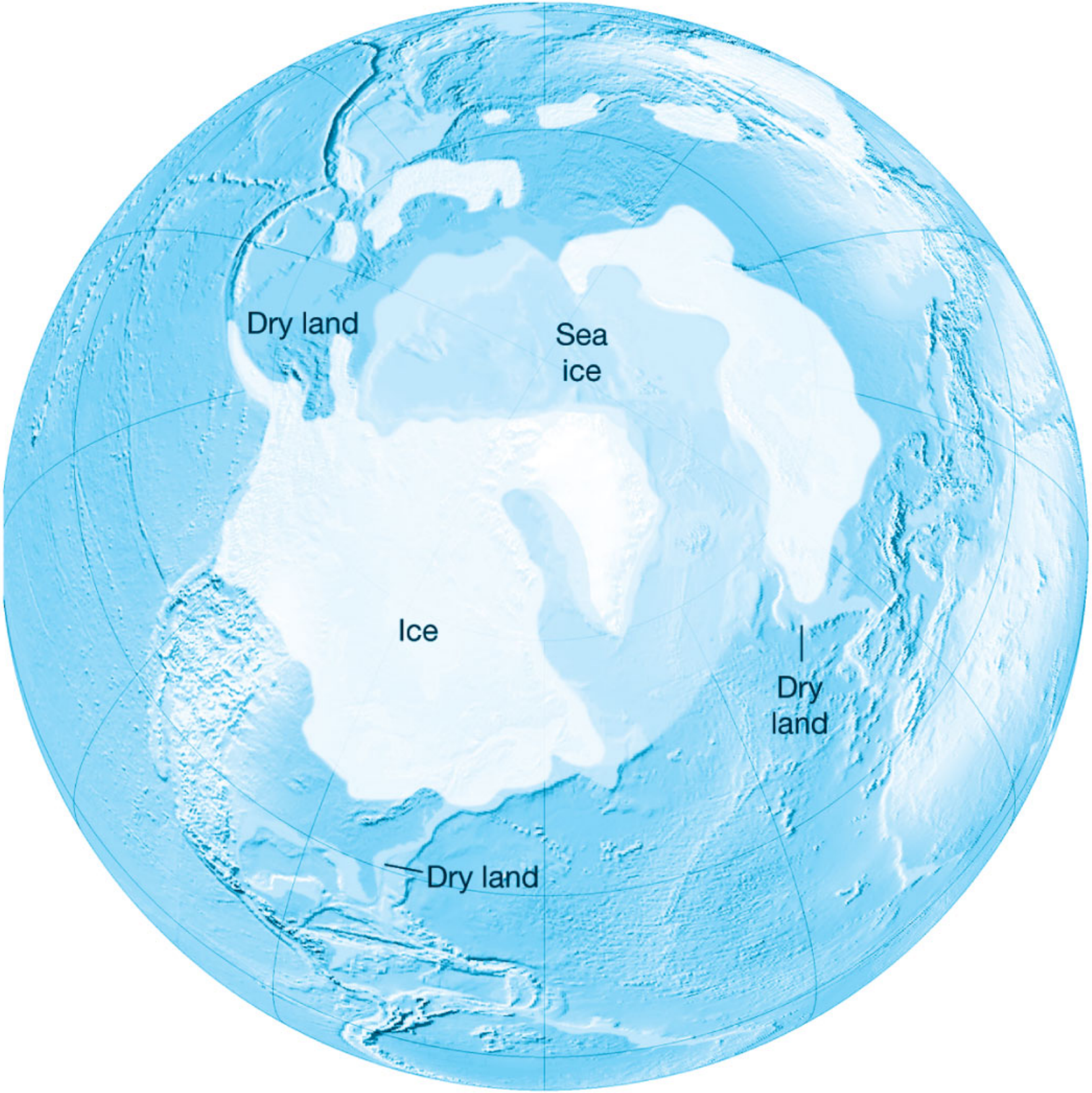
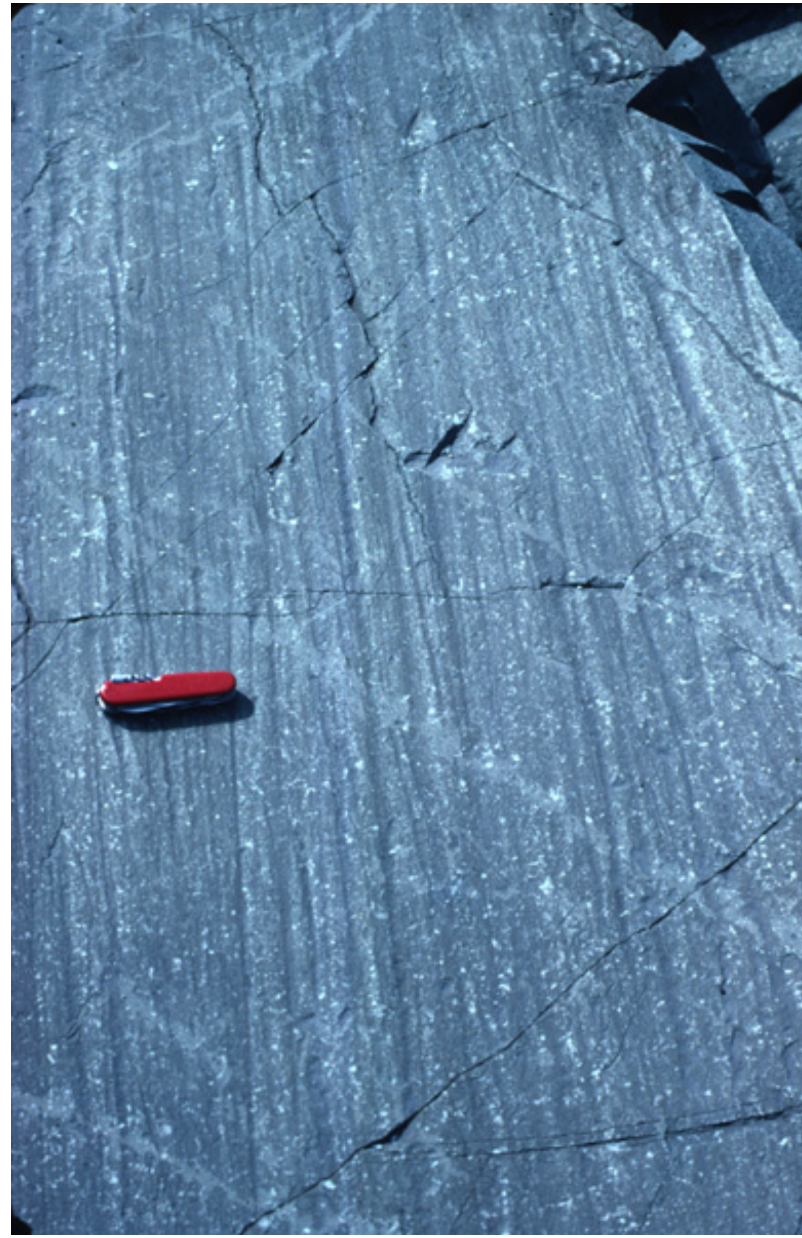
Ch. 14: Pleistocene Glaciations

