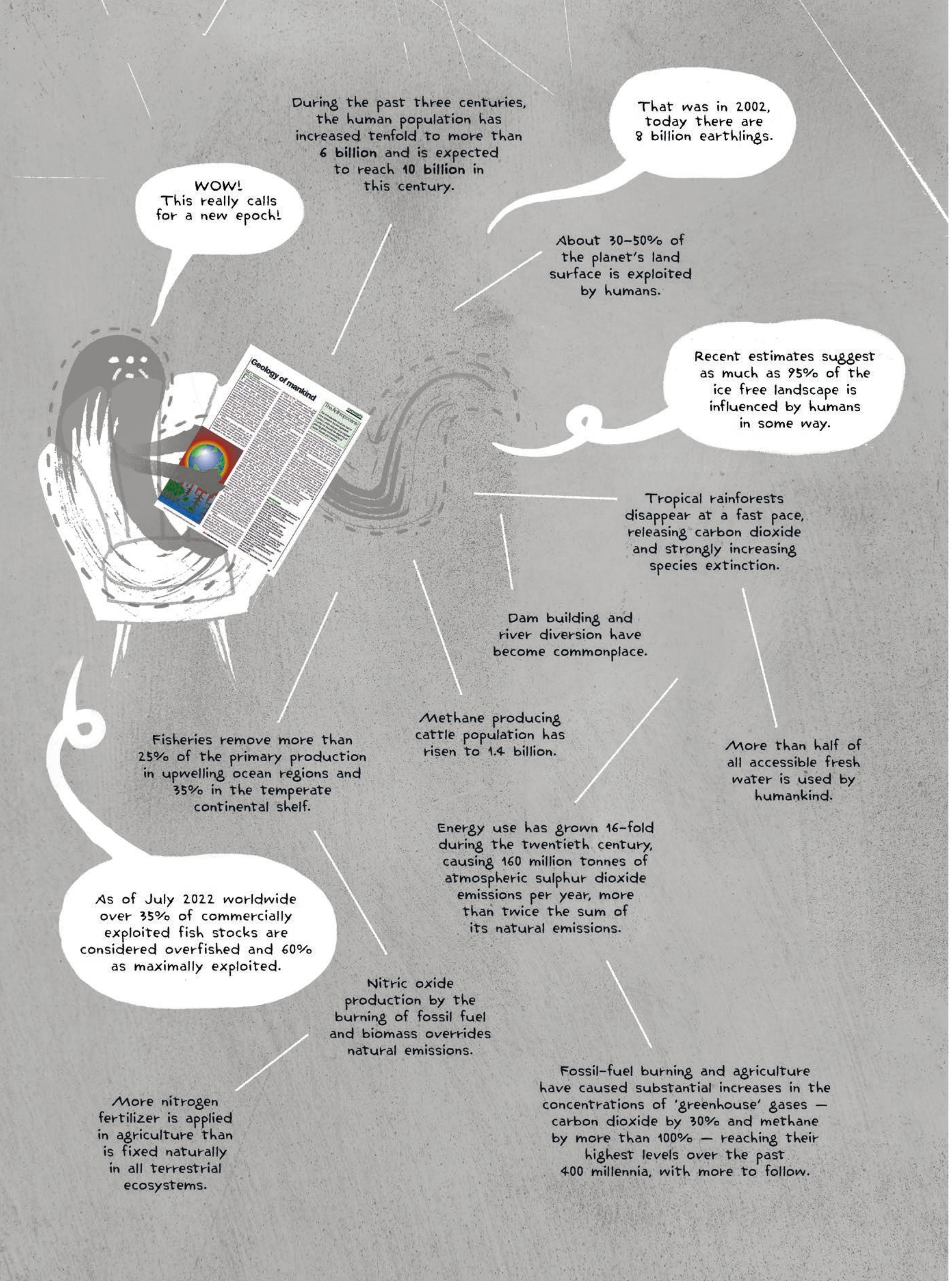

ANTHROPOCENE
You can already see this in the sediments.

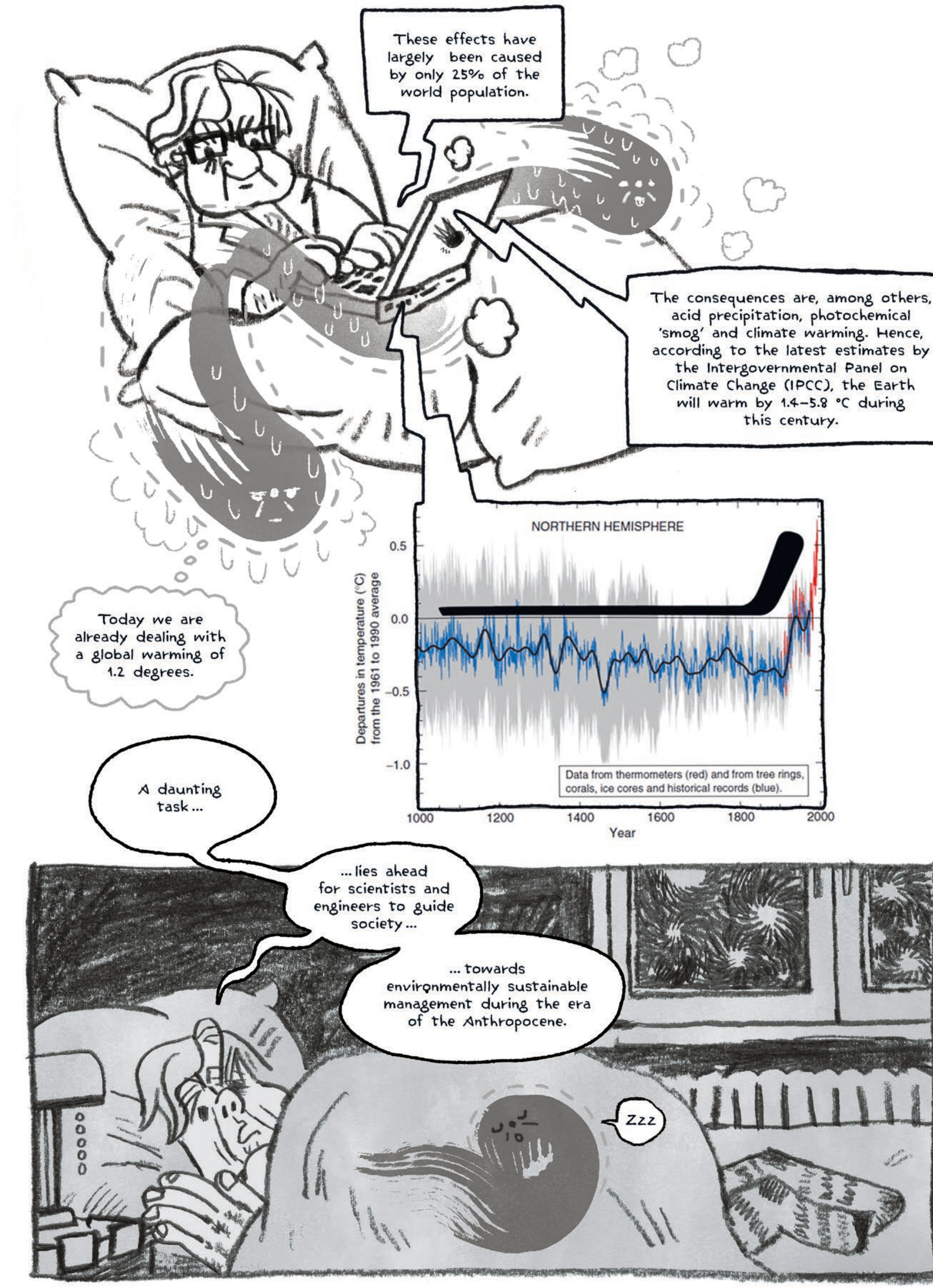
***IGBP:** Internatonal Geosphere Biosphere Programme, founded in 1986 with the aim of understanding the interactive physical, chemical and biological processes that regulate the Earth system and analyzing the interrelationships of their natural and anthropogenic changes.

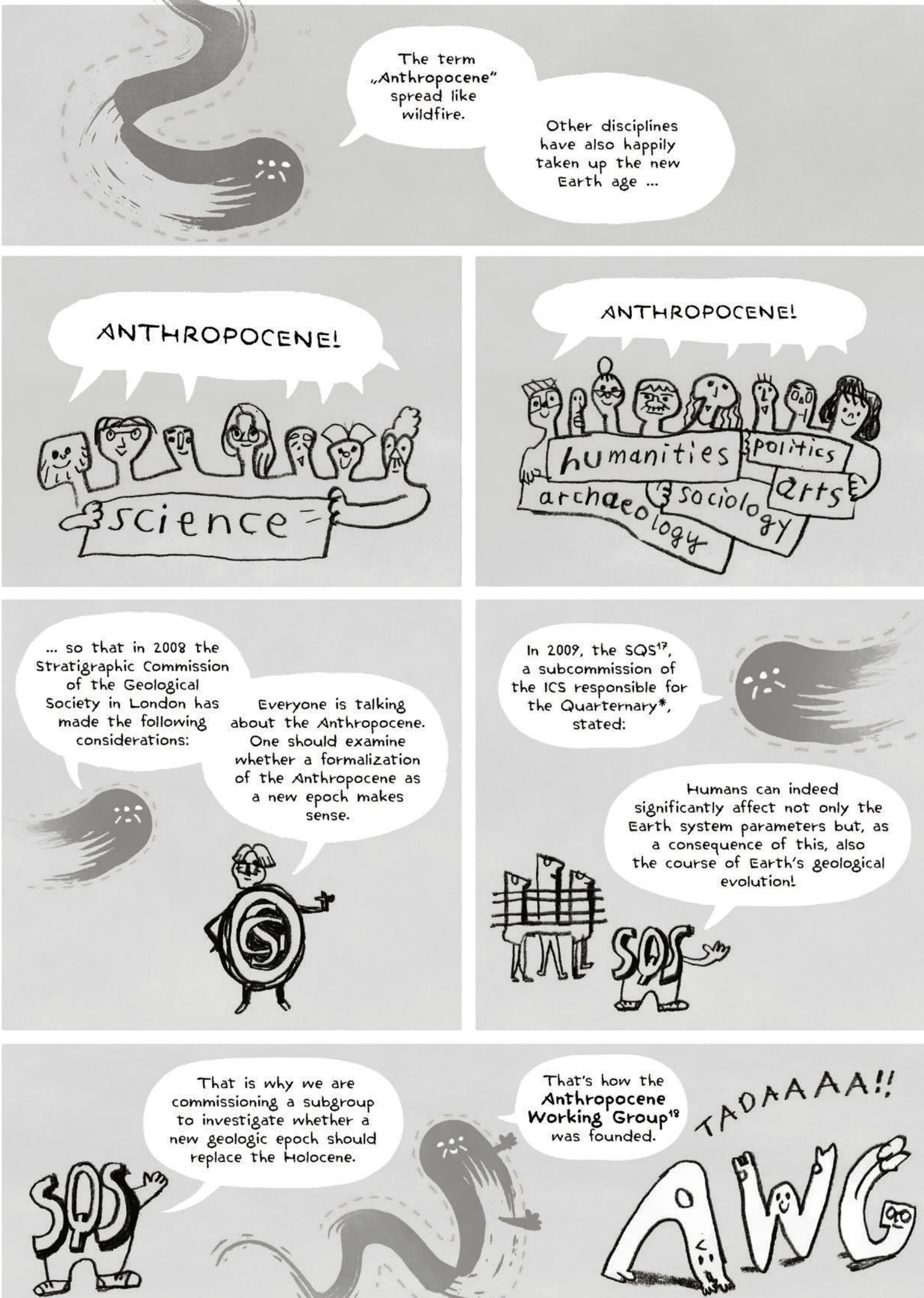
***Anthropocene:** Literally translates to the man-made new; The Earth age of Man



***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!
Geology of mankind
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.
Fisheries remove more than 25% of the primary production in upwelling ocean regions and 35% in the temperate continental shelf.
Methane producing cattle population has risen to 1.4 billion.
More than half of all accessible fresh water is used by humankind.
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.
As of July 2022 worldwide over 35% of commercially exploited fish stocks are considered overfished and 60% as maximally exploited.
Nitric oxide production by the burning of fossil fuel and biomass overrides natural emissions.
More nitrogen fertilizer is applied in agriculture than is fixed naturally in all terrestrial ecosystems.
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.


These effects have largely been caused by only 25% of the world population.
The consequences are, among others, acid precipitation, photochemical 'smog' and climate warming. Hence, according to the latest estimates by the Intergovernmental Panel on Climate Change (IPCC), the Earth will warm by 1.4–5.8 °C during this century.
Today we are already dealing with a global warming of 1.2 degrees.
NORTHERN HEMISPHERE
Departures in temperature (°C) from the 1961 to 1990 average
0.5
0.0
−0.5
−1.0
Data from thermometers (red) and from tree rings, corals, ice cores and historical records (blue).
1000
1200
1400
1600
1800
2000
Year
A daunting task…
…lies ahead for scientists and engineers to guide society…
…towards environmentally sustainable management during the era of the Anthropocene.
Zzz

