A history of global glaciations

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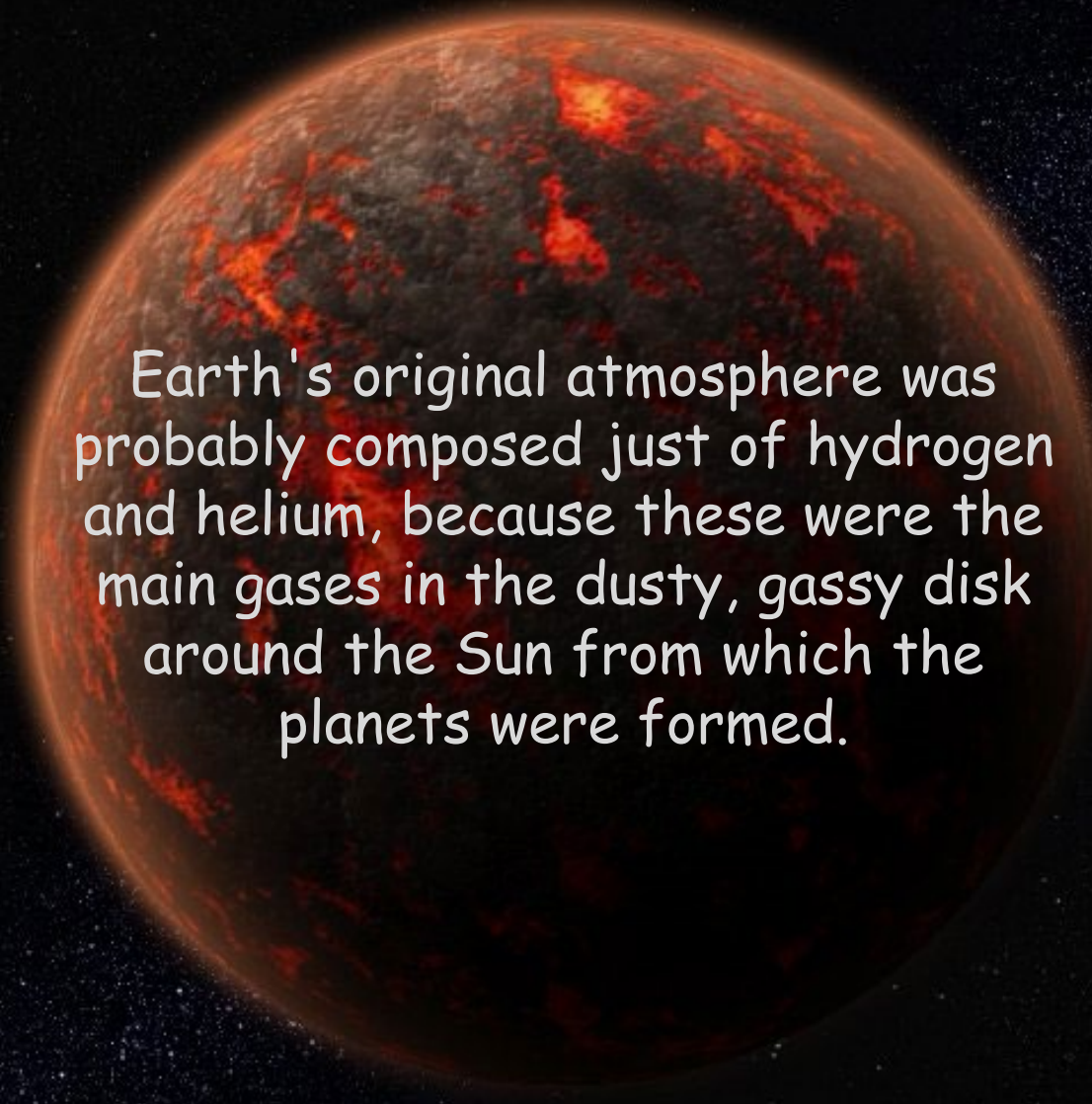
Some 4.55 Ga (giga-annum, 10^9 years) ago…



Earth's original atmosphere was probably composed just of hydrogen and helium, because these were the main gases in the dusty, gassy disk around the Sun from which the planets were formed.

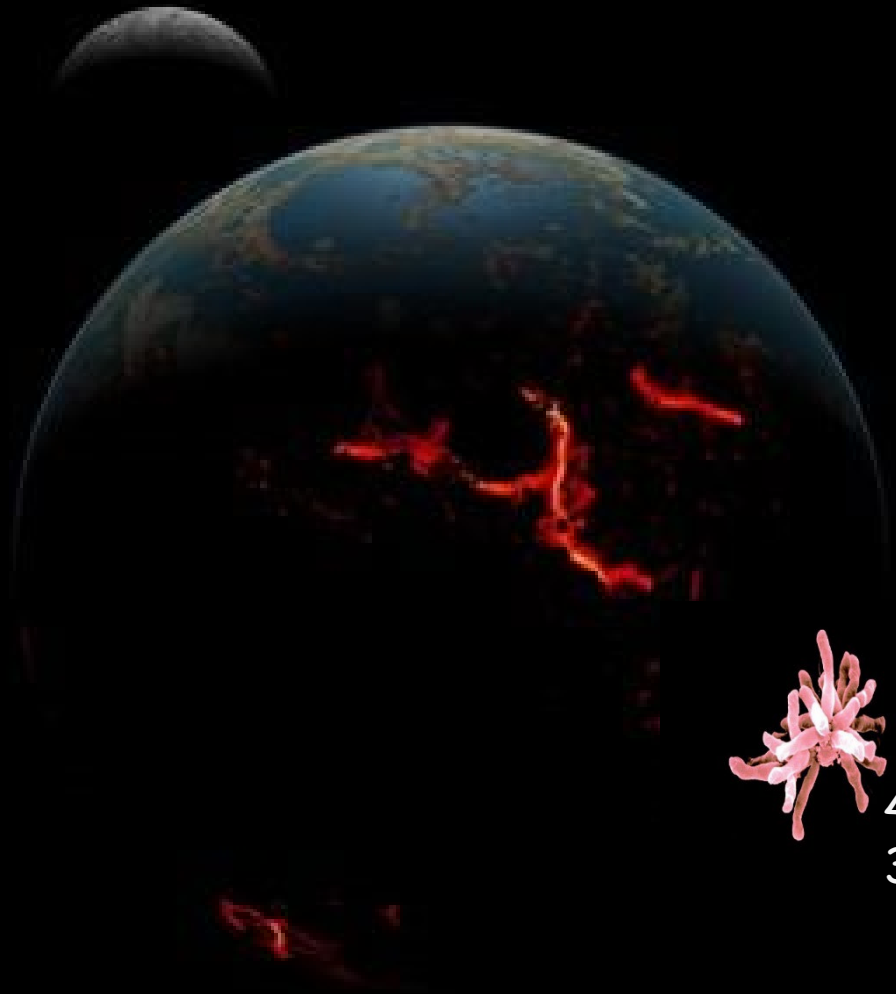
Atmosphere of the early (pre-biotic) Earth: Hadean

- The primordial Earth's atmosphere include also volatile constituents that escaped from the molten and solid planet by degassing. They were mainly water vapour, carbon dioxide, nitrogen.

- As the Earth cooled down, most of the water vapour condensed and formed the oceans. The main constituents of the early atmosphere remained CO_2 and N_2

- At the turn of Hedean/Archean atmospheric pressure might have been around 50-60 bars.

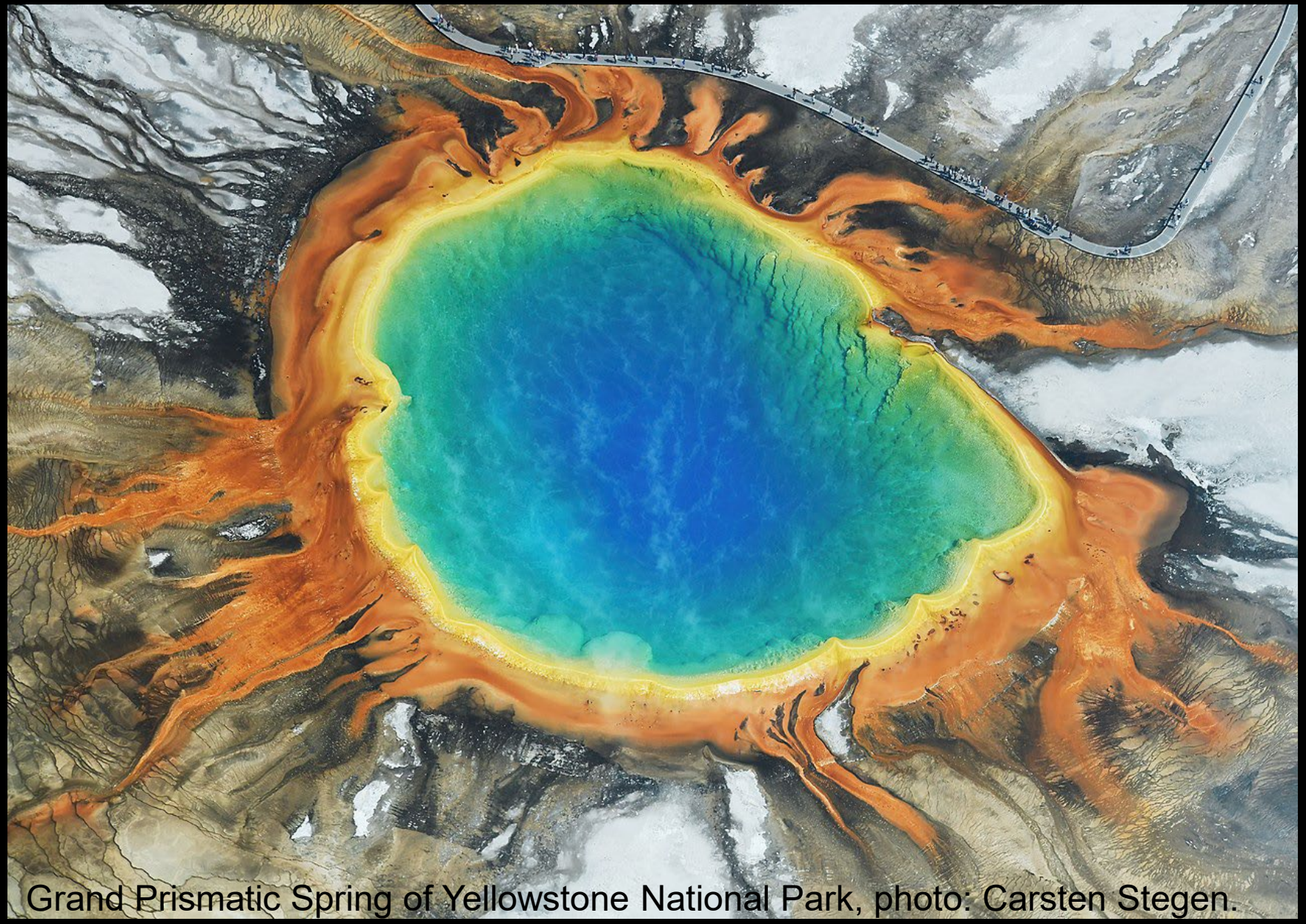
The early ocean became the nursery of prokaryotes, the first organisms on Earth.



4.20 Ga?
3.90-3.75 Ga

Graphic sources: Bank Wiedzy, Wikipedia

Autothrophic organisms could trive in the vicinity of geysers or undersea exhalations (45°-80°C).



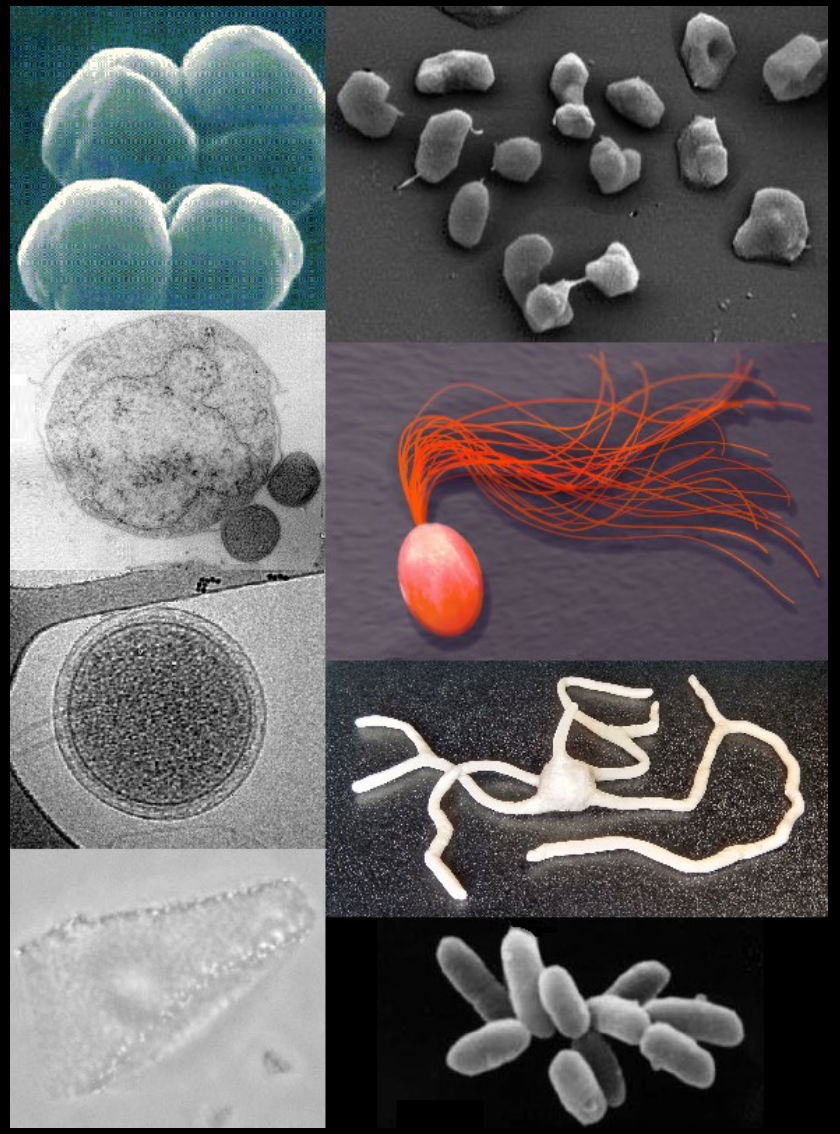
Grand Prismatic Spring of Yellowstone National Park, photo: Carsten Stegen.

Archaea appeared in the aquatic environment about 3.7 billion years ago.

Carbon dioxide (CO_2) was the substrate for Archaea metabolism, while methane (CH_4) was a by-product.

Thus, with the begining of life, the Earth's atmosphere get quickly enriched in methane (CH_4) at the expense of the original CO_2.

Microscopic images of the present-day Archaea



źródło: Wikipedia

Some 3.00 Ga ago, evolved cyanobacteria with
chlorophyll
becoming the key climatic „game changer"

Due to chlorophyll, a free
oxygen,
was formed in seas,
as a by-product of photosynthesis

Cyanobacteria colonies retained clay particles, building microbial mats, called stromatolites

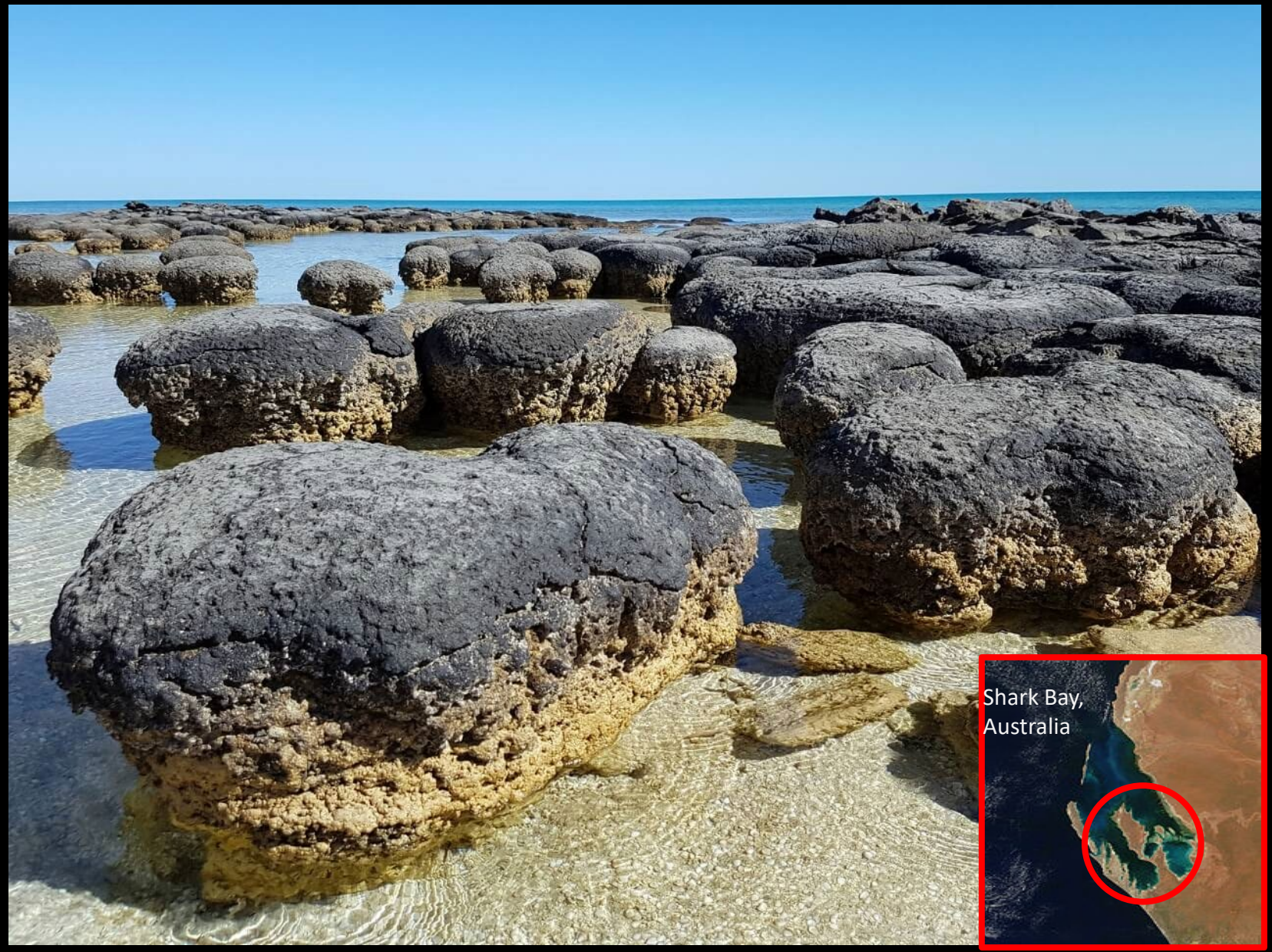


Figure source: Wikipedia

Initially oxygen was bound by ferroneous ions in the oceanic waters, forming banded iron formations (BIF)

