

# Global warming - physicist's perspective - 03

Szymon P. Malinowski

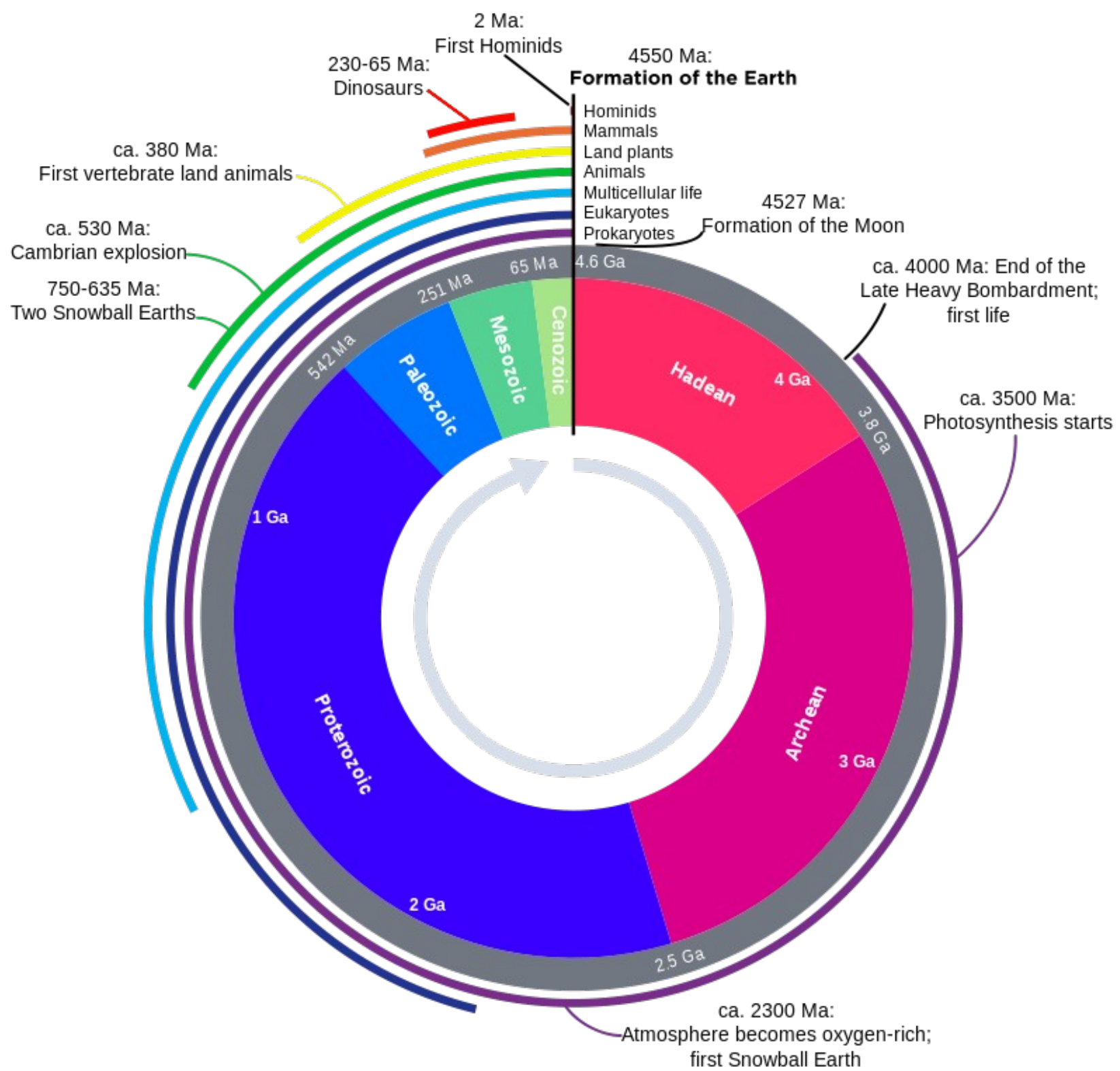
University of Warsaw, Faculty of Physics, Institute of Geophysics



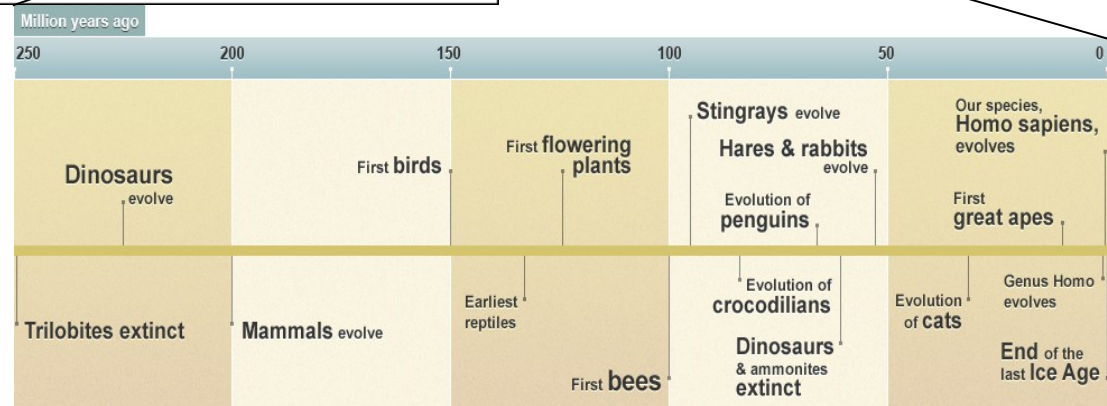
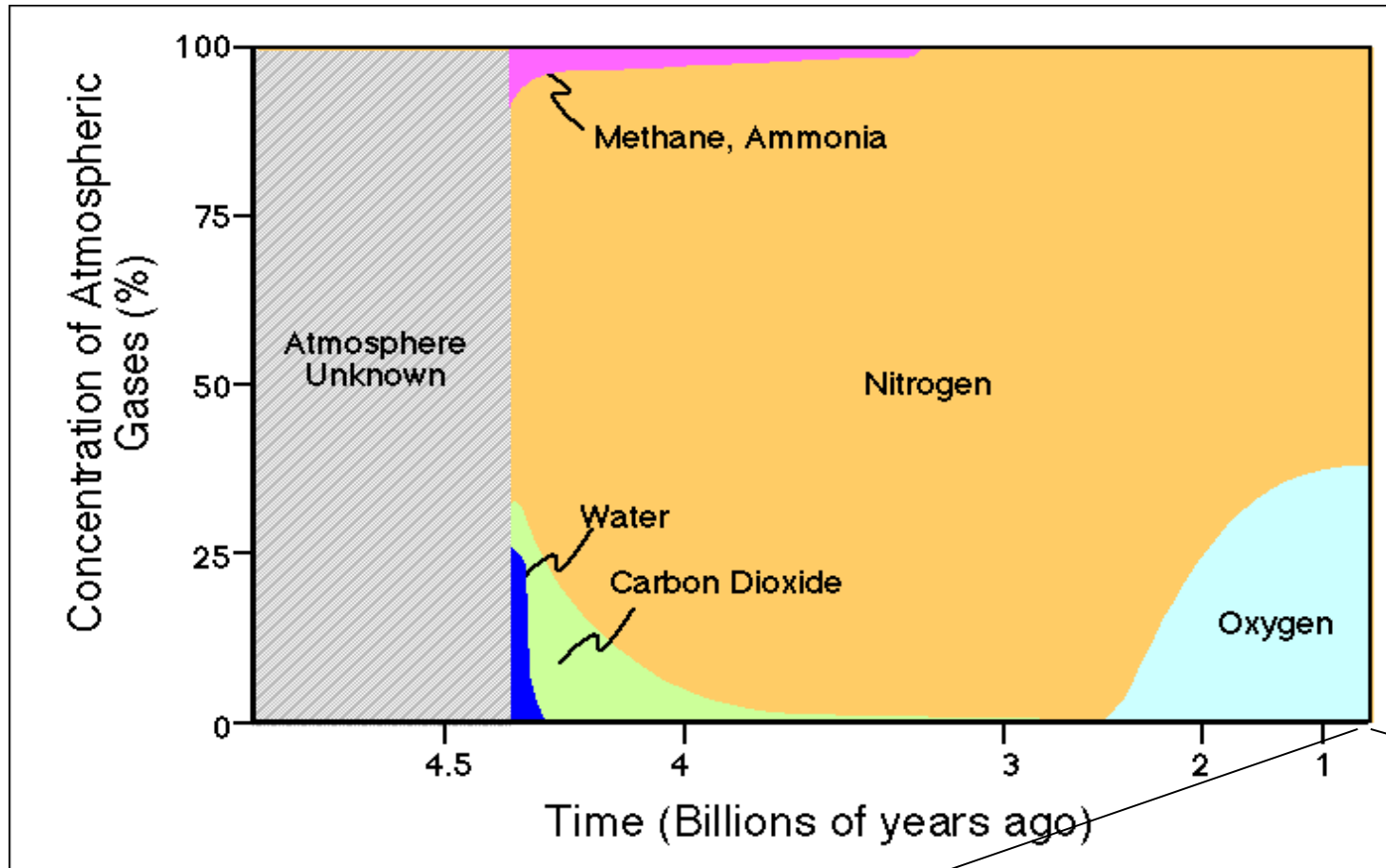
**NAUKA O KLIMACIE**  
DLA SCEPTYCZNYCH



UNIVERSITY  
OF WARSAW



# Changes in atmospheric composition



Paleoclimatic data

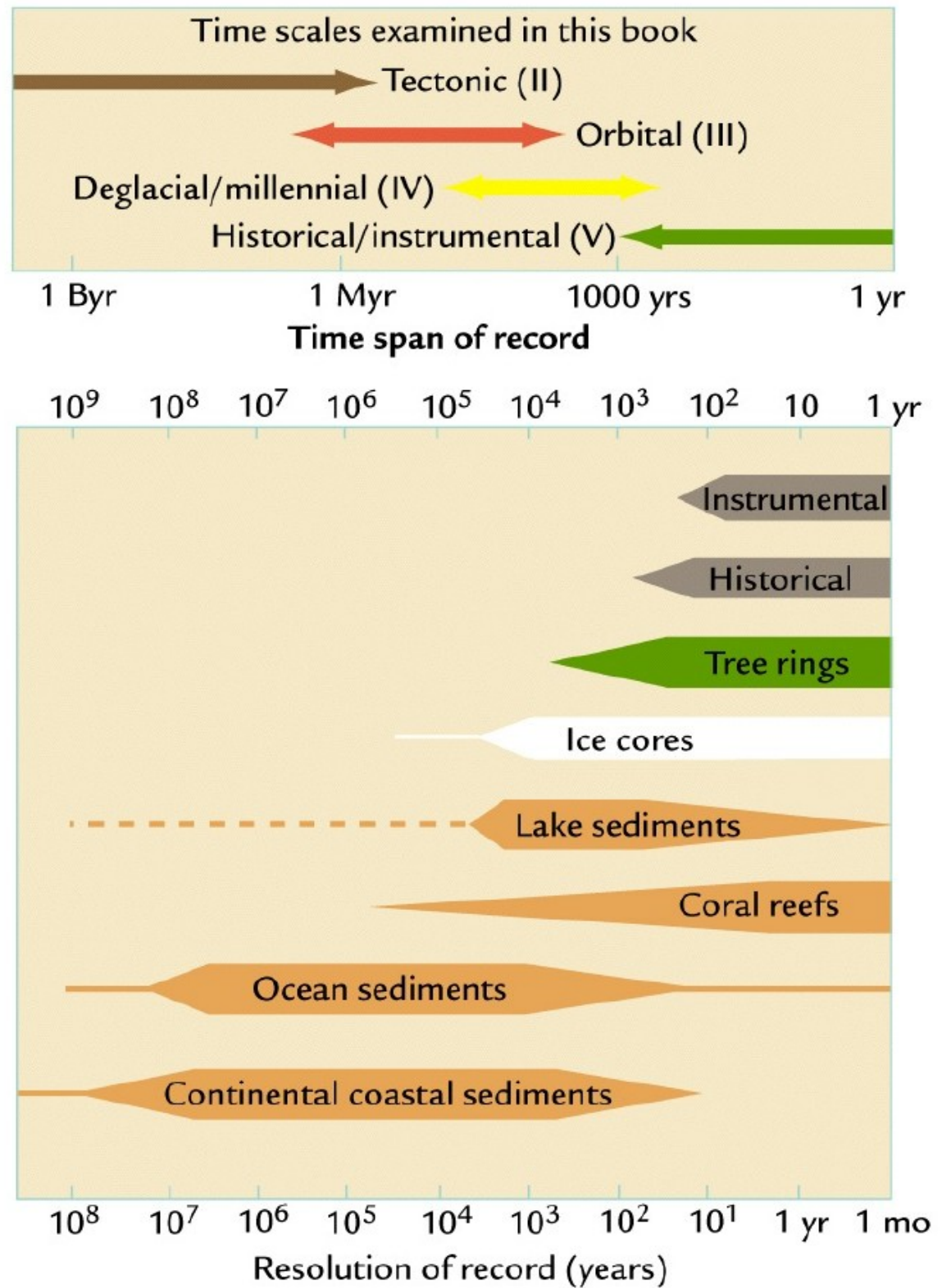
Dating methods

- 1.1 Radiometric dating
- 1.2 Fission-track dating
- 1.3 Cosmogenic nuclide

geochronology

- 1.4 Luminescence dating
- 1.5 Incremental dating
- 1.6 Paleomagnetic dating
- 1.7 Magnetostratigraphy
- 1.8 Chemostratigraphy
- 1.9 Correlation of marker