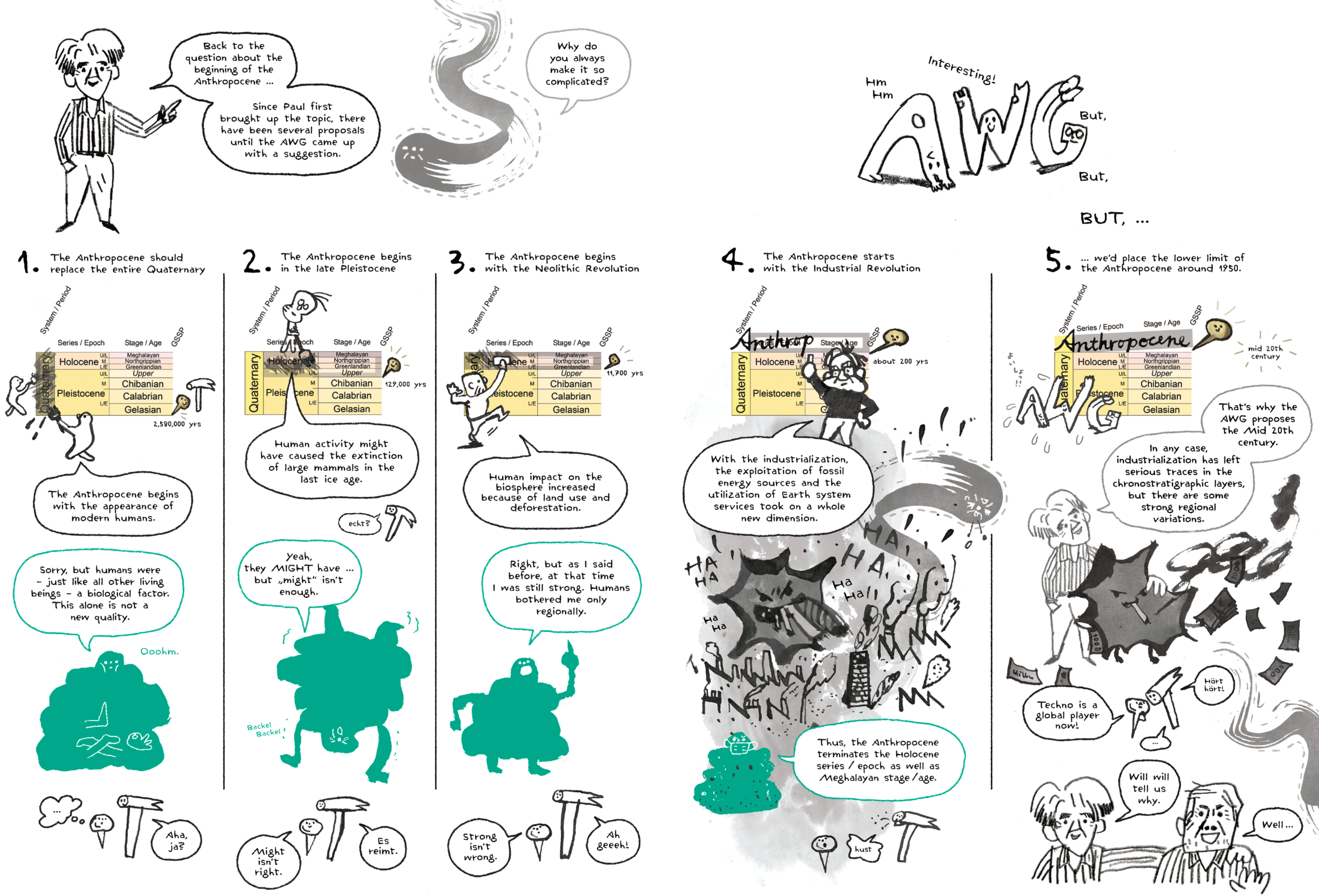


*Quaternary: a unit of time within the Cenozoic Era, beginning 2,588,000 years ago and continuing to the present day

*b2k: before the year 2000 AD

*members of the AWG until summer 2023

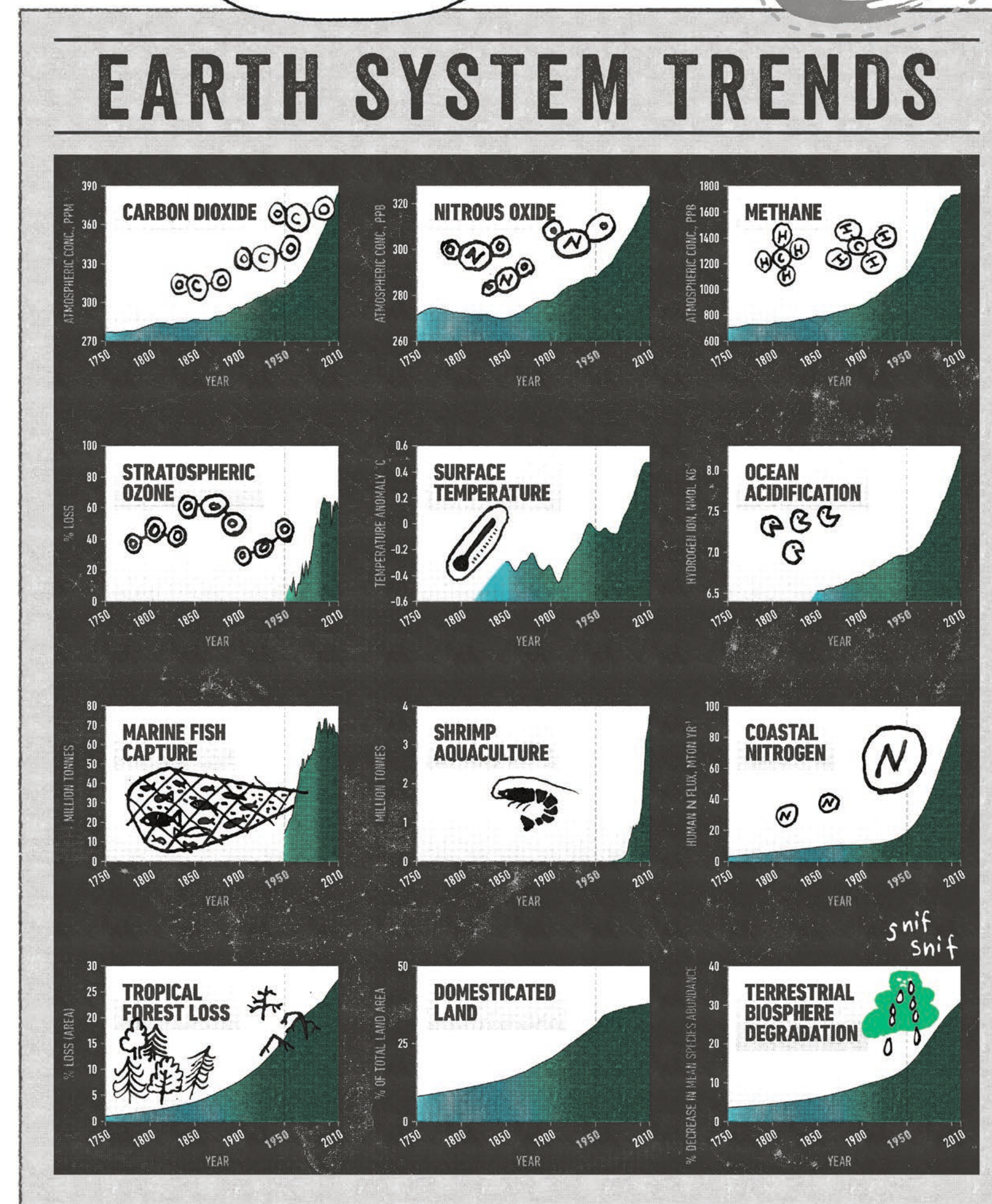
*sadly died January 29, 2023

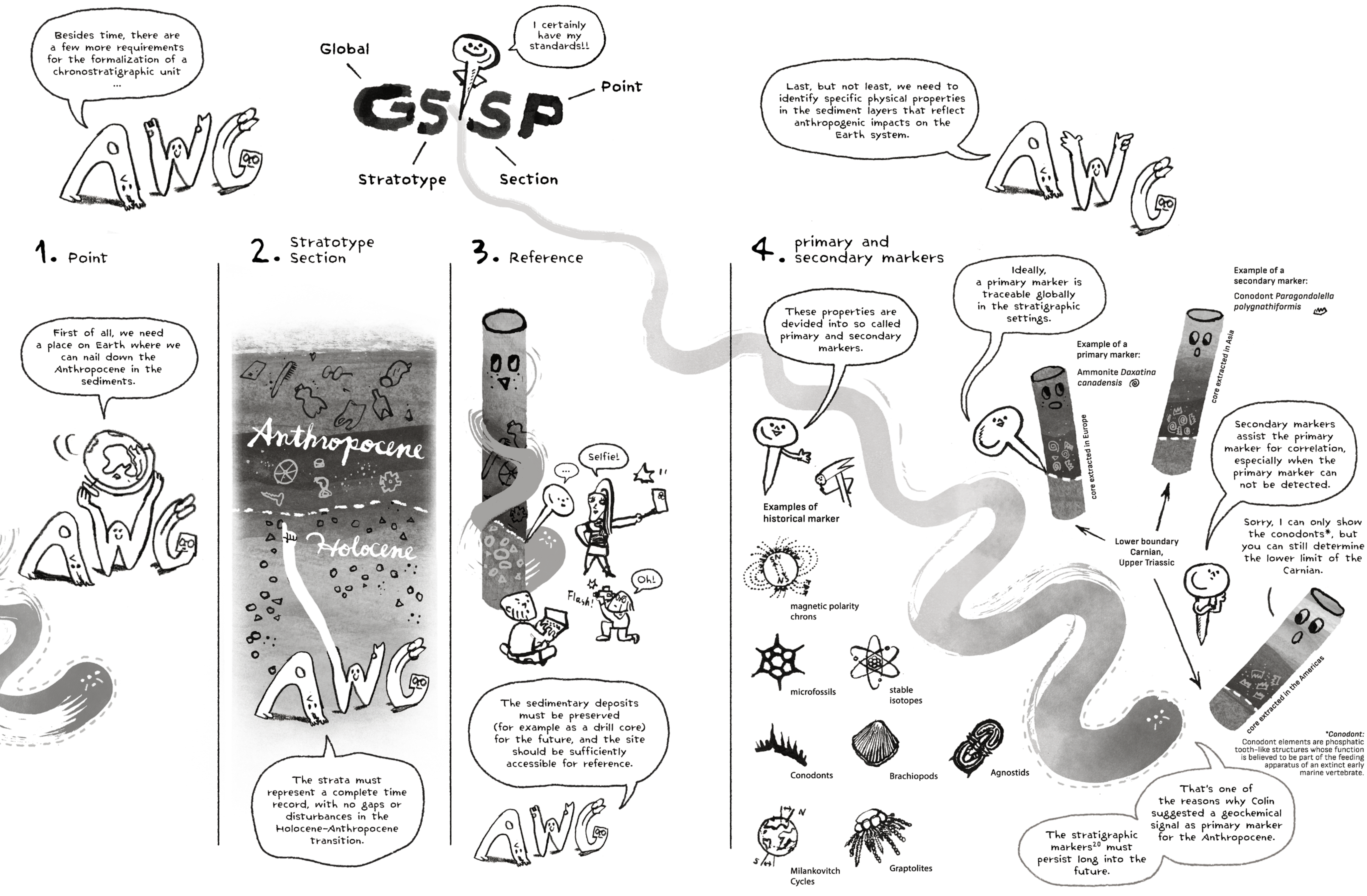


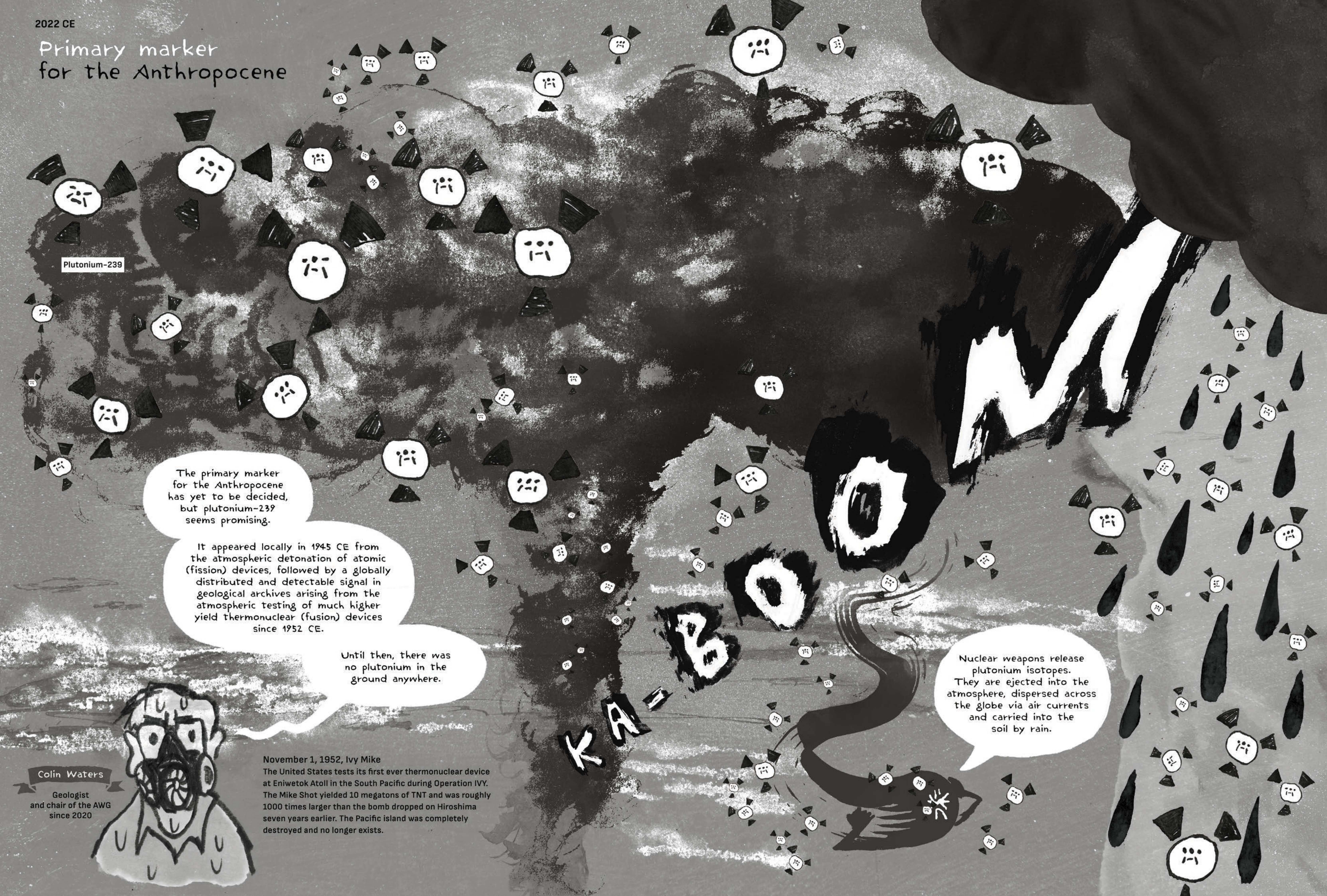
Back to the question about the beginning of the Anthropocene ...
Since Paul first brought up the topic, there have been several proposals until the AWG came up with a suggestion.
Why do you always make it so complicated?
Hm Hm
Interesting!
AWG
But,
But,
BUT, ...
1. The Anthropocene should replace the entire Quaternary
System / Period
Series / Epoch
Stage / Age
GSSP
Quaternary
Holocene
Pleistocene
U/L
M
L/E
Meghalayan
Northgrippian
Greenlandian
Upper
Chibanian
Calabrian
Gelasian
2,580,000 yrs
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.
Ooohm.
...
Aha, ja?
2. The Anthropocene begins in the late Pleistocene
129,000 yrs
Human activity might have caused the extinction of large mammals in the last ice age.
echt?
Yeah, they MIGHT have ... but „might" isn't enough.
Backel Backel
Might isn't right.
Es reimt.
3. The Anthropocene begins with the Neolithic Revolution
11,700 yrs
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.
Strong isn't wrong.
Ah geeeh!
4. The Anthropocene starts with the Industrial Revolution
Anthrop
about 200 yrs
With the industrialization, the exploitation of fossil energy sources and the utilization of Earth system services took on a whole new dimension.
HA HA
HA HA
Ha Ha!
Ha Ha
Thus, the Anthropocene terminates the Holocene series / epoch as well as Meghalayan stage / age.
hust
5. ... we'd place the lower limit of the Anthropocene around 1950.
Anthropocene
mid 20th century
That's why the AWG proposes the Mid 20th century.
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!
Hört hört!
...
Will will tell us why.
Well ...