Fortescue Falls, Australia
(Photo: Graeme Churchard)

Excess of oxygen was released from the water to the atmosphere, causing the

Great Oxygenation Event (GOE)

and resulting in oxidation of methane to carbon dioxide

$$CH_4 + 2O_2 = CO_2 + 2H_2O$$

Such transformation of atmospheric components had resulted in global temperature drop, since

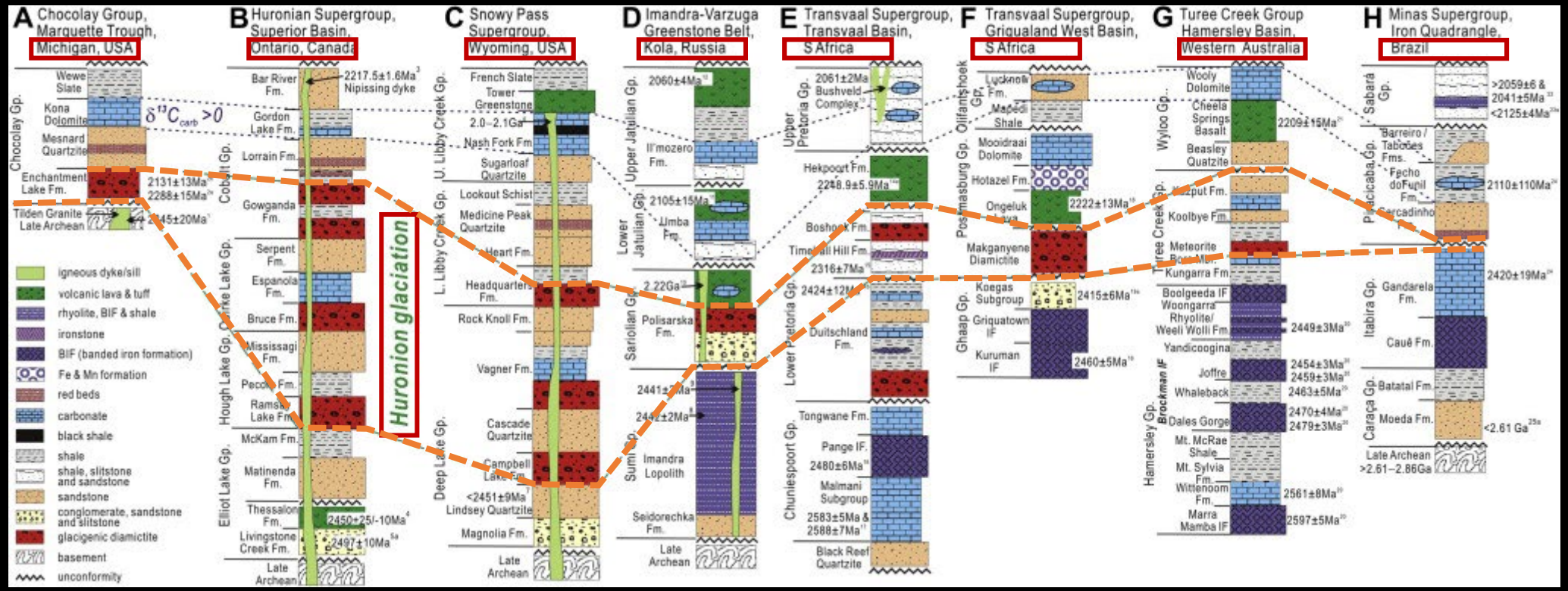
$$CH_{4\ RF} >> CO_{2\ RF},$$

where RF stands for the Radiative Factor

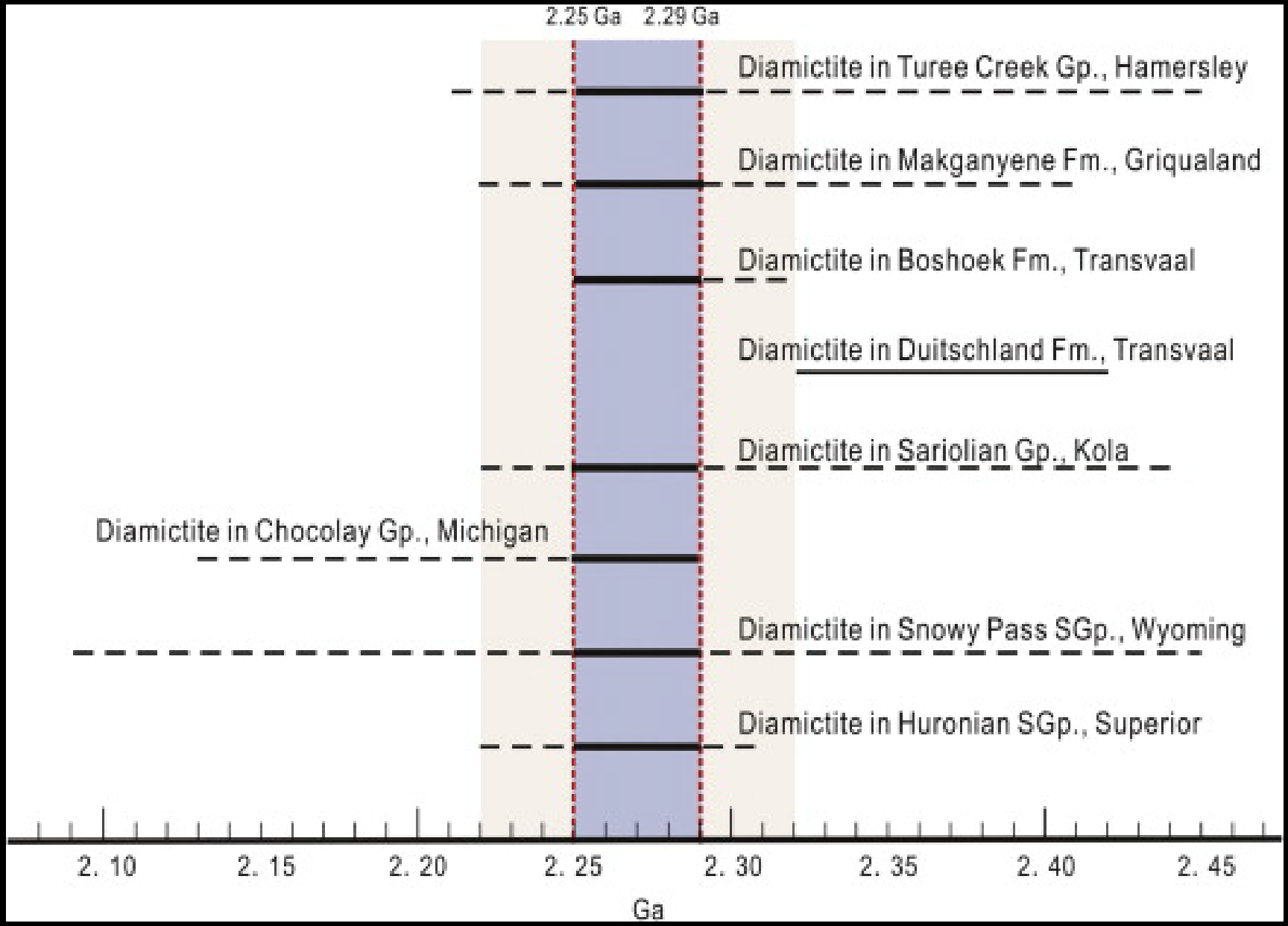
Global cooling #1:

Huronian Global Glaciation
(2.29 – 2.25 Ga ago)

Global distribution of the Huronian diamictites



Tan & Chen, Gescience Frontiers, 2013



Tan & Chen, Gescience Frontiers, 2013


Greetings from the Huronian equator!!!
source: Oceanwide

Some 1.5 Ga later, in the Ediacaran period (720-541 Ma),
plants were absent on lands, which resembled rocky deserts

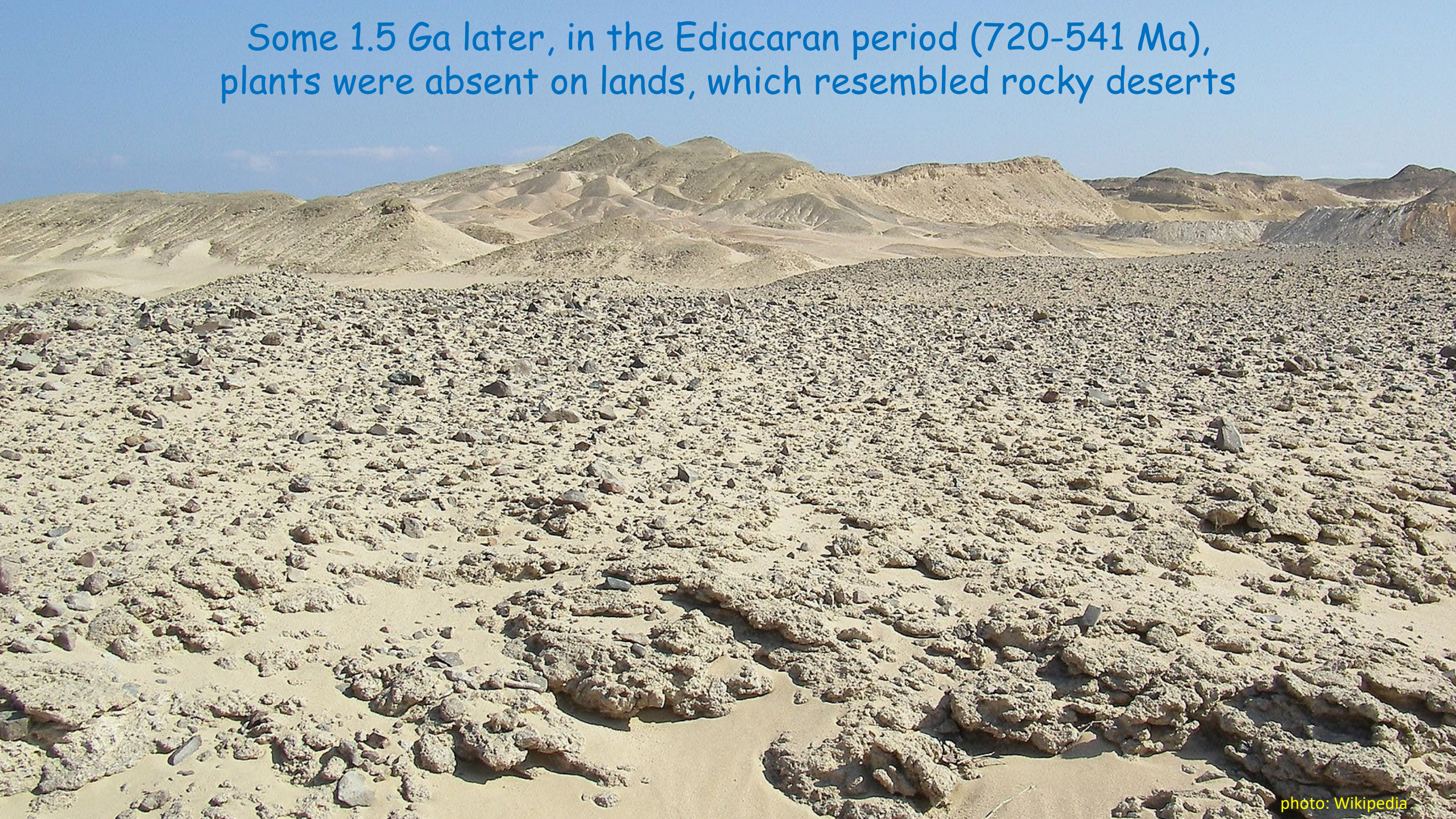
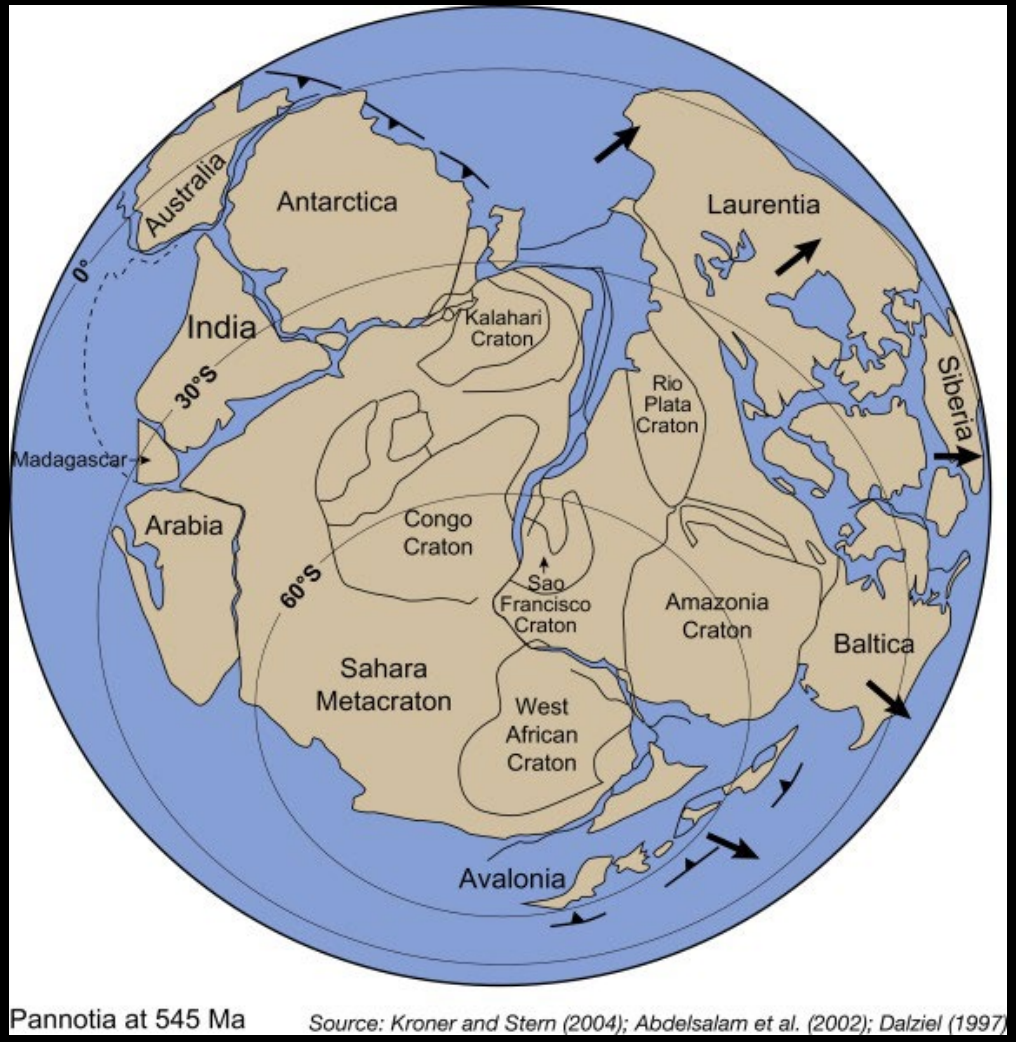
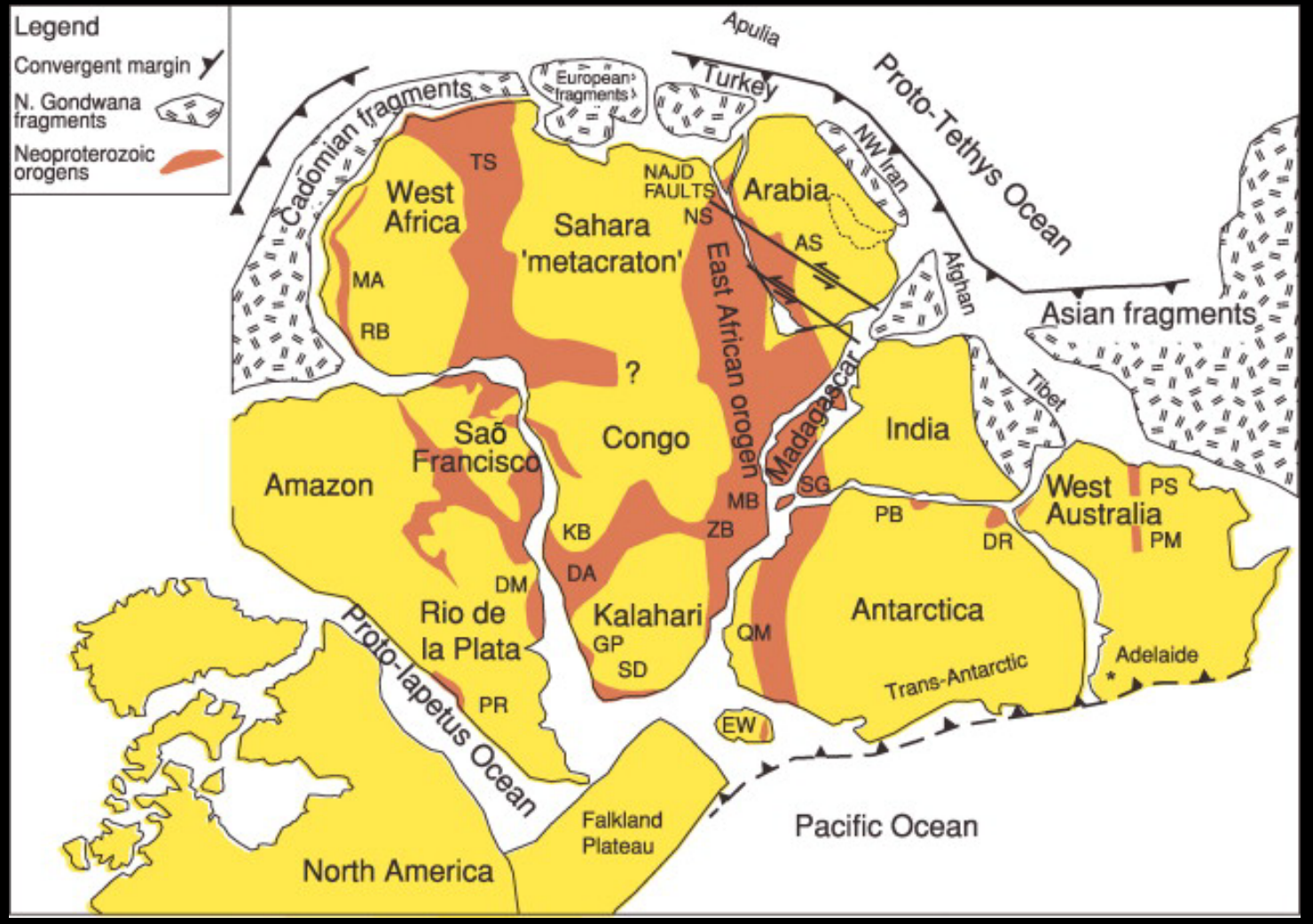


photo: Wikipedia

Collisions ➡ orogens ➡ erosion ➡ carbonatization

(inorganic sequestration of CO_2)



