ISTIDER

Foredrag i Vendsyssel Stenklub

mandag den 6. februar 2012

Sven Madsen

- Definitioner
- Nogle undersøgelsesmetoder
- Hvad bestemmer vores klima
- Gennemgang af de enkelte istidsperioder

Istid

En istid er en længerevarende periode i Jordens historie med et klima, der er så koldt, at det resulterer i udbredte iskappedannelser på kontinenterne og udbredt havisdannelse.

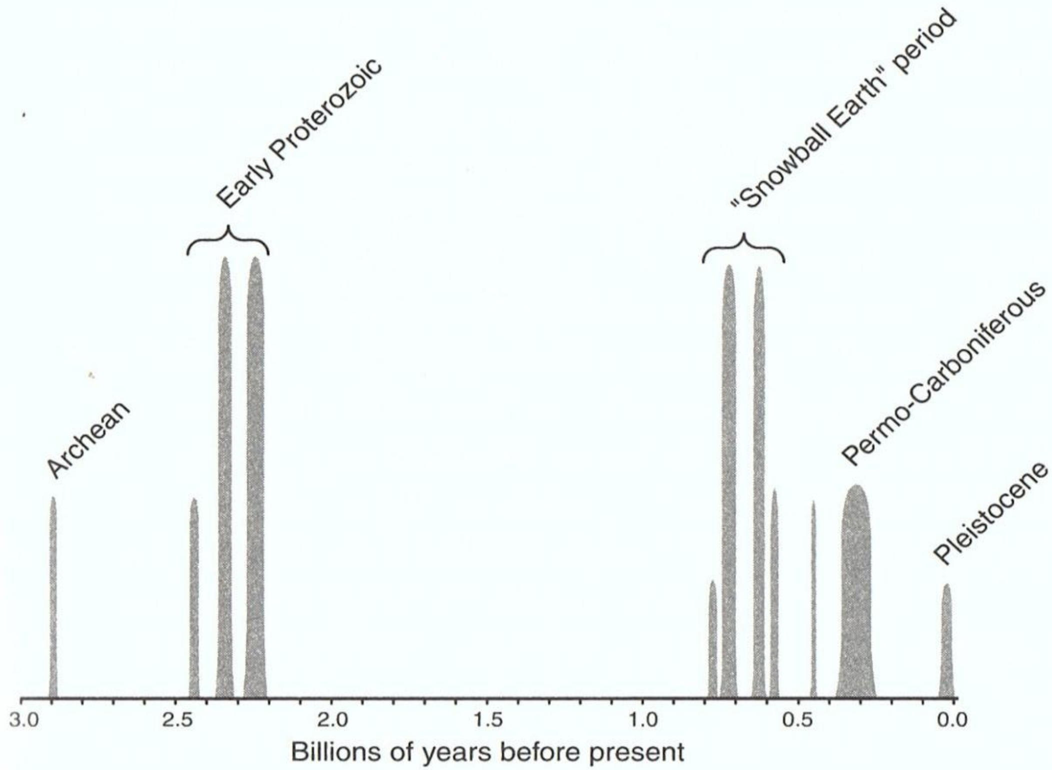
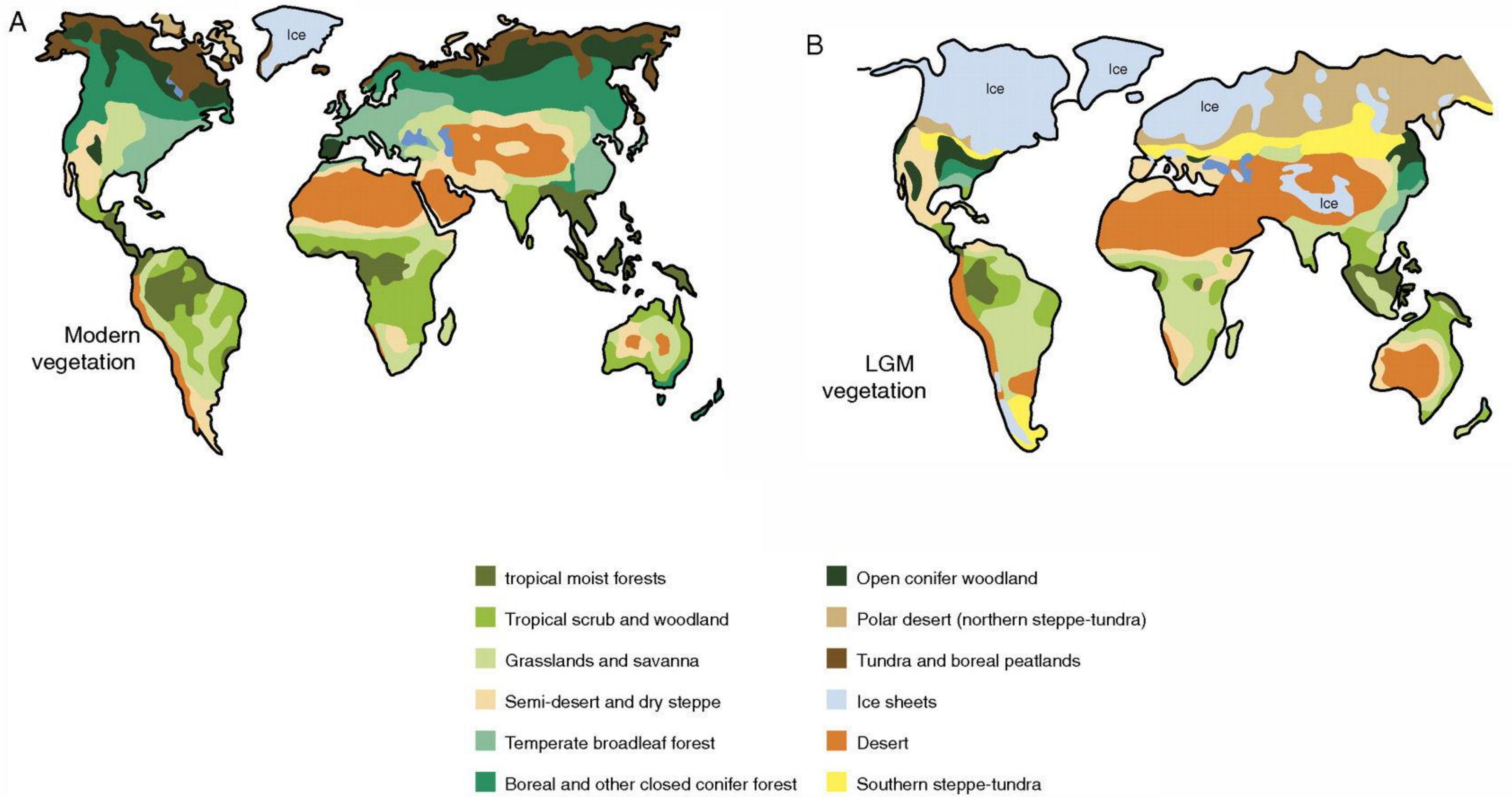


Figure 17. The Earth's major ice ages, as identified from glacial drift, tillite, varves, and glacially scoured bedrock. Heights of the shaded bars give a rough indication of the intensity of these glacial periods, although the estimates are speculative for the glaciations between 2.2 and 2.4 billion years ago. In addition to the four major ice age periods before the Pleistocene discussed in the text, a further cold period that occurred 450 million years ago has been identified and is shown here. It is not possible to represent the durations of ice ages accurately on this small graph.

Glacialer/interglacialer

Under istider skifter klimaet mellem kolde glacialperioder og varmere interglacialperioder.
Vi befinder os i en interglacial-periode i den istid, som startede for ca. 2,5 millioner år siden.


A
Ice
Modern
vegetation
B
Ice
Ice
Ice
Ice
LGM
vegetation
tropical moist forests
Tropical scrub and woodland
Grasslands and savanna
Semi-desert and dry steppe
Temperate broadleaf forest
Boreal and other closed conifer forest
Open conifer woodland
Polar desert (northern steppe-tundra)
Tundra and boreal peatlands
Ice sheets
Desert
Southern steppe-tundra

Stadialer/ Interstadialer

Under glacialer skifter klimaet mellem kolde stadialer (eks: Yngre Dryas) og varmere interstadialer (eks: Allerød).

I interglacialer er klimaet generelt mere stabilt.

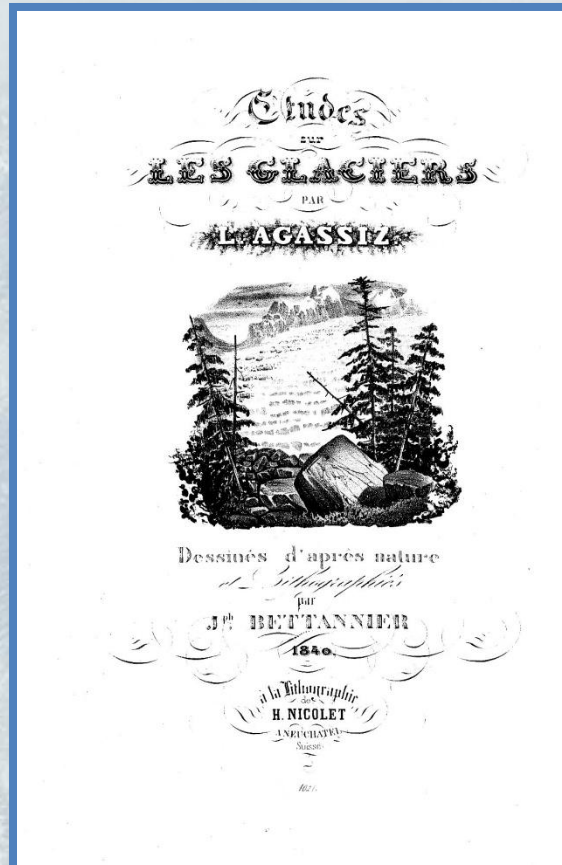
Glaziale/ Interglaziale	Stadiale/ Interstadiale[1]	Zeitraum (v. Chr.)[2]
Weichsel-Spätglazial	*Jüngere Dryaszeit*	10.730–9.700
	Alleröd-Interstadial	11.400–10.730
	Ältere Dryaszeit	11.590–11.400
	Bölling-Interstadial	11.720–11.590
	Älteste Dryaszeit	11.850–11.720
	Meiendorf-Interstadial	12.500–11.850
Weichsel-Hochglazial	*Mecklenburg-Phase*	17.000
	Pommern-Phase	17.600
	Frankfurt-Phase	22.300
	Brandenburg-Phase	24.000
	Denekamp-Interstadial	32.000
	Hengelo-Interstadial	39.000
	Moershoofd-Interstadial	48.700
	Glinde-Interstadial	51.500
	Ebersdorf-Stadial	53.500
	Oerel-Interstadial	57.700
Weichsel-Frühglazial	*Schalkholz-Stadial*	60.000
	Odderade-Interstadial	74.000
	Rederstall-Stadial	?
	Brörup-Interstadial	?
	Amersfoort-Interstadial	?
	Herning-Stadial	115.000
Eem-Warmzeit		126.000

Danske polarforskere får ret: Istiden sluttede for 11.711 år siden

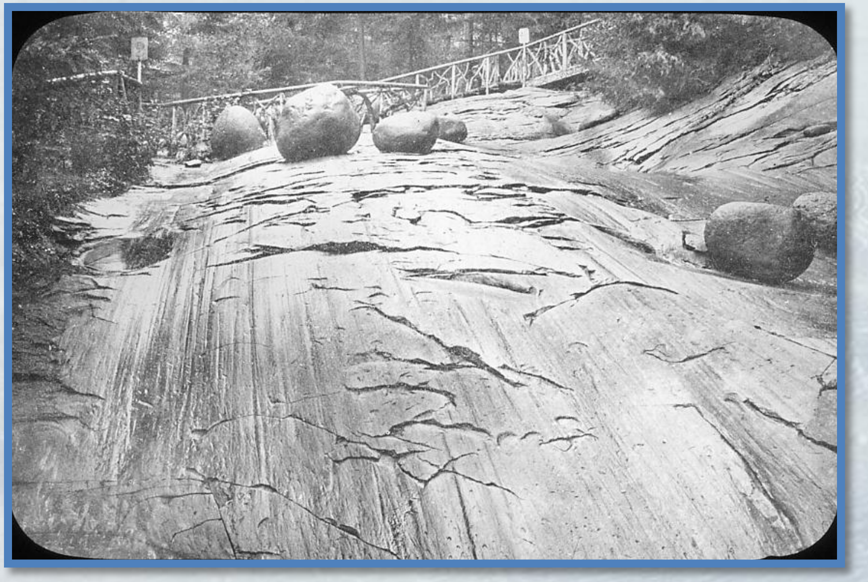
Med en advokat i ryggen sikrede Danmark sig den internationale standardreference for, hvornår istiden slutter, og nutiden begynder på Grønland - nemlig for præcis 11.711 år siden. (2008)

Tegn på istidsperioder

- **Geologiske**
  - Vandreblokke
  - Moræner (tillit, diamictit)
  - Skurestriber
  - Landskabsformer
  - Dropsten
  - Varv
- **Isotop-geokemiske**
  - Dybhavssedimenter
  - Iskerneboringer
- **Palæontologiske**



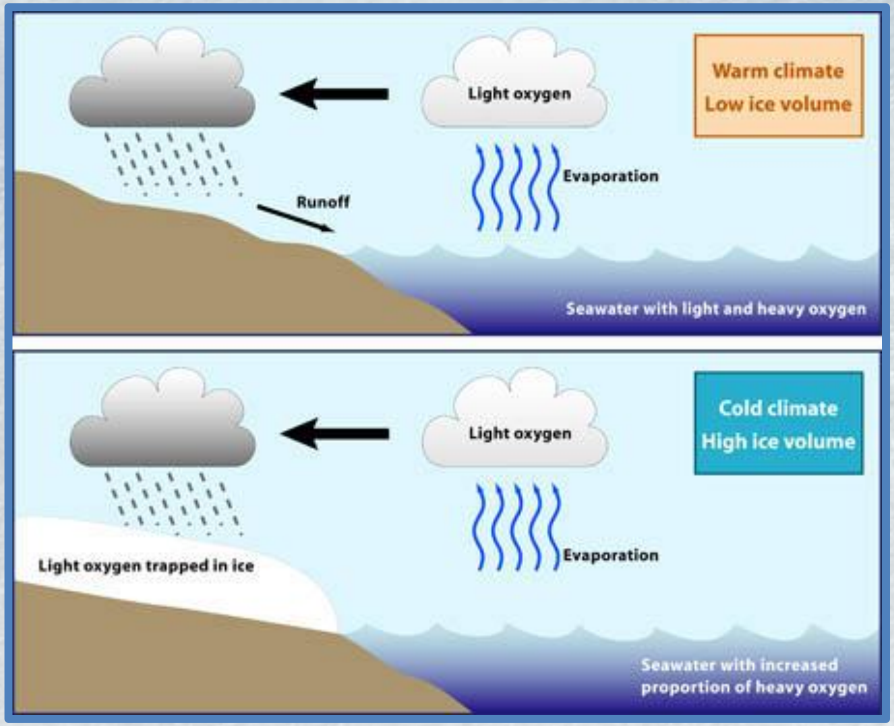
Louis Agassiz 1874-1927 - Glaciologiens far



- Erratic boulders – vandreblokke
- Moræneaflejringer
- Skurestriber
- Glaciologiske studier