The Great Acceleration[19]

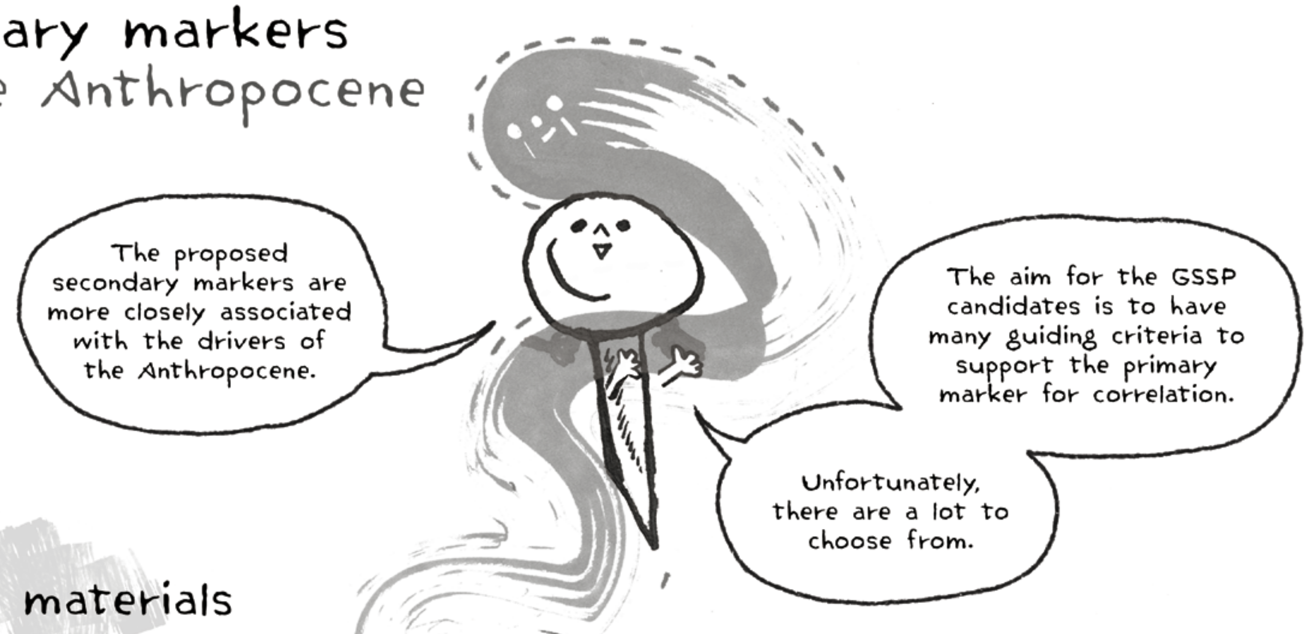
Graphic adapted from Steffen et al, Global Change and the Earth System, 2004, Design: Globaia



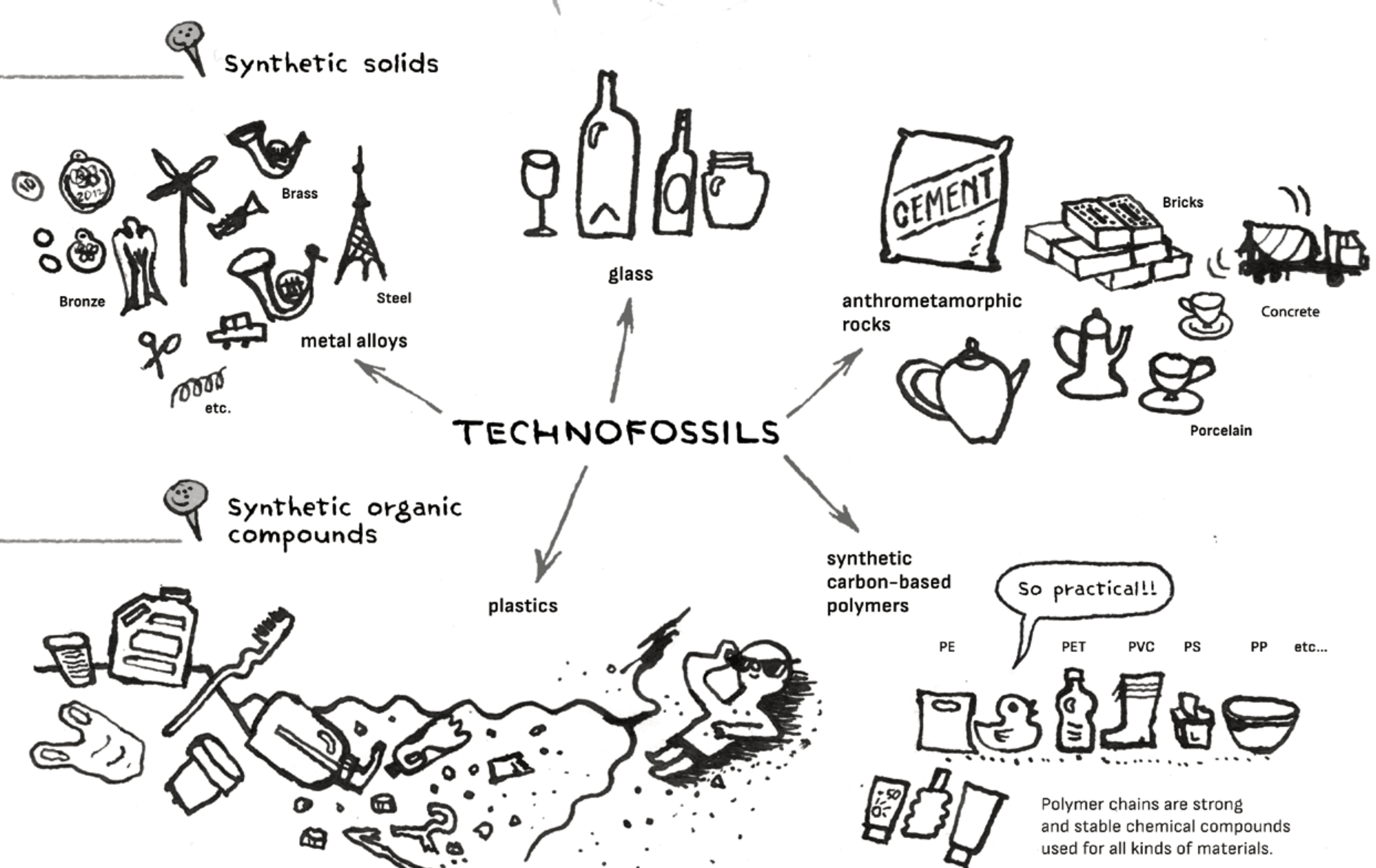

Besides time, there are a few more requirements for the formalization of a chronostratigraphic unit ...
AWG
Global
I certainly have my standards!!
GSSP
Point
Stratotype
Section
Last, but not least, we need to identify specific physical properties in the sediment layers that reflect anthropogenic impacts on the Earth system.
AWG
1. Point
First of all, we need a place on Earth where we can nail down the Anthropocene in the sediments.
AWG
2. Stratotype Section
Anthropocene
Holocene
AWG
The strata must represent a complete time record, with no gaps or disturbances in the Holocene-Anthropocene transition.
3. Reference
Selfie!
...
Flash!
Oh!
The sedimentary deposits must be preserved (for example as a drill core) for the future, and the site should be sufficiently accessible for reference.
AWG
4. primary and secondary markers
These properties are devided into so called primary and secondary markers.
Ideally, a primary marker is traceable globally in the stratigraphic settings.
Example of a primary marker:
Ammonite *Daxatina canadensis*
core extracted in Europe
Example of a secondary marker:
Conodont *Paragondolella polygnathiformis*
core extracted in Asia
Secondary markers assist the primary marker for correlation, especially when the primary marker can not be detected.
Examples of historical marker
magnetic polarity chrons
microfossils
stable isotopes
Conodonts
Brachiopods
Agnostids
Milankovitch Cycles
Graptolites
Lower boundary Carnian, Upper Triassic
Sorry, I can only show the conodonts*, but you can still determine the lower limit of the Carnian.
core extracted in the Americas
*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[20] must persist long into the future.


2022 CE
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.
Colin Waters
Geologist and chair of the AWG since 2020
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.
KA-BOOOM
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.

Secondary markers for the Anthropocene

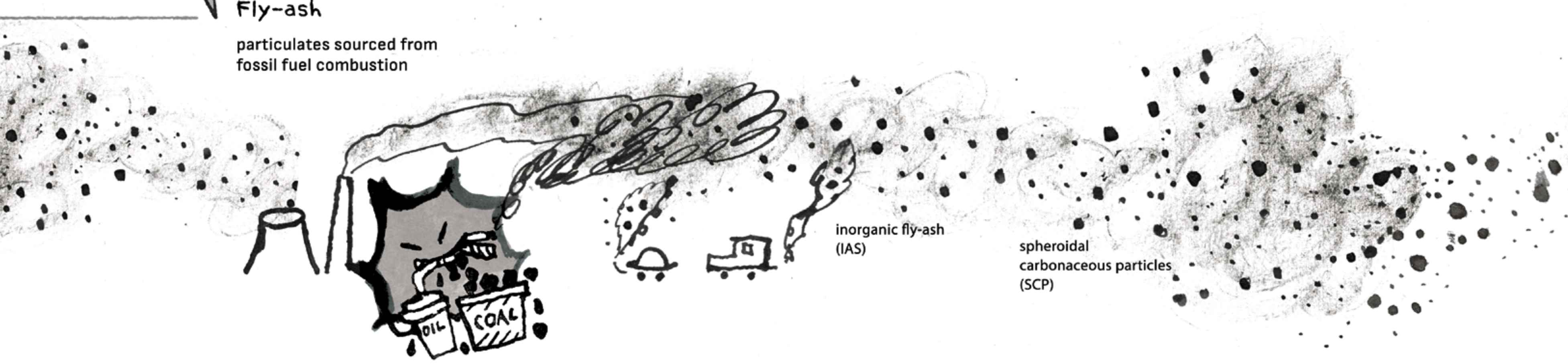


Novel materials



Fly-ash

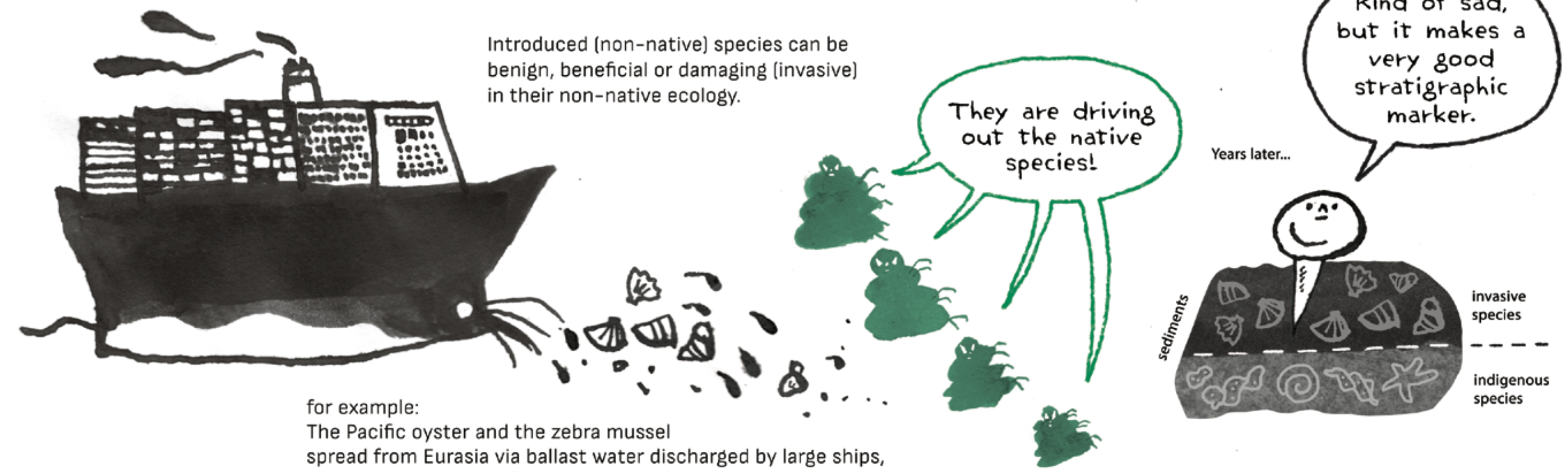
particulates sourced from fossil fuel combustion



Biotic markers

Neobiota[21] (invasive species)

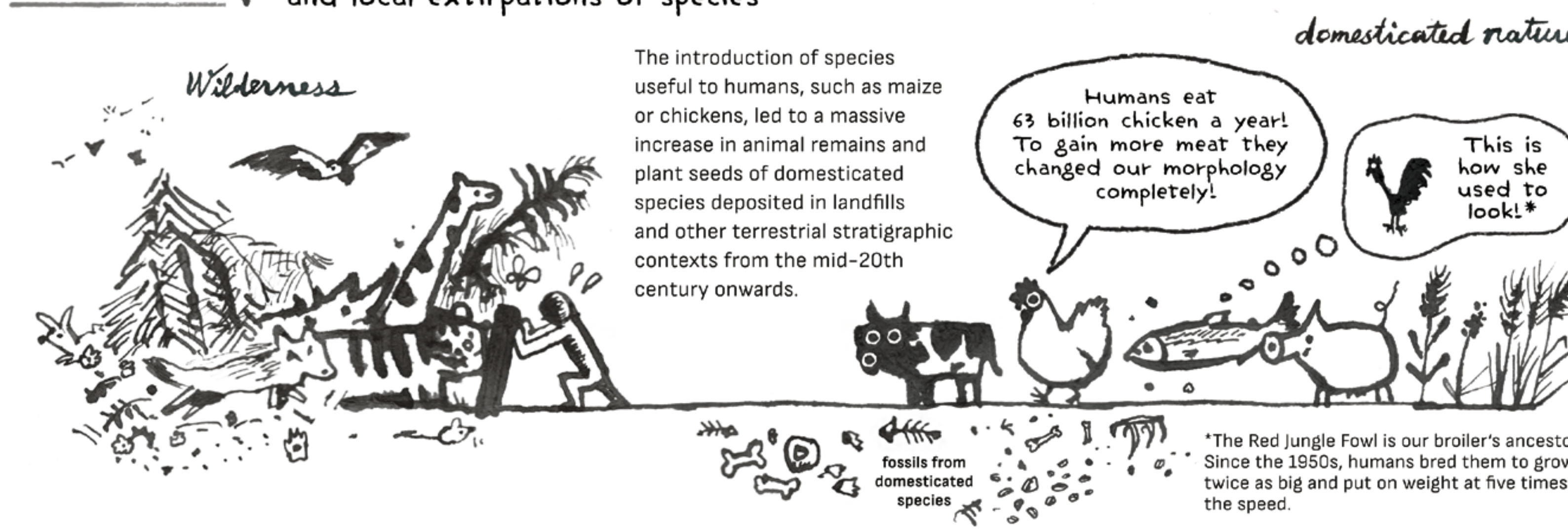
Introduced (non-native) species can be benign, beneficial or damaging (invasive) in their non-native ecology.



for example:
The Pacific oyster and the zebra mussel spread from Eurasia via ballast water discharged by large ships, displacing native shellfish over much of the planet.

