Paleoclimate

source: NASA

Day 1.1 : Overview

- Modus operandi
- The science of paleoclimatology
- Methods overview
- Planet Earth and its main constituents
- Earth History

Who am I?

- PhD in physics @ IUP in 2017
- Post-Doc @ GeoW for 3 years
- Post-Doc @ UNIL for 2 years
- Marie Sklodowska-Curie Fellow since 2023

UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

UNIL | Université de Lausanne

Funded by the European Union

- Main work:
  - Paleoclimatology & Paleoceanography
  - Geochemistry with marine sediments

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- Contact: patrick.blaser@unil.ch
  https://patrick-blaser.github.io/

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Modus operandi

- 5 x 14:00 – 17:00
- 2 slots each, 30 min coffee breaks ~ 15:15 – 15:45
- Tuesday need to finish 15 min early!

Monday	Introduction	Earth History
Tuesday	Proxies I	Cenozoic Hot & Warm House
Wednesday	Specific Climate System components	Pleistocene G-IG climate
Thursday	Proxies II & Climate System Interactions	Abrupt Climate Change
Friday	Current Climate Change	Future & Synthesis

Modus operandi

Ask questions and interact!

Literature suggestions

- Princeton Primers in Climate series
  - Paleoclimate (Michael L. Bender, 2013)
    Princeton University Press

- Introduction to Climate Science
  Open Textbook by Andreas Schmittner, 2019
  (https://open.oregonstate.education/climatechange)

- IPCC (Sixth Assessment Report, 2021)
  (https://www.ipcc.ch)

What is Paleoclimatology?

What is Paleoclimatology?

Paleo **Climatology**

What is Paleoclimatology?

Physics

Paleo **Climatology**

What is Paleoclimatology?

Chemistry Physics

Biology

Paleo **Climatology**

What is Paleoclimatology?

Chemistry Physics

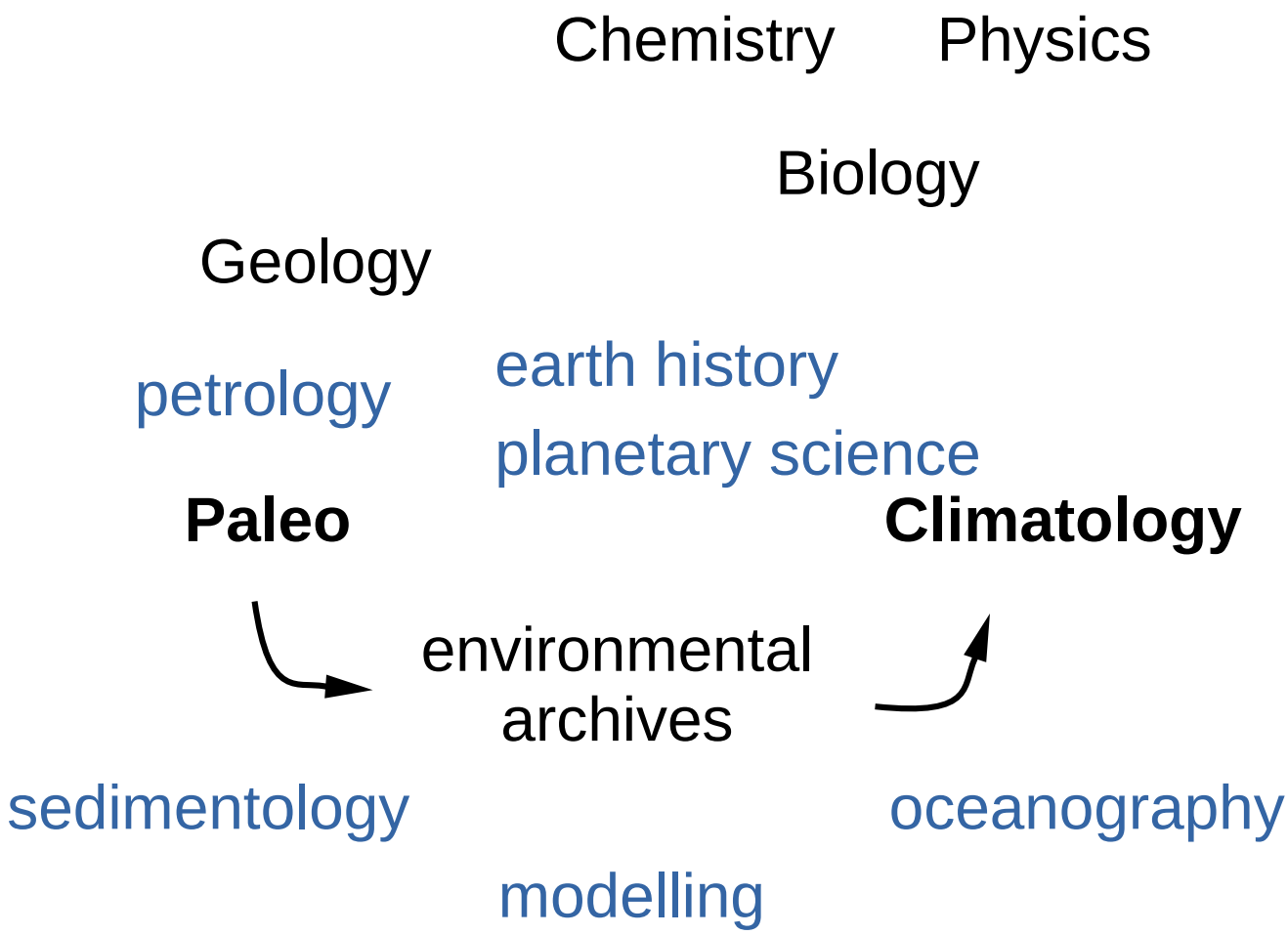
Biology

Geology

Paleo **Climatology**

environmental archives

What is Paleoclimatology?



Objectives of Paleoclimatology

- understand Earth History (planetary science)
- understand evolution and past habitats (paleobiology)
- understand the climate system (earth system science)

Relevance of Paleoclimatology

- understand Earth History (planetary science)
  - fundamental interest in “our” history
  - origin of life and cosmology
- understand evolution and past habitats (paleobiology)
  - fundamental interest in life on Earth
  - adaptability and evolution
- understand the climate system (earth system science)
  - spectrum of possible climates on Earth
  - climate system under different boundary conditions
  - perturbations of the climate system
  - natural variations

Paleoclimatological methods

- theories and conceptual models
- geological observations
  (across scales from landscapes to microscopic)
- geochemistry and biology
  (either via system knowledge or modern analogues)
- numerical modelling

Paleoclimatological methods

***proxy* observations:**

observations of a certain parameter in an environmental archive that is related to a quantity of interest

e.g.: tree ring thickness ~ duration of growth period

problems: secondary effects, complexity, modern analogue, linearity, calibration, preservation, existence of archive...

Paleoclimatological methods

***proxy* observations:**

often inaccurate, imprecise, and prone to bias

many quantities cannot (yet) be reconstructed

→ patchy observations

→ combine different “independent” proxy observations

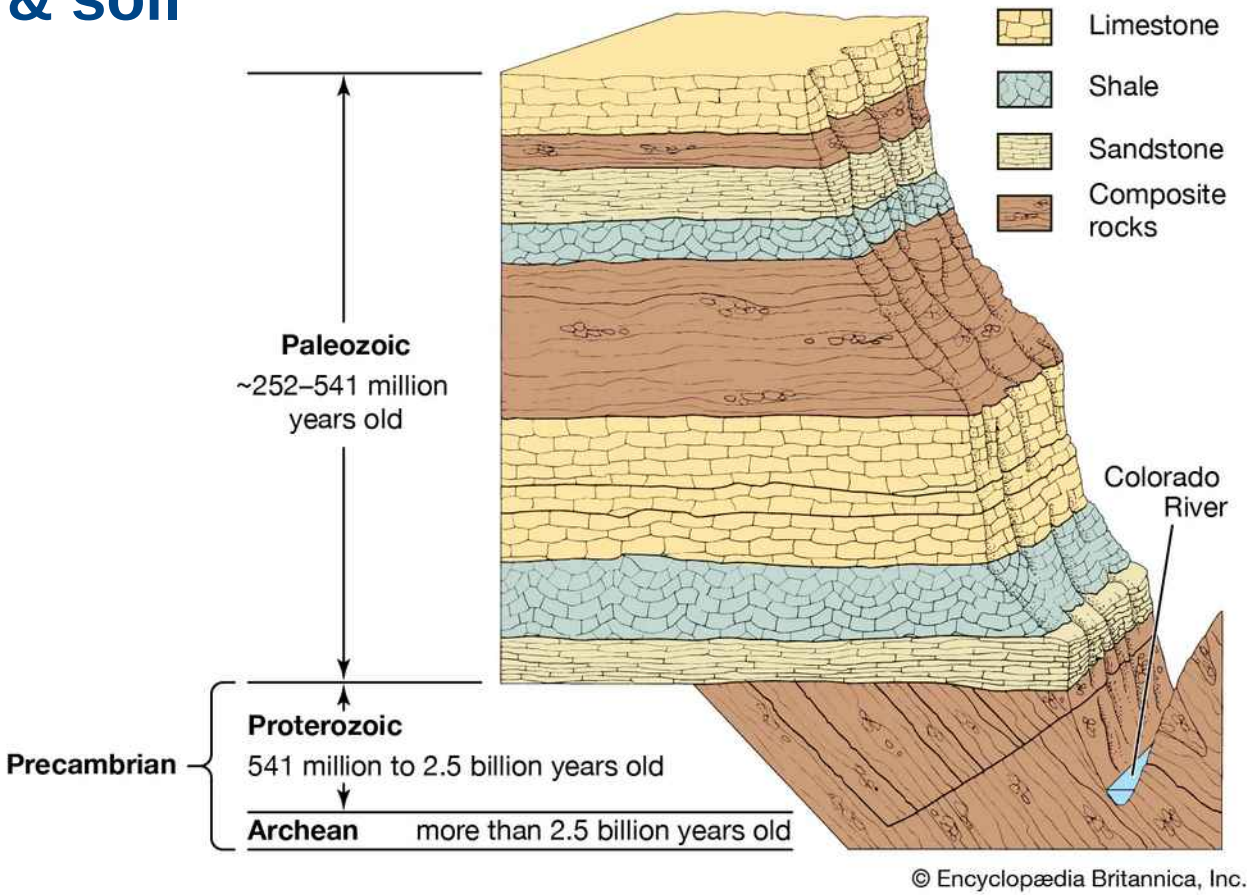
still, quantitative reconstructions are often not possible or limited to low precision