horizons



# Radiometric dating

**TABLE 3-1** Radioactive Decay Used to Date Climate Records

Parent isotope	Daughter isotope	Half-life	Useful for ages:	Useful for dating:
Rubidium-87 ( <sup>87</sup> Rb)	Strontium-87 ( <sup>87</sup> Sr)	47 Byr	100 Myr	Granites
Uranium-238 ( <sup>238</sup> U)	Lead-206 ( <sup>206</sup> Pb)	4.5 Byr	>100 Myr	Many rocks
Uranium-235 ( <sup>235</sup> U)	Lead-207 ( <sup>207</sup> Pb)	0.7 Byr	>100 Myr	Many rocks
Potassium-40 ( <sup>40</sup> K)	Argon-40 ( <sup>40</sup> Ar)	1.3 Byr	>100,000 years	Basalts
Thorium 230 ( <sup>230</sup> Th)	Radon-226* ( <sup>226</sup> Ra)	75,000 years	<400,000 years	Corals
Carbon-14 ( <sup>14</sup> C)	Nitrogen-14* ( <sup>14</sup> N)	5,780 years	<50,000 years	Anything that contains carbon

*\*Daughter is a gas that has escaped and cannot be measured.*

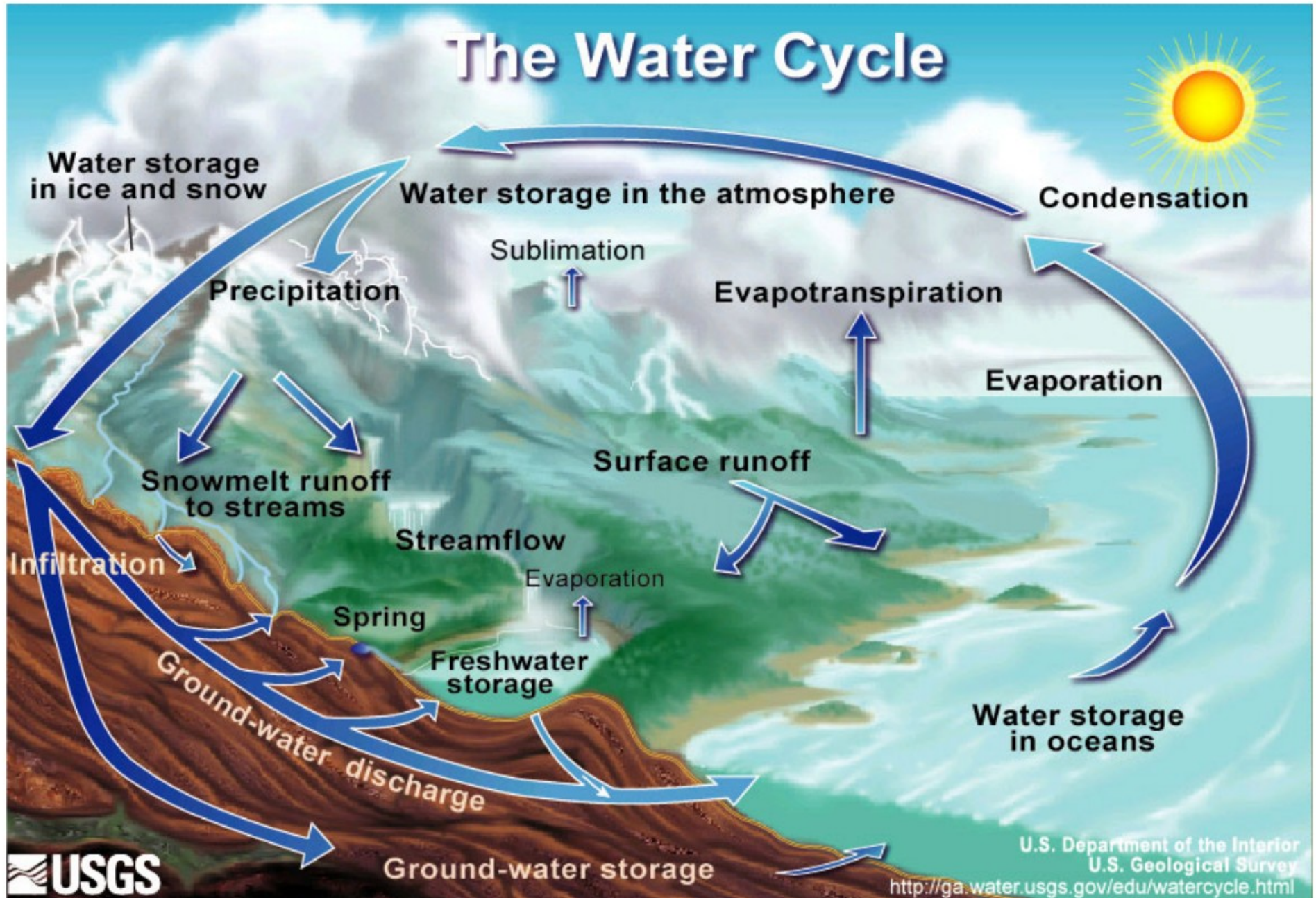


# Isotope systematics in the hydrological cycle:

The isotope composition of natural meteoric waters (which form the main reservoirs of freshwater on earth, ice caps, lakes, rivers and groundwater) is determined by three main factors.

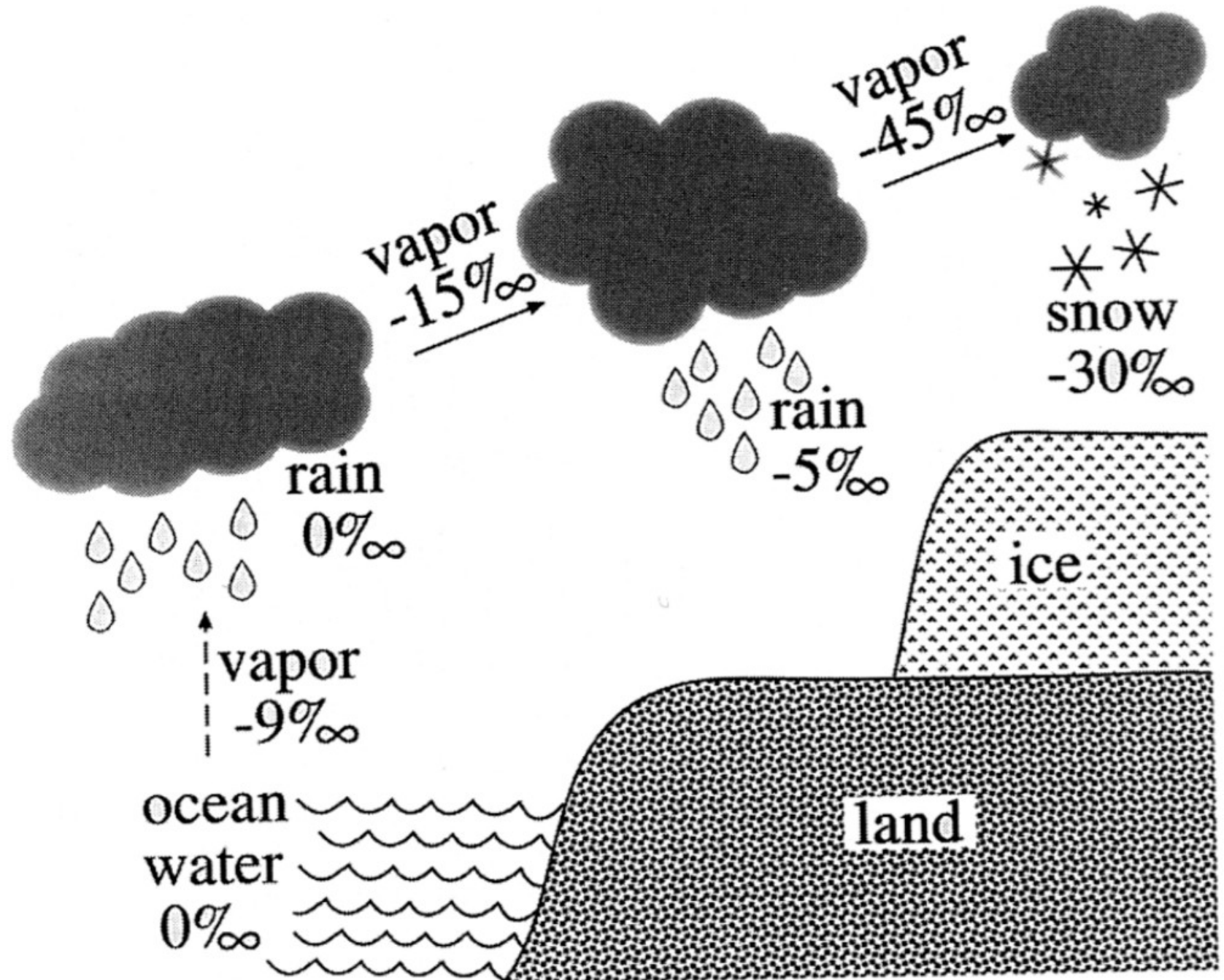
- 1) The isotopic composition of the source of the moisture i.e. the ocean, the largest water reservoir on earth.
- 2) Processes of fractionation during evaporation from the ocean.
- 3) Fractionation processes during condensation in the cloud and precipitation to the ground.

