European Geosciences Union

GIFT – Geosciences Information For Teachers

How volcanic eruptions caused Earth's greatest mass extinction…

…and what that tells us about its future

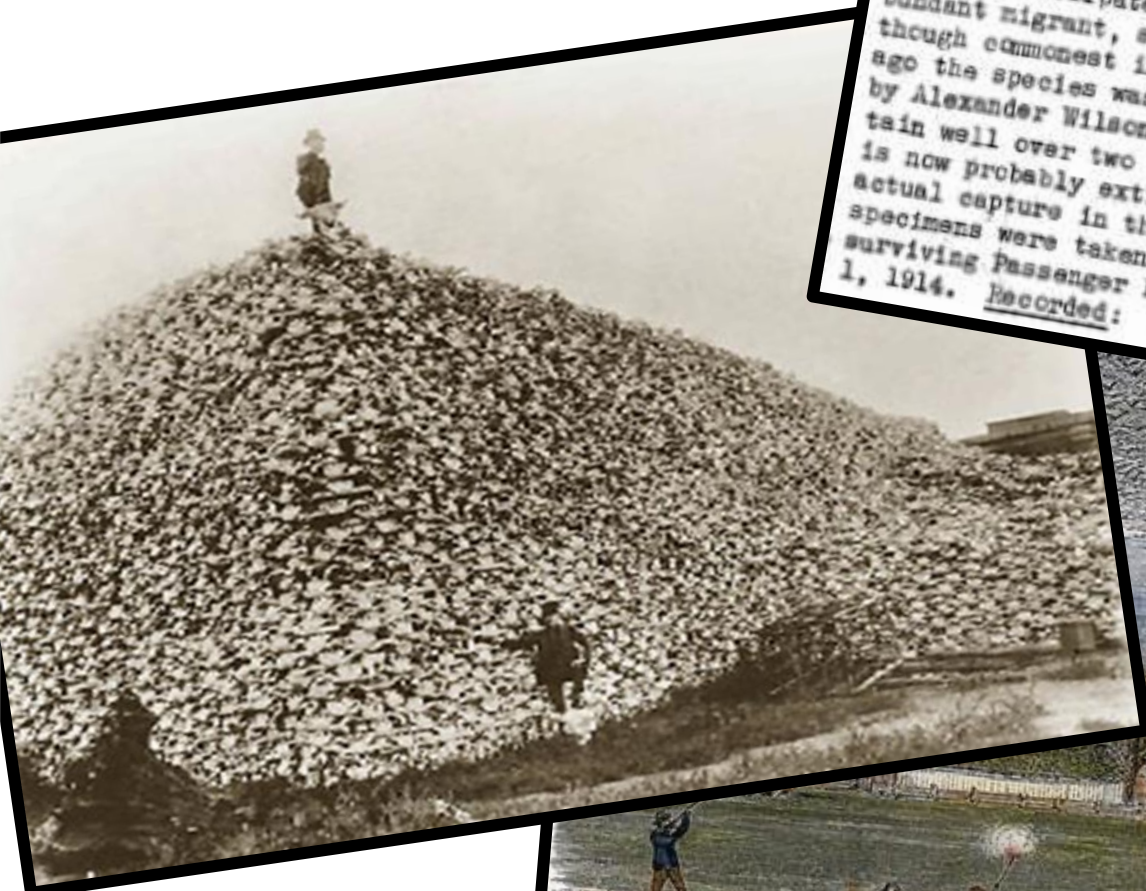
David Bond,
University of Hull

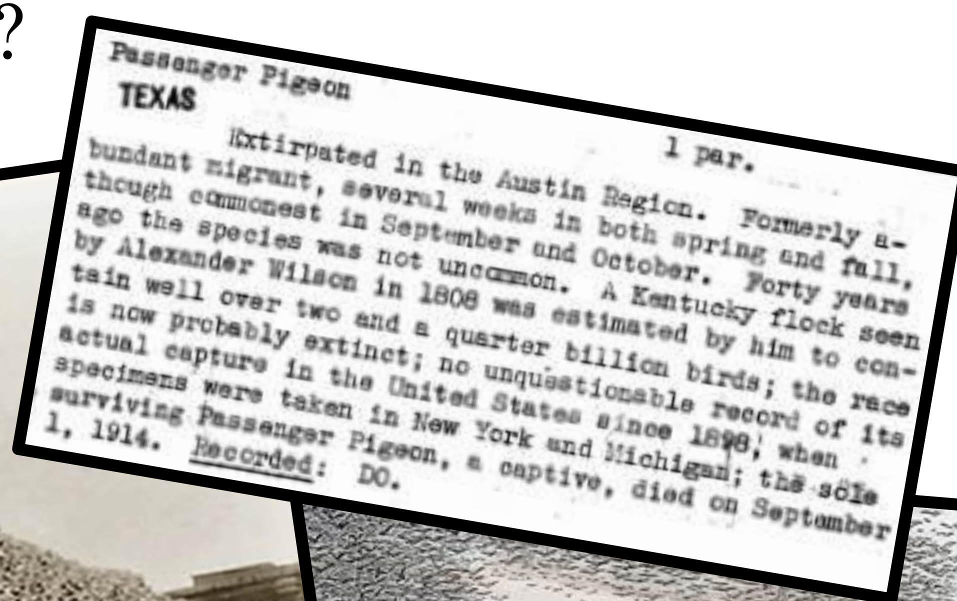
European Geosciences Union,
Tuesday 10th April, 2018

NERC SCIENCE OF THE ENVIRONMENT

UNIVERSITY OF HULL

So, what is extinction?





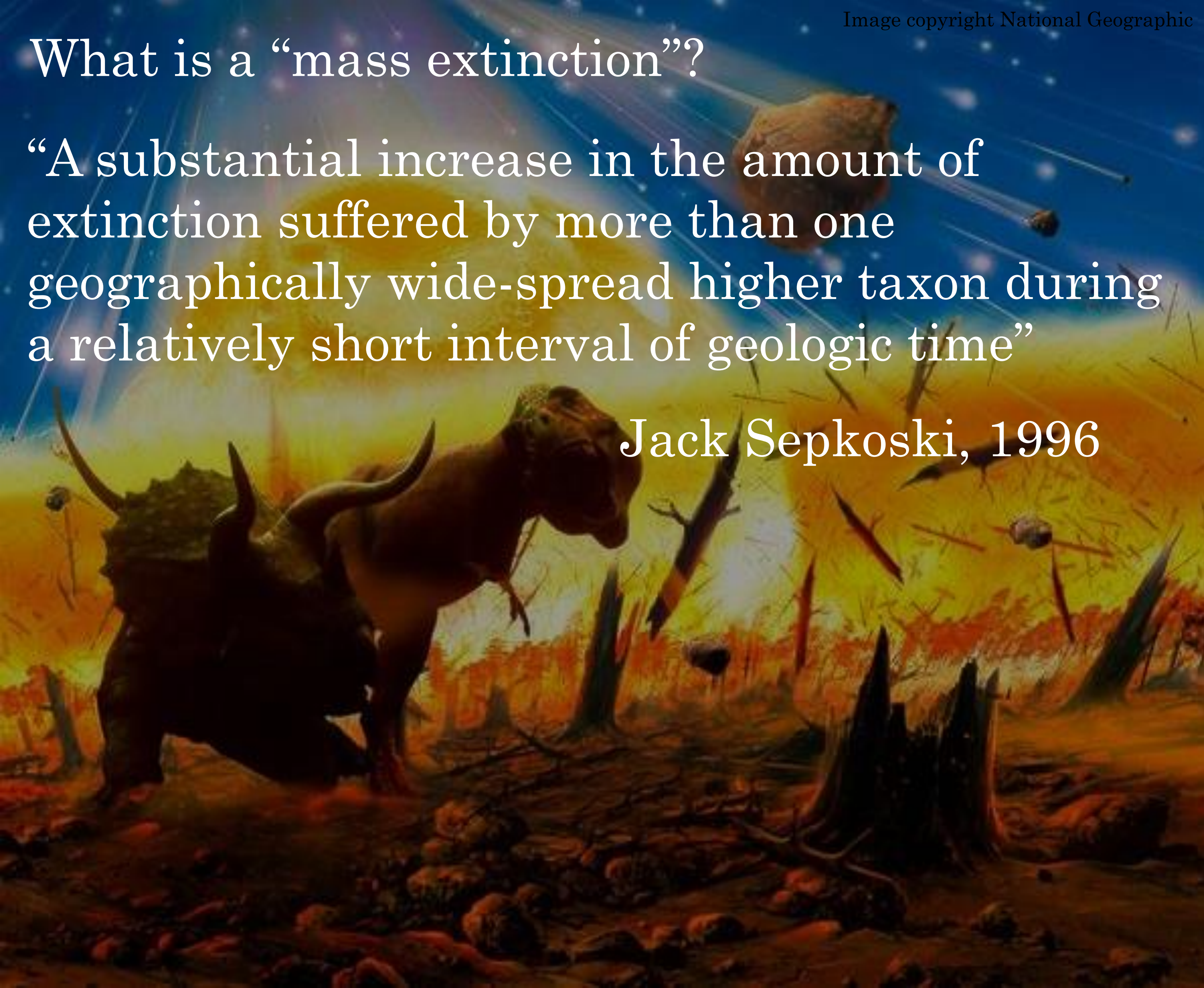
Passenger Pigeon
TEXAS

1 par.

Extirpated in the Austin Region. Formerly abundant migrant, several weeks in both spring and fall, though commonest in September and October. Forty years ago the species was not uncommon. A Kentucky flock seen by Alexander Wilson in 1808 was estimated by him to contain well over two and a quarter billion birds; the race is now probably extinct; no unquestionable record of its actual capture in the United States since 1898, when specimens were taken in New York and Michigan; the sole surviving Passenger Pigeon, a captive, died on September 1, 1914. Recorded: DO.

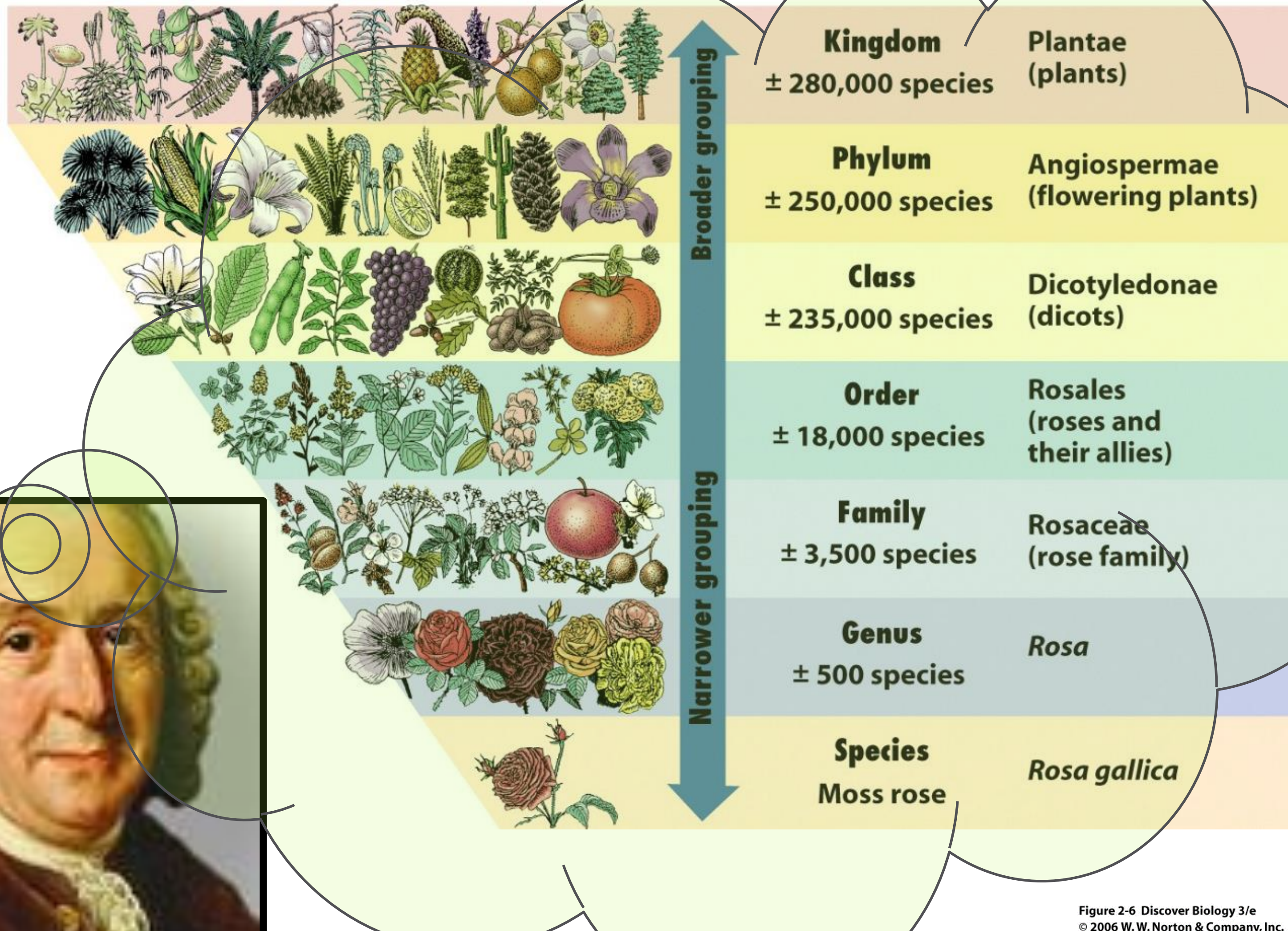
Image copyright National Geographic

What is a "mass extinction"?