many fundamental findings are robust,
even though details may be less certain

Paleoenvironmental Methods

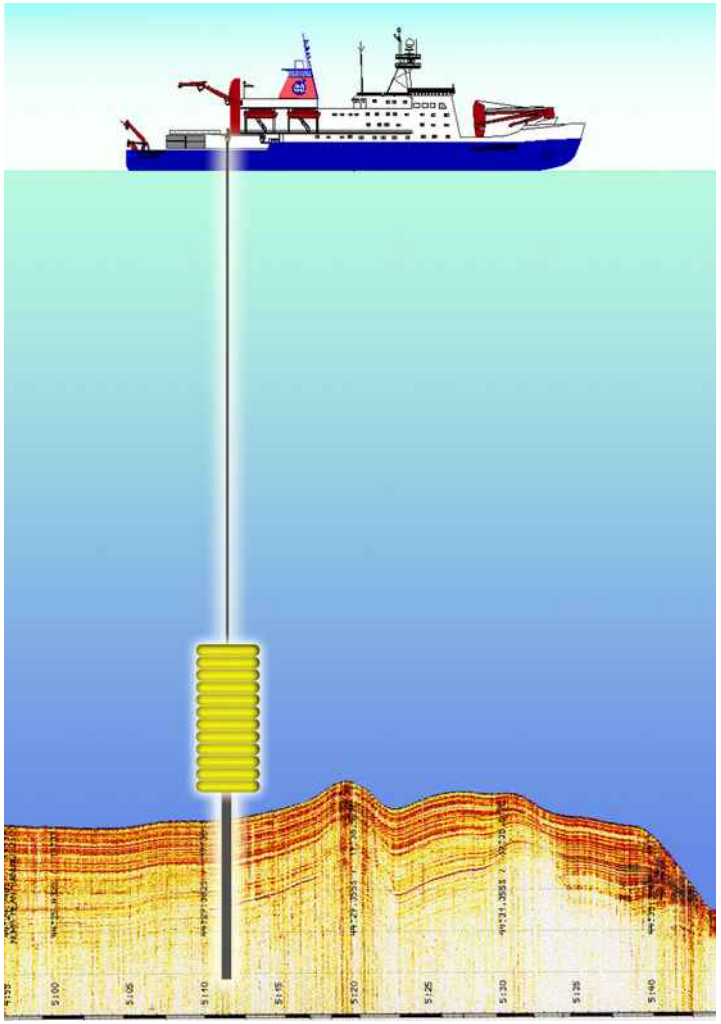
Environmental archives

rock & soil



Environmental archives

marine sediments

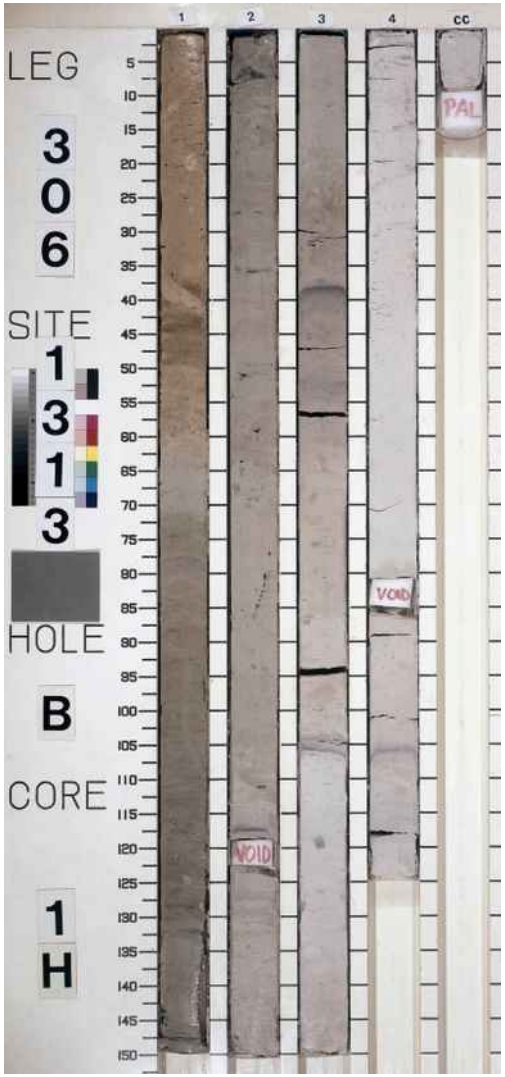


Wikipedia

Environmental archives

marine sediments

Bremen Core Repository



International Ocean Discovery Program

Environmental archives

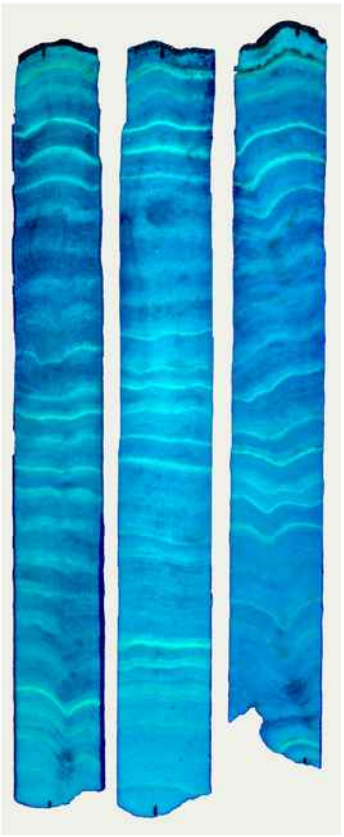
tree rings

willyswilderness.org

speleothems

speleothemscience.org

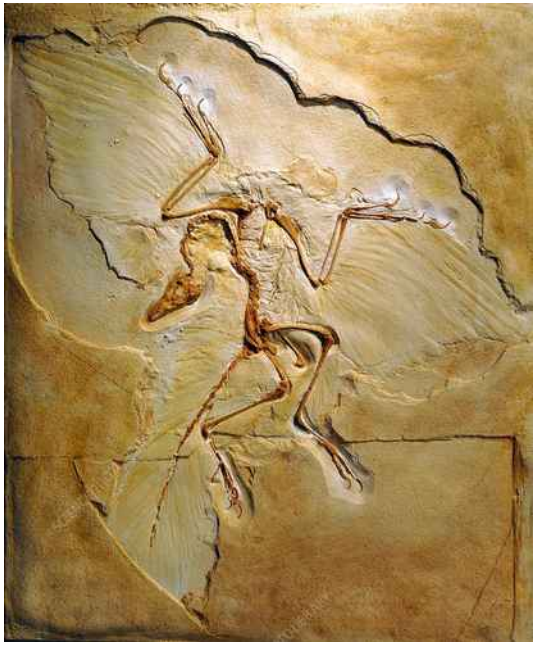
corals



quantamagazine.org

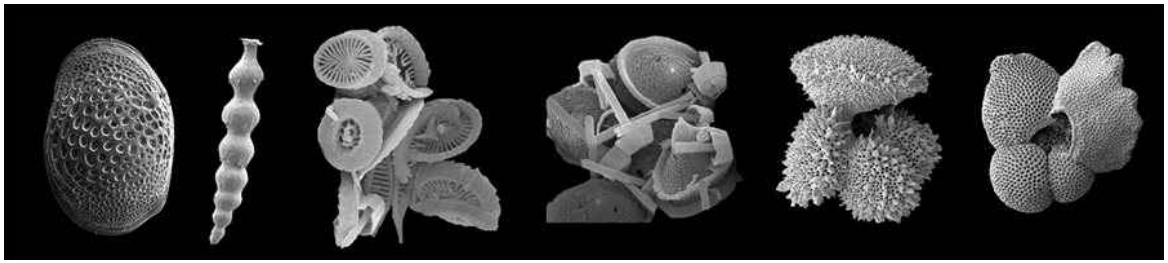
Environmental archives

fossils



sciencephoto.com

fossilmuseum.net



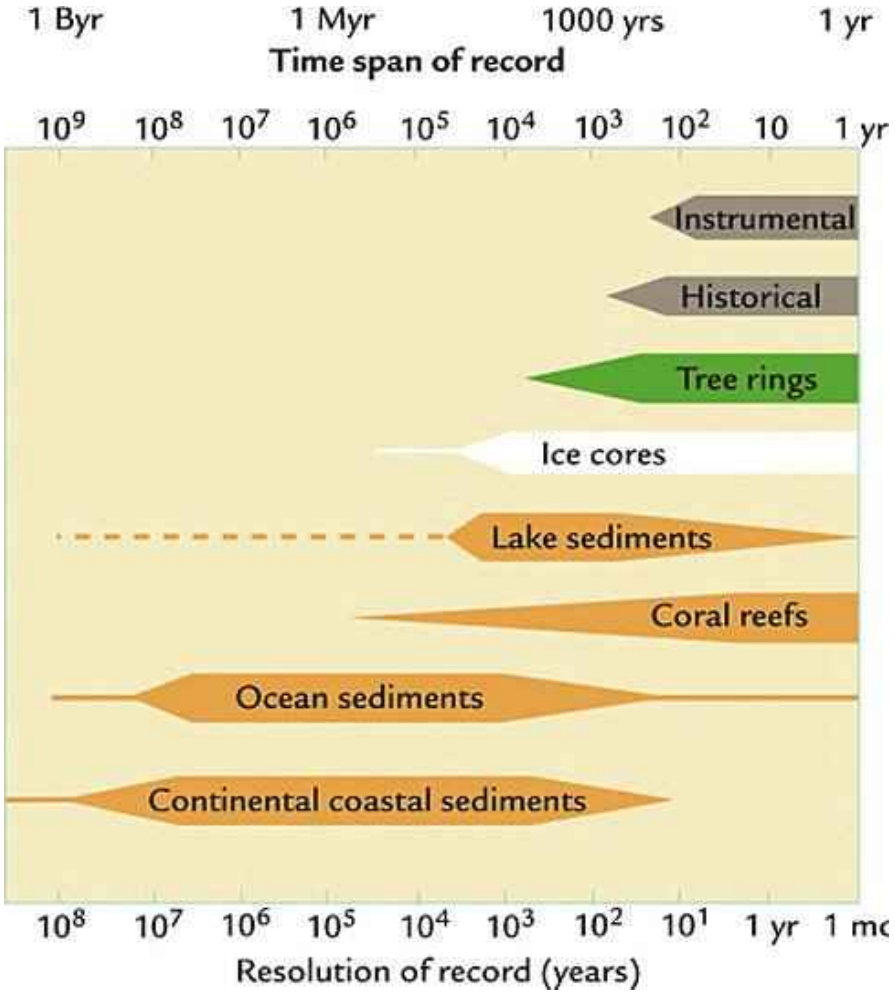
University of Birmingham

Environmental archives

ice

icecores.org

Environmental archives



Piovano et al. (2014)
Latin American Journal
of Sedimentology and
Basin Analysis

Paleoclimatology workflow

- retrieve a sample from the environment
- check (or hope) that sample is representative
- figure out how old it is
- check (or hope) that it was not too much altered
- measure something that relates to a quantity of interest

- marvel at the fact that you are seeing into the past

- come up with a reasonable theory
- measure many other parameters and samples to verify

  (or wait for others to do it)

Planet Earth

Planet Earth

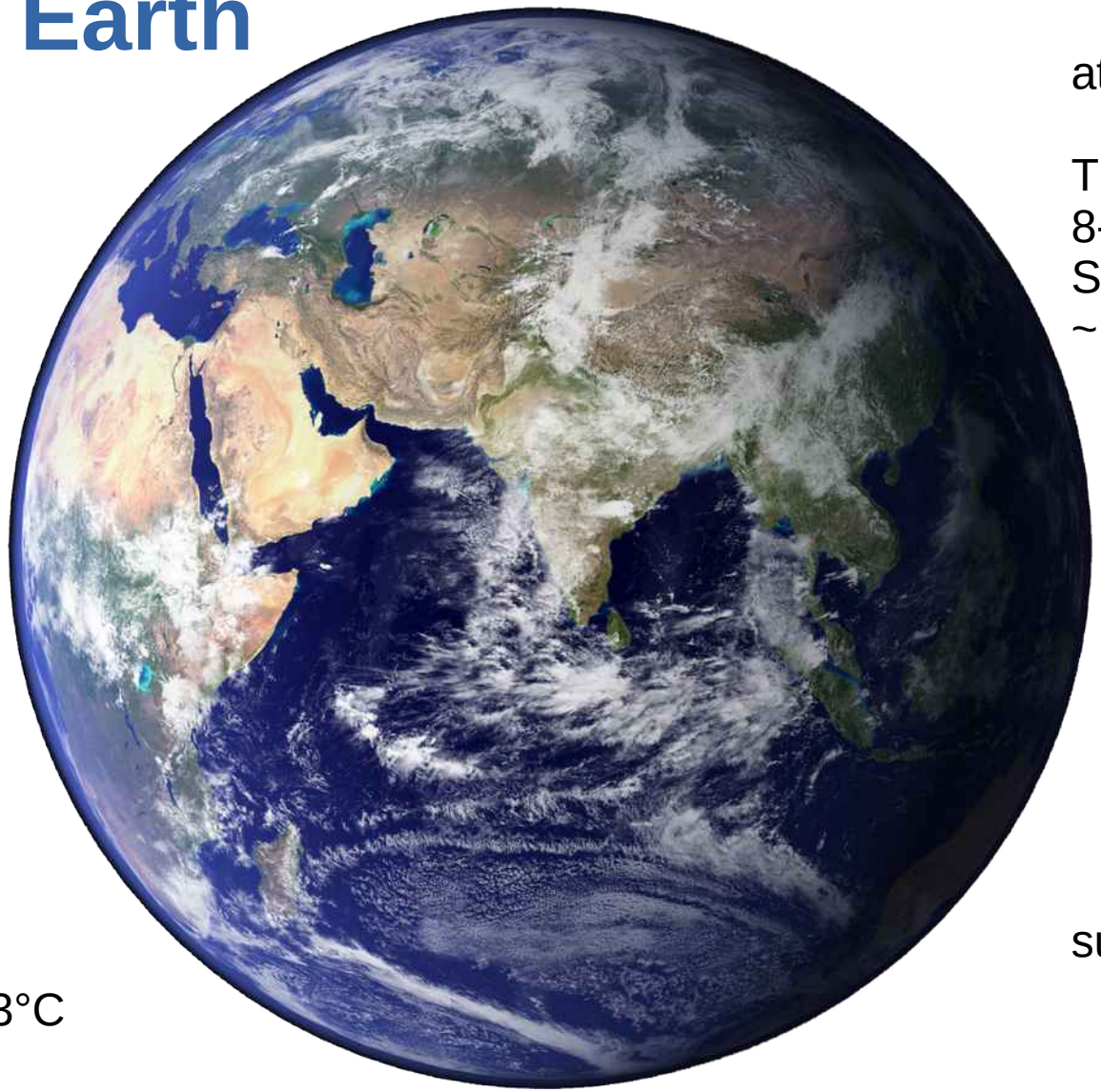
Planet Earth

climate:
weather on
long time scales
(>= 30 years)

mean & variability

most important:
- surface T
- precipitation
- humidity
- wind

Planet Earth



atmosphere:

Troposphere:
8-18 km
Stratosphere:
~ 50 km

composition:
N_2 ~ 78%
O_2 ~ 21%
Ar ~ 1%
CO_2 ~ 0.04%
CH_4 ~ 0.002%
H_2O ~ 0.1 – 3%

oceans:

cover ~ 71%

mean
depth ~ 3.8 km

deep ocean ~ 3°C

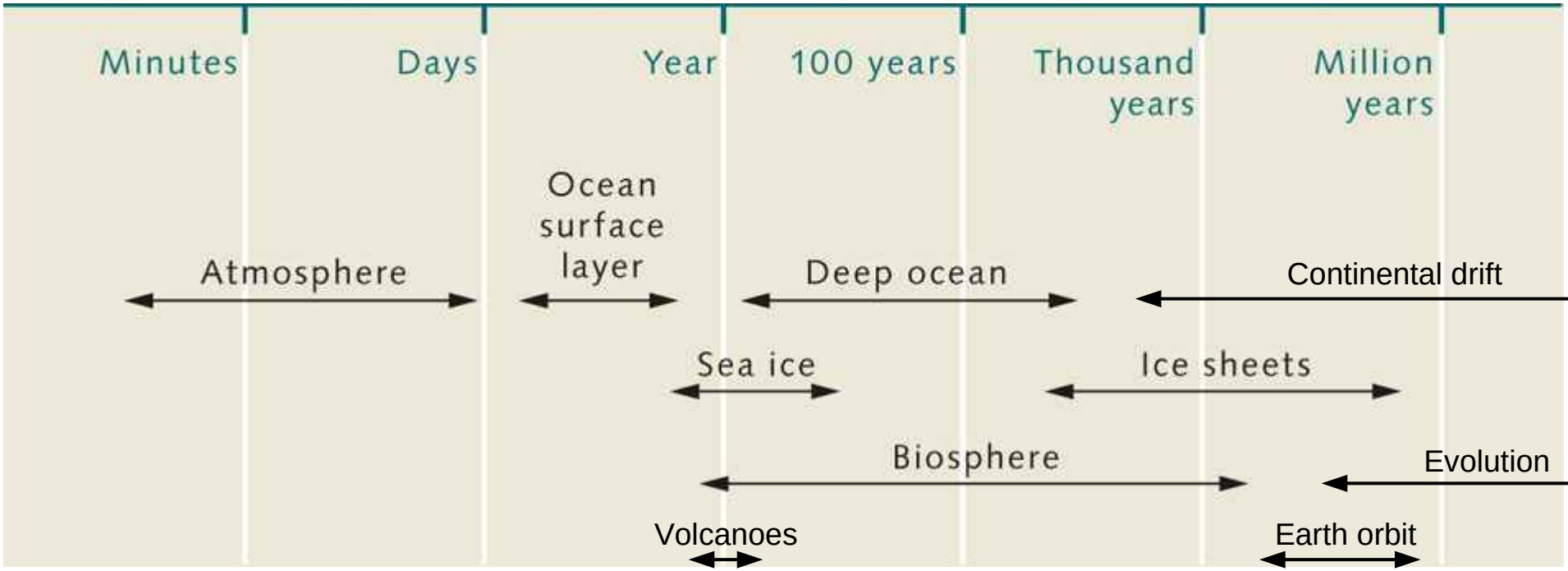
surface T: ~ 15°C

The main actors

- **Sun** (luminosity)
- **Earth orbit** (distribution of radiation)
- **Earth interior** (source for heat and matter)
- **Earth surface** (topography, weathering)

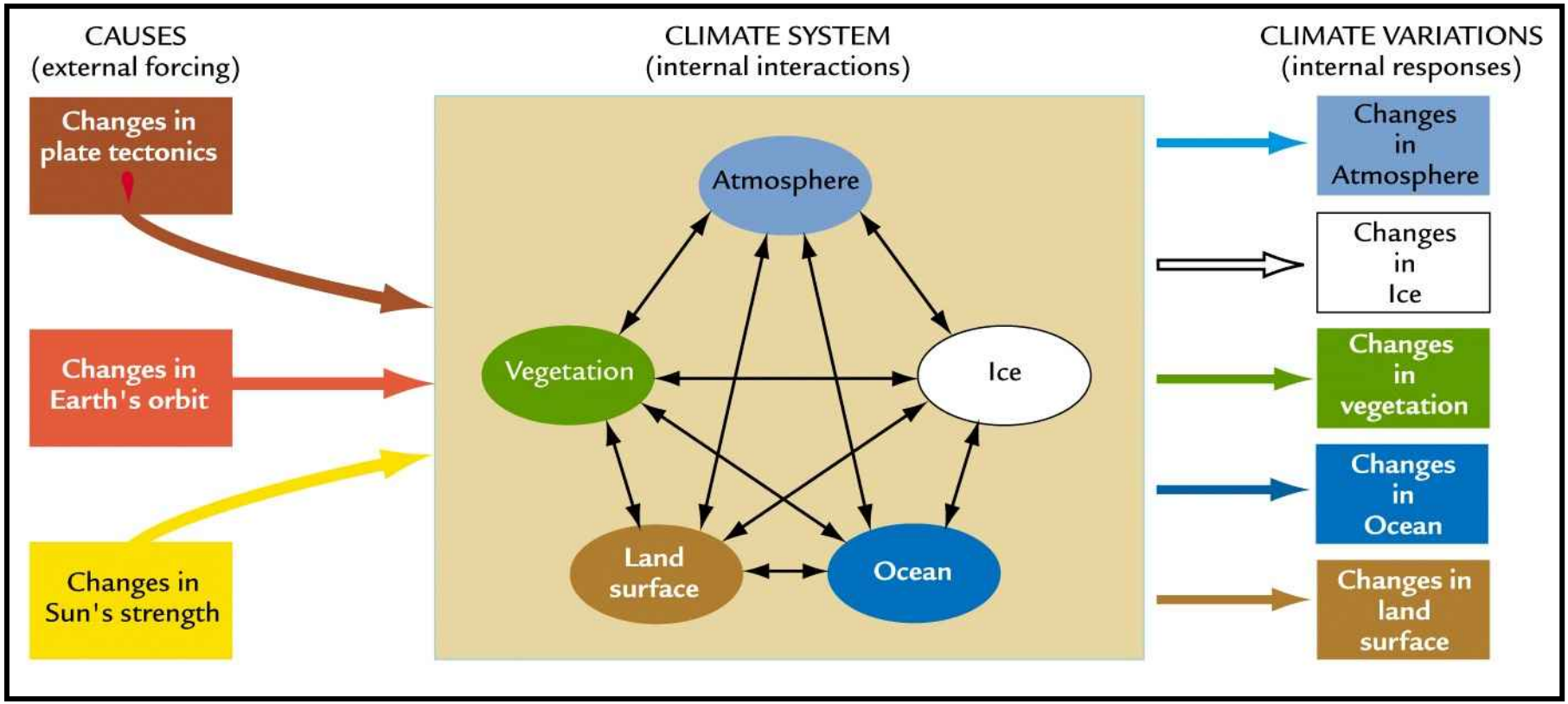
- **atmosphere** (absorbance, transport, chemistry)
- **oceans:**
  - **surface** (buffer, transport, chemistry, albedo)
  - **deep** (long term storage)
- **cryosphere** (albedo, topography, cover)
- **biosphere** (all above, chemistry)

The main actors



Wold Ocean Review,
after Meincke and Latif 1995,
modified

The main actors



NOAA

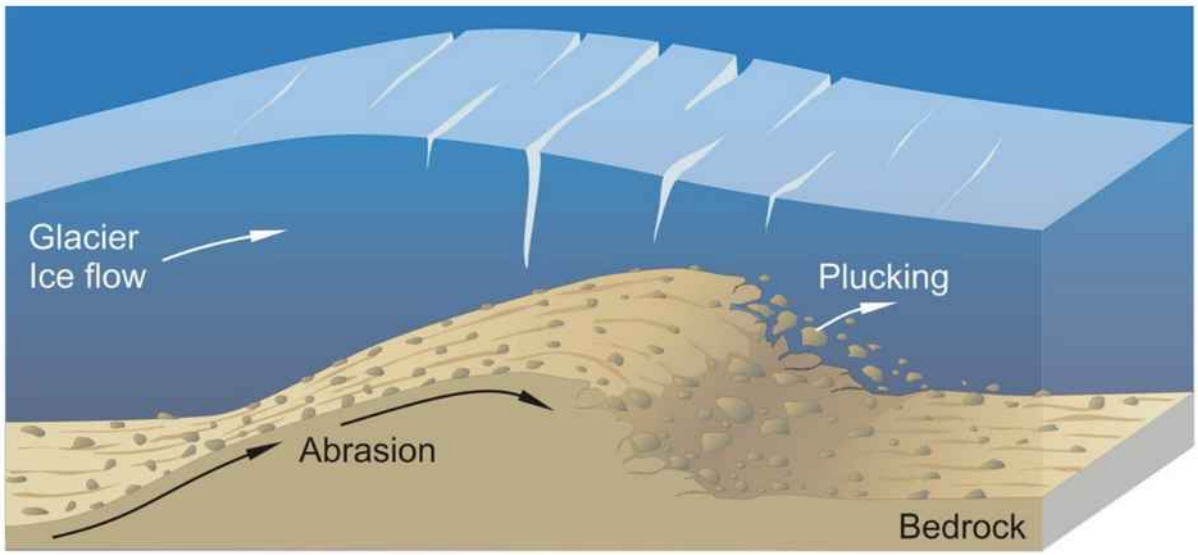
History: past glaciations

History: past glaciations

- in 18th century, scientists wondered where erratic boulders came from (Alps & Northern Europe)
- there was more and more evidence from erratics, land forms, scrapings on rocks, and more
- extends of glaciers and ice sheets could be mapped
- finally, marine sediments showed details about cyclicity and extent of glaciations