# $\delta^{18}\text{O}$ - Tracer of the water cycle





# Isotope water cycle



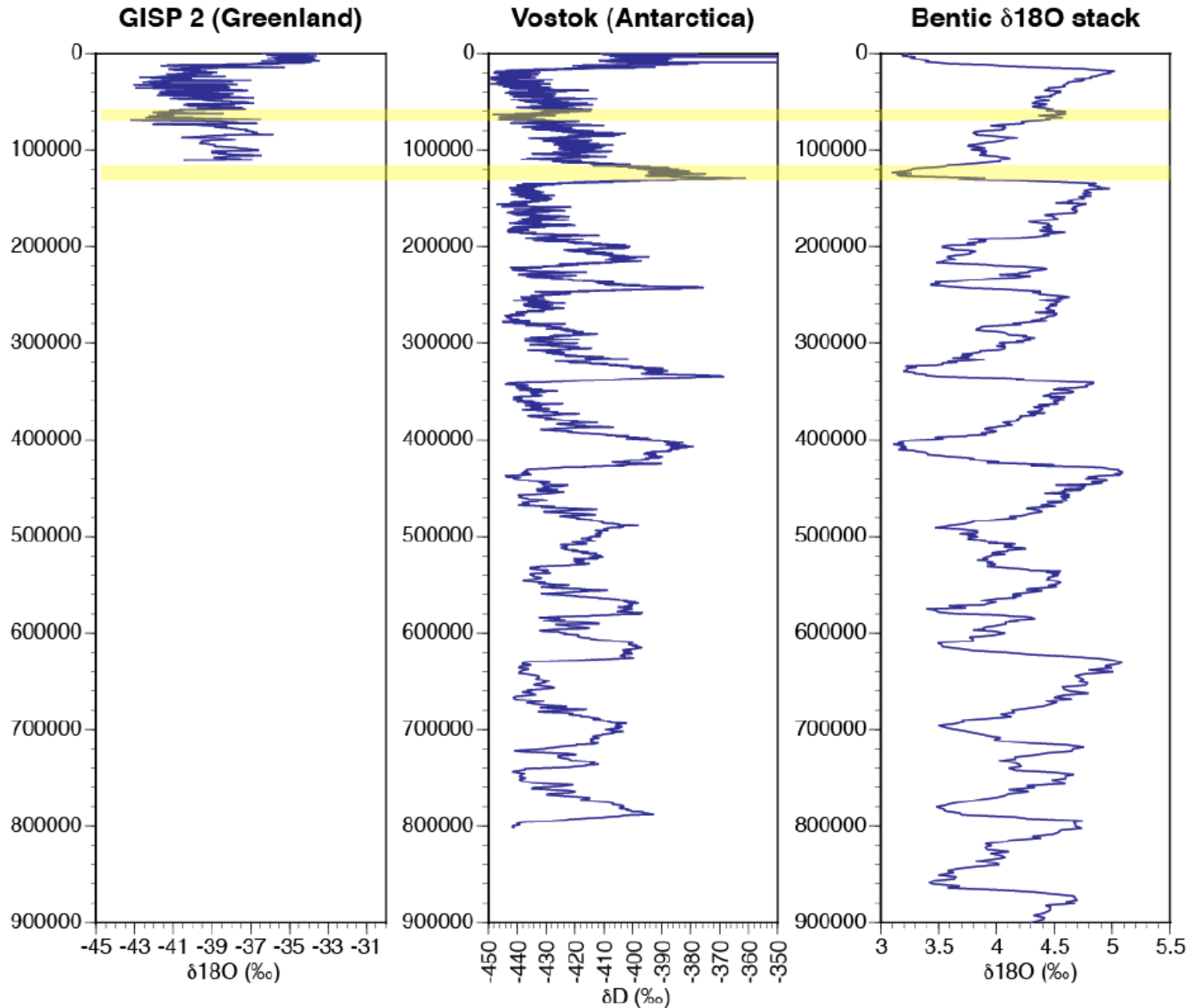


# $\delta^{18}\text{O}$ signal in different climate archives

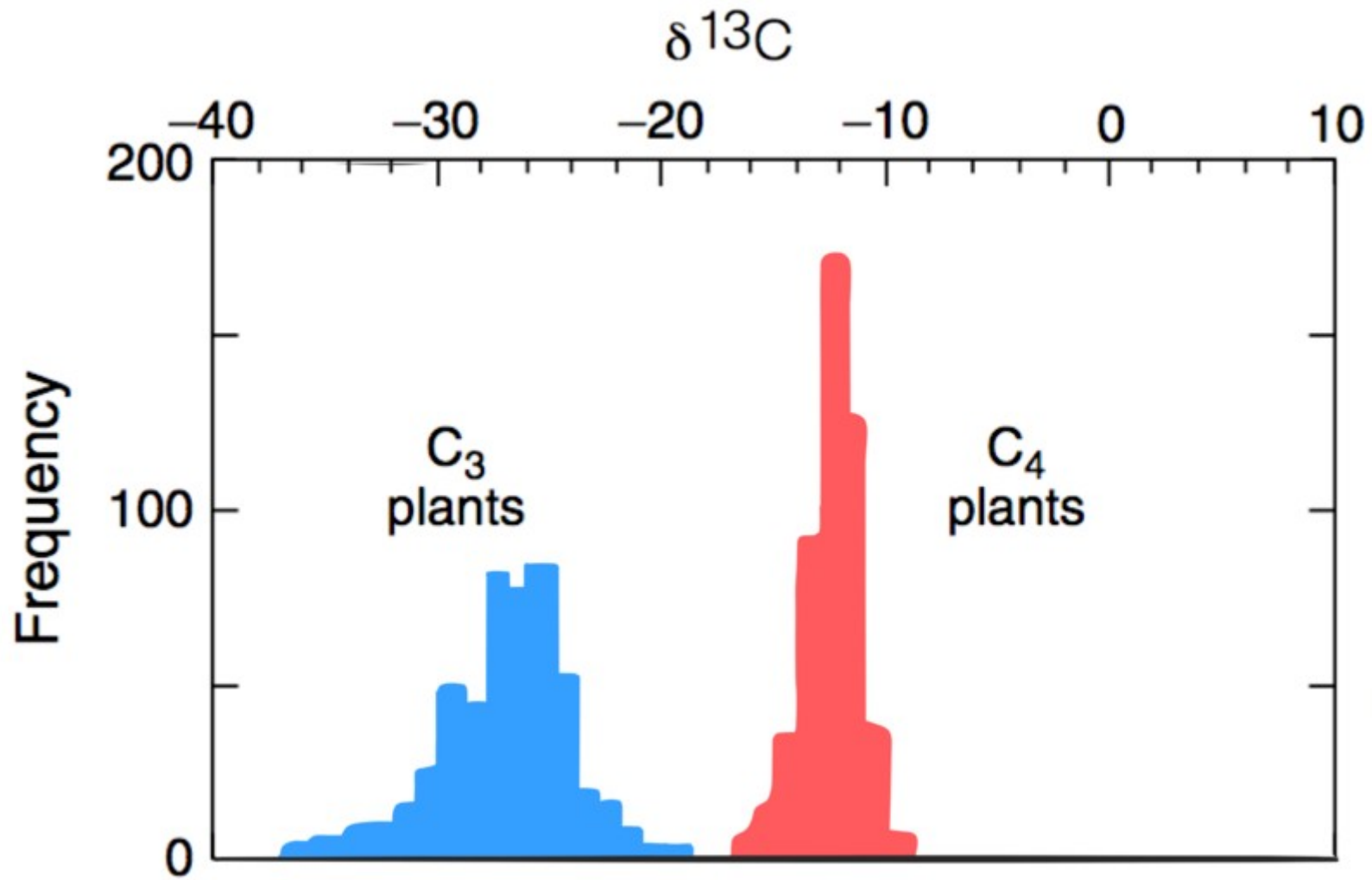
- $\text{H}_2^{16}\text{O}$

Abundance:

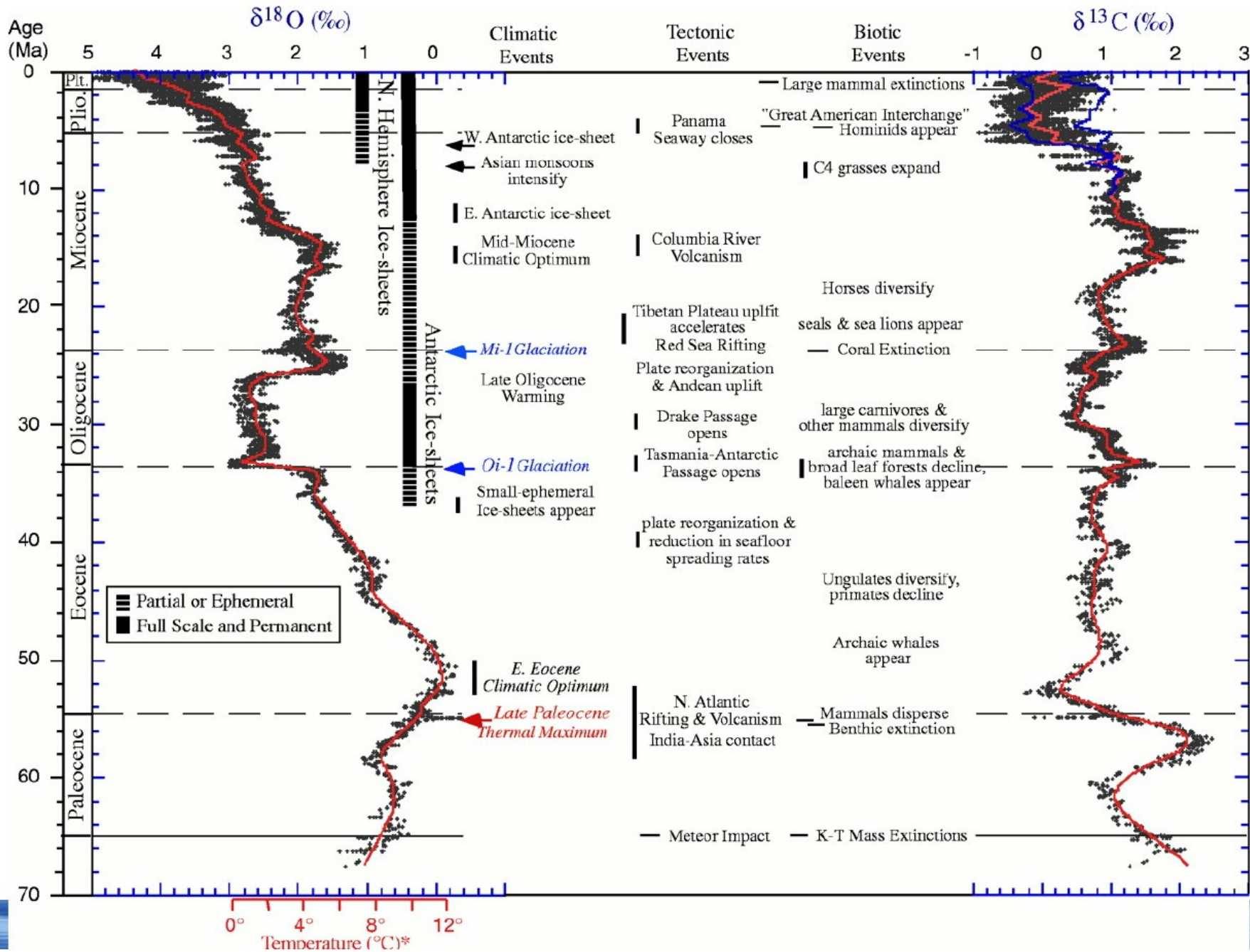
- $^{16}\text{O} = 99.7621$   
 $^{17}\text{O} = 0.03790$   
 $^{18}\text{O} = 0.20004$
- $\text{H} = 99.9844$   
 $\text{D} = 0.01557$



Reduced amount of carbon stable isotope  $^{13}\text{C}$  in plants dependig on fotosynthesis type.

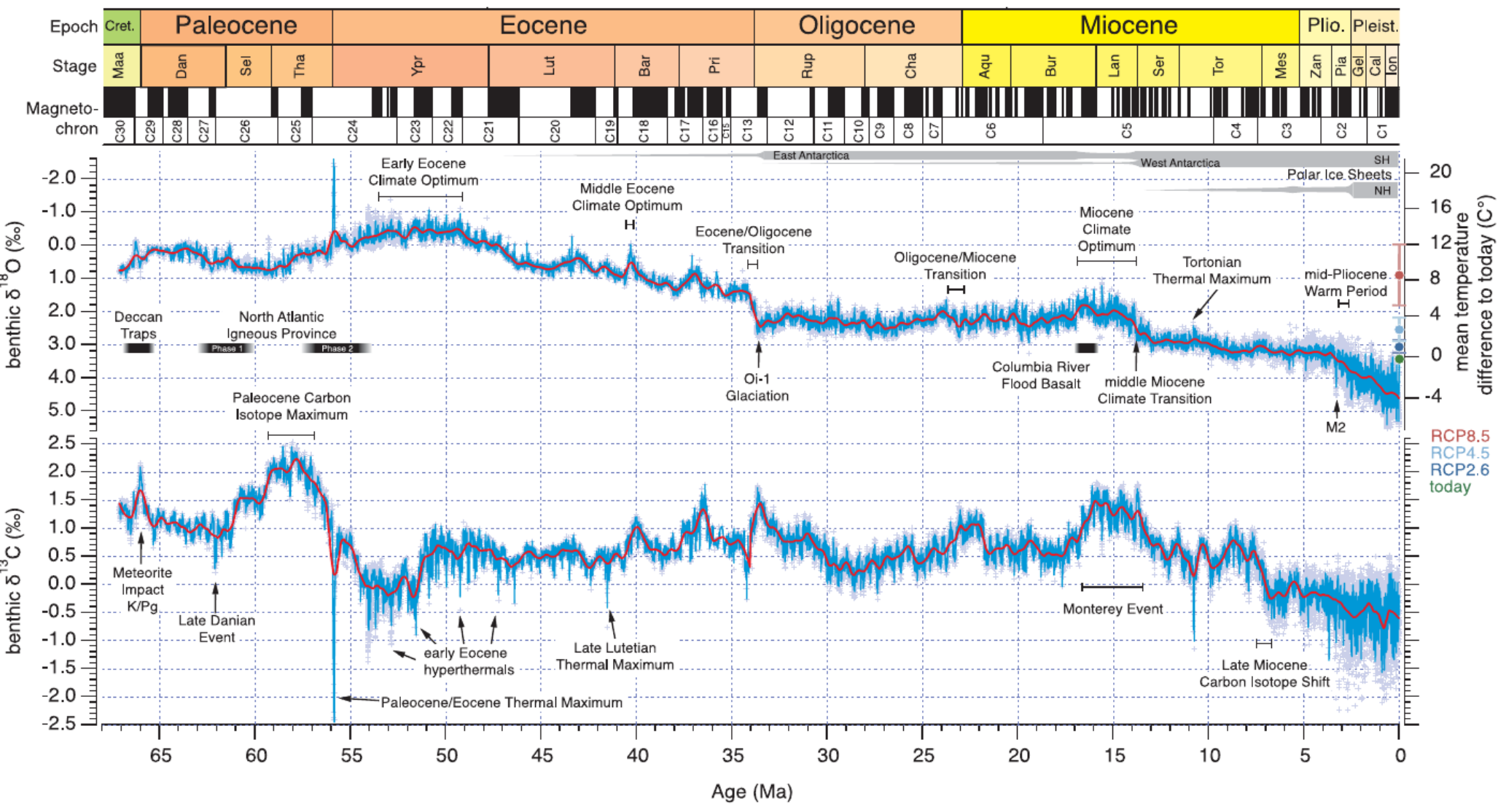


# Long-term $\delta^{18}\text{O}$ evolution



Zachos et al,  
2001, Science,  
v.292, p.686





Westerhold, T., N Marwan, AJ Drury, D Liebrand, C Agnini, E Anagnostou, JSK Barnet, SM Bohaty, D Vleschouwer, F Florindo, T Frederichs, DA Hodell, AE Holbourn, D Kroon, V Lauretano, K Littler, LJ Lourens, M Lyle, H Pälike, U Röhl, J Tian, RH Wilkens, PA Wilson, JC Zachos, 2020, An astronomically dated record of Earth's climate and its predictability over the last 66 Million Years, Science, v. 369, Issue 6509, pp. 1383-1387. DOI: 10.1126/science.aba6853