Isotopundersøgelser

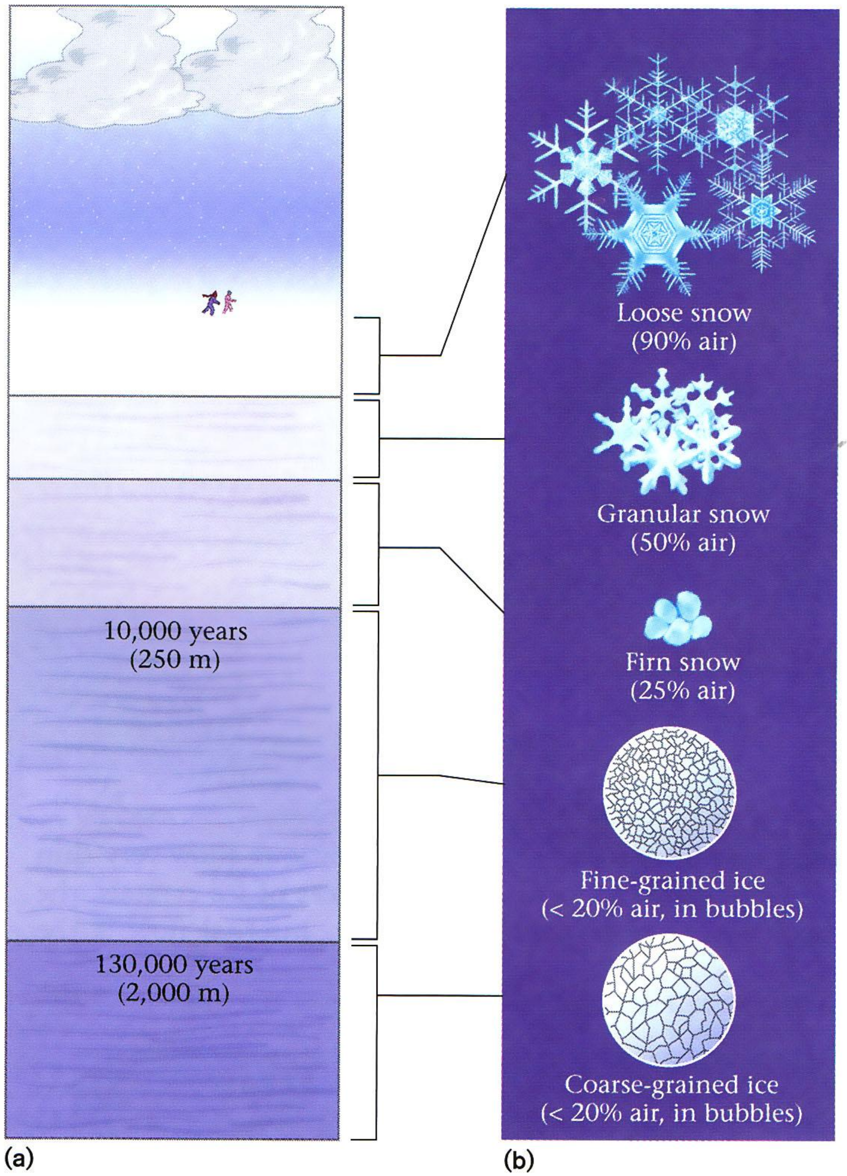
Fig. 4.3: *Denne sofistikerede forsøgsopstilling på græsplænen blev begyndelsen til 40 års arbejde.*



Willy Dansgaard (1922-2011)

Der er mere af den lette iltisotop i vand, der fordamper fra havet og som bindes i iskappen.

FIGURE 22.8 (a) Snow compacts and melts to form firn, which recrystallizes to make ice. (b) The size of ice crystals increases with depth in a glacier, where some crystals grow at the expense of others.



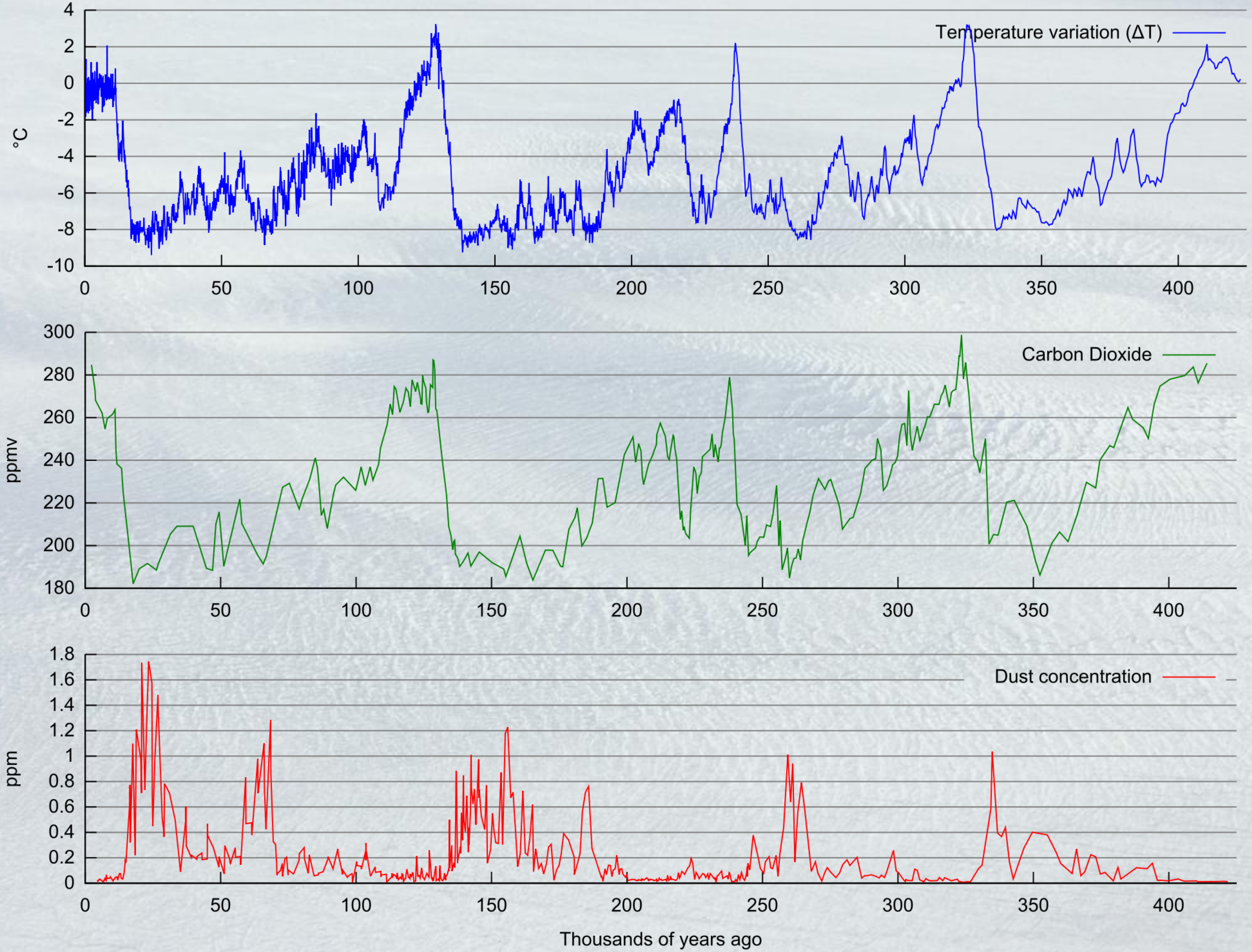
- Temperatur , da sneen faldt
- Luftens sammensætning
- Isens støvindhold

Grønland:

120.000 år
Stor opløselighed

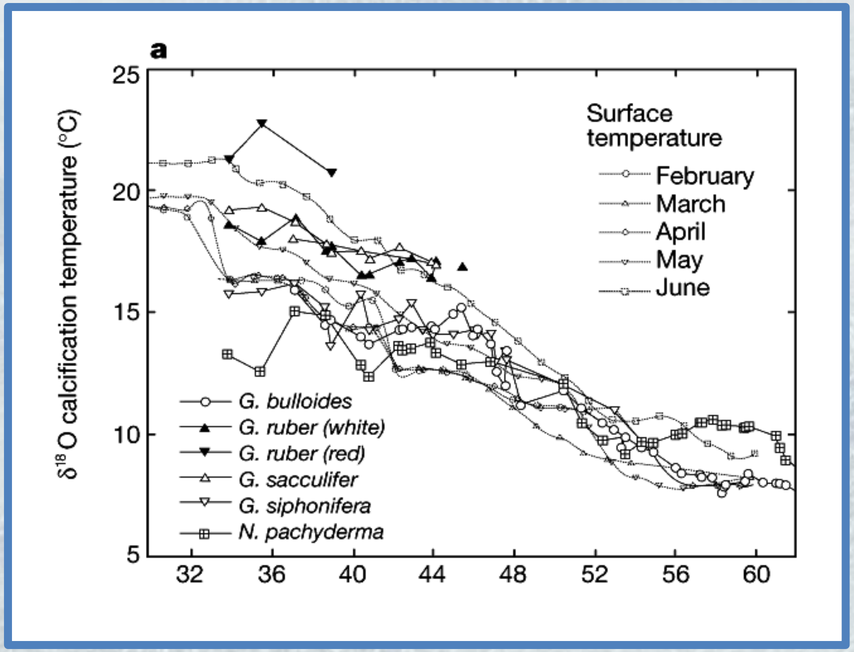
Antarktis:

600.000 år
Mindre opløselighed



Temperature variation (ΔT)
°C
4
2
0
-2
-4
-6
-8
-10
Carbon Dioxide
ppmv
300
280
260
240
220
200
180
Dust concentration
ppm
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
300
350
400
Thousands of years ago

$^{18}O/^{16}O$ i foraminiferer



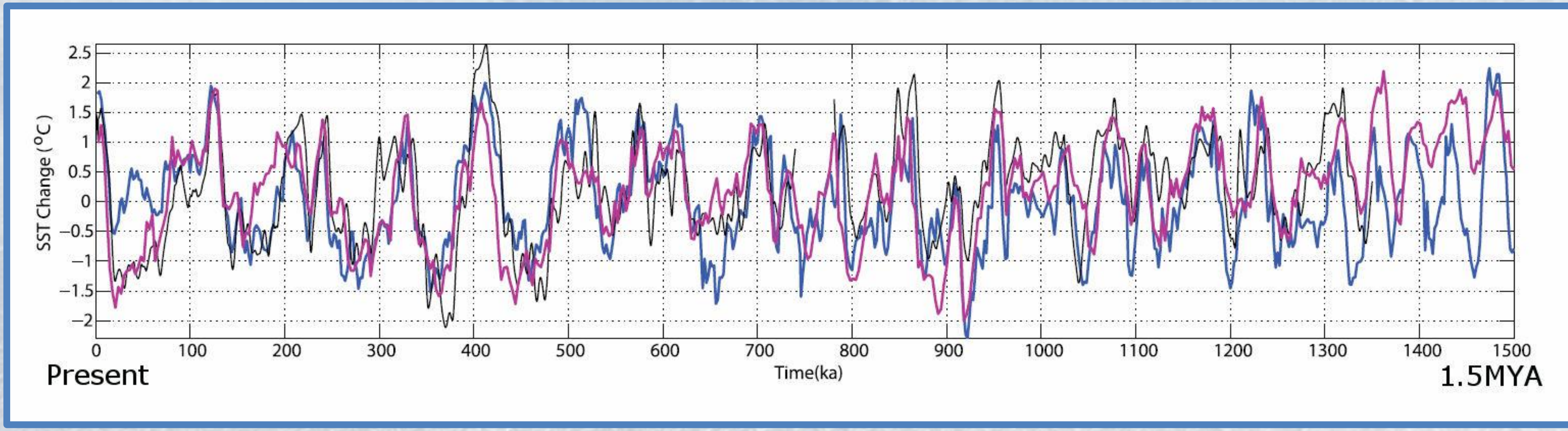
Indholdet af det lette iltisotop i kalkskaller på foraminiferer, coccolither mm. er lavere jo lavere temperatur kalkdannelsen foregår ved.

Dybhavssedimenter

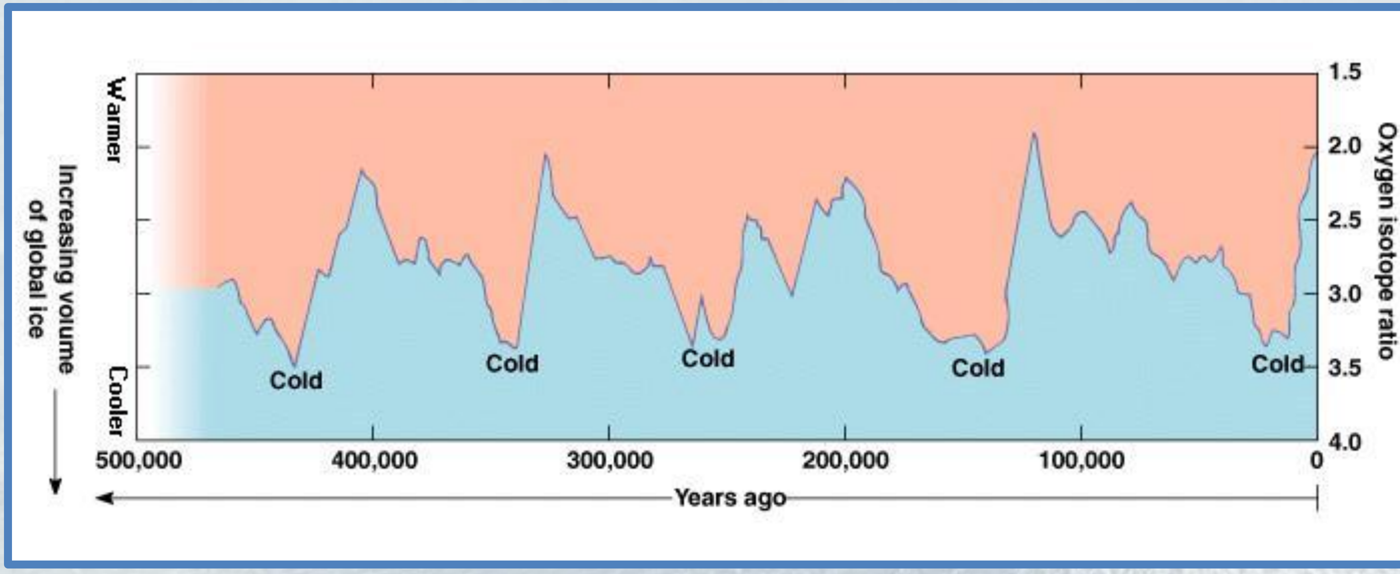
$^{18}O/^{16}O$ i foraminiferer

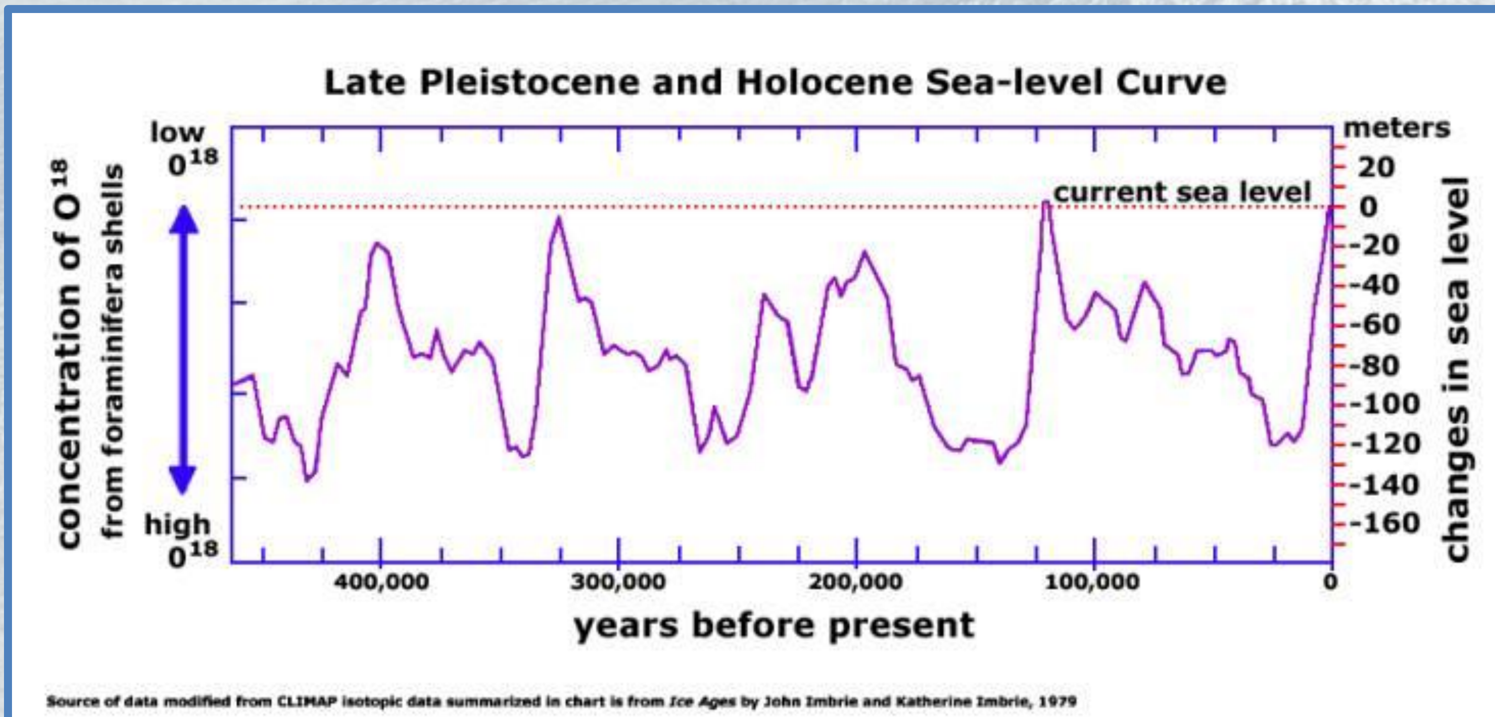
- Vandtemperatur
- Mængden af vand bundet i iskapper