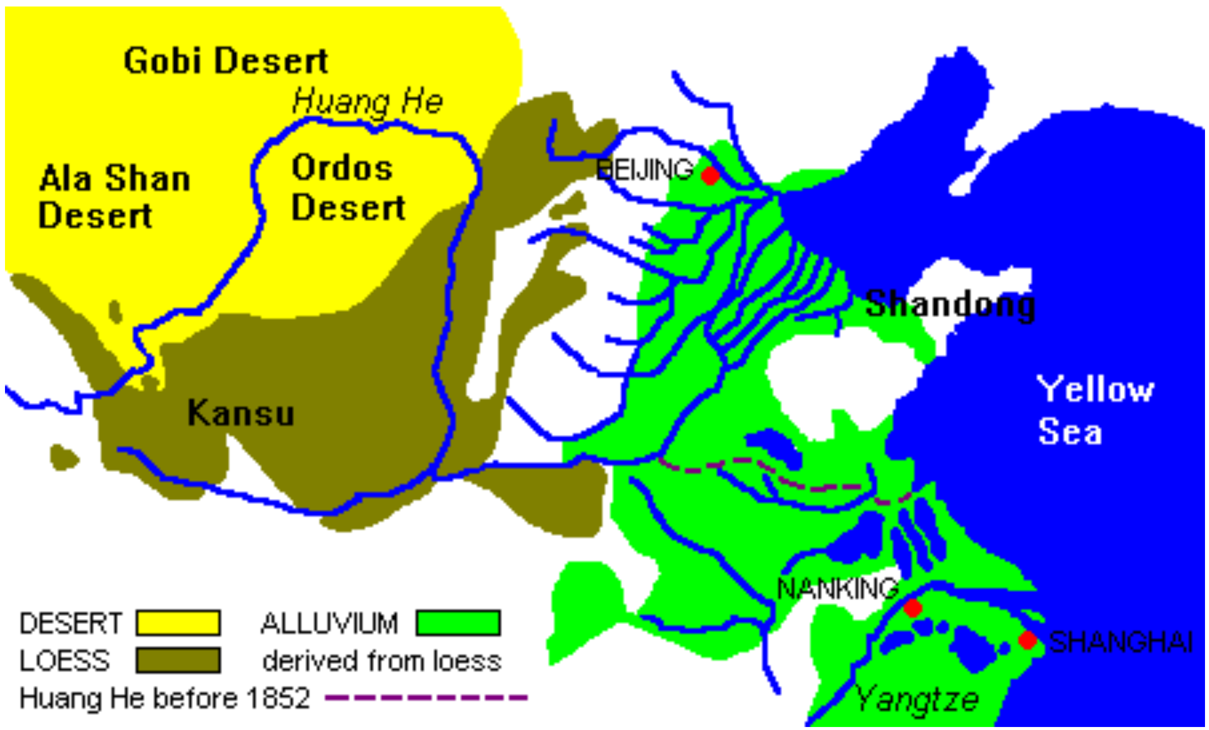

Dry land
Sea
ice
Ice
Dry
land
Dry land

Glacial Striations

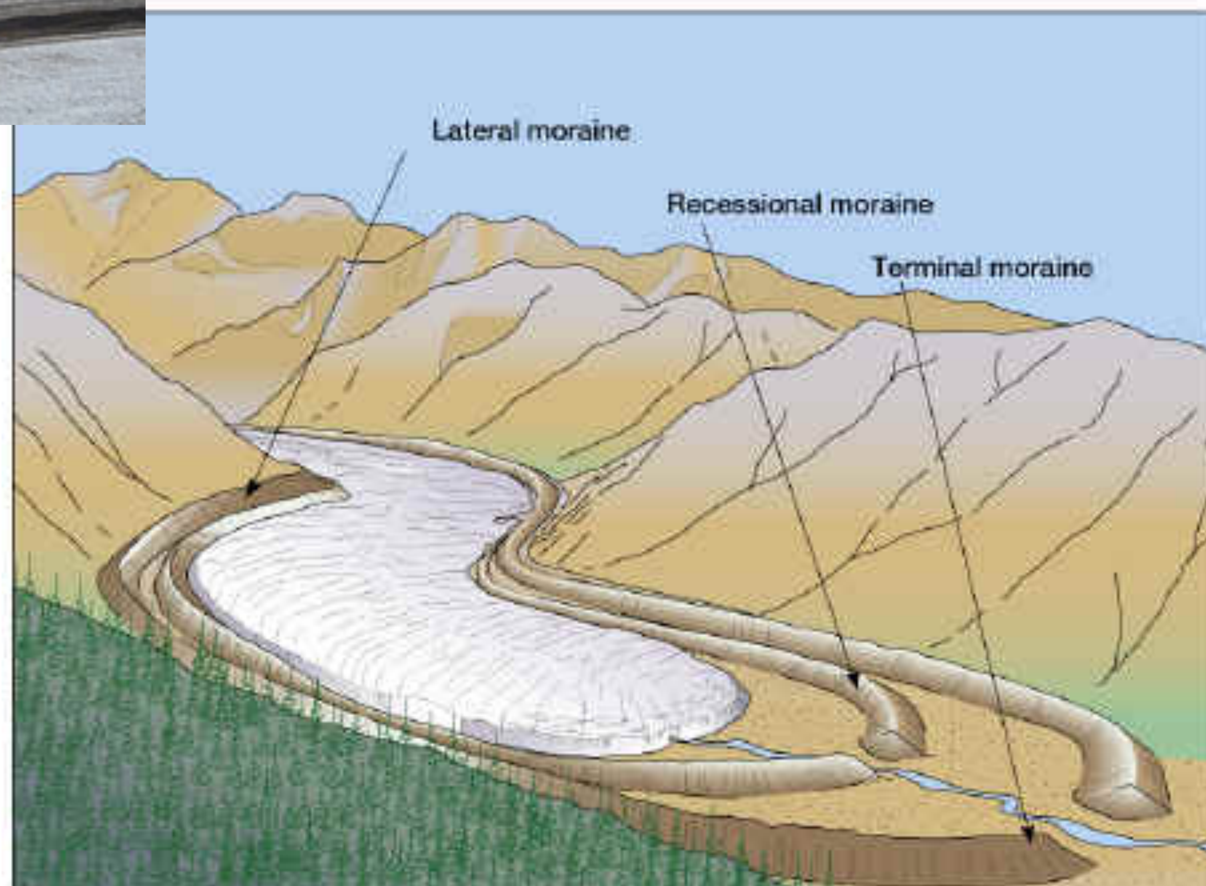


Glacial Till

Loess


Gobi Desert
Huang He
Ala Shan
Desert
Ordos
Desert
Kansu
BEIJING
Shandong
Yellow
Sea
NANKING
SHANGHAI
Yangtze
DESERT
LOESS
ALLUVIUM
derived from loess
Huang He before 1852

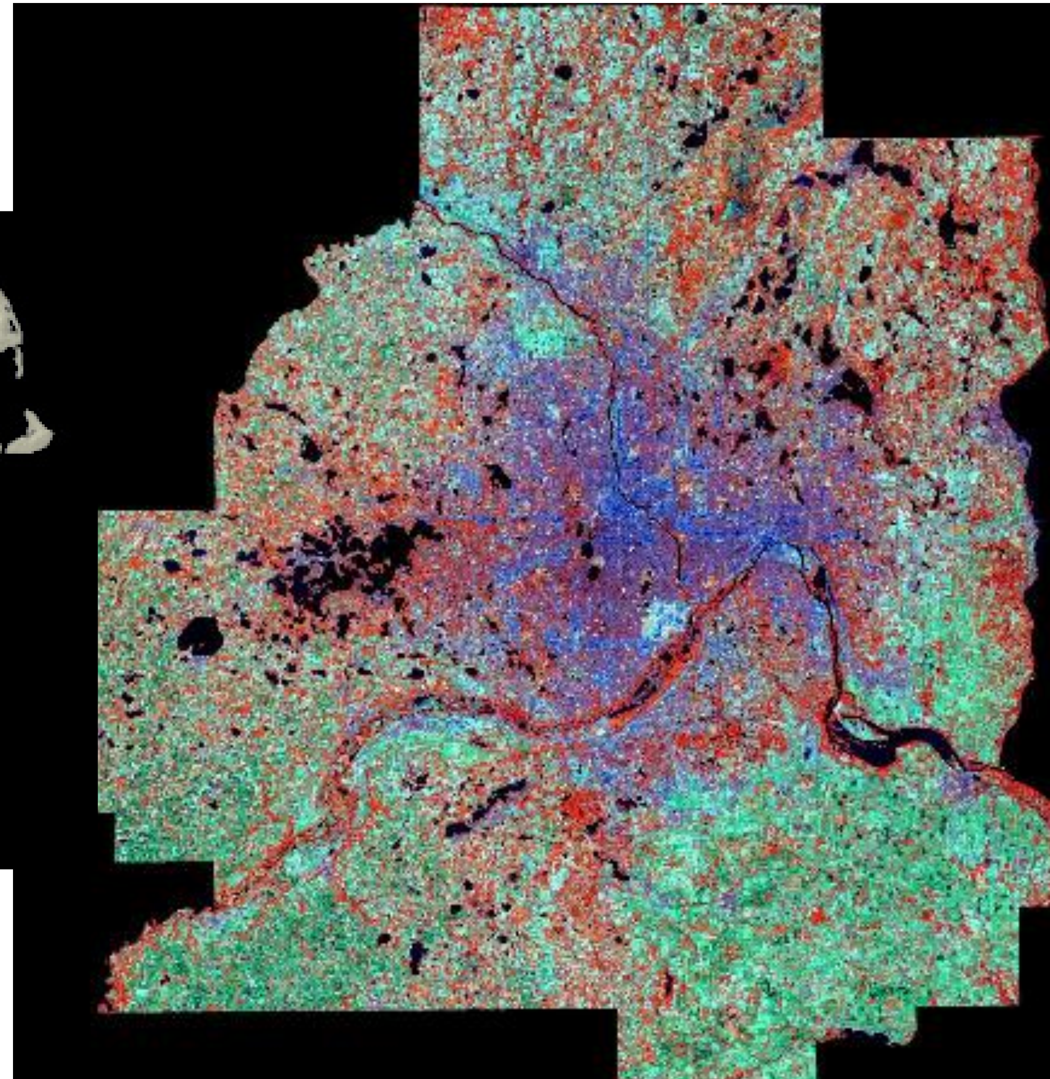
Moraines


Lateral moraine
Recessional moraine
Terminal moraine


RAO



Glacial Landscapes



Eskers

Oxygen Isotope Fractionation

- …Between ocean and ice

$$\delta^{18}O_{sample} = \left[\frac{\left(\frac{^{18}O}{^{16}O}\right)_{sample} - \left(\frac{^{18}O}{^{16}O}\right)_{standard}}{\left(\frac{^{18}O}{^{16}O}\right)_{standard}} \right] \times 1000$$