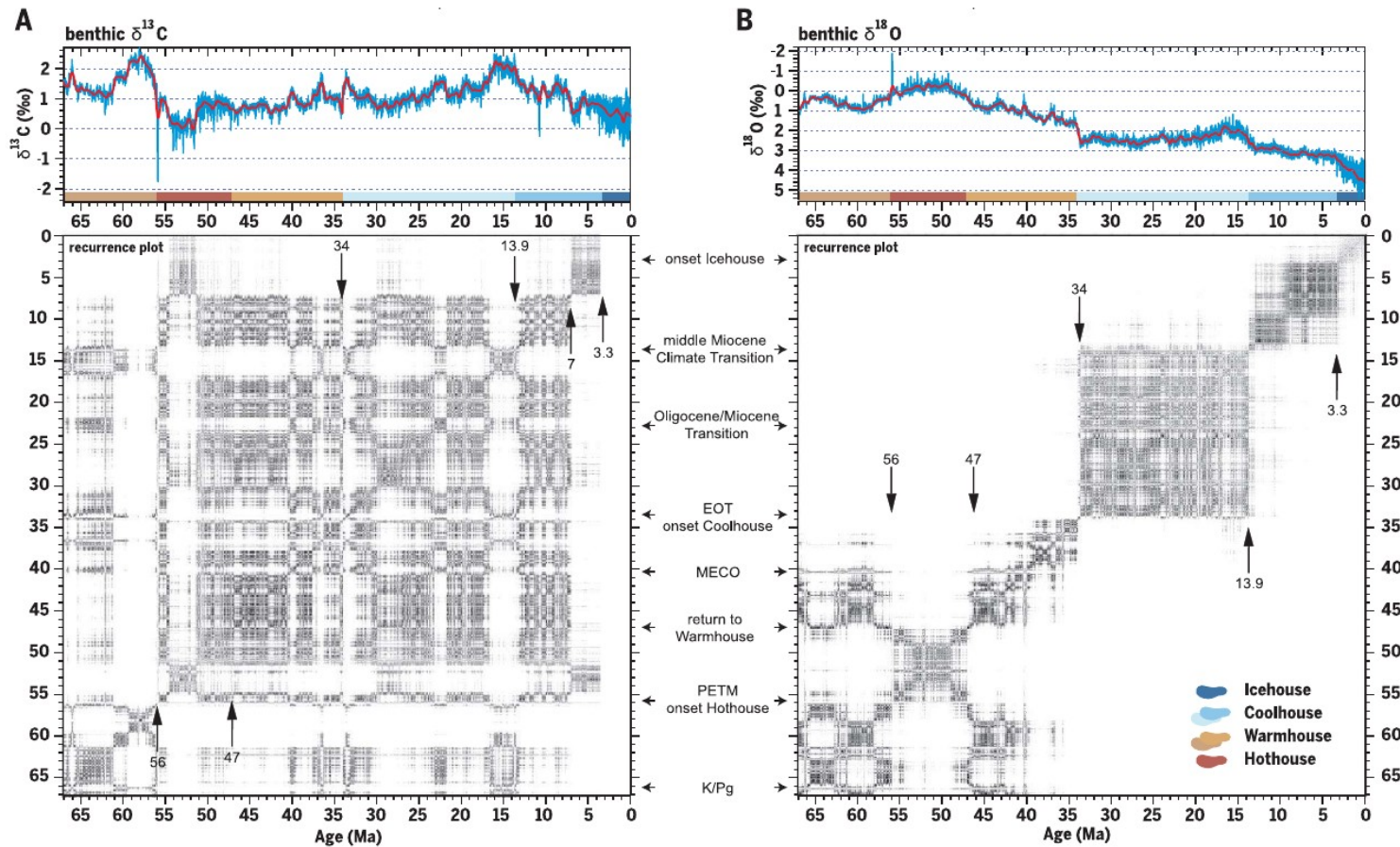
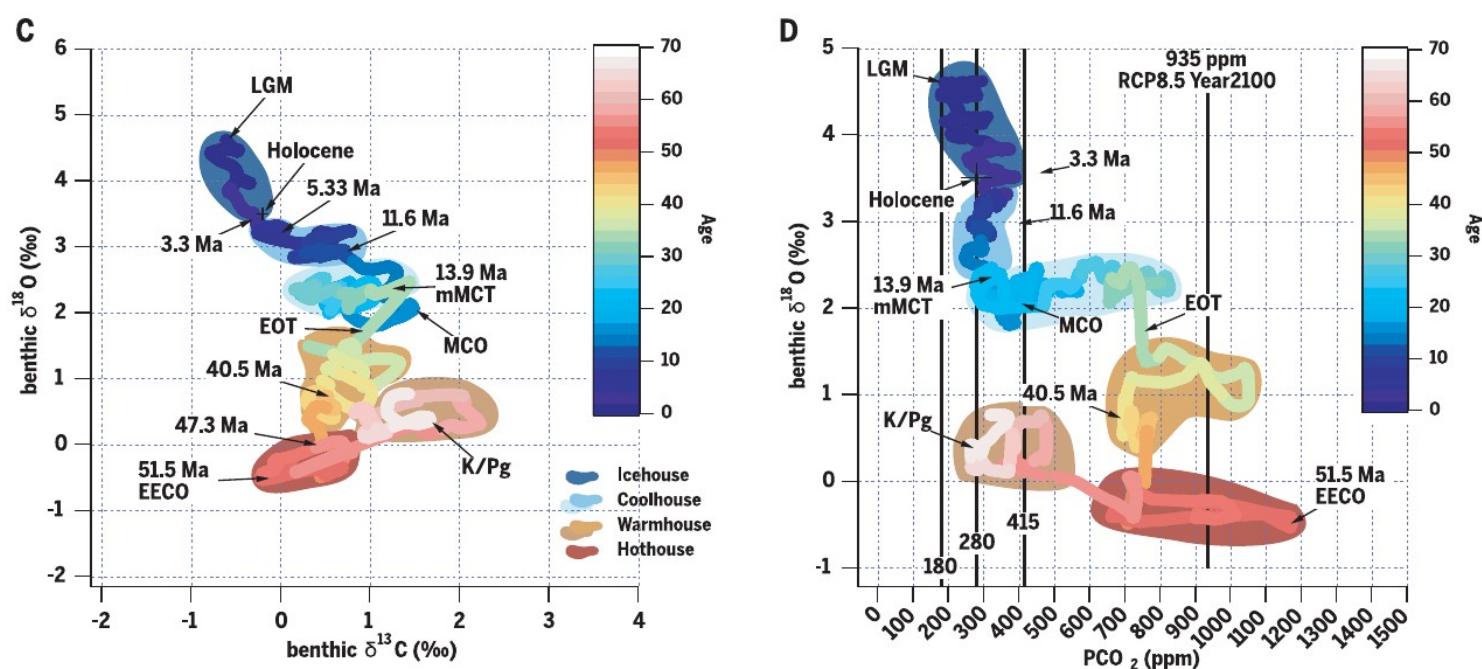
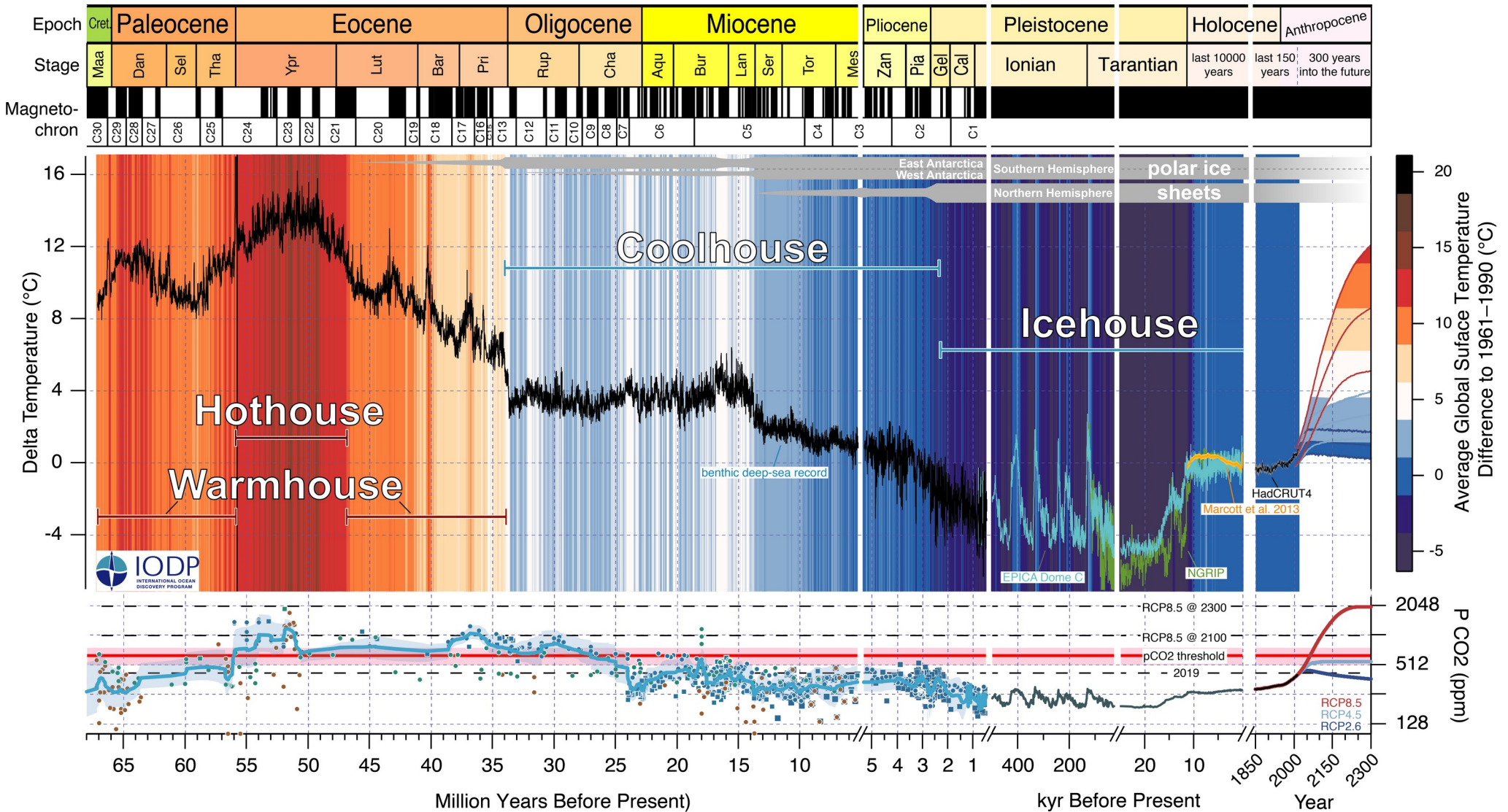


Fig. 2. Climate states of the Cenozoic. Deep-sea benthic foraminifer high-resolution carbon (A) and oxygen (B) isotope records and the respective recurrence plots as well as scatterplots of long-term benthic foraminifer carbon versus oxygen values (C) and oxygen values versus atmospheric CO<sub>2</sub> concentrations (D).