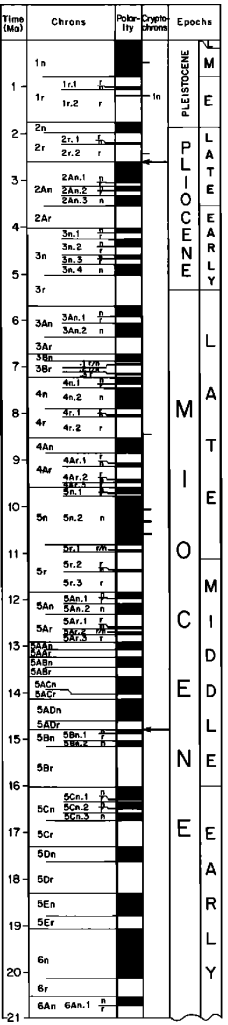


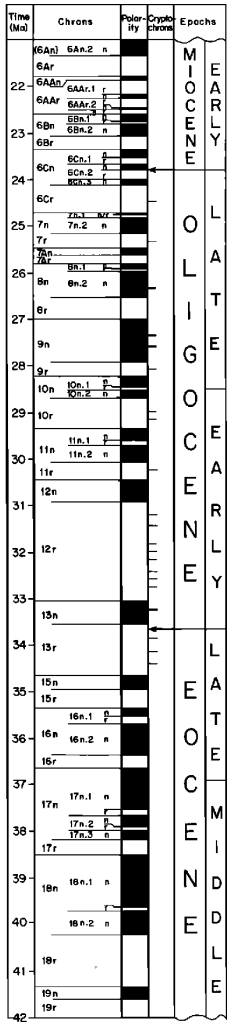
Global cooling #2
Neoproterozoic Global Glaciation
(720-550 Ma ago)

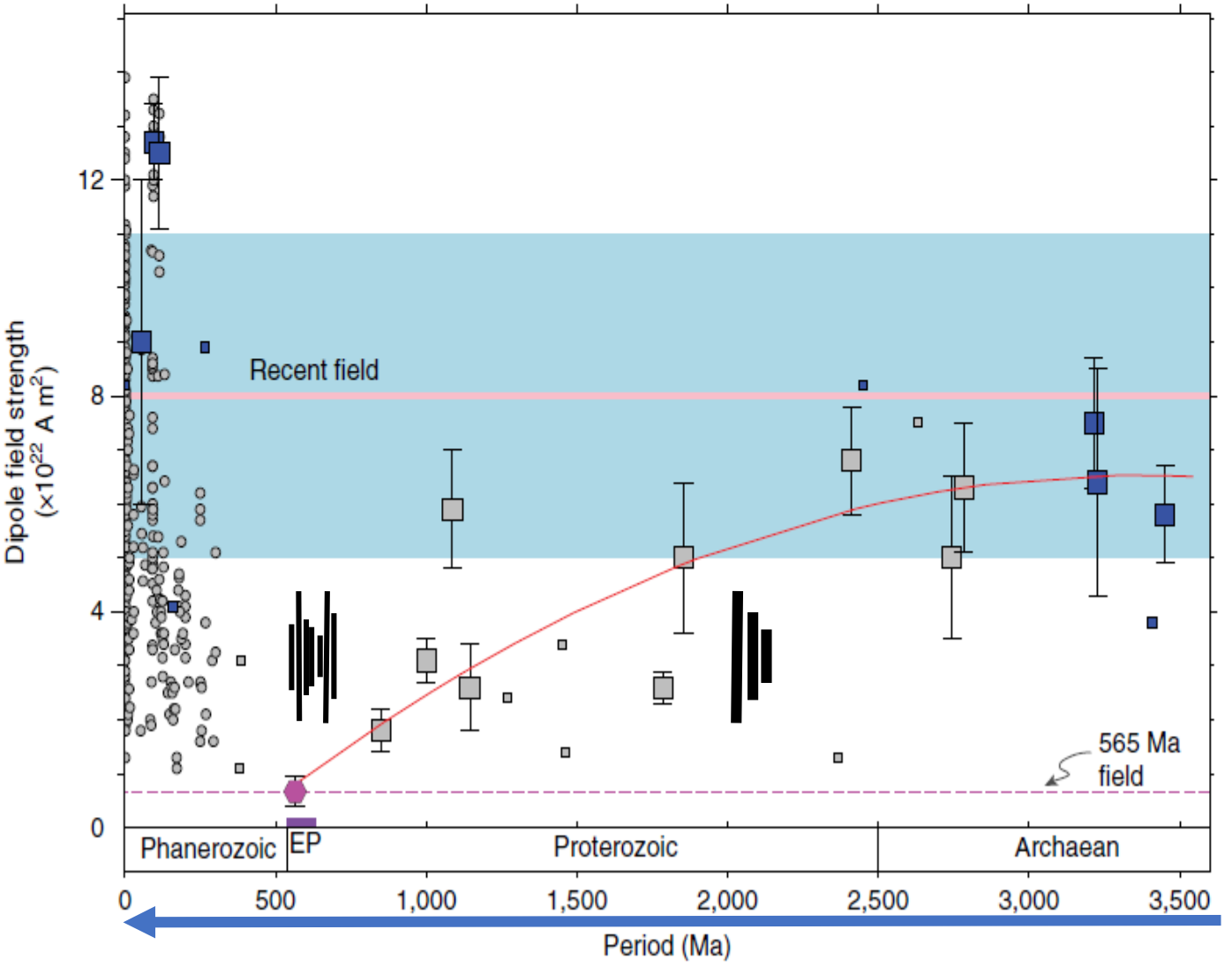
Causes:

- Drawdown of atmospheric CO_2 as a result of carbonatization (i.e. reaction of rocks with carbon dioxide to form carbonates) of eroded Cadomian mountains
- Development of marine photosynthetic organisms
- ?Atmosphere thinning by the solar wind in result of the extremaly weak Earth's magnetic field?

NATURE GEOSCIENCE







Hypothesis:

Earth's weak magnetic field enable solar wind to move atmospheric ions outflow (solar-wind stripping), resulting in atmosphere thining , and greenhouse effect reduction.

Global glaciations

Figure: Bono et al., 2019

Snowball/Flushball Earth #2

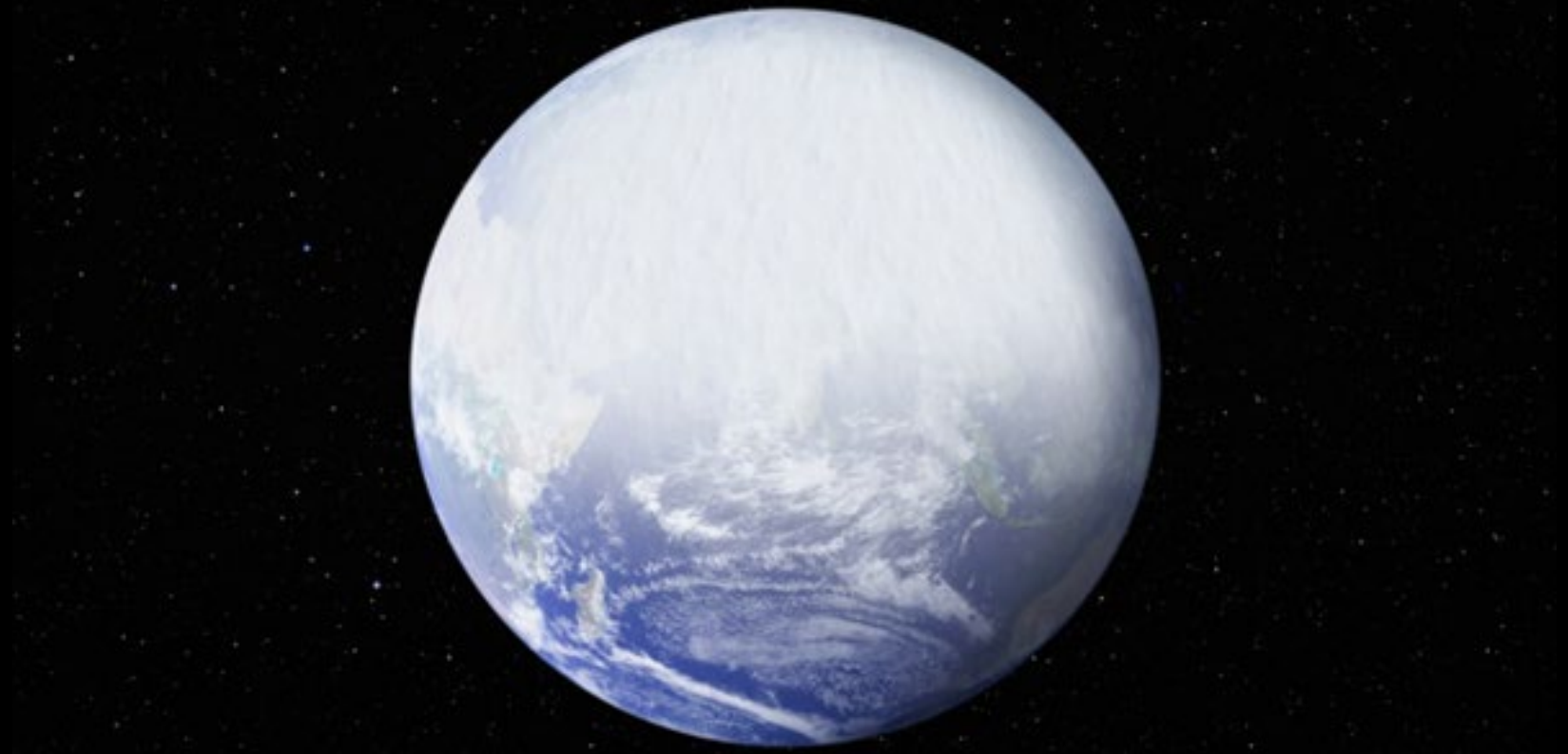
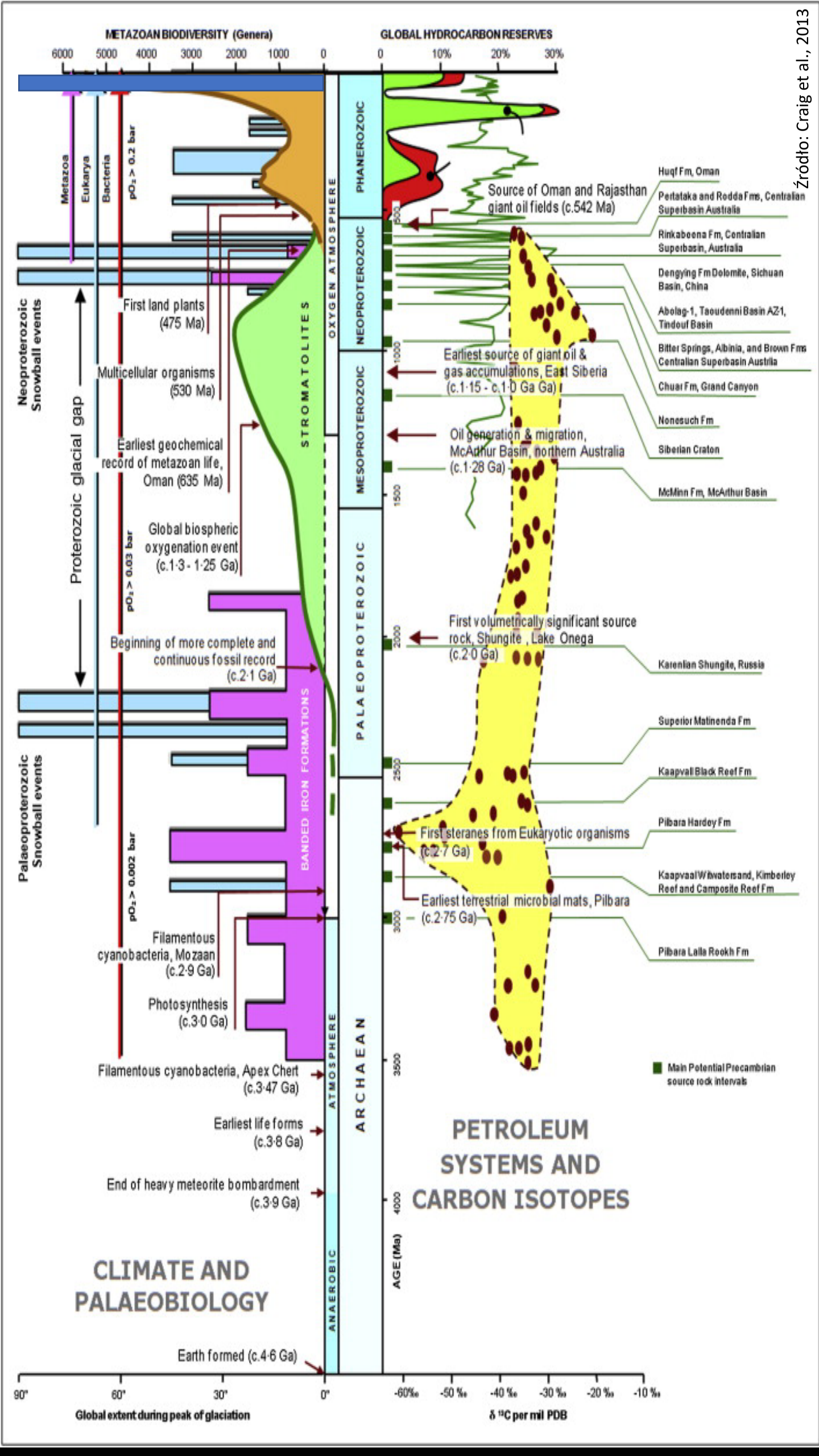
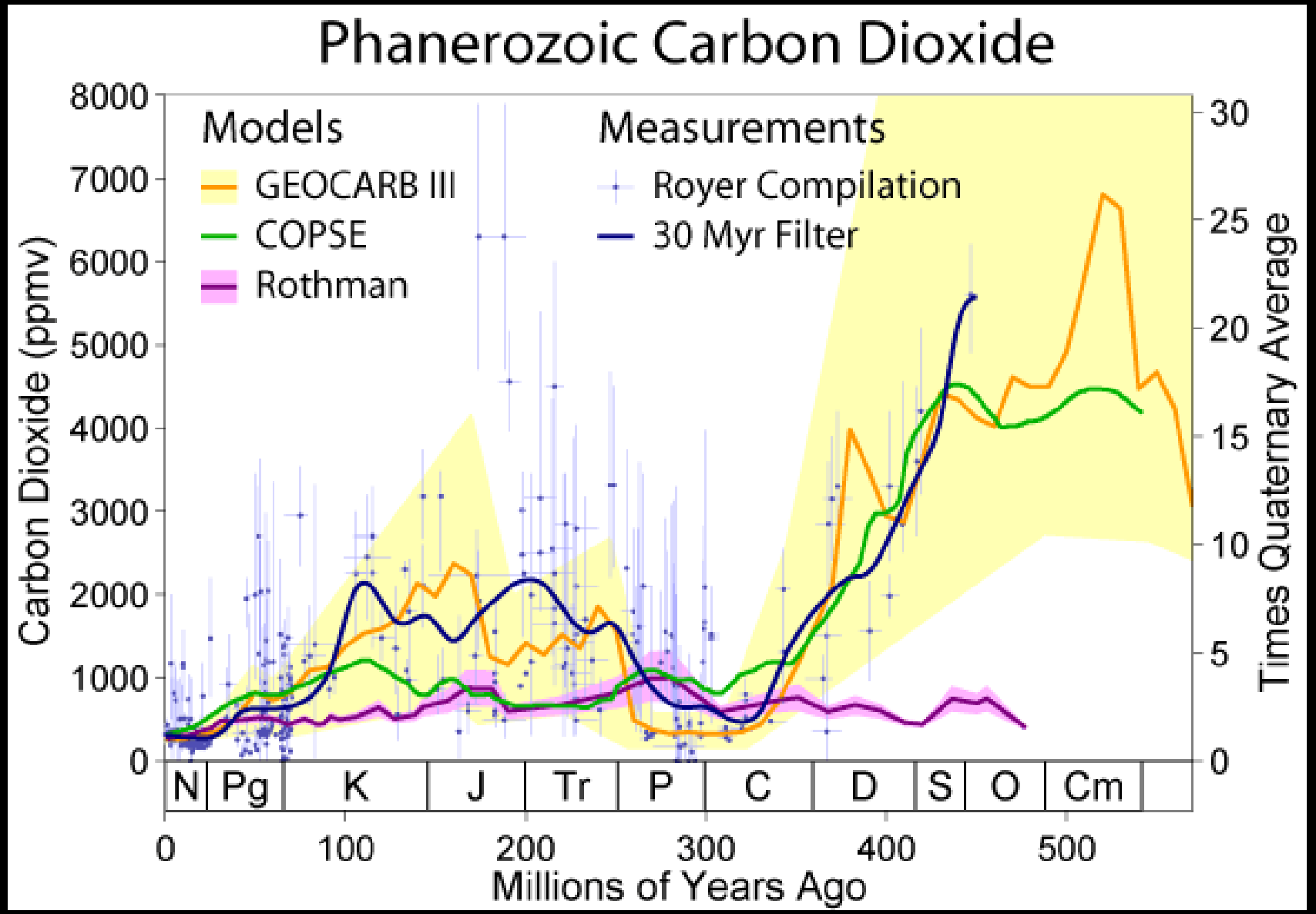