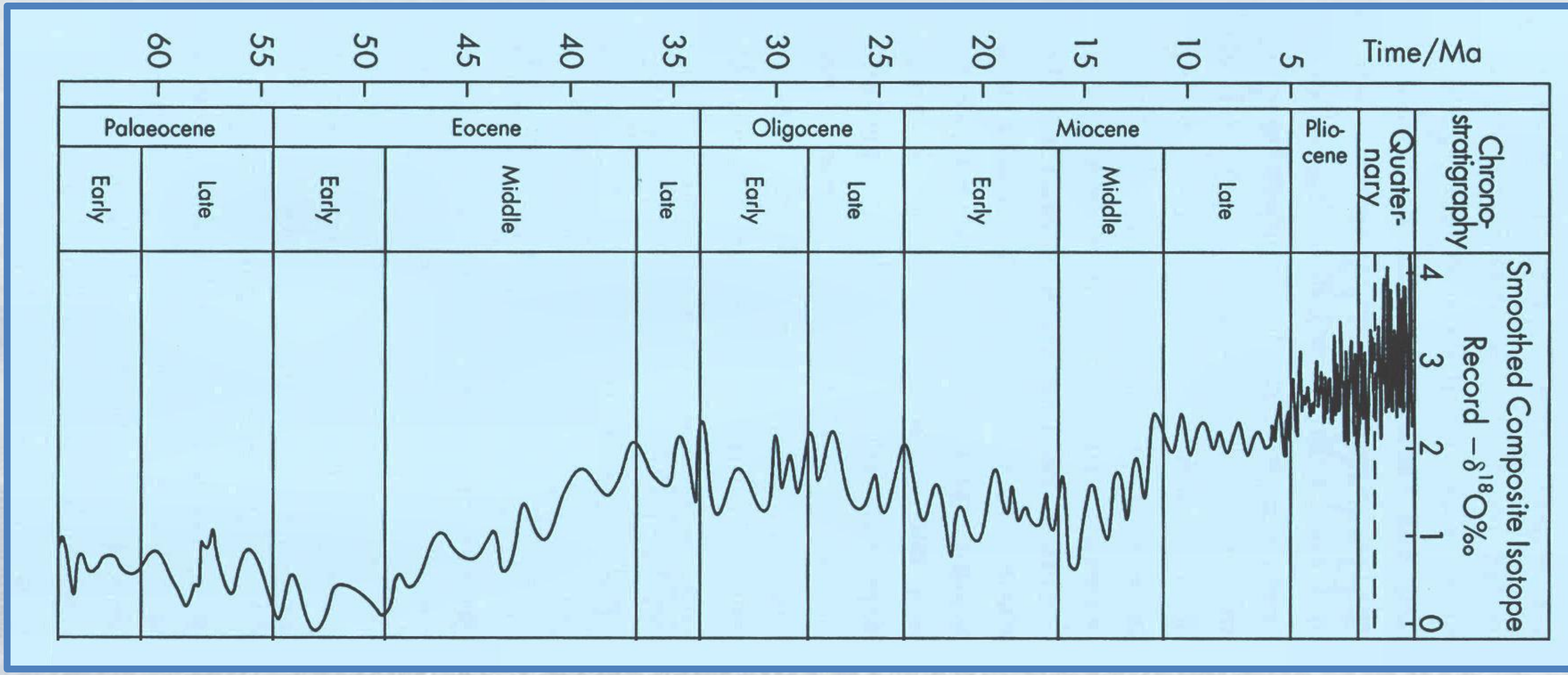
Tp-ændringer i overflade-havvand



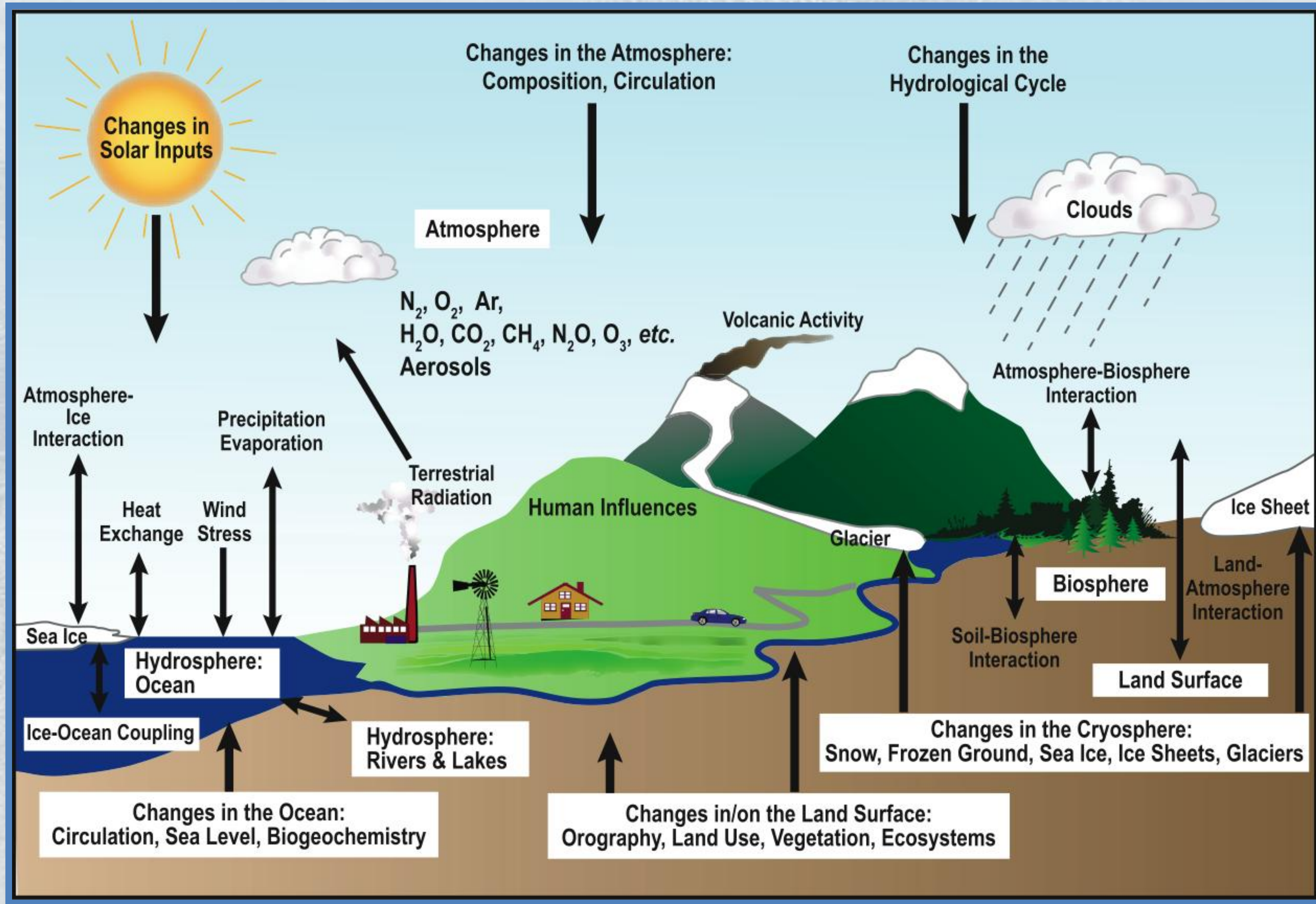
Blå: Nordatlantisk. Sort og lilla: Tropisk


Warmer
Cooler
Increasing volume of global ice
Cold
Cold
Cold
Cold
Cold
1.5
2.0
2.5
3.0
3.5
4.0
Oxygen isotope ratio
500,000
400,000
300,000
200,000
100,000
0
Years ago


Late Pleistocene and Holocene Sea-level Curve
low 0^{18}
high 0^{18}
concentration of O^{18} from foraminifera shells
current sea level
meters
20
0
-20
-40
-60
-80
-100
-120
-140
-160
changes in sea level
400,000
300,000
200,000
100,000
0
years before present
Source of data modified from CLIMAP isotopic data summarized in chart is from *Ice Ages* by John Imbrie and Katherine Imbrie, 1979

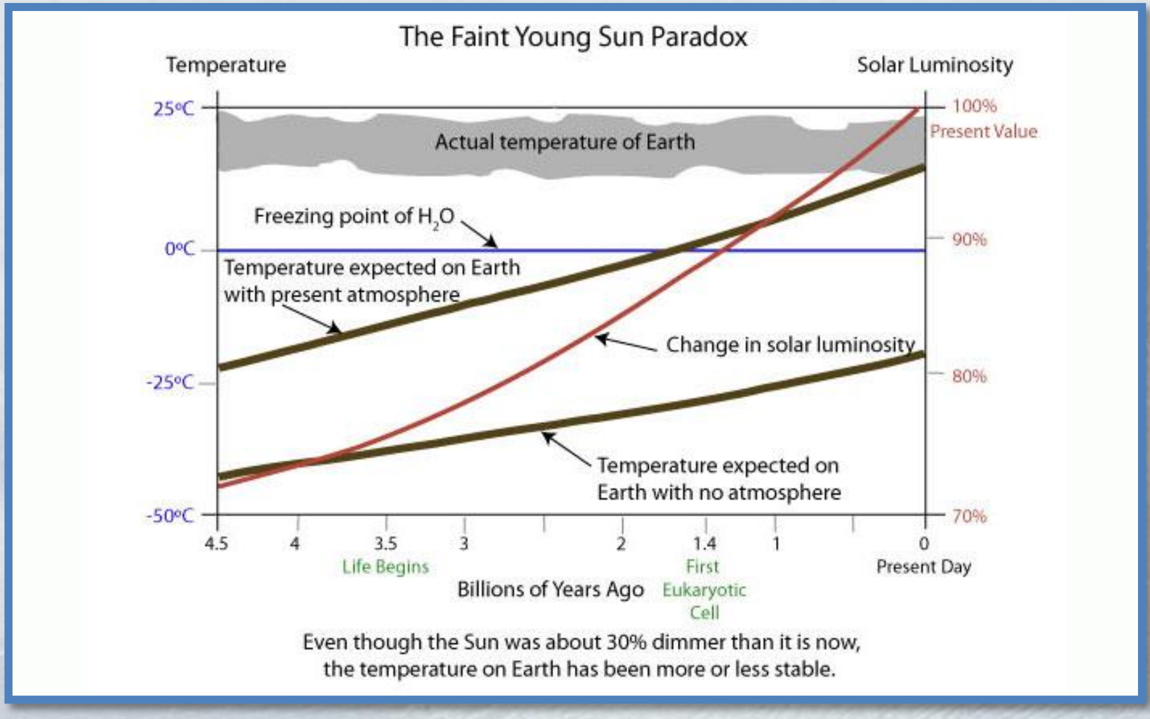

Time/Ma
60
55
50
45
40
35
30
25
20
15
10
5
Chrono-stratigraphy
Palaeocene
Eocene
Oligocene
Miocene
Plio-cene
Quater-nary
Early
Late
Early
Middle
Late
Early
Late
Early
Middle
Late
Smoothed Composite Isotope Record $-\delta^{18}O$‰
4
3
2
1
0

Det komplicerede klima



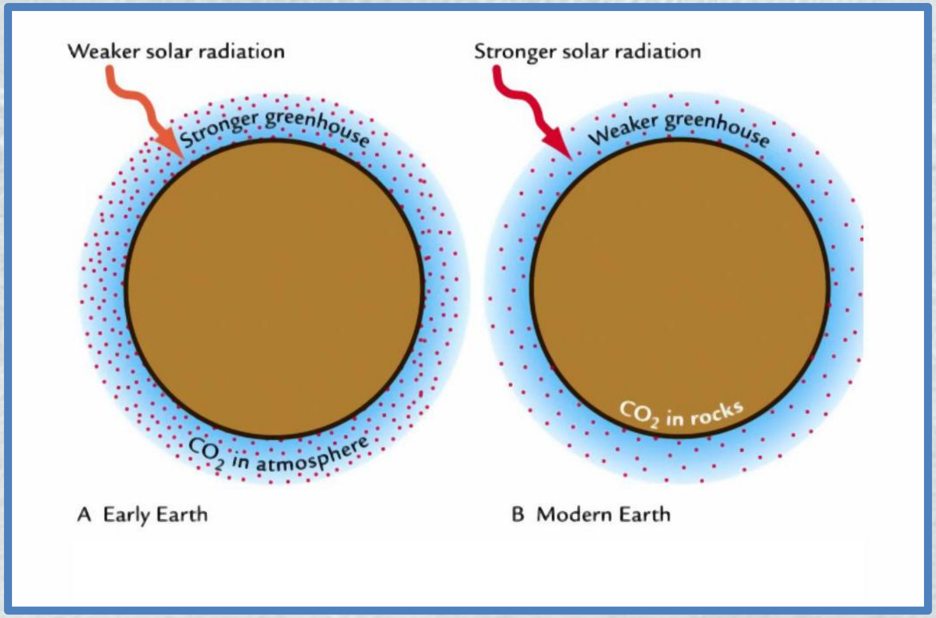
Årsager til klimaændringer

- Ændringer i Solens stråling
- Ændringer i kontinenternes placering (pladetektonik)
- Ændringer i Jordens bevægelse om Solen
- Ændringer i koncentrationen af drivhusgasser i Jordens atmosfære
- Vulkanudbrud
- Astronomiske begivenheder