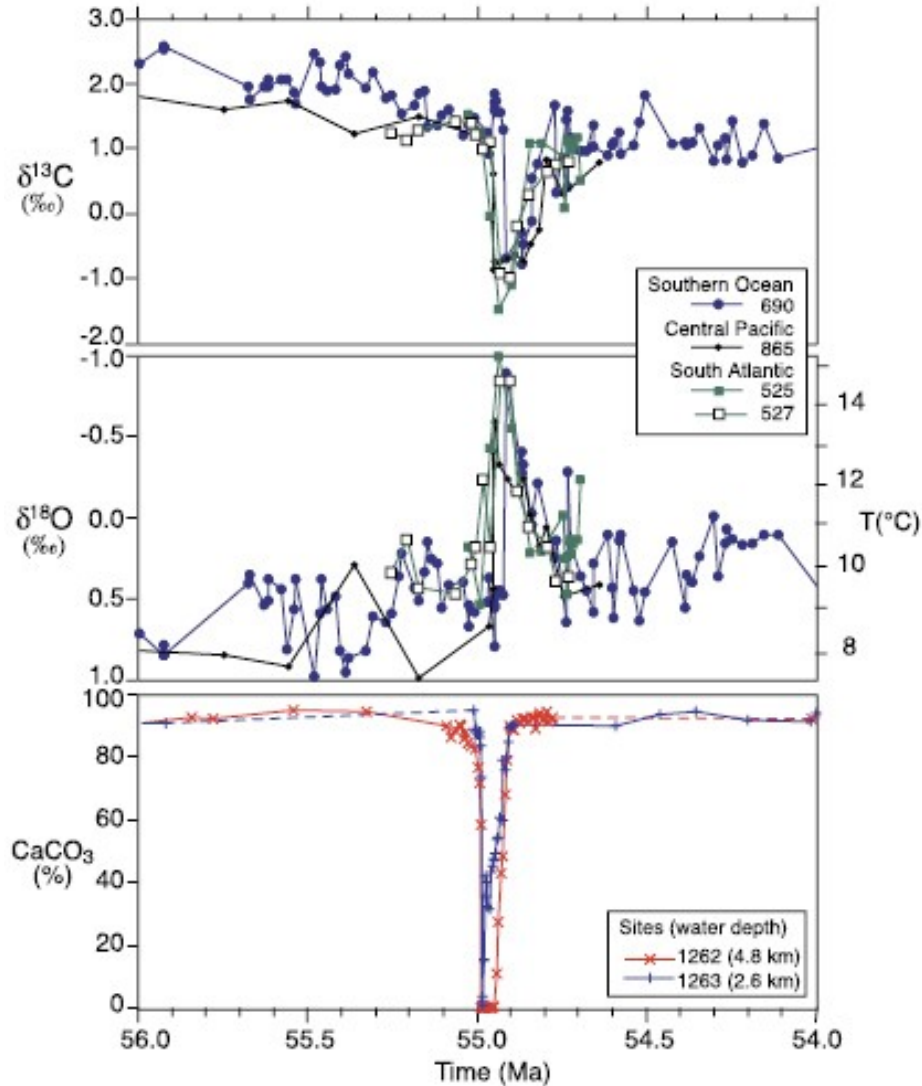


[https://websites.pmc.ucsc.edu/~jzachos/images/CENOGRID\\_Cartoon\\_withProjection\\_alternate.png](https://websites.pmc.ucsc.edu/~jzachos/images/CENOGRID_Cartoon_withProjection_alternate.png)



- Long-term (> 10s of millions of years to 4.6Gyr) climate history information can come from geology.
- Oxygen isotopes ( $\delta^{18}\text{O}$ ) from carbonate ( $\text{CaCO}_3$ ) can be used as a paleotemperature proxy.
- Can also use similar techniques to measure ancient carbon dioxide levels.
- Earth has only had polar ice for ~15% of its history; frequently there is sufficient equator-to-pole heat transport to allow palm trees at the poles.
- Specific example: Snowball Earth, when Earth froze over 600 Myr ago.
- Snowball Earths are reversed by build up of carbon dioxide, and are followed by global hothouses when the ice melts.
- Earth's climate history is a total roller coaster on 10 million year to billion year timescales.

# Abrupt Climate Change – example: PETM



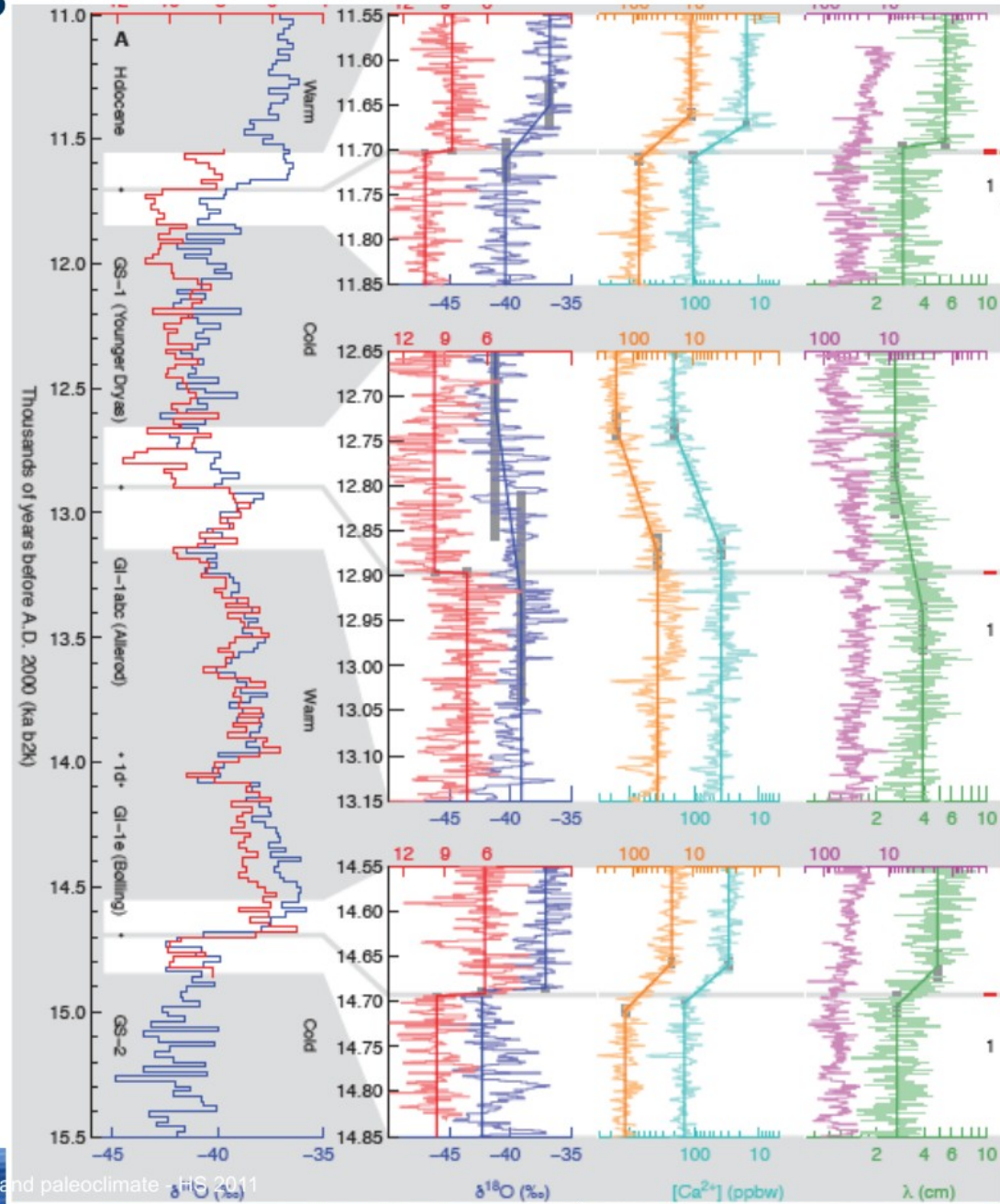
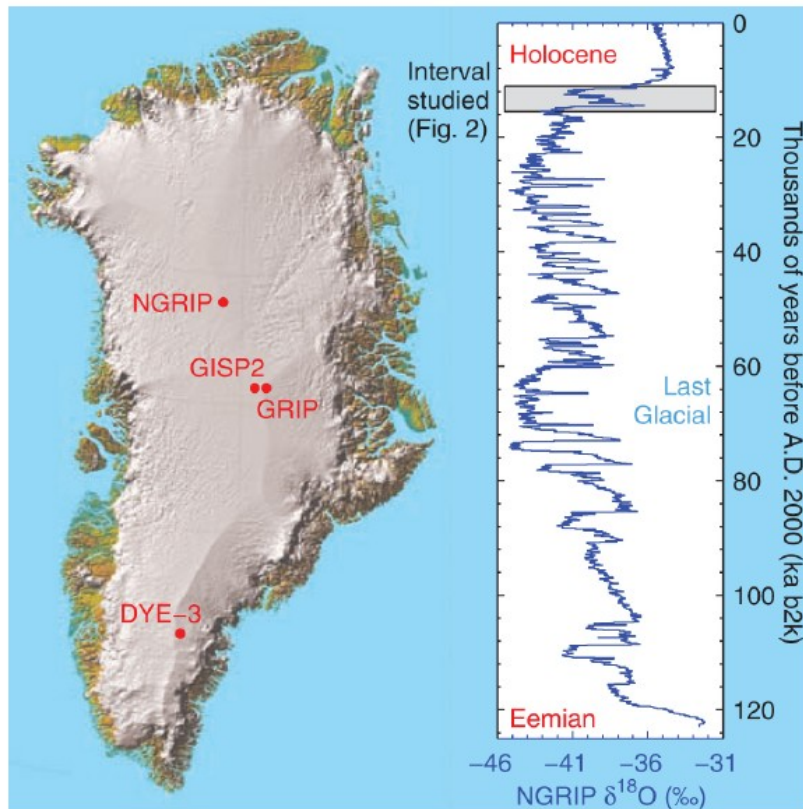
The Palaeocene-Eocene Thermal Maximum as recorded in benthic (bottom dwelling) foraminifer (*Nuttallides truempyi*) isotopic records from sites in the Antarctic, south Atlantic and Pacific (see Zachos et al., 2003 for details). The rapid decrease in carbon isotope ratios in the top panel is indicative of a large increase in atmospheric greenhouse gases  $\text{CO}_2$  and  $\text{CH}_4$  that was coincident with an approximately  $5^\circ\text{C}$  global warming (centre panel). Using the carbon isotope records, numerical models show that  $\text{CH}_4$  released by the rapid decomposition of marine hydrates might have been a major component ( $\sim 2,000$  GtC) of the carbon flux (Dickens and Owen, 1996).

IPCC 2007

# Application in ice cores

## Abrupt climate change

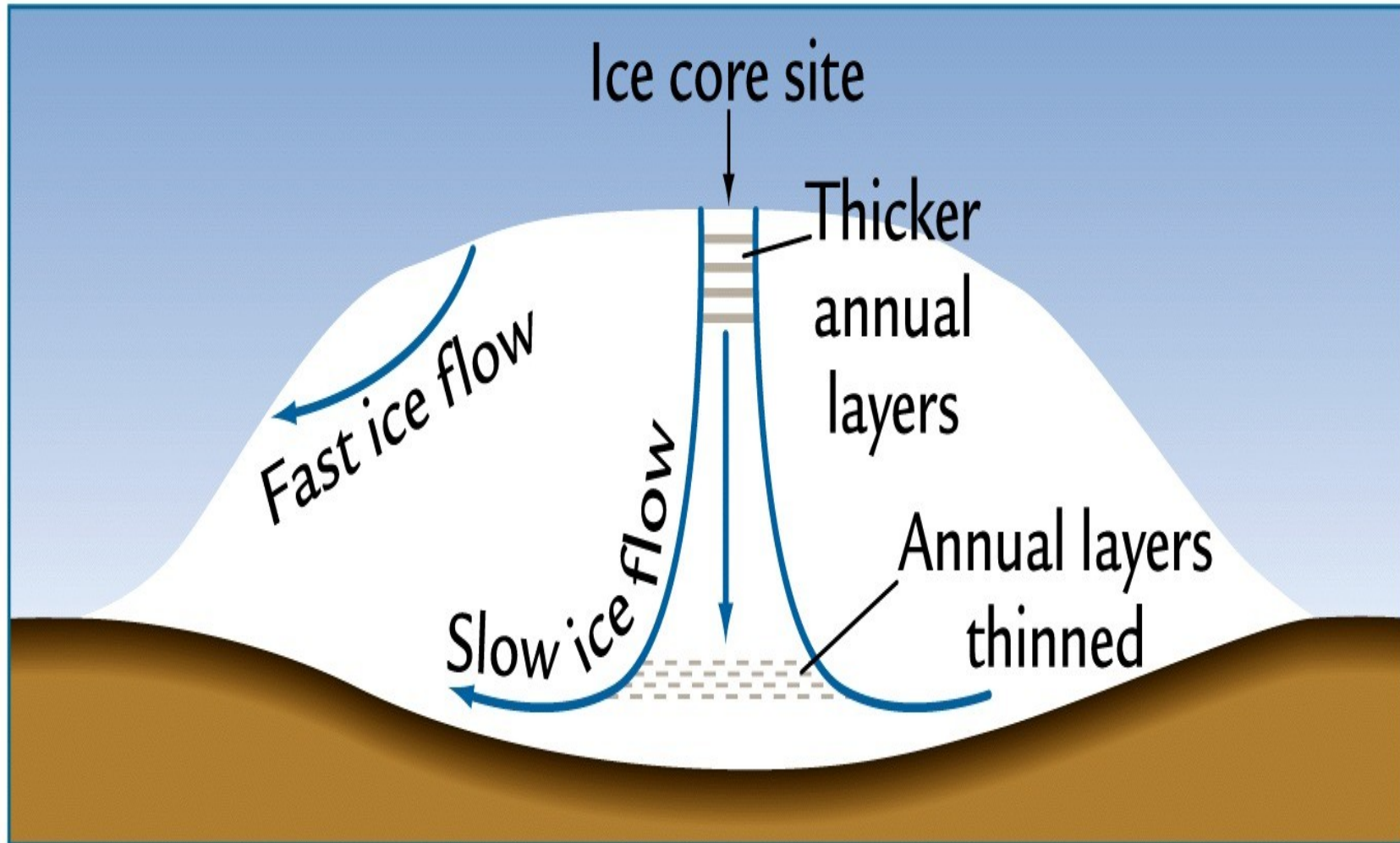
- Study the long ice record in Greenland