History: past glaciations

glacier landforms and erosion



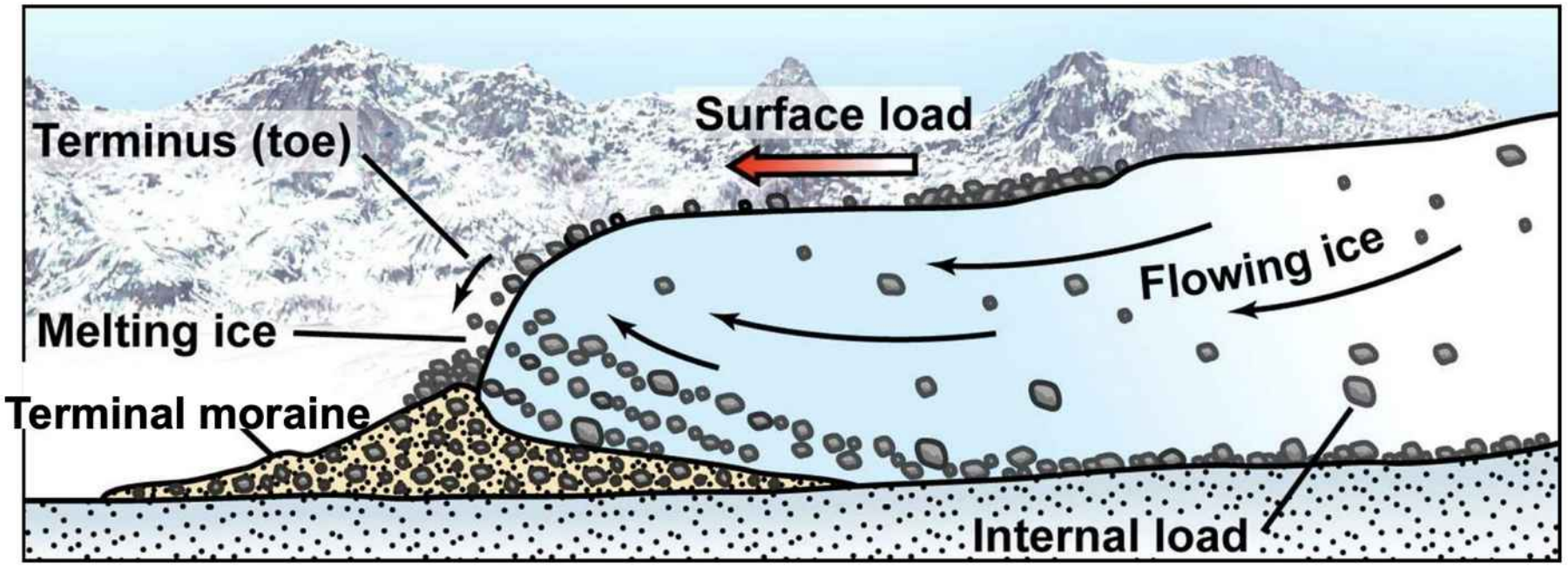
Glacial abrasion - striations

Plucking or glacial quarrying

earthsurface.
readthedocs.io

History: past glaciations

glacier landforms
and erosion



earthsurface.readthedocs.io

History: past glaciations

glacier landforms
and erosion

geograph.org.uk

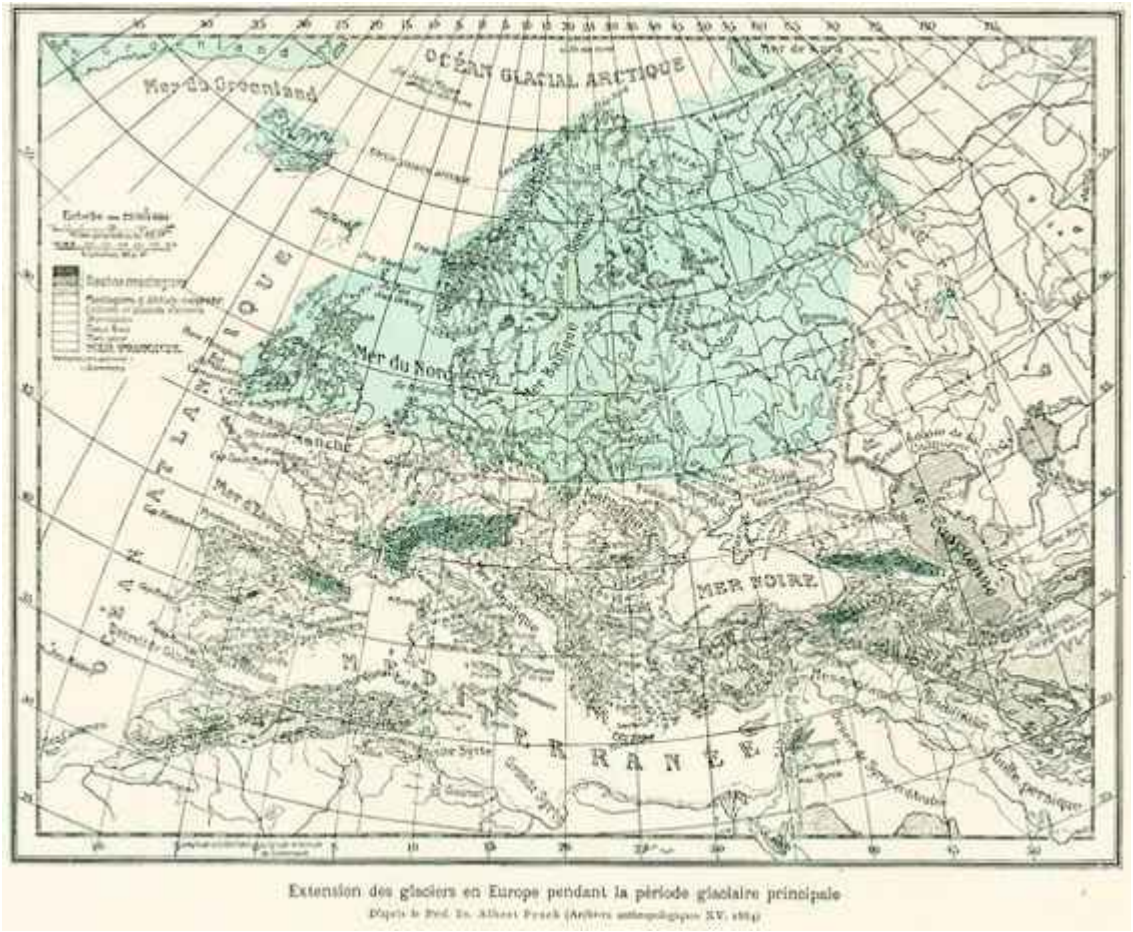
History: past glaciations

glacier landforms
and erosion

National Geographic

History: past glaciations

Ice sheet map from 1908



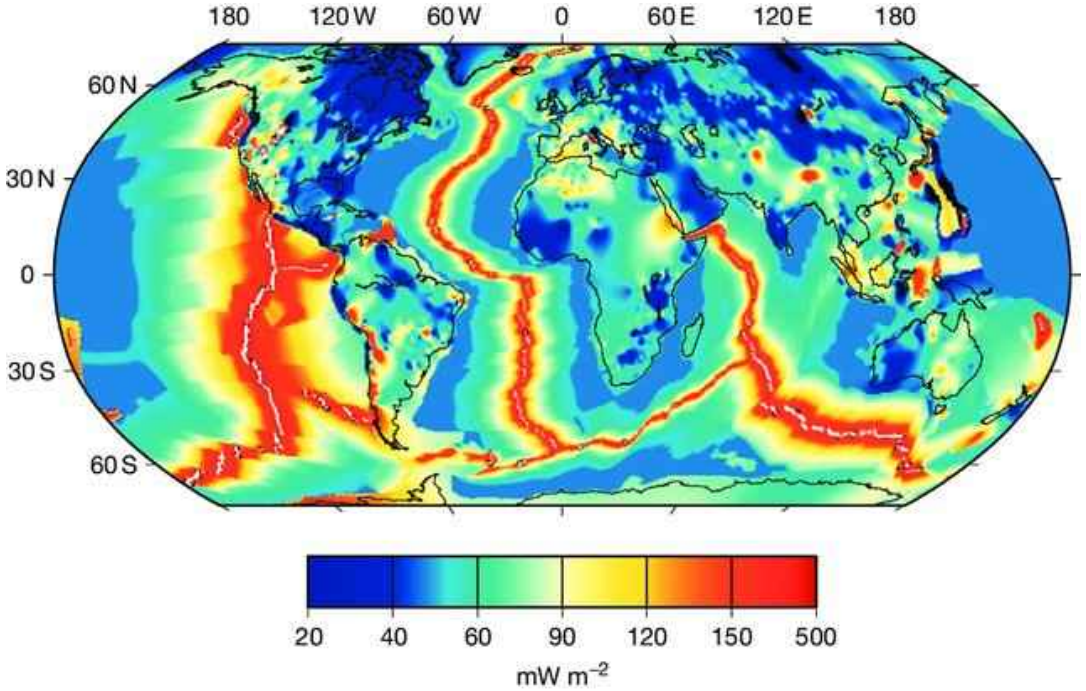
Extension des glaciers en Europe pendant la période glaciaire principale

Pinterest,
from French Natural
History Encyclopedia

Earth's energy budget

Earth's energy budget

geothermal heat

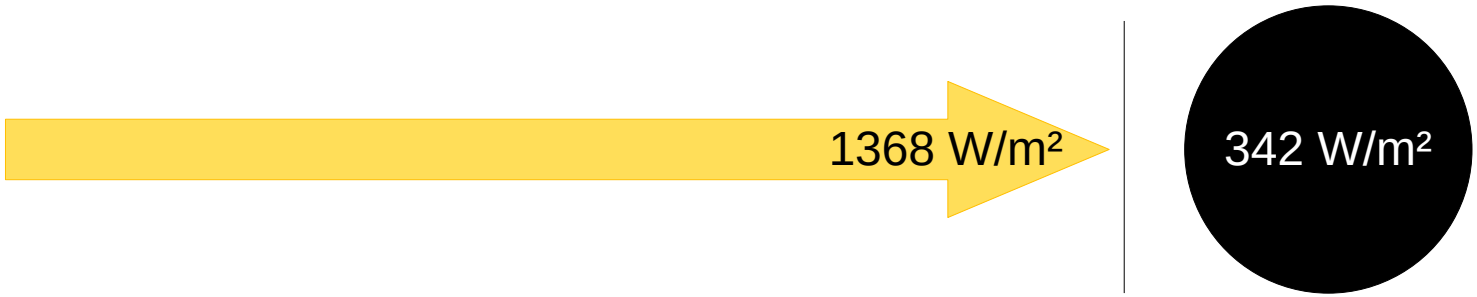


Mareschal (2011),
Encyclopedia of Solid Earth Geophysics

source:
radioactive decays of ^{238}U, ^{235}U, ^{232}Th, ^{40}K
+ primordial heat

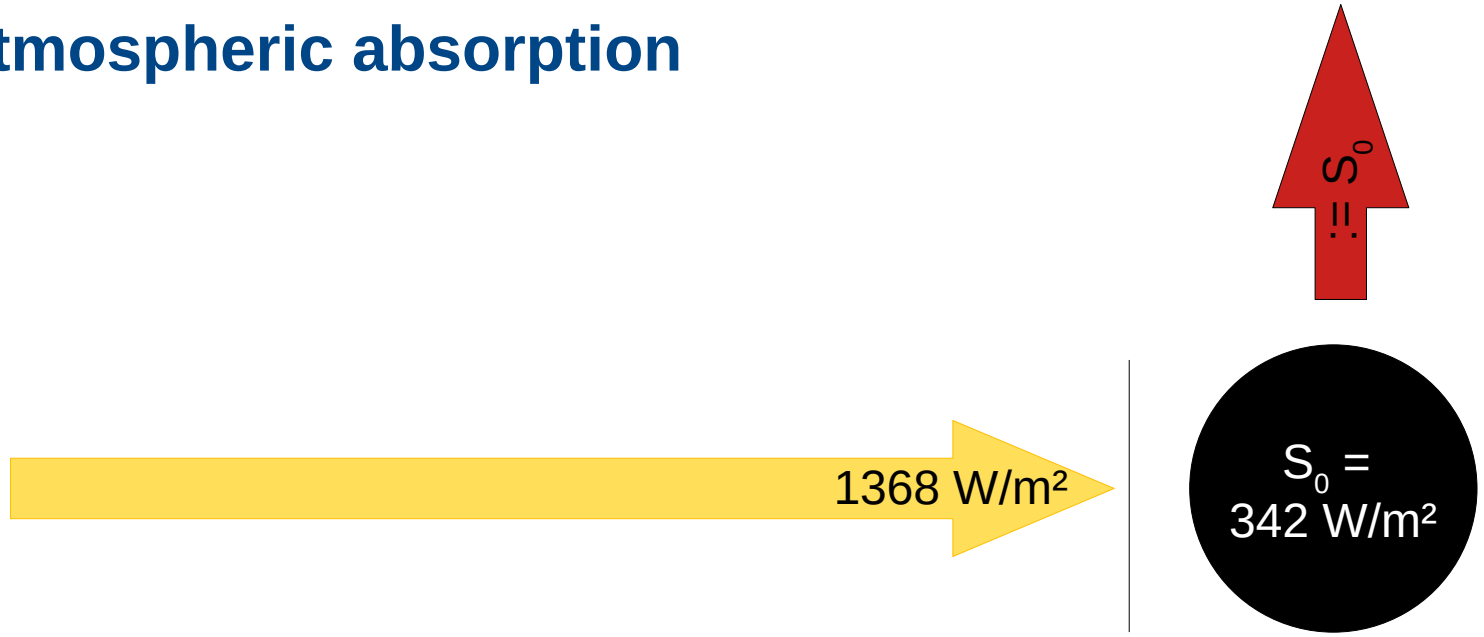
Earth's energy budget

atmospheric absorption



Earth's energy budget

atmospheric absorption



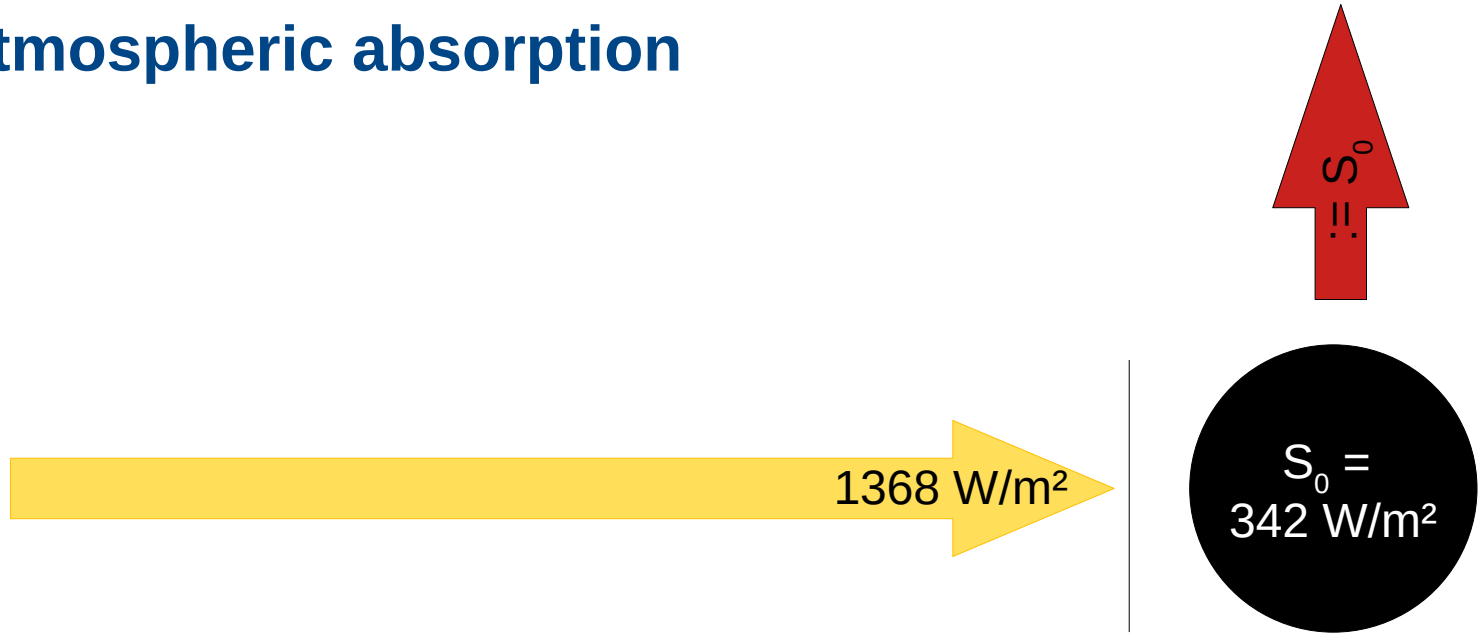
equilibrium: $P/A = \sigma T^4$

$T = 6°C$

but actually Earth's equilibrium T = 15°C!

