Global warming - physicist's perspective - 03

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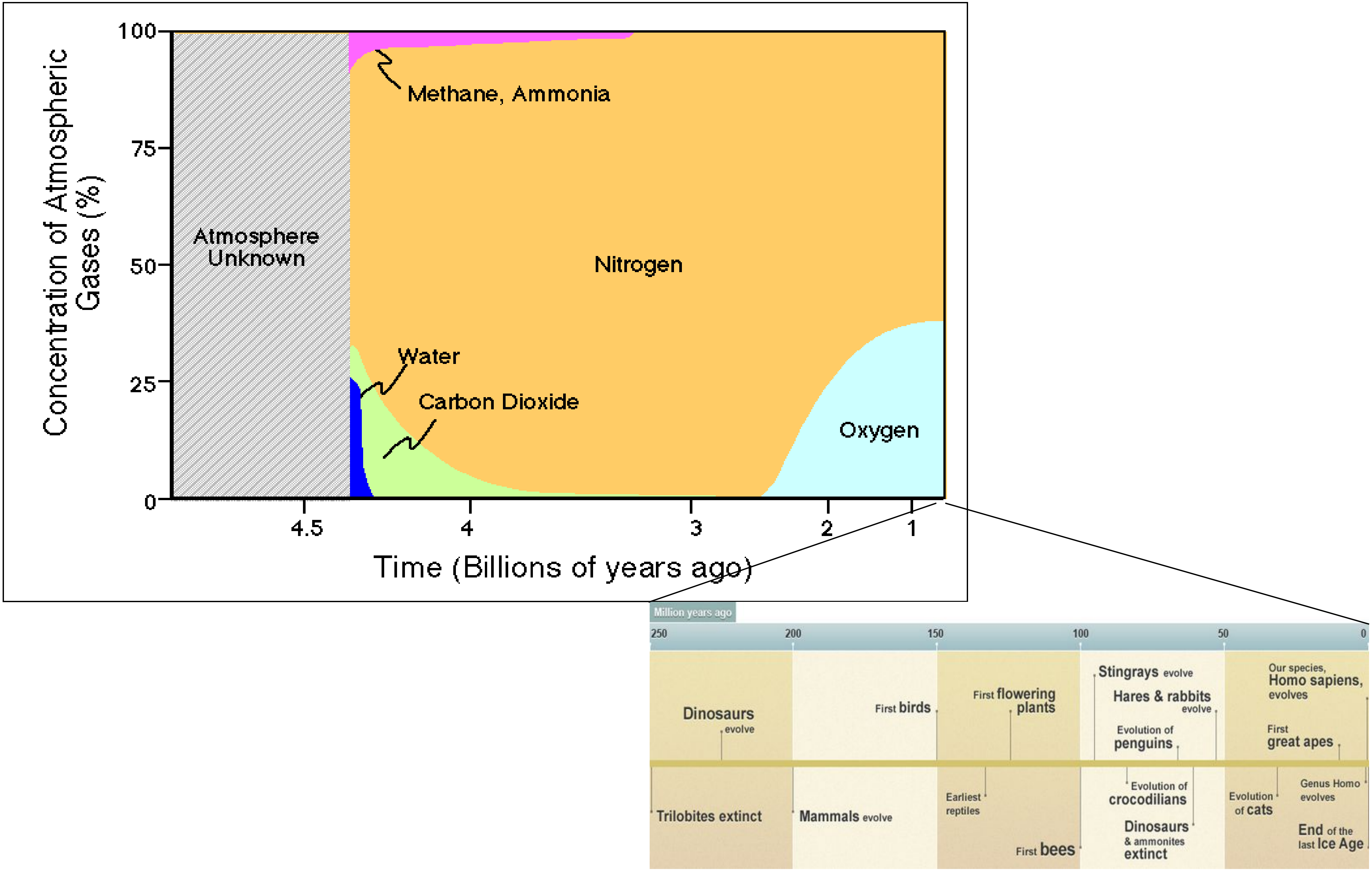
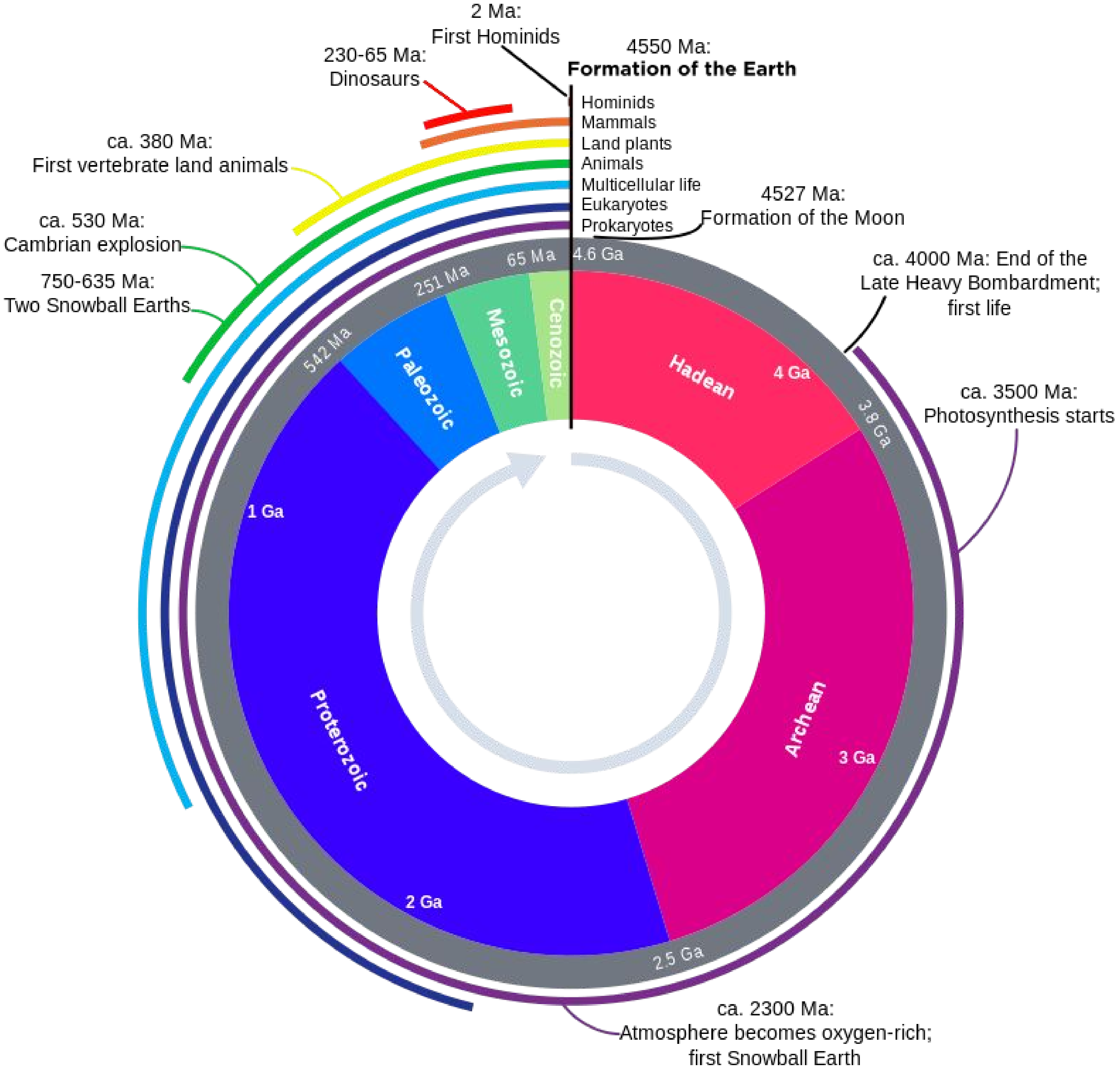
Changes in atmospheric composition