"A substantial increase in the amount of extinction suffered by more than one geographically wide-spread higher taxon during a relatively short interval of geologic time"

Jack Sepkoski, 1996



Carl Linnaeus, botanist, 1707-1778

Time 1 | Time 2

Family = Motorcaridae
Genera = Forda
Species = *sierra, fiesta, t, focus, capri, transit*

Family = Motorcaridae
Genera = Forda
Species = *fiesta, focus, transit, S max, ka, 350*

You have to kill a lot of species before you kill a genus / family

and actually Ford's have radiated – no diversity loss

Jack Sepkoski (l) and Dave Raup: pioneers in extinction studies in the 1980s

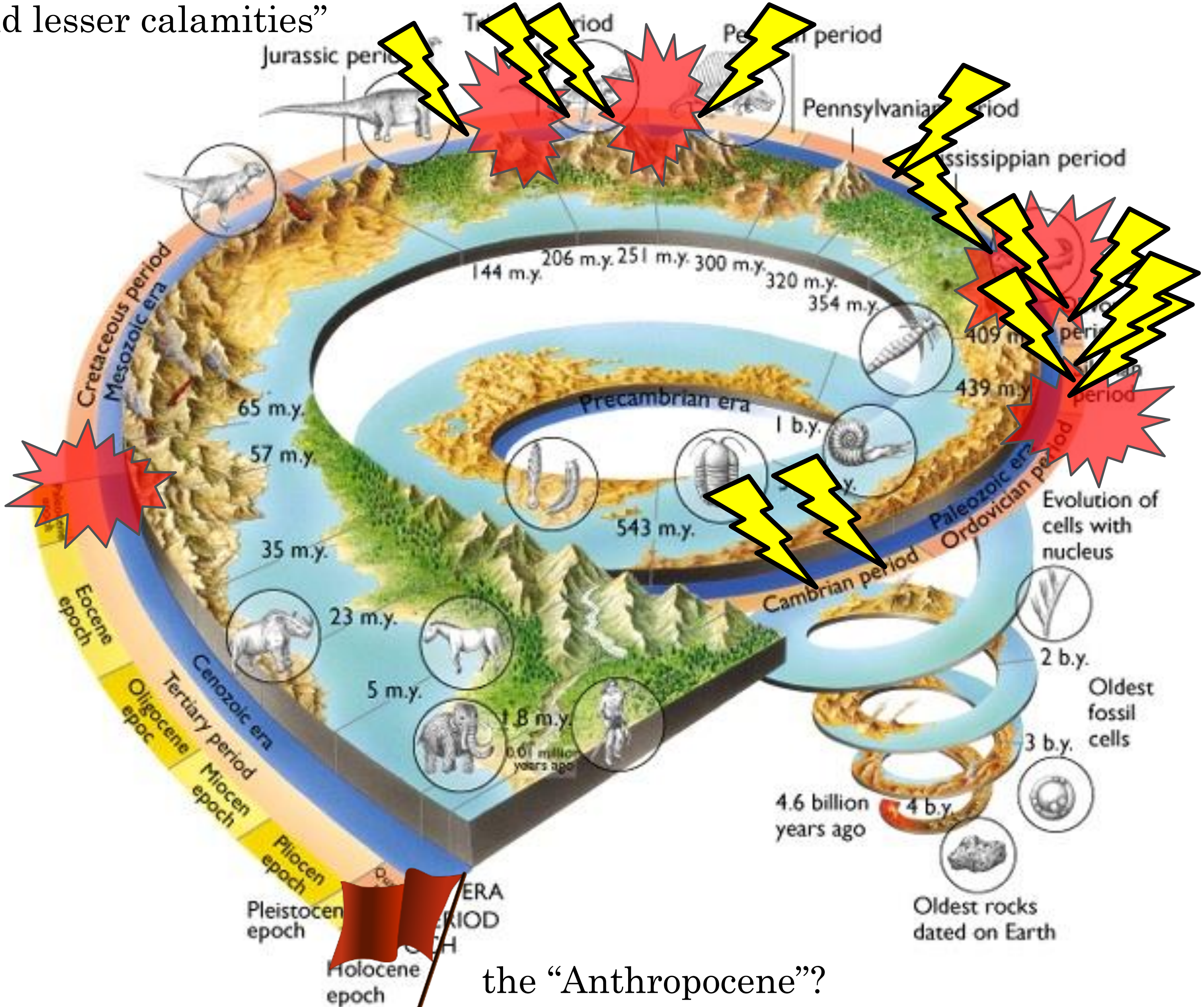
Image copyright University of Chicago

Number of genera through time
(database of > 30000 fossil marine genera)

SPECIES EXTINCTION LEAGUE TABLE

1. End Permian, 250 Myr:	96%
2. End Triassic, 200 Myr:	75%
2. End Cretaceous, 66 Myr:	75%
4. Late Devonian, 370 Myr:	70%
5. End Ordovician, 440 Myr:	60%
- “Anthropocene, 0 Myr:	0%

“mass extinctions
and lesser calamities”

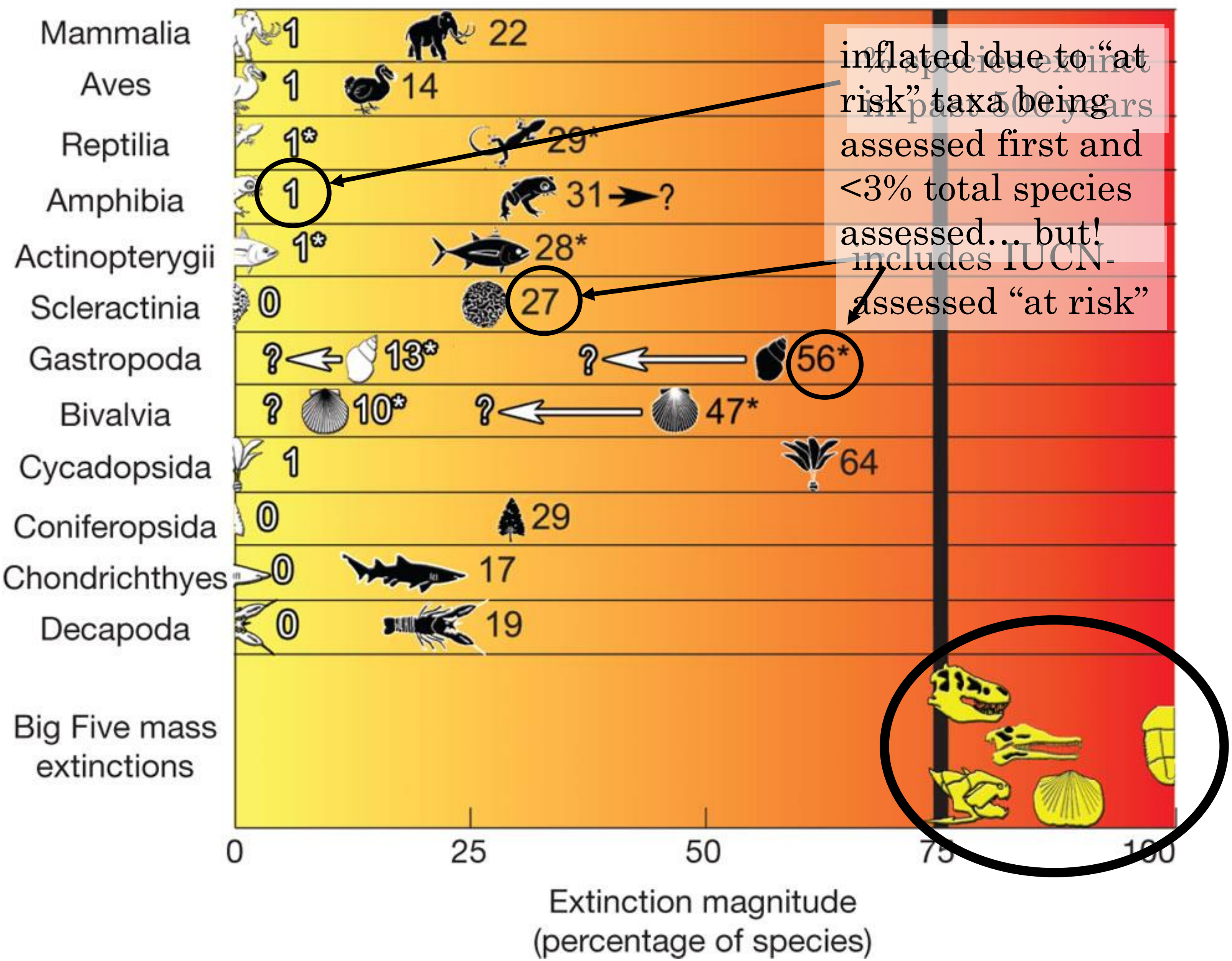


the “Anthropocene”?

Volcanism and mass extinction

Has the Earth's sixth mass extinction already arrived?

Barnosky, A., et al. 2011, Nature 471, 51–57, doi:10.1038/nature09678



Are we living in a new geological age characterised by human-driven extinctions?

The Trinity test, 1945: the start of the Anthropocene?

If extinction has happened before,
it could happen again.

But what might it look like?