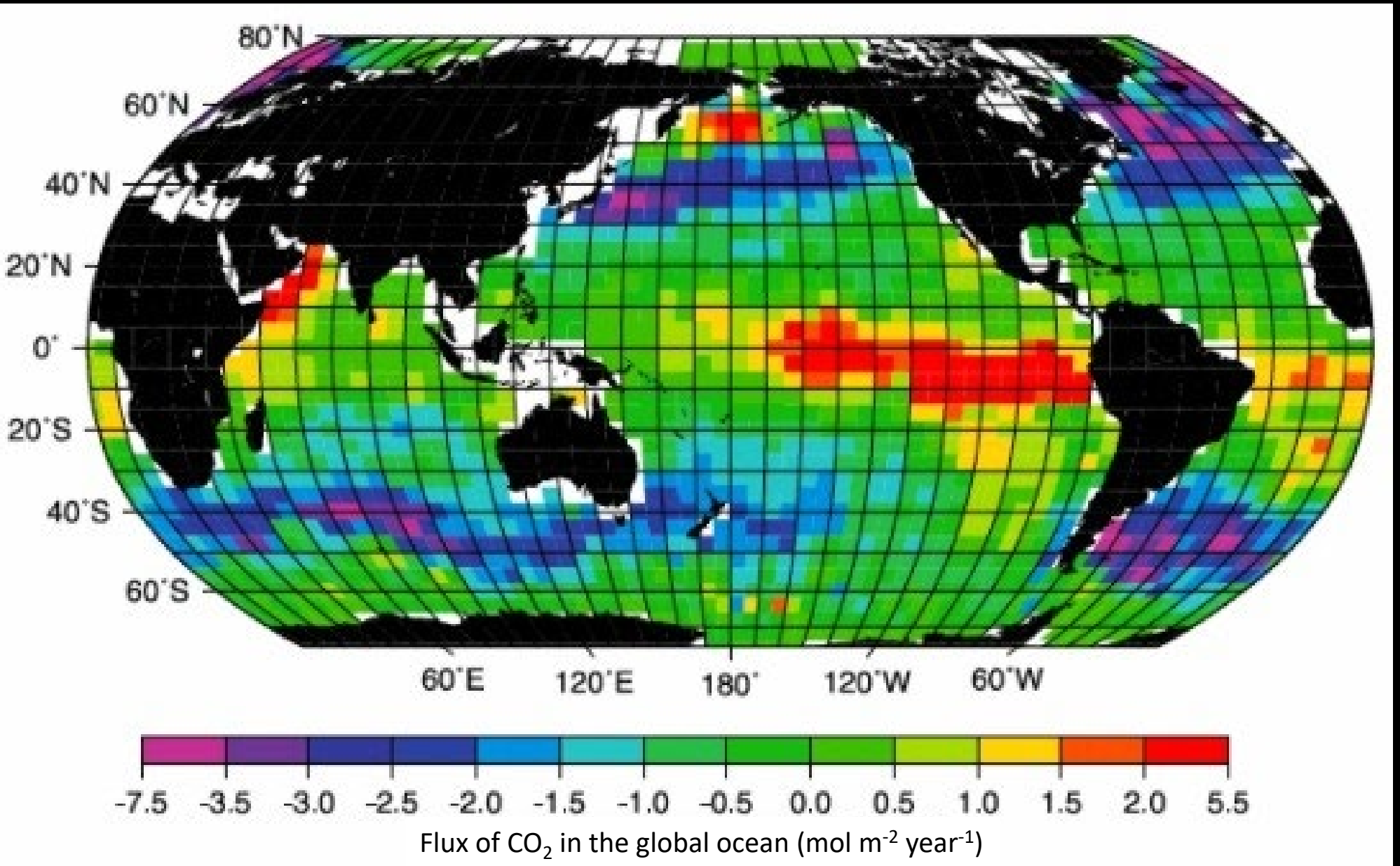
Figure: Muratart/Shuttershock

Bunger Hills, East Antarctica, photo: Adam Nawrot



Źródło: Craig et al., 2013


Phanerozoic Carbon Dioxide
Models
GEOCARB III
COPSE
Rothman
Measurements
Royer Compilation
30 Myr Filter
Carbon Dioxide (ppmv)
Times Quaternary Average
Millions of Years Ago
8000
7000
6000
5000
4000
3000
2000
1000
0
30
25
20
15
10
5
0
N
Pg
K
J
Tr
P
C
D
S
O
Cm
0
100
200
300
400
500



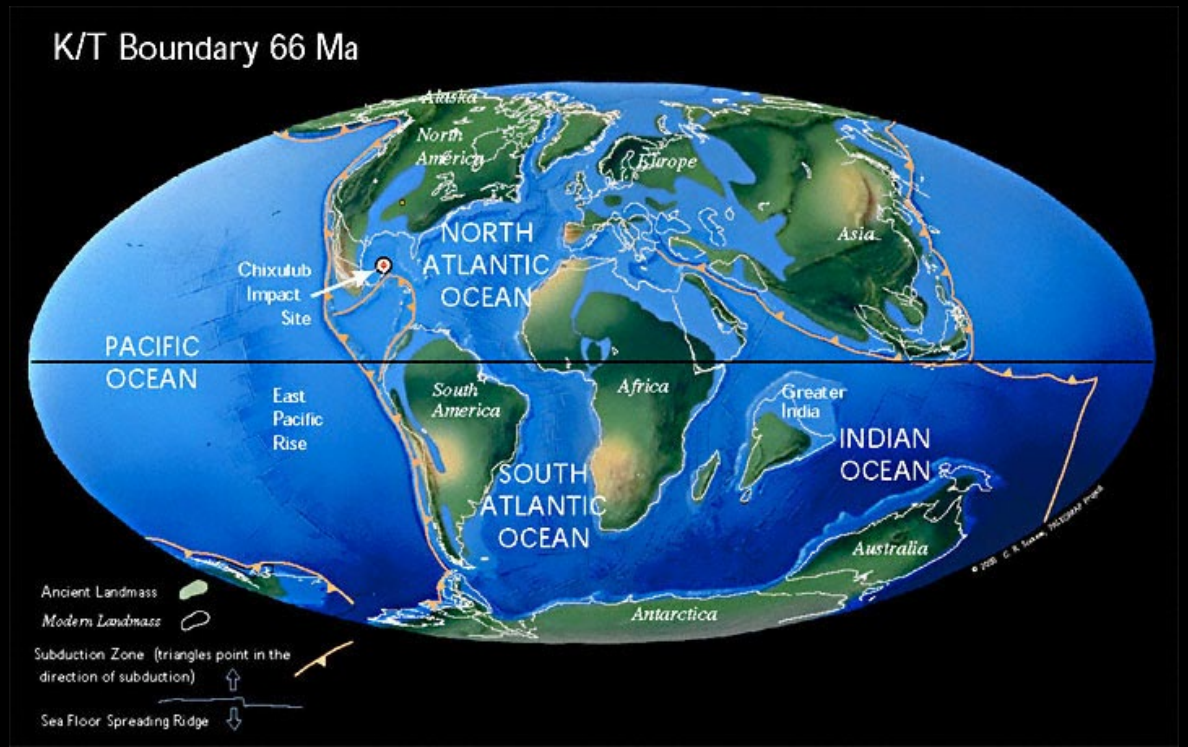
Flux of CO_2 in the global ocean (mol m^{-2} $year^{-1}$)

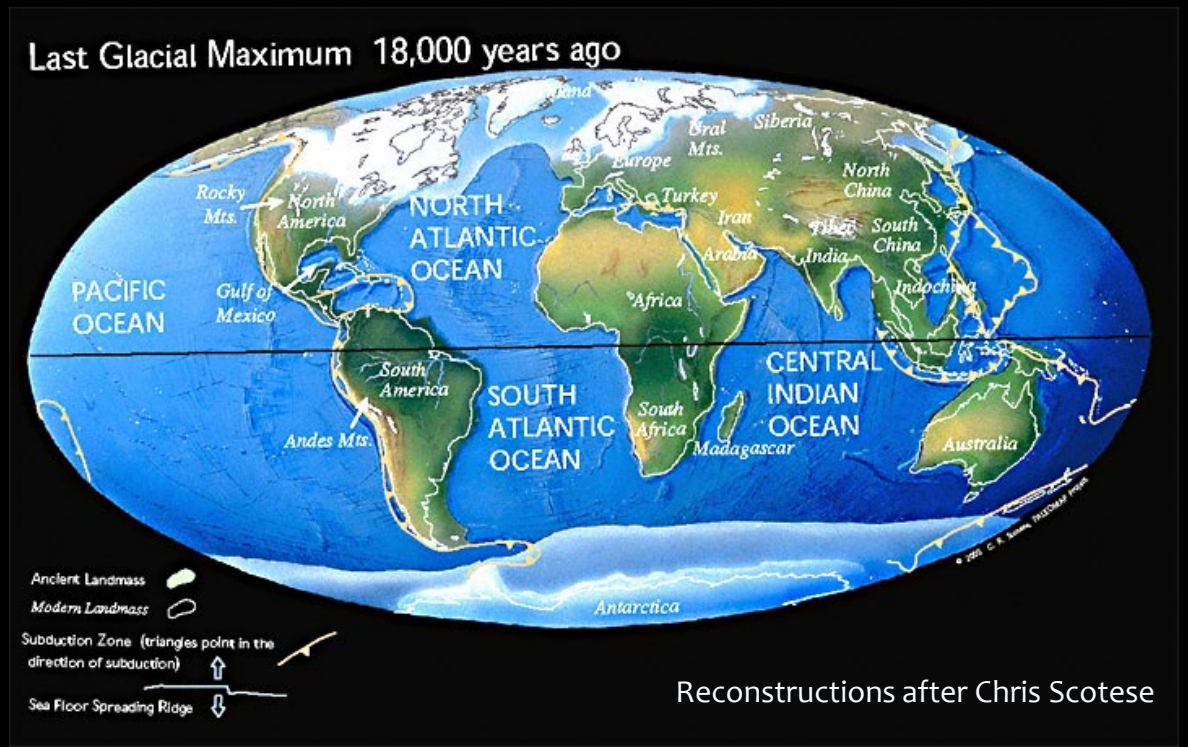
Global ocean acts as a CO_2 buffer, solubility of the gas inversly proportional to the water temperature

Today, total mass of C dissolved in the global ocean is ca. 60x greater than in the atmosphere

Figure from the 4th IPCC report, 2007

Cenozoic Earth's system revolution: from the greenhouse to the icehouse world



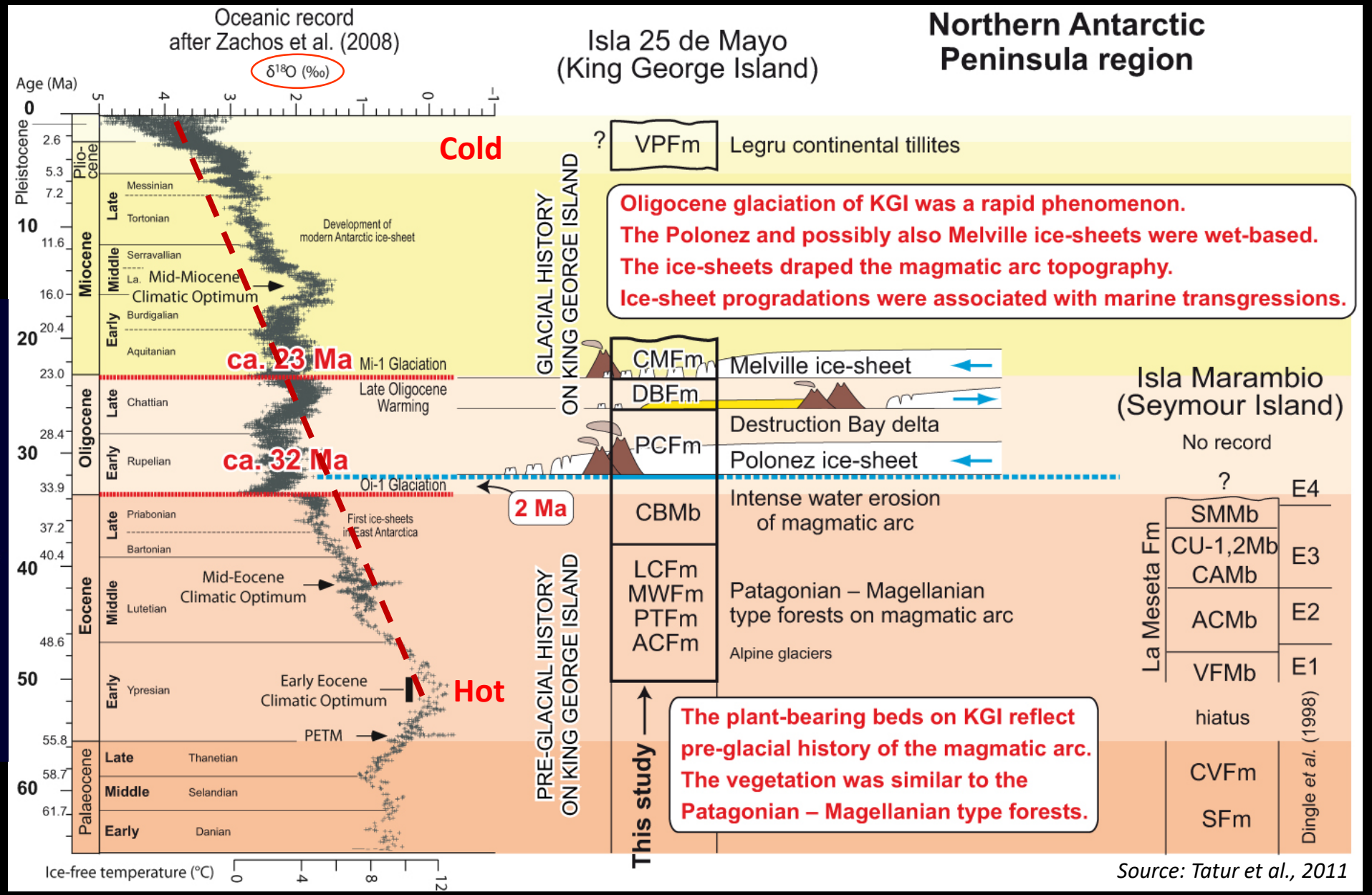


Reconstructions after Chris Scotese

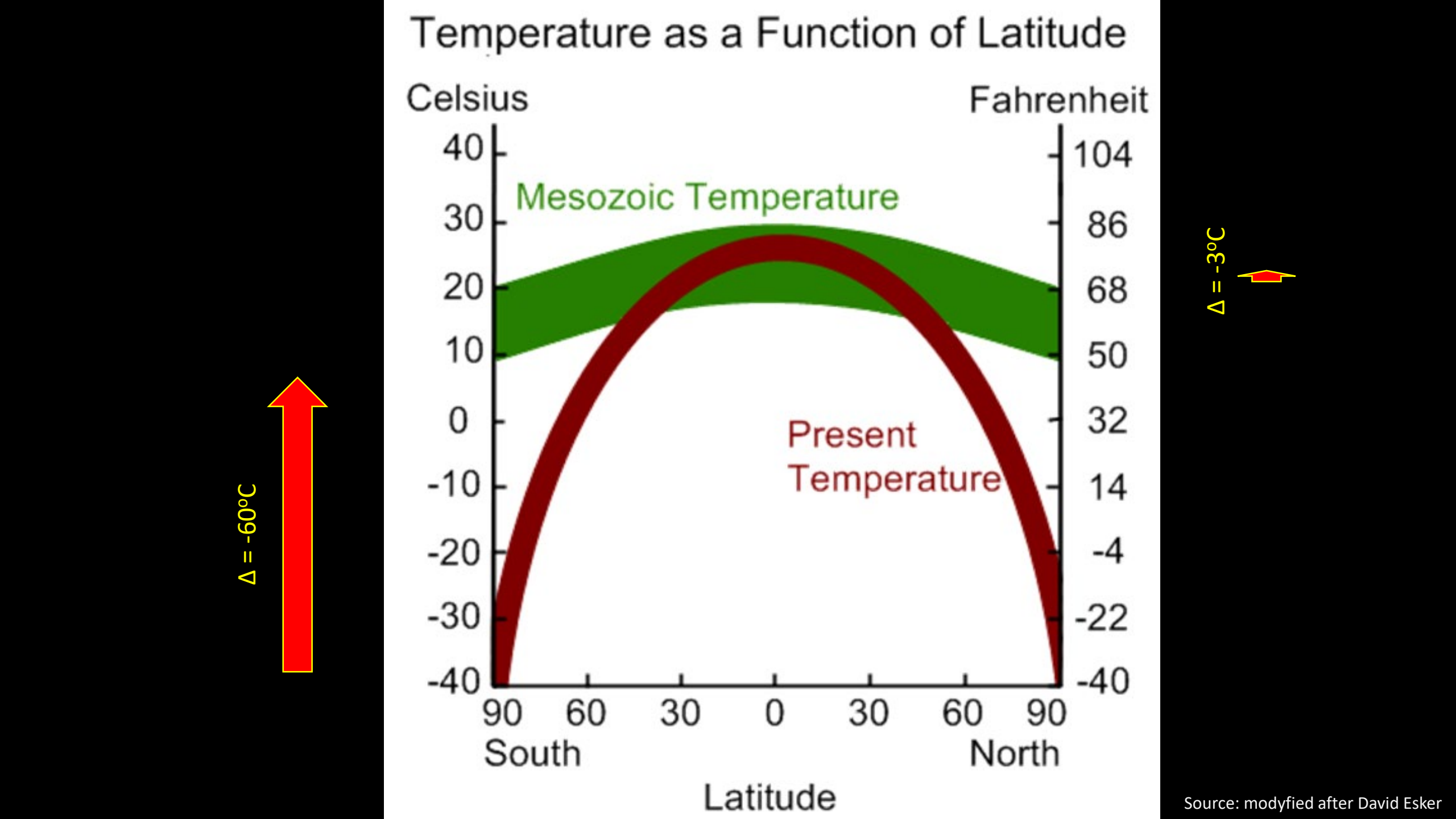
Global cooling #3:
Cenozoic Global Glaciation

- Drawdown of atmospheric CO_2 as a result of weathering of the Alpine orogens
- Extinction of giant herbivores at the end of Mesozoic – land flora development, incl. grass
- Fortunate continental disposition, with the Antartica plate centered at the South pole
- ?Continuous atmosphere thinning (frequent geomagnetic inversions, solar wind activity)?