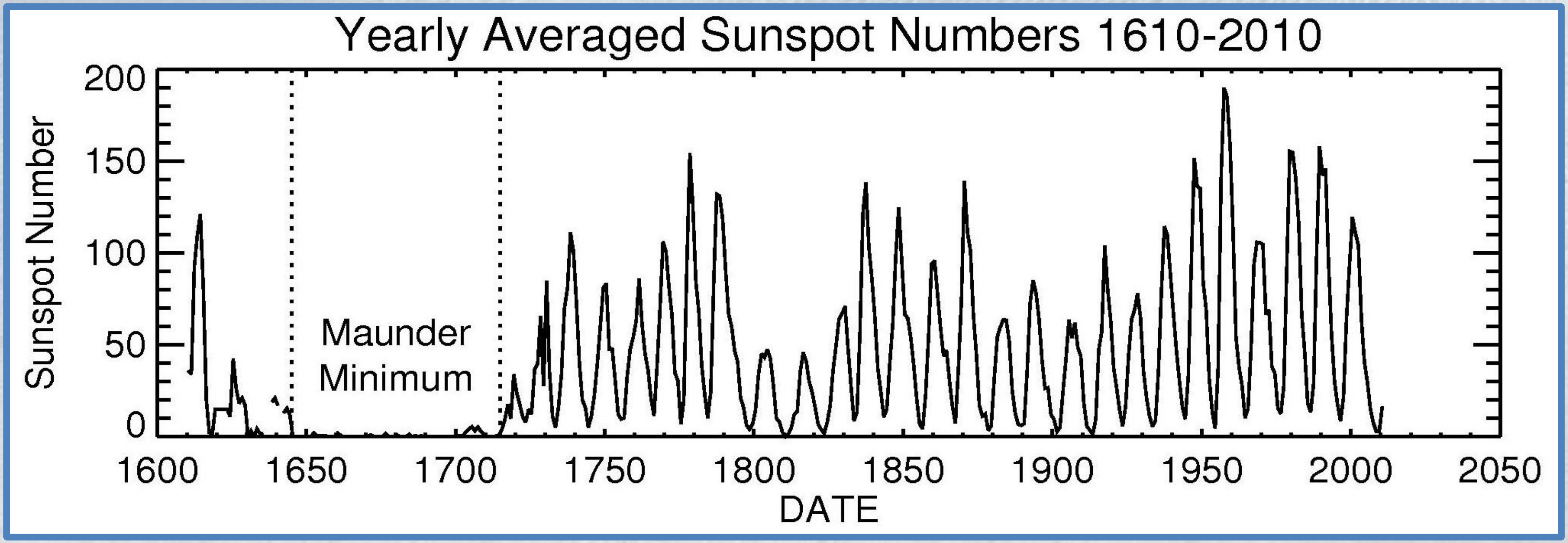


Solens stråling

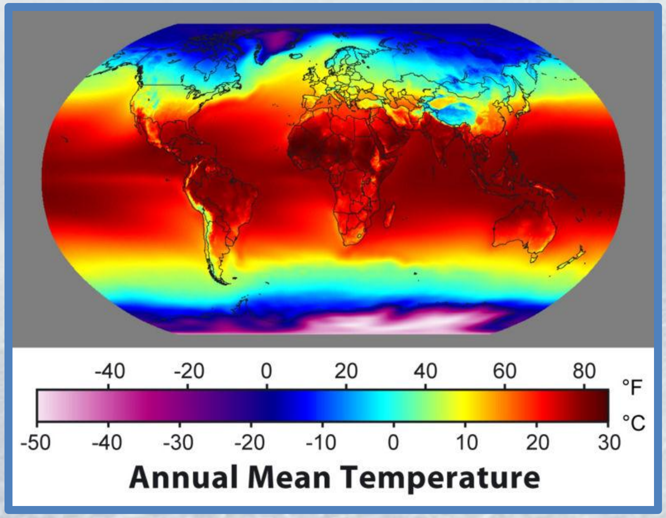
"Den svage, unge sol - paradoxet"

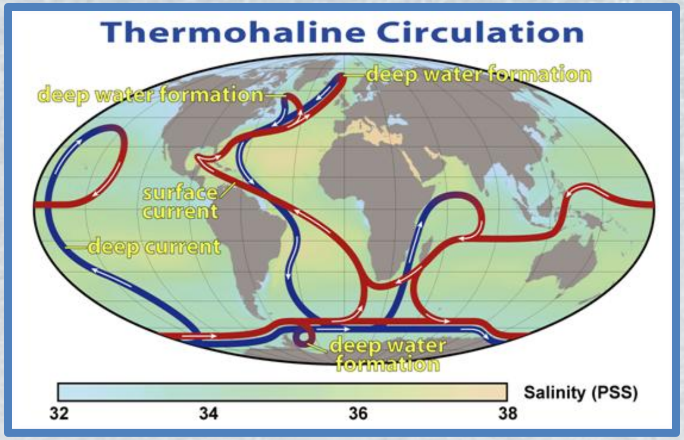


Solpletter


Yearly Averaged Sunspot Numbers 1610-2010
Sunspot Number
200
150
100
50
0
Maunder
Minimum
1600
1650
1700
1750
1800
1850
1900
1950
2000
2050
DATE

Pladetektonikkens betydning

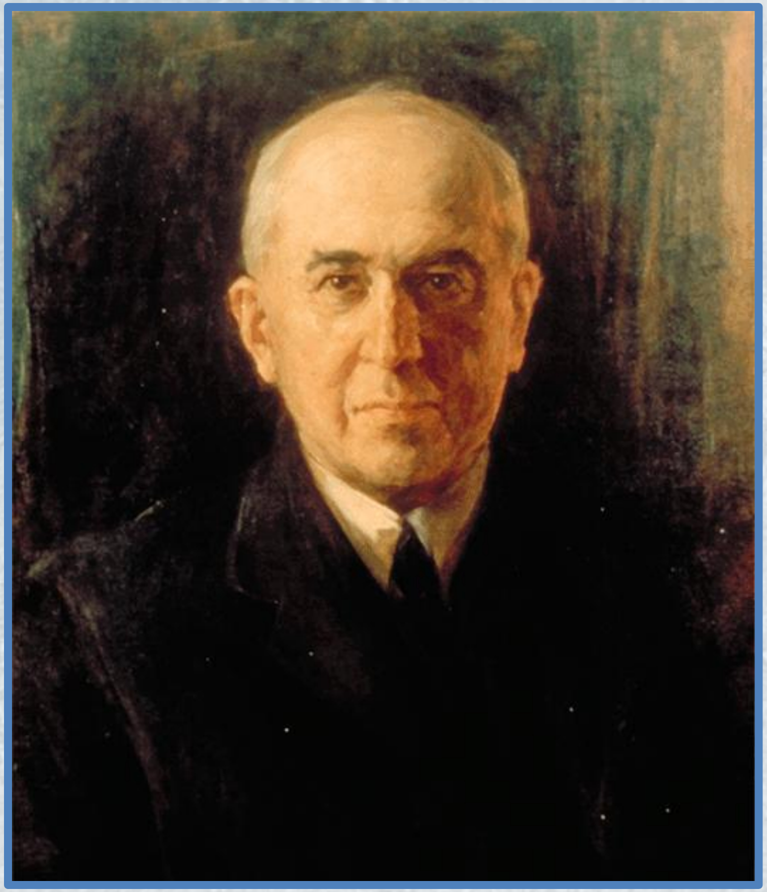




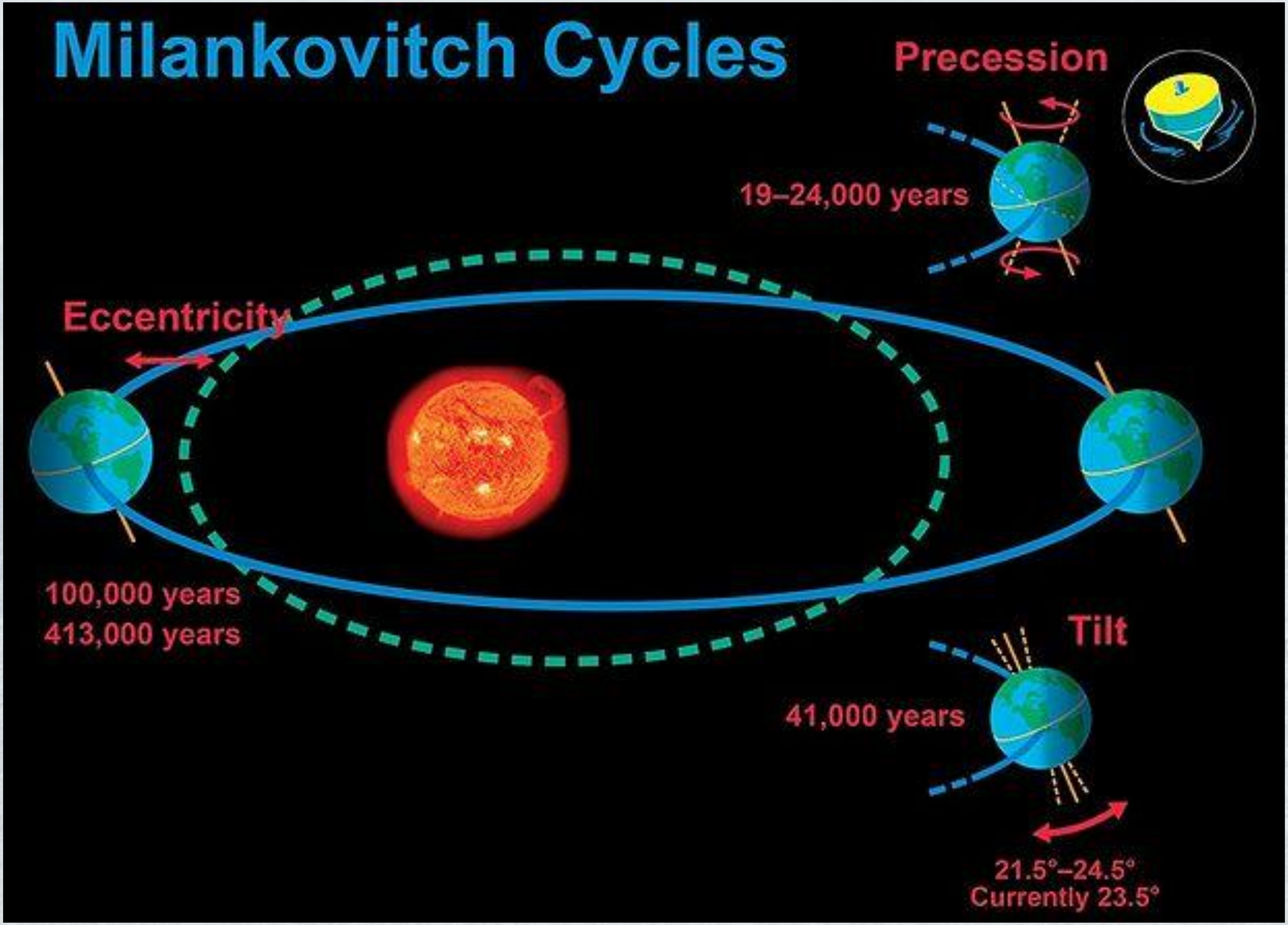
- Kontinenter i polare regioner giver mulighed for dannelse af iskapper.
- Nogle konfigurationer af kontinenternes placering forhindrer varmeudligning fra ækvatoriale områder til polare områder både via havstrømme og via vindsystemer.
- Kollision mellem kontinenter fører til hævning af store plateauer (Tibet) med snedække.

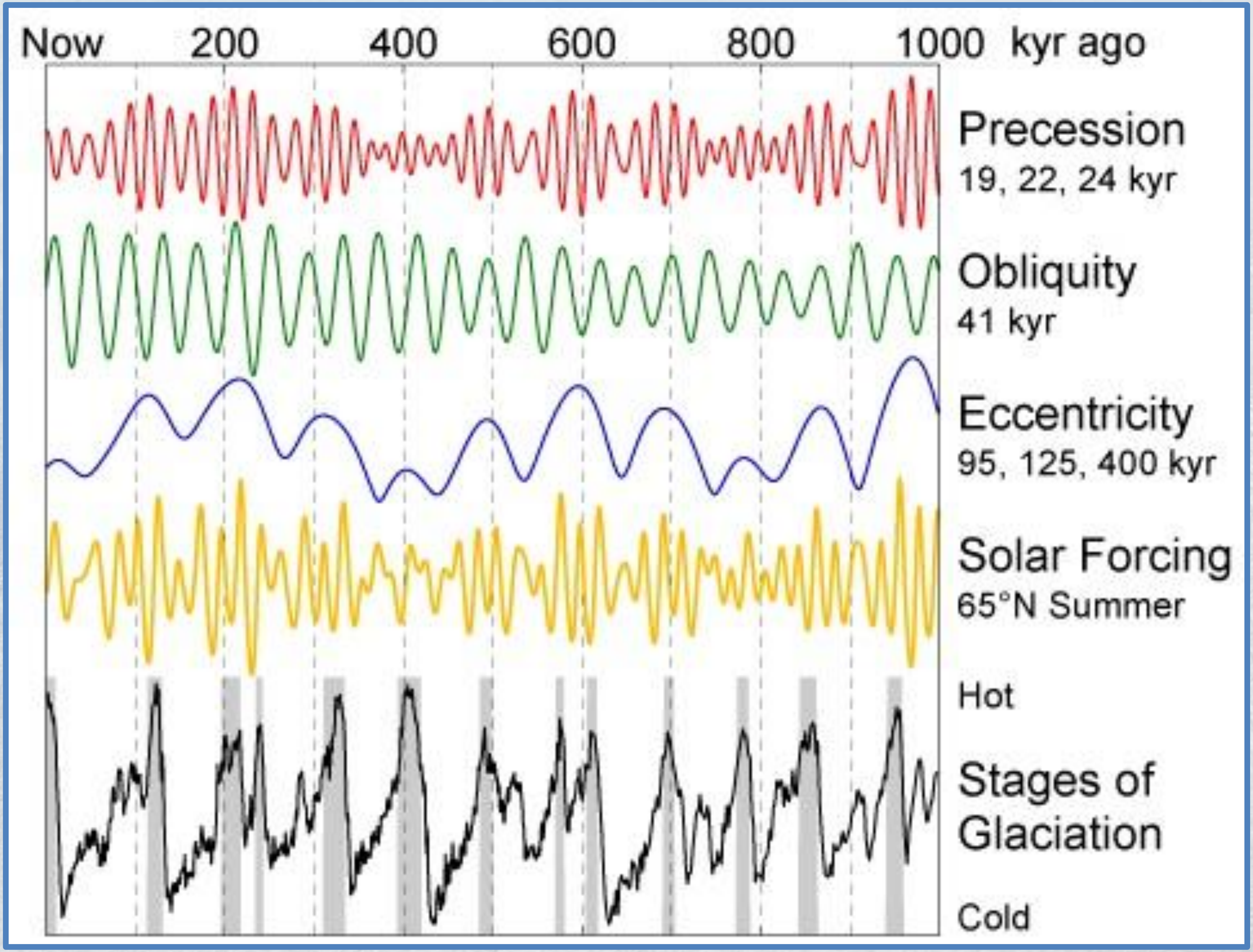
Jordens bane omkring Solen

James Croll (1821-1890)