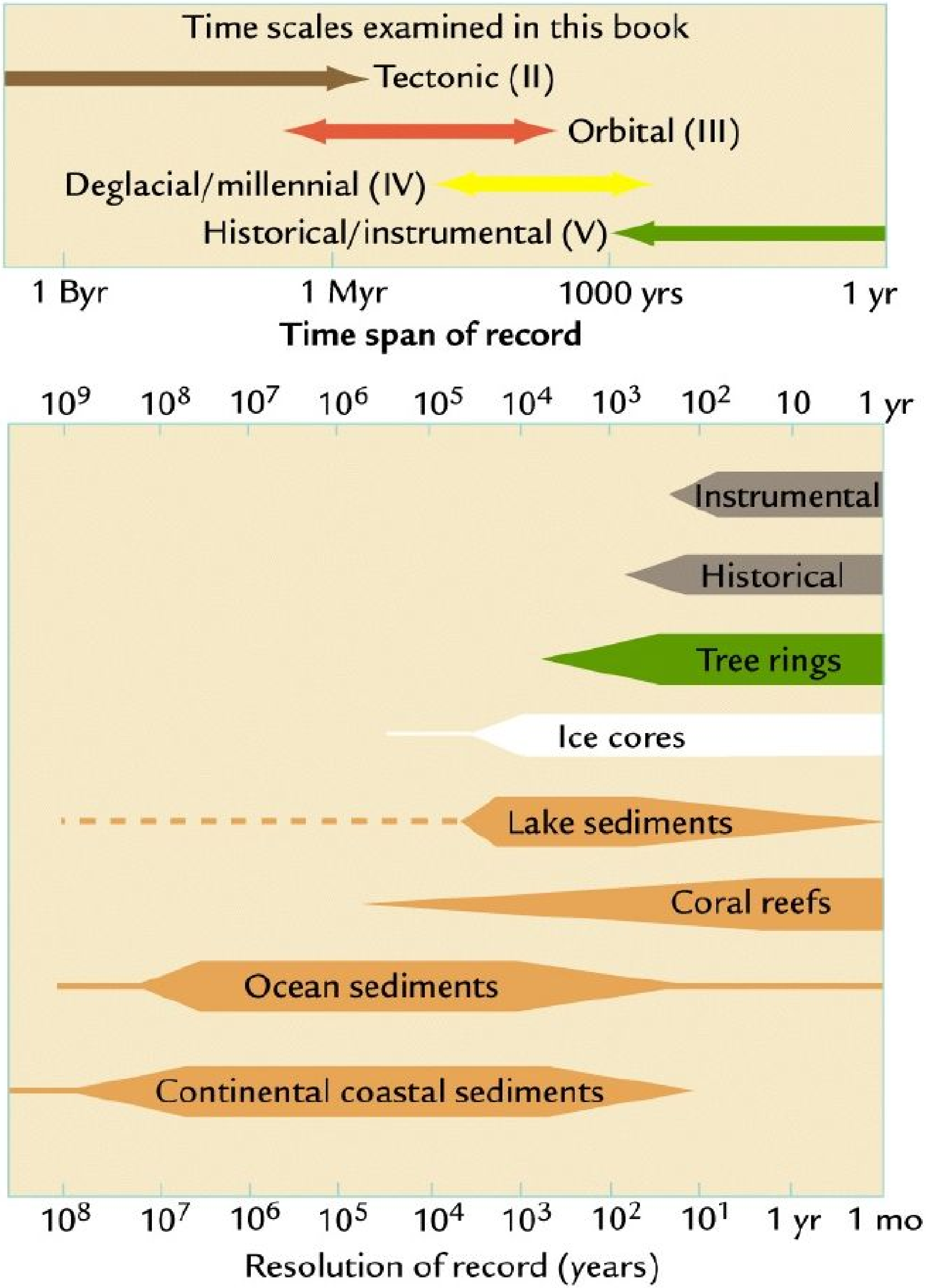



2 Ma:
First Hominids
4550 Ma:
Formation of the Earth
230-65 Ma:
Dinosaurs
Hominids
Mammals
Land plants
Animals
Multicellular life
Eukaryotes
Prokaryotes
4527 Ma:
Formation of the Moon
ca. 380 Ma:
First vertebrate land animals
ca. 530 Ma:
Cambrian explosion
750-635 Ma:
Two Snowball Earths
ca. 4000 Ma: End of the
Late Heavy Bombardment;
first life
ca. 3500 Ma:
Photosynthesis starts
65 Ma
4.6 Ga
251 Ma
542 Ma
Cenozoic
Mesozoic
Paleozoic
Hadean
4 Ga
3.8 Ga
1 Ga
Proterozoic
Archean
3 Ga
2 Ga
2.5 Ga
ca. 2300 Ma:
Atmosphere becomes oxygen-rich;
first Snowball Earth

Paleolclimatic 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

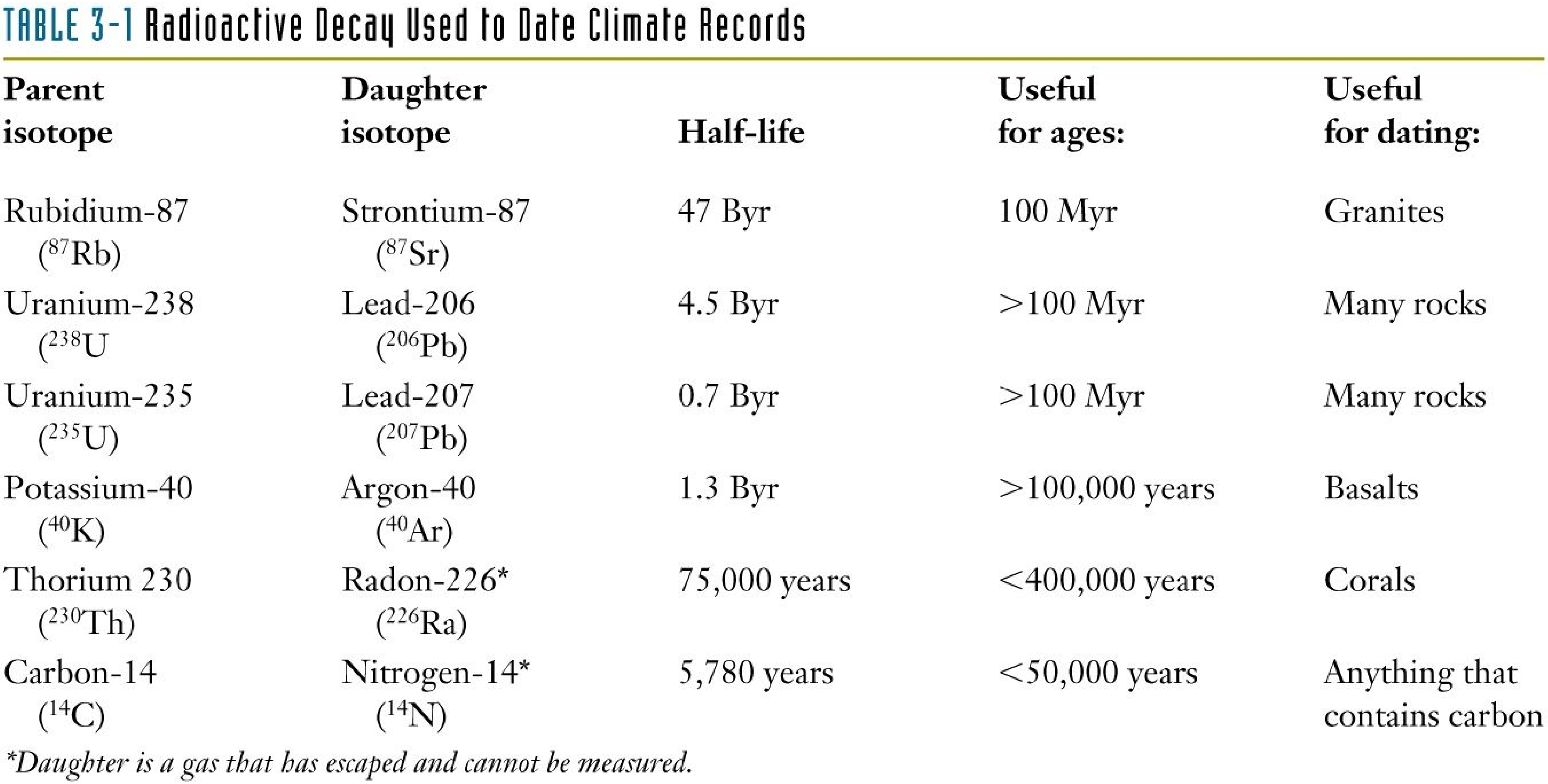


TABLE 3-1 Radioactive Decay Used to Date Climate Records

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

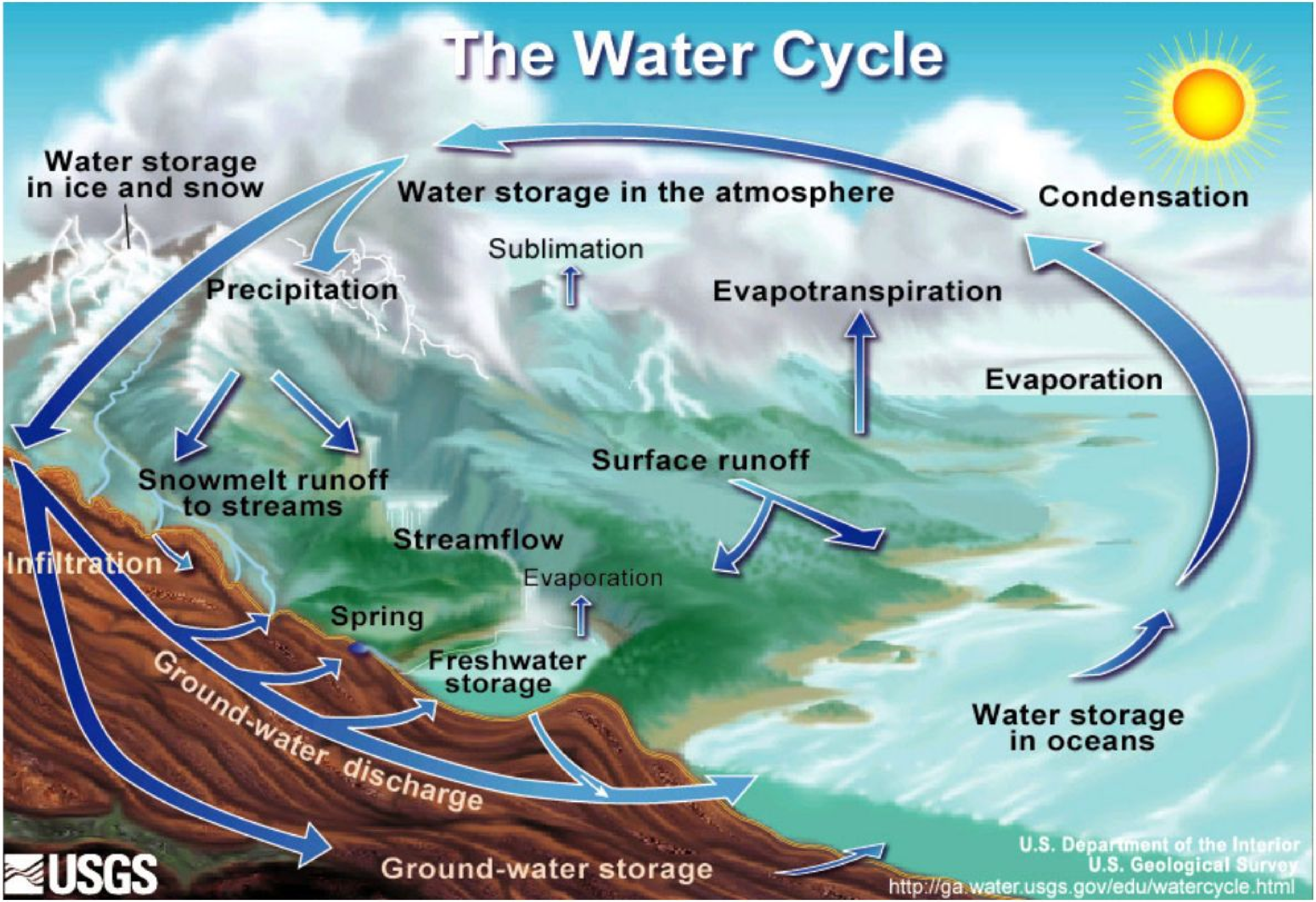
**Daughter is a gas that has escaped and cannot be measured.*

Isotope systematics in the hydrological cycle:

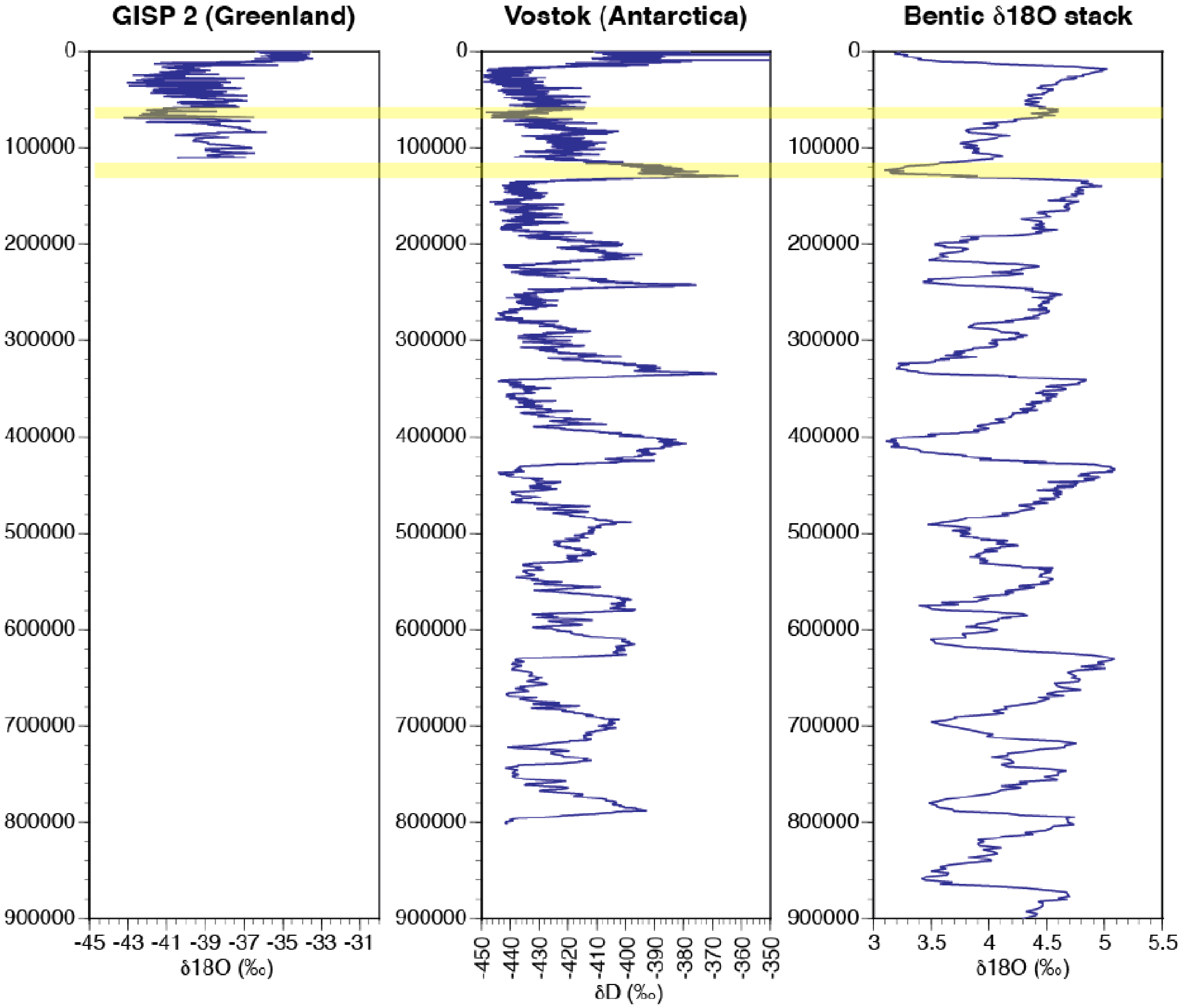
The isotope composition of natural meteoric waters (which form the main reservoirs of freshwater on earth, ice caps, lakes, rivers and groundwater) is determined by three main factors.

- 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.

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



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

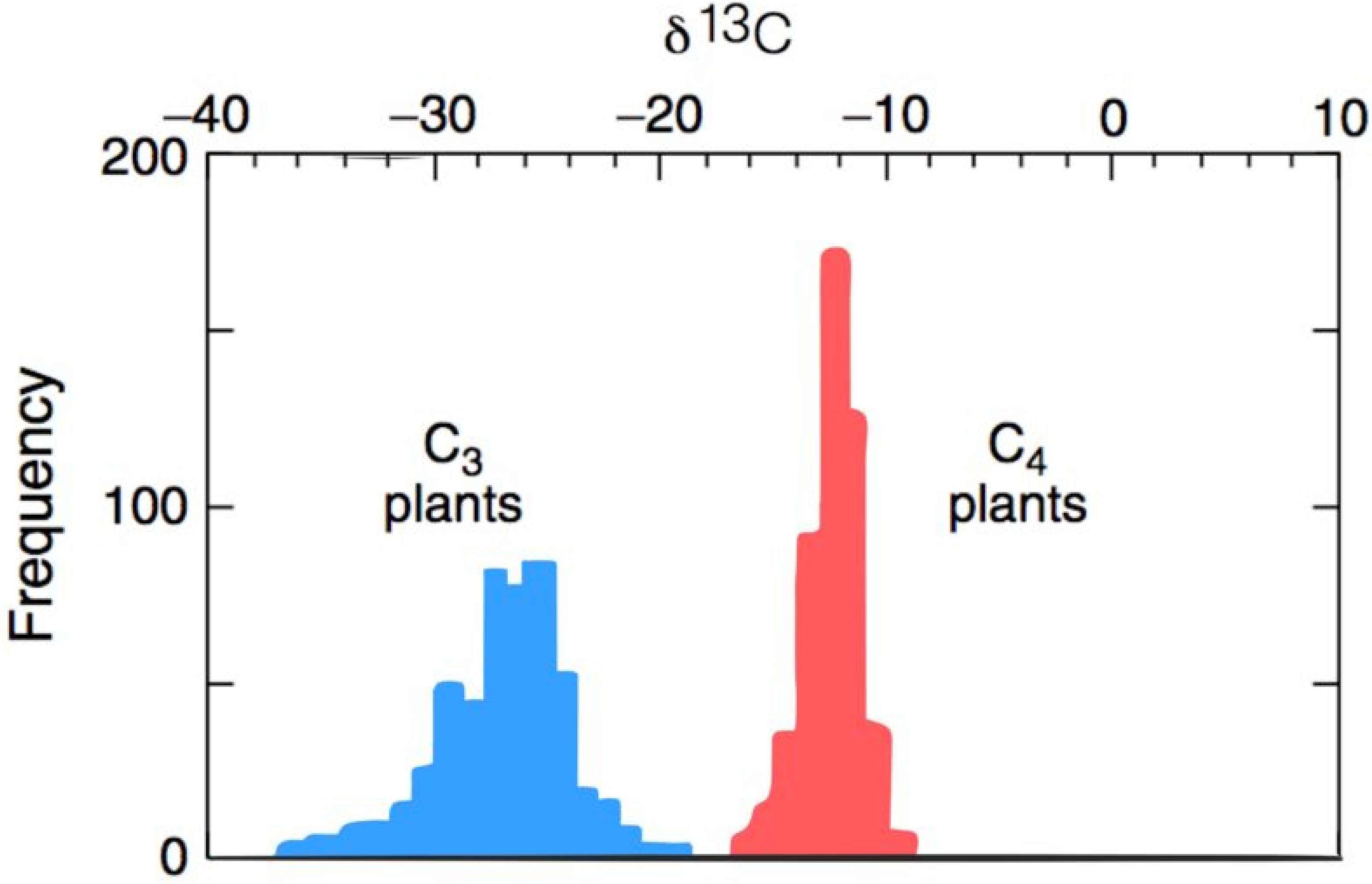


- $H_2{}^{16}O$

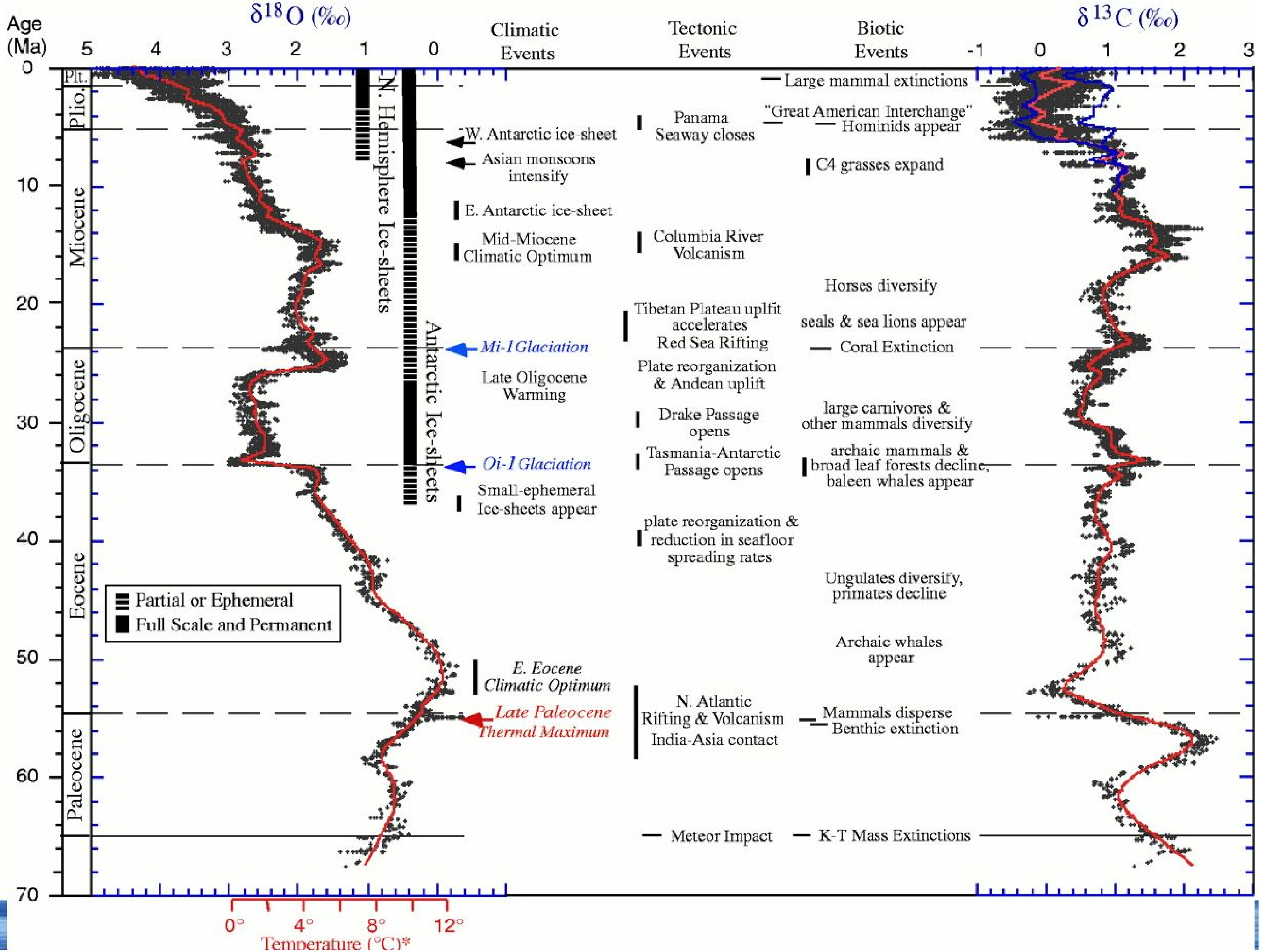
Abundance:

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

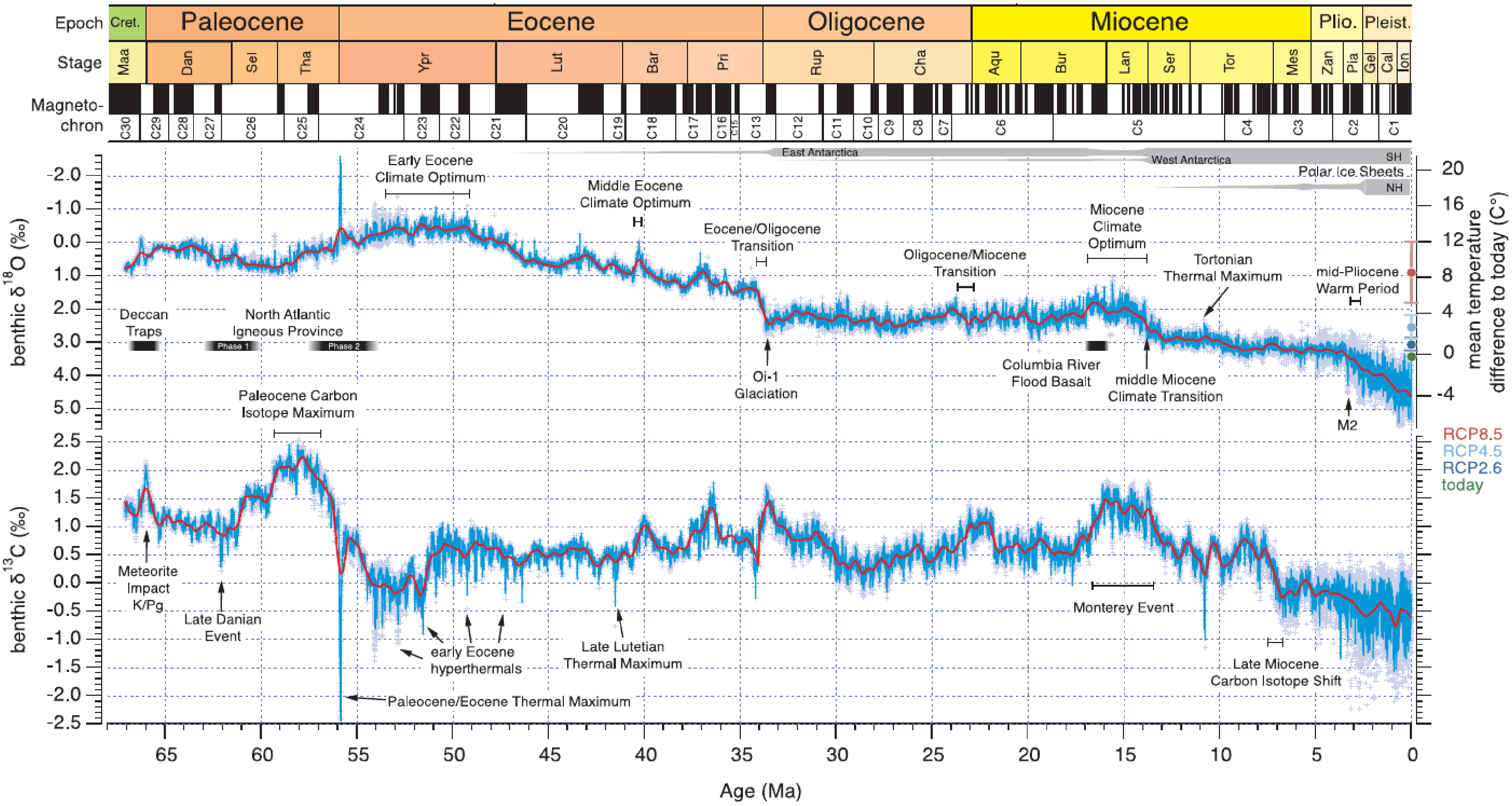
Reduced amount of sarbon stable isotope ^{13}C in plants dependig on fotosynthesis type.



Long-term $\delta^{18}O$ 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 Vleeschouwer, 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

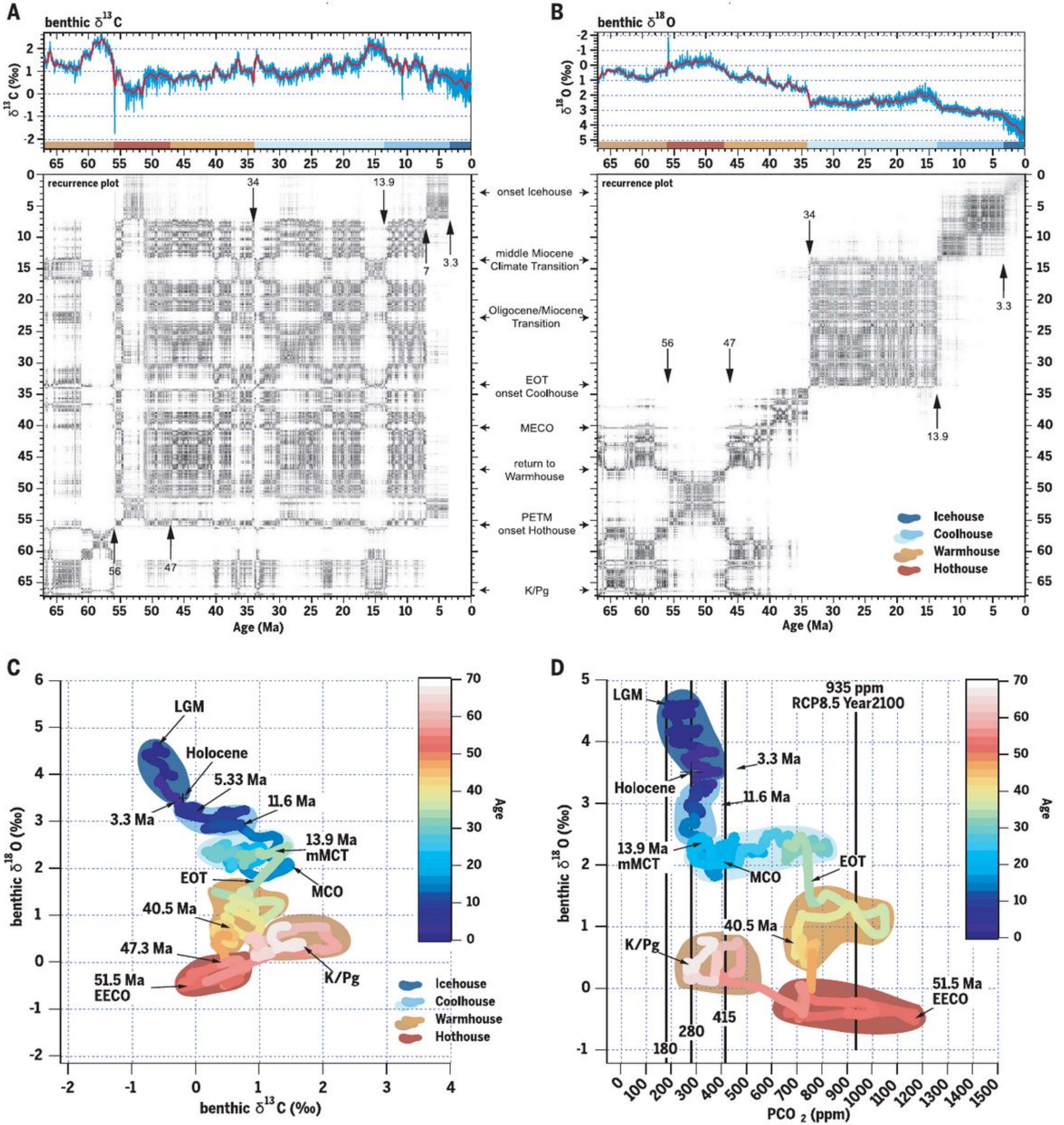
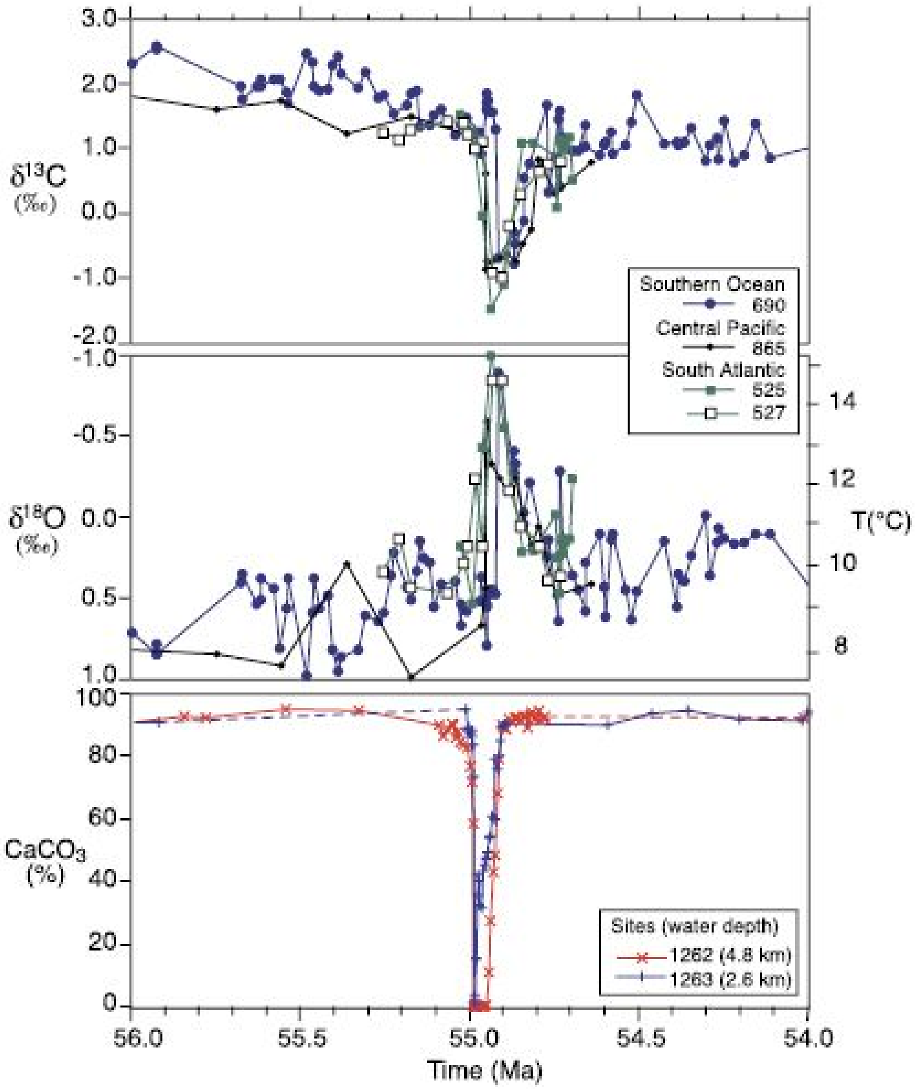


Fig. 2. Climate states of the Cenozoic. Deep-sea benthic foraminifer high-resolution carbon (A) and oxygen (B) isotope records and the respective recurrence plots as
well as scatterplots of long-term benthic foraminifer carbon versus oxygen values (C) and oxygen values versus atmospheric CO2 concentrations (D).