Fractionation Processes…

- $H_2{}^{16}O$ evaporates more readily than $H_2{}^{18}O$
- $H_2{}^{18}O$ condenses more readily than $H_2{}^{16}O$ in rain…
- Ice in ice sheets is enriched in $H_2{}^{16}O$, and oceans become enriched in $H_2{}^{18}O$

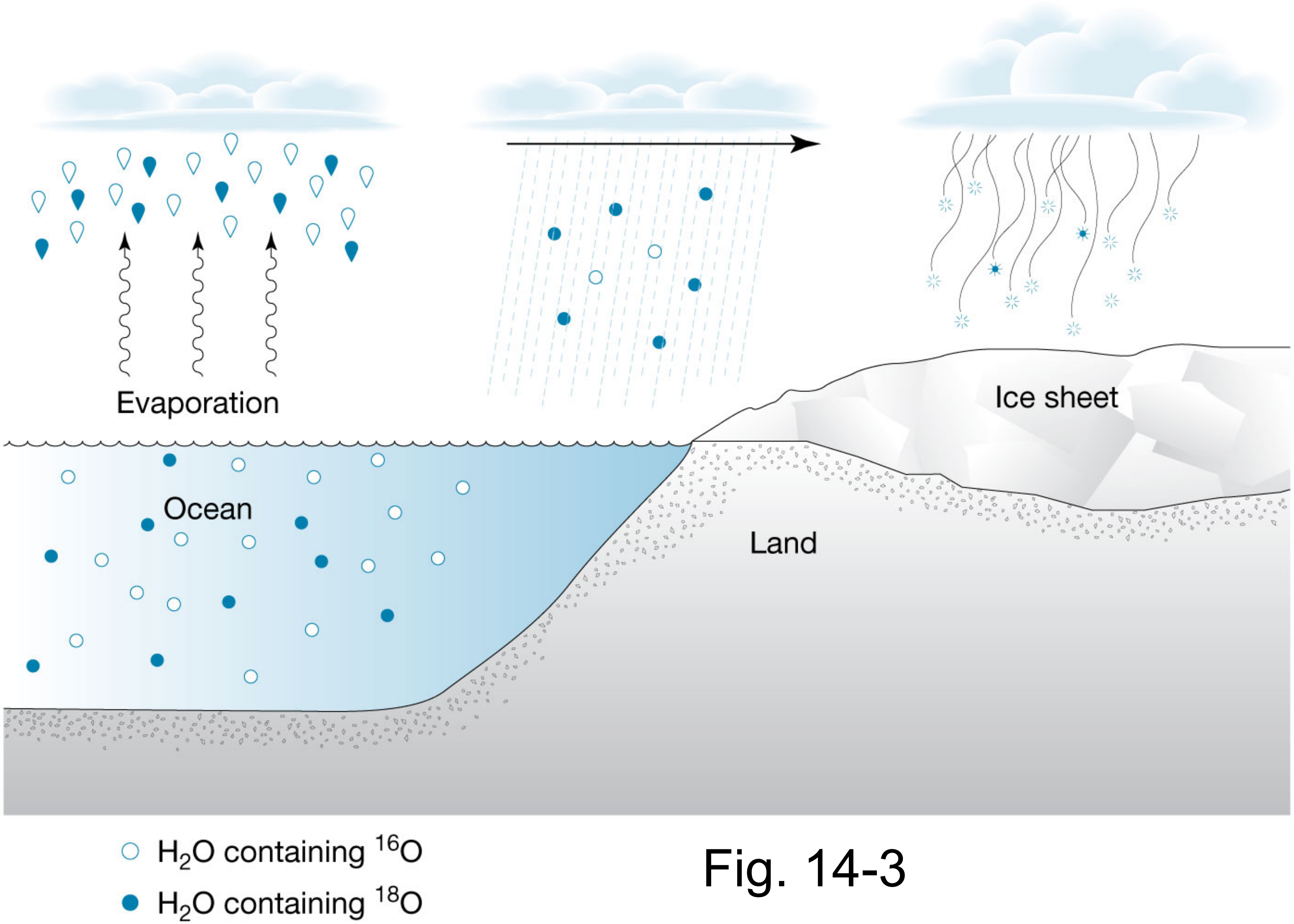
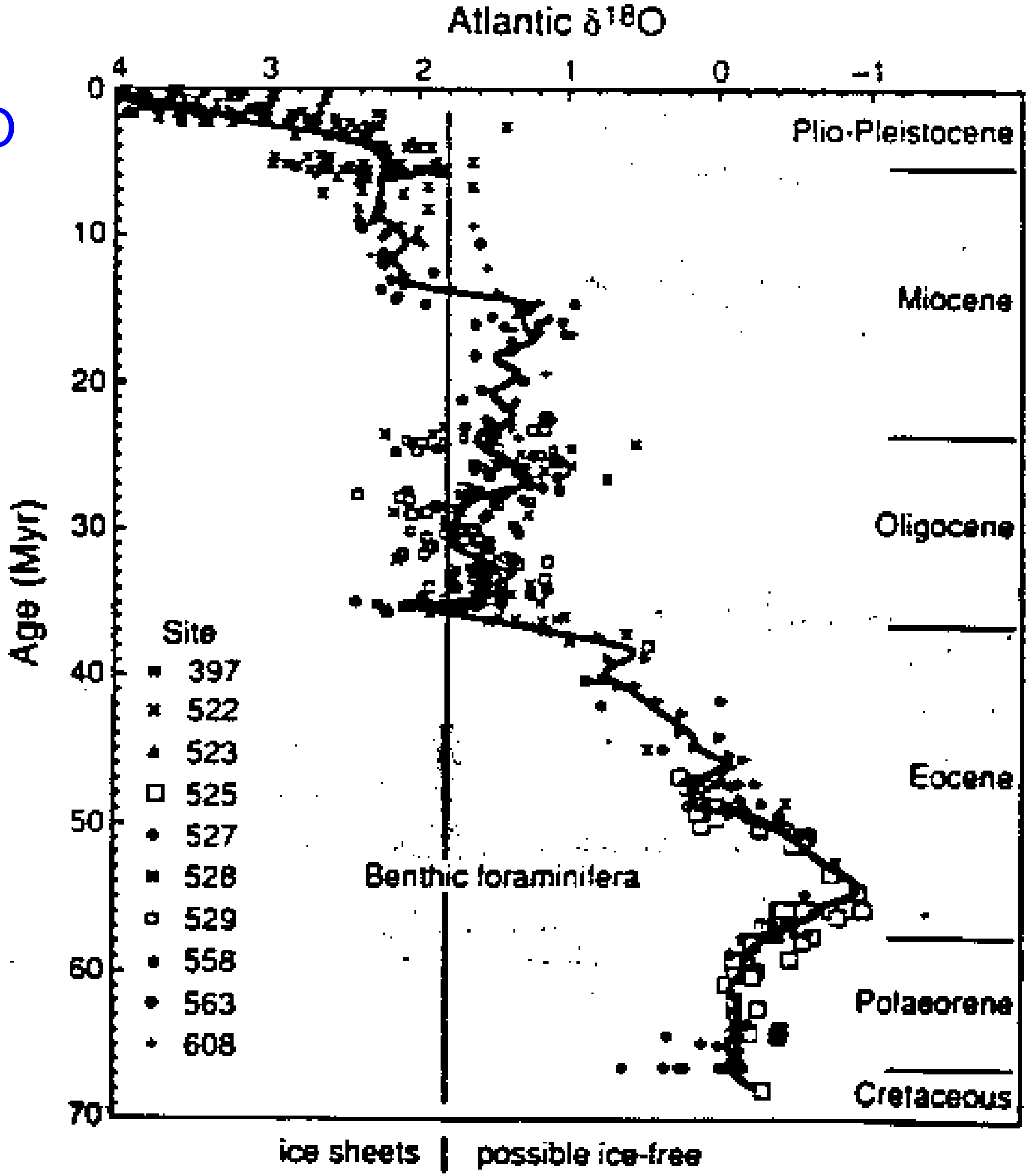

Evaporation
Ice sheet
Ocean
Land
H2O containing 16O
H2O containing 18O

Fig. 14-3

Example:

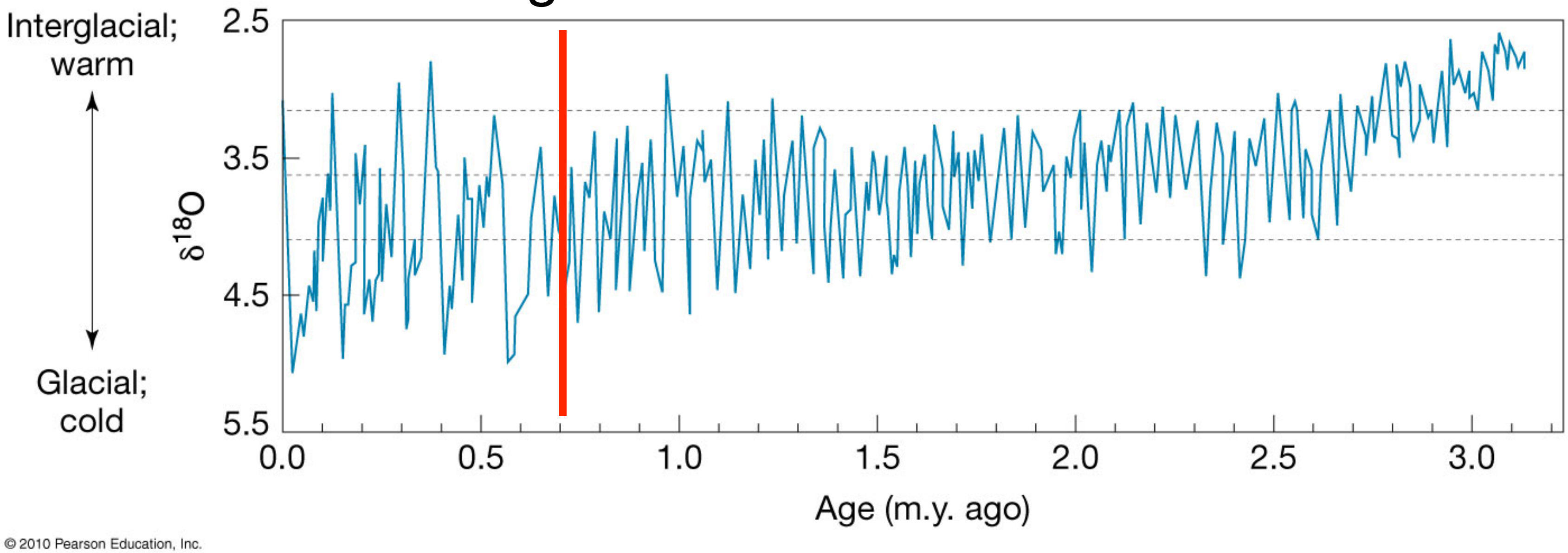
This is $\delta^{18}O$ record for ocean - what is happening to ^{16}O??



Recent Ice Ages:

- What causes ice ages?
- Why do they change frequency over time?

Fig. 14-4



- For the last 700,000 years, glaciations occur roughly every 100,000 years
- Prior to this, cold periods occurred about every 40,000 years
- Something fundamental changed at about 700,000 years ago

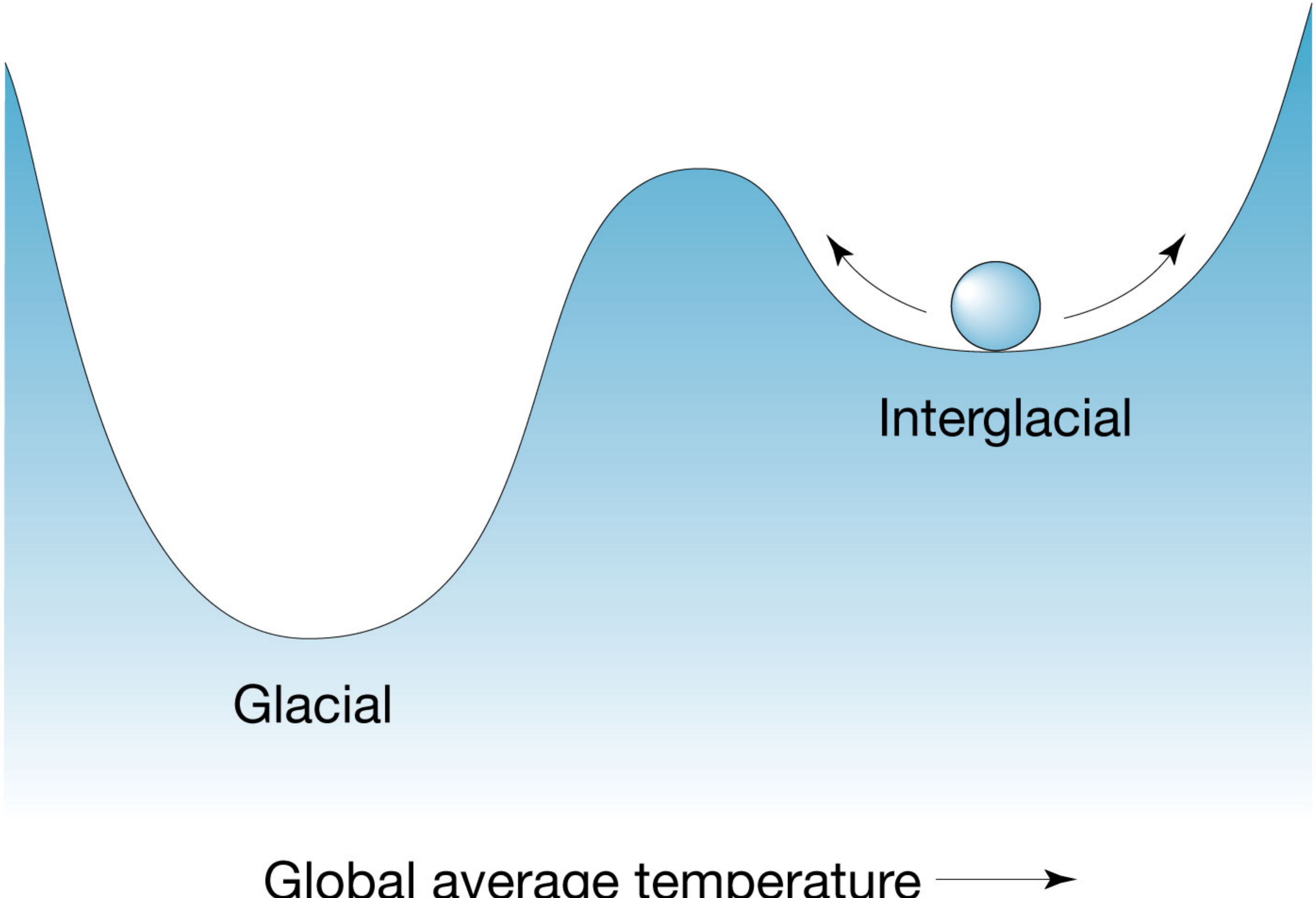


Fig. 14-7

Milankovitch Cycles

Variations in Earth's orbital parameters definitely affect total solar insolation a key latitudes!

-Insolation equatorially is not so important

-Insolation at ~65°N latitude is VERY important!