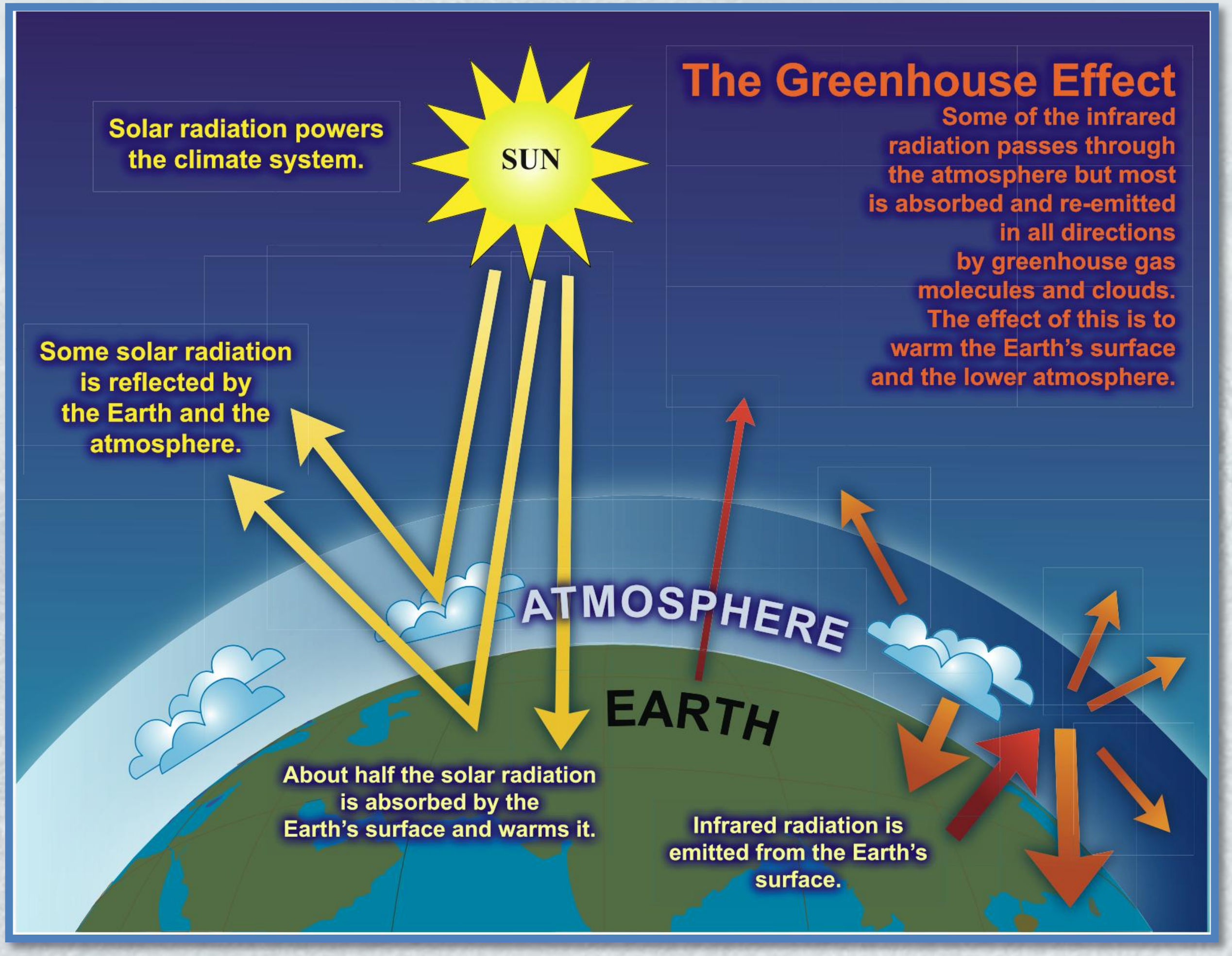
Milutin Milankovic (1879-1958)


Milankovitch Cycles
Precession
19–24,000 years
Eccentricity
100,000 years
413,000 years
Tilt
41,000 years
21.5°–24.5°
Currently 23.5°



Now
200
400
600
800
1000
kyr ago
Precession
19, 22, 24 kyr
Obliquity
41 kyr
Eccentricity
95, 125, 400 kyr
Solar Forcing
65°N Summer
Hot
Stages of
Glaciation
Cold

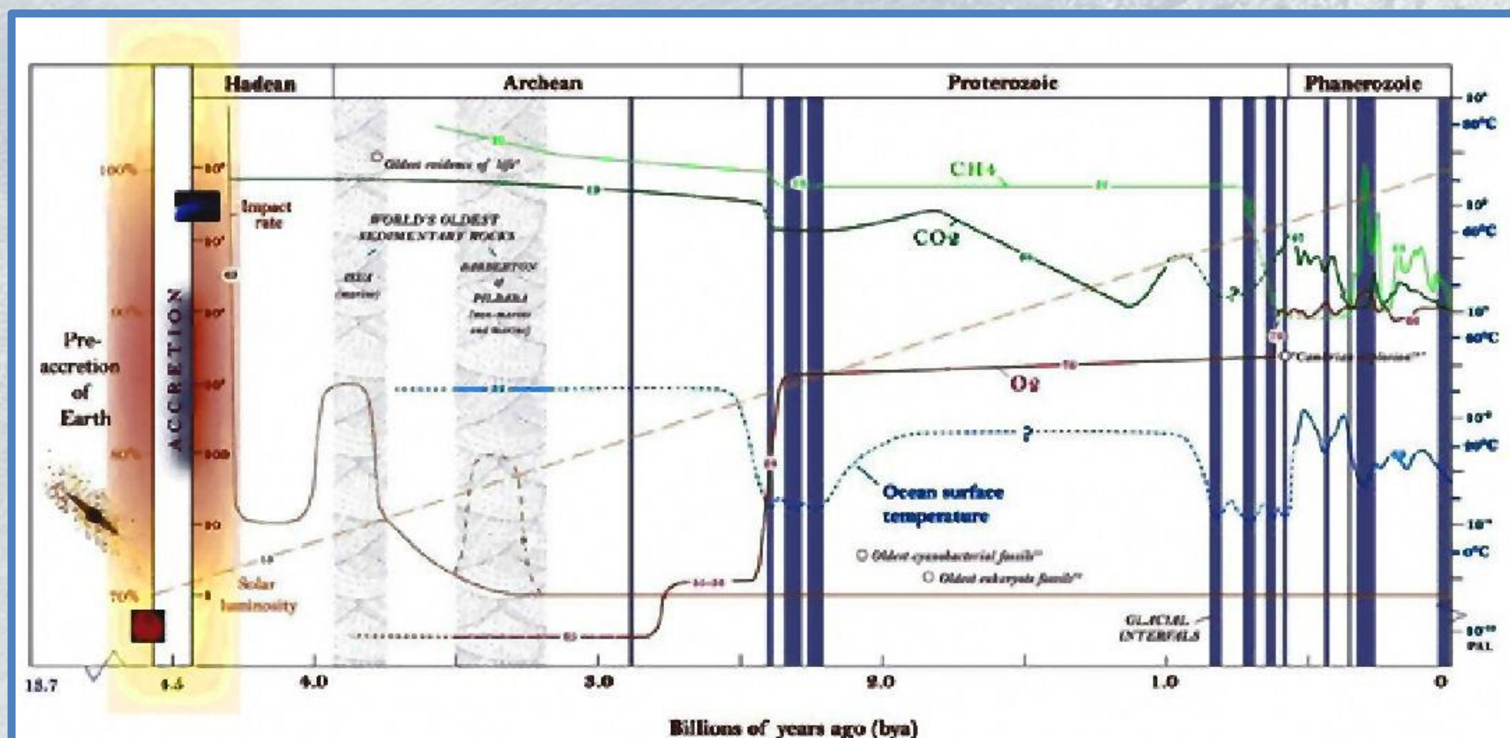
Drivhusgasser



- Vanddamp og skyer
- Ikke kondenserende drivhusgasser: CO_2, CH_4, N_2O mm

”Naturlige” drivhusgasser

Greenhouse Gas	Human Sources	Average Time in the Troposphere	Relative Warming Potential Compared to Carbon Dioxide
Carbon dioxide	Burning fossil fuels, deforestation, plant burning	50-120 years	1
Methane	Rice paddies, cattle, landfills, coal production, natural gas leaks from oil and gas pipelines	12-18 years	23
Nitrous oxide	Burning fossil fuels, fertilizers, live-stock waste	112-120 years	296
Chlorofluorocarbons (CFCs)	Air conditioners, refrigerators, plastic foam (the use of CFCs is being phased out)	11-20 years	900-8300
Hydrochlorofluorocarbons (HCFCs)	Air conditioners, refrigerators, plastic foam	9-390 years	470-2000
Hydrofluorocarbons (HFCs)	Air conditioners, refrigerators, plastic foam	15-390 years	130-12700
Halons	Fire extinguishers	68 years	5500
Carbon tetrachloride	Cleaning solvent	42 years	1400



Pongola-istid 2,9 Ga

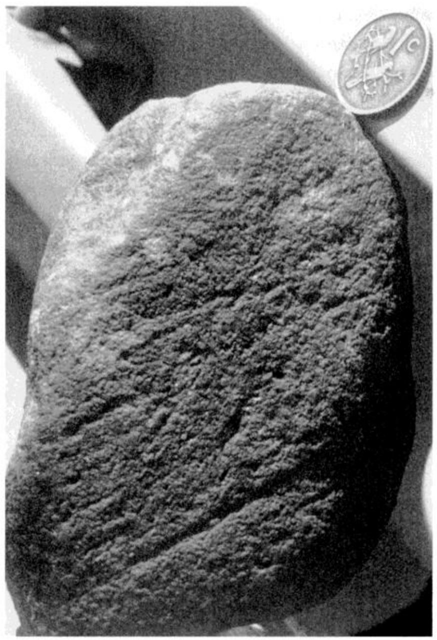
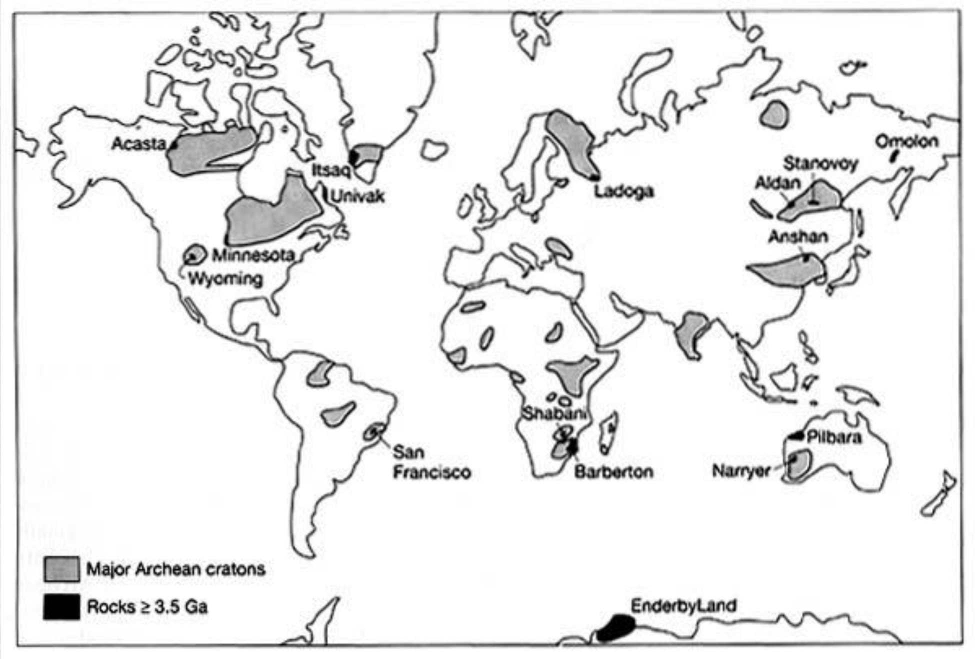


Figure 19. A glacially scratched and faceted boulder from the Earth's oldest known ice age. This sample comes from a tillite in South Africa that is estimated to be between 2.9 and 3.0 billion years old. Photograph courtesy Professor John Crowell, University of California, Santa Barbara.



Vaalbara-superkontinent 3,1-2,5 Ga

Årsag og omfang usikker

- Tillit med faceterede klaster med skurestriber
- Dropsten
- ~48°

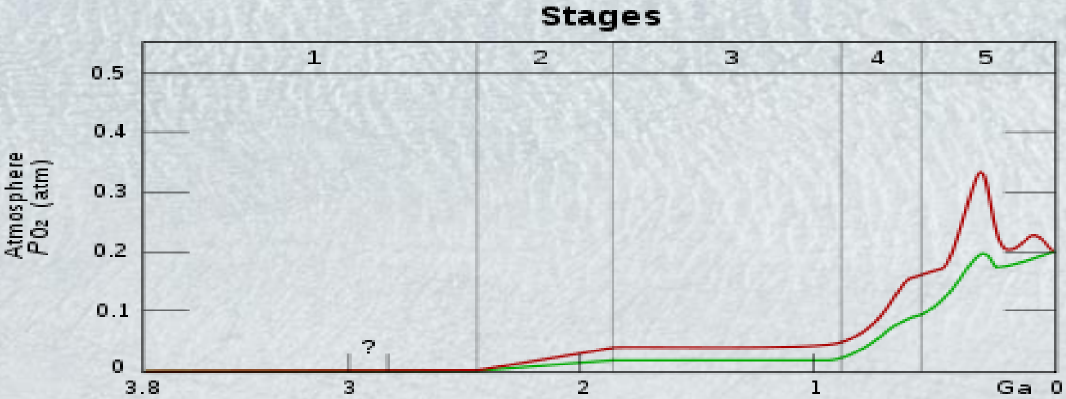
Huron-istid 2,4-2,1 Ga

Formentlig flere adskilte istider afsluttende med ”Snowball Earth”

Geologiske tegn i Canada og Sydafrika: Tillit, dropsten, varv

Iltkatastrofen – GOE (Great Oxygen Event)