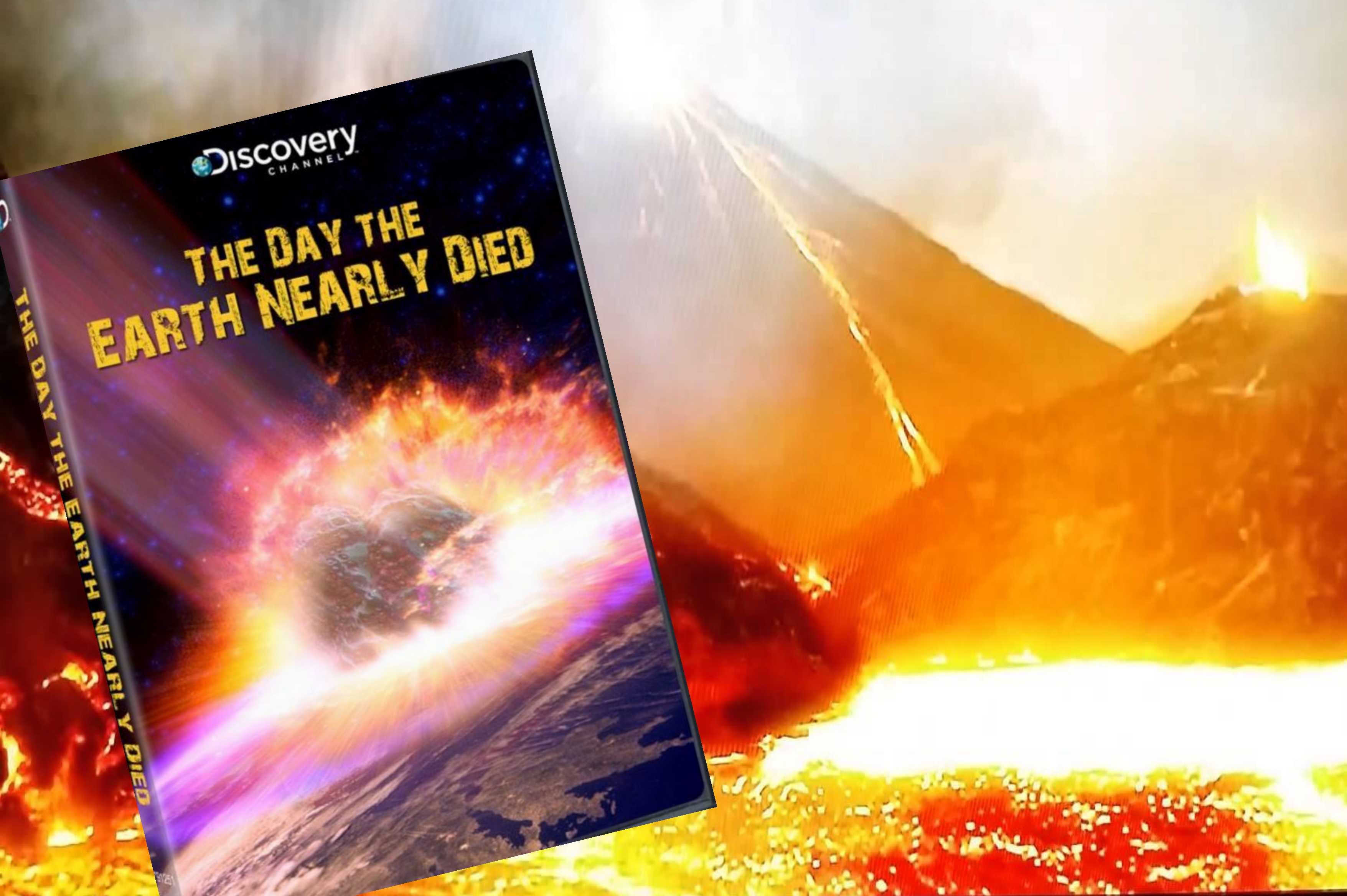
Extinction metrics and severity

#	Event	%[1]	Event	%[2]	Event	%[3]	Severity ranking[4]
1	End Permian	−58	End Permian	−57	End Permian	−83	End Permian
2	End Ordovician	−49	End Ordovician	−43	End Triassic	−73	End Cretaceous
3	Capitanian	−47	Capitanian	−36	End Ordovician	−52	End Triassic
4	End Triassic	−40	End Cretaceous	−34	End Devonian	−50	Frasnian-Famennian
5	End Cretaceous	−39	End Triassic	−33	End Cret., Fras-Fam.	−40	Capitanian
6	Frasnian-Famennian	−35	Frasnian-Famennian	−22	N.A.	NA	Serpukhov.
7	Givetian	−30	Serpukhovian	−13	Serpukhovian	−39	End Dev., End Ordovician
8	End Devonian	−28	Givetian	−10	Givetian	−36	NA
9	Eifelian	−24	End Dev., Ludford.	−7	Eifelian	−32	Givetian
10	Serpuk., Ludford.	−23	N.A.	NA	Capitanian	−25	Eifelian, Ludford.
11	N.A.	NA	Eifelian	−6	Ludfordian	−9	NA

% marine genera extinct: [1]Sepkoski (1996), [2]Bambach et al. (2004) and [3]McGhee et al. (2013) and their severity ranking[4] - the “ecological impact”.

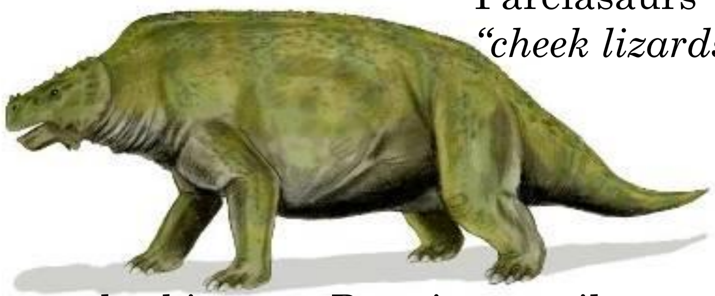
The end-Permian mass extinction (252 million years ago)

"Out of the frying pan and into the fire"



The Permian-Triassic World

Victims on land



Pareiasaurs
"cheek lizards"