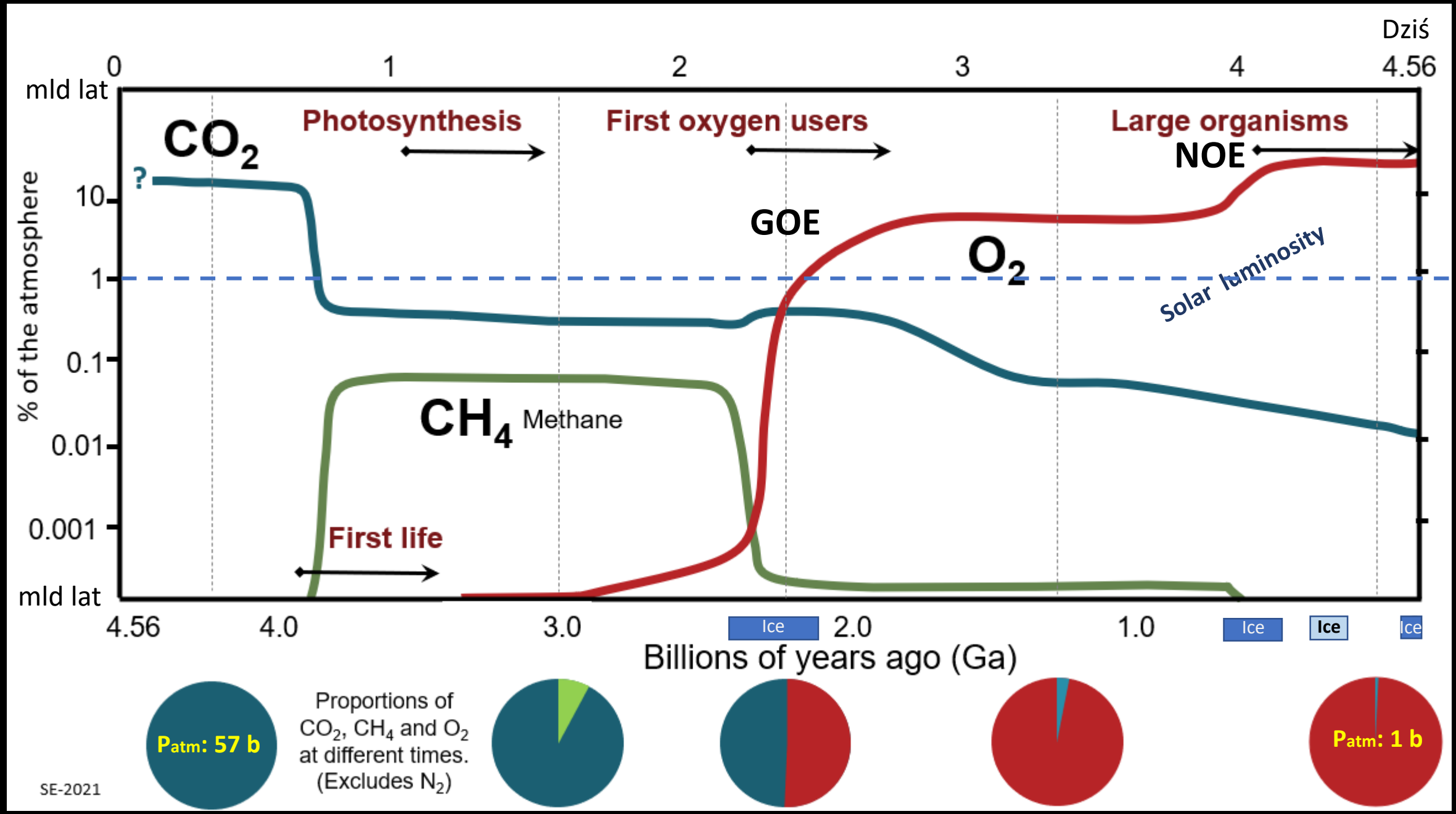
(King George Island, Antarctica)



Source: Tatur et al., 2011



Source: modyfied after David Esker



Modified after lectures by Dr J. Imamura: University of Oregon

NOTE:

although there is almost no CO_2 in the atmosphere today, the Earth didn't frozen totaly because of stronger solar radiation:

NO SNOWNBALL EARTH ANYMORE!

Sun luminosity

First global glaciation

Huronian (2.29-2.25 Ga)

High CO_2 concetration
High-density atmosphere

Present-day global glaciation

Today (0 Ga)

Low CO_2 concetration
Low-density atmosphere

$$RF_{GHG}/RF_{SOL}=const.$$

$$T_{mean\ 4.5\ Ga} \approx 15^{o}\ (\pm 10^{o}\ C)$$

Conclusions:

1. Since the Hadean, the atmosphere density decreased by factor of ca. 50 and changed from unoxic, carbon dioxide-rich to oxygen-rich, and carbon dioxide-poor atmosphere

2. Huronian, Neoprecambrian and Cenozoic global glaciations are combined effect of:

- continuous CO_2 drawndown due to inreasing mass of photosynthetic organisms
- feedbacks and interactions within the volatile crust, as to carbonate-silicate geochemical cycle, cooling of the global ocean, variable pattern of the continental disposition, all leading to the global temperature decrease

3. Cenozoic global glaciation is the last in the Earth's history

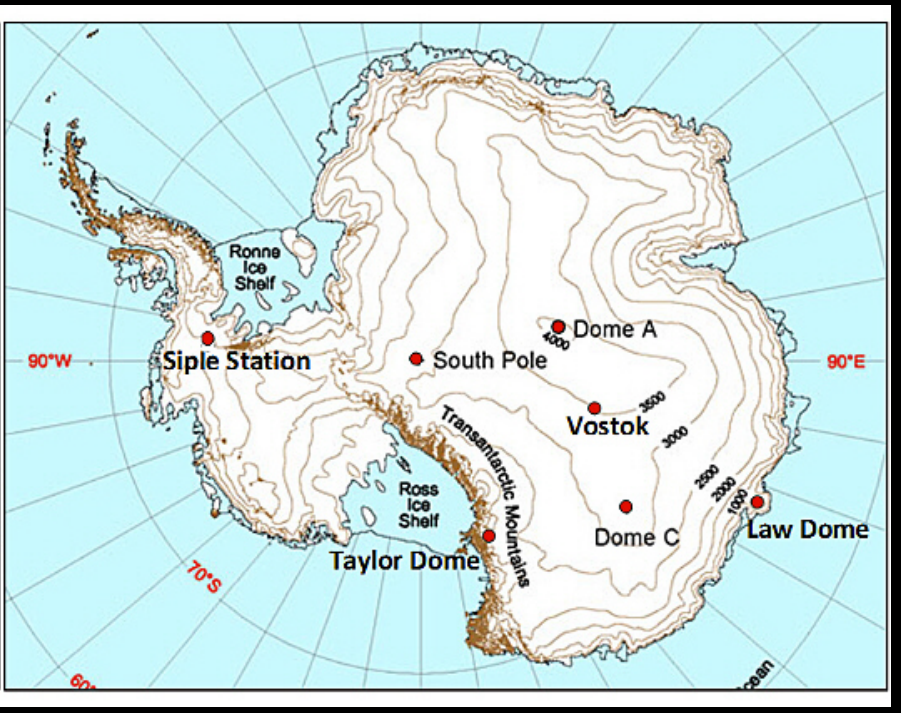
Thank you!

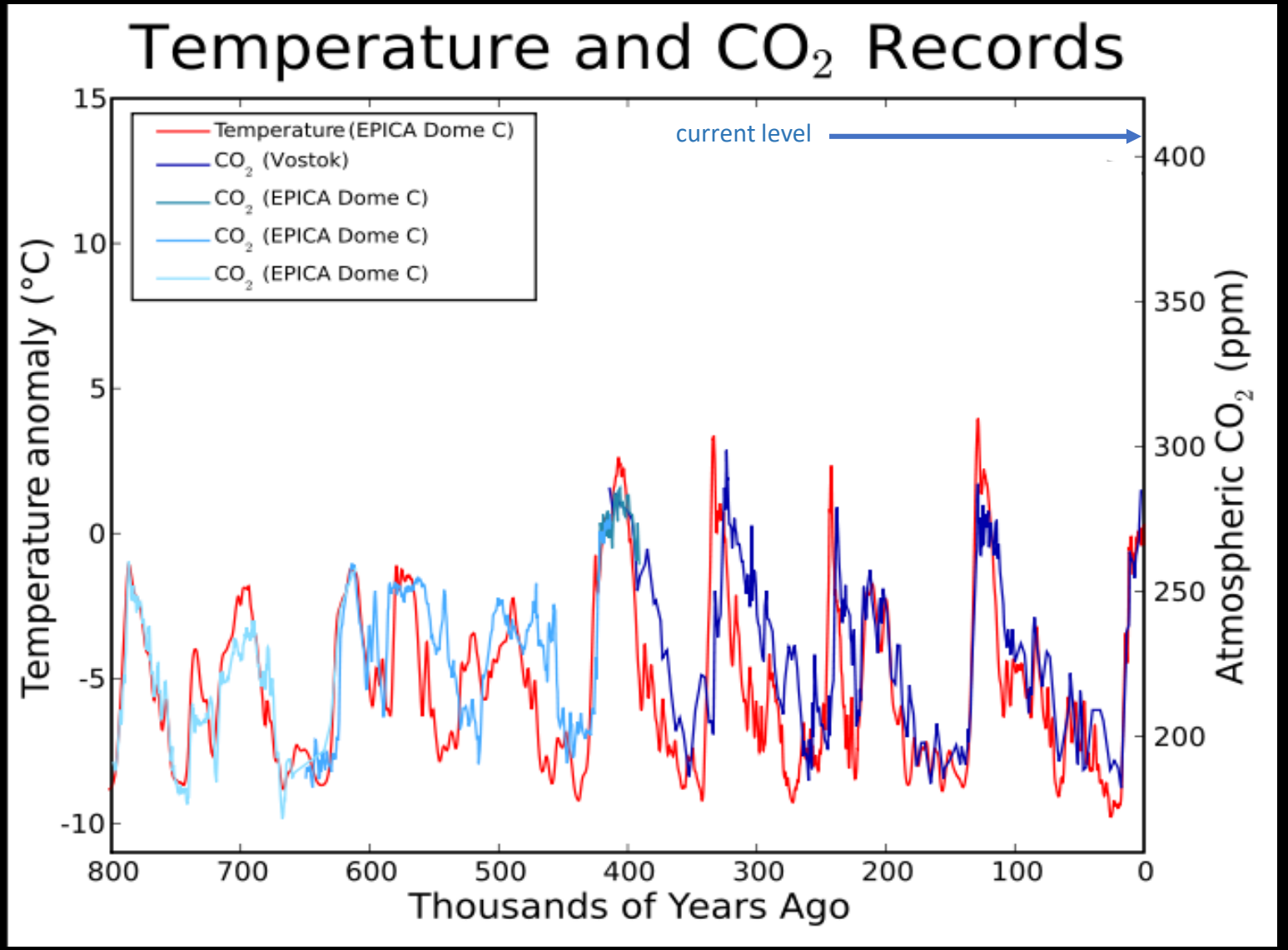
Reasons for CO_2 concentration increase in Mezosoic:

1. Carbon dioxide is emitted from the Earth mantle through subaerial volcanism, in the spreading zones and ridges on the ocean floor, and from magmatic plumes and hot spots.

Left photo:
Large Igneous Provinces (LIPs): lava bluffs & basalt columns, Columbia River Basal Group, LIP

Source: Wikipedia, public domain

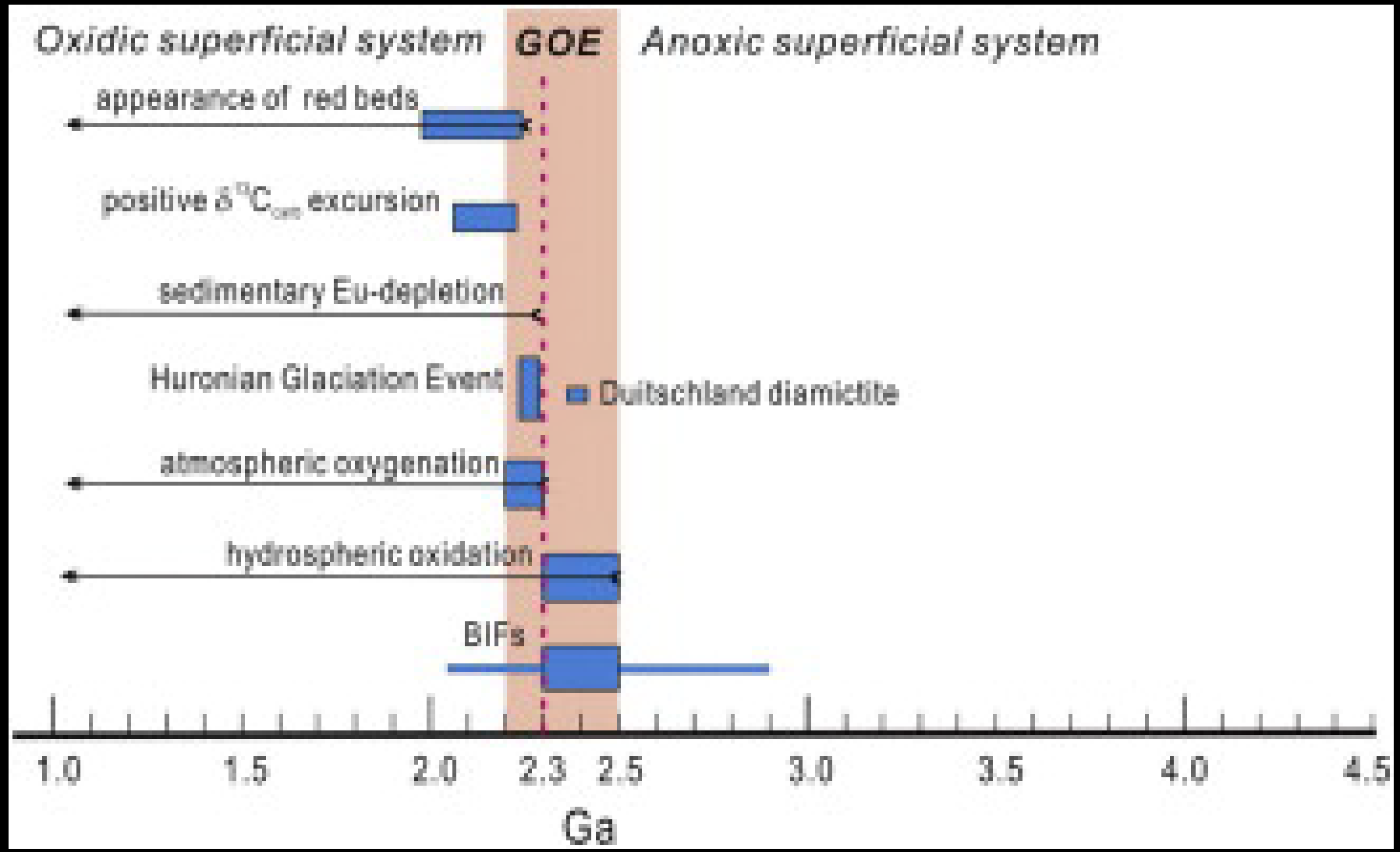




sources: CDIAC, Wikipedia


N
Latest Volcanic Deposit(s)
Impact Crater
Foliation
Relict Glacier
Post-Glacial Regional Volcanic Deposit(s)
Thrust-Moraine Bands
Tic-Tac-Toe Crevasses
Splaying Crevasses
Thrust Planes
Rootless Cones
Marginal or Splaying Crevasses
1 km

Biogeochemical oxygenic photosynthesis, the Great Oxidation Event (GOE)

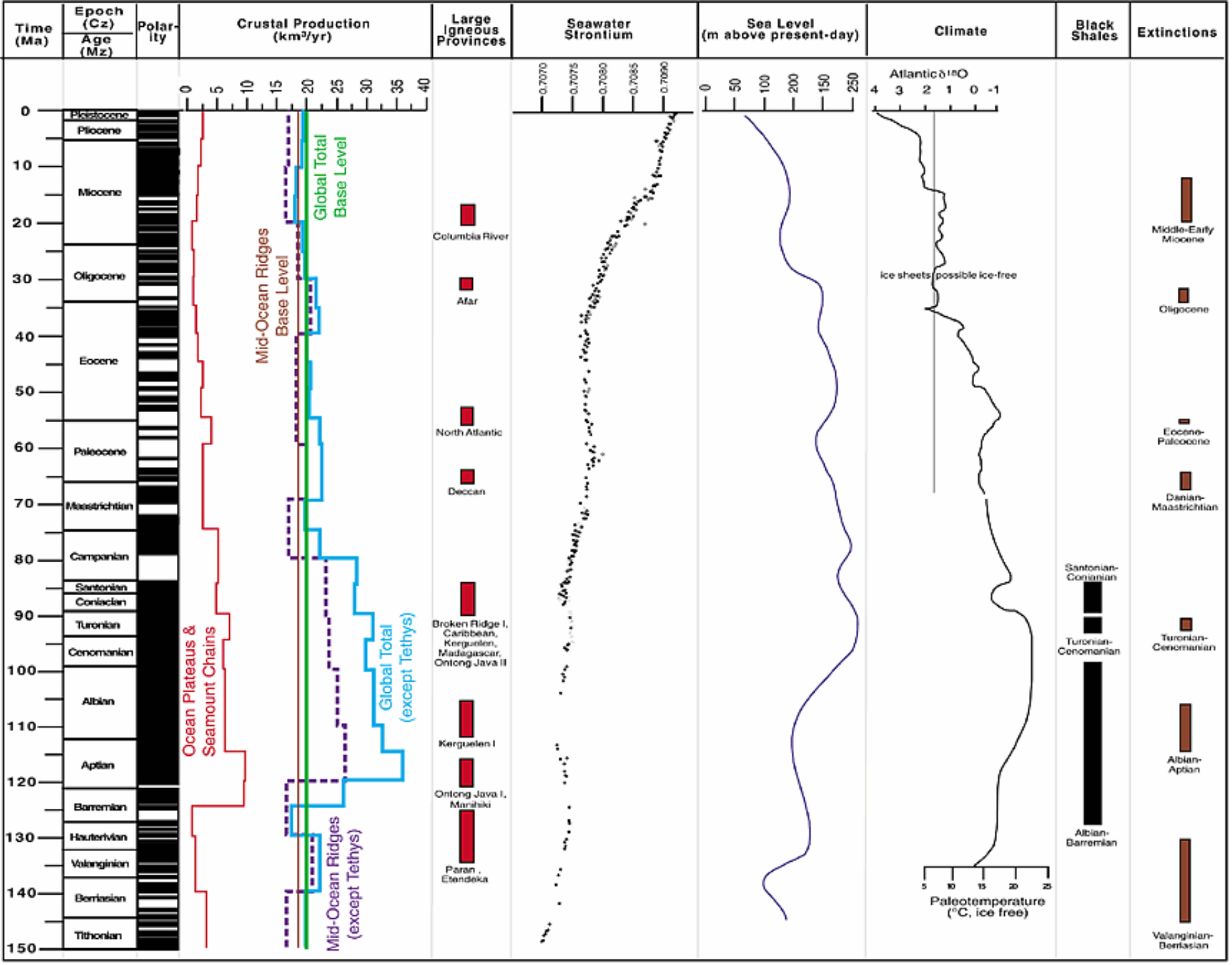


Tan & Chen, Gescience Frontiers, 2013

źródło: australiaforeveryone.com.au

The lack of effective herbivores enabled the extremely lush development of vegetation, which is witnessed today by the Carboniferous coal beds.