Earth's energy budget

atmospheric absorption

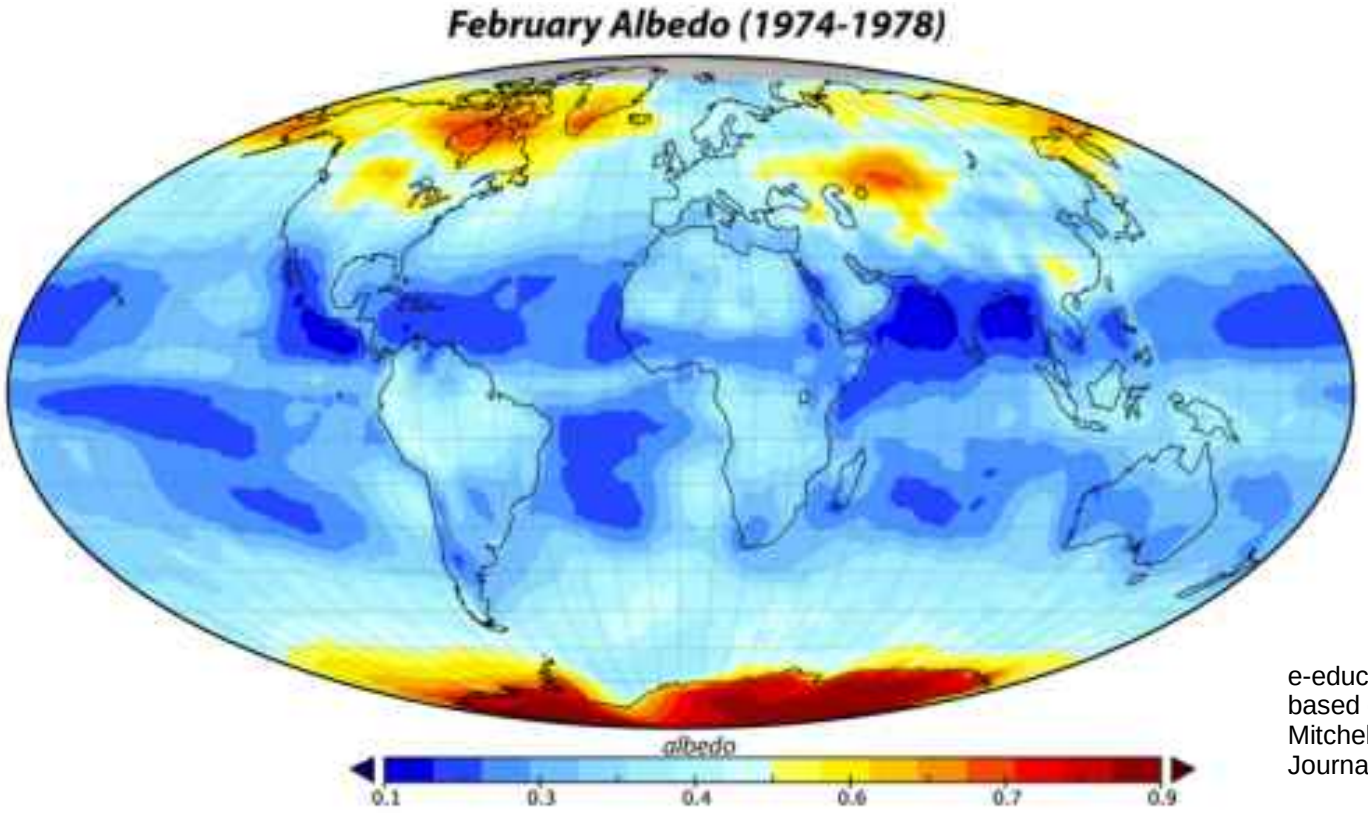


equilibrium: $P/A = \sigma T^4$

$T = 6°C$

Earth's energy budget

atmospheric absorption: albedo

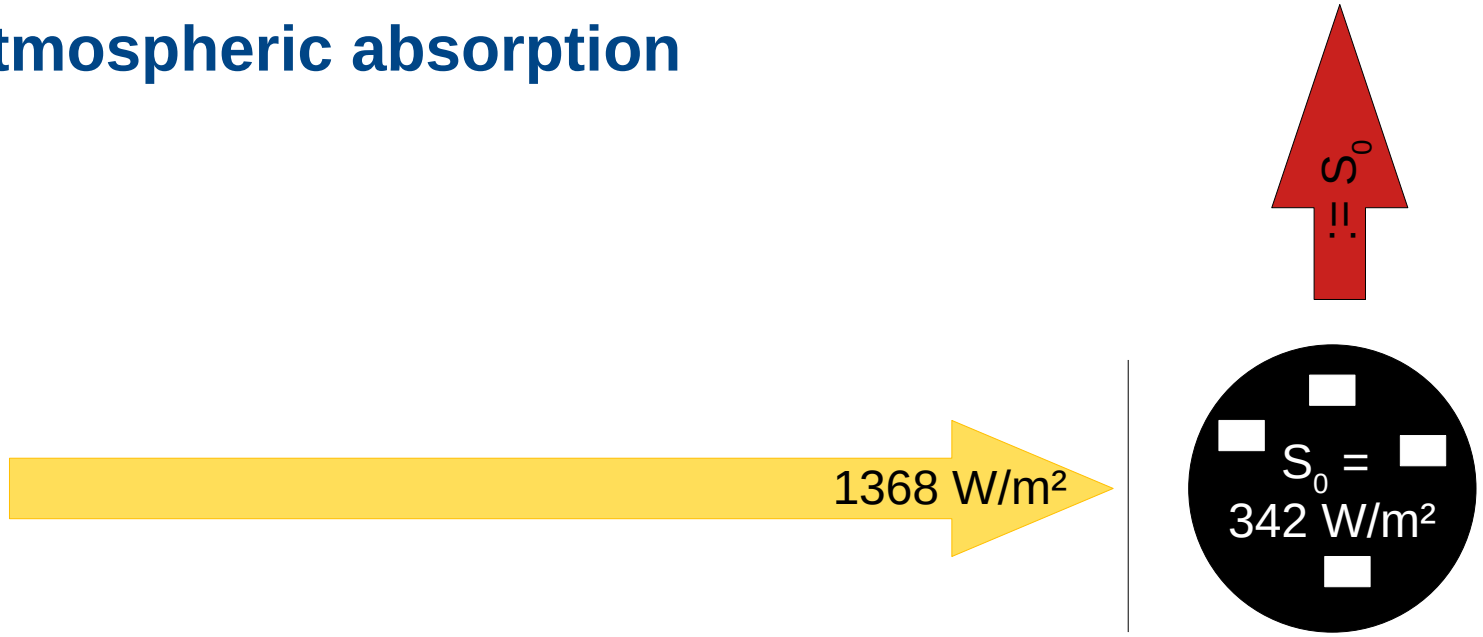


e-education.psu.edu,
based on
Mitchell and Wallace (1992),
Journal of Climate

long-term average: 0.31

Earth's energy budget

atmospheric absorption



equilibrium: $P/A = \sigma T^4$

Albedo ~ 0.31

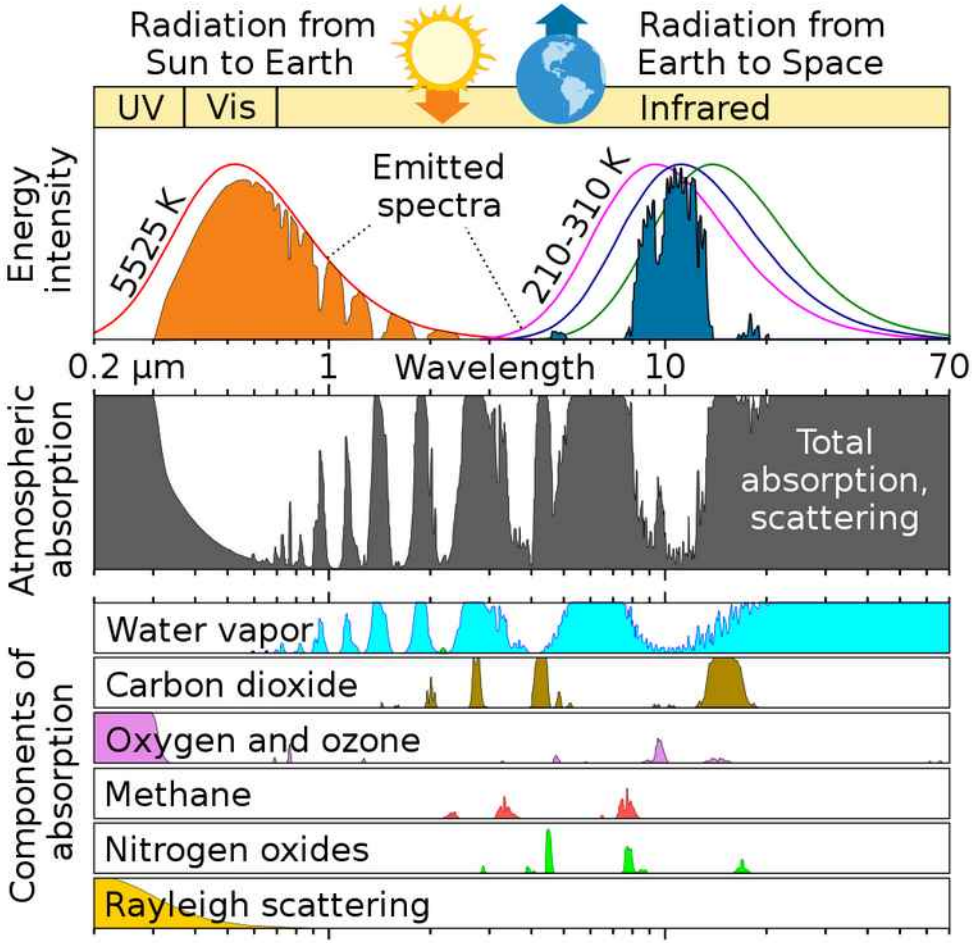
$T = -19°C$

$\Delta T = 31°C \rightarrow$ Greenhouse effect

at ~ 5km height

Earth's energy budget

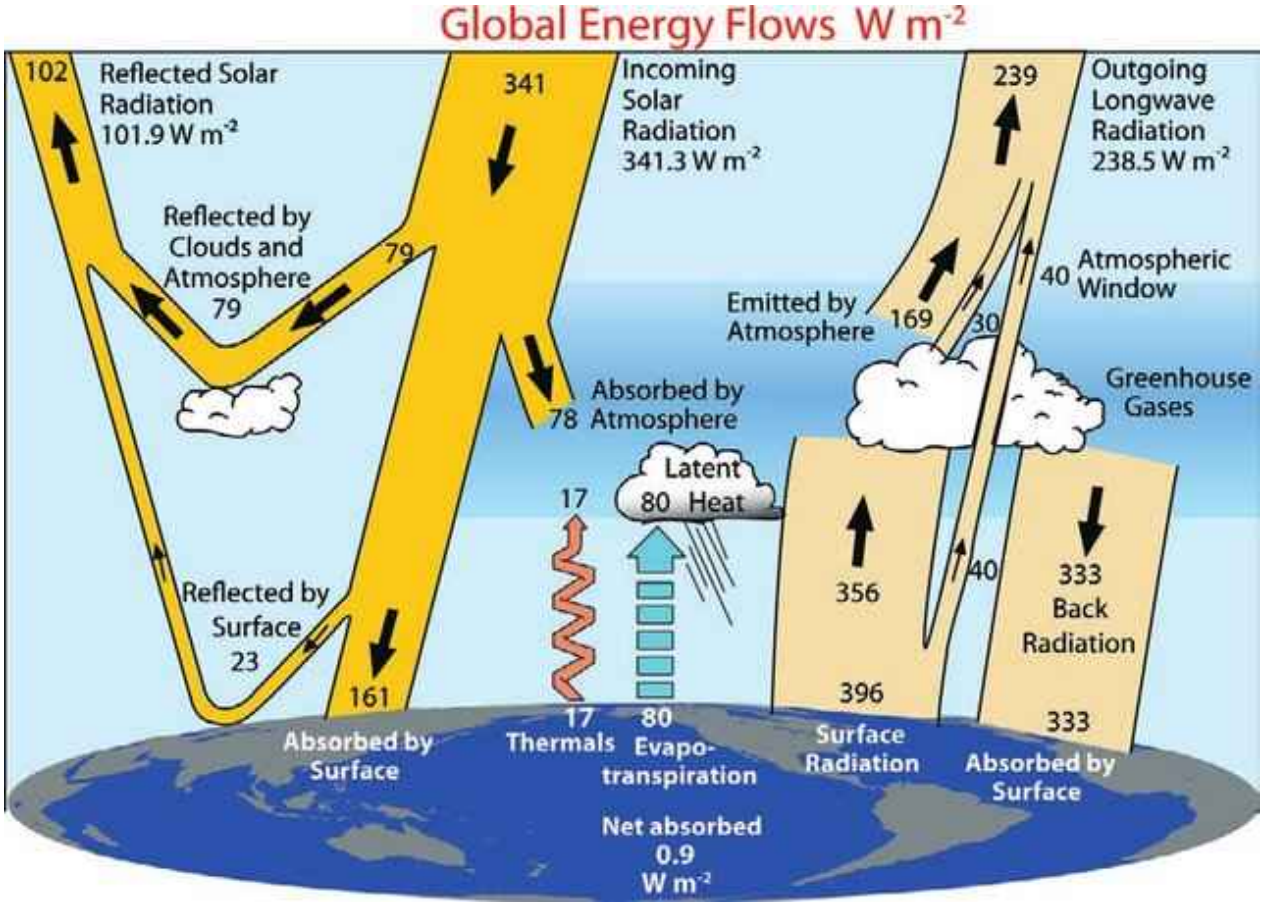
atmospheric absorption



Wikipedia

Earth's energy budget

solar radiation



Trenberth et al. (2009), Bulletin of the American Meteorological Society

Earth's energy budget

how to change Earth's temperature?

change either of:

- solar irradiation
- surface albedo
- atmospheric composition

Earth's energy budget

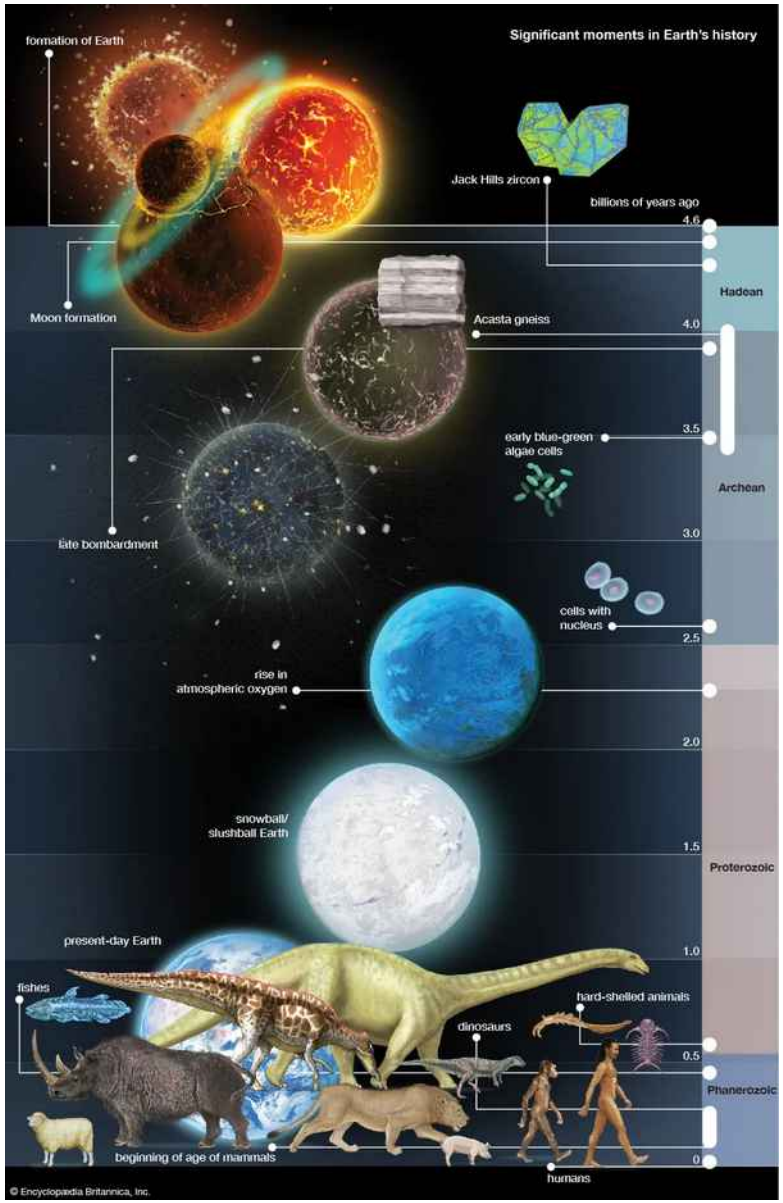
how to change Earth's (equilibrium) temperature?

change either of:

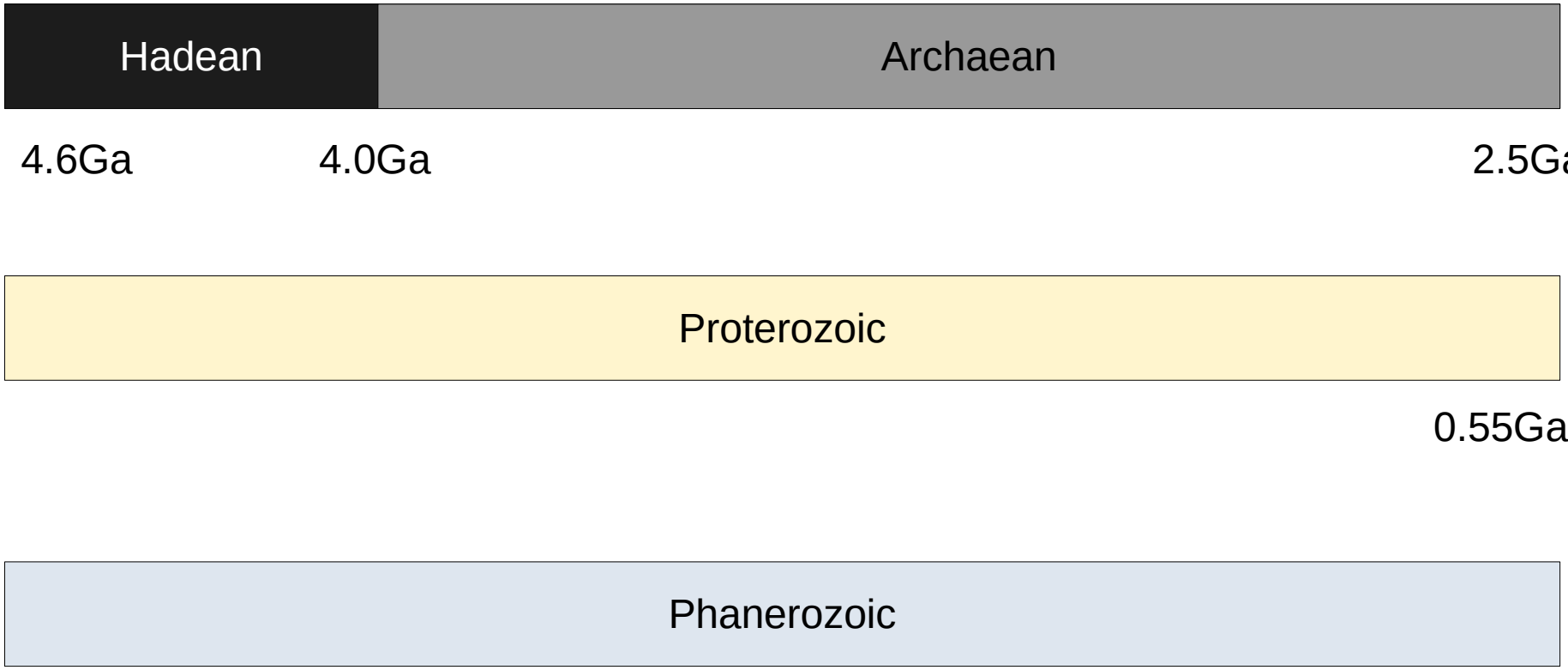
- solar irradiation (~ constant on Ga)
- albedo (ocean/continents, fauna, ice, clouds)
- atmospheric composition (CO_2, CH_4, or others)

Earth history

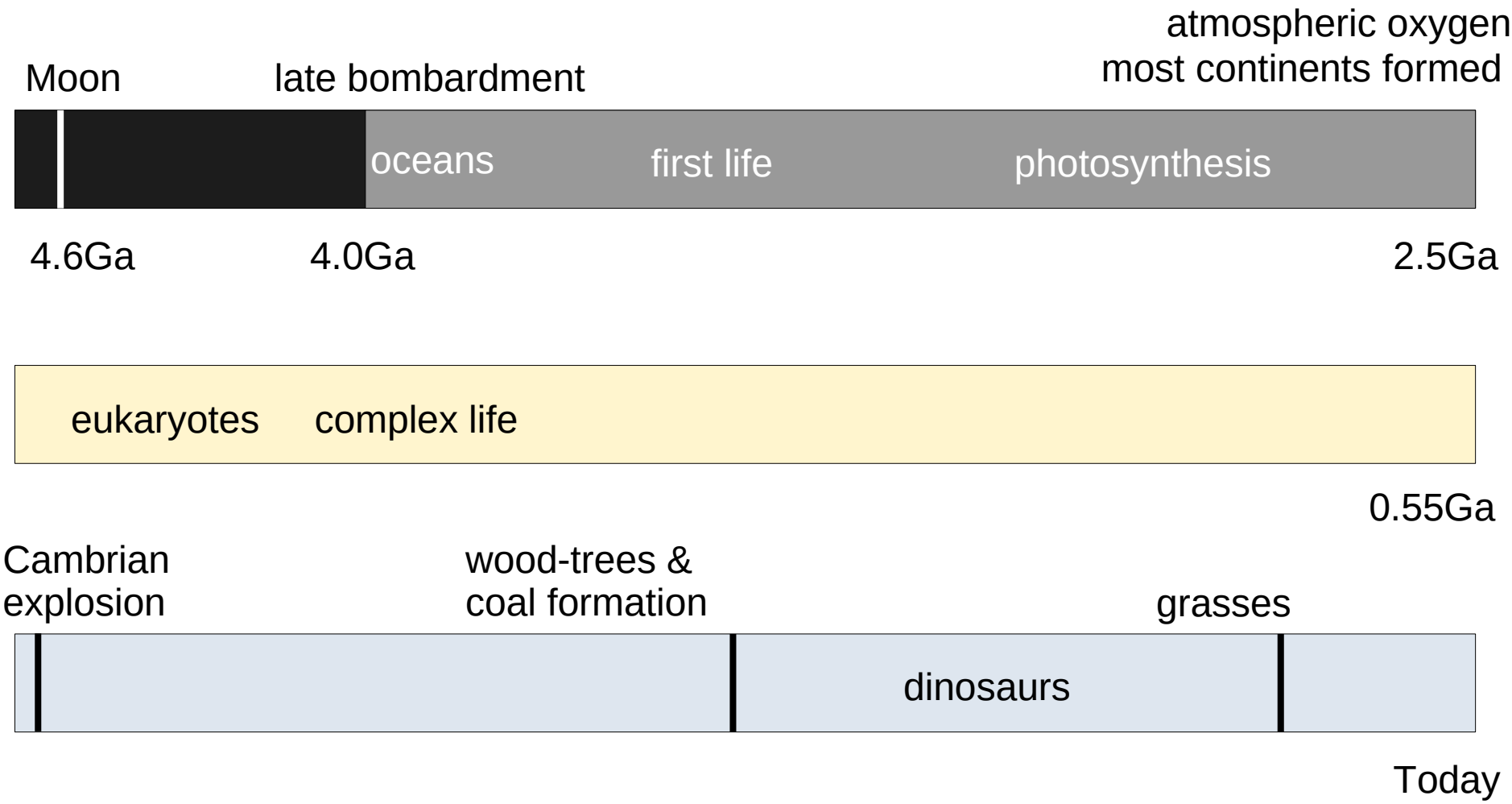
Earth history



Earth history



Earth history



Earth history

Paleozoic

Pangaea

550 Ma

250 Ma

Mesozoic dinosaurs

ocean anoxic events

Chicxulub

Stegosaurus

T-Rex

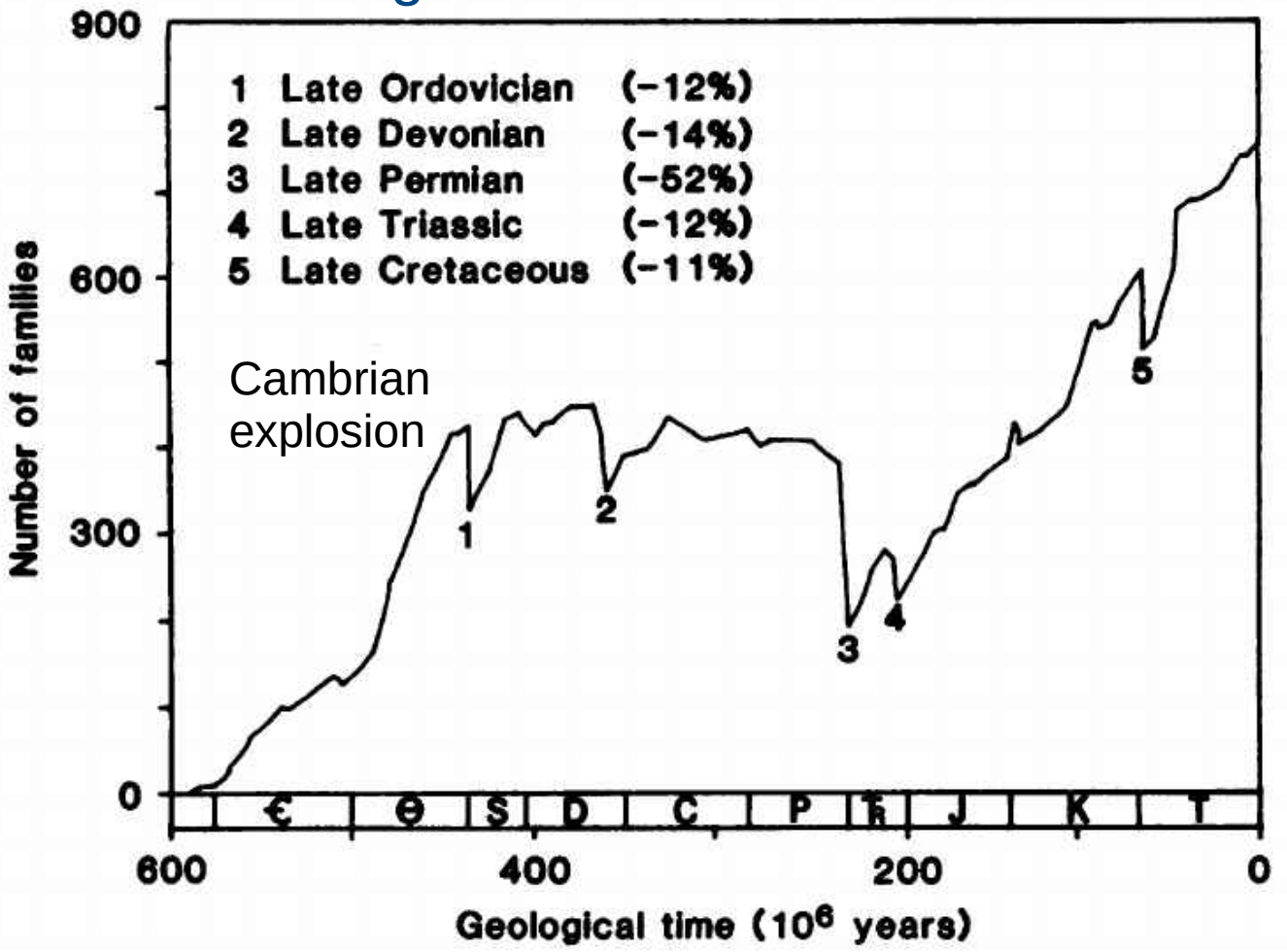
65 Ma

Cenozoic

Today

Earth history

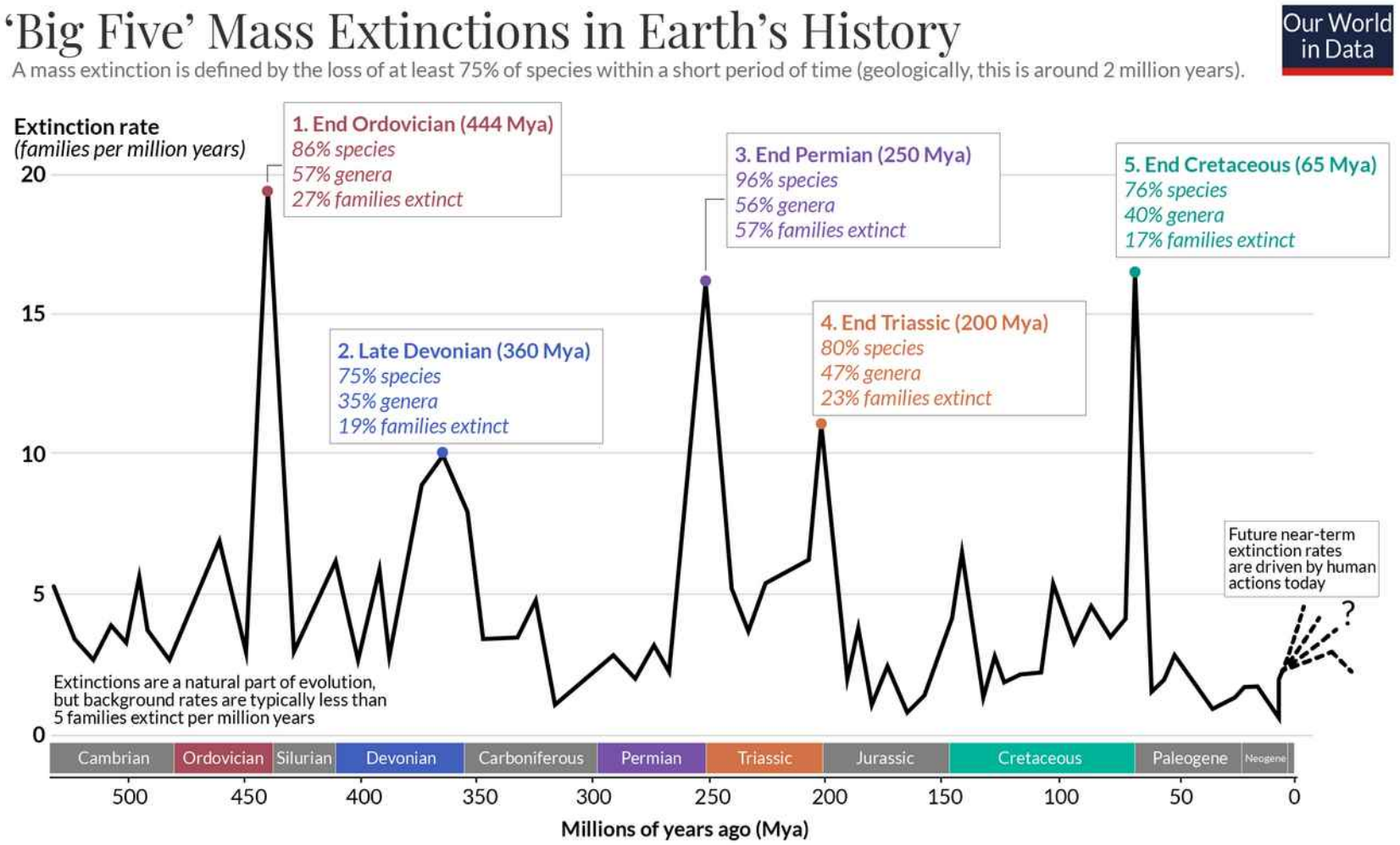
The Big Five Mass Extinctions



Raup & Sepkoski 1982,

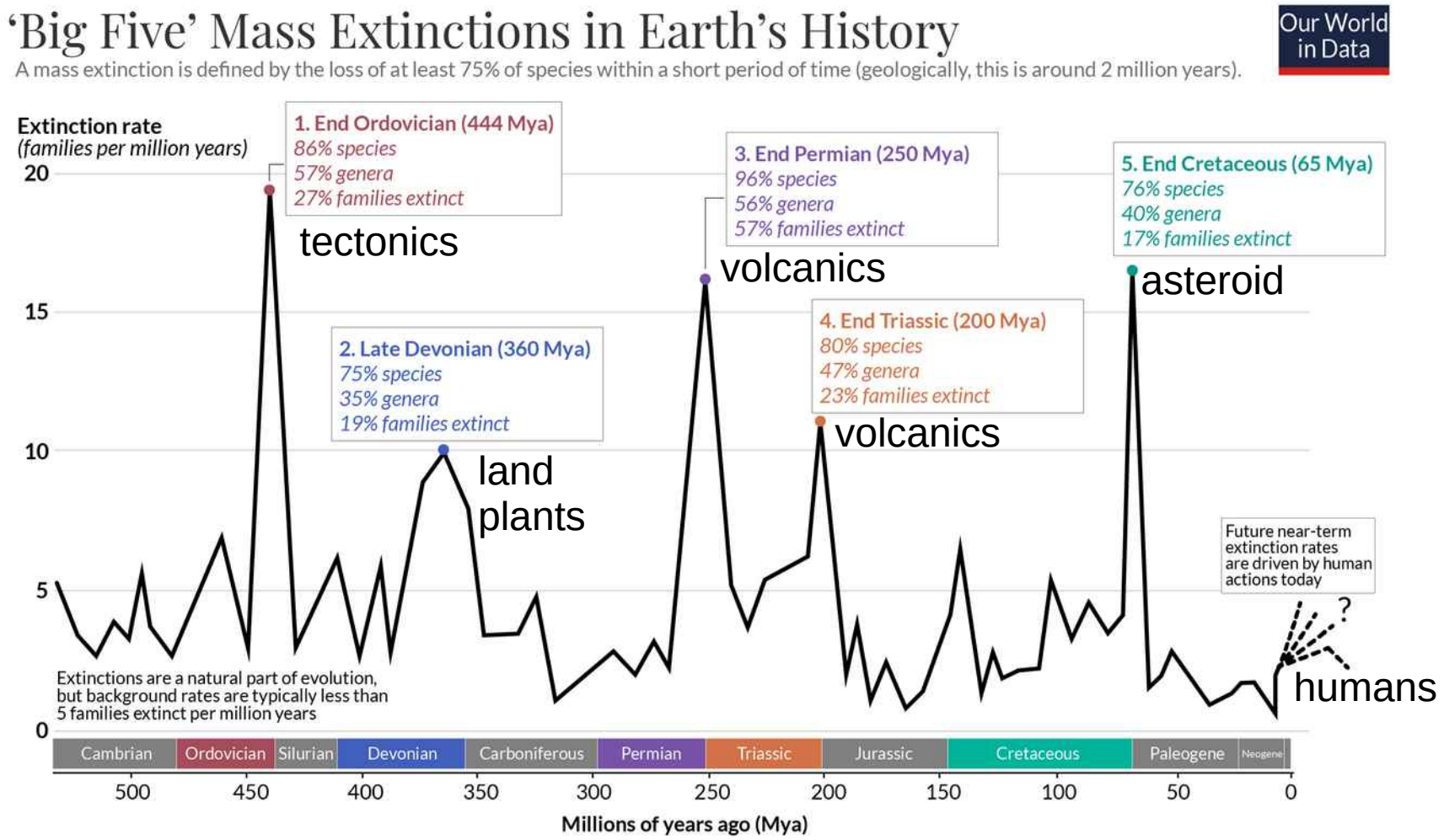
marine species

Earth history



Sources: Barnosky et al. (2011); Howard Hughes Medical Institute; McCallum (2015). Vertebrate biodiversity losses point to a sixth mass extinction.
OurWorldinData.org – Research and data to make progress against the world's largest problems.