Large, herbivorous Permian reptiles

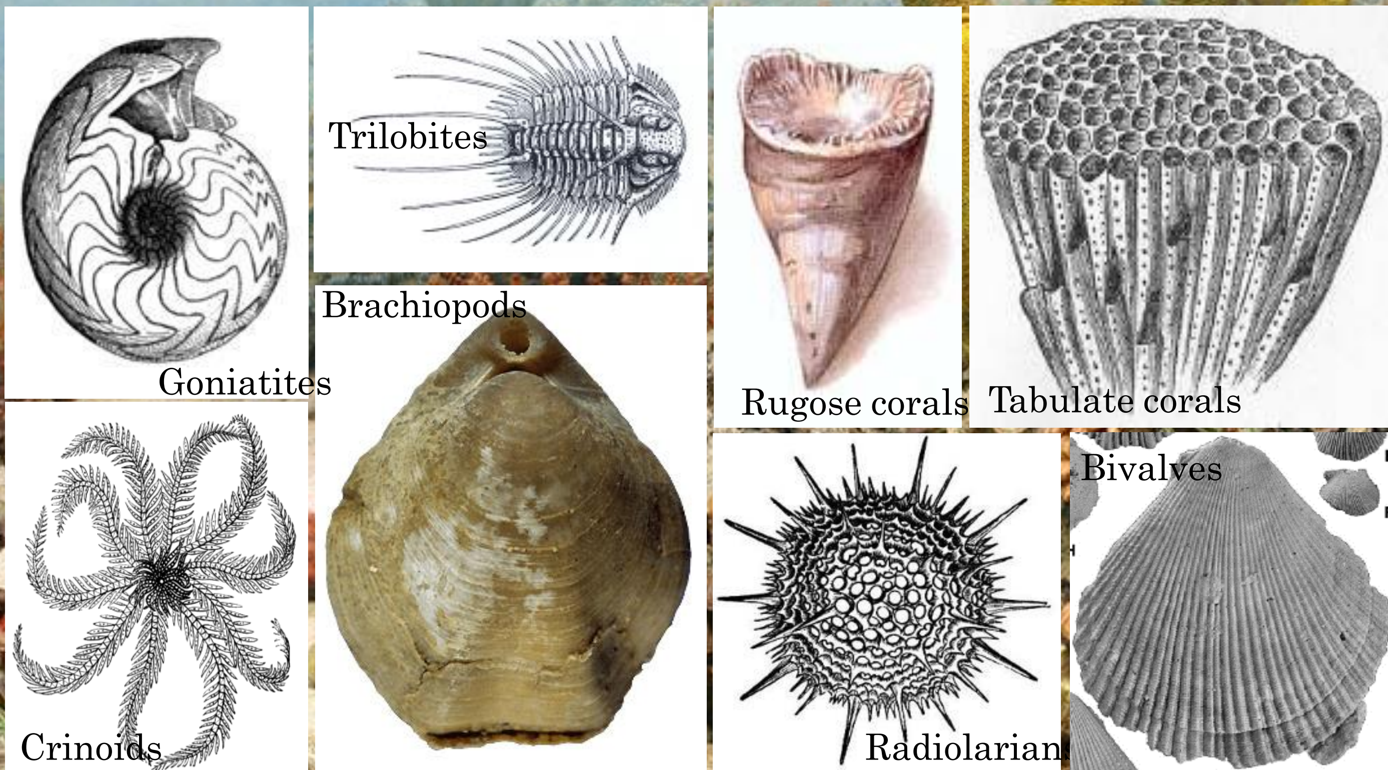
Gorgonopsids: top Permian therapsids

Insects

Most gymnosperms (*"naked seeds"* that formed coals

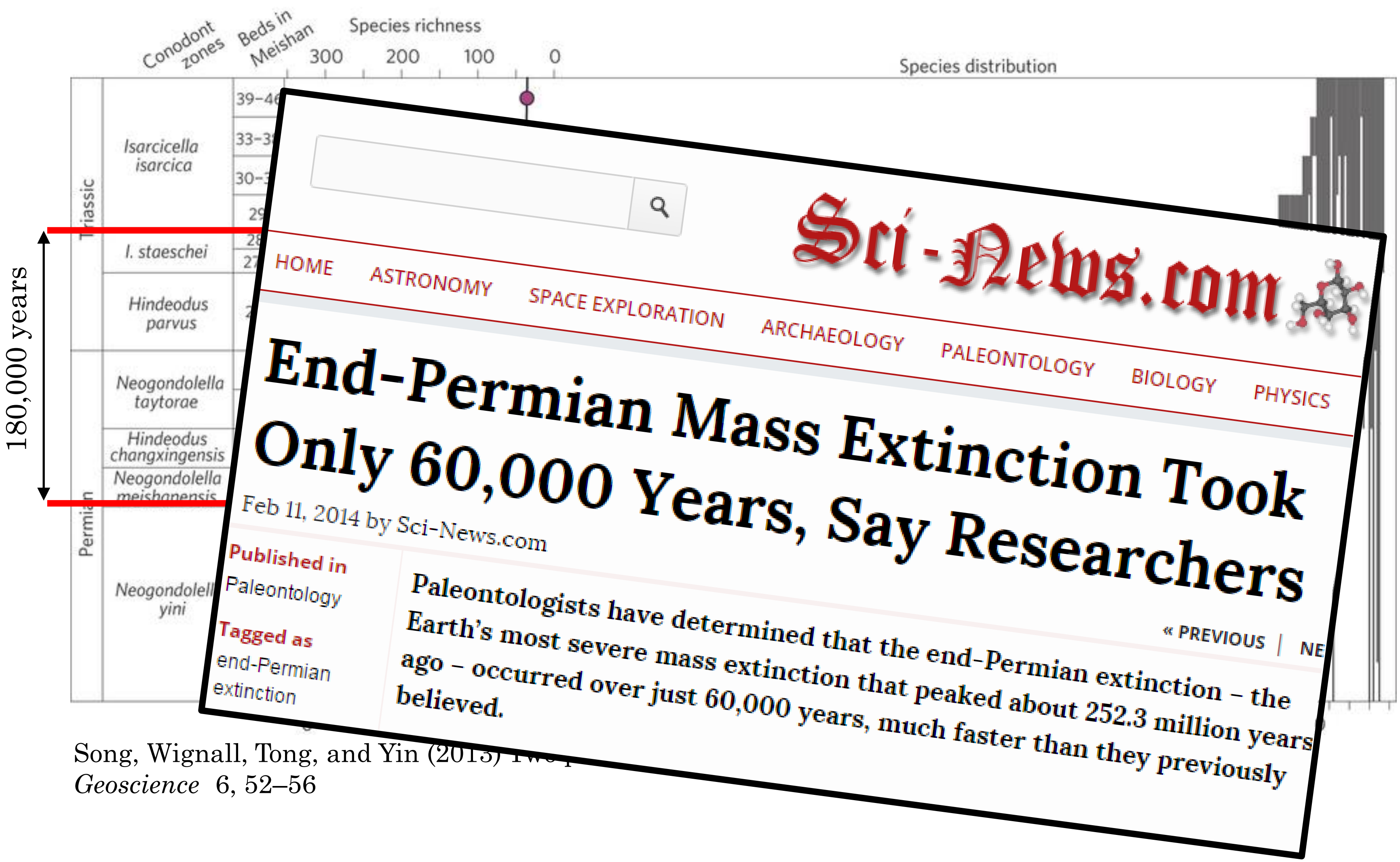
Glossopteris

…and in the oceans



As many as 96% of species globally became extinct

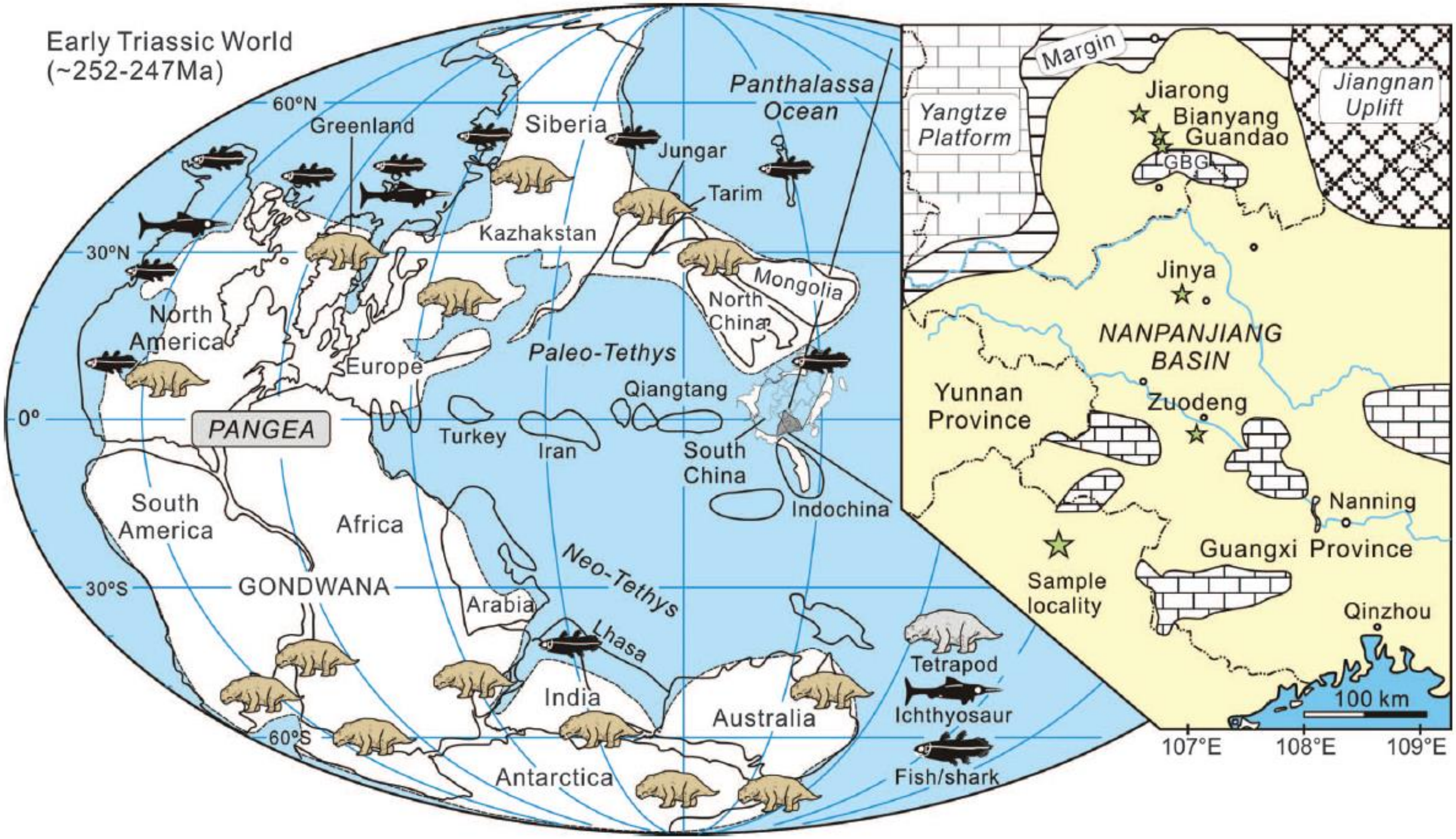
How fast was this greatest of all catastrophes?



Song, Wignall, Tong, and Yin (2013) Two p... *Geoscience* 6, 52–56

Since "challenged" by Wang et al. 2014 based on statistical treatment of sites in China / Pakistan – they argue for much more abrupt extinction.

How nasty did it get?



Sun, Joachimski, Wignall, Yan, Chen Y, Jiang, Wang, and Lai (2012) Lethally hot temperatures during the Early Triassic greenhouse. *Science* 338, 366-370.

Global warming due to increased CO_2

What else was around? Acid oceans, toxic metals…

Ocean acidification drove Earth's largest mass extinction

By **Deanna Conners** *in* **EARTH** | April 20, 2015

New evidence suggests that ocean acidification played a key role in the Permian–Triassic mass extinction event 252 million years ago that killed most life on Earth.

During the Permian–Triassic mass extinction event 252 million years ago, most life on Earth perish… Scientists have … in the … now obtained evidence that ocean acidification played a key role in the die-off. The new research … journal *Science* on April 10, 2015.

livescience

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TECH HEALTH PLANET EARTH SPACE

Ocean of Acid Blamed for Earth's 'Great Dying'

Sci-News.com

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Mercury May Have Caused End-Permian Mass Extinction

Ozone depletion caused by volcanic gases?


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Mass extinction the res
acid rain and ozone lo
BY IAN RANDALL | 2 DECEMBER 2013
Climate model links sulfur and ha
Earth's life died
ns to The Great Dying when


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Vinegar-Like Acid Rain May Have Fallen During Earth's Worst Extinction
Vanilla-flavored rocks hint at a planet scoured by intense acid rain during the Great Dying 252 million years ago


'The Great Dying': World's worst-ever extinction event 'caused by UV radiation'
Destruction of planet's ozone layer by volcanic eruptions may have made trees infertile and caused collapse of ecosystems, according to new study
Josh Gabbatiss Science Correspondent | @josh_gabbatiss | Thursday 8 February 2018 15:18 GMT | 2 comments
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Or in contrast, a deadly ice age?

SCIENTIFIC REPORTS

OPEN

Timing of global regression and microbial bloom linked with the Permian-Triassic boundary mass extinction: implications for driving mechanisms

Received: 12 October 2016
Accepted: 26 January 2017
Published: 06 March 2017

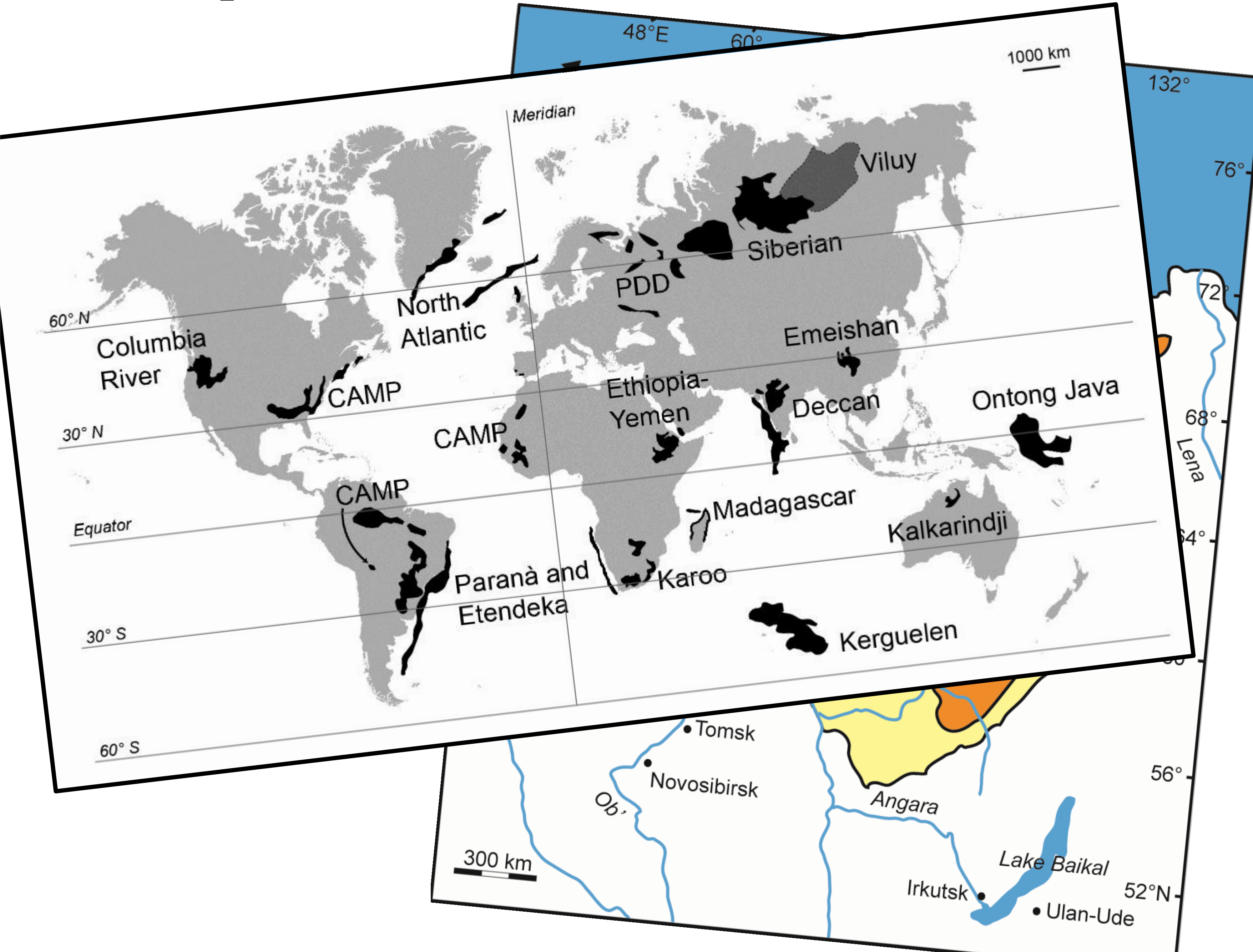
Björn Baresel[1], Hugo Bucher[2], Borhan Bagherpour[2], Morgane Brosse[2], Kuang Guodun[3] & Urs Schaltegger[1]

hinges on the synchronicity of the hiatus with the onset of the Siberian Traps volcanism. This early eruptive phase released sulfur-rich volatiles into the stratosphere, thus simultaneously eliciting a short-lived ice age responsible for the global regression and a brief but intense acidification. Abrupt cooling, shrunk habitats on shelves and acidification may all have synergistically triggered the PTBME.

The culprit for all this nastiness?
The Siberian Traps - 6 *million* km^3 of lava

Enough to bury the whole of Austria in 71.5km lava!