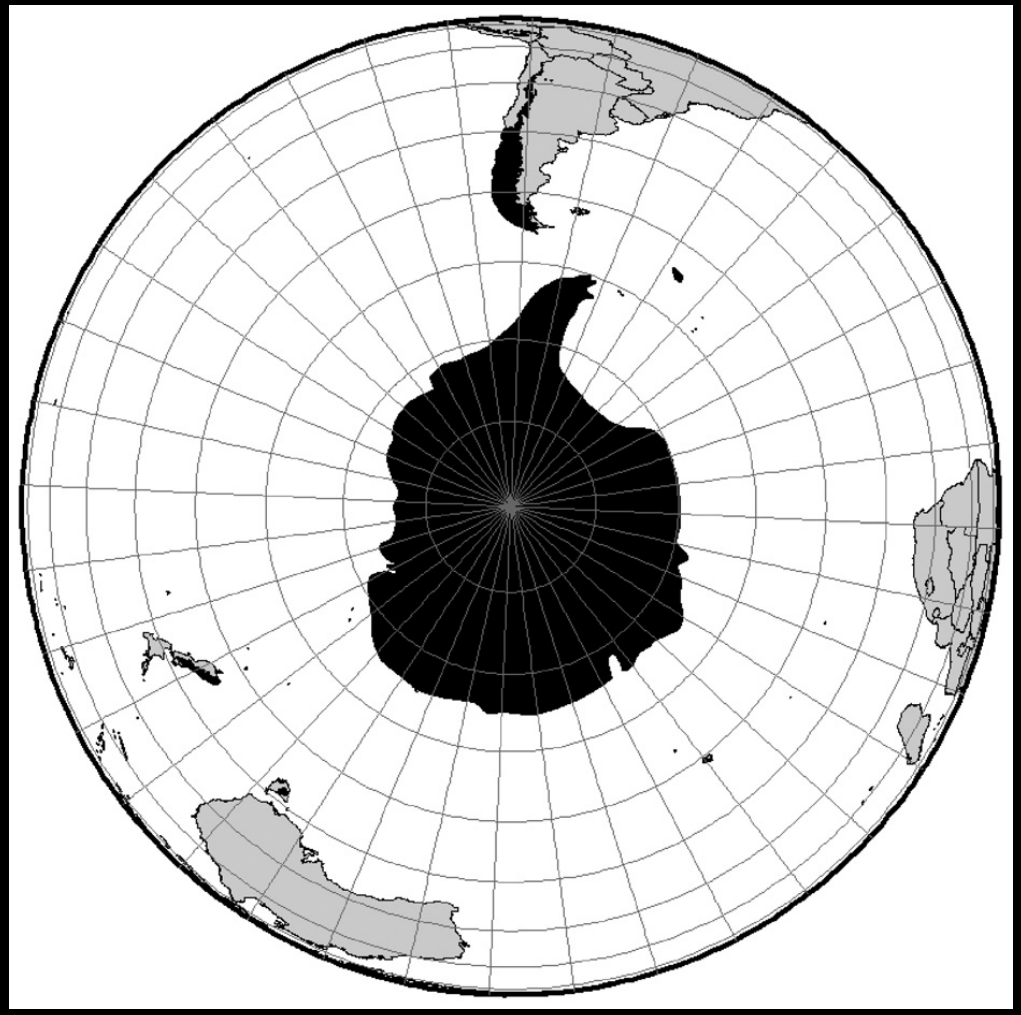
Photosynthesis and carbonatization of the Variscan orogen depleted the atmosphere of CO_2 near to zero.



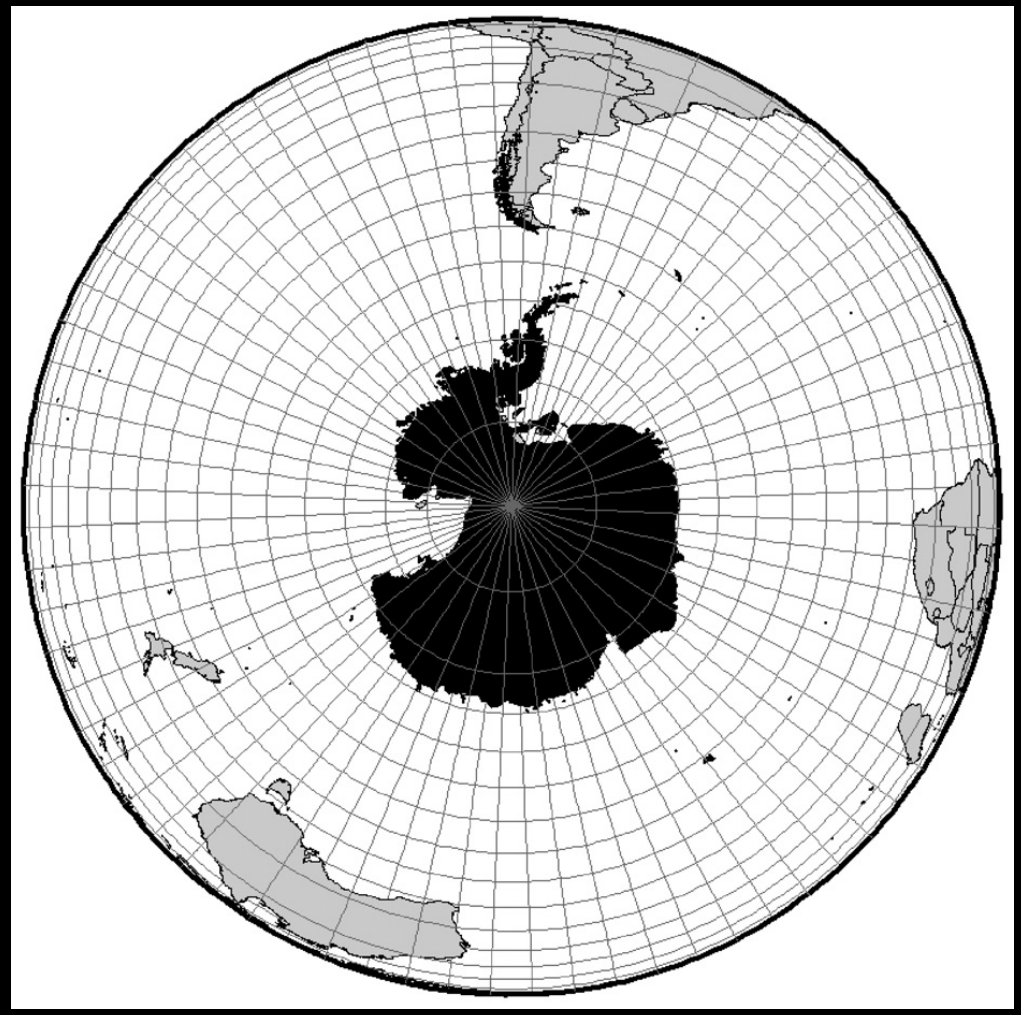
Enigma of Mezosoic increase of CO_2 concentration: Large Ingneous Provinces (LIPs)