Atmosfærens methan omdannes til kuldioxid



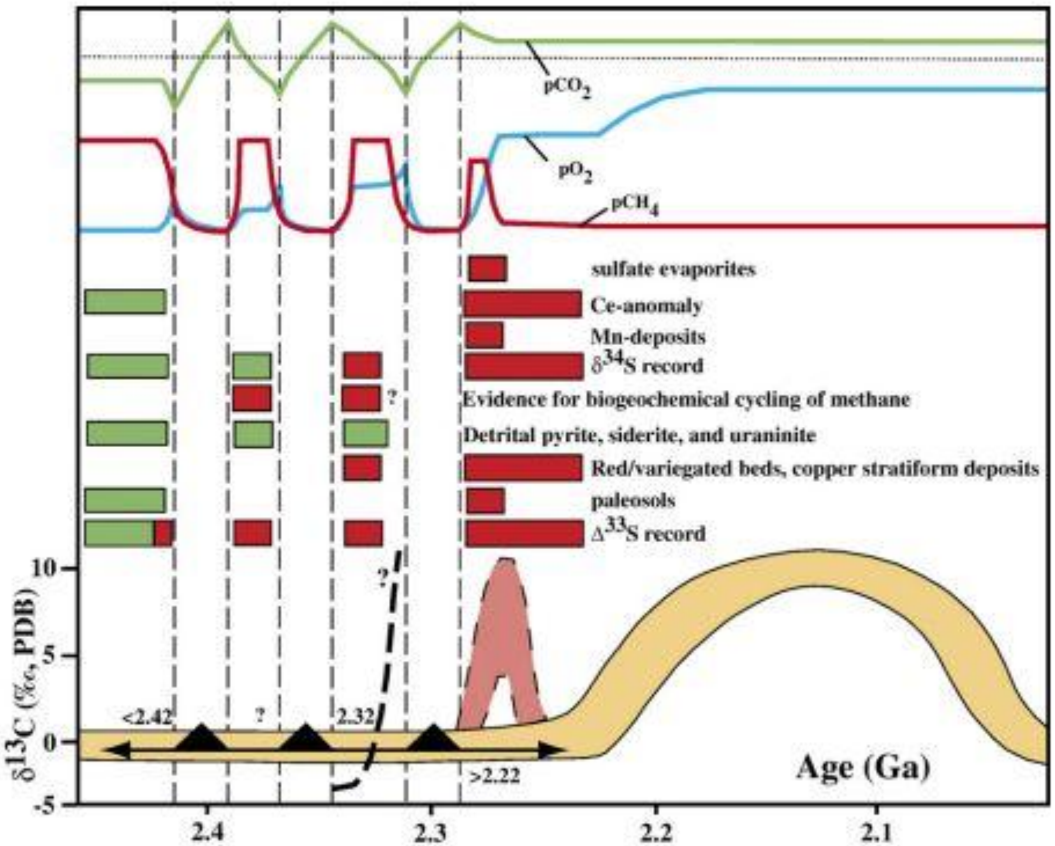
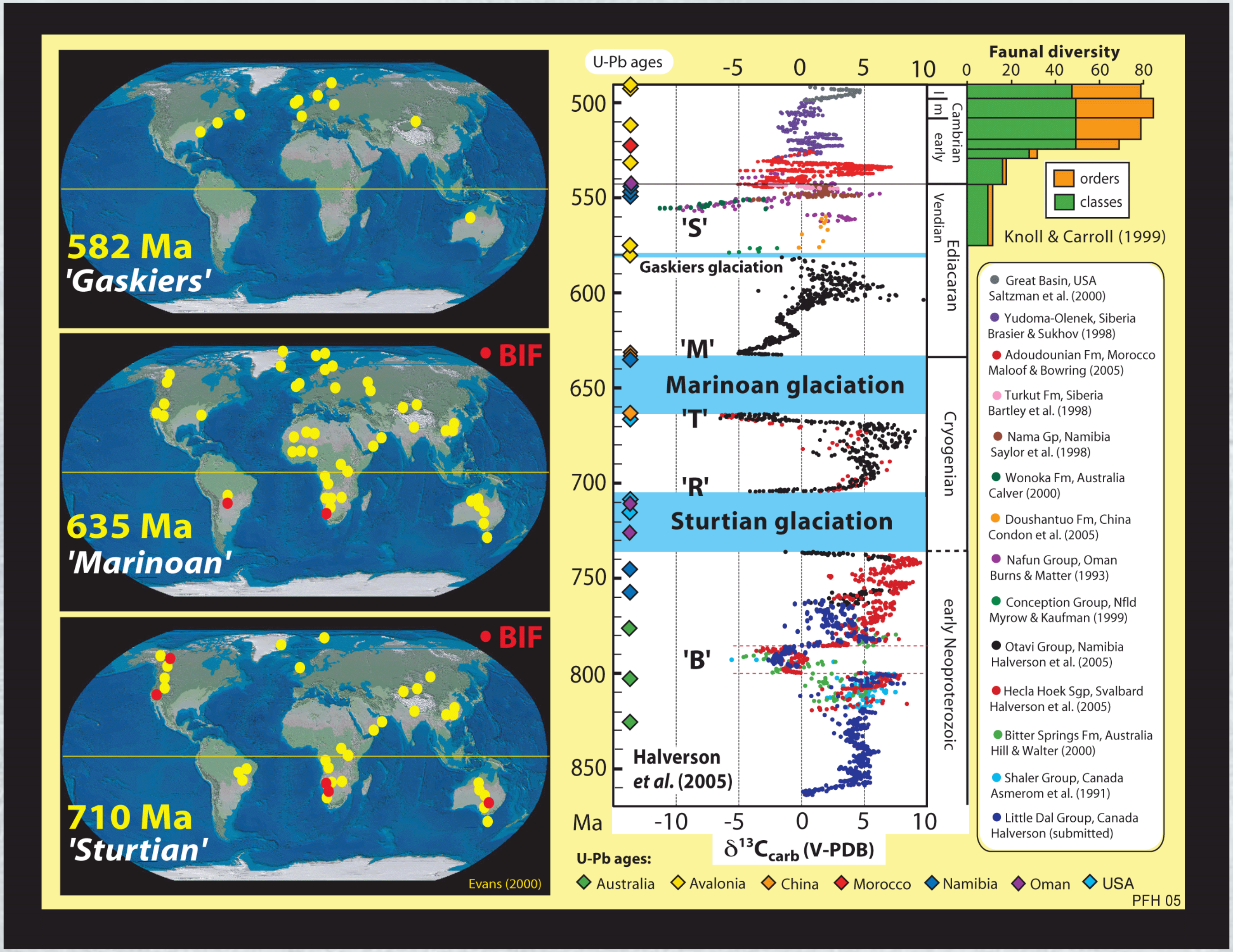


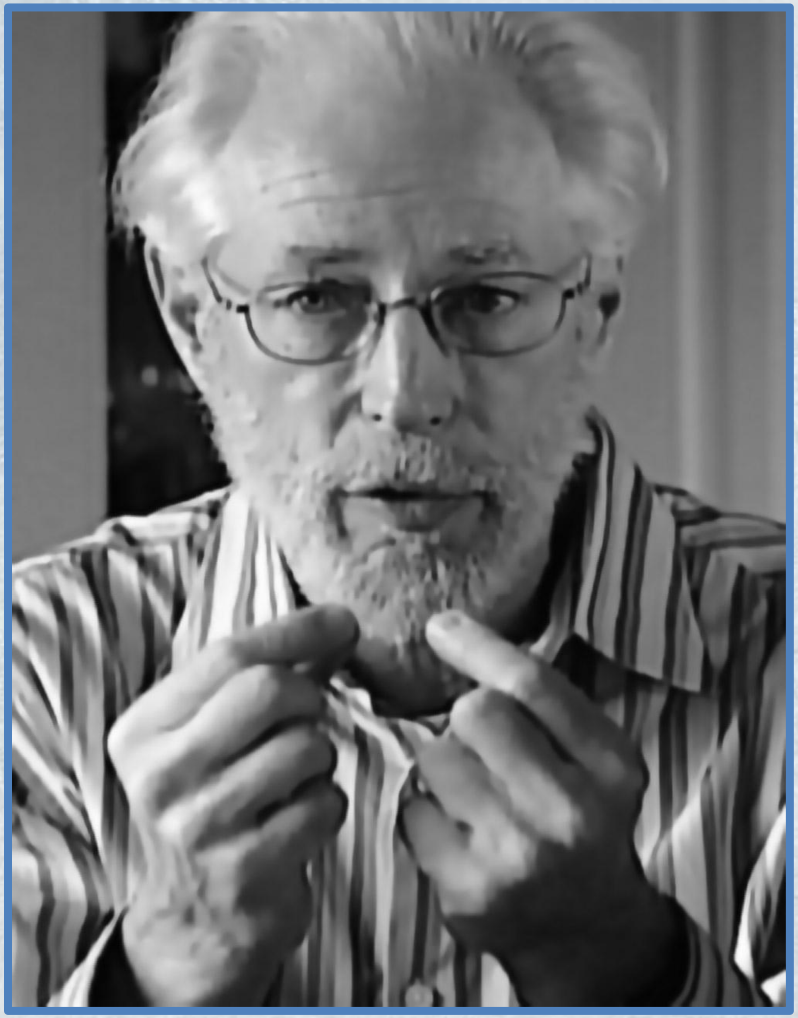
Fig. 6. Schematic presentation of Paleoproterozoic secular carbon isotope variations from Bekker et al. [23] with additional information from Bekker et al. [82] shown in light grey with a dashed border. Black triangles represent three Paleoproterozoic glaciations with their age constraints shown. Indicators of atmospheric and ocean redox state (green — reducing; red — oxidized) relevant to this paper are from Bekker et al. [23]. Atmospheric methane, carbon dioxide, and oxygen levels shown schematically fluctuated during the Paleoproterozoic glacial epoch and induced climate changes (see text for discussion). Dashed line represents atmospheric carbon dioxide level required to maintain greenhouse conditions alone. Positive carbon isotope excursion in the aftermath of the third Huronian glaciation (shown in pink) marks irreversible transition to the oxygenated atmosphere with carbon dioxide acting as a major greenhouse gas thereafter. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Cryogenium-istider 850-630 Ma



”Snowball Earth”

Joseph Kirschvink



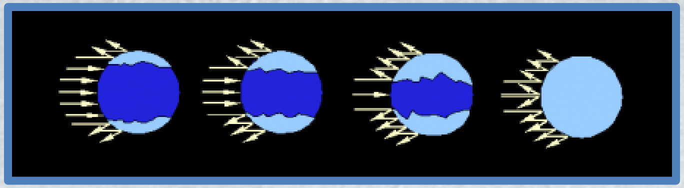
Paul Hoffman

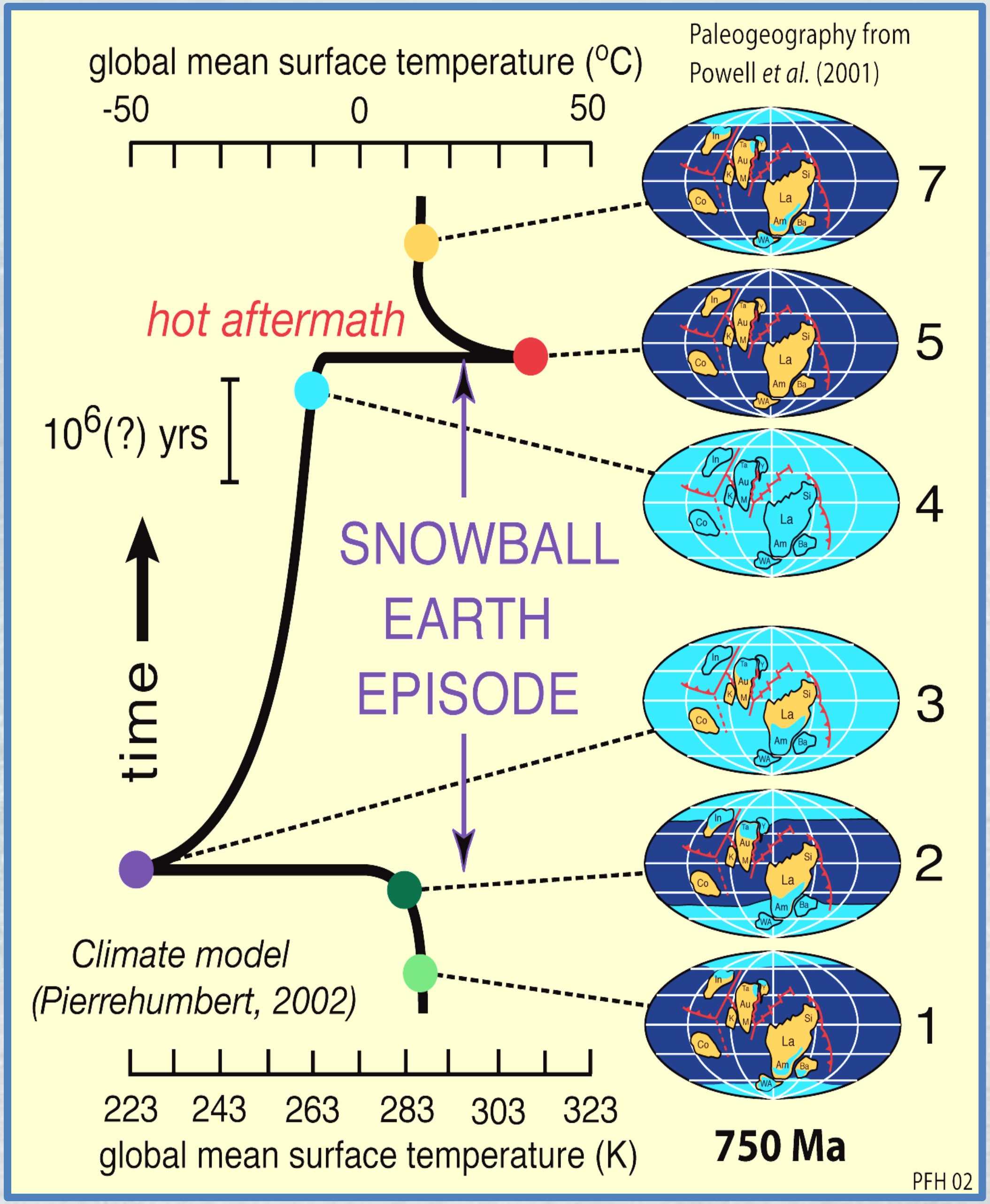
Ice-rafted dropstone in proglacial marine strata, Ghaub Fm lower member, Otavi Group, Namibia

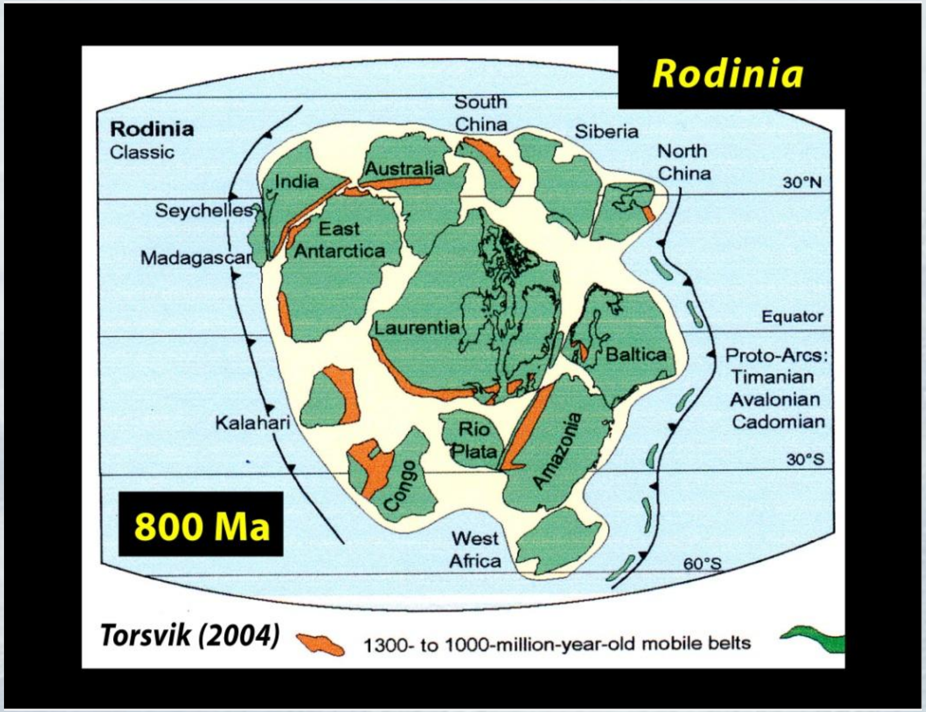
Moonlight Valley diamictite, East Kimberleys, Western Australia

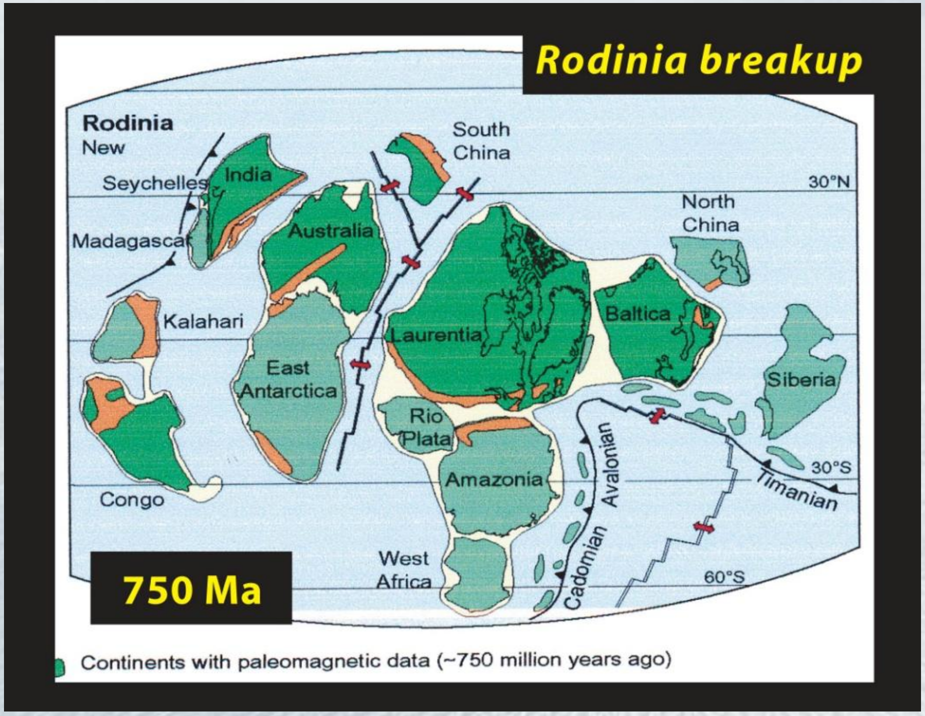
Surface	Albedo/reflectivity (%)
Fresh snow	80–95
Ice	20–40
Desert sands	35–45
Forest	15–20
Water (solar elevation 30º)	6
Water (solar elevation 60º)	3