Total CO_2 released: 30,000 Gt (10 x today's atmosphere)



Volcanism and mass extinction

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[…]l and basalt and the end-Permian

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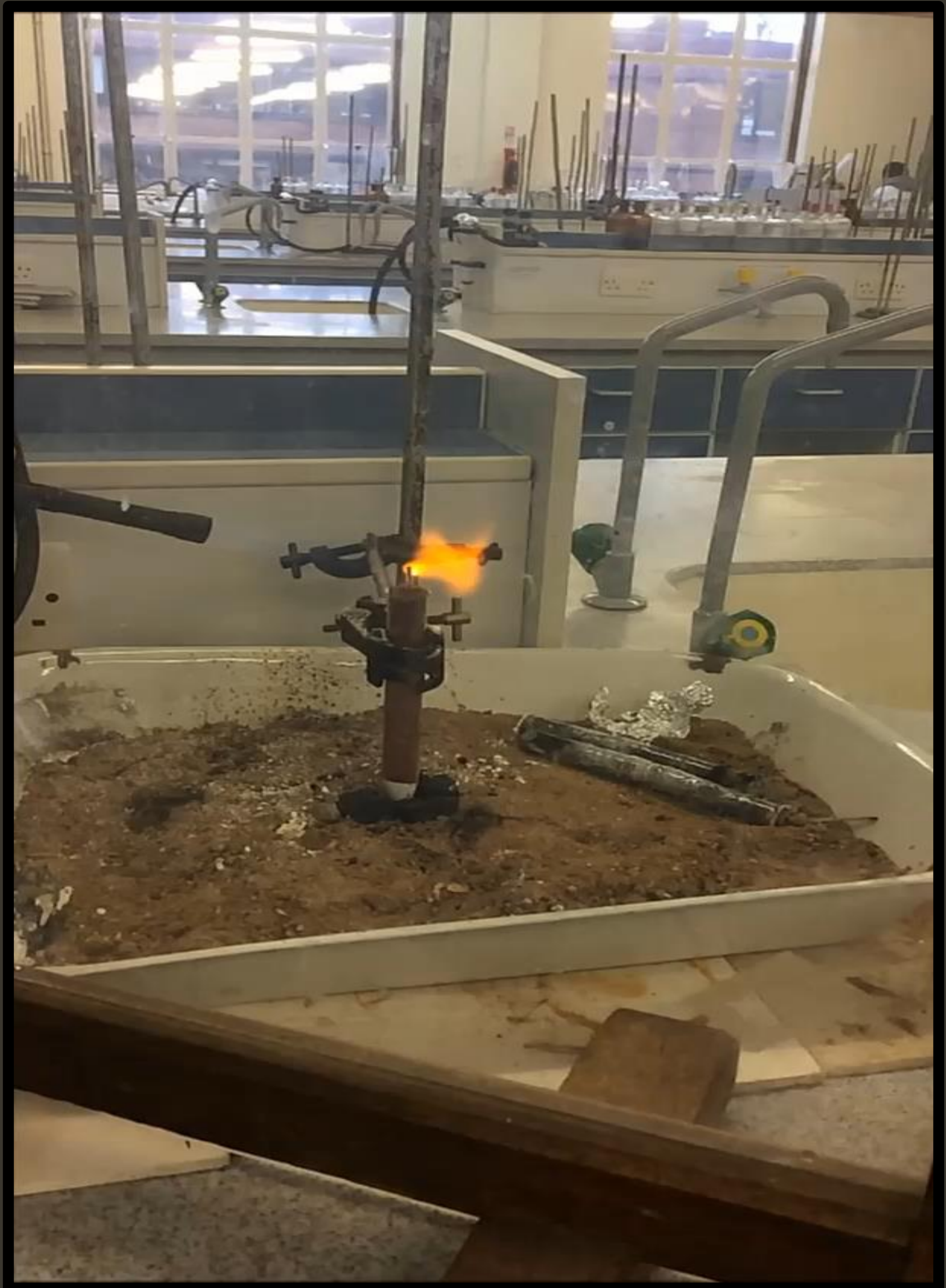
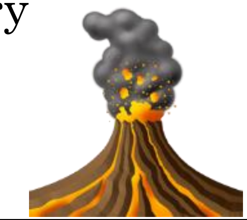
NATURE GEOSCIENCE | LETTER

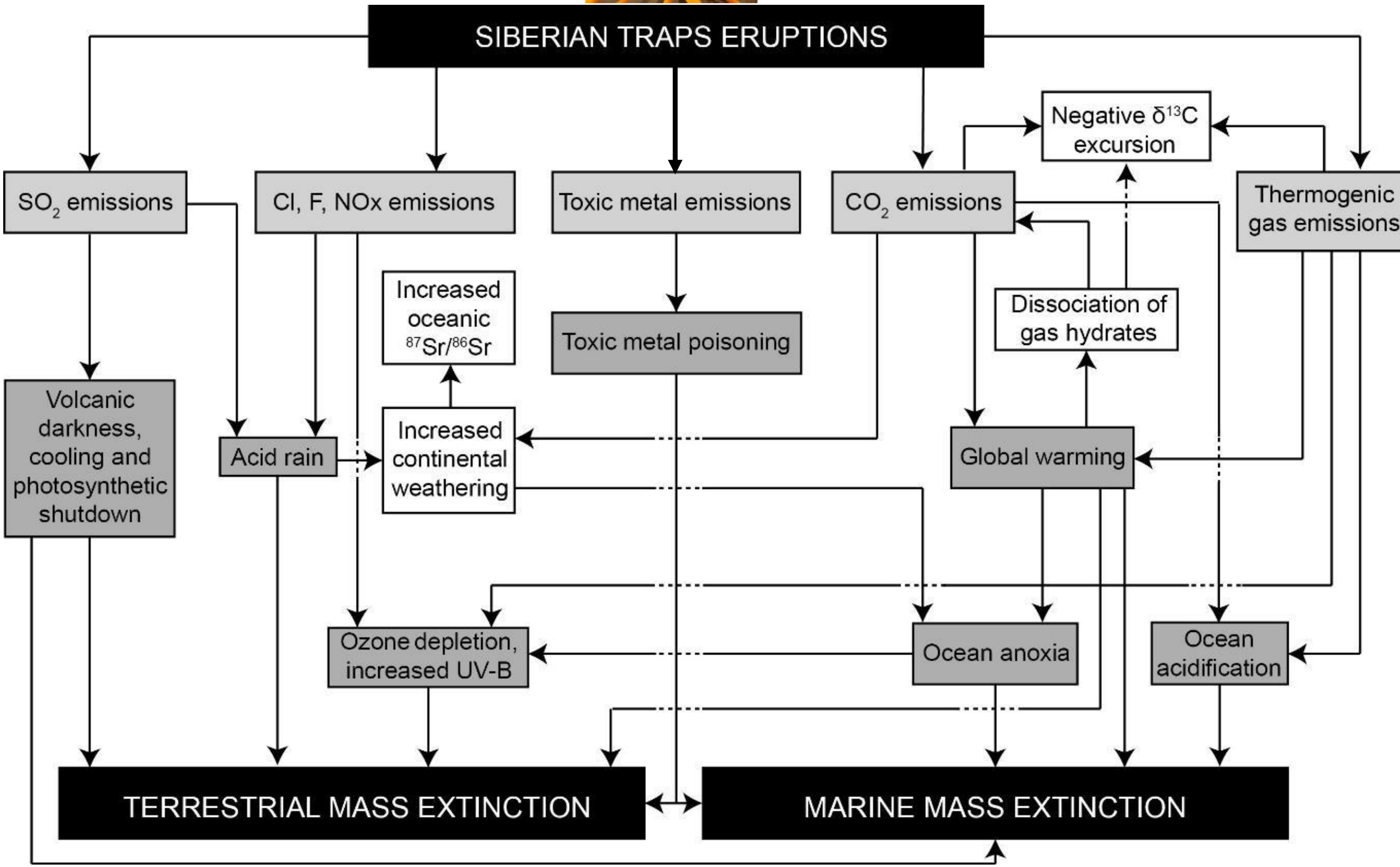
Catastrophic dispersion of coal fly ash into oceans during the latest Permian extinction

Stephen E. Grasby, Hamed Sanei & Benoit Beauchamp

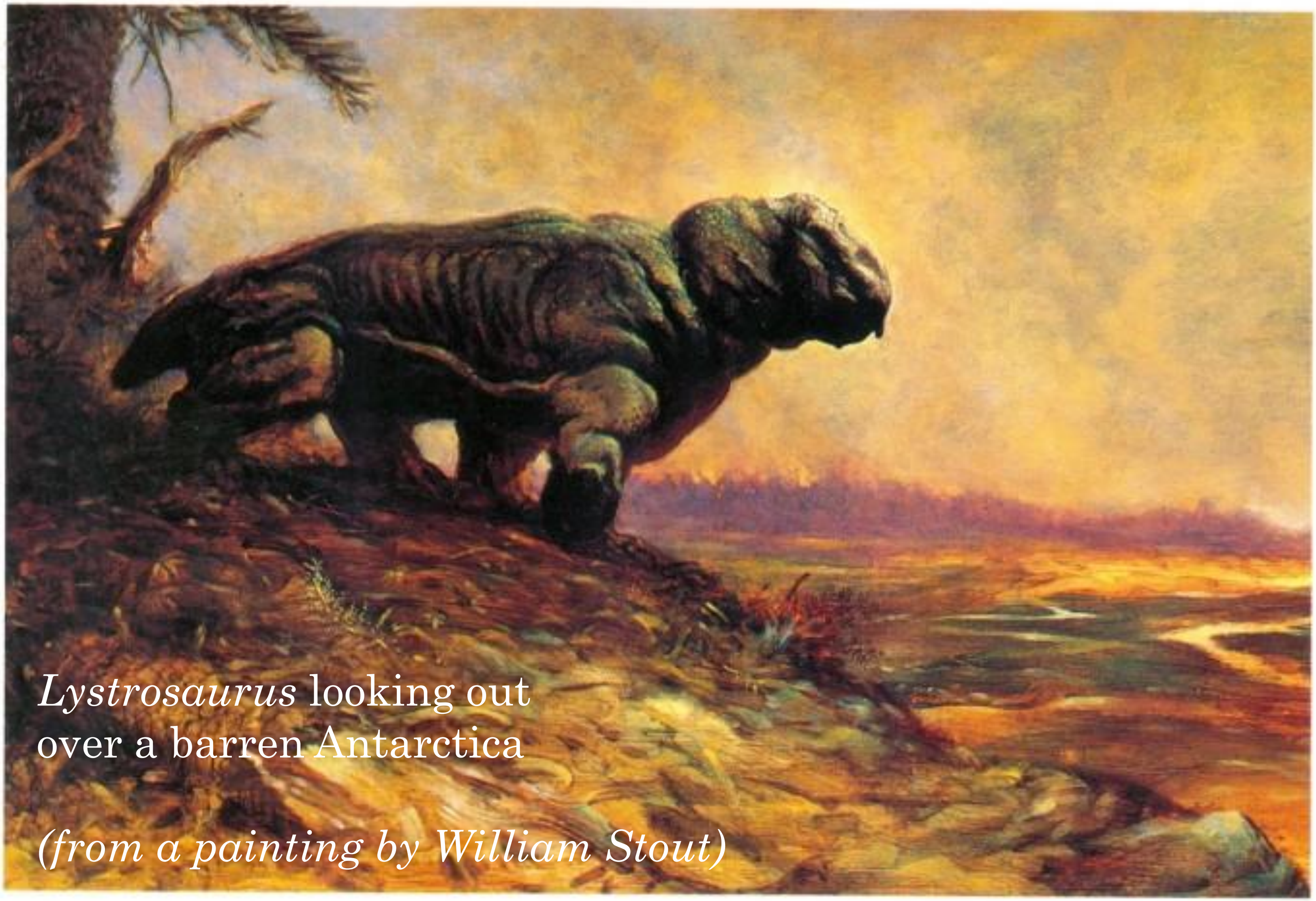


The Permian-Triassic boundary





The Triassic aftermath:
coal gaps, reef gaps, and other gaps in life's record

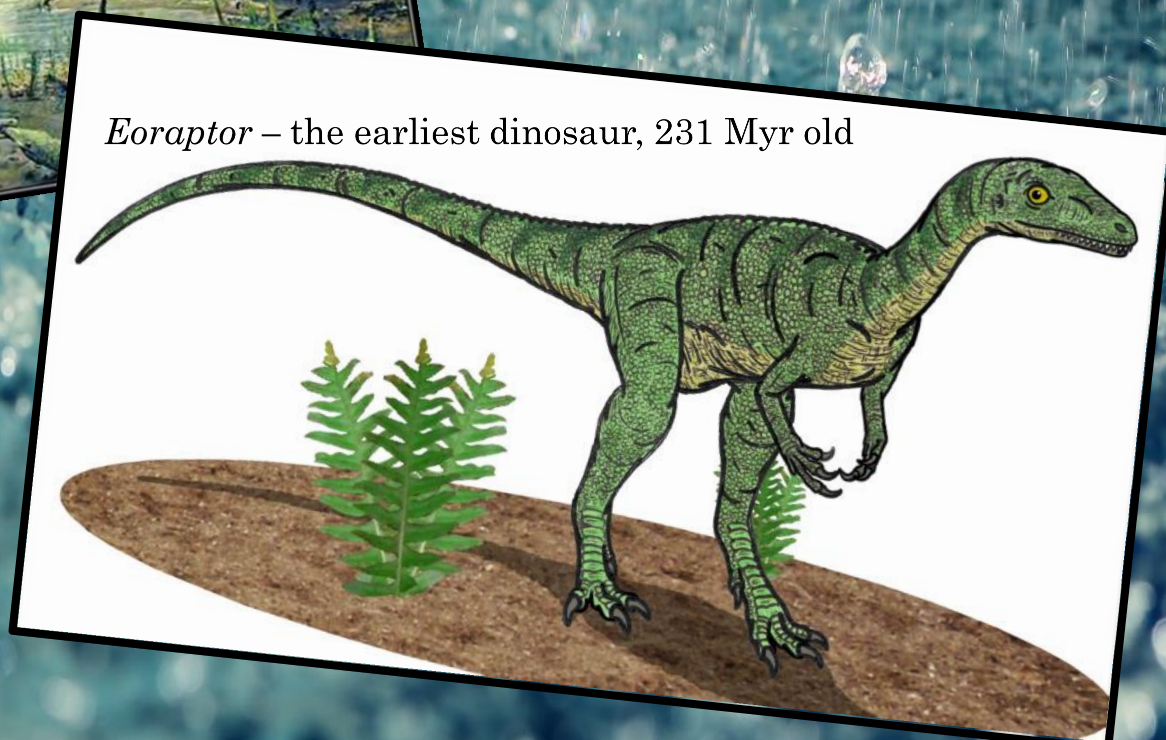


Lystrosaurus looking out over a barren Antarctica

(from a painting by William Stout)

The delayed recovery took unusually long (10 Myr)
But ultimately paved the way for the dinosaurs

Find out more
in the next talk!