- Long-term (> 10s of millions of years to 4.6Gyr) climate history information can come from geology.
- Oxygen isotopes ($\delta^{18}O$) from carbonate ($CaCO_3$) 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

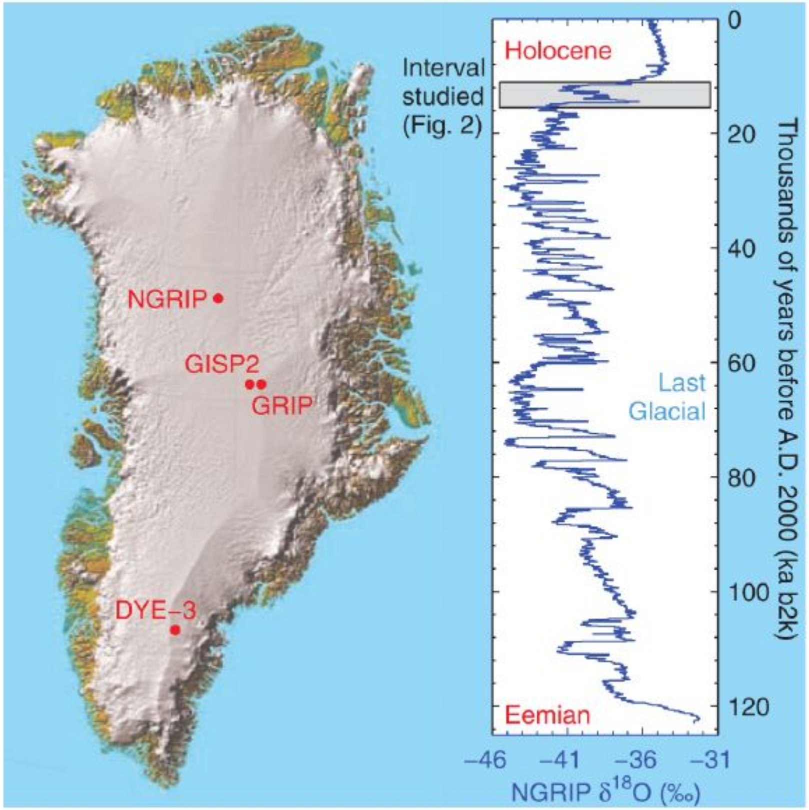


The Palaeocene-Eocene Thermal Maximum as recorded in benthic (bottom dwelling) foraminifer (Nuttallides truempyi) isotopic records from sites in the Antarctic, south Atlantic and Pacific (see Zachos et al., 2003 for details). The rapid decrease in carbon isotope ratios in the top panel is indicative of a large increase in atmospheric greenhouse gases CO2 and CH4 that was coincident with an approximately 5°C global warming (centre panel). Using the carbon isotope records, numerical models show that CH4 released by the rapid decomposition of marine hydrates might have been a major component (~2,000 GtC) of the carbon flux (Dickens and Owen, 1996).

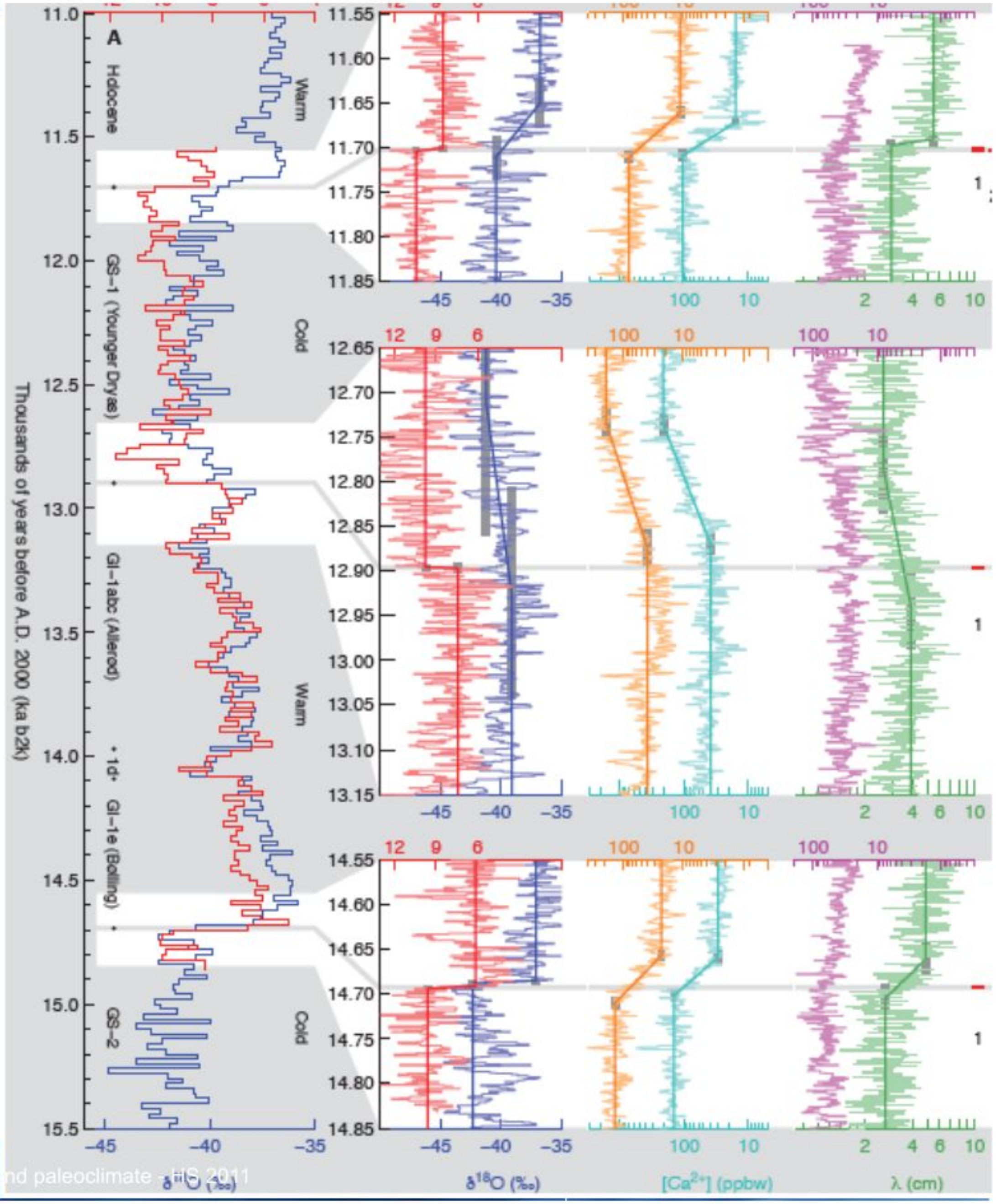
IPCC 2007

Application in ice cores
Abrupt climate change

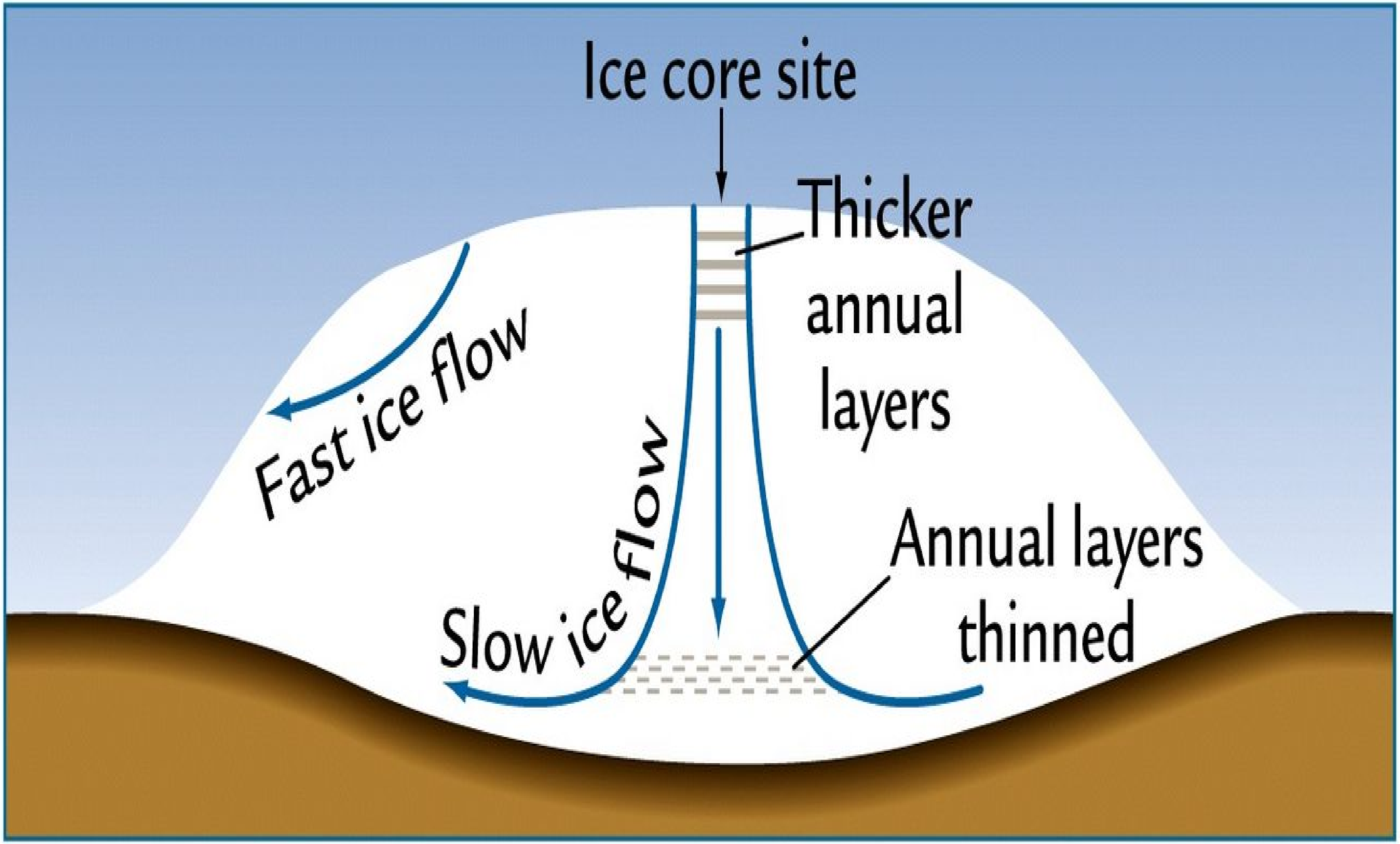
- Study the long ice record in Greenland