Steffensen et al, Science, 321, 1. August 2008

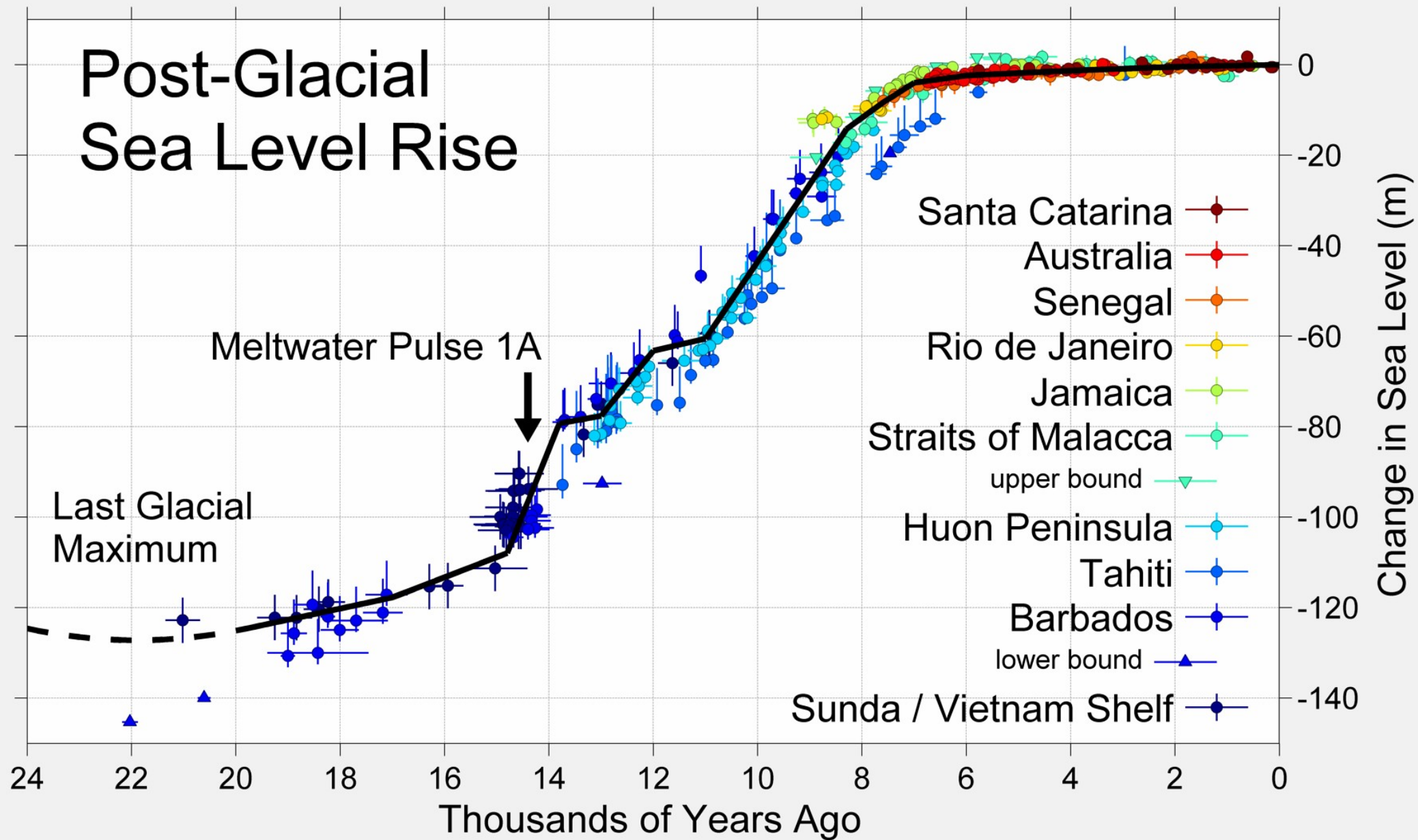


# Ice Cores and Ice Sheet Flow



Age of Ice: annual layers (Greenland) and ice flow models (Antarctica)

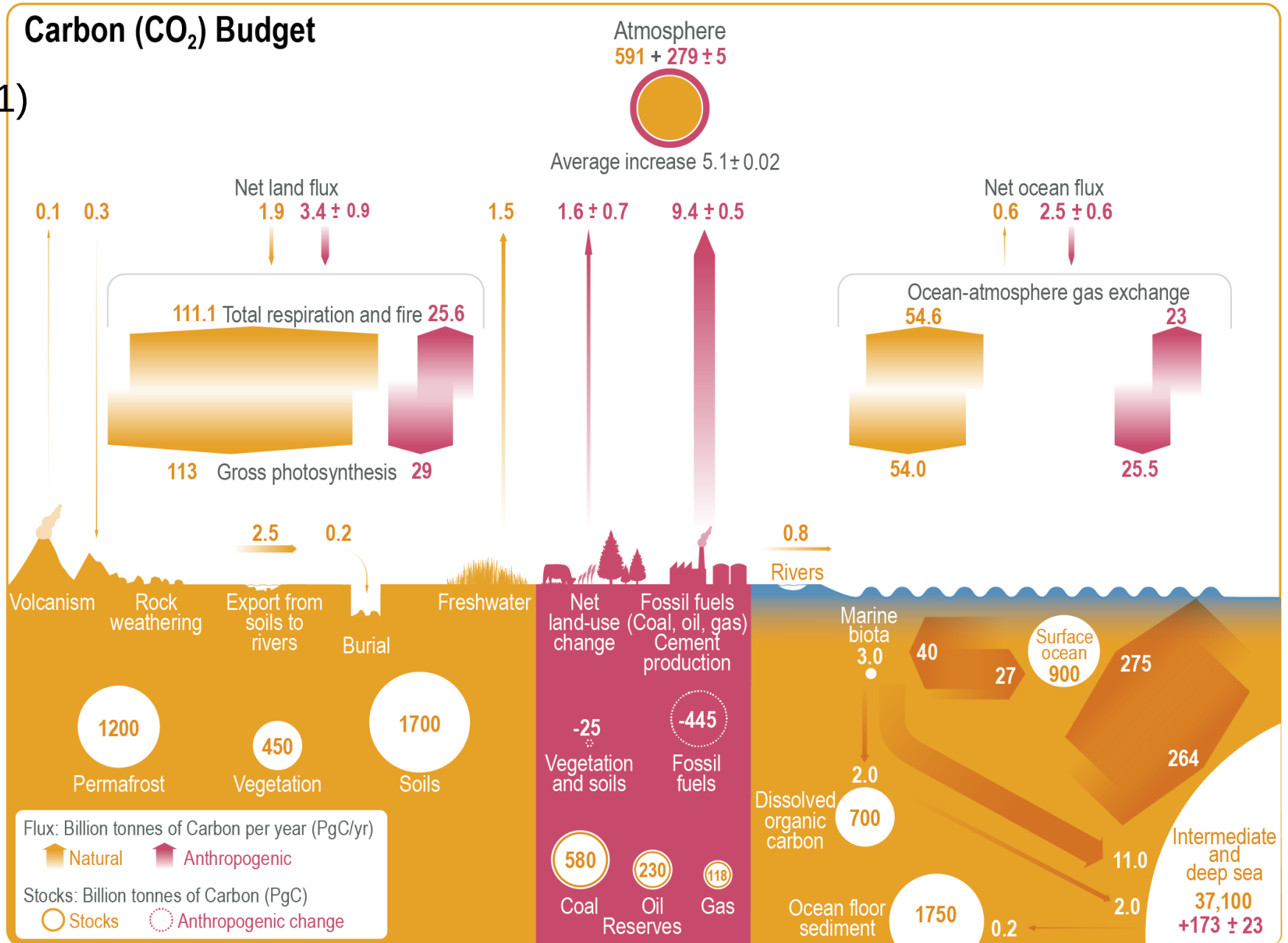
# Post-Glacial Sea Level Rise



# Carbon in climate system

## Carbon (CO<sub>2</sub>) Budget

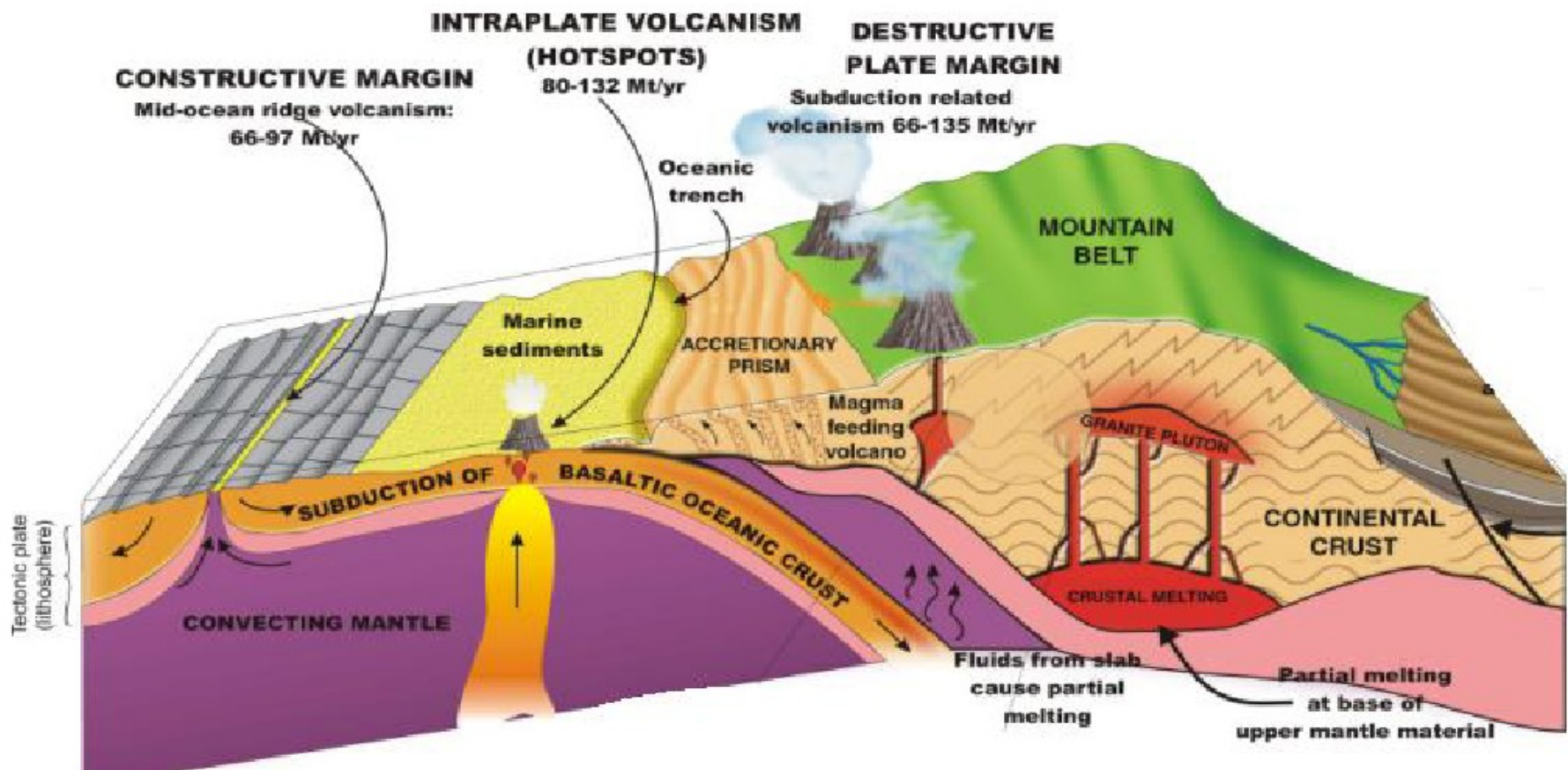
(IPCC 2021)