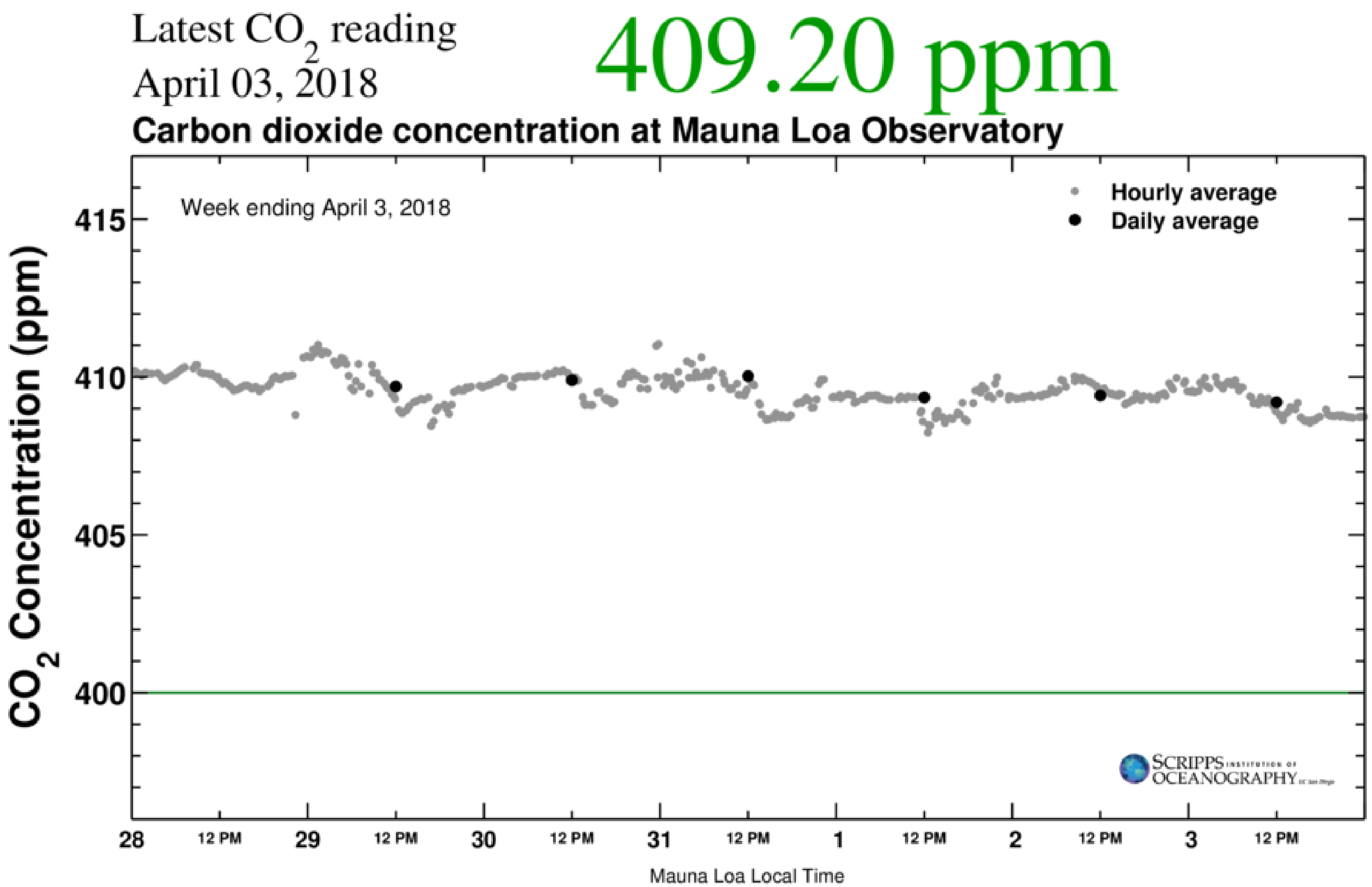
Eoraptor – the earliest dinosaur, 231 Myr old

What are the effects of massive volcanic eruptions and how might they drive a mass extinction?

- thermal stress: cooling, long-term global warming;
- marine anoxia as a result of warming;
- ocean acidification due to elevated pCO_2;
- ozone damage by halogens, increased UV-B radiation;
- acid rain;
- toxic metal poisoning;
- darkness and photosynthetic shutdown.

The atmosphere provides the link between terrestrial and marine biospheres

Speaking of today's atmosphere…



Let's examine what three CO_2-induced stresses do: warming, anoxia, and ocean acidification.

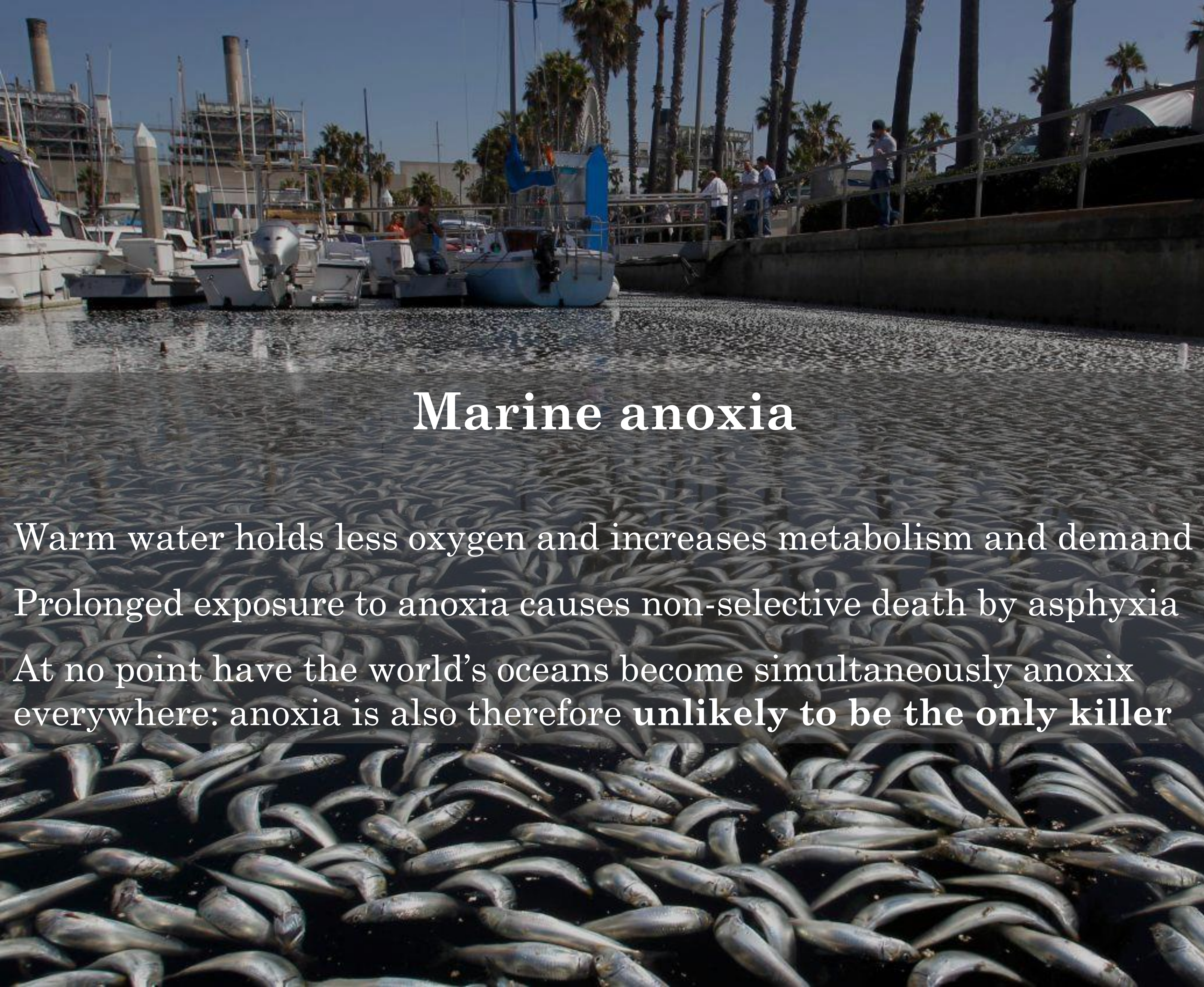
Thermal stress

The IPCC predict global ocean warming of 1.1 °C to 6.4 °C by 2100 (compare with an estimated ~15 °C end-Permian warming)

Warming increases aerobic metabolism in animals (Q_{10} law, 10 °C = x2) and stress occurs when O_2 demand exceeds an animal's aerobic scope

Active organisms can elevate their metabolic rate compared to less active organisms, making them more likely to survive extinctions (Clapham, 2016)

Modest temperature rises are **unlikely to be the only killer** in mass extinction scenarios but extreme end-Permian warming took life past a survival threshold (e.g. 37-40 °C, Sun et al., 2012)