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

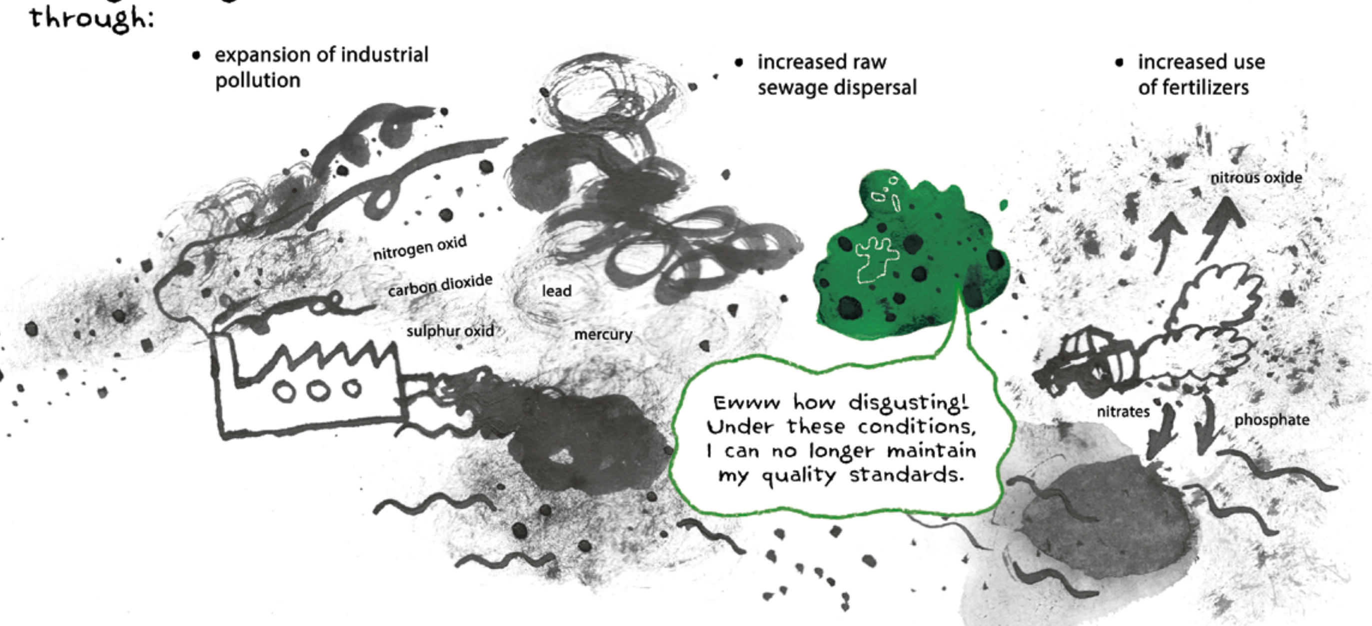
The introduction of species useful to humans, such as maize or chickens, led to a massive increase in animal remains and plant seeds of domesticated species deposited in landfills and other terrestrial stratigraphic contexts from the mid-20th century onwards.



*The Red Jungle Fowl is our broiler's ancestor. Since the 1950s, humans bred them to grow twice as big and put on weight at five times the speed.

Ecological degradation through:

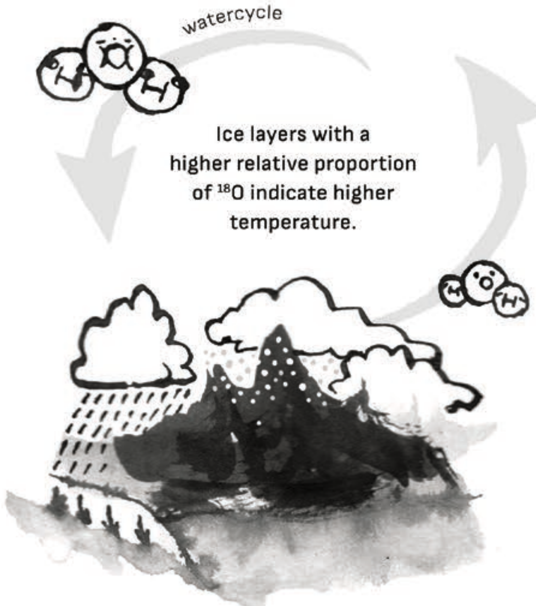
- expansion of industrial pollution
- increased raw sewage dispersal
- increased use of fertilizers



Additionally there are also…

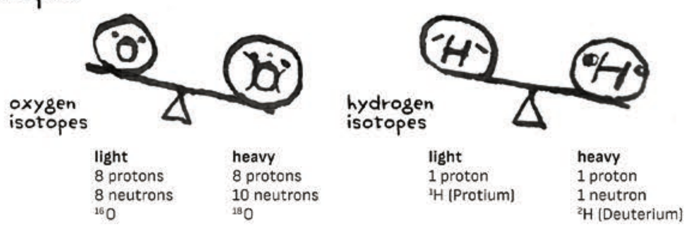
Geochemical markers

like:



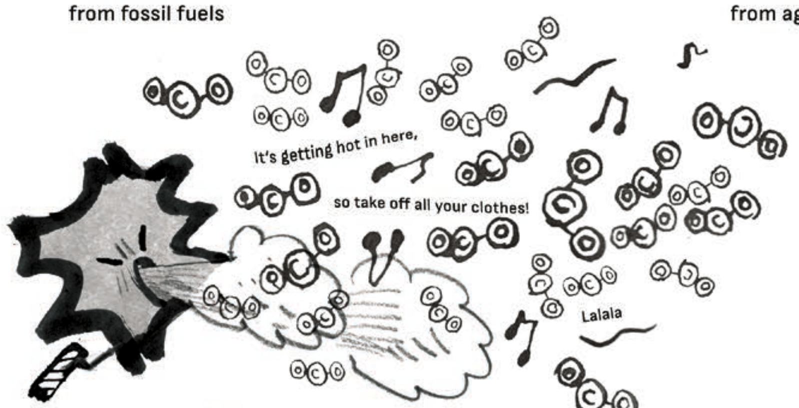
Oxygen and hydrogen isotopes

important climate change proxies



Atmospheric CO_2

from fossil fuels

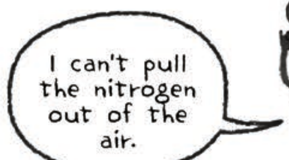


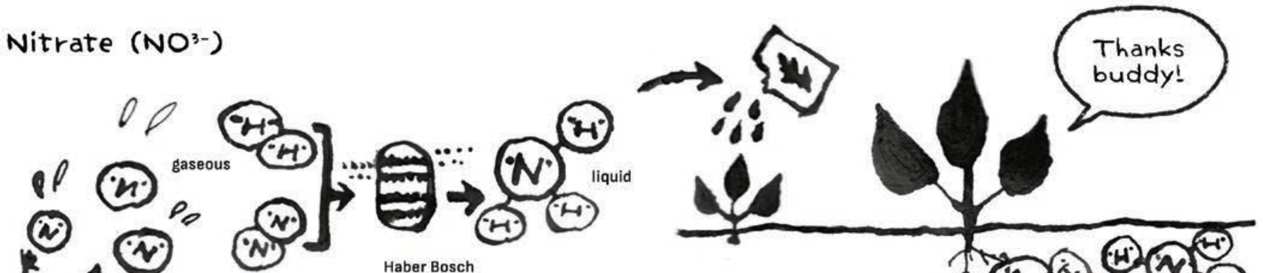
and methane

from agriculture

Nitrate (NO^{3-})

Concentrations went up mainly due to the production of fertilizers.

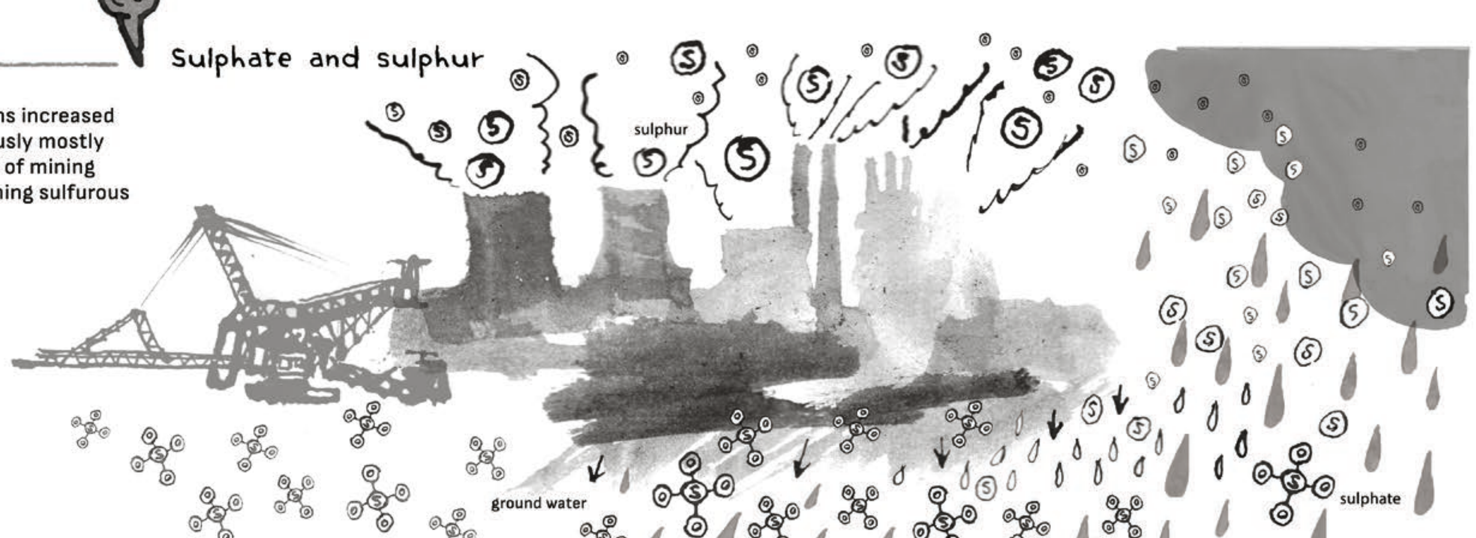




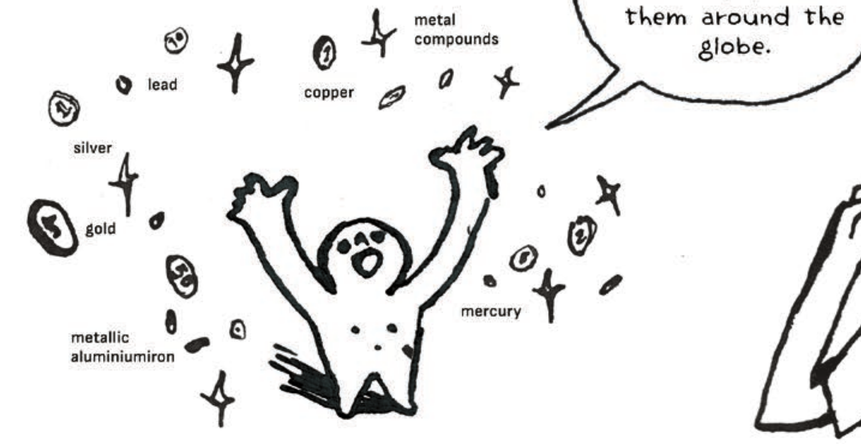
The *Haber Bosch* process transforms atmospheric nitrogen and hydrogen into ammonia, making nitrogen available to plants. The invention was a huge step for world nutrition.