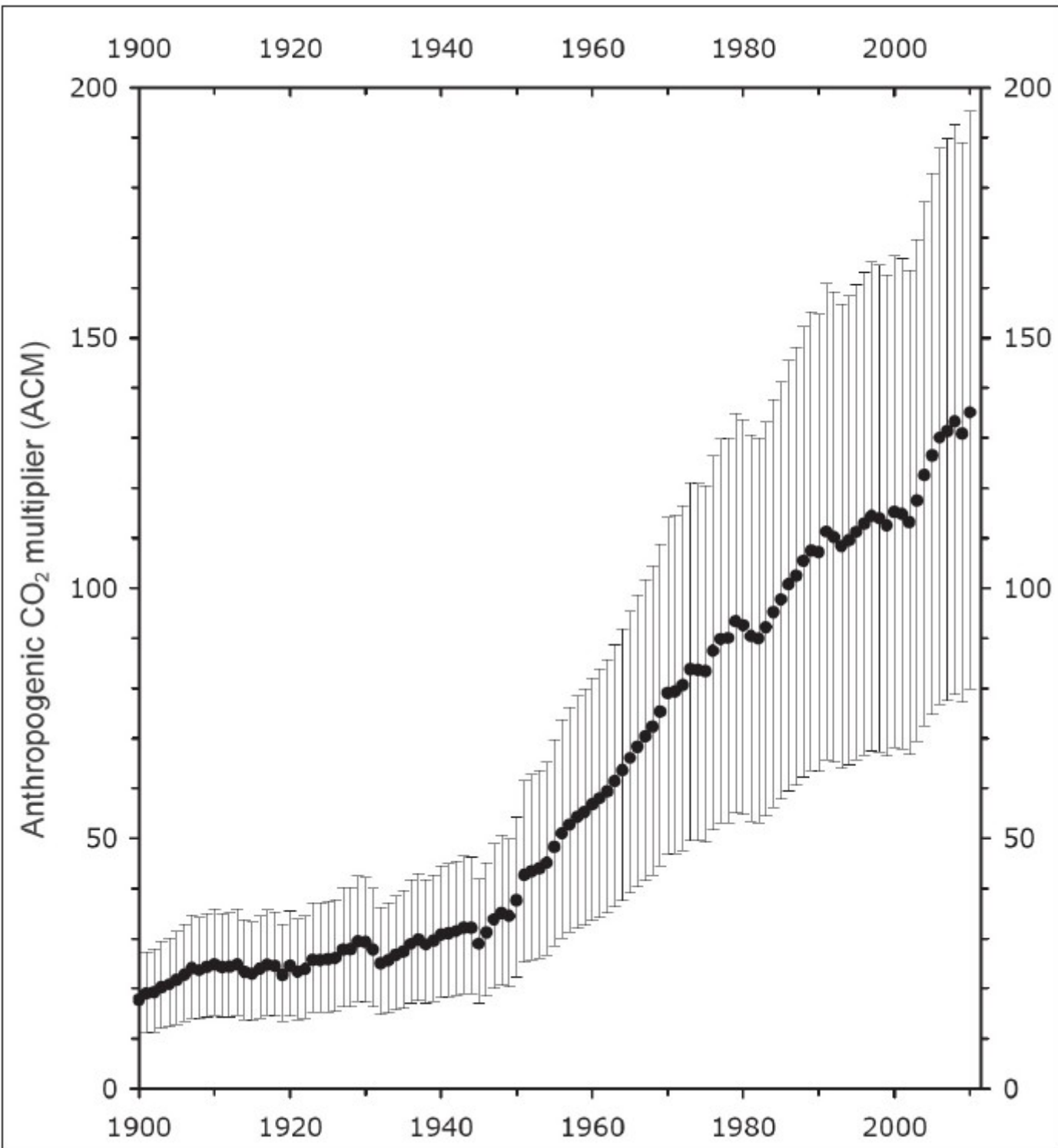


## 5 Present day volcanic carbon flux estimates

Terrestrial volcanism occurs within both the hydrosphere and atmosphere. Submarine and subaerial volcanism originate almost entirely within different tectonic environments (as outlined above), tapping different, although not entirely exclusive volatile sources, shown schematically in Figure 2, below.



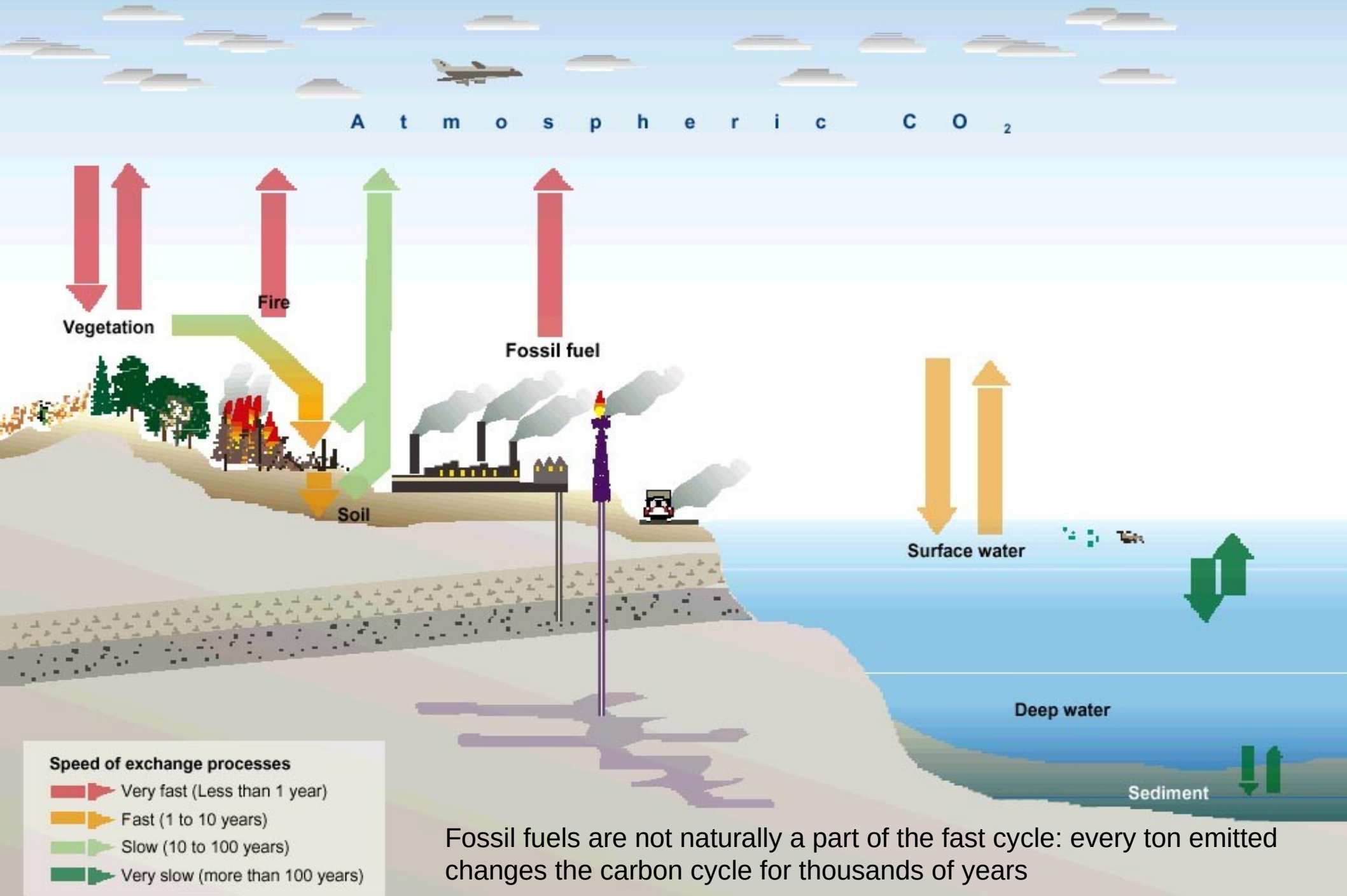
**Figure 2.** Diagrammatic representation of the different volcanic environments with estimates of CO<sub>2</sub> emission rates and their relationship to plate tectonic environment.



Antropogenic  
vs. volcanic  
CO<sub>2</sub>  
emissions.

Gerlach, T. (2011): "Volcanic  
Versus Anthropogenic Carbon  
Dioxide", EOS, Trans. AGU,  
92:24, 201-208

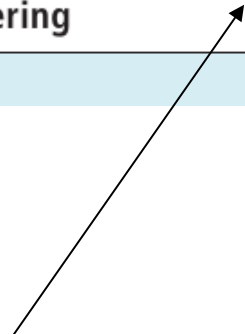
# Fast and slow processes in the carbon cycle





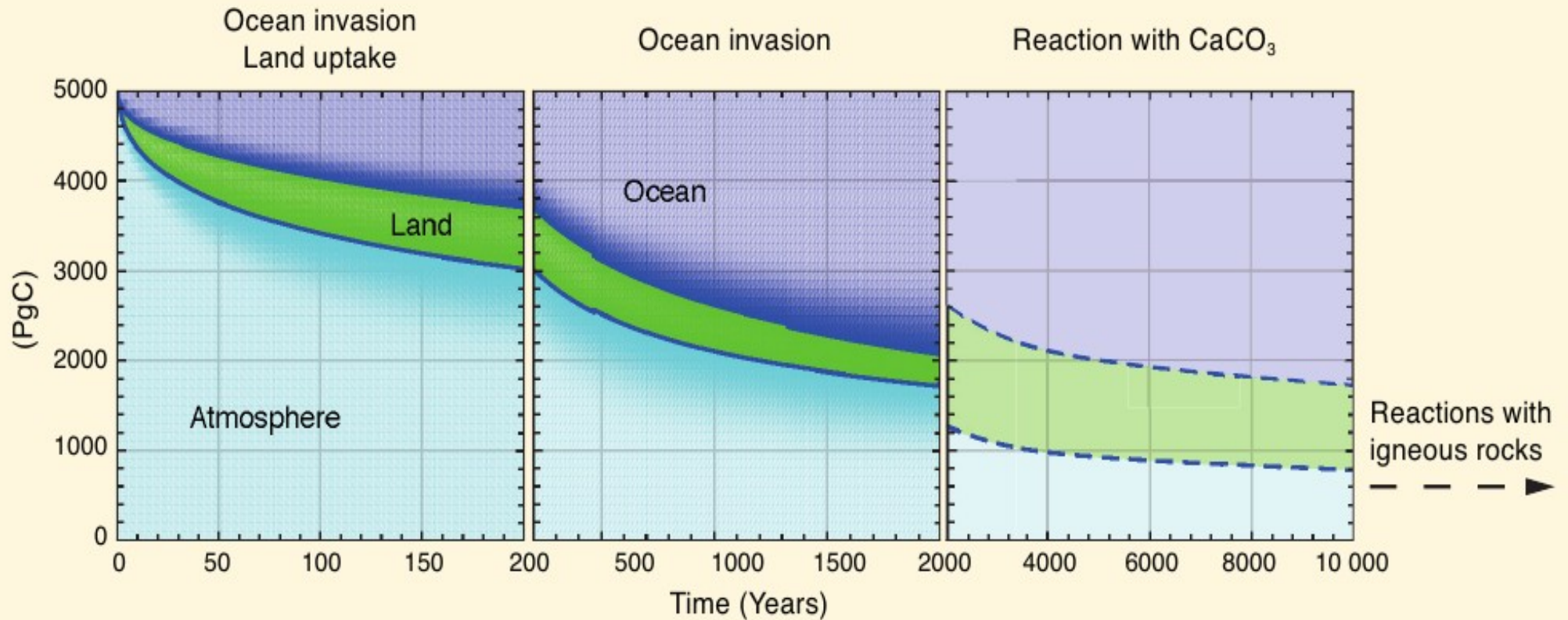
**Box 6.1, Table 1** | The main natural processes that remove CO<sub>2</sub> consecutive to a large emission pulse to the atmosphere, their atmospheric CO<sub>2</sub> adjustment time scales, and main (bio)chemical reactions involved.