Fig. 14-5

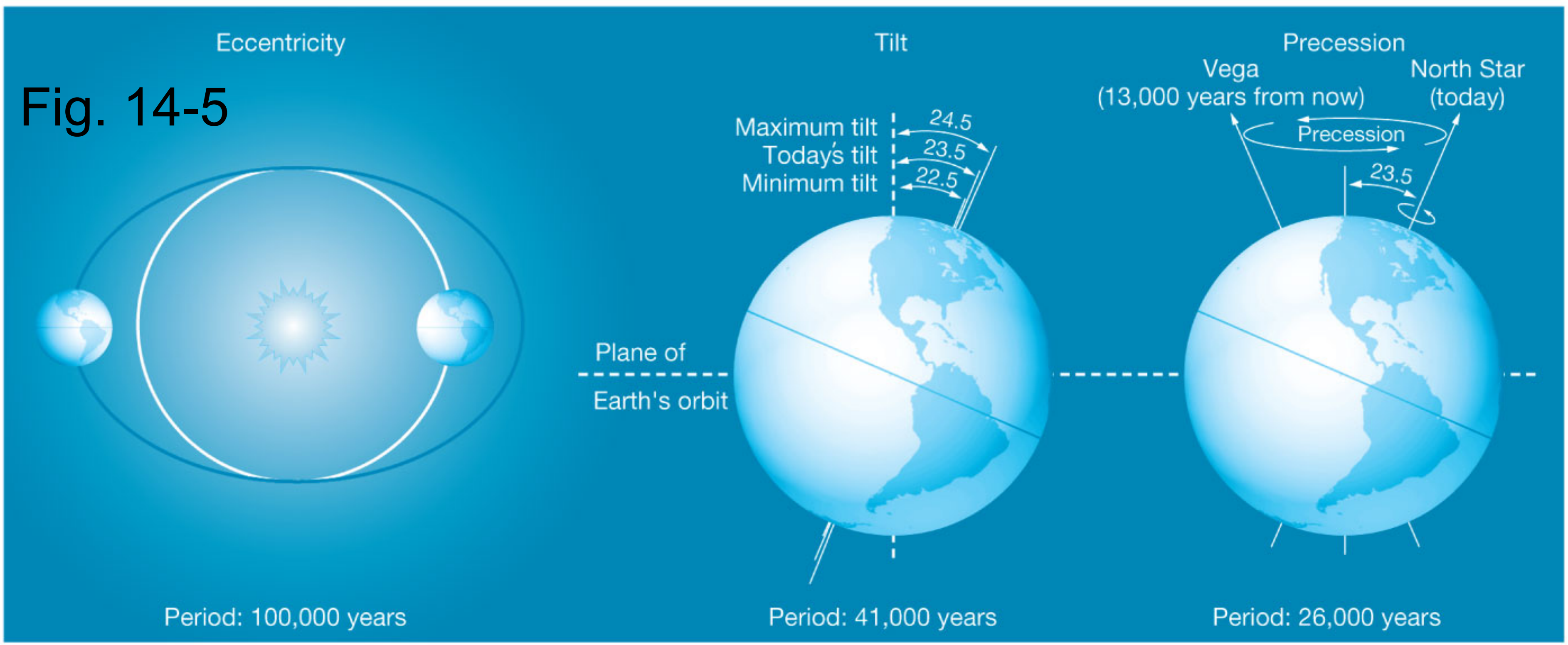
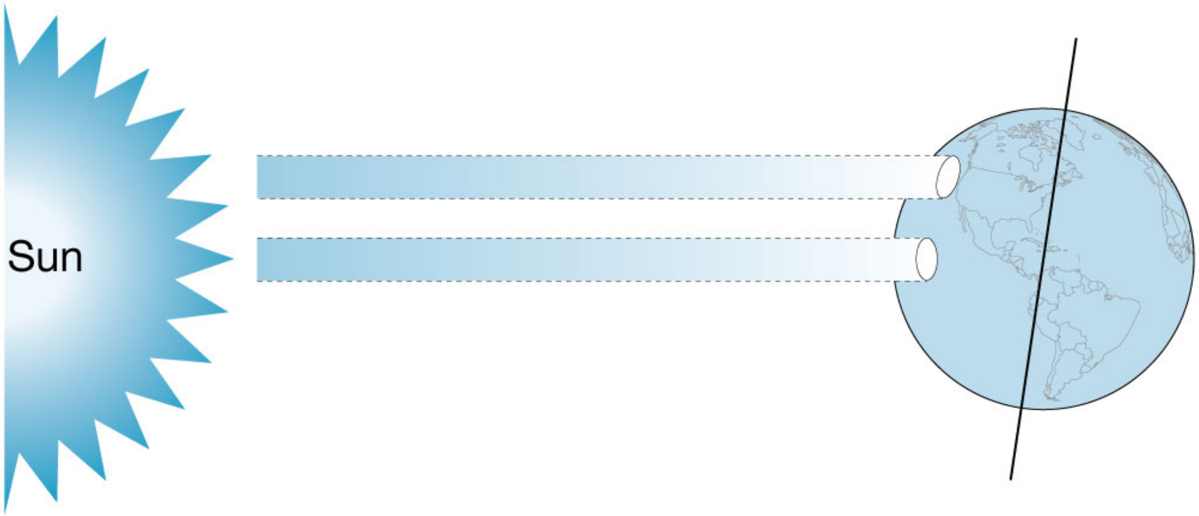
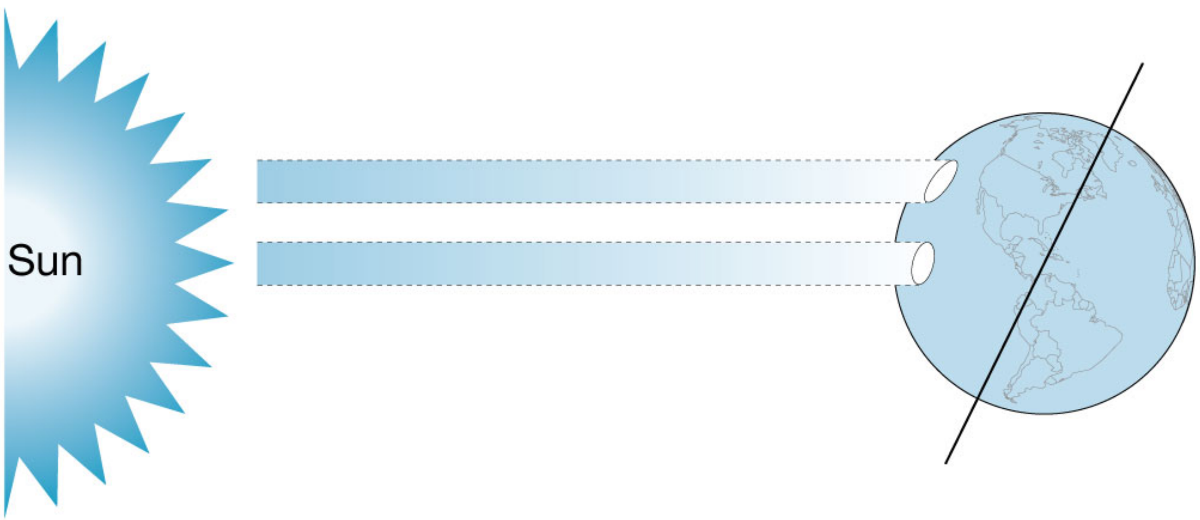