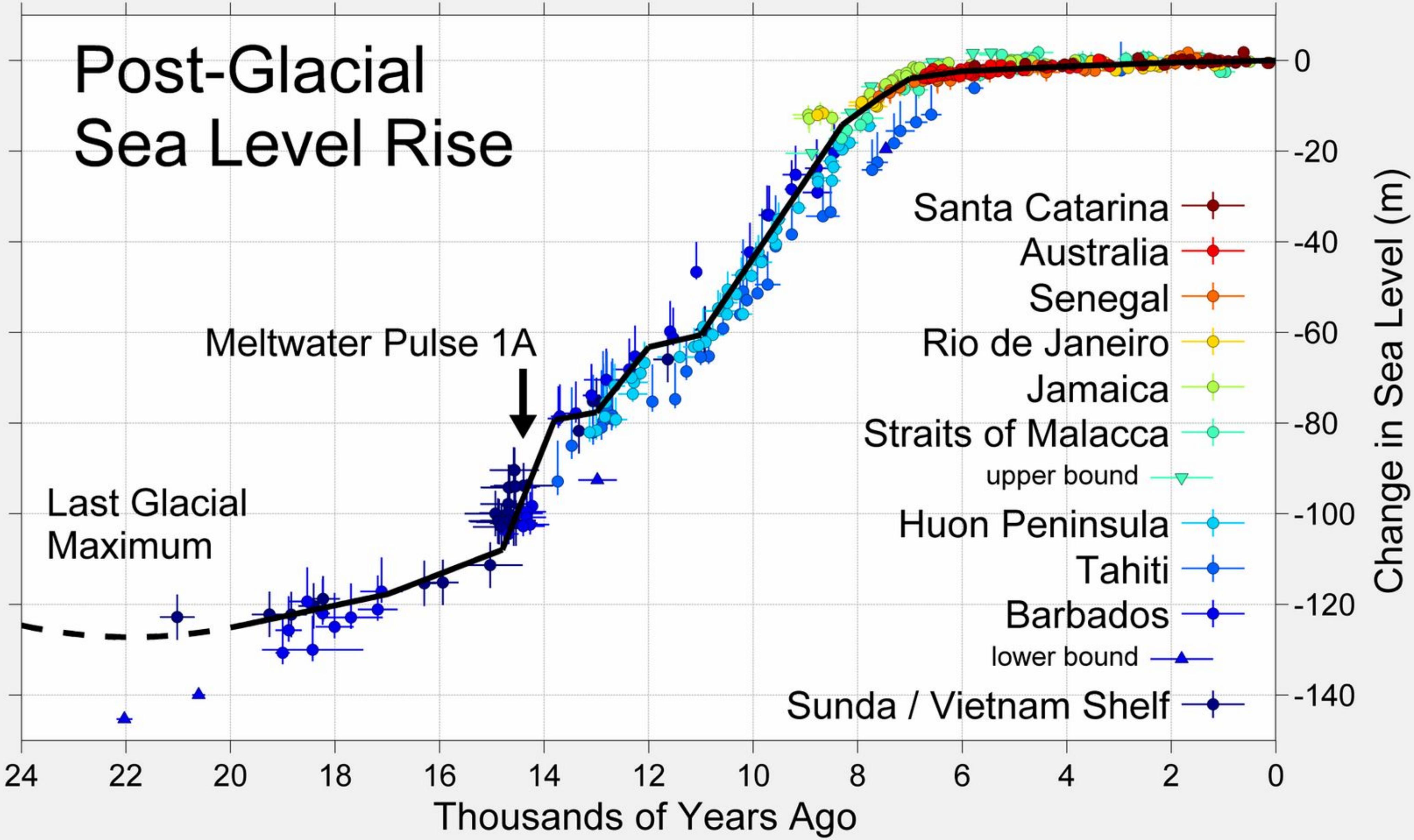
Steffensen et al, Science, 321, 1. August 2008



Ice Cores and Ice Sheet Flow



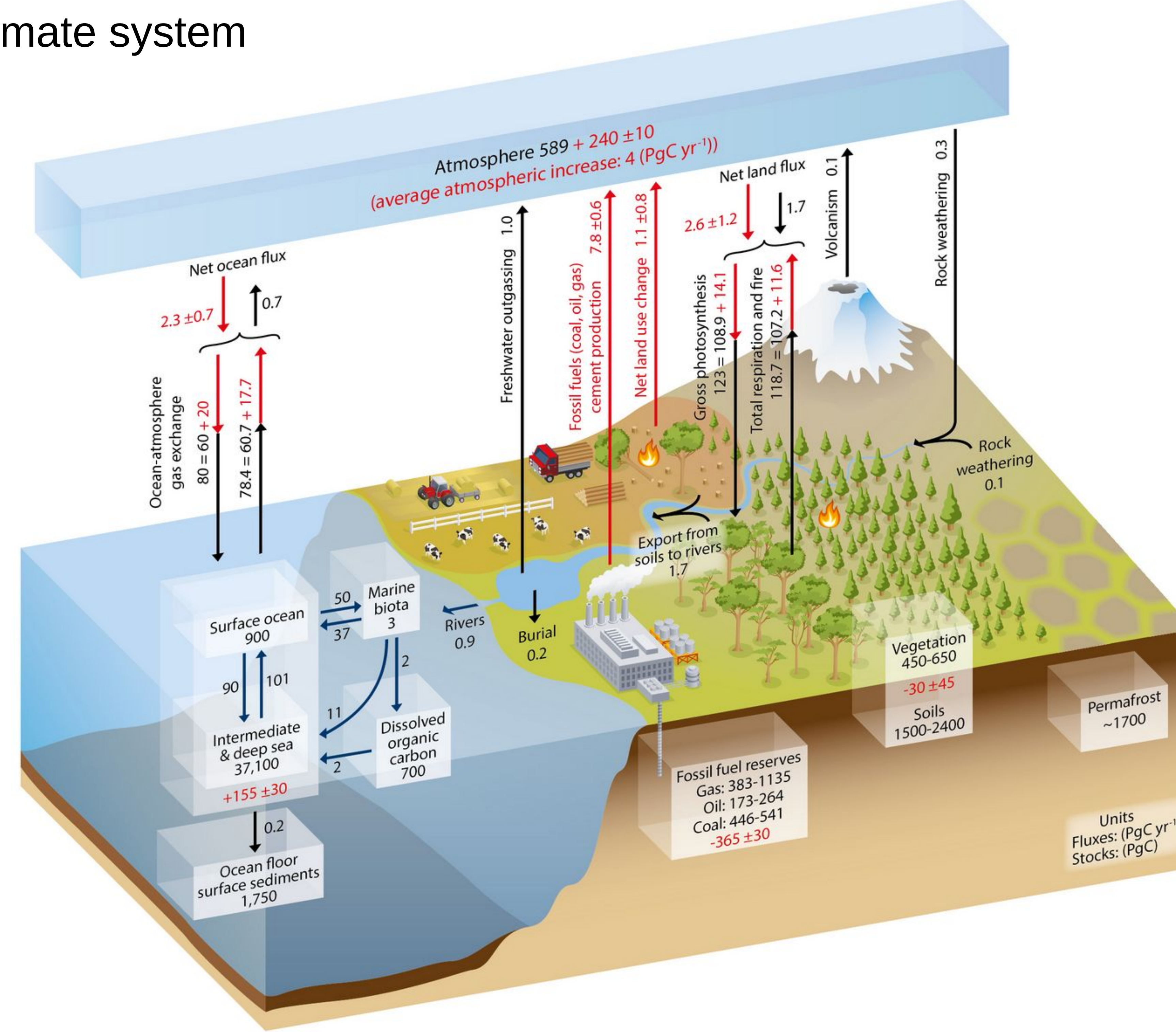
Age of Ice: annual layers (Greenland) and ice flow models (Antarctica)


Post-Glacial Sea Level Rise
Meltwater Pulse 1A
Last Glacial Maximum
Santa Catarina
Australia
Senegal
Rio de Janeiro
Jamaica
Straits of Malacca
upper bound
Huon Peninsula
Tahiti
Barbados
lower bound
Sunda / Vietnam Shelf
0
-20
-40
-60
-80
-100
-120
-140
Change in Sea Level (m)
24
22
20
18
16
14
12
10
8
6
4
2
0
Thousands of Years Ago

Carbon in climate system

Black – preindustrial capacities of carbon reservoirs in GtC and fluxes in Gt/yr.

Red – changes from pre-industrial to 2010. (IPCC 2013)



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.