After: Millard F. Coffin

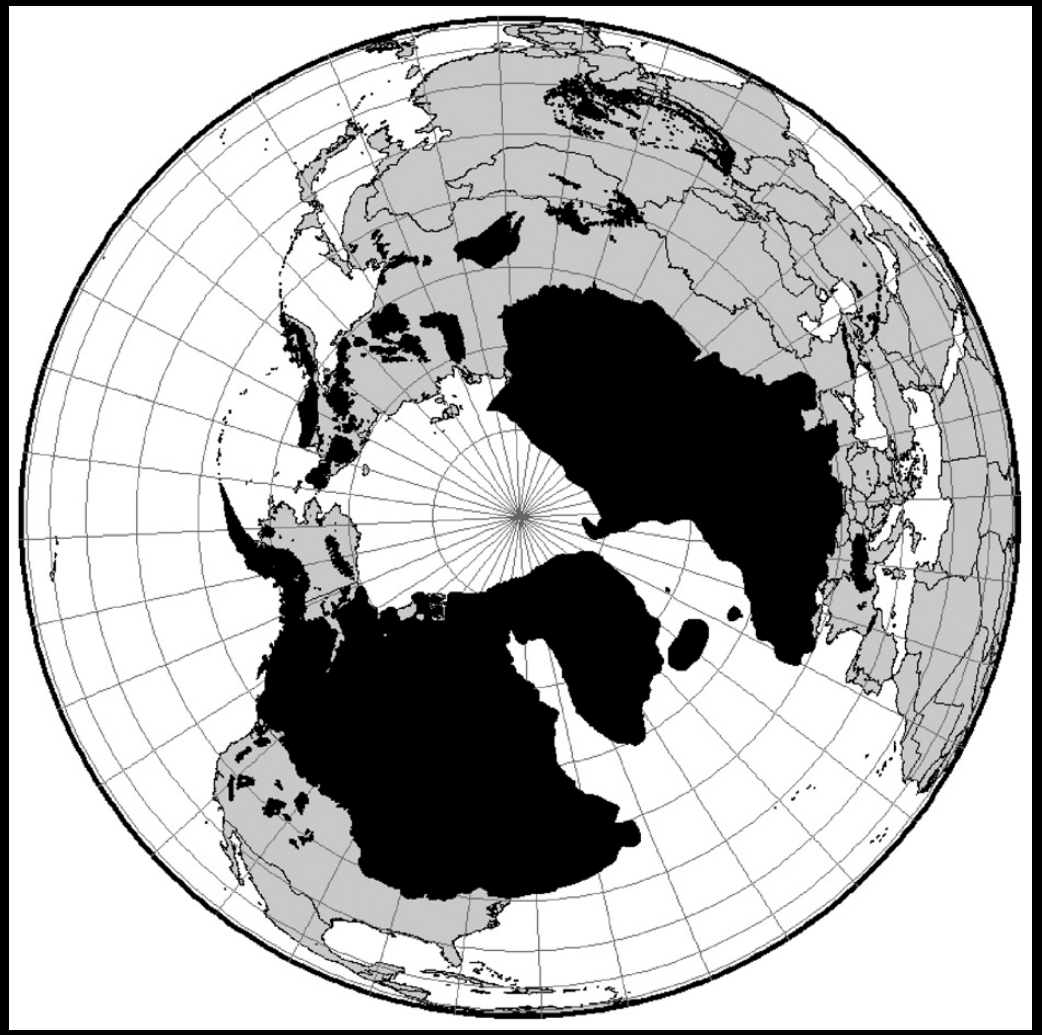
Last Glaciation Maximum 18k ago



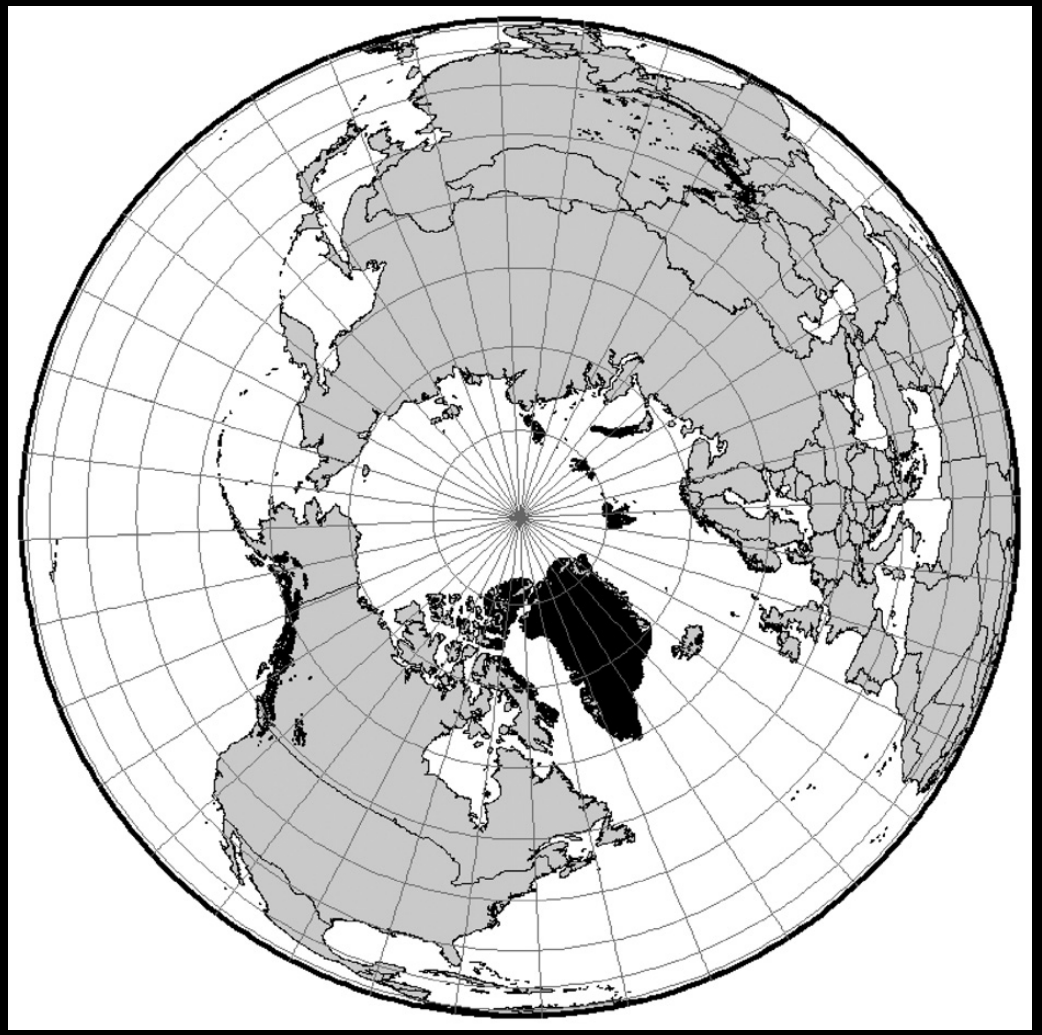
Today



Last Glaciation Maximum 18k ago



Today



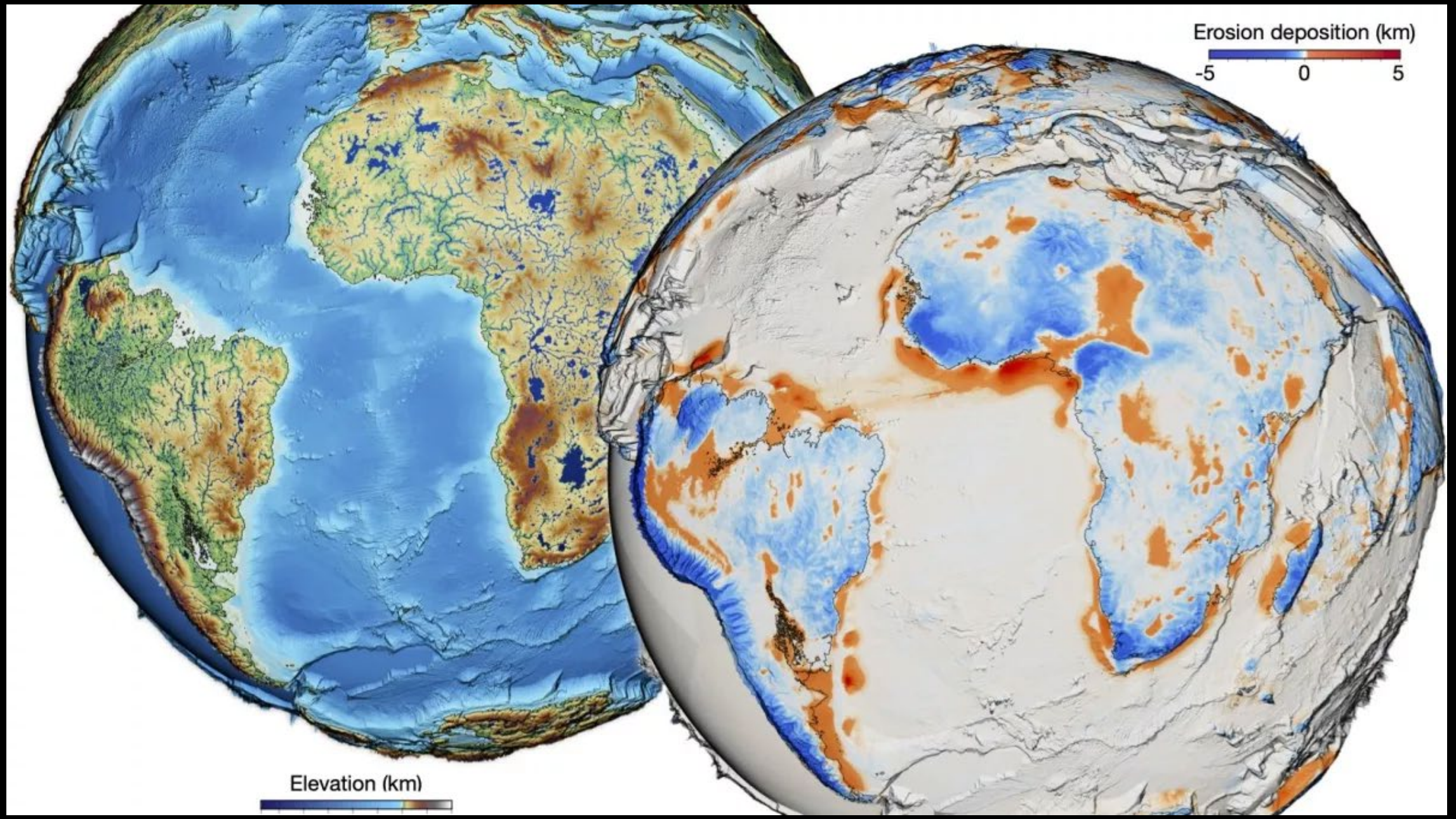
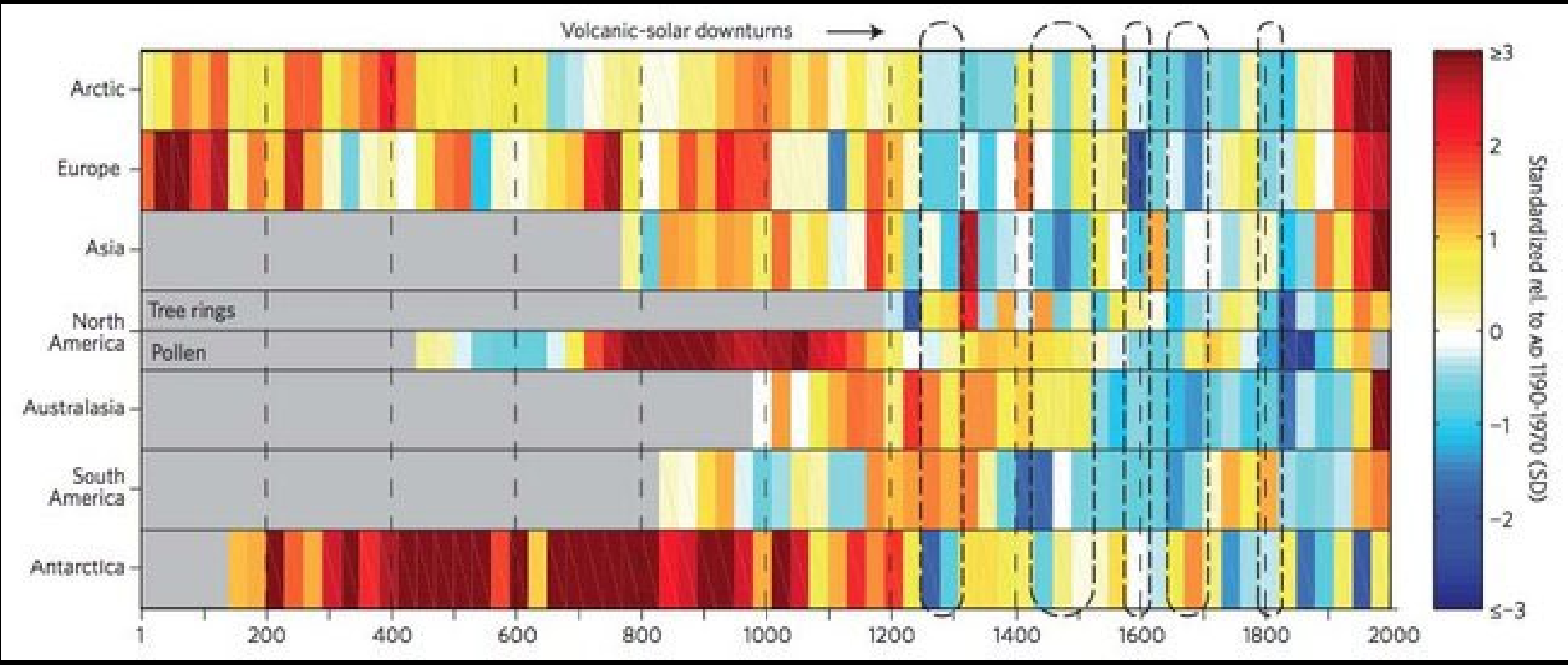


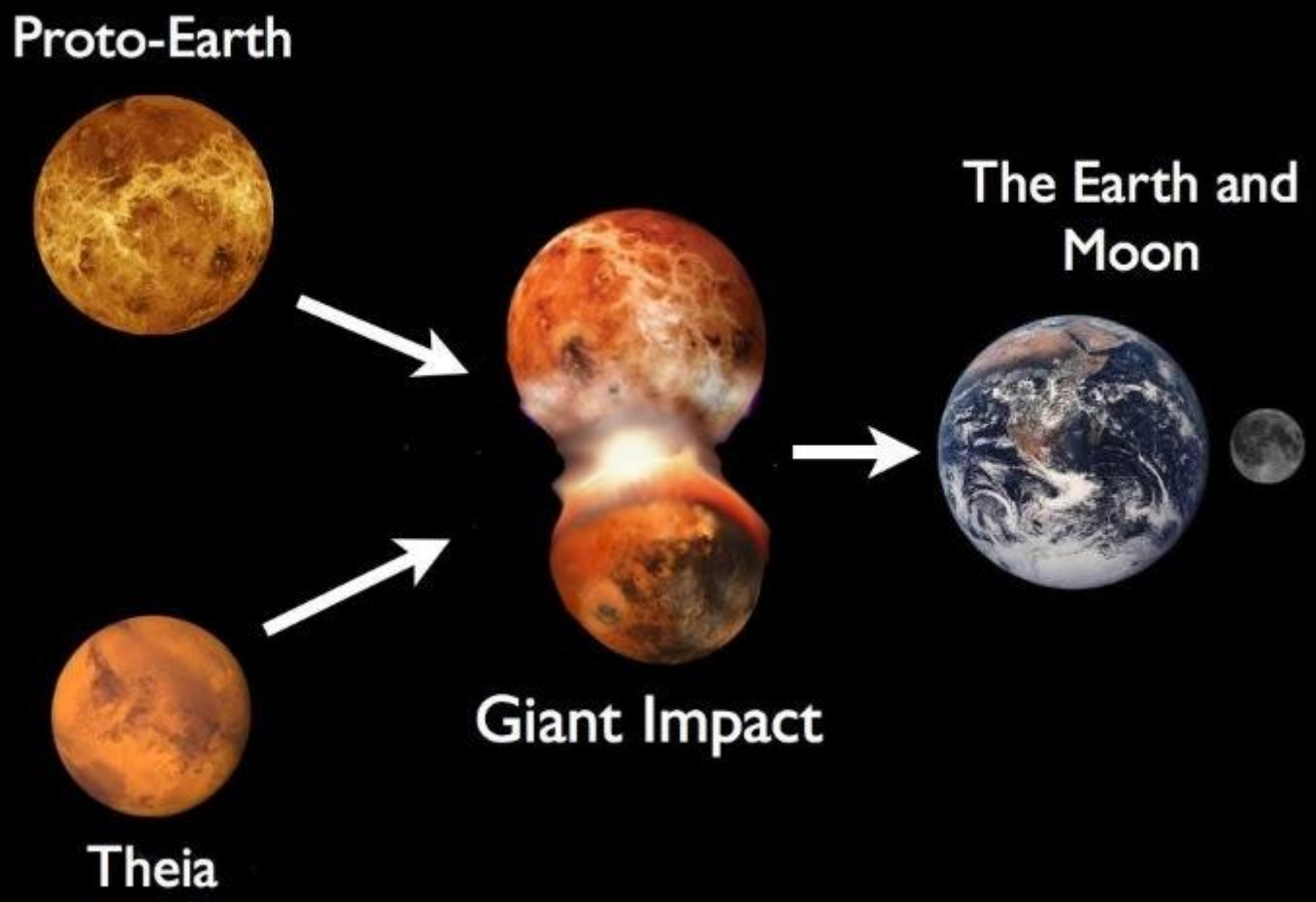
Image credit: Tristan Salles, University of Sydney

Bubbles of the ancien atmosphere in the ice cores of Antarctica are a source of knowledge on the CO_2 concentration

$^{18}O/^{16}O$ studies of ice points to a global paleotemperature



Credit: Nature / Kaufman et al.

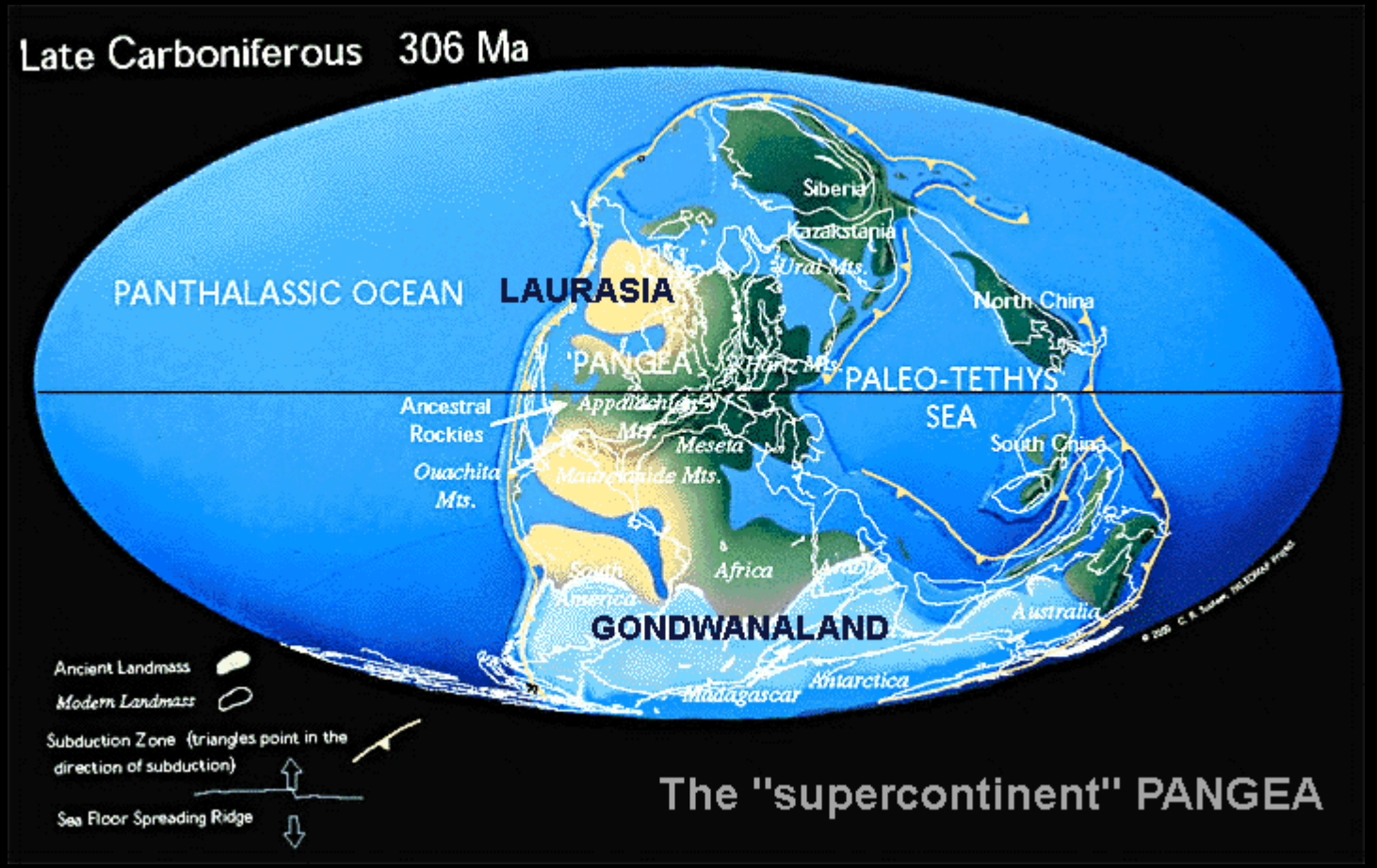


https://palereddot.org/pl/category/expert-insights/

Global cooling #3
(Carboniferous, 350 -260 Ma ago)

The lack of effective herbivores enabled the extremely lush development of vegetation, which is witnessed today by the Carboniferous coal beds.

Photosynthesis and carbonatization of the Variscan orogen depleted the atmosphere almost to zero of CO_2.

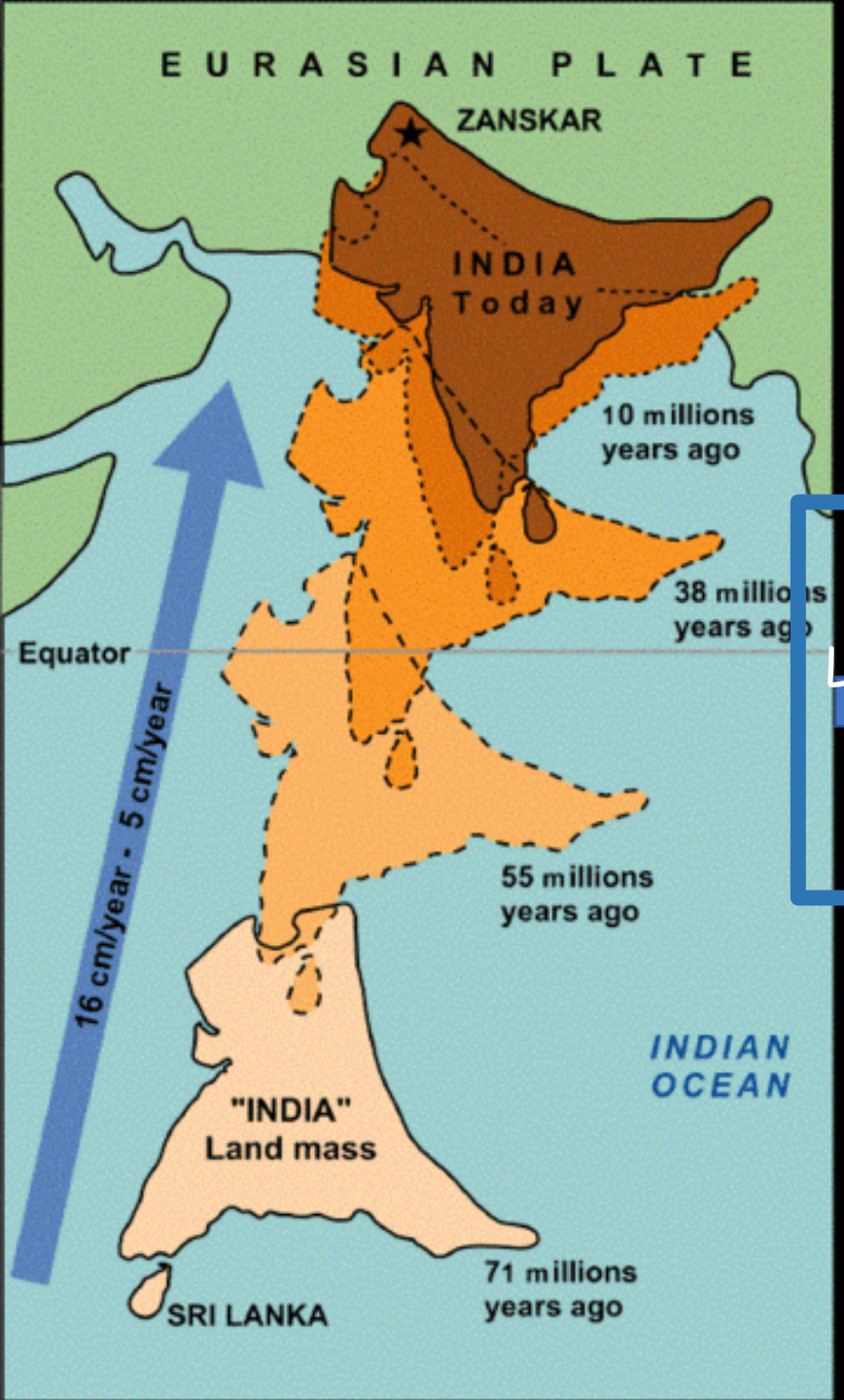


Reconstruction by Chris Scotese

Huronian tilites

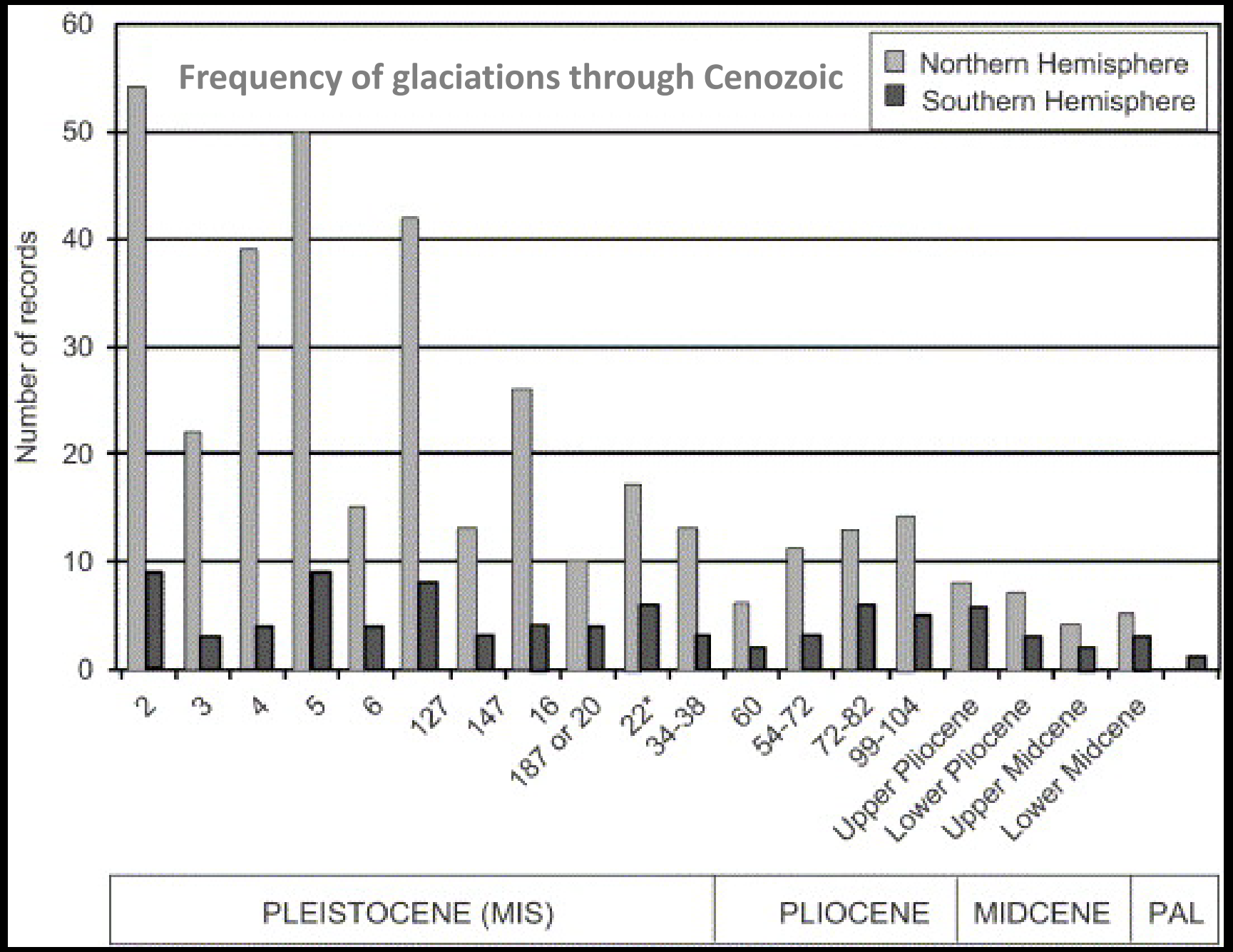
Pieces of rocks in a clay matrics (diamictites):
fossil evidence of glaciations