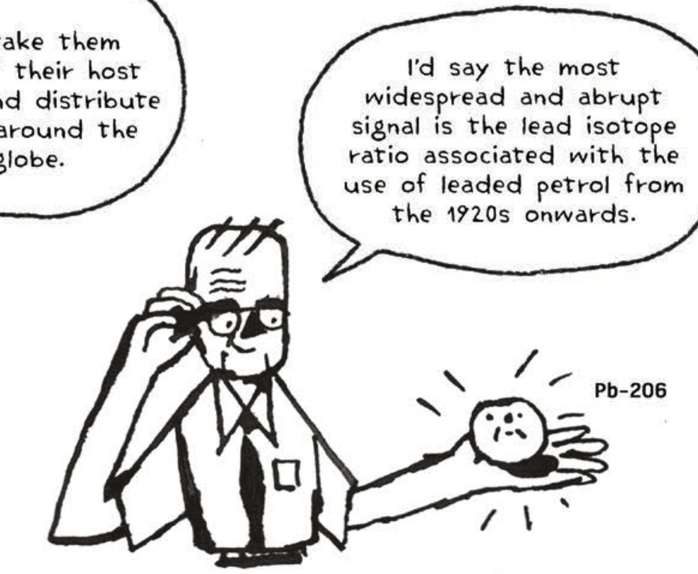
Sulphate and sulphur

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



Pure metals





Organic compounds

like the insecticide DDT

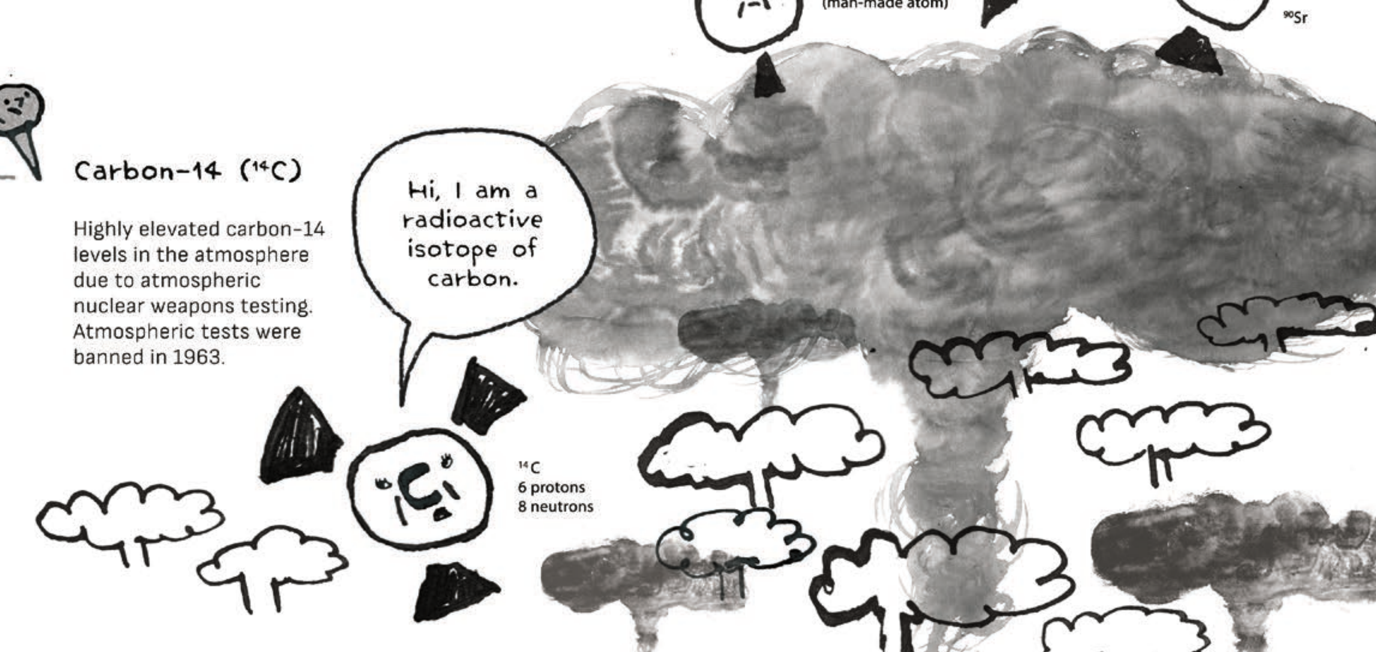
Persistent organic pollutants (POPs), including organochlorine pesticide (OCP) signals such as DDT, aldrin and dieldrin and various polychlorinated biphenyls (PCBs) and brominated flame retardants, e.g. polybrominated diphenyl ethers, PBDEs.

Anthropogenic radionuclides

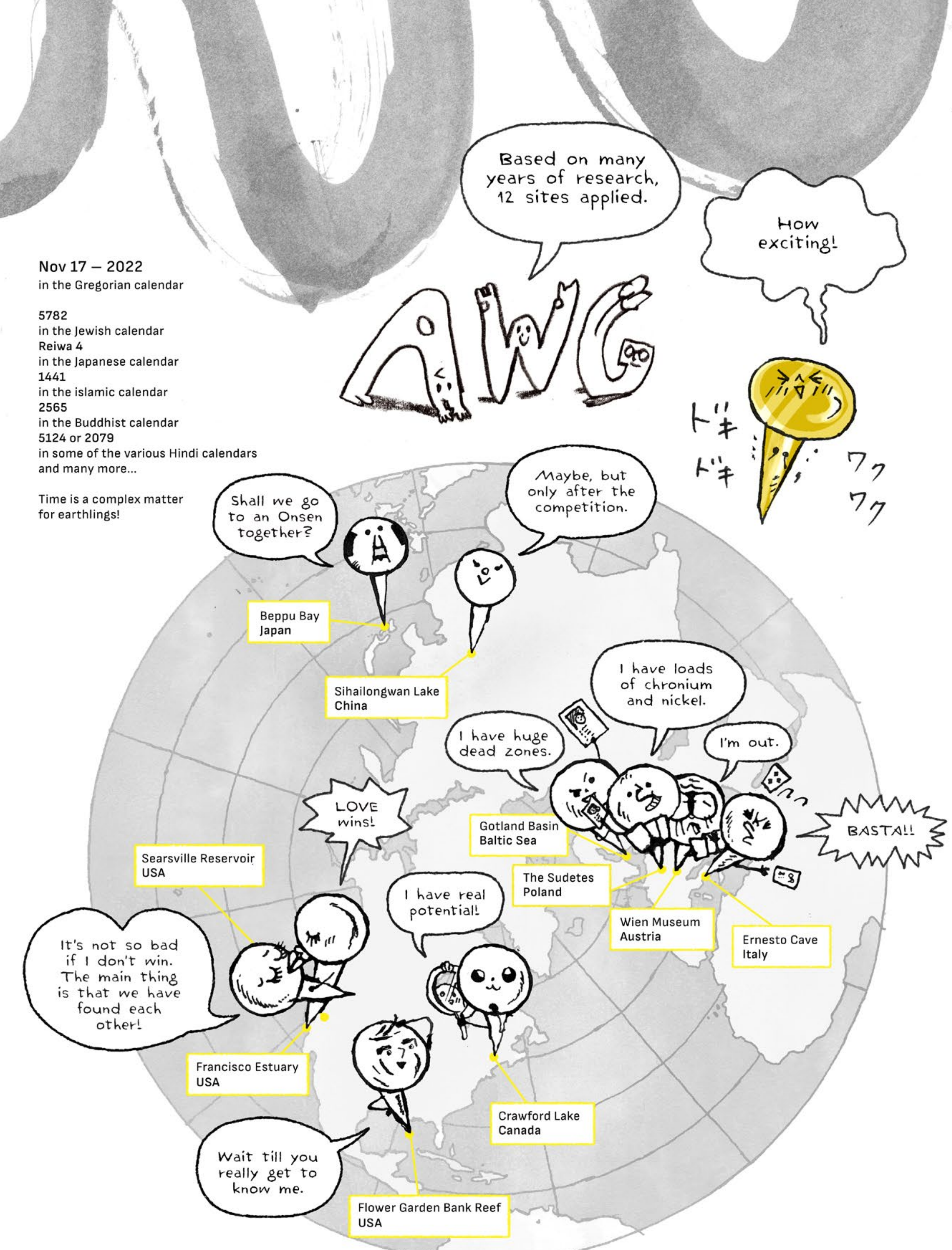
Radionuclides that are absent or rare in nature, such as plutonium-239, americium-241, caesium-137, strontium-90 and plutonium-240, etc. released by 543 atmospheric nuclear weapons tests.

Carbon-14 (^{14}C)

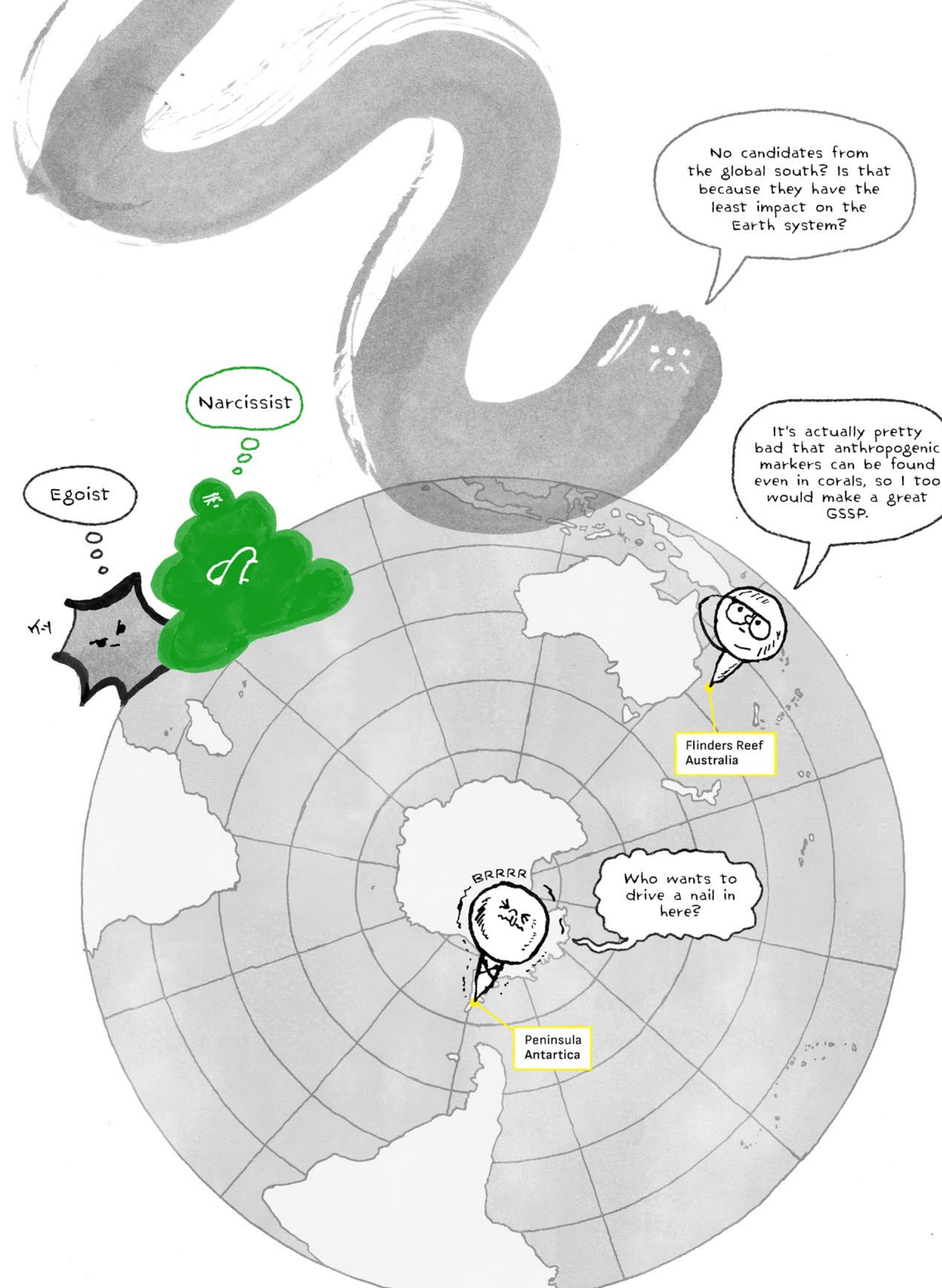
Highly elevated carbon-14 levels in the atmosphere due to atmospheric nuclear weapons testing. Atmospheric tests were banned in 1963.



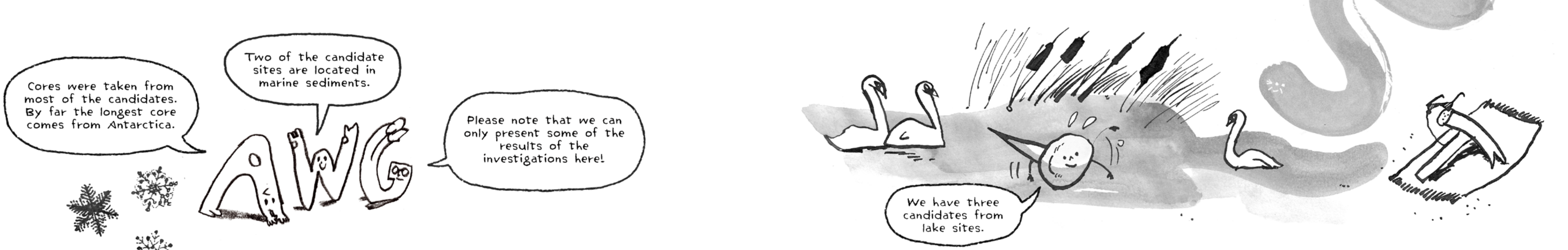
THE CANDIDATES



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.
AWG
How exciting!
ドキドキ
ワクワク
Shall we go to an Onsen together?
Maybe, but only after the competition.
Beppu Bay
Japan
Sihailongwan Lake
China
I have loads of chronium and nickel.
I have huge dead zones.
I'm out.
BASTA!!
LOVE wins!
Gotland Basin
Baltic Sea
Searsville Reservoir
USA
The Sudetes
Poland
Wien Museum
Austria
Ernesto Cave
Italy
I have real potential!
It's not so bad if I don't win. The main thing is that we have found each other!
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
BRRRR
Who wants to drive a nail in here?
Peninsula
Antartica