Marine anoxia

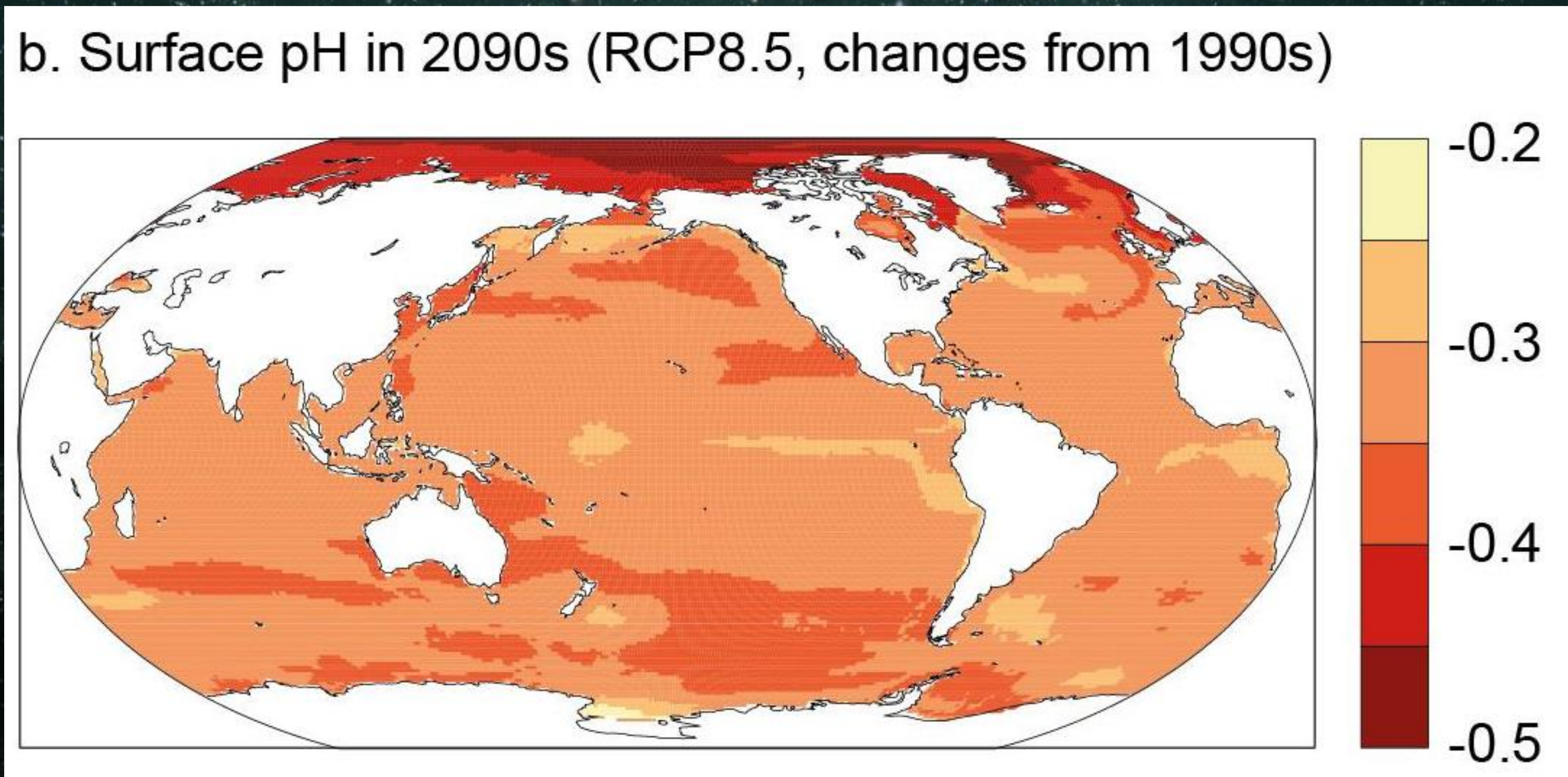
Warm water holds less oxygen and increases metabolism and demand

Prolonged exposure to anoxia causes non-selective death by asphyxia

At no point have the world's oceans become simultaneously anoxix everywhere: anoxia is also therefore **unlikely to be the only killer**

$>CO_2$ / Reduced pH ("ocean acidification")

IPCC predict ocean pH down by ~0.5 by 2090

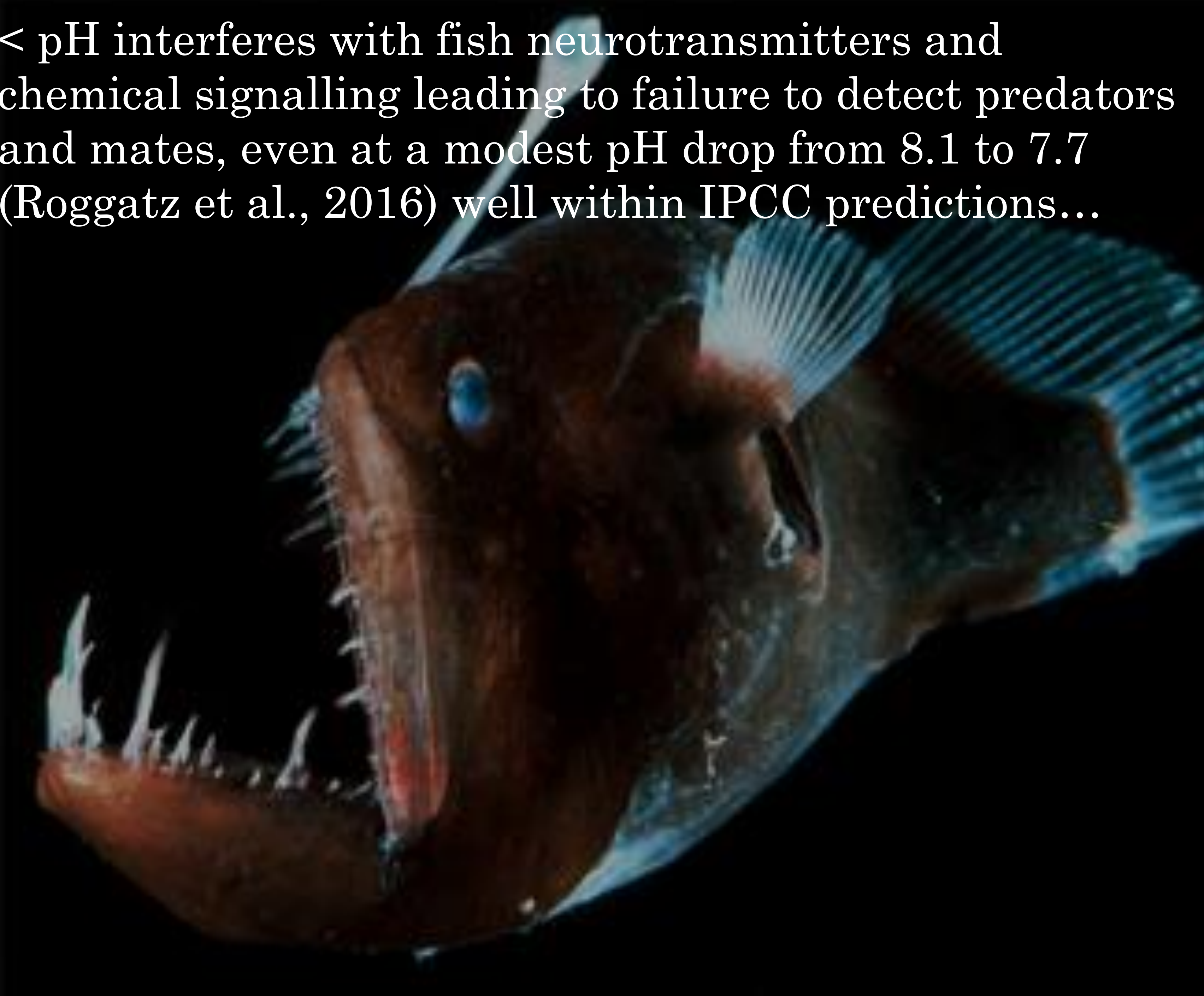


From IPCC 2013

> CO_2 decreases capacity of respiratory pigments to oxygenate tissues (hypercapnia), leading to death

< pH makes it more costly to build a carbonate skeleton – a big problem for corals and calcareous plankton

< pH interferes with fish neurotransmitters and chemical signalling leading to failure to detect predators and mates, even at a modest pH drop from 8.1 to 7.7 (Roggatz et al., 2016) well within IPCC predictions…



Is this really what drives extinction? Losing 1 % of individuals per generation can drive a species to extinction in little over a century (Knoll, 2007).

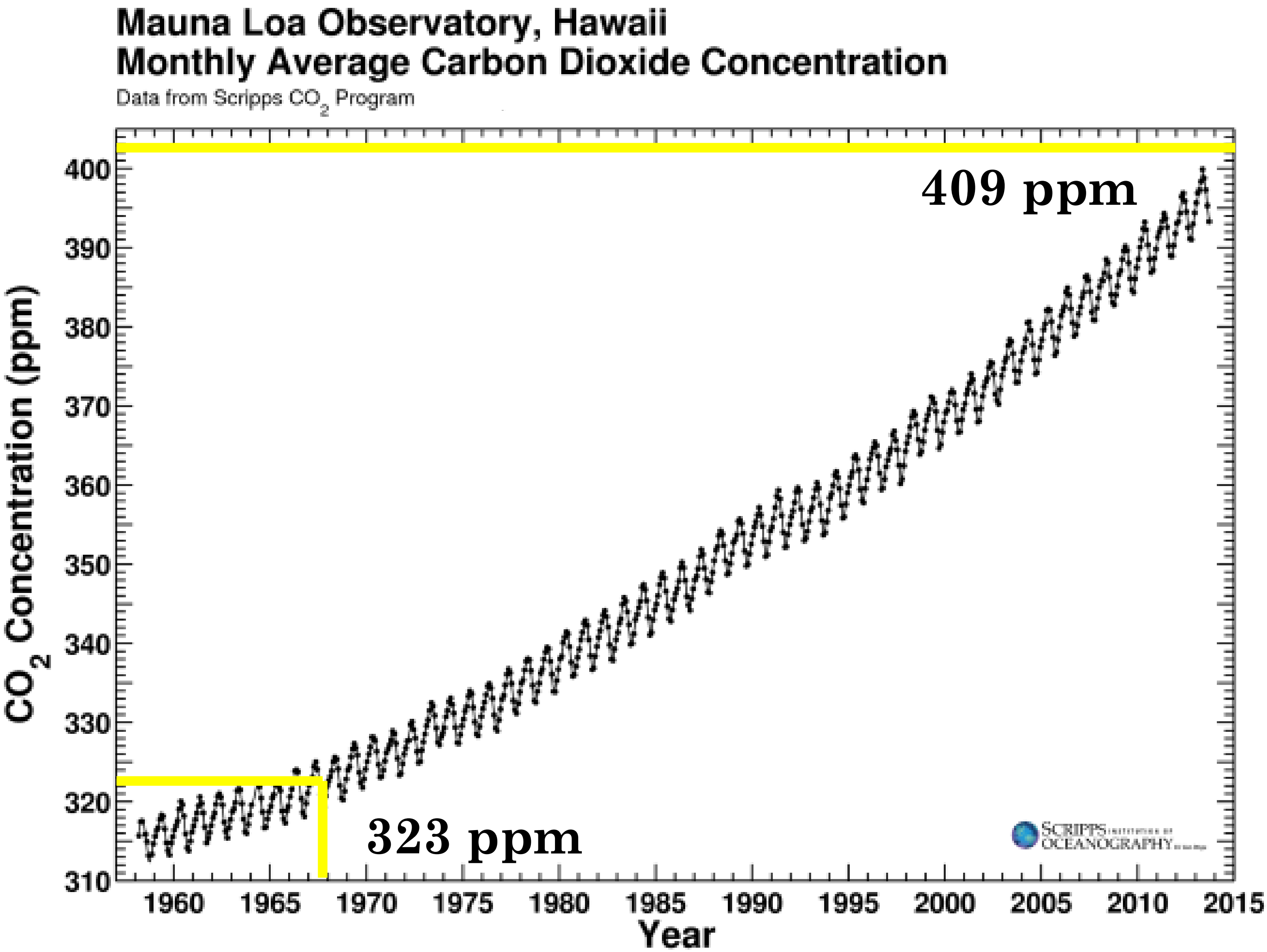
Theoretically, <pH **could be the lone killer**

So is life on Earth doomed?

Total mass CO_2 in atmosphere: 2.996×10^{12} tonnes (3000 Gt)

Siberian Traps CO_2 release = 30,000 Gt

30,000 / 3,000 = 10… the Traps emitted 10 x modern budget


Mauna Loa Observatory, Hawaii
Monthly Average Carbon Dioxide Concentration
Data from Scripps CO2 Program
409 ppm
323 ppm
CO2 Concentration (ppm)
Year
400
390
380
370
360
350
340
330
320
310
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
SCRIPPS INSTITUTION OF OCEANOGRAPHY

When might we reach end-Permian CO_2 levels?