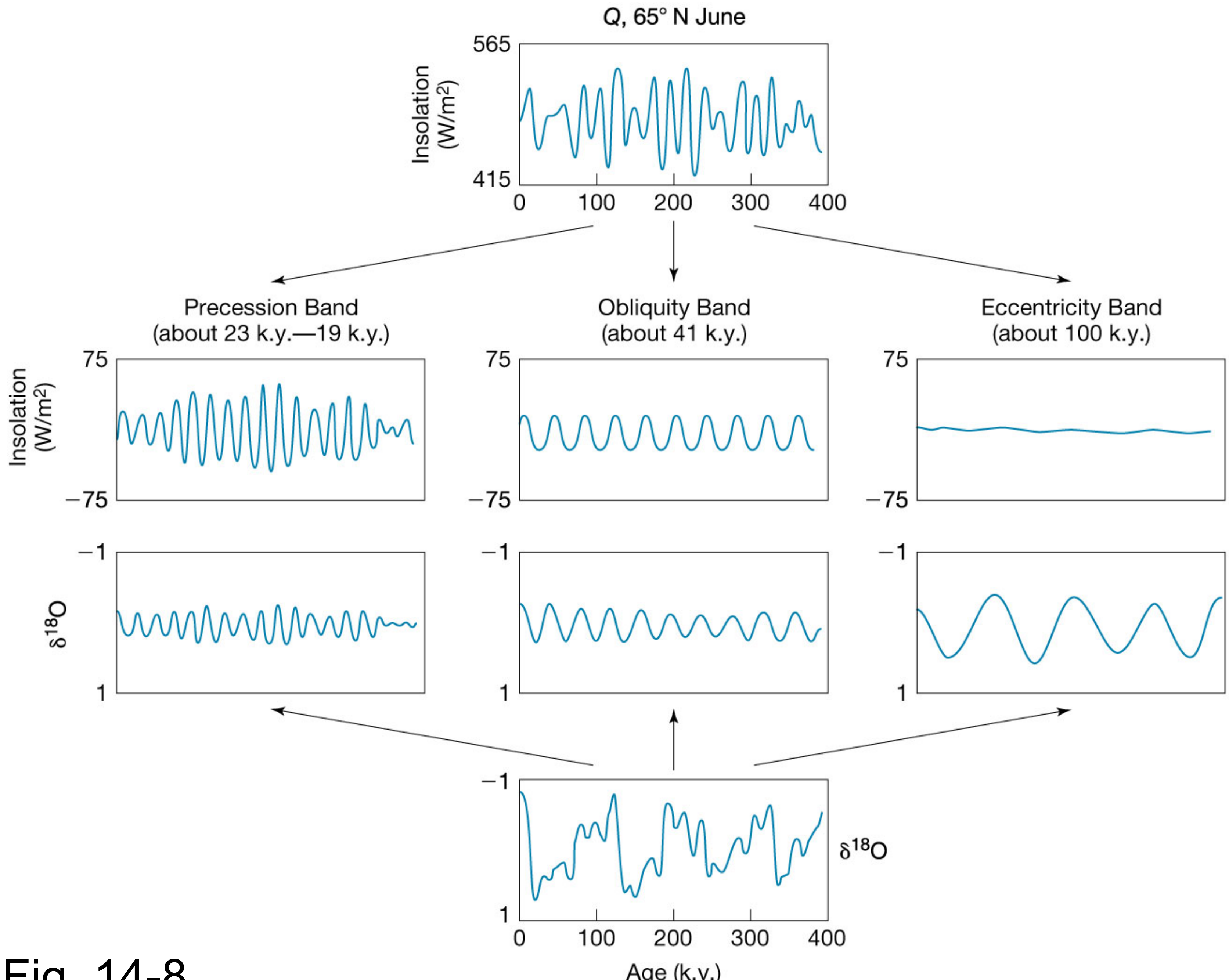
Fig. 14-6



(a) Low obliquity

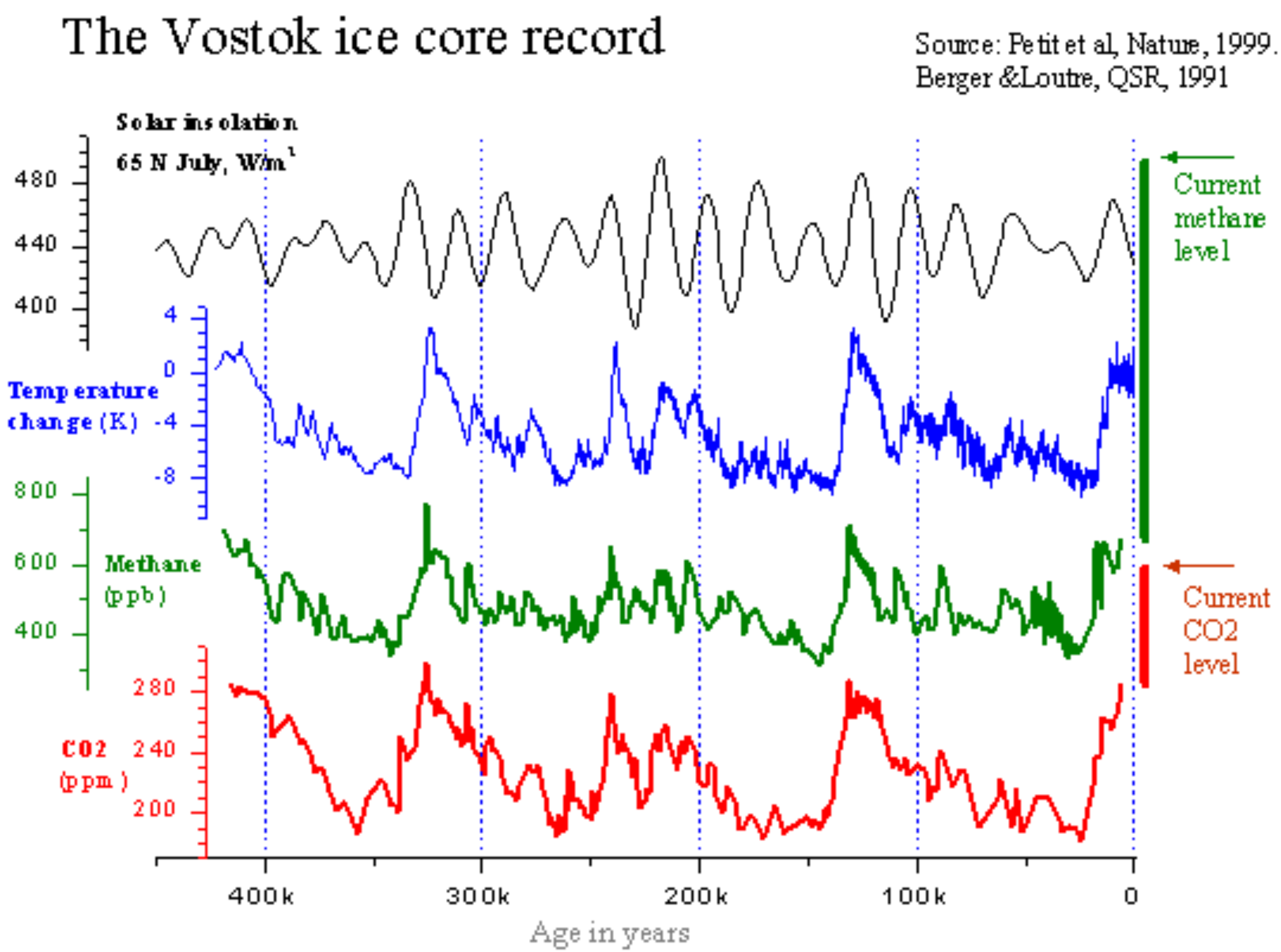


(b) High obliquity



Q, 65° N June
565
Insolation (W/m²)
415
0
100
200
300
400
Precession Band
(about 23 k.y.—19 k.y.)
Obliquity Band
(about 41 k.y.)
Eccentricity Band
(about 100 k.y.)
75
Insolation (W/m²)
−75
−1
δ18O
1
δ18O
Age (k.y.)

Fig. 14-8



A close link between global temperatures, greenhouse gasses, and global ice volume

Feedbacks…

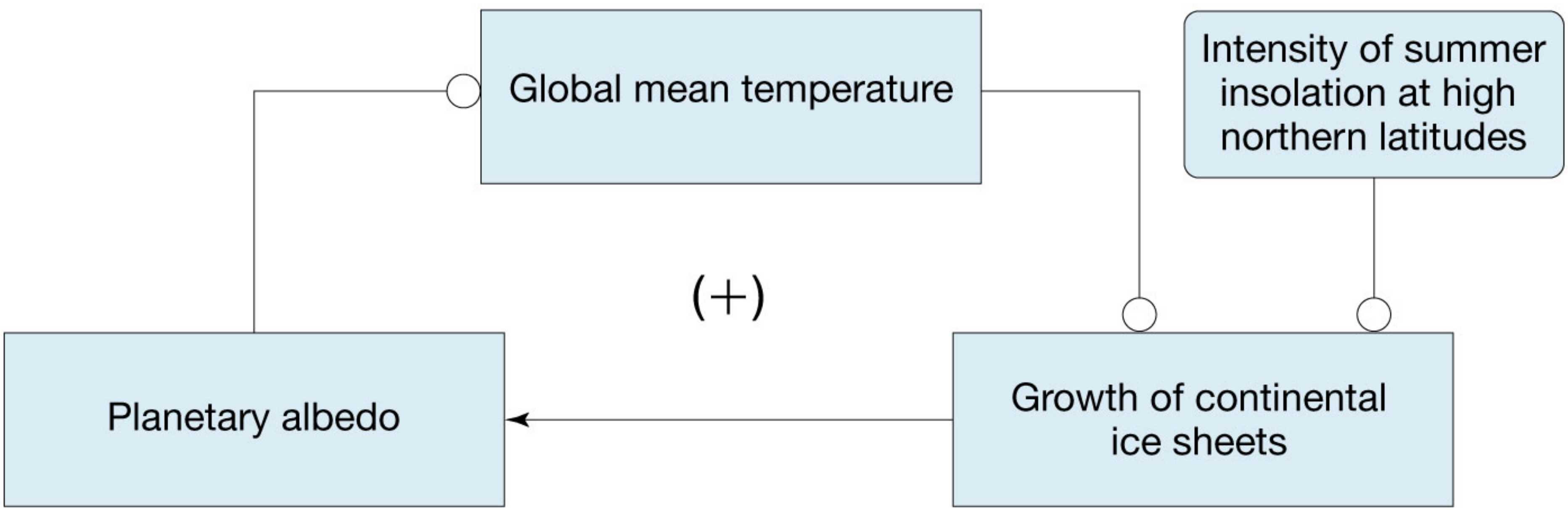
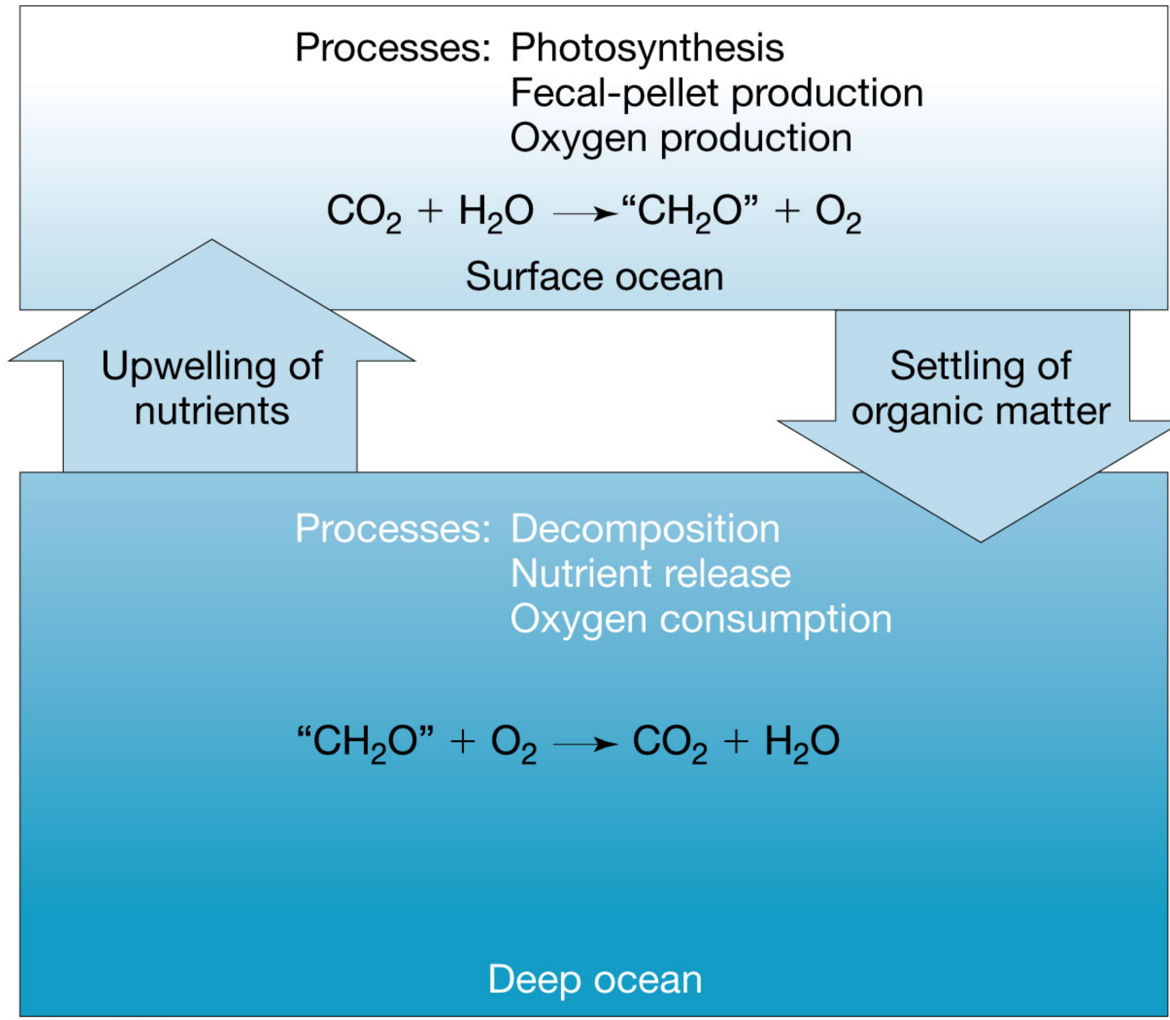