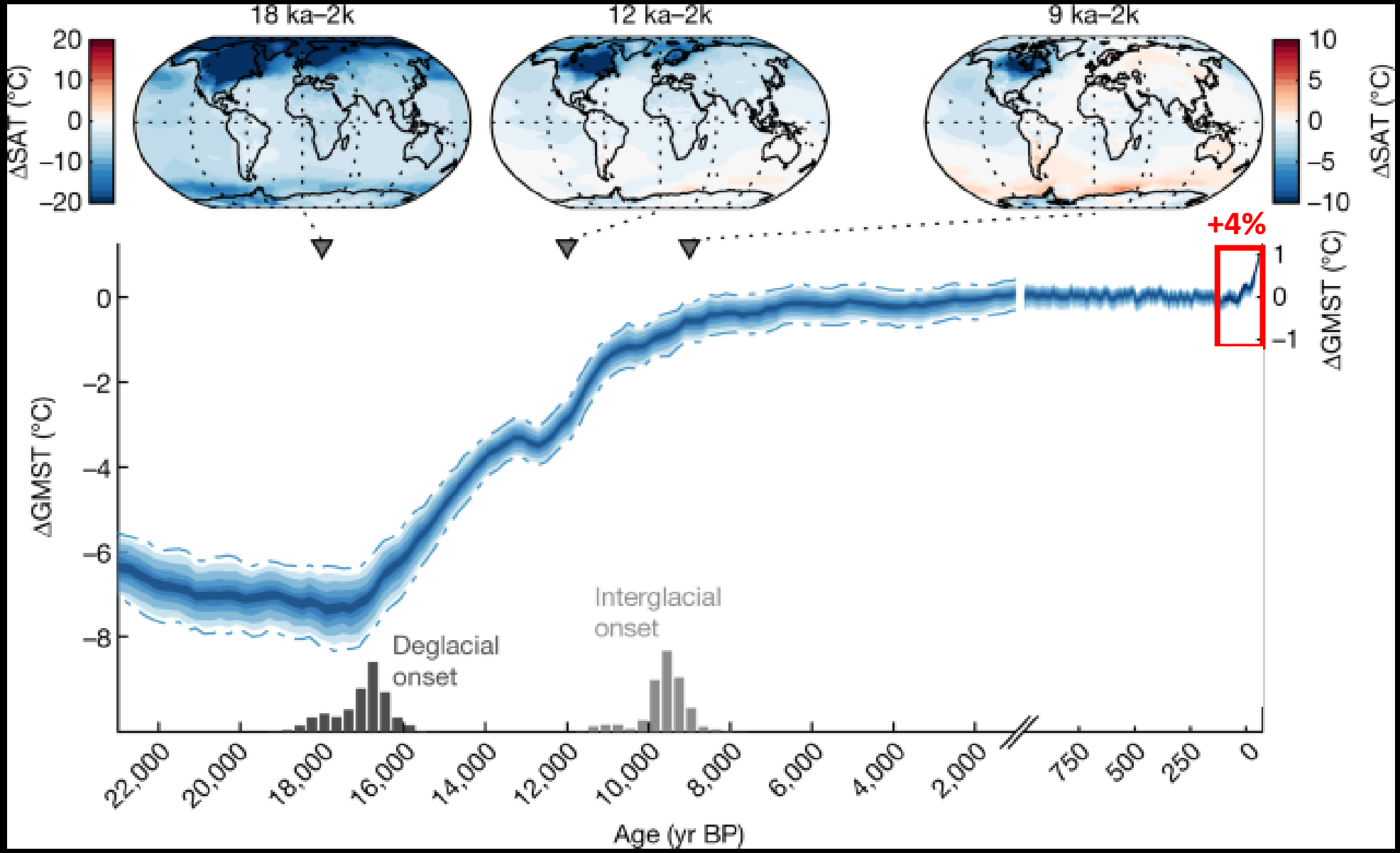
photos: Wikipedia



The 4th global glaciation
Cenozoic 50-0 Ma

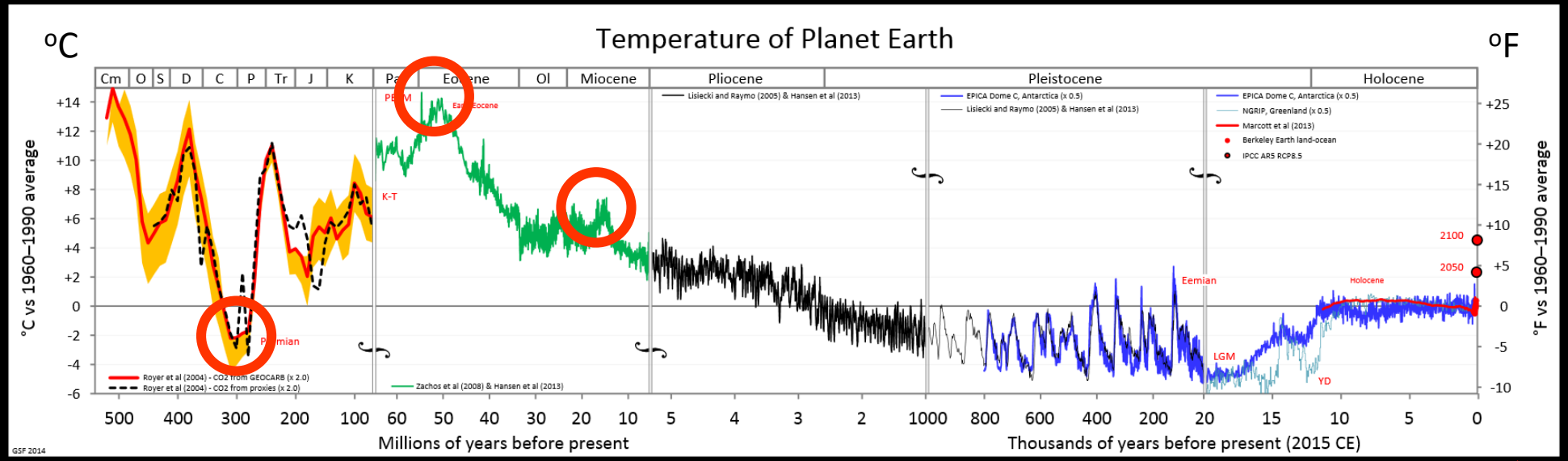
Alpine orogeny (carbonatization)
No large herbivores after dinosaurs extintion (plants development)
Land vegetation (CO_2 assymilation and sequestration), decrease of CO_2 concentration
Cooling, beginning of Antarctica icecup development
Feedback: cooler ocean – higher CO_2 dissolution

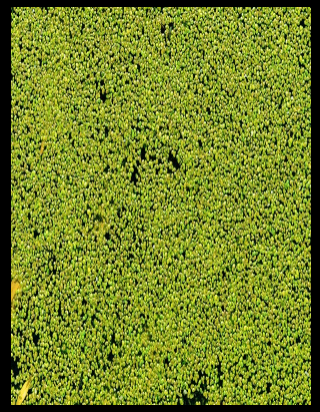

Frequency of glaciations through Cenozoic
Northern Hemisphere
Southern Hemisphere
Number of records
60
50
40
30
20
10
0
2
3
4
5
6
127
147
16
187 or 20
22*
34-38
60
54-72
72-82
99-104
Upper Pliocene
Lower Pliocene
Upper Midcene
Lower Midcene
PLEISTOCENE (MIS)
PLIOCENE
MIDCENE
PAL
2,58 Ma
5,33 Ma
23,03 Ma

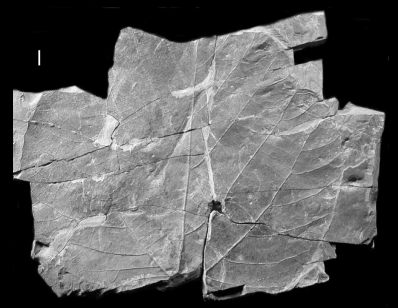


źródło: Nature, Osman et al., 2021

Temperature on the Earth's Surface (based on $^{18}O/^{16}O$)

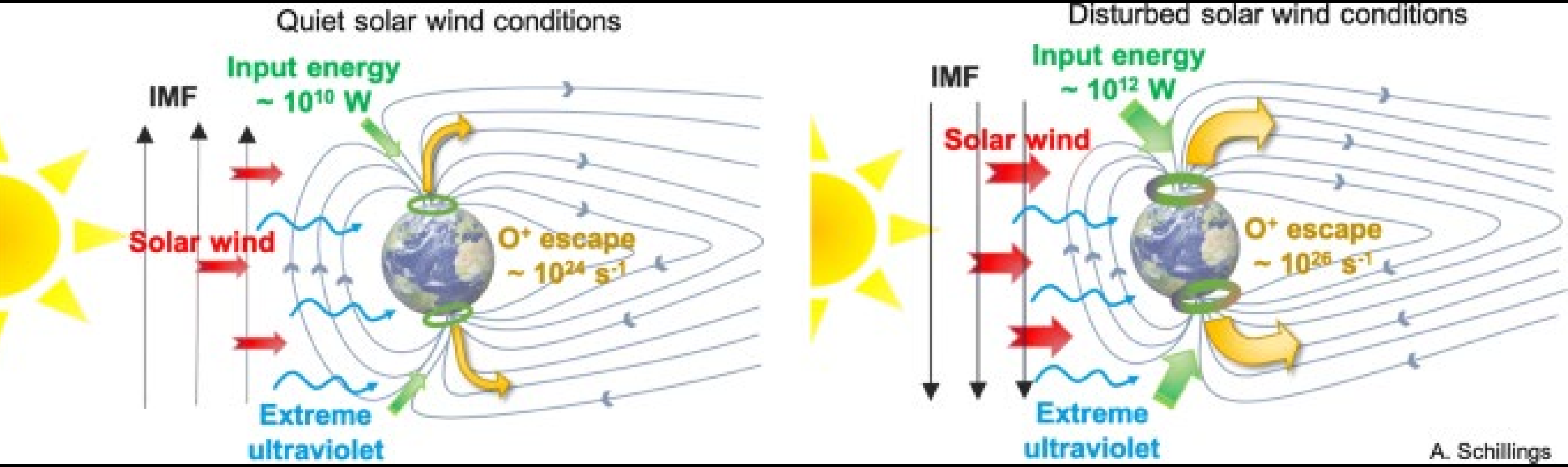


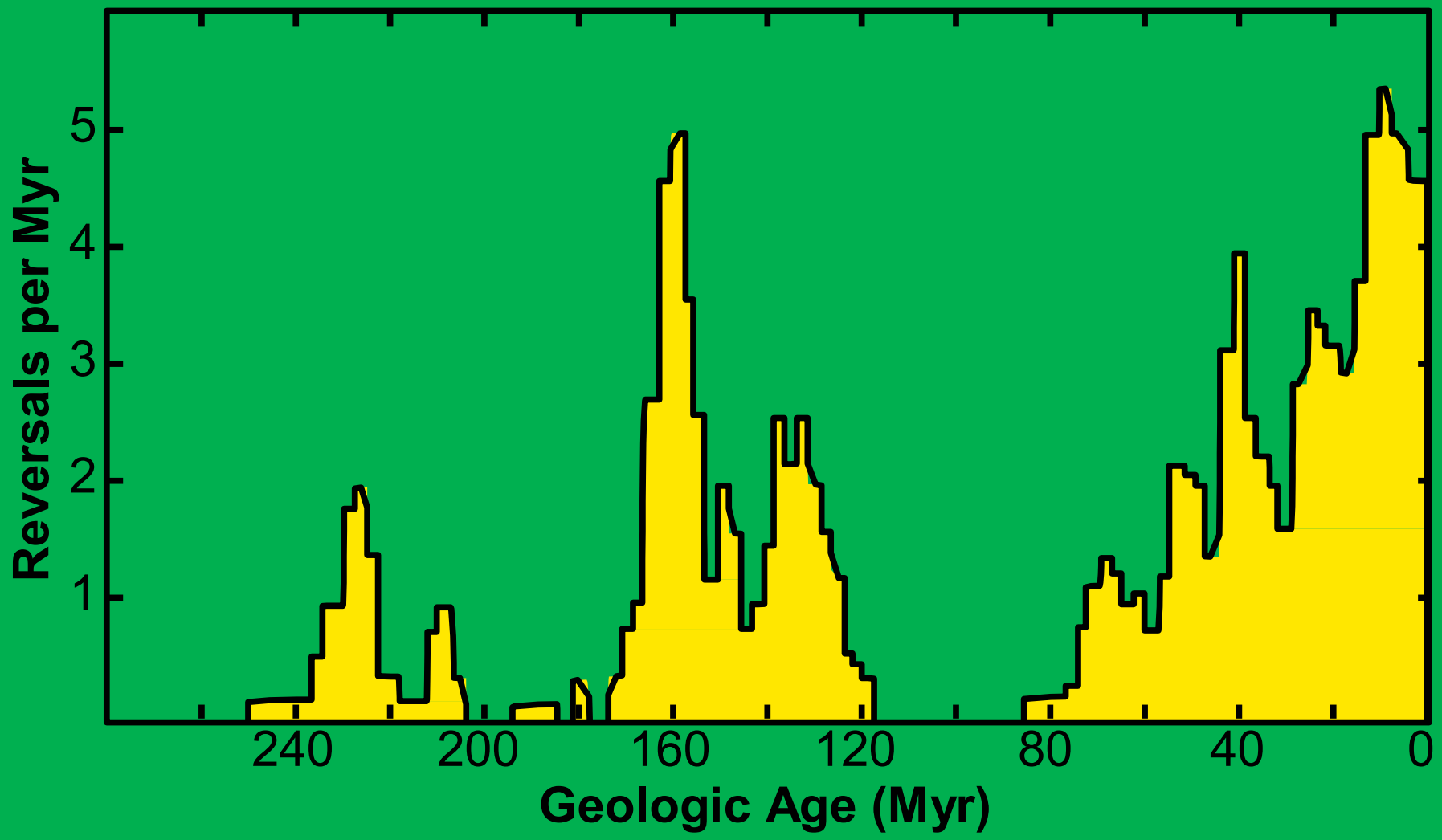




Homo saphiens - a child of chill

Glen Fergus, 2015. dane źródłowe: https://commons.wikimedia.org/wiki/File:All_palaeotemps.png


Quiet solar wind conditions
IMF
Input energy
~ 10^10 W
Solar wind
O+ escape
~ 10^24 s^-1
Extreme
ultraviolet
Disturbed solar wind conditions
IMF
Input energy
~ 10^12 W
Solar wind
O+ escape
~ 10^26 s^-1
Extreme
ultraviolet
A. Schillings



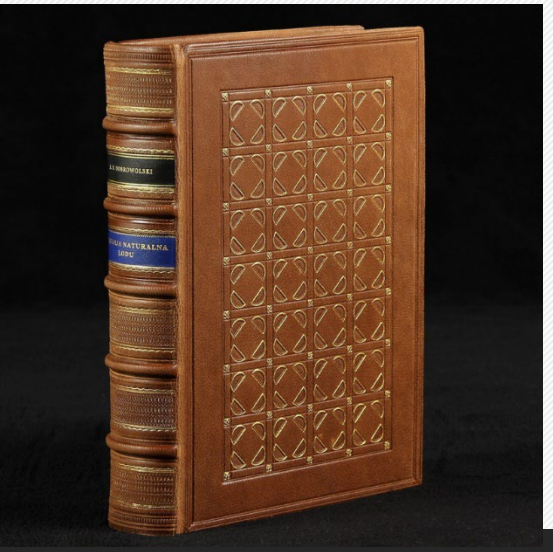
Hypothesis:

atmosphere thinning took place with every period of geomagnetic field intensity drop during the inversion

Figure 2. Apparent reversal frequency versus geologic "age" (Pal & Creer, 1986, pp. 148–150).

Models advanced to explain the onset of the Huronian Glaciation Event

- greenhouse effect resulted from CH_4 elimination by atmospheric oxygenation (Pavlov et al., 2000; Kasting, 2004, Kasting, 2005; Kopp et al., 2005)
- drawdown of atmospheric CO_2 as a result of carbonatization (i.e. reaction with carbon dioxide to form carbonates) due to weathering of rock masses uplifted in result of Archean plate tectonics (Young, 1991, Evans et al., 1997; Evans, 2003)
- **Multiple causes acting at the same time (Melezhik, 2006)**



A history of global glaciations

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Napisałem "Historję naturalną lodu" po polsku. Wywołało to zagranicą, po części nawet w kraju, lekkie zdumienie. Niemcy się nawet oburzyli: "Autor chyba wiedział, że umiejących czytać po polsku fizyków ziemskich i geografów niema nawet 1%" (Süring, redaktor "Meteorologische Zeitschrift"). Wiem, że może byłoby lepiej wydać ją w jednym z języków "międzynarodowych". Ale w statucie Kasy im. Mianowskiego, mego wydawcy, jest klauzula, która to uniemożliwiła. Zresztą nie jestem z tego powodu bynajmniej zmartwiony.

Antoni Bolesław Dobrowolski: *Mój życiorys naukowy*, 1928, s.184,194