In 50 years CO_2 has increased by 86 ppm (that's 1.72 ppm/yr)

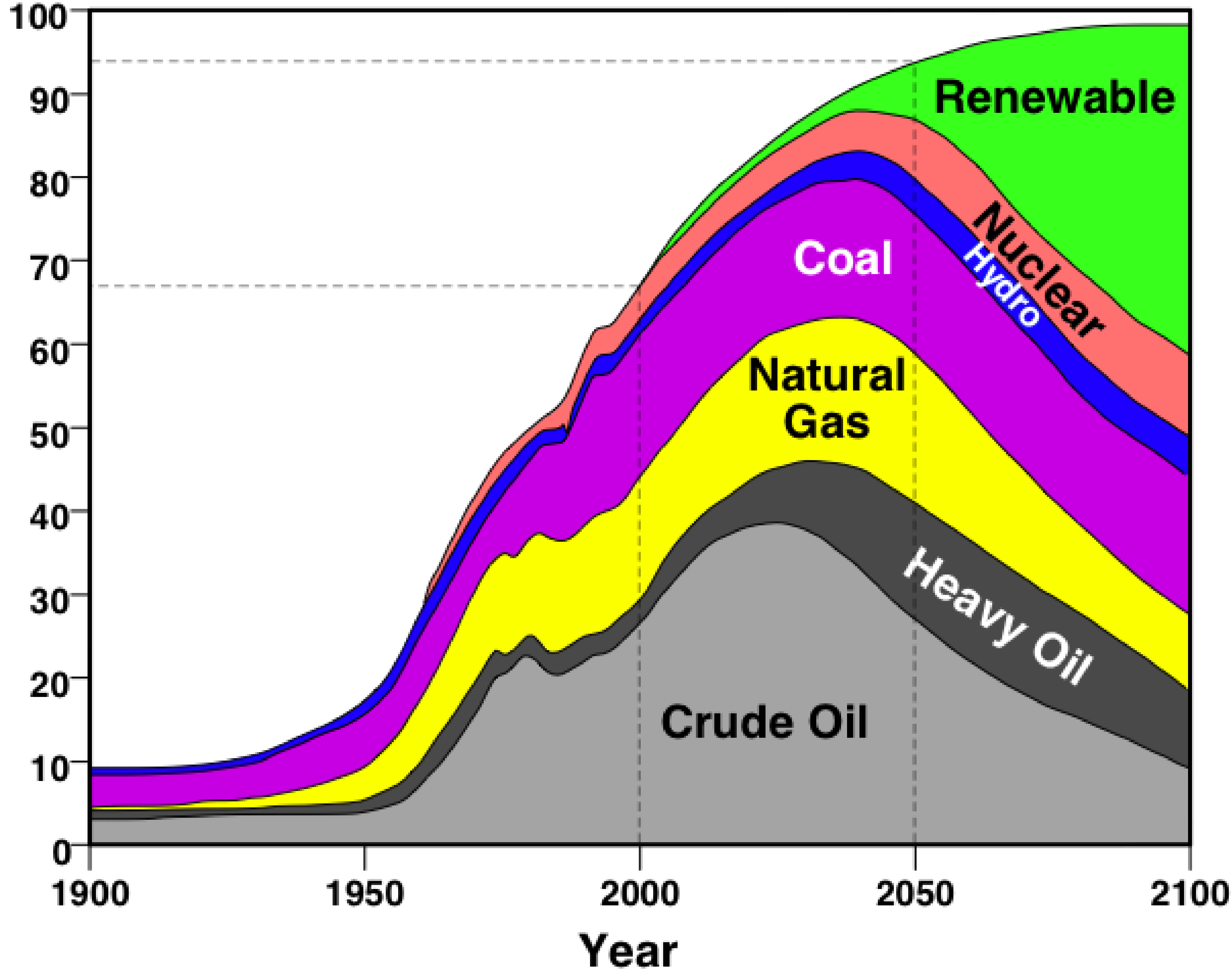
How long would it take to reach 10 x present (i.e. 4090 ppm)?

We'd need to add [4090 – 409 ppm] = 3681 ppm

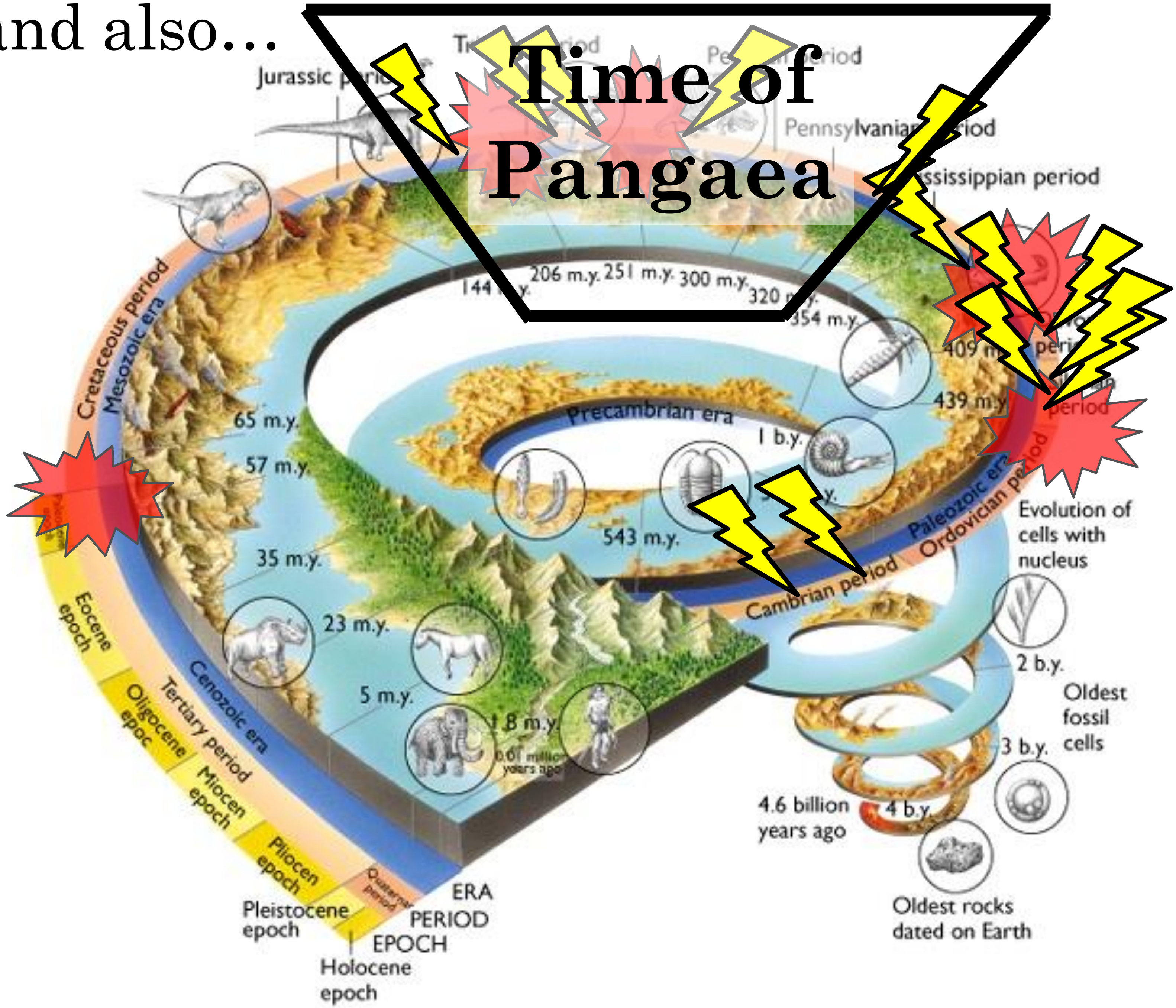
That would take [3681 / 1.72] = 2140.116 years

Which means catastrophe could strike in May 4158

But is this realistic and could it happen?



Edwards, J. D., 2001, AAPG Memoir 74, p. 21-34 and also…



Time of Pangaea
Jurassic period
Pennsylvanian period
Mississippian period
Cretaceous period
Mesozoic era
65 m.y.
57 m.y.
35 m.y.
23 m.y.
5 m.y.
1.8 m.y.
144 m.y.
206 m.y.
251 m.y.
300 m.y.
320 m.y.
354 m.y.
439 m.y.
Precambrian era
1 b.y.
543 m.y.
Paleozoic era
Ordovician period
Cambrian period
Evolution of
cells with
nucleus
2 b.y.
Oldest
fossil
cells
3 b.y.
4.6 billion
years ago
4 b.y.
Oldest rocks
dated on Earth
Eocene
epoch
Oligocene
Tertiary period
Cenozoic era
Miocen
epoch
Pliocen
epoch
Pleistocene
epoch
Holocene
epoch
ERA
PERIOD
EPOCH

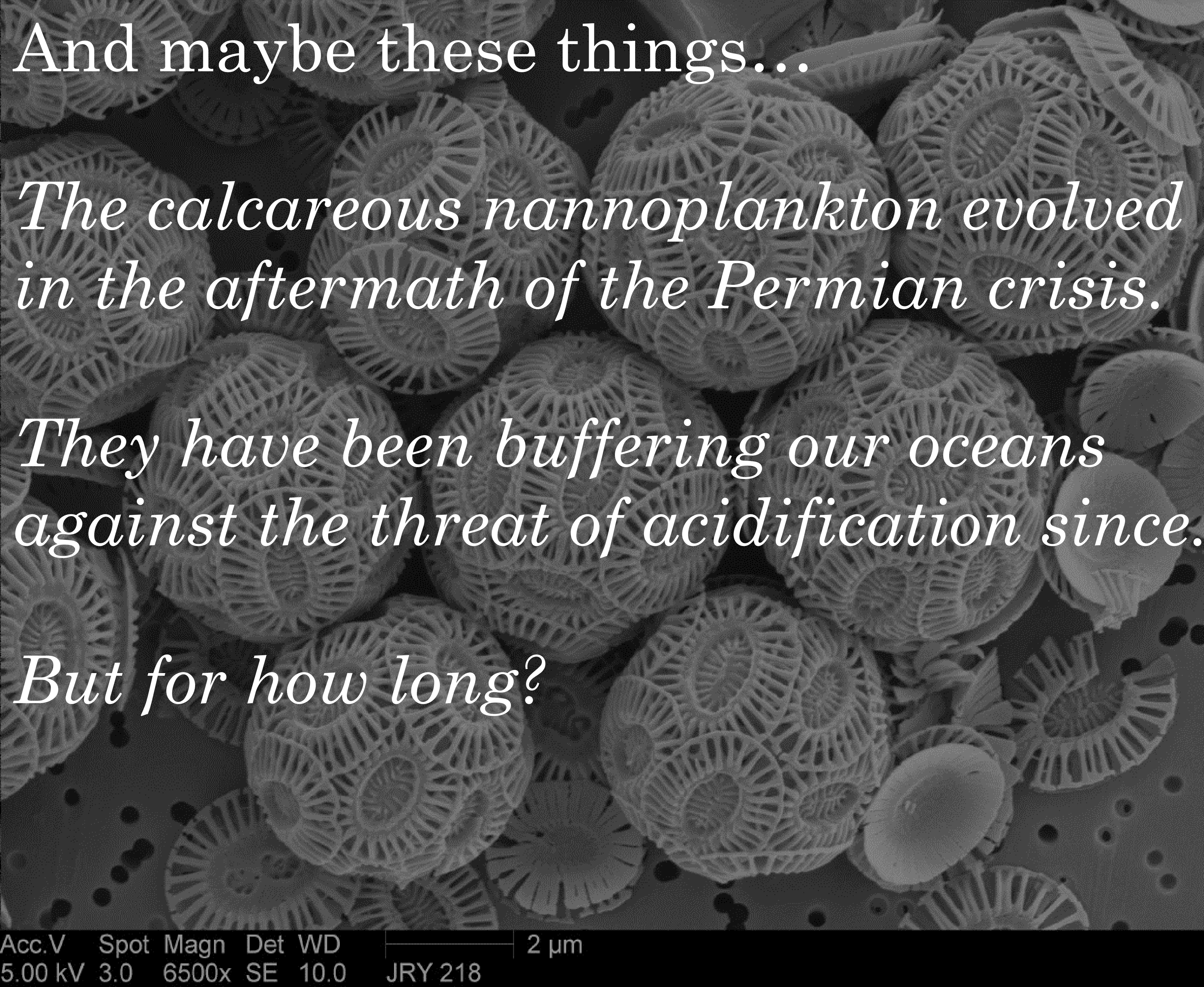
Perhaps Earth can take solace in the absence of a supercontinent

And maybe these things…

The calcareous nannoplankton evolved in the aftermath of the Permian crisis.

They have been buffering our oceans against the threat of acidification since.

But for how long?



THE END