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

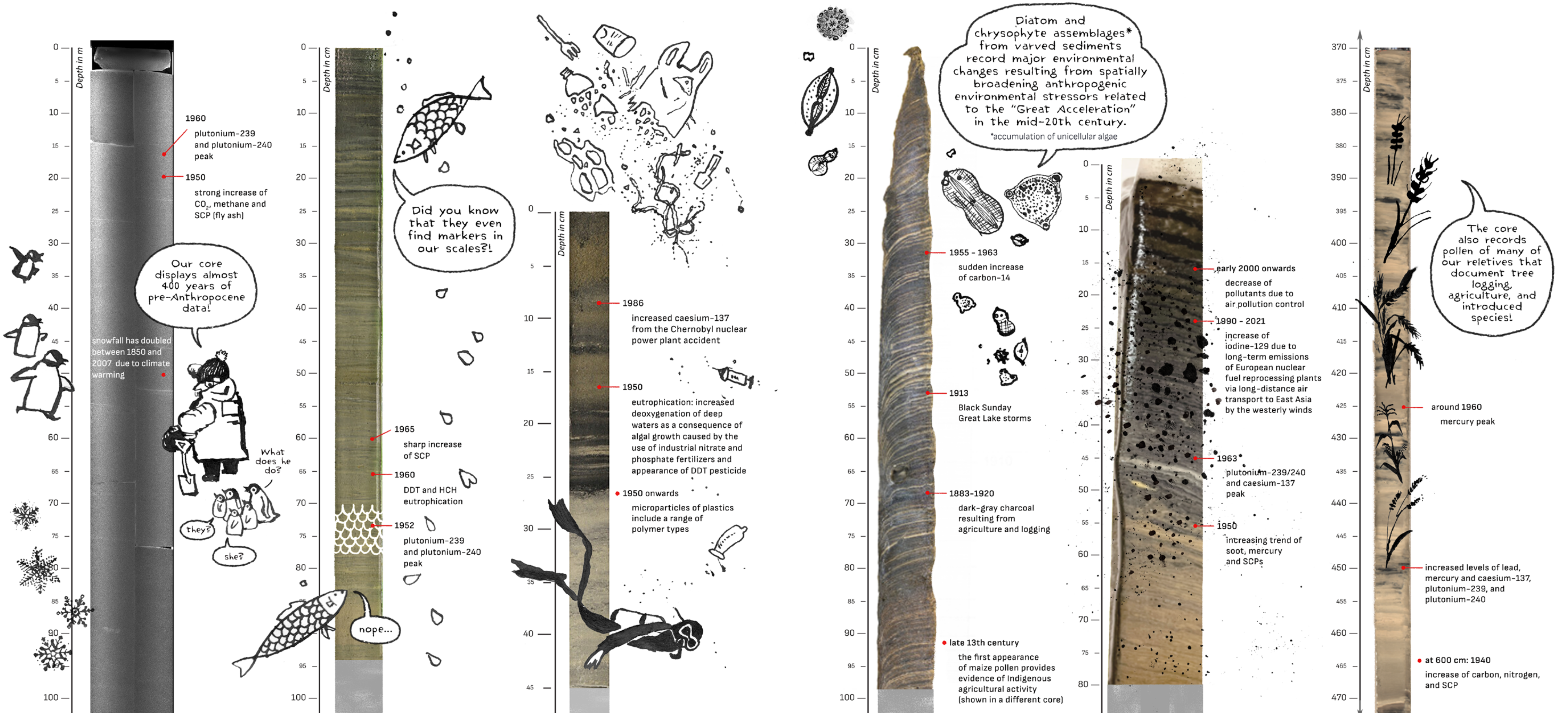
name – CRW19-2FT-B2
length – 98 cm
time – 1820 - 2019

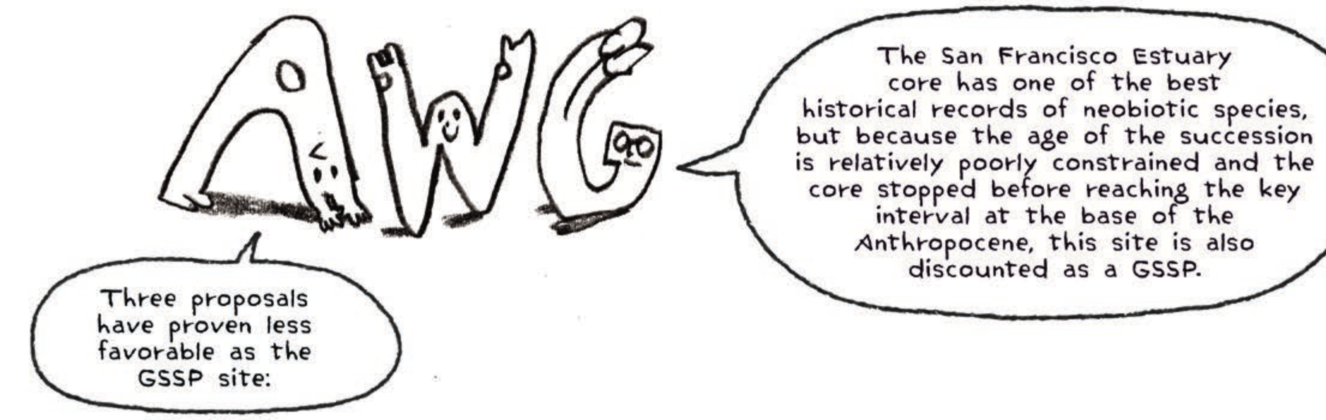
Sihailongwan Lake
China

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

Searsville Reservoir
USA

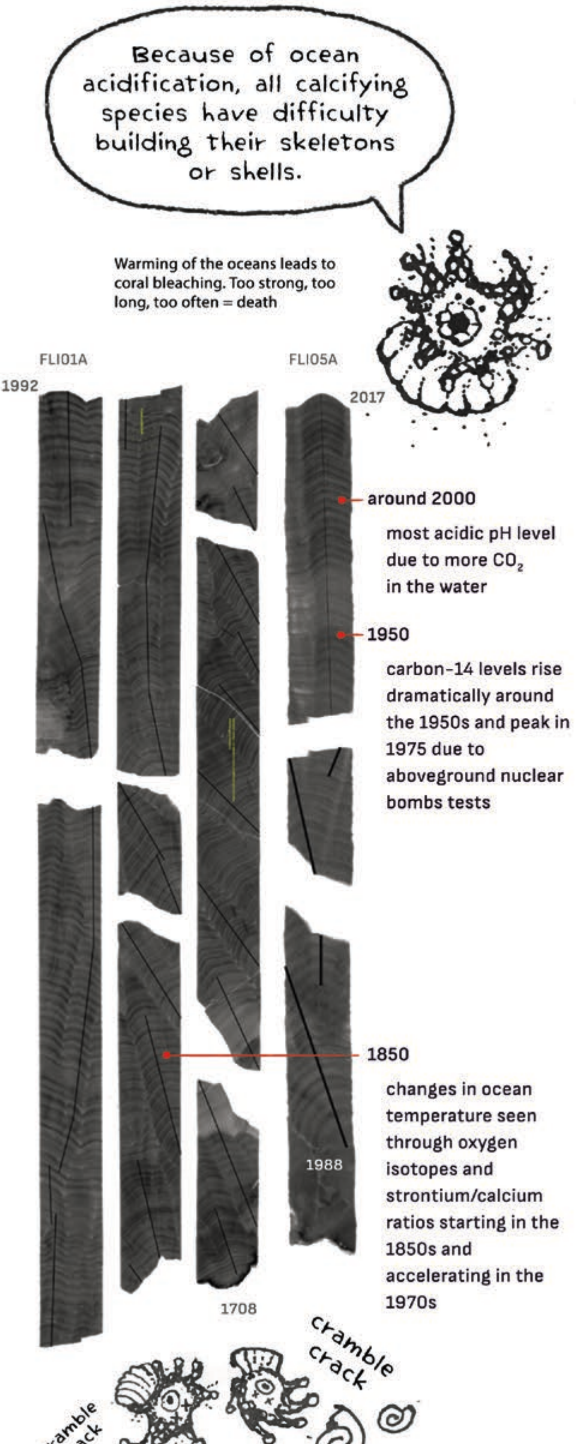
name – JRBP2018-VC01B
lenght – 944.5 cm
time – 1900-2018





Flinders Reef
Australia

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



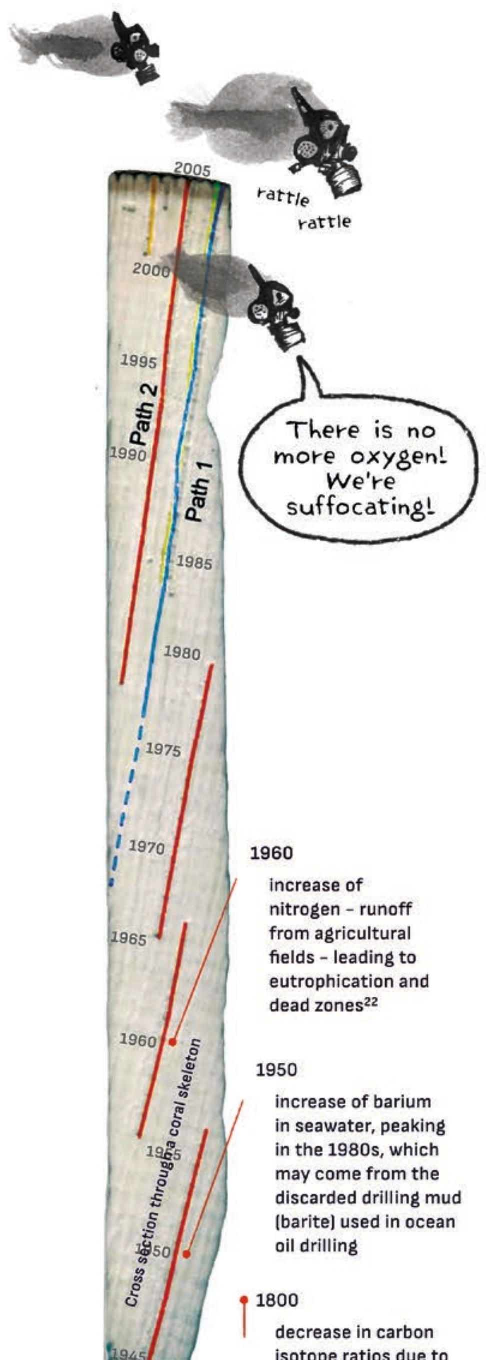
around 2000
most acidic pH level due to more CO_2 in the water

1950
carbon-14 levels rise dramatically around the 1950s and peak in 1975 due to aboveground nuclear bombs tests

1850
changes in ocean temperature seen through oxygen isotopes and strontium/calcium ratios starting in the 1850s and accelerating in the 1970s

West Flower Garden Bank Reef
USA

name – 0FWFGB3-1
length – 174 cm
time – 1752 - 2005



1960
increase of nitrogen - runoff from agricultural fields - leading to eutrophication and dead zones[22]

1950
increase of barium in seawater, peaking in the 1980s, which may come from the discarded drilling mud (barite) used in ocean oil drilling

1800
decrease in carbon isotope ratios due to fossil fuel combustion accelerating in the twentieth century with the burning of oil

The Sudetes
Poland

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

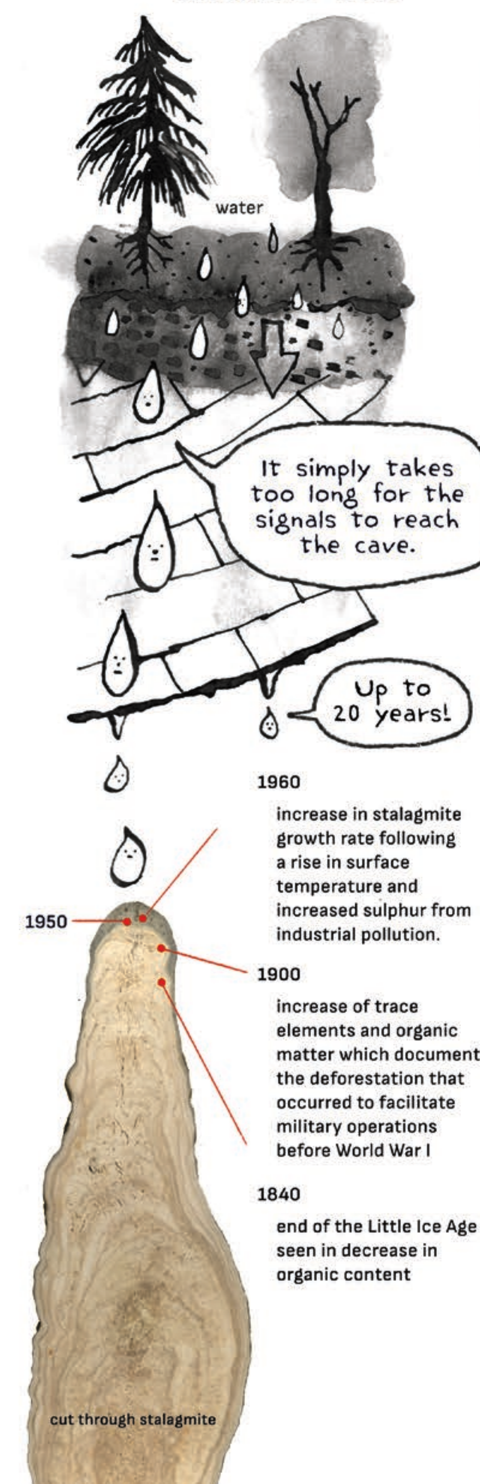
1970
chromium and nickel deposits peak in 1970 are indicative of regional industry in the Black Triangle area

1950
SCPs and SAPs from fossil fuel combustion appearing around 1950 and peaking in the 1970s

1920
chromium and nickel deposits—starting in the 1880s and peaking in 1920—are likely a result of nickel ore smelting and stainless steel production by the Krupp company in Germany.

Ernesto Cave
Italy

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



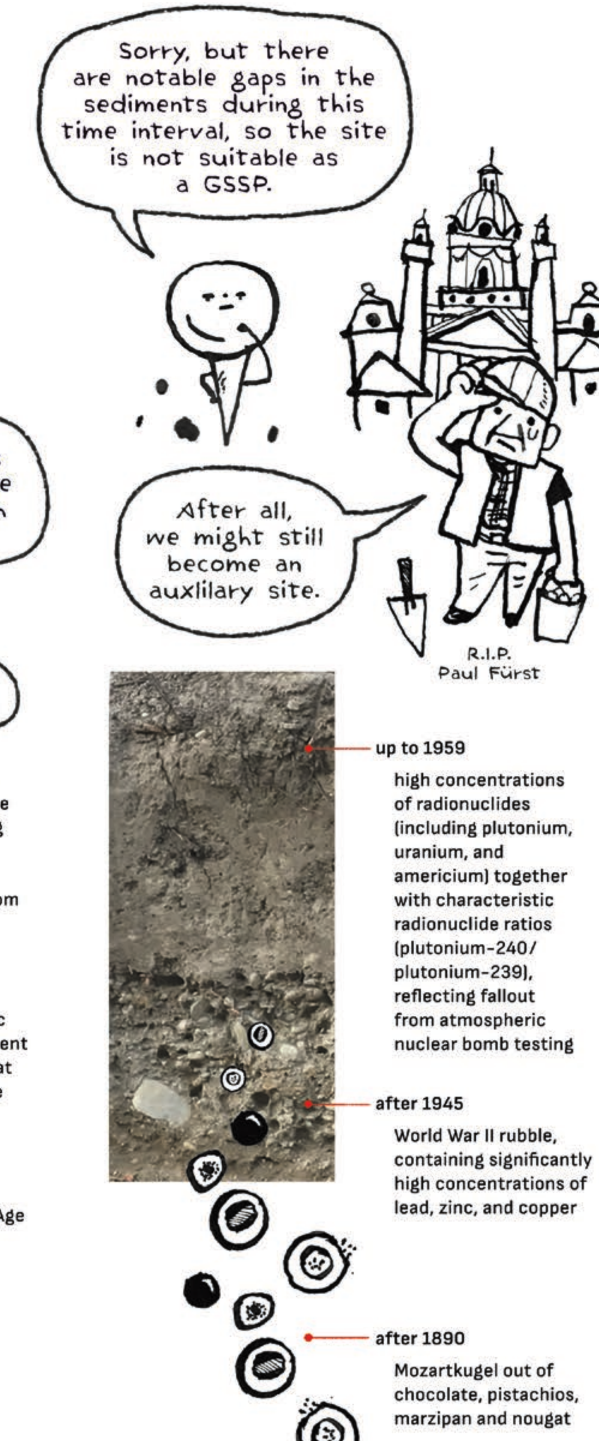
1960
increase in stalagmite growth rate following a rise in surface temperature and increased sulphur from industrial pollution.