Earth history



“Snowball Earth” events

“Snowball Earth”

Imagine you find:

- geological evidence for large ice sheets

“Snowball Earth”

Imagine you find:

- geological evidence for large ice sheets
- in several Ga old rocks

“Snowball Earth”

Imagine you find:

- geological evidence for large ice sheets
- in several Ga old rocks
- with evidence that these ice sheets were:
  - located in the tropics

“Snowball Earth”

Imagine you find:

- geological evidence for large ice sheets
- in several Ga old rocks
- with evidence that these ice sheets were:
  - located in the tropics
  - extending into shallow marine environments

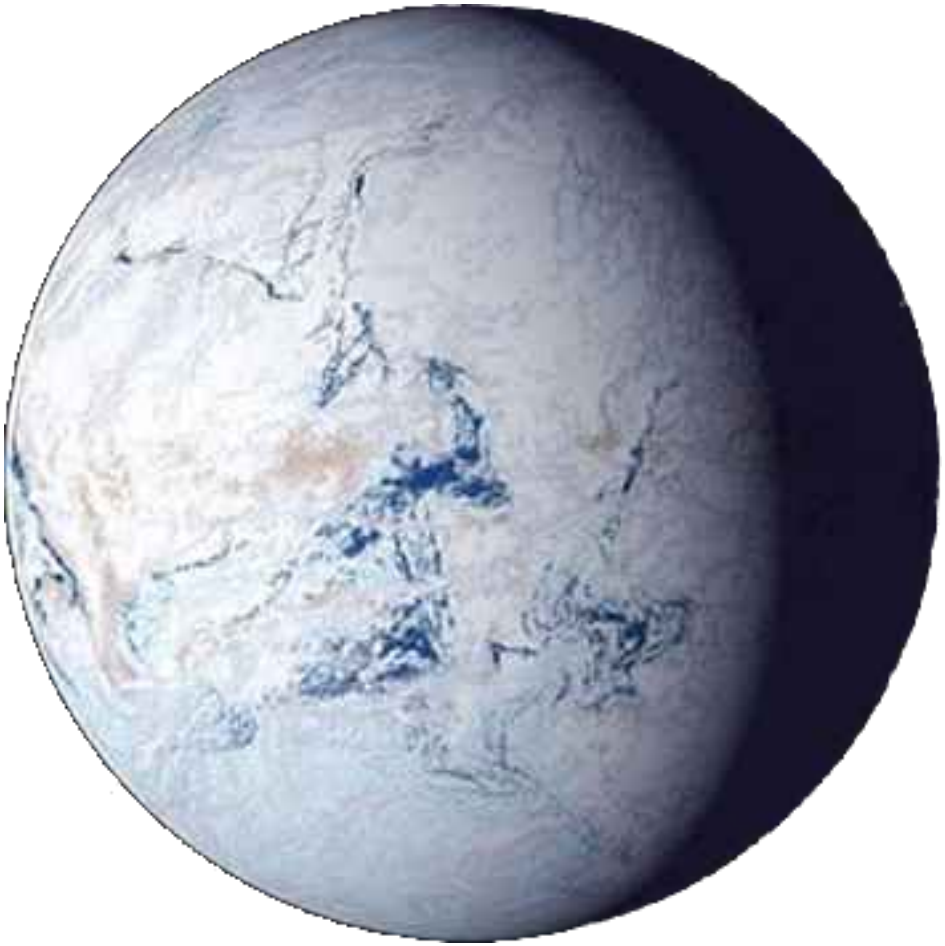
“Snowball Earth”

Imagine you find:

- geological evidence for large ice sheets
- in several Ga old rocks
- with evidence that these ice sheets were:
  - located in the tropics
  - extending into shallow marine environments

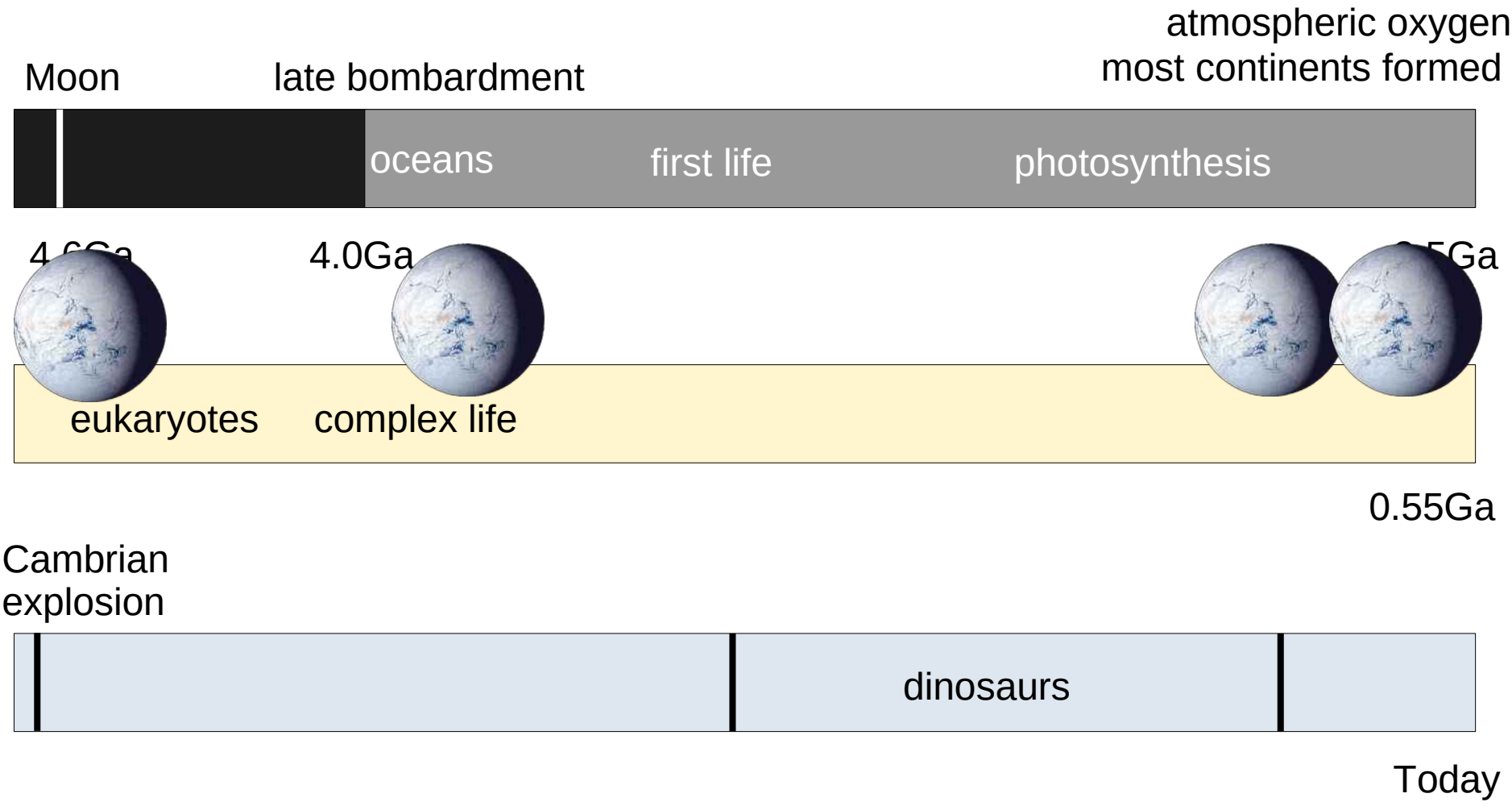
if sea level tropics were glaciated → everything was!

“Snowball Earth”



NASA

“Snowball Earth”



“Snowball Earth”

Causes:

CO2 drawdown

- from atmospheric oxygenation?
- from weathering (low latitude continents)?
- from early bioproductivity and extensive shelves?

Termination:

probably slow buildup of CO_2

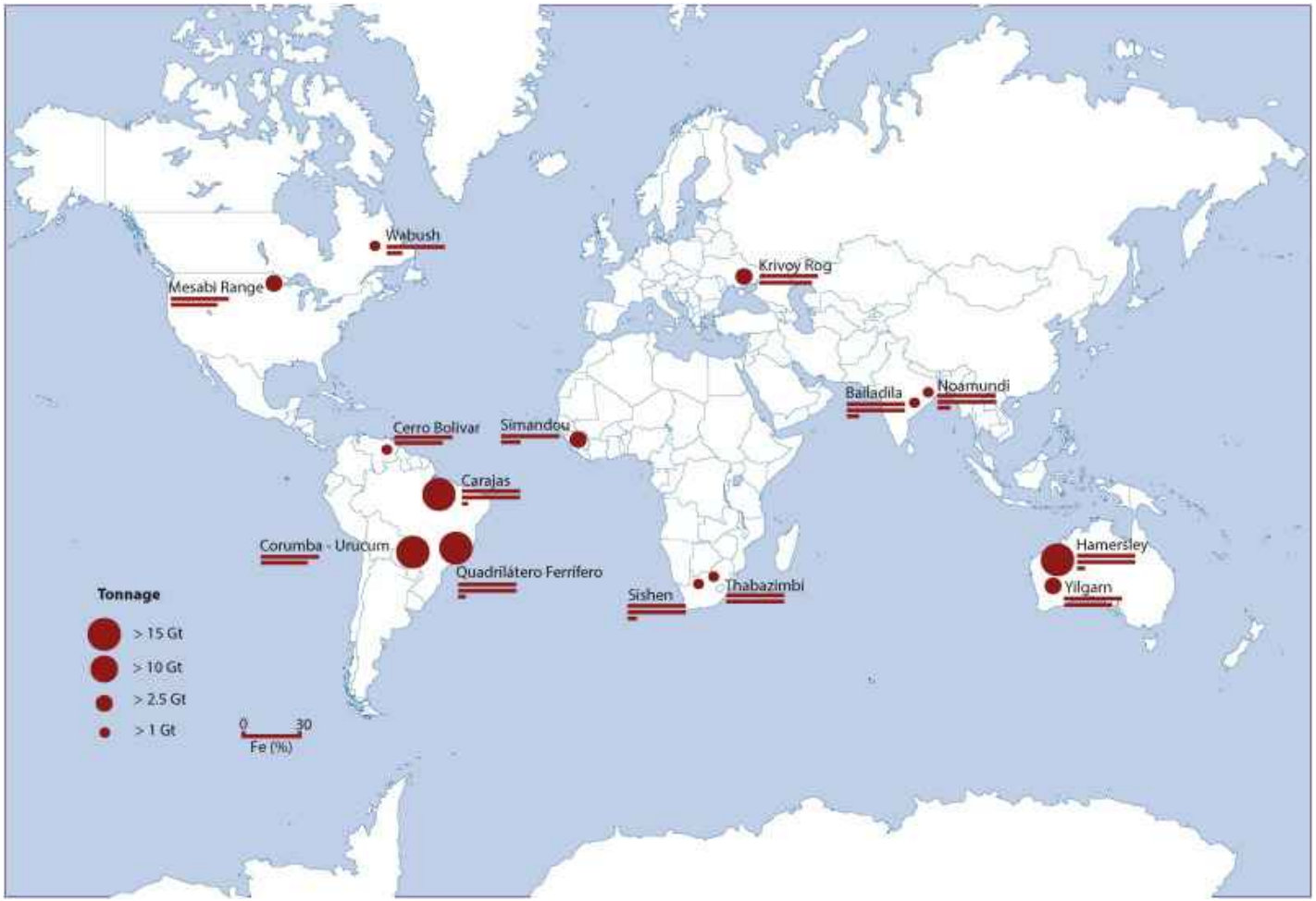
Banded Iron Formations

and the Great Oxidation Event

Banded Iron Formations

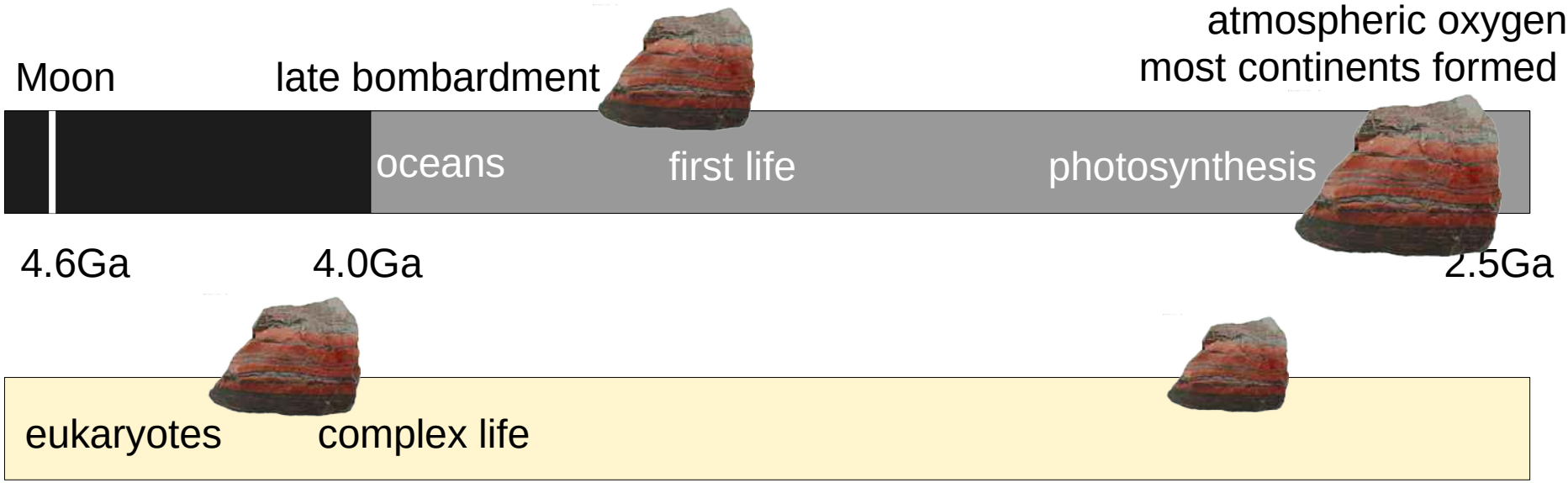
alchetron.com

Banded Iron Formations

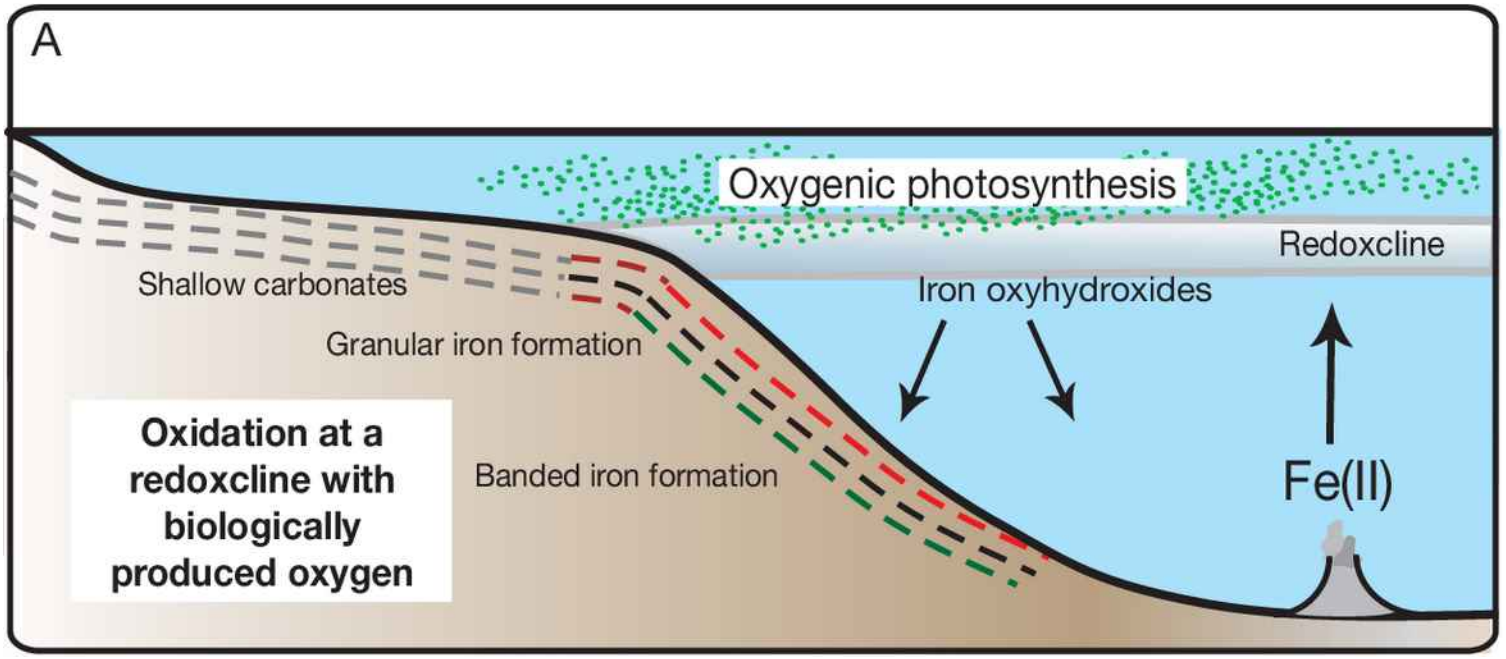


Hagemann et al. (2016), Ore Geology Reviews

Banded Iron Formations

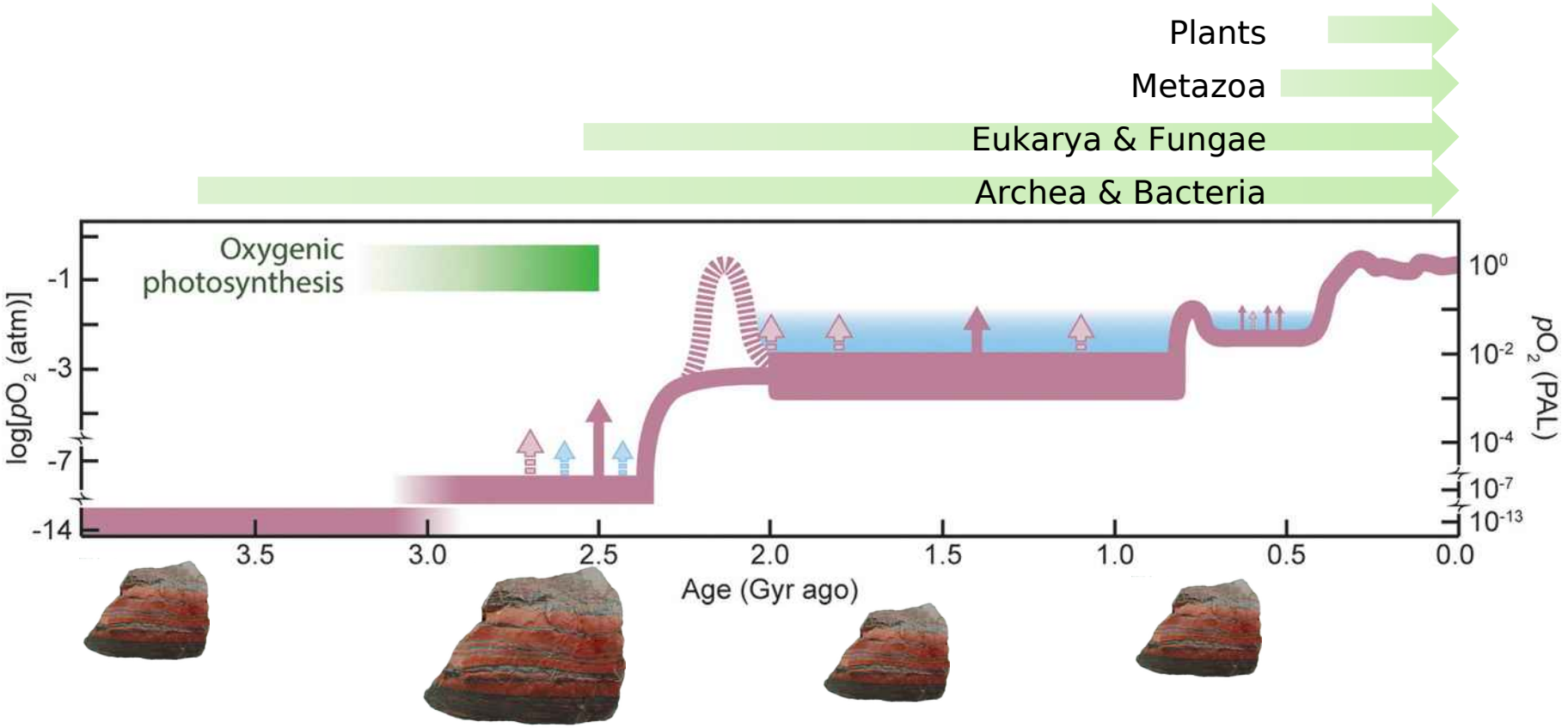


Banded Iron Formations



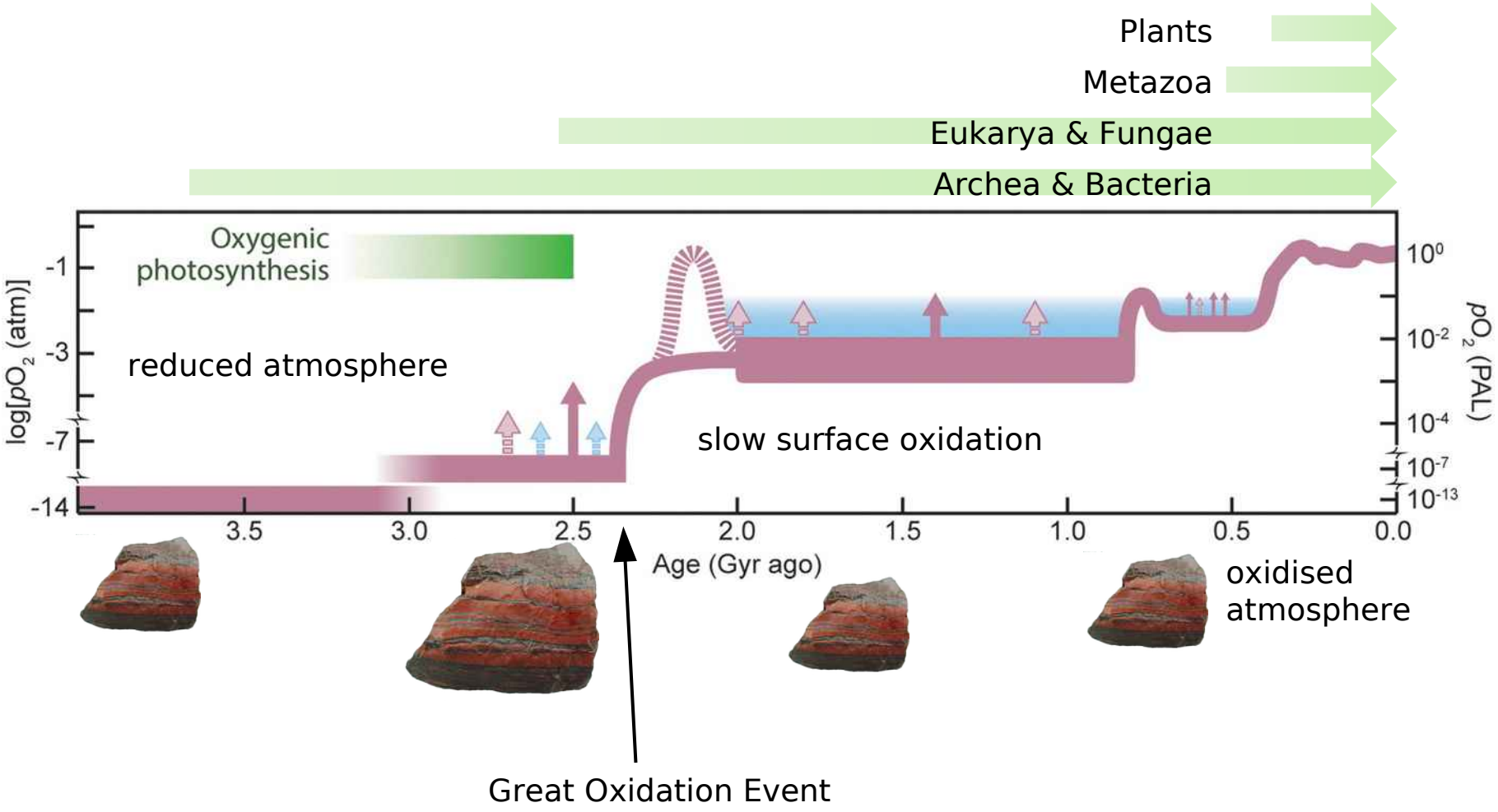
semanticscholar.org

Banded Iron Formations



modified after
Lyons et al. (2021),
Astrobiology

Banded Iron Formations



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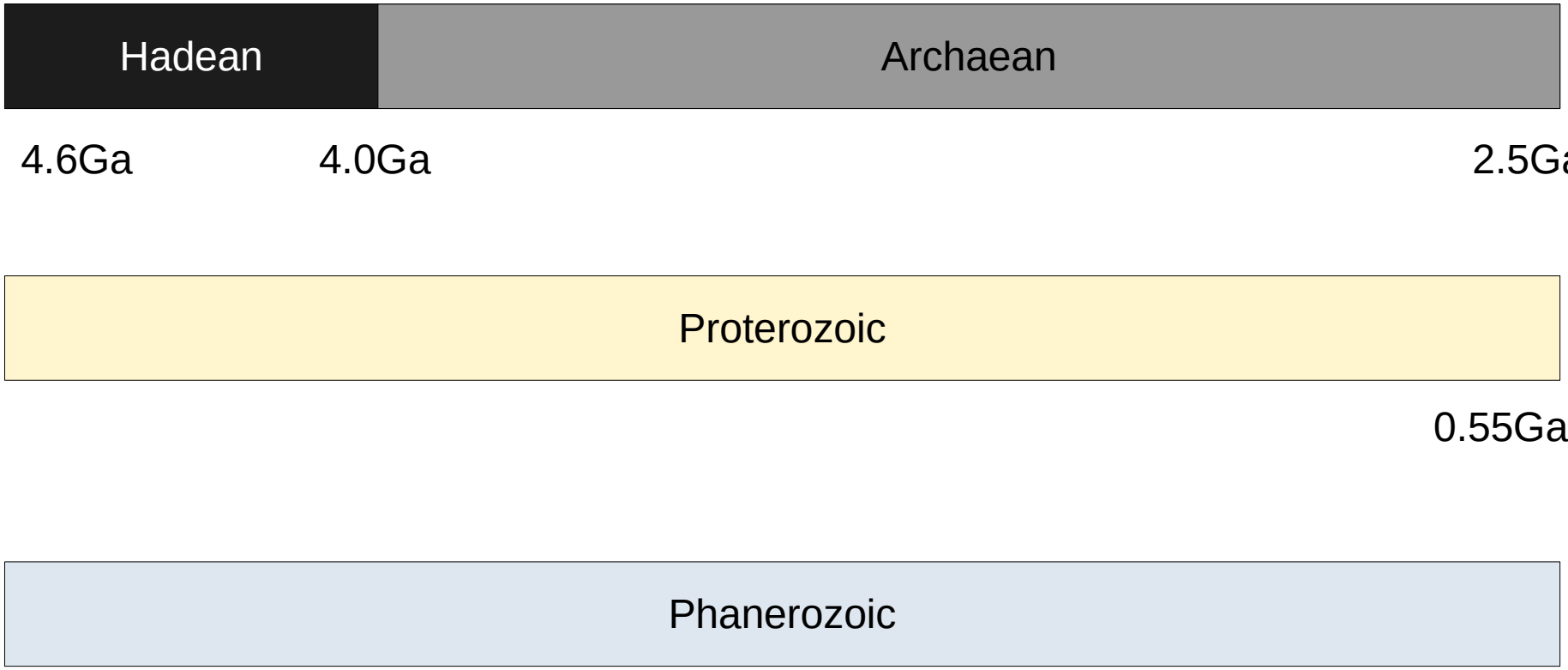
Earth history



Earth history

Paleozoic

Pangaea

550 Ma

250 Ma

Mesozoic dinosaurs

ocean anoxic events

Chicxulub

Stegosaurus

T-Rex

65 Ma

Cenozoic

Tuesday

Wednesday

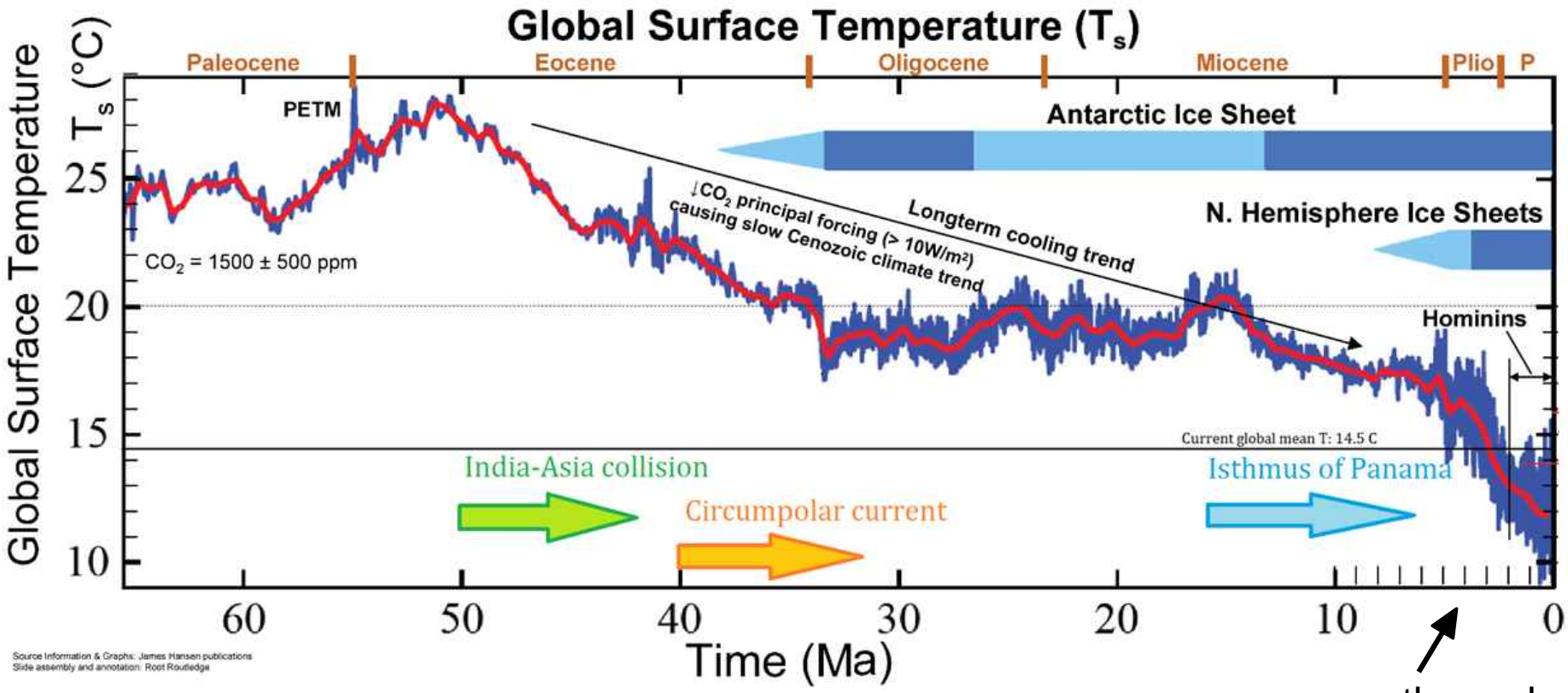
Today's Summary

- Paleoclimatology is very interdisciplinary
- many different archives and proxies, but data patchy and often uncertain

- long term climate determined by:
  insolation, albedo, and greenhouse gases

- Early Earth climate has changed completely
- Life and Evolution have shaped Earth's chemistry