Processes	Time scale (years)	Reactions
Land uptake: Photosynthesis–respiration	1–10 <sup>2</sup>	$6\text{CO}_2 + 6\text{H}_2\text{O} + \text{photons} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$ $\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{heat}$
Ocean invasion: Seawater buffer	10–10 <sup>3</sup>	$\text{CO}_2 + \text{CO}_3^{2-} + \text{H}_2\text{O} \rightleftharpoons 2\text{HCO}_3^-$
Reaction with calcium carbonate	10 <sup>3</sup> –10 <sup>4</sup>	$\text{CO}_2 + \text{CaCO}_3 + \text{H}_2\text{O} \rightarrow \text{Ca}^{2+} + 2\text{HCO}_3^-$
Silicate weathering	10 <sup>4</sup> –10 <sup>6</sup>	$\text{CO}_2 + \text{CaSiO}_3 \rightarrow \text{CaCO}_3 + \text{SiO}_2$

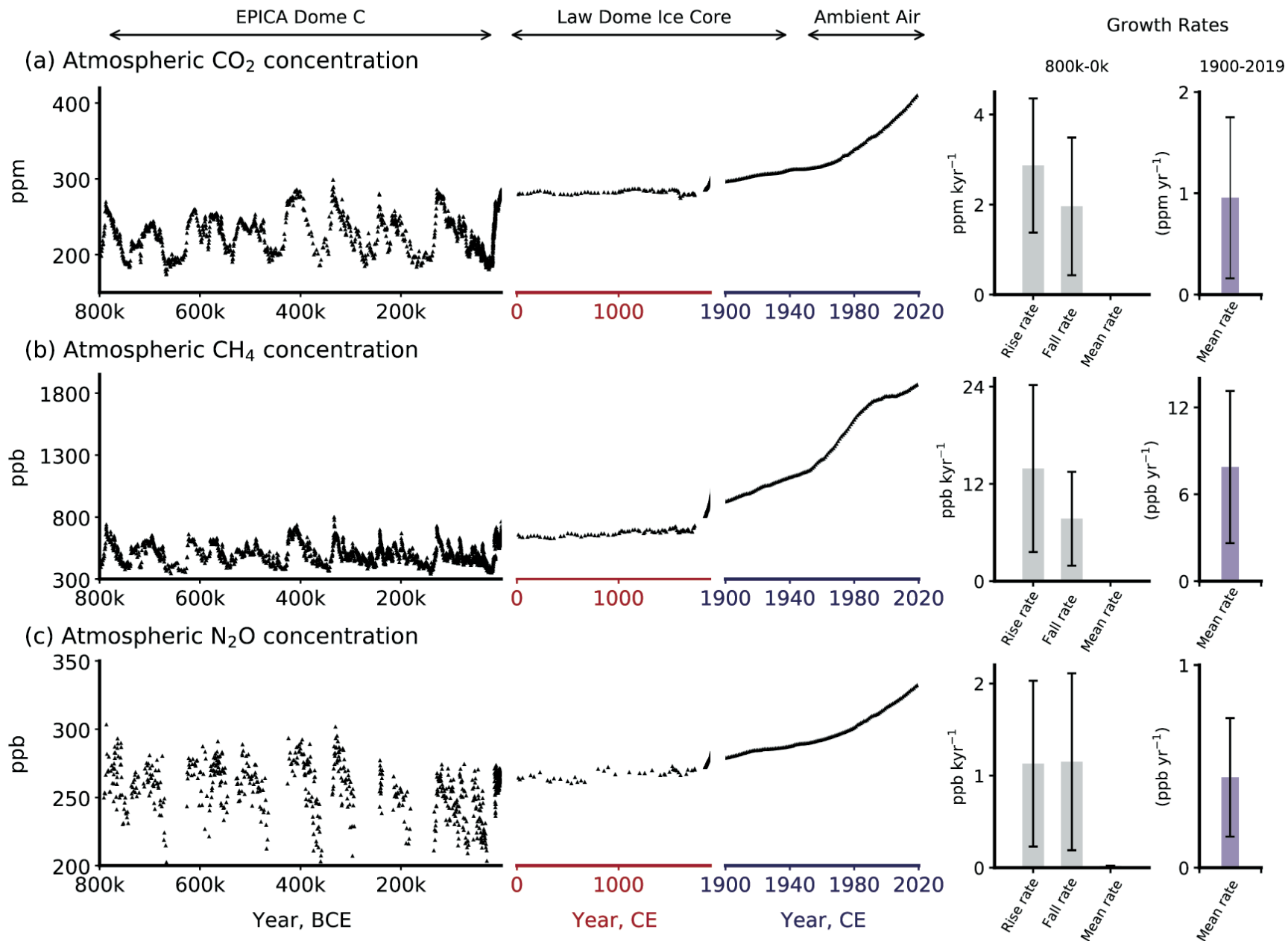


this + volcanic emissions + coal/oil/gas formation  
from organic carbon = slow carbon cycle

# Timescales of carbon removal.

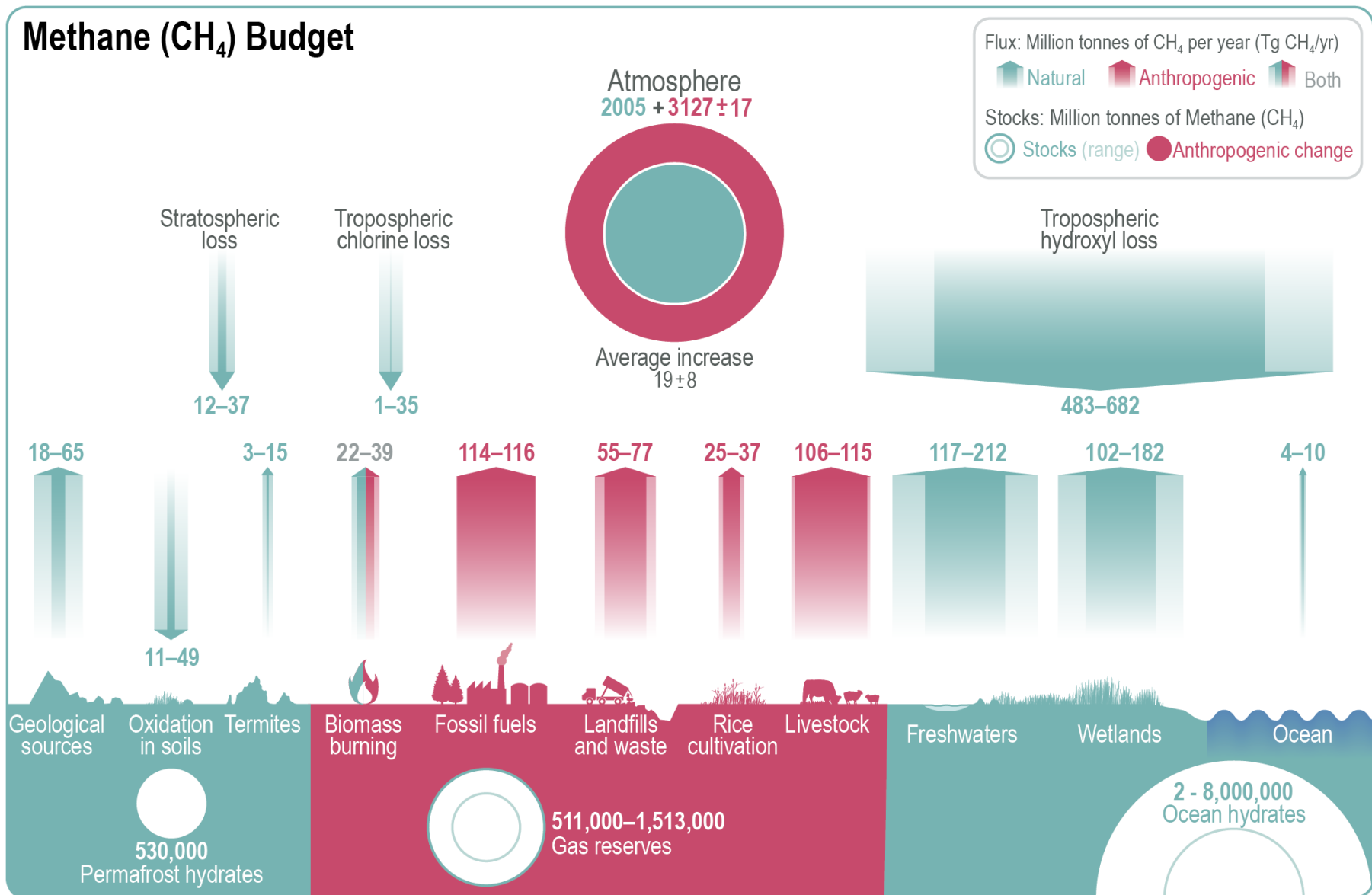


**FAQ 6.2, Figure 2** | Decay of a CO<sub>2</sub> excess amount of 5000 PgC emitted at time zero into the atmosphere, and its subsequent redistribution into land and ocean as a function of time, computed by coupled carbon-cycle climate models. The sizes of the colour bands indicate the carbon uptake by the respective reservoir. The first two panels show the multi-model mean from a model intercomparison project (Joos et al., 2013). The last panel shows the longer term redistribution including ocean dissolution of carbonaceous sediments as computed with an Earth System Model of Intermediate Complexity (after Archer et al., 2009b).

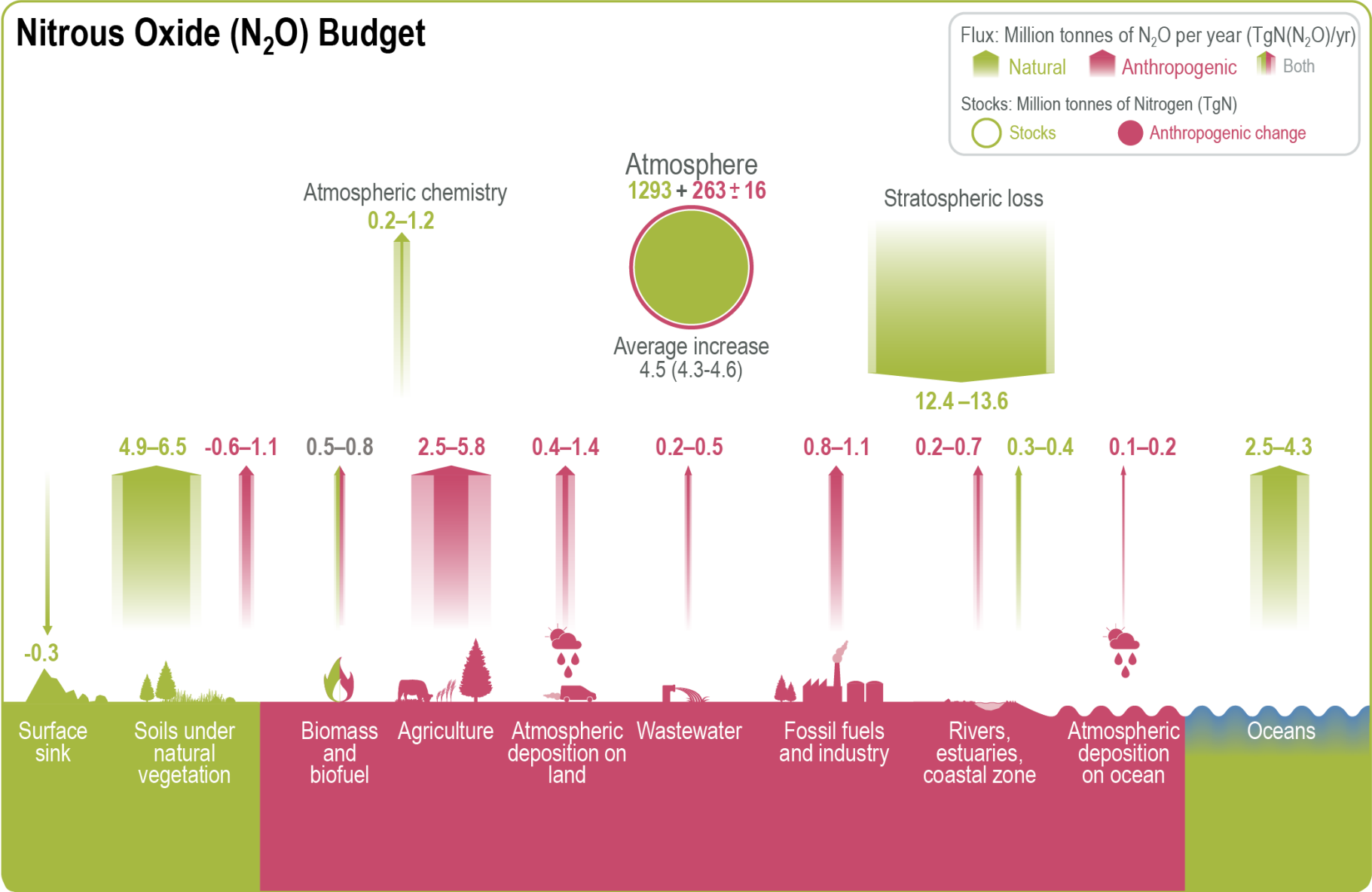




# CH<sub>4</sub> in climate system



# N<sub>2</sub>O in climate system



## Summary:

Paleoclimatology gives insight into past climates.

Paleoclimatological analysis leads to increase our understanding of climate forcings and feedbacks, especially related to distortions of carbon cycle and other cycles.