Fig. 14-9

Back to the "biological pump":

- Long-term inorganic carbon cycle is too long for the glacial-interglacial cycle
- Focus on the biological pump because it operates on the right time scale



Efficiency with P_{CO2}

- At preindustrial 280 ppm CO_2, biological pump operates at intermediate efficiency
- If bio-pump were 100% efficient and used all nutrients to their limit, P_{CO2} would be about 165 ppm
- If bio-pump ceased, P_{CO2} would be about 720 ppm!

Low P_{CO2} = efficient bio-pump?

- In other words, you can substantially affect atmospheric CO_2 and the greenhouse effect by changing nutrient supply to the oceans
- Shelf-nutrient hypothesis
- Iron-fertilization hypothesis
- Coral-reef hypothesis

Shelf-nutrient hypothesis

- Nutrient availability: Balance between supply and burial

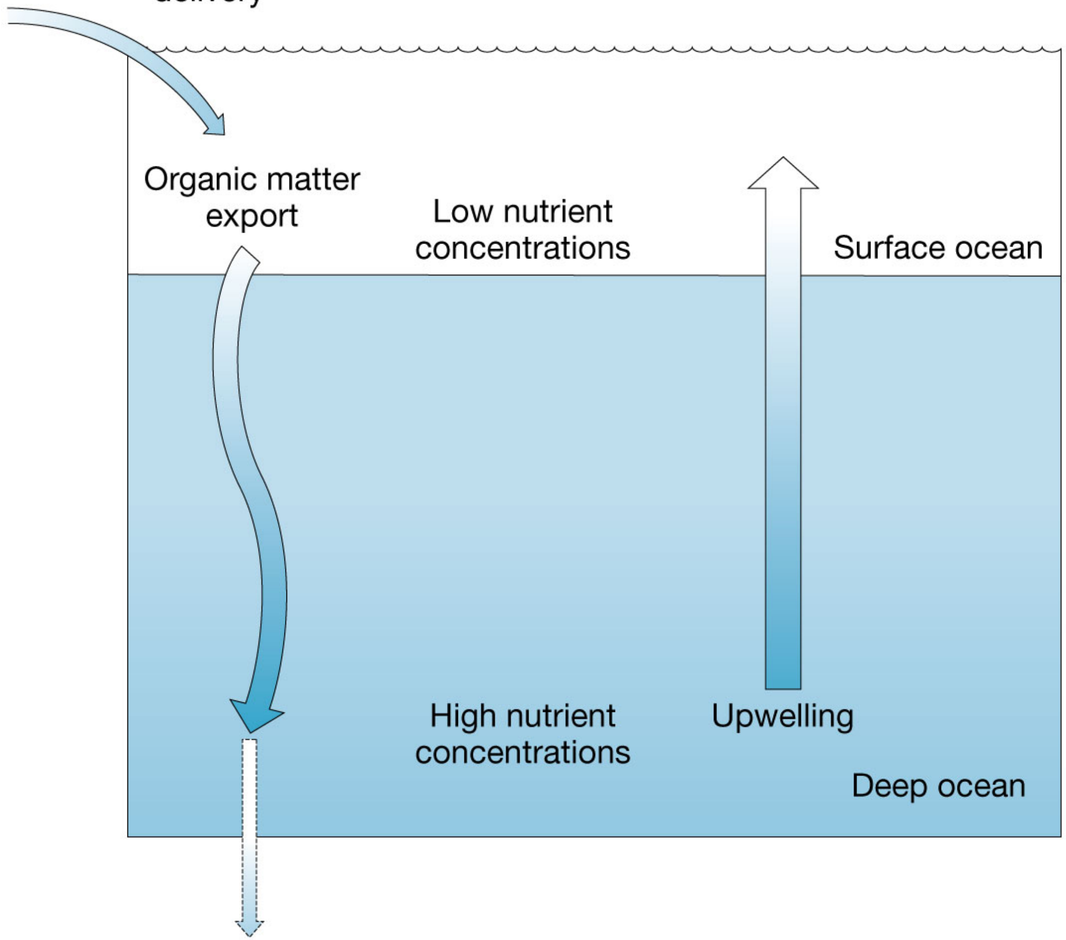


Fig. 14-10

More ice, lower sea-level

- Rivers draining exposed shelf bring nutrients from sediments

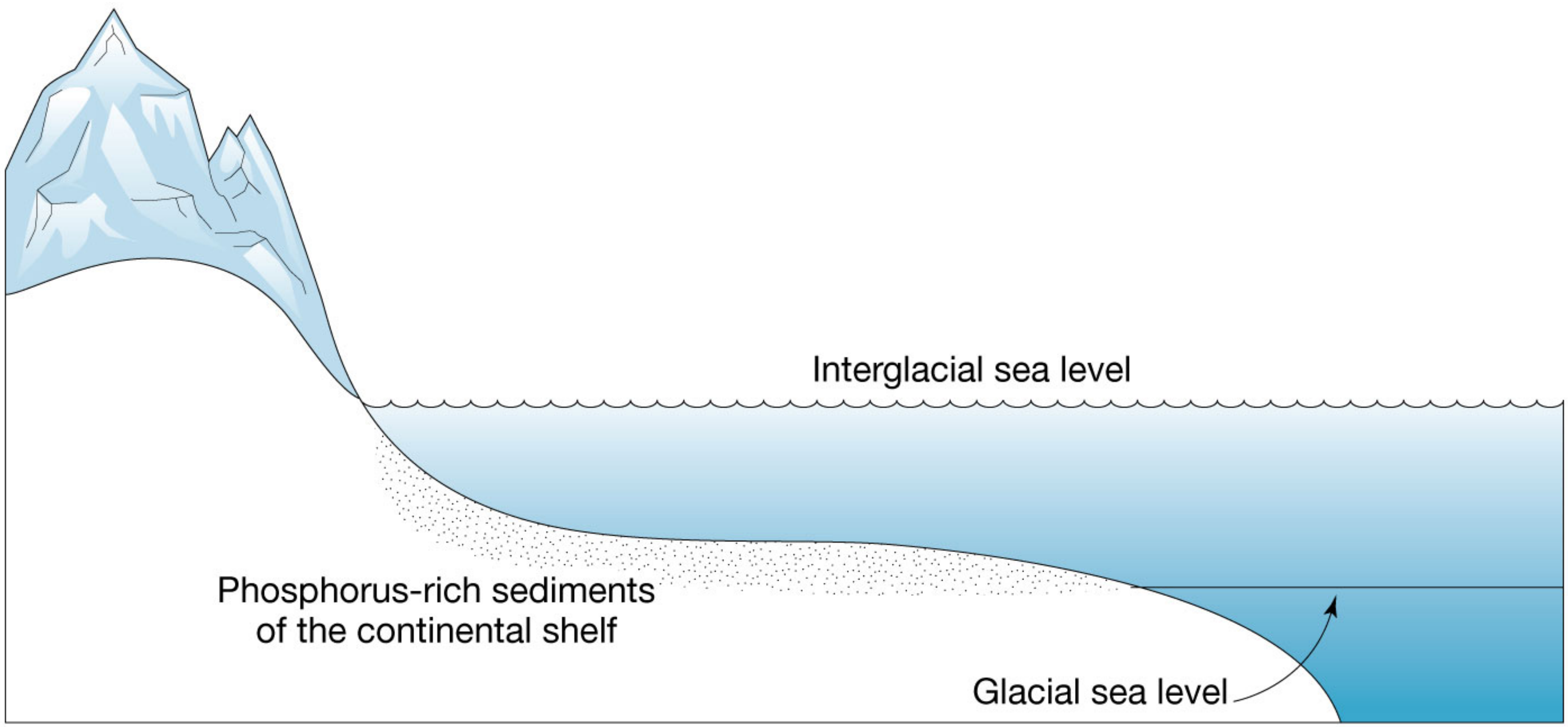
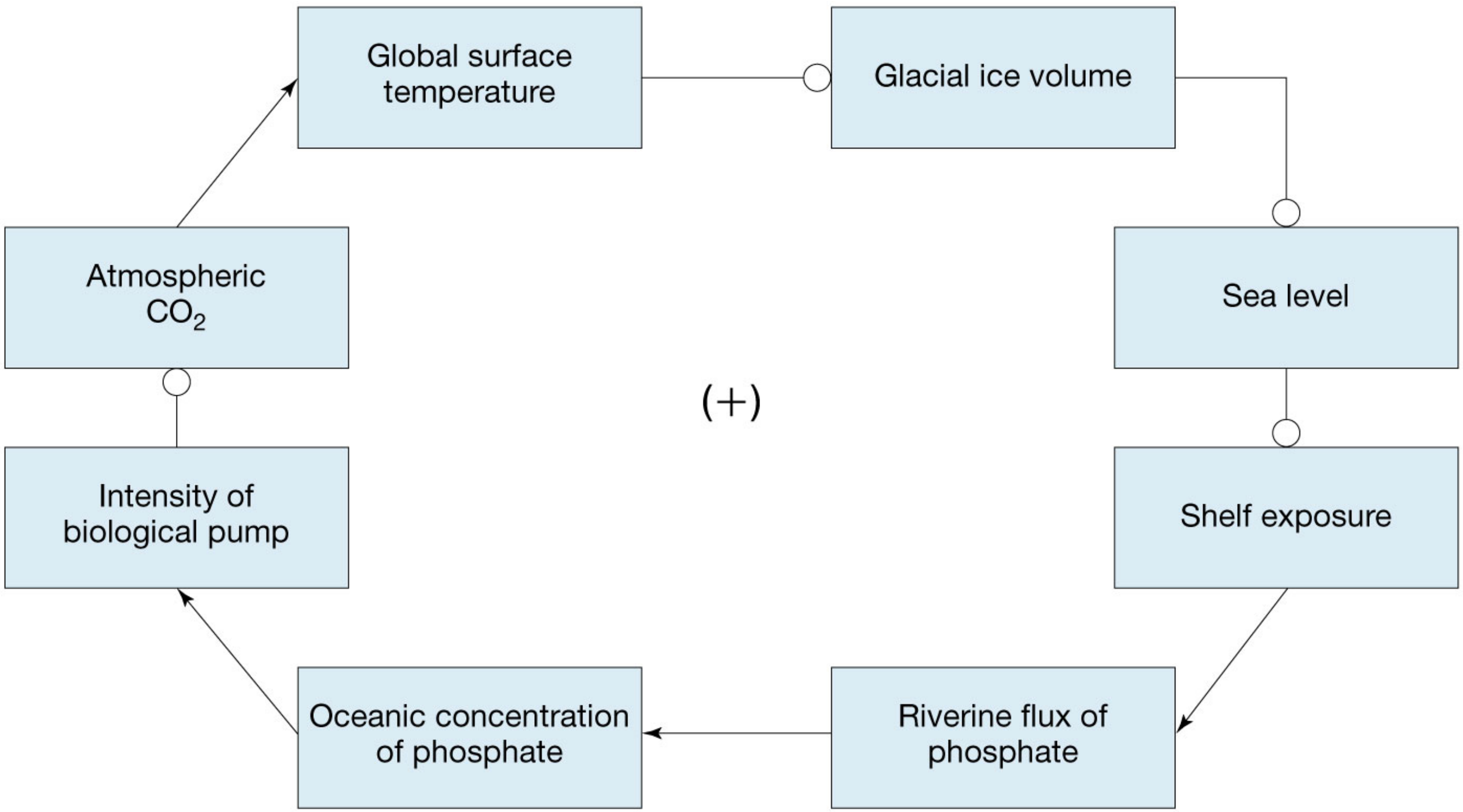


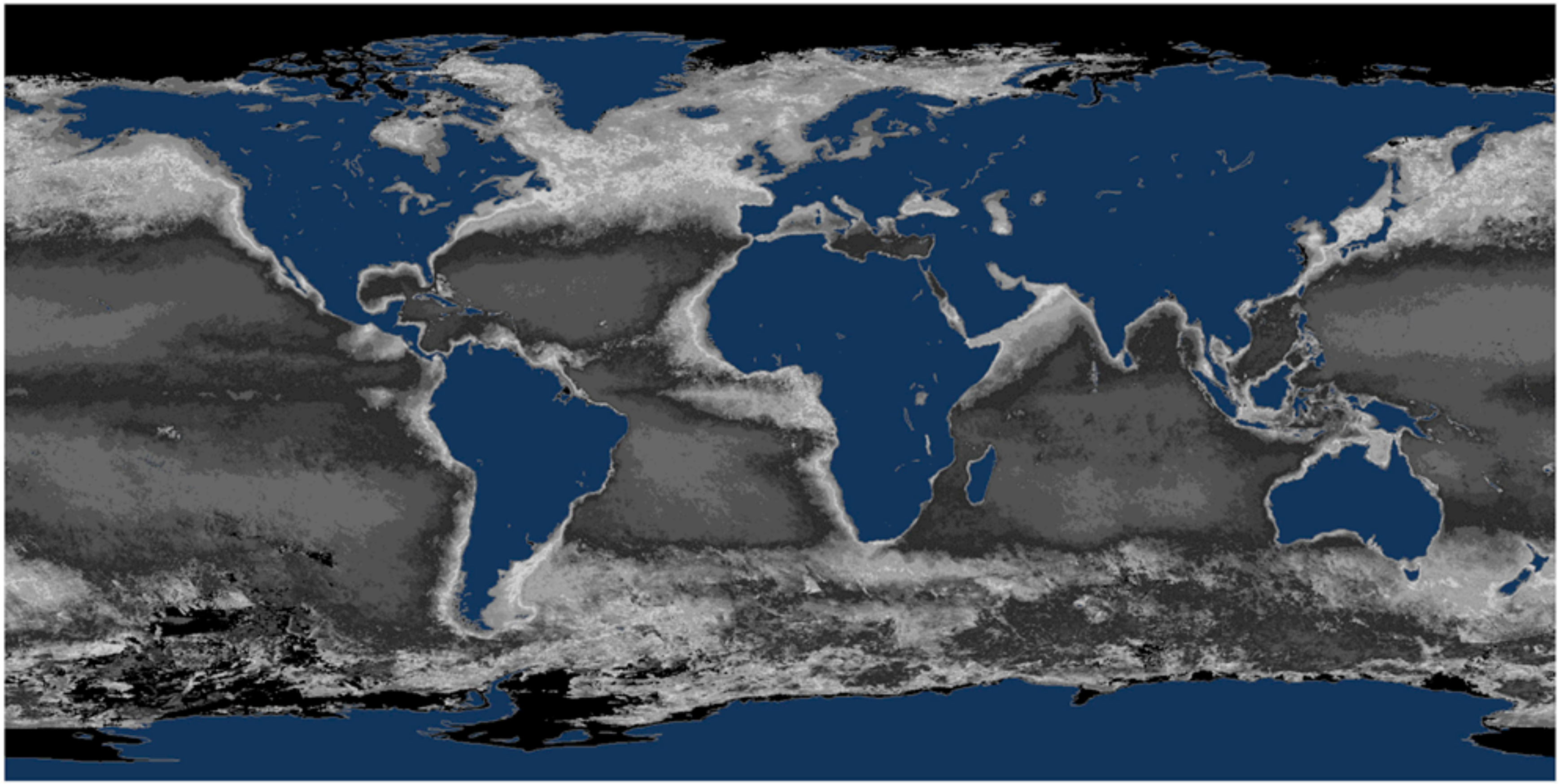
Fig. 14-11