Cenozoic climate



modern mammals

mammoths and saber-toothed cats

better records with plenty marine sediment cores

Earle (2016), opentextbc.ca
after James Hansen and Root Routledge

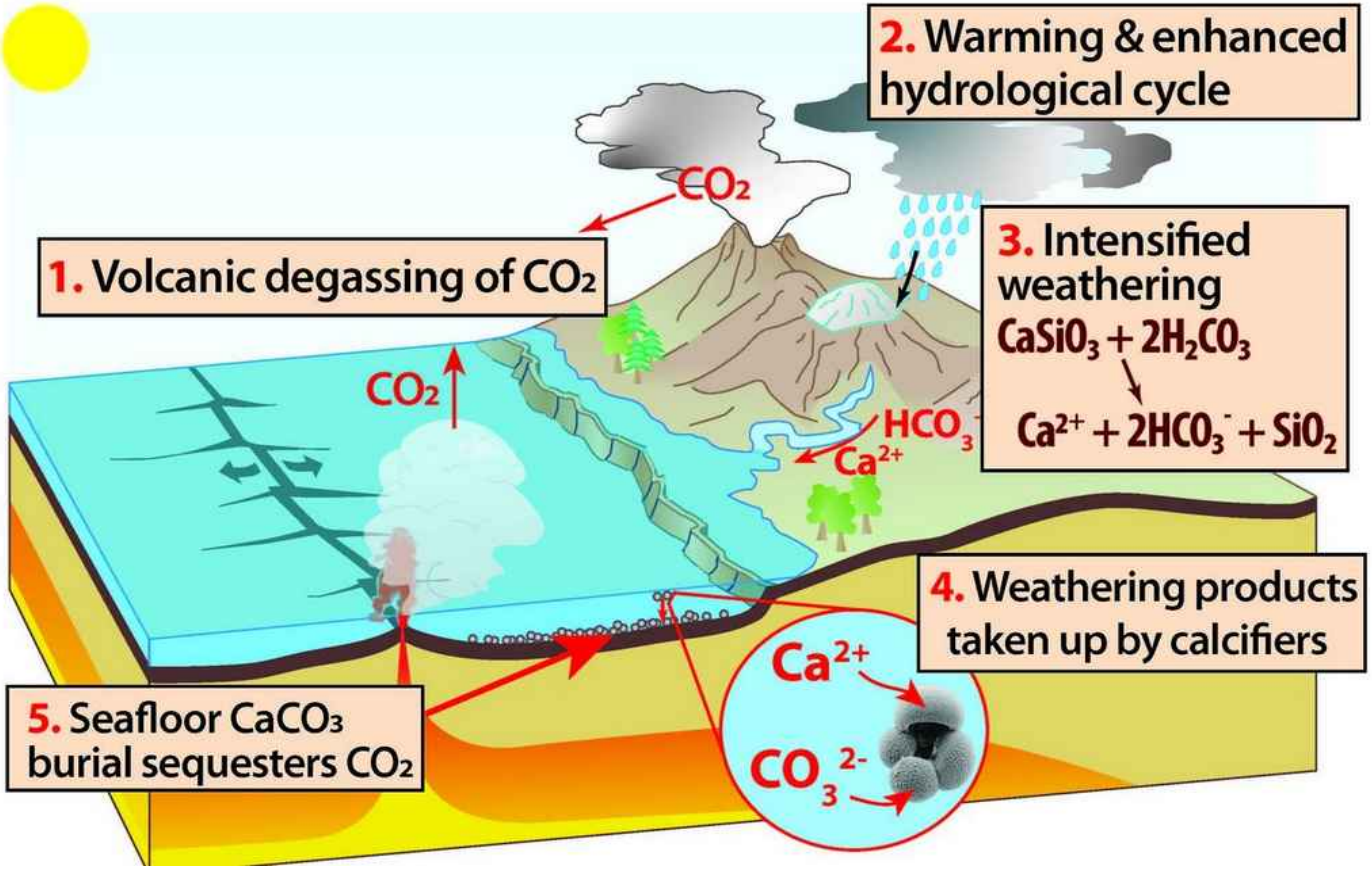
Outlook

Tomorrow we finish at 16:45!

Monday	Introduction	Earth History
Tuesday	Proxies I	Cenozoic Hot & Warm House
Wednesday	Specific Climate System components	Pleistocene G-IG climate
Thursday	Proxies II & Climate System Interactions	Abrupt Climate Change
Friday	Current Climate Change	Future & Synthesis

Earth's atmosphere

weathering



GFZ Potsdam

Earth's atmosphere

weathering rates

chemical weathering:

- CO_2 ↗
- temperature ↗
- humidity ↗

worldatlas.com

physical weathering:

- temperature ↘
- humidity ↗

easyscienceforkids.com

Earth's atmosphere

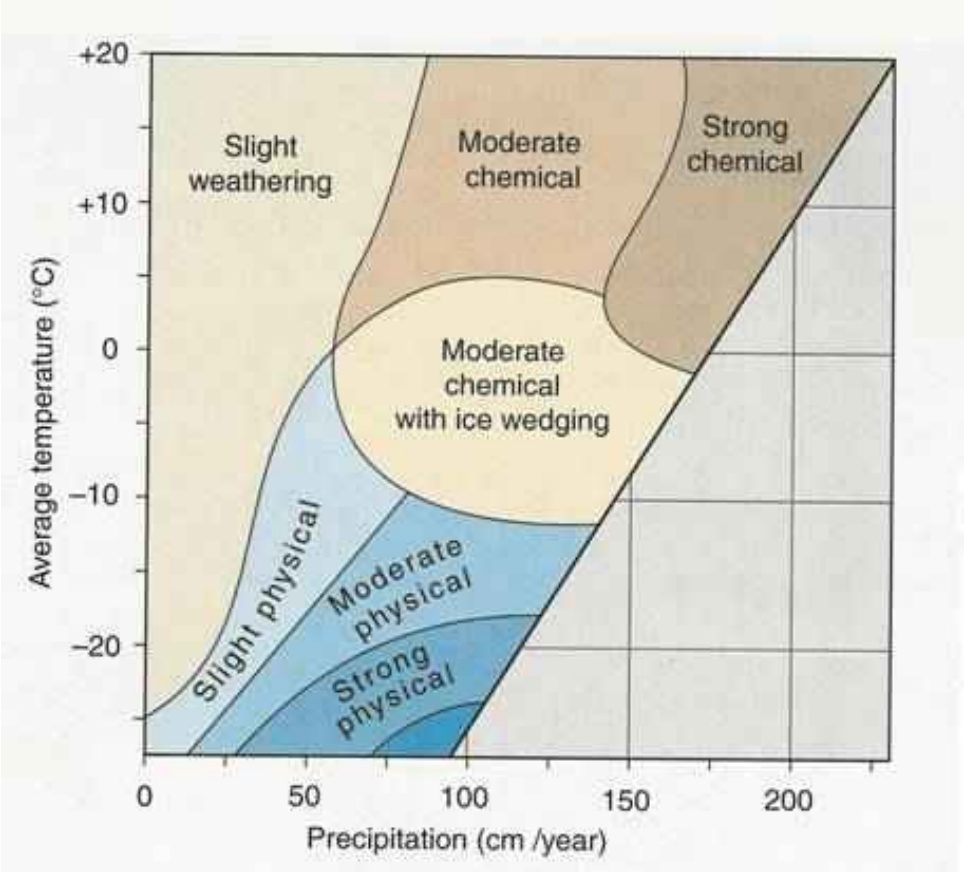
weathering rates

chemical weathering:

- CO_2 ↗
- temperature ↗
- humidity ↗

physical weathering:

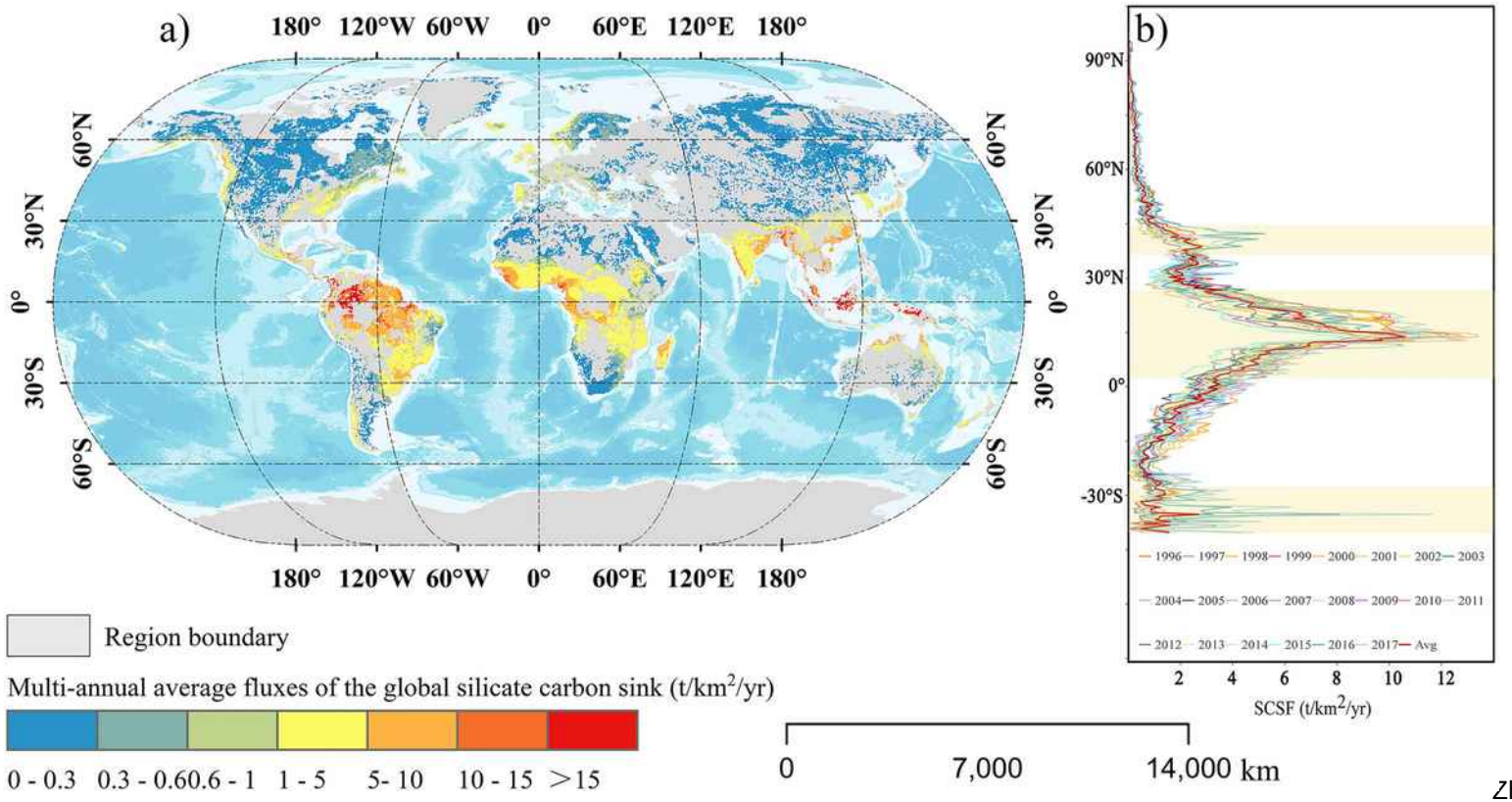
- temperature ↘
- humidity ↗



geocaching.com

Earth's atmosphere

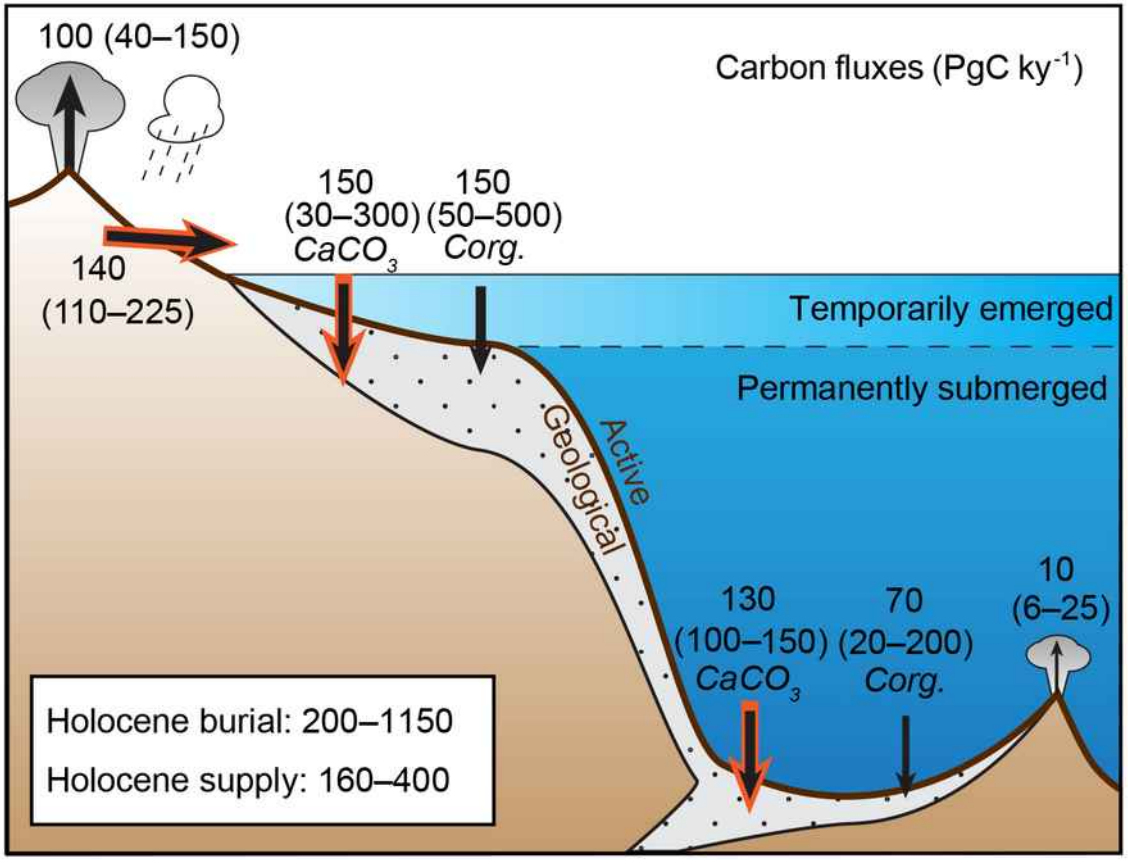
weathering rates



Zhang et al. (2021), Earth's Future

Earth's atmosphere

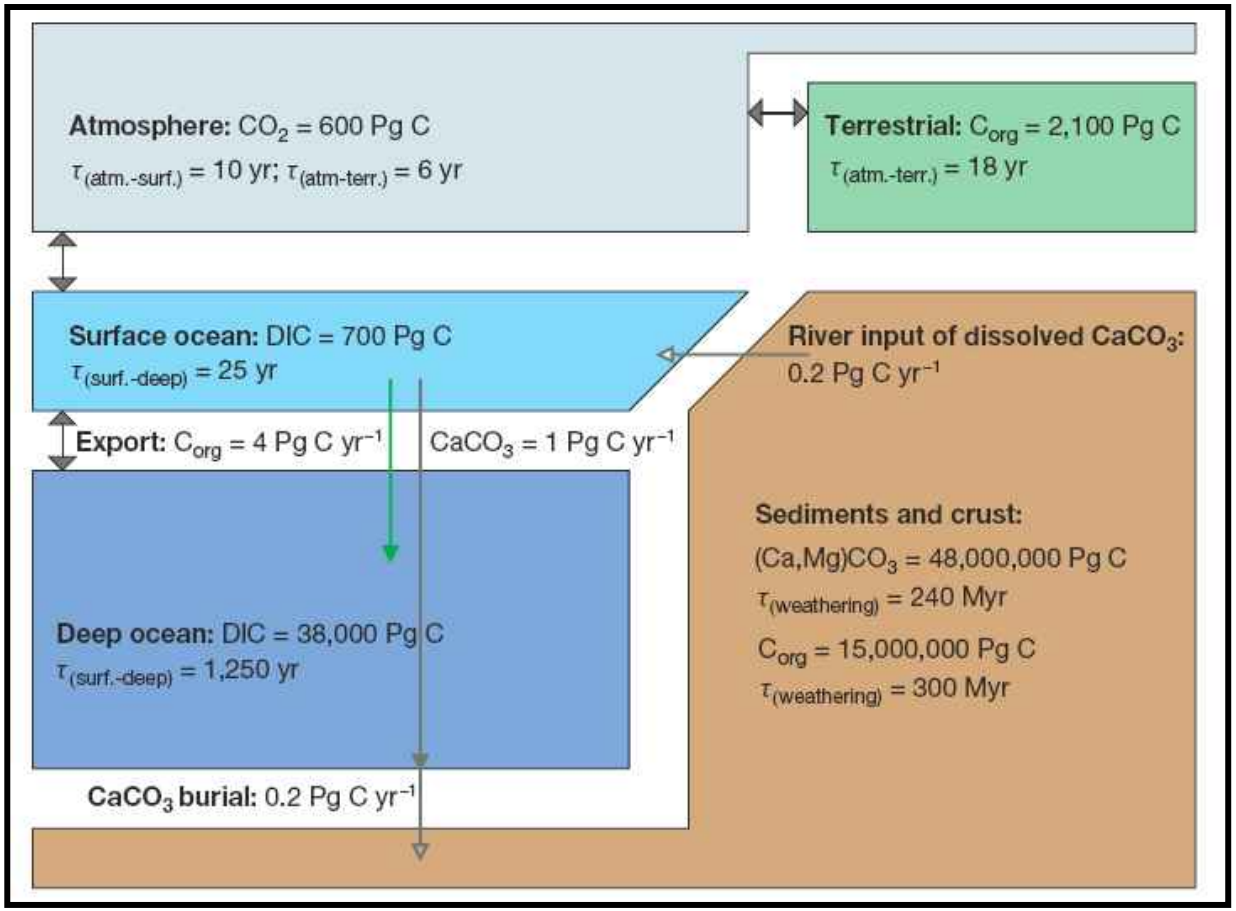
the marine carbon pump(s)



Cartapanis et al. (2018), Climate of the Past

Earth's atmosphere

the carbon cycle



Pg C = Gt = 10^{12} g C

Sigman & Boyle (2000), Nature