Table showing reflectivity (albedo effect) of different surfaces









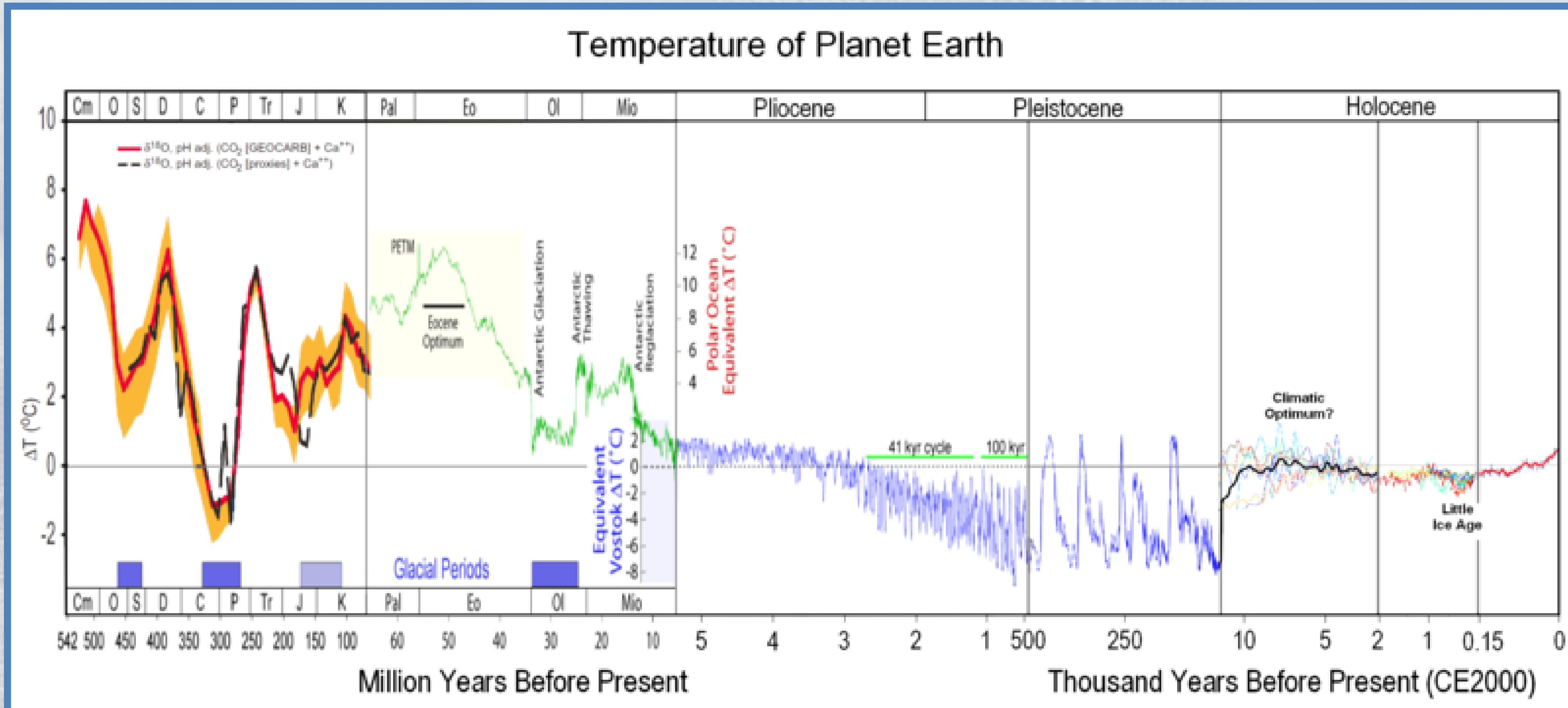
Årsager til disse istider stadig omdiskuteret.

- Kraftig forøgelse af forvitringen af silikatbjergarter i forbindelse med øget nedbør da Rodinia brød op.
- Meget længere kyststrækninger giver mulighed for større primærproduktion, dvs. flere cyanobakterier, som danner organisk stof ved fotosyntese. Dette passer med at iltkoncentrationen i atmosfærer stiger.

Begge disse processer suger drivhusgassen CO_2 ud af atmosfæren.

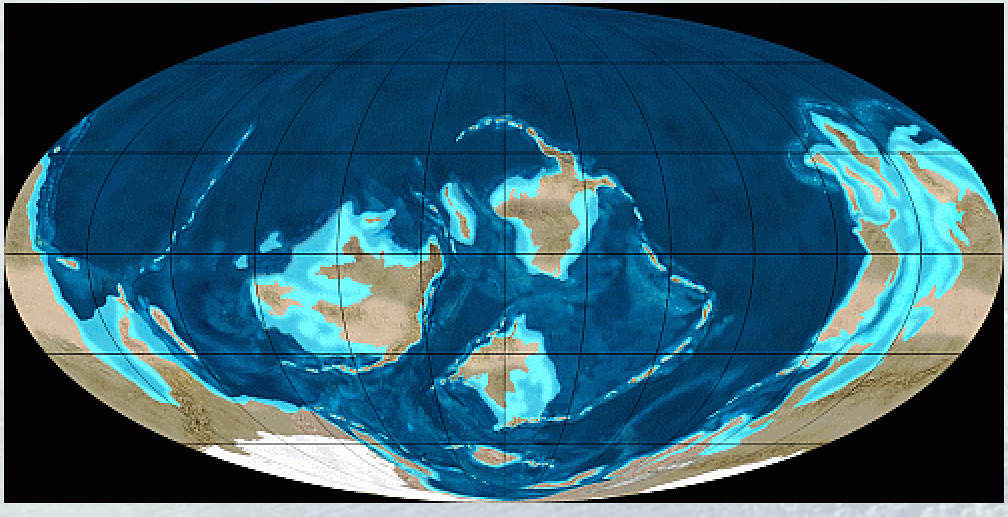
Ediacara

Kambrium



Temperature of Planet Earth
Cm O S D C P Tr J K Pal Eo Ol Mio
Pliocene
Pleistocene
Holocene
ΔT (°C)
PETM
Eocene Optimum
Antarctic Glaciation
Antarctic Thawing
Antarctic Reglaciation
Polar Ocean Equivalent ΔT (°C)
Equivalent Vostok ΔT (°C)
41 kyr cycle
100 kyr
Climatic Optimum?
Little Ice Age
Glacial Periods
Million Years Before Present
Thousand Years Before Present (CE2000)

Sen-ordovicisk istid (Andes-Sahara-istid)   450-420 Ma (?)

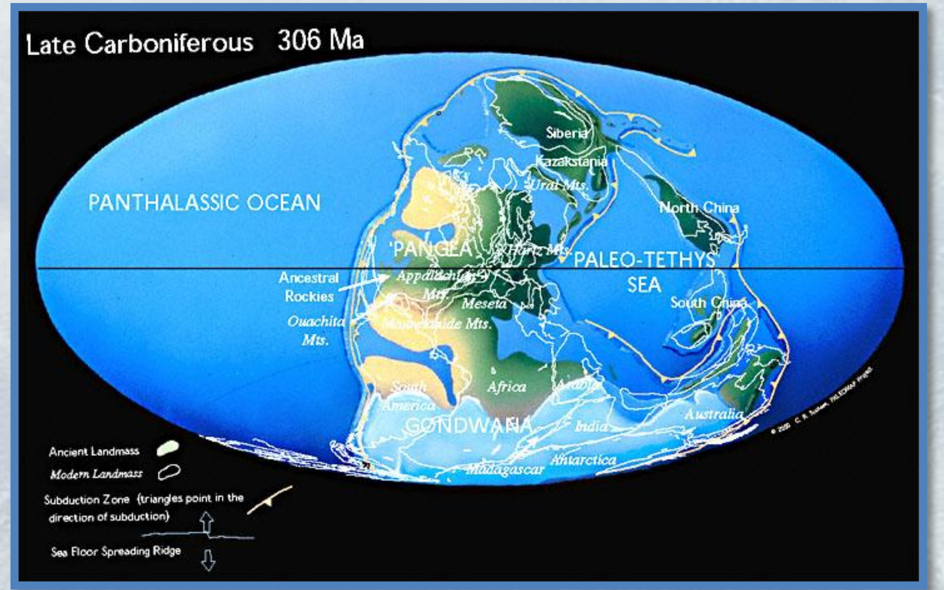


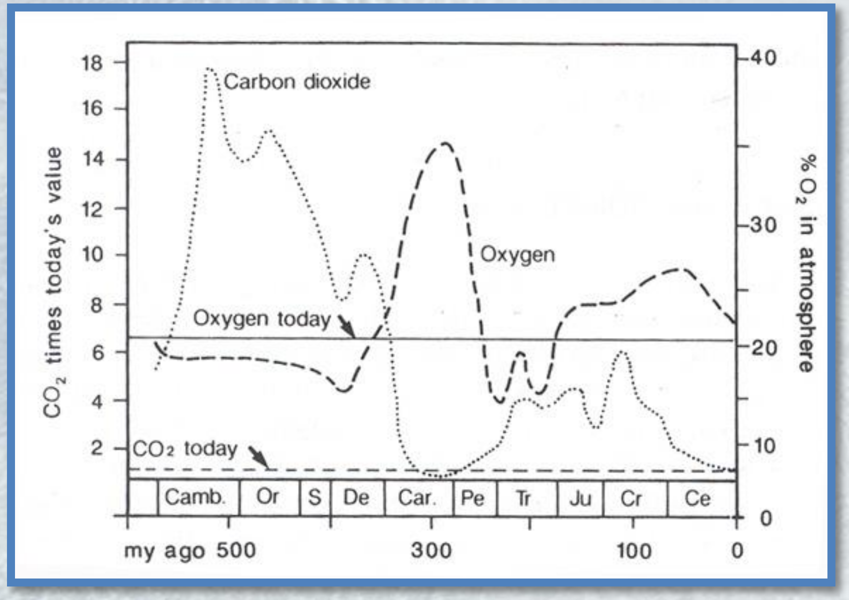
Det centrale Gondwana (Afrika og Sydamerika) glider hen over sydpolen og dækkes af en iskappe. Varmt i Nordamerika, Europa og Sibirien.
Havoverfladen falder ca. 80 m.
Masseuddøen – især primærproduktionen.

Gammaglimt fra supernova i Mælkevejen?
10 sek. Stråling. Ozonlag destrueres. Ilt+kvælstof danner salpetersyre.

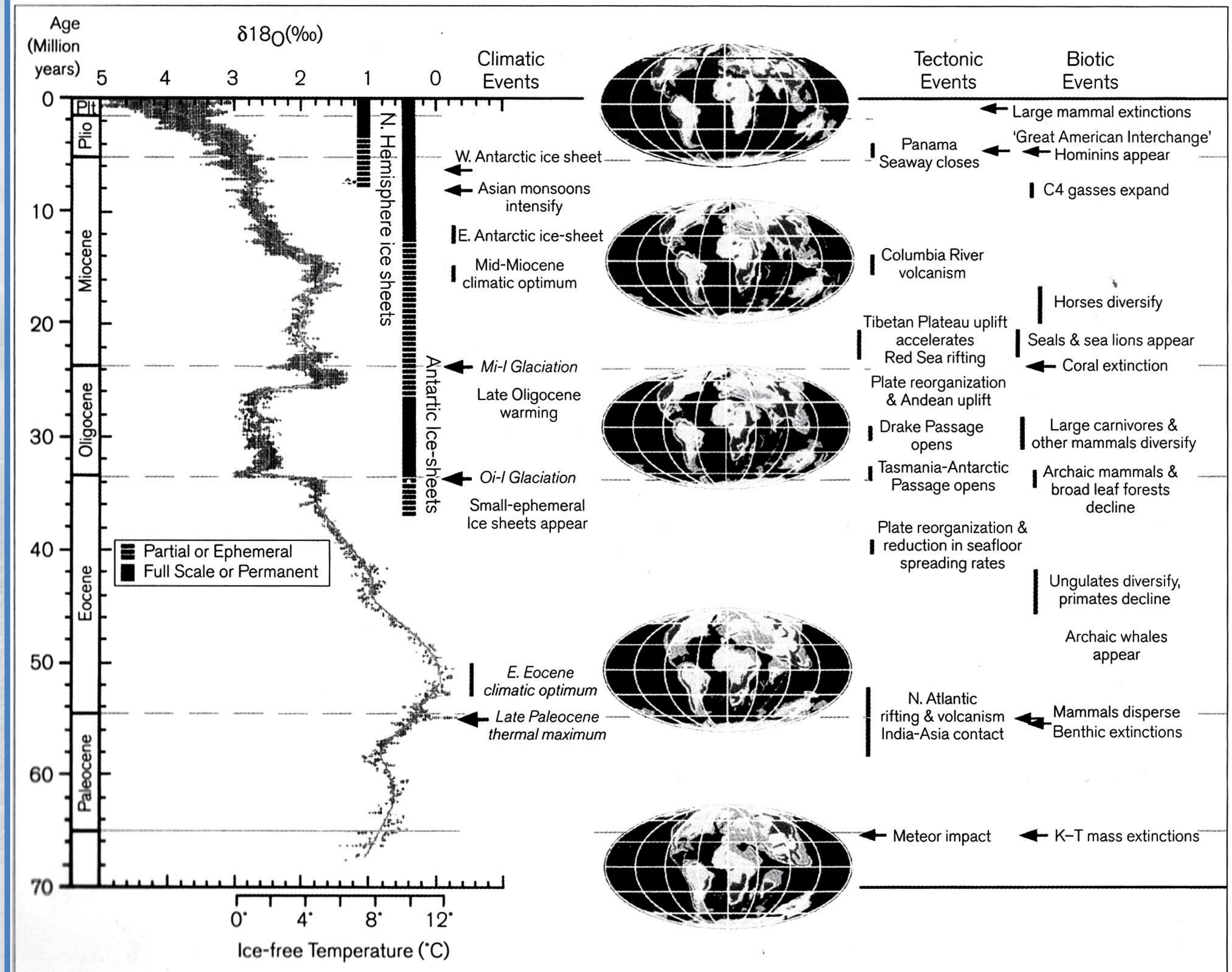
Den overlevende fauna der genbefolkede verden synes at være kommet fra dybt vand og høje breddegrader.