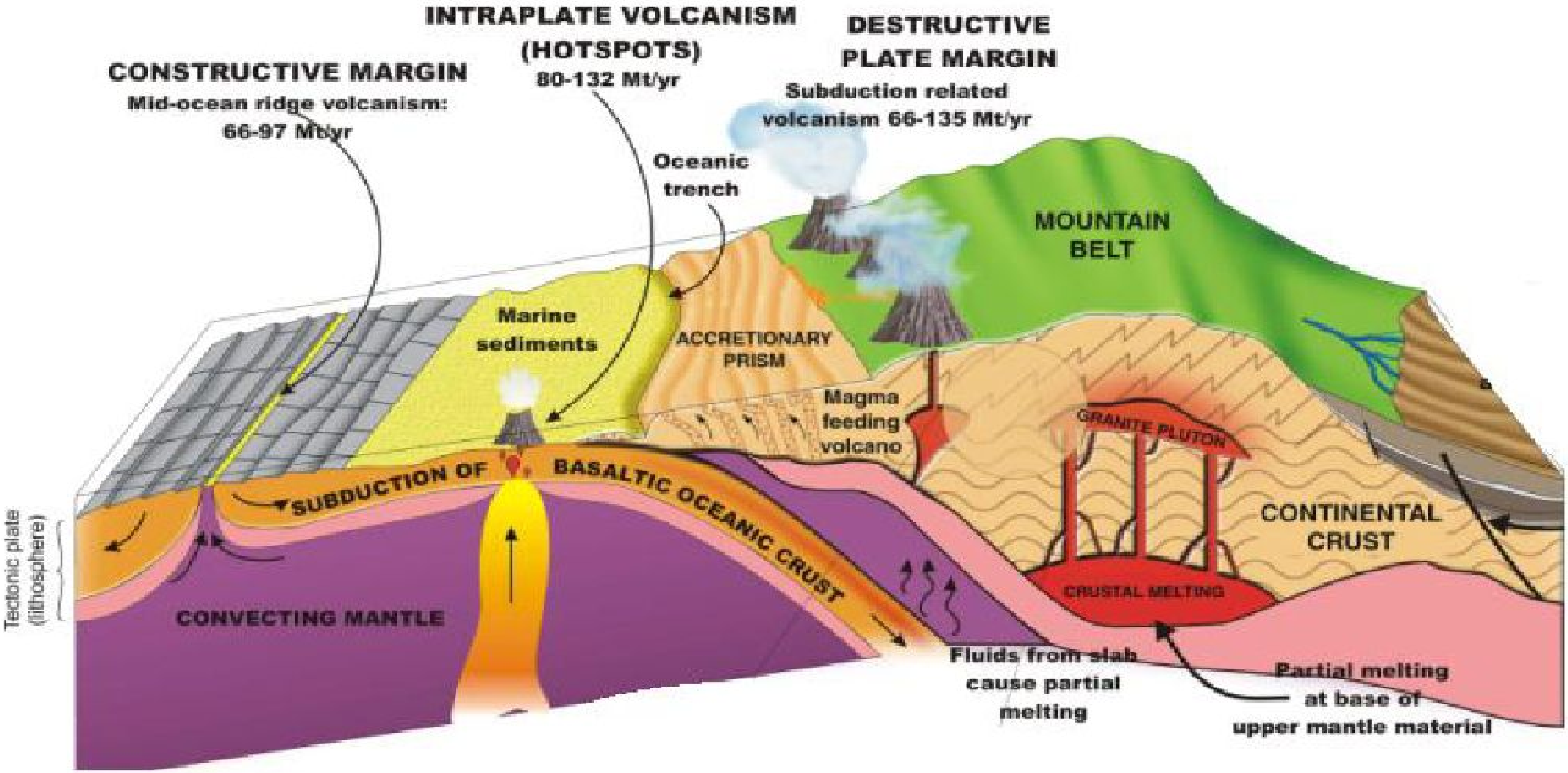
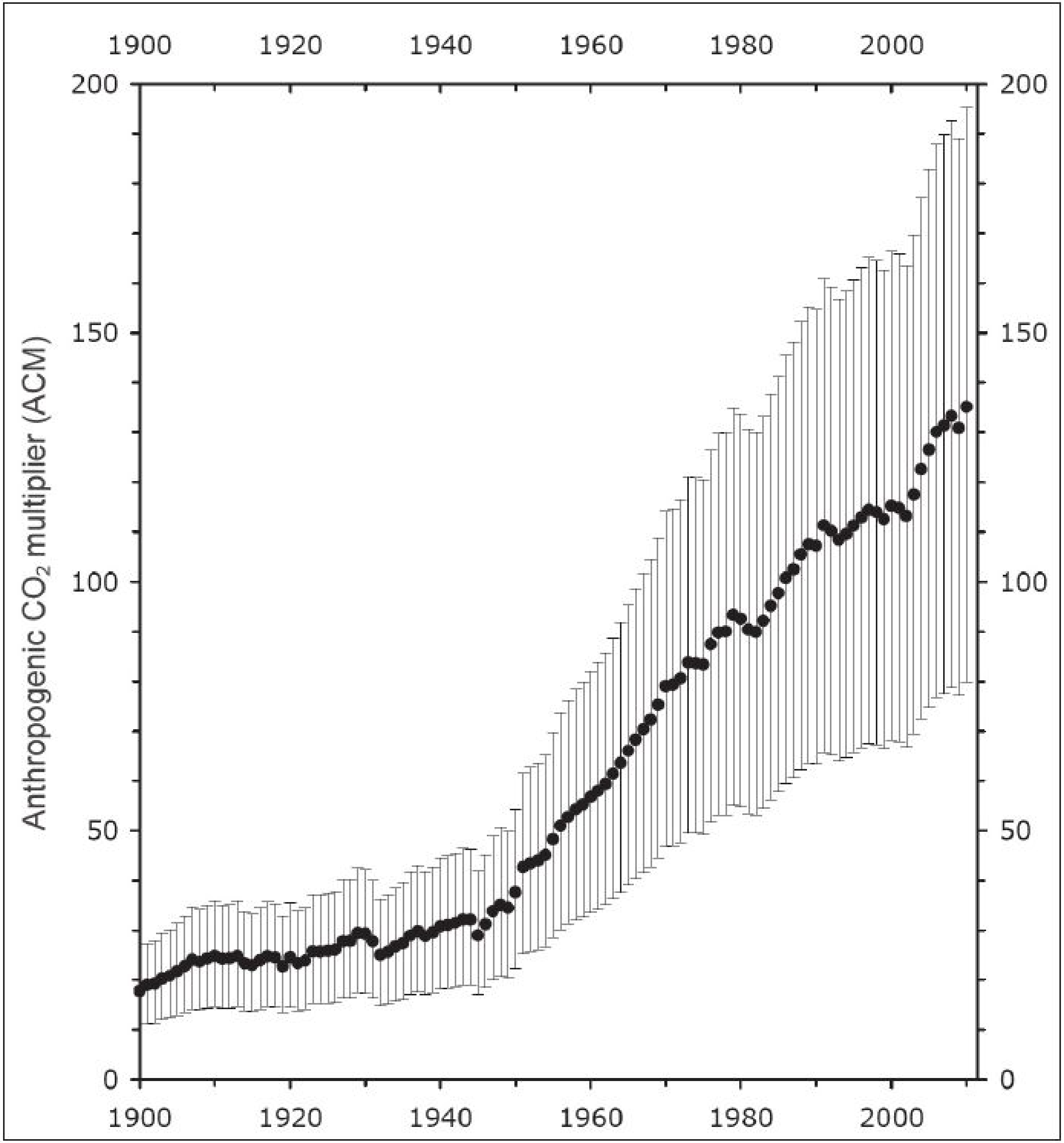


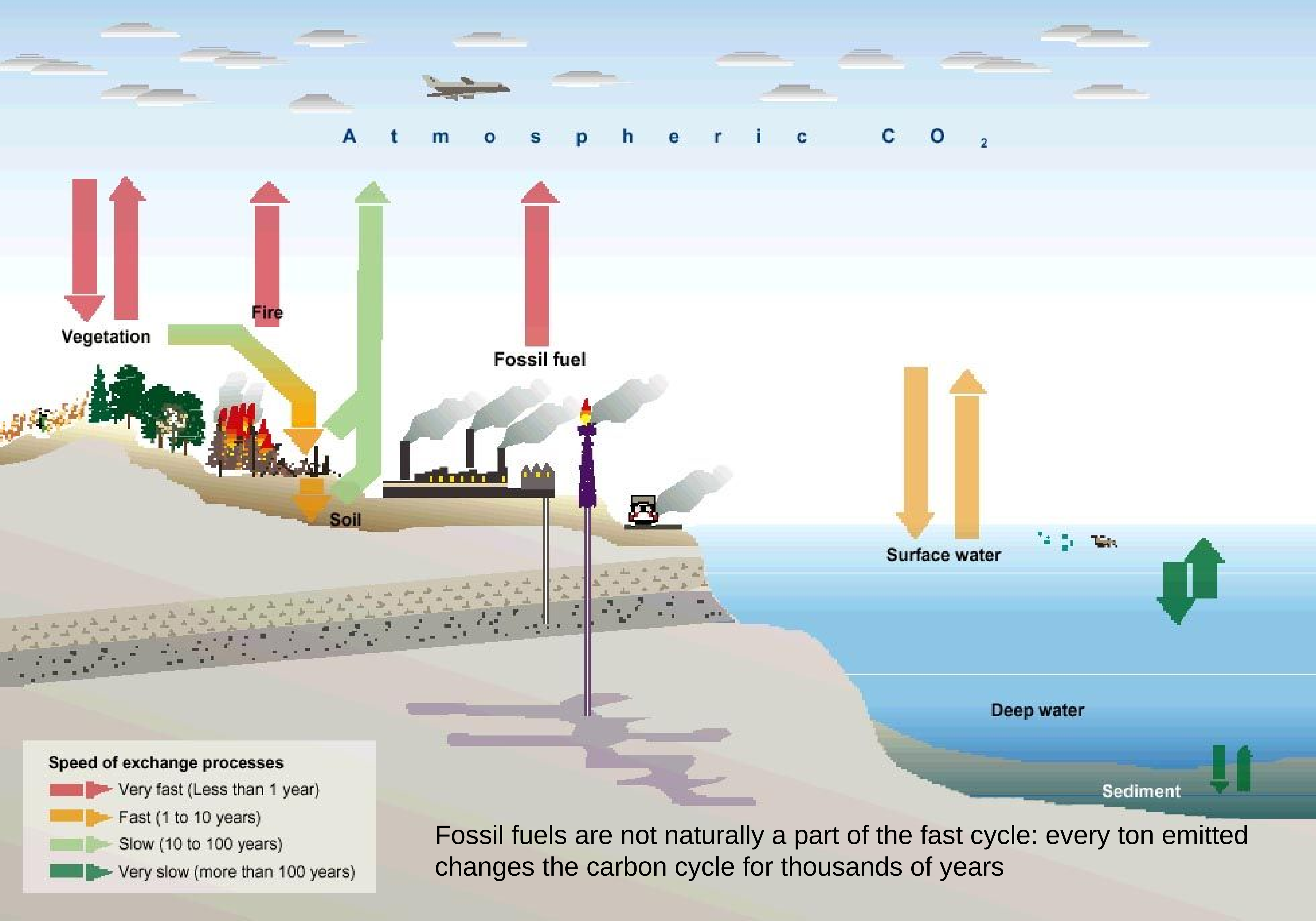
Figure 2. Diagrammatic representation of the different volcanic environments with estimates of CO_2 emission rates and their relationship to plate tectonic environment.