1900
increase of trace elements and organic matter which document the deforestation that occurred to facilitate military operations before World War I

1840
end of the Little Ice Age seen in decrease in organic content

Karlsplatz, Vienna
Austria

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



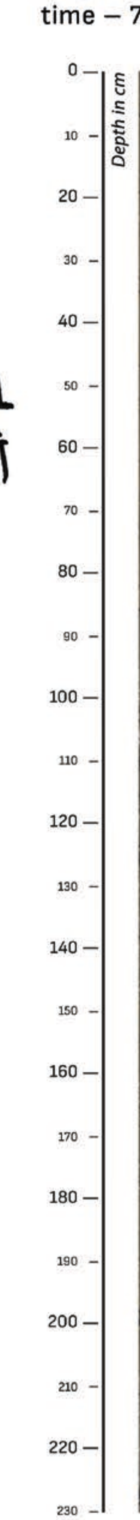
up to 1959
high concentrations of radionuclides (including plutonium, uranium, and americium) together with characteristic radionuclide ratios (plutonium-240/ plutonium-239), reflecting fallout from atmospheric nuclear bomb testing

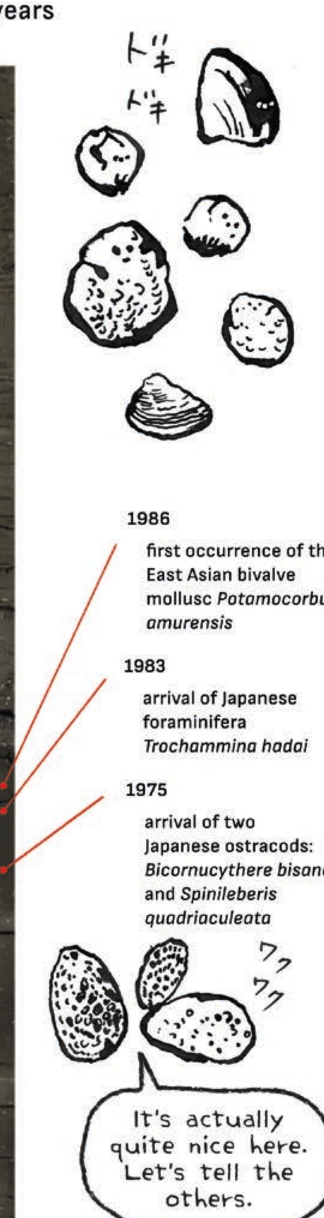
after 1945
World War II rubble, containing significantly high concentrations of lead, zinc, and copper

after 1890
Mozartkugel out of chocolate, pistachios, marzipan and nougat

San Francisco Estuary
USA

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



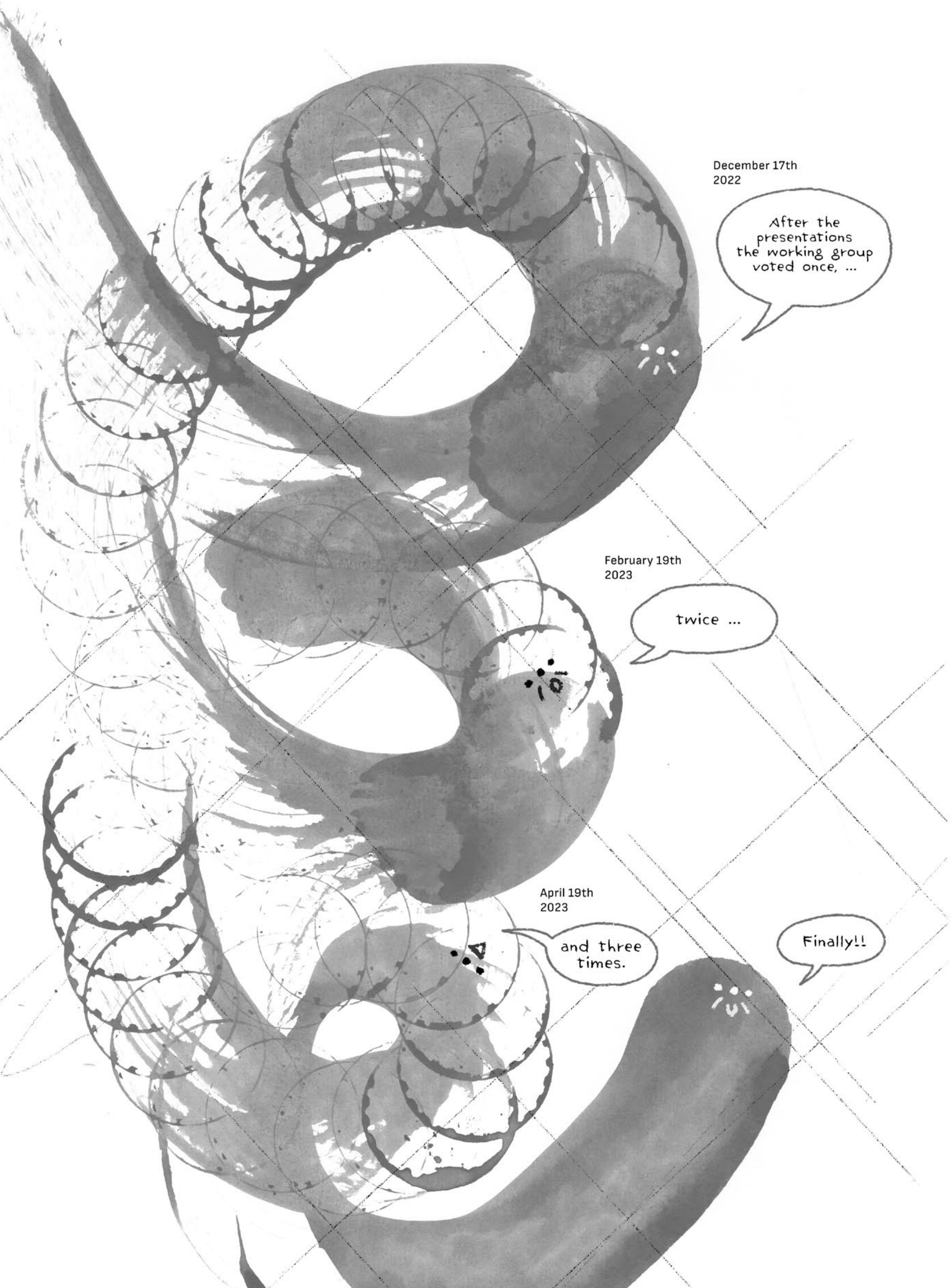


1986
first occurrence of the East Asian bivalve mollusc *Potamocorbula amurensis*

1983
arrival of Japanese foraminifera *Trochammina hadai*

1975
arrival of two Japanese ostracods: *Bicornucythere bisanensis* and *Spinileberis quadriaculeata*

1960
to end of 1970
significant rise in mercury levels—perhaps evidence of mining as well as mercury emitted into the atmosphere by fossil fuel combustion



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). In the best case this will take until summer 2024.


So, what do you think?
Well done!
What do you say, Will?
Paul! Good to see you again!

Cite this work as:

Hamann, Alexandra; Leinfelder, Reinhold; Shimizu, Maki (2023): Taming Time. A Golden Spike for the Anthropocene.- Refubium Open Access-Server, Freie Universität Berlin, http://dx.doi.org/10.17169/refubium-40617

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

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 (mintwissen.com)

illustrator — Maki Shimizu (makishimizu.com)

graphic designer — Inês Gomes Ferreira

copy editing — Yoko Hamann

in collaboration with — Freie Universität Berlin

Many thanks to

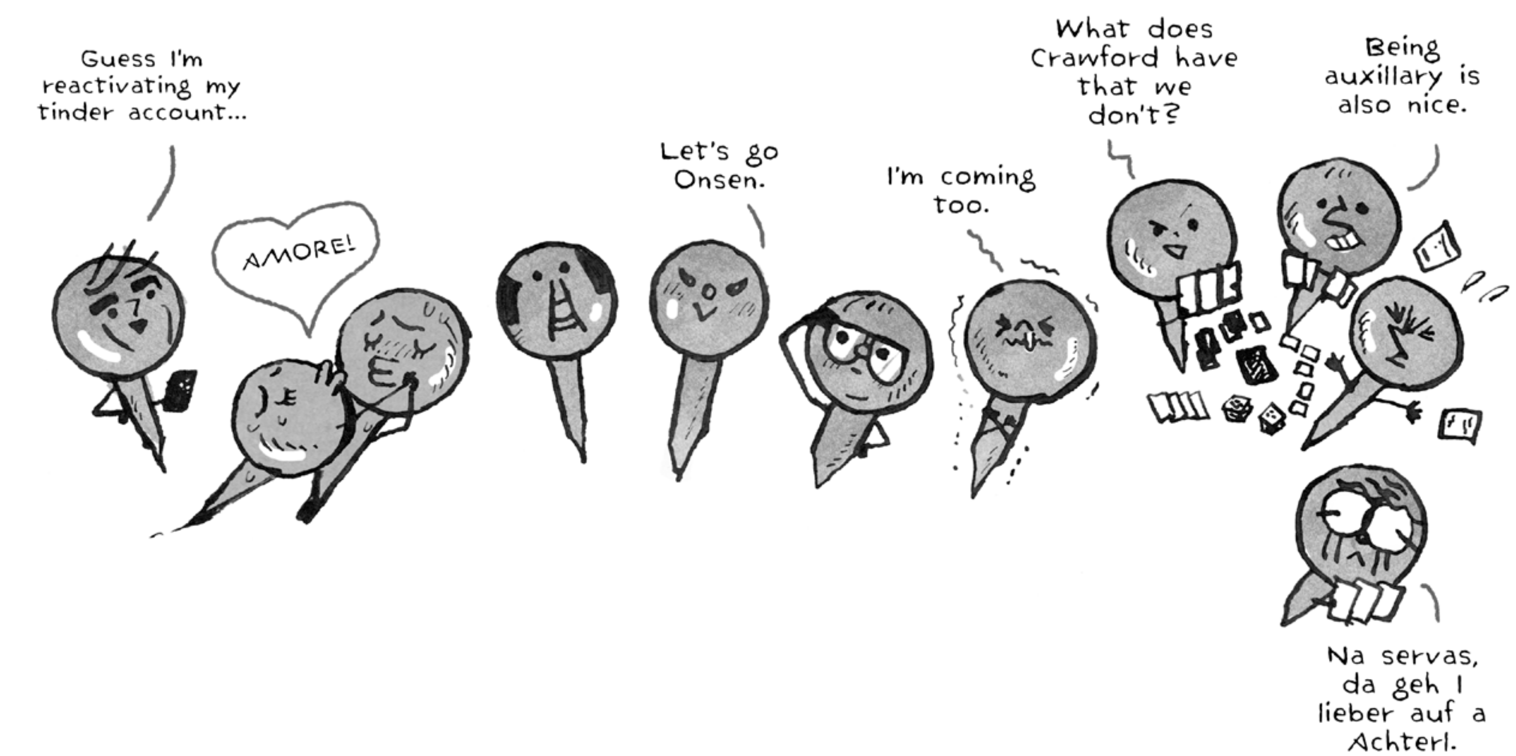
Marcia Bjornerud (author of the wonderful book „Timefulness: How Thinking Like a Geologist Can Help Save the World")

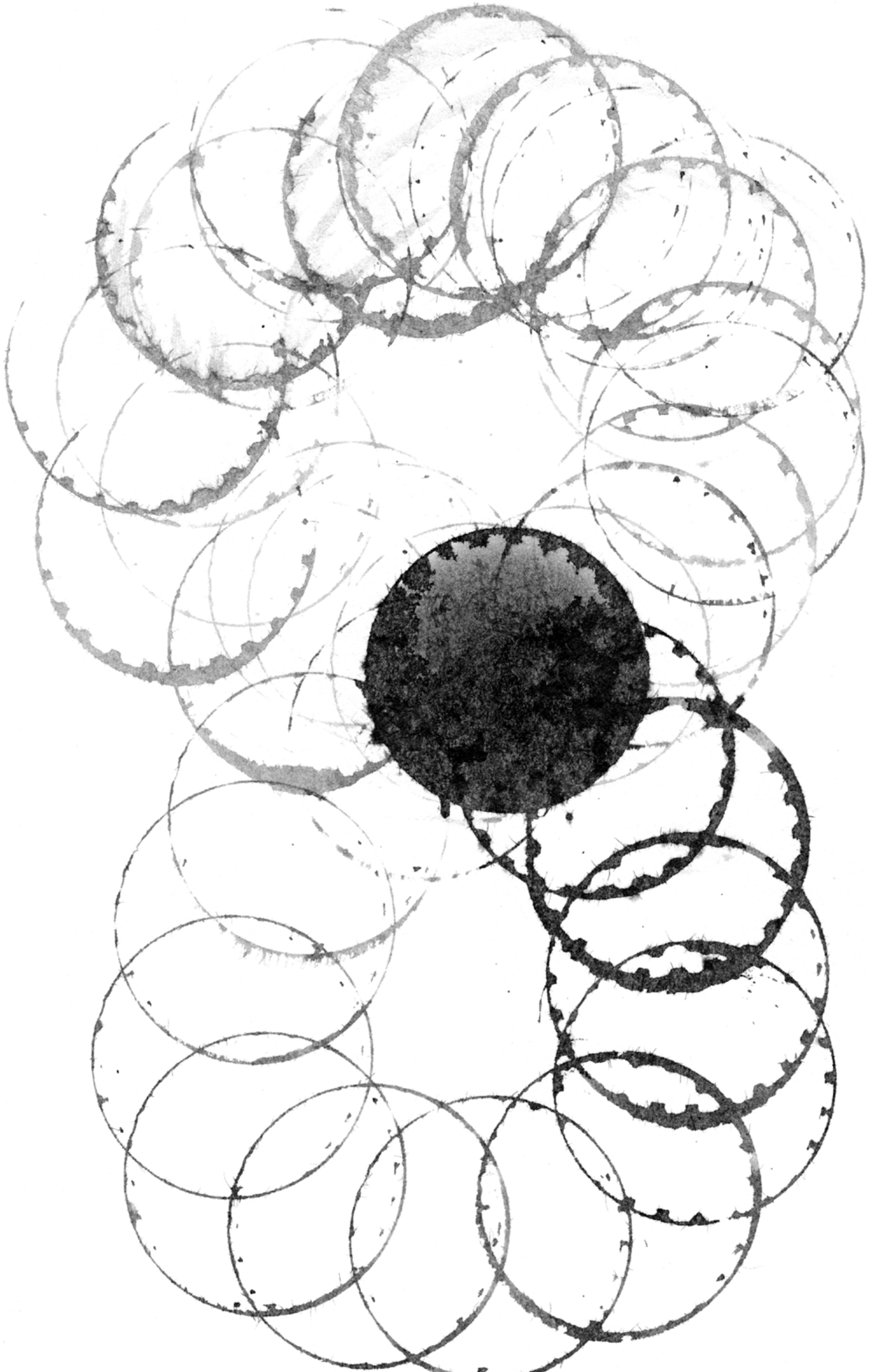
Simon Turner (member of the AWG)

Colin Waters (member of the AWG)

Mark Williams (member of the AWG)

Jan Zalasiewicz (member of the AWG)





EPILOGUE


View into the
Year 2100 CE
from different perspectives
TECHNOS' PARADISE
R.I.P.
BIOSPHERE
Buy yourself mechanical bodies.
Then you don't need anymore O_2, H_2O, Vitamin C.....
Thanks to you, we have finally become independent of nature.
We are married!
... and dependent on me. Heheheheh!
Wir machen Kinder!
HUNGER!
!?
No Jobs!
No Money!
What a toxic couple!
What do you know about that?
I hope this doesn't turn into a toxic throuple!
I LOVE YOU! Both!!
So do I.
Sorry. I don't feel it yet ...
EARTHLINGS' PARADISE
BIOS' PARADISE
Knead
knead
Zzzz...


Time will tell...
La
La
yeah, time!
La
La
La

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.

Notes

(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).

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 archeology, 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 holotype — 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 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 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 Fe_2O_3 has iron in its positive 3-valent form and oxygen in its preferred, hence negative 2-valent form ($2Fe^{3+}+3O^{2-}$). Owing to its red colour it is called hematite ("blood stone") when found as a natural mineral. FeO ($Fe^{2+}+O^{2-}$) 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, carnivores), 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 funghi 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 Cretacous-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.

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 stratotype 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.

Literature

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

- Marcia Bjornerud (2018),*Timefulness: How Thinking Like a Geologist Can Help Save the World*, Princeton University Press
- Michael Leddra (2010), *Time matters: Geology’s Legacy to Scientific Thought*, John Wiley & Sons
- Weltmaschine: https://www.weltmaschine.de (german)
- Martin Rudwick (2014) *Earth’s Deep History: How It Was Discovered and Why It Matters*, University of Chicago Press
- Steven Stanley (2014), *Earth System History*, W.H.Freeman & Co Ltd
- 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
- Leinfelder, R. (2020), *Das Anthropozän - mit offenem Blick in die Zukunft der Bildung*. In: Sippl, C., Rauscher, E. & Scheuch, M. (Hrsg.), Das Anthropozän lernen und lehren, S. 17-65, Innsbruck, Wien (Studien-Verlag). (Reihe: Pädagogik für Niederösterreich Band 9, ISBN 978-3-7065-5598-2). https://doi.org/10.53349/oa.2022.a2.130

Neolithic, industrialization, technosphere, energy, biomass

- Ellis, E.C. & Ramankutty, N. (2008). *Putting people in the map: anthropogenic biomes of the world*. Frontiers in Ecology and the Environment, 6, 439—447
- Syvitski, J., Waters, C.N., Day, J., Milliman, J.D., Summerhayes, C., Steffen, W., Zalasiewicz, J., Cearreta, A., Galuszka, A., Hajdas,I., Head, M.J., Leinfelder, R., McNeill, J.R., Poirier, C., Rose, N., Shotyk, W., Wagreich, M. & Williams, M. (2020), *Extraordinary human energy consumption and resultant geological impacts beginning around 1950 CE initiated the proposed Anthropocene Epoch*. Communications Earth & Environment, 1 (32), https://doi.org/10.1038/s43247-020-00029-y
- John L. Brooke (2014), *Climate Change and the Course of Global History. A Rough Journey*, Cambridge University Press
- Leinfelder, R. (2022), *Auch Maschinen haben Hunger - Biosphäre als Modell für die Technosphäre im Anthropozän*.- In: Sippl, C. & Rauscher, E. (Hrsg.), Kulturelle Nachhaltigkeit lernen und lehren. Reihe: Pädagogik für Niederösterreich, Band 11, S 489-521. Innsbruck, Wien (StudienVerlag). https://doi.org/10.53349/oa.2022.a2.110
- Bar-On, Y.M., Phillips, R., Milo, R. (2018). *The biomass distribution on Earth*. Proceedings of the National Academy of Sciences, 115 (25), 6506—6511, doi: 10.1073/pnas.1711842115
- Greenspoon, L., Krieger, E., Sender, R., Rosenberg, Y., Bar-On, Y.M., Moran, U., Antman, T., Meiri, S., Roll, U., Noor, E. and Milo, R. (2023), *The global biomass of wild mammals*. PNAS , 120/10, https://doi.org/10.1073/pnas.2204892120
- Zalasiewicz, J., Williams, M., Waters, C.N., Barnosky, A.D., Palmesino, J., Rönnskog, A.S., Edgeworth, M., Neil, C., Cearreta, A., Crutzen, E., Fairchild, I.J., Grinevald, J., Haff, P., Ivar do Sul, J.A., Jeandel, C., Leinfelder, R., McNeill, J.R., Odada, E., Oreskes, N., Price, S.J., Revkin, A., Steffen, W., Summerhayes, C., Vidas, D., Wing, S. & Wolfe, A.P. (2017). *Scale and diversity of the physical technosphere: A geological perspective*. The Anthropocene Review, 4 (1), 9—22 doi:10.1177/2053019616677743
- Leinfelder, R. (2021). *The human made mass* — Der Anthropozäniker, 9 pp, Refubium, Freie Universität Berlin, https://refubium.fu-berlin.de/handle/fub188/32375

Paul Crutzen, Anthropocene

- Crutzen, P.J. & Stoermer, E.F. (2000). *The "Anthropocene"*. Global Change Newsletter, 41, 17–18.
- Crutzen, P.J. (2002). *Geology of mankind*. Nature, 415, 23.

Anthropocene (AWG)

- Adeney Thomas, L., Williams, M. & Zalasiewicz, J. (2020), *The Anthropocene: A Multidisciplinary Approach*. 288pp, Wiley.
- Waters, C.N., Zalasiewicz, J., Summerhayes, C., Barnosky, A.D., Poirier, C., Galuszka, A., Cearreta, A., Edgeworth, M., Ellis, E.C., Ellis, M., Jeandel, C., Leinfelder, R., McNeill, J.R., Richter, D. de B., Steffen, W., Syvitski, J., Vidas, D., Wagreich, M., Williams, M., Zhisheng, A., Grinevald, J., Odada, E., Oreskes, N. & Wolfe, A.P. (2016). *The Anthropocene is functionally and stratigraphically distinct from the Holocene*. Science, 351 (6269), https://doi.org/10.1126/science.aad2622
- Williams, M., Zalasiewicz, J., Waters, C.N., Edgeworth, M., Bennett, C., Barnosky, A.D., Ellis, E.C., Ellis, M.A., Cearreta, A., Haff, P.K., Ivar do Sul, J.A., Leinfelder, R., McNeill, J.R., Odada, E., Oreskes, N., Revkin, A., Richter, D. d., Steffen, W., Summerhayes, C., Syvitski, J.P., Vidas, D., Wagreich, M., Wing, S.L., Wolfe, A.P. & Zhisheng, A. (2016). *The Anthropocene: a conspicuous stratigraphical signal of anthropogenic changes in production and consumption across the biosphere*. Earth's Future, 4, 34—53, https://doi.org/10.1002/2015EF000339
- Williams, M., Zalasiewicz, J., Waters, C., Himson, S., Summerhayes, C., Barnosky, A., Leinfelder, R. (2018). *The palaeontological record of the Anthropocene*. Geology Today, 34 (5), 188—193, https://doi.org/10.1111/gto.12246
- Zalasiewicz, J., Waters, C., Williams, M. & Summerhayes, C. (eds.) (2019a). *The Anthropocene as a Geological Time Unit. A Guide to the Scientific Evidence and Current Debate*. Cambridge: Cambridge UP.
- Zalasiewicz, J., Waters, C.N., Ellis, E.C., Head, M.J., Vidas, D., Steffen, W., Adeney Thomas, J., Horn, E., Summerhayes, C.P., Leinfelder, R., McNeill, J. R., Gałuszka, A., Williams, M., Barnosky, A.D., Richter, D. deB., Gibbard, P.L., Syvitski, J., Jeandel, C., Cearreta, A., Cundy, A.B., Fairchild, I.J., Rose, N.L., Ivar do Sul, J.A., Shotyk, W., Turner, S., Wagreich, M. & Zinke, J. (2021). *The Anthropocene: comparing its meaning in geology (chronostratigraphy) with conceptual approaches arising in other disciplines*. Earth's future, EFT2777, https://doi.org/10.1029/2020EF001896
- Jan Zalasiewicz, Colin Waters, Mark Williams, Colin Summerhayes, (eds)(2019). *The Anthropocene as a Geological Time Unit. A Guide to the Scientific Evidence and Current Debate*, 382 pp. Cambridge (Cambridge University Press)
- AWG-Working Group: http://quaternary.stratigraphy.org/working-groups/anthropocene/
- Steffen, W., Broadgate, W., Deutsch, L., Gaffney, O., Ludwig, C. (April 2015), *The trajectory of the Anthropocene: The Great Acceleration*. The Anthropocene Review. 2 (1): 81—98. https://doi.org/10.1177/2053019614564785
- Steffen, W., Leinfelder, R., Zalasiewicz, J., Waters, C.N., Williams, M., Summerhayes, C., Barnosky, A.D., Cearreta, A., Crutzen, P., Edgeworth, M., Ellis, E.C., Fairchild, I.J., Galuszka, A., Grinevald, J., Haywood, A., Sul, J.I.d., Jeandel, C., McNeill, J.R., Odada, E., Oreskes, N., Revkin, A., Richter, D.d.B., Syvitski, J., Vidas, D., Wagreich, M., Wing, S.L., Wolfe, A.P. & Schellnhuber, H.J. (2016). *Stratigraphic and Earth System Approaches to Defining the Anthropocene*. Earth's Future, 4 (8), 324—345, https://doi.org/10.1002/2016EF000379
- Head, M.J., Steffen, W., Fagerlind, D., Waters, C.N., Poirier, C., Syvitski, J., Zalasiewicz, J., Barnosky, A.D., Cearreta, A., Jeandel, C., Leinfelder, R., McNeill, J.R., Rose, N.L., Summerhayes, C., Wagreich, M., Zinke, J. (2022), *The Great Acceleration is real and provides a quantitative basis for the proposed Anthropocene Series/Epoch*. Episodes 2022; 45(4): 359-376, https://doi.org/10.18814/epiiugs/2021/021031
- Waters, C.N., Zalasiewicz, J., Summerhayes, C., Fairchild, I.J., Rose, N.L., Loader, N.J., Shotyk, W., Cearreta, A., Head, M.J., Syvitski, J.M.P., Williams, M., Barnosky, A.D., Zhisheng, A., Leinfelder, R., Jeandel, C., Galuszka, A., Ivar do Sul, J.A., Gradstein, F. Steffen, W., McNeill, J.R., Wing, S., Poirier, C. & Edgeworth, M. (2018). *Global Boundary Stratotype Section and Point (GSSP) for the Anthropocene Series: Where and how to look for potential candidates*. Earth Science Reviews, 178, 379—429, https://doi.org/10.1016/j.earscirev.2017.12.016
- Waters, C.N., Turner, S.D., Zalasiewicz, J., Head, M.J. (eds) (2023), Special Issue: *Global boundary Stratotype Section and Point for the Anthropocene series*. The Anthropocene Review. Volume 10 Issue 1, April 2023

Epilogue

- Leinfelder, R. (2023). *Die Zukunft als Skalen- und Perspektivenproblem - Tiefenzeit-Einsichten, Szenarien und Partizipation als Grundlage für Futures Literacy.* In: Sippl, C., Brandhofer, G. & Rauscher, E. (eds.), Futures Literacy - Zukunft lernen und lehren. Pädagogik für Niederösterreich, Bd. 13, 35-60. Innsbruck, Innsbruck, Vienna (StudienVerlag), https://doi.org/10.53349/oa.2022.a2.170 (for volume)

some more graphic novels on the Anthropocene

- Hamann A., Leinfelder R., Trischler H., Wagenbreth H. (2014), *Anthropocene Milestones: Illustrating the Path to the Age of Humans* (engl. version see https://www.carsoncenter.uni-muenchen.de).
German version: *Anthropozän — 30 Meilensteine auf dem Weg in ein neues Erdzeitalter, Eine Comic-Anthologie*, Deutsches Museum, 2014, ISBN 978-3-940396-45-7
- Hamann A., Zea-Schmidt C., Leinfelder R. (2013), *The Great Transformation. Climate — Can we beat the heat?*, German Advisory Council on Global Change WBGU, download pdf: https://www.wbgu.de
German version: *Die Große Transformation. Klima — Kriegen wir die Kurve?*, Jacoby & Stuart, 2013, see also www.die-grosse-transformation.de
- Leinfelder,R., HamannA., Kirstein J., Schleunitz M. (2016), *Eating Anthropocene. Curd Rice, Bienenstich and a Pinch of Phosphorus — Around the World in Ten Dishes,* Springer-Verlag Berlin/Heidelberg, 2016, ISBN 978-3-662-50402-4 (http://anthropocene-kitchen.com)
German version: *Die Anthropozän-Küche: Matooke, Bienenstich und eine Prise Phosphor — in zehn Speisen um die Welt,* Springer-Verlag Berlin/Heidelberg, 2016, ISBN 978-3-662-49871-2
- Laibl, M., Jegelka,C. & Leinfelder, R. (2022), *WErde wieder wunderbar. 9 Wünsche fürs Anthropozän. Ein Mutmachbuch*, 64 S., Edition Nilpferd, G&G-Kinderbuchverlag (Wien). ISBN: 978-3-7074-5272-3 (excerpts: https://www.ph-noe.ac.at)