Carbon-Perm-istiden 360-260 Ma

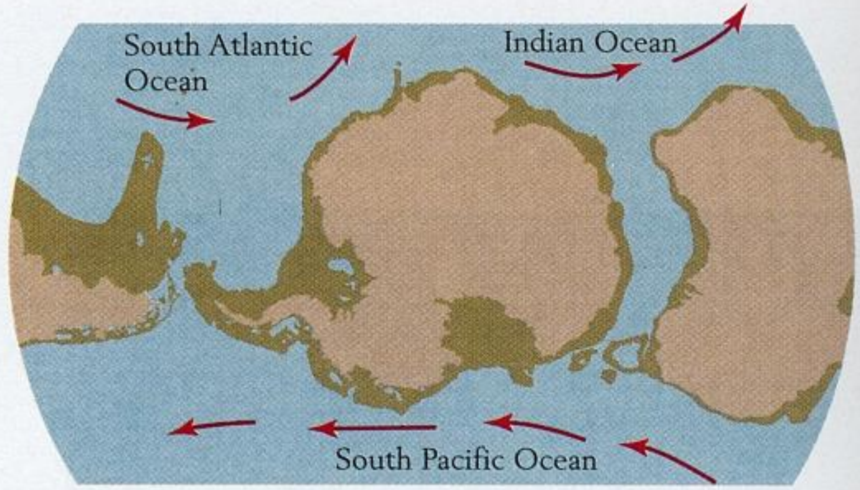




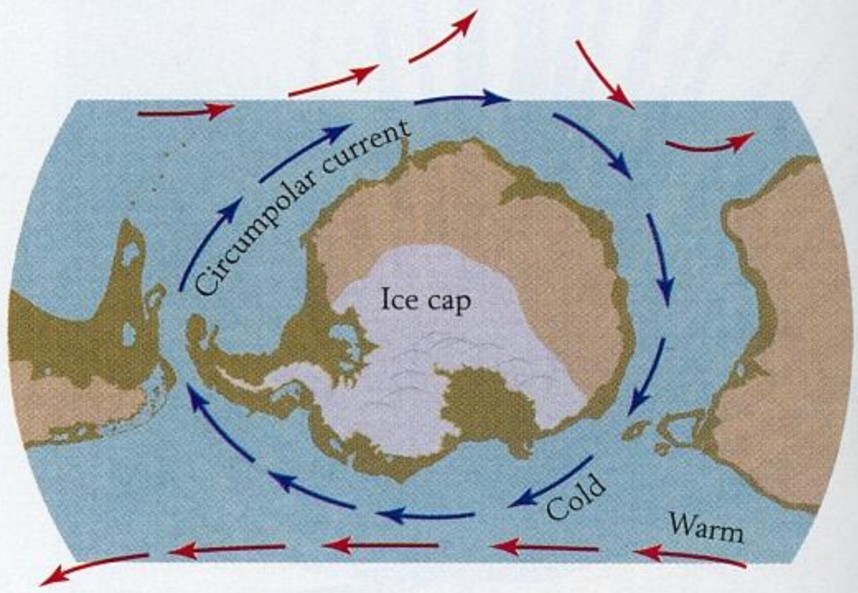
Store mængder kulstof deponeret i vegetation, som senere blev til de store kulforekomster.
CO_2 i atmosfæren faldt som følge heraf.
Store fluktuationer i løbet af perioden.



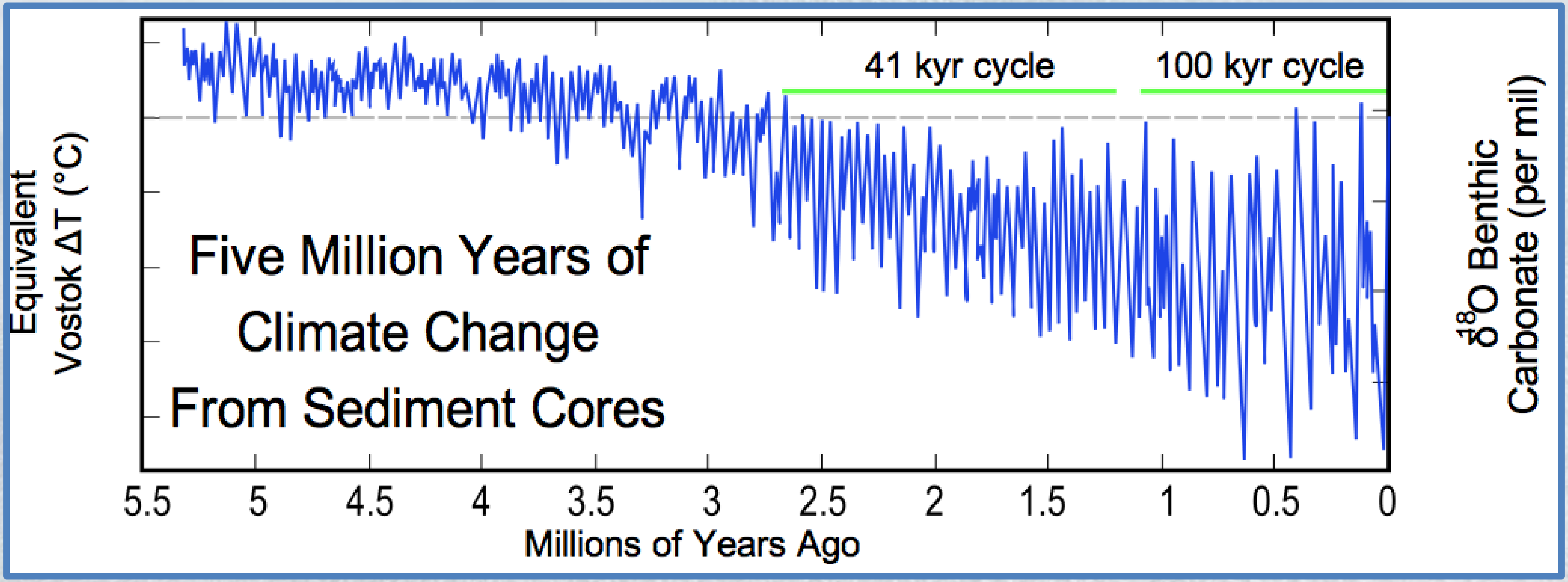
Age (Million years)
δ18O(‰)
5 4 3 2 1 0
Climatic Events
Tectonic Events
Biotic Events
0
10
20
30
40
50
60
70
Plt
Plio
Miocene
Oligocene
Eocene
Paleocene
N. Hemisphere ice sheets
Antartic Ice-sheets
Partial or Ephemeral
Full Scale or Permanent
0° 4° 8° 12°
Ice-free Temperature (°C)
W. Antarctic ice sheet
Asian monsoons intensify
E. Antarctic ice-sheet
Mid-Miocene climatic optimum
Mi-I Glaciation
Late Oligocene warming
Oi-I Glaciation
Small-ephemeral Ice sheets appear
E. Eocene climatic optimum
Late Paleocene thermal maximum
Panama Seaway closes
Columbia River volcanism
Tibetan Plateau uplift accelerates
Red Sea rifting
Plate reorganization & Andean uplift
Drake Passage opens
Tasmania-Antarctic Passage opens
Plate reorganization & reduction in seafloor spreading rates
N. Atlantic rifting & volcanism
India-Asia contact
Meteor impact
Large mammal extinctions
'Great American Interchange'
Hominins appear
C4 gasses expand
Horses diversify
Seals & sea lions appear
Coral extinction
Large carnivores & other mammals diversify
Archaic mammals & broad leaf forests decline
Ungulates diversify, primates decline
Archaic whales appear
Mammals disperse
Benthic extinctions
K–T mass extinctions



A MIDDLE EOCENE

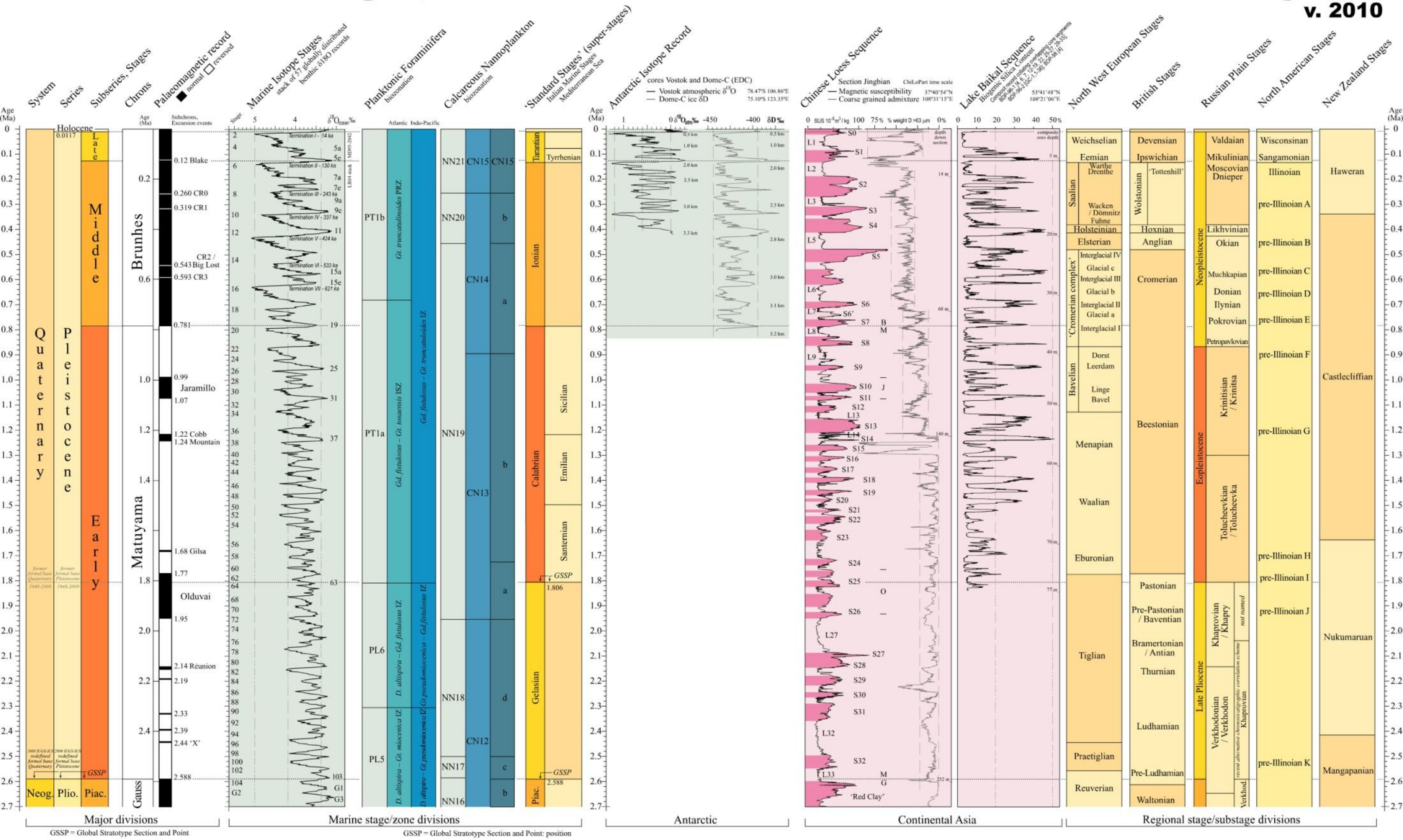


B EARLY OLIGOCENE


Five Million Years of
Climate Change
From Sediment Cores
41 kyr cycle
100 kyr cycle
Equivalent
Vostok ΔT (°C)
δ18O Benthic
Carbonate (per mil)
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Millions of Years Ago

Global chronostratigraphical correlation table for the last 2.7 million years

v. 2010



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http://www.cam.ac.uk/

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http://www-qpg.geog.cam.ac.uk/

Universiteit Utrecht

http://www.geo.uu.nl/

International Union for Quaternary Research (INQUA), Stratigraphy and Chronology Commission (SACCOM).

http://www.inqua.tcd.ie/

International Union of Geological Sciences (IUGS), International Commission on Stratigraphy (ICS), Subcommission on Quaternary Stratigraphy (SQS).

http://www.stratigraphy.org/

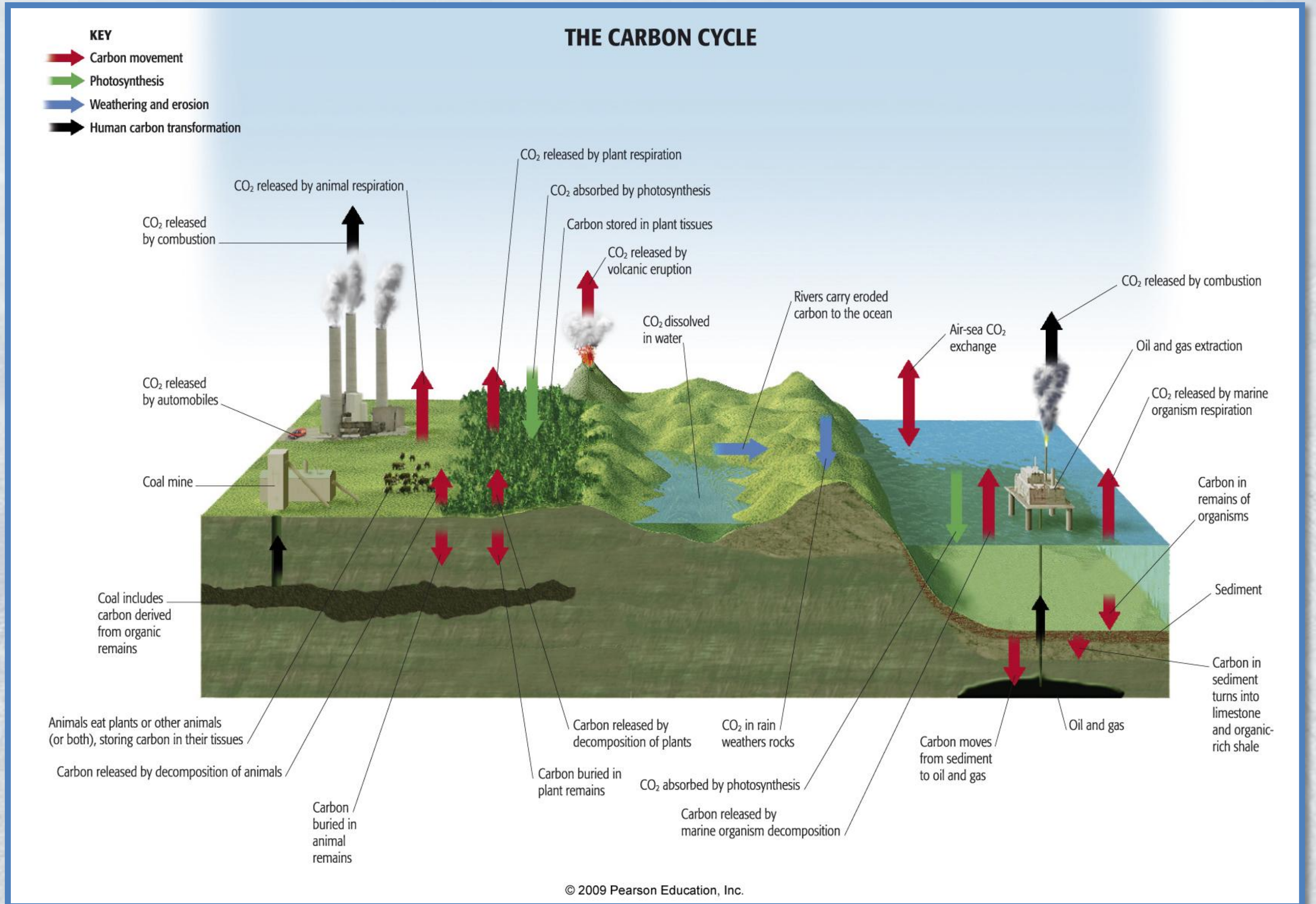
KONKLUSIONER

Pladetektonikken danner konfigurationer af kontinenterne, som muliggør at der opstår istider.

Andre forhold som f. eks. biosfærens påvirkning af atmosfæren, vulkanudbrud og astronomiske begivenheder kan udløse en istid.

Langsigtede negative feedback-mekanismer sørger for, at Jordens klima holder sig inden for ret snævre rammer med flydende vand.

Mere kortsigtede positive feedback-mekanismer sørger for at der inden for dette temperaturområde opstår ret betydelige og hurtige svingninger.



Den helt afgørende faktor en kulstofkredsløbet – som er en indviklet sag at forstå til bunds!

SLUT