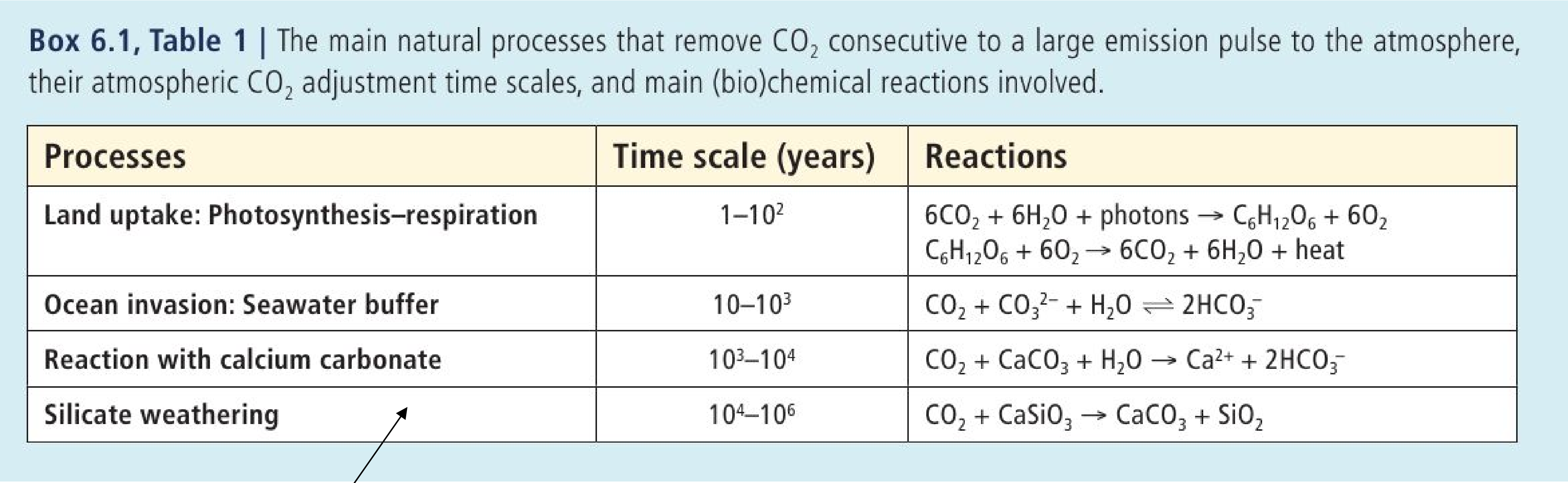
Antropogenic vs. volcanic CO_2 emissions.

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

Fast and slow processes in the carbon cycle



Fossil fuels are not naturally a part of the fast cycle: every ton emitted changes the carbon cycle for thousands of years

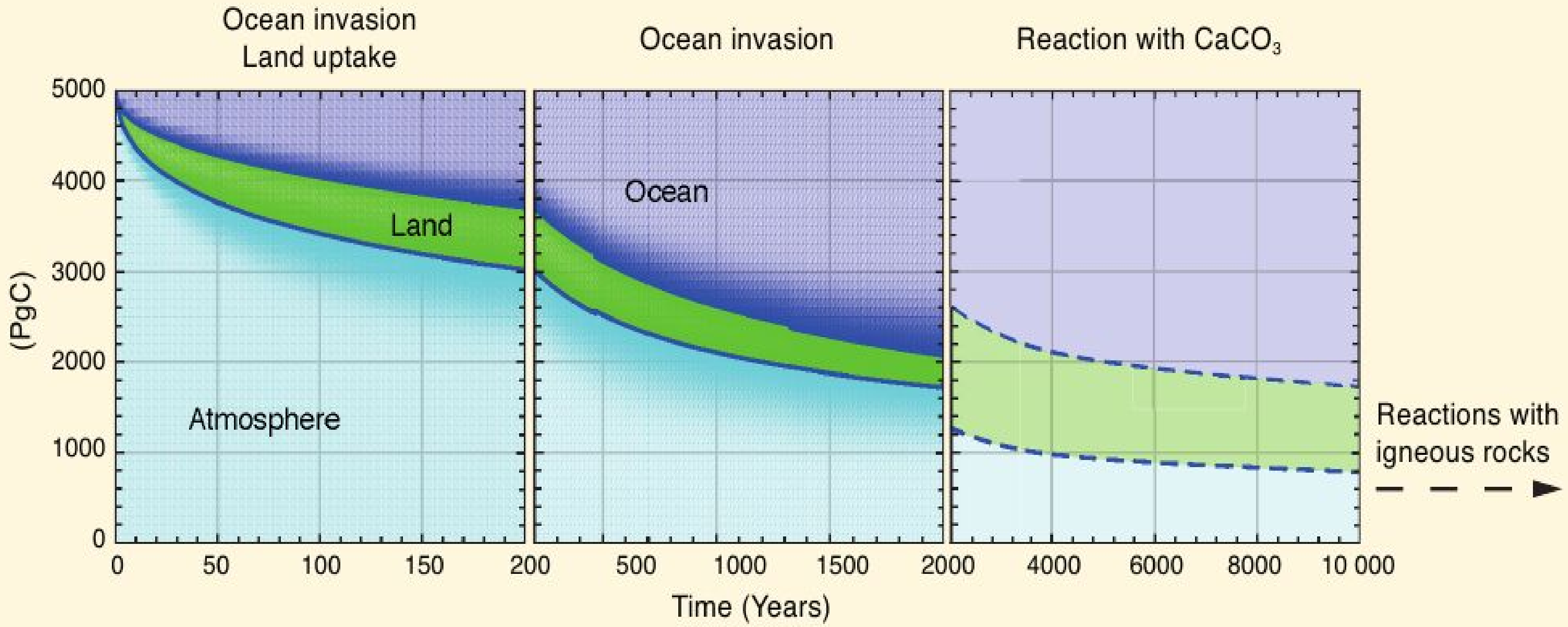


Box 6.1, Table 1 | The main natural processes that remove CO_2 consecutive to a large emission pulse to the atmosphere, their atmospheric CO_2 adjustment time scales, and main (bio)chemical reactions involved.

Processes	Time scale (years)	Reactions
Land uptake: Photosynthesis–respiration	$1–10^2$	$6CO_2 + 6H_2O + \text{photons} \rightarrow C_6H_{12}O_6 + 6O_2$ $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{heat}$
Ocean invasion: Seawater buffer	$10–10^3$	$CO_2 + CO_3^{2-} + H_2O \rightleftharpoons 2HCO_3^-$
Reaction with calcium carbonate	$10^3–10^4$	$CO_2 + CaCO_3 + H_2O \rightarrow Ca^{2+} + 2HCO_3^-$
Silicate weathering	$10^4–10^6$	$CO_2 + CaSiO_3 \rightarrow CaCO_3 + SiO_2$

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

Timescales of carbon removal.

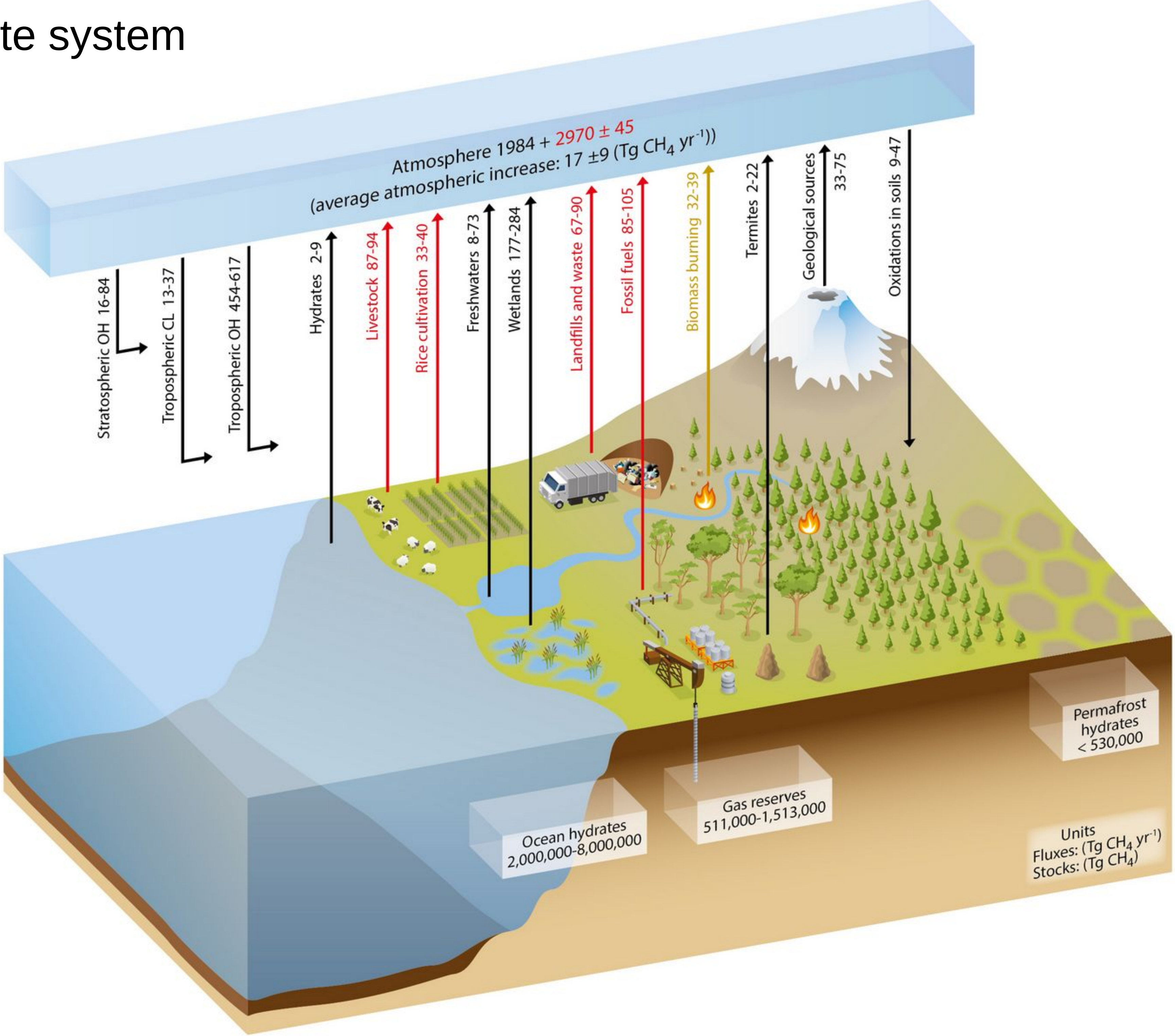


FAQ 6.2, Figure 2 | Decay of a CO_2 excess amount of 5000 PgC emitted at time zero into the atmosphere, and its subsequent redistribution into land and ocean as a function of time, computed by coupled carbon-cycle climate models. The sizes of the colour bands indicate the carbon uptake by the respective 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_4 in climate system

Black – preindustrial reservoirs in MtC and fluxes in MtC/yr .

Red – changes since pre-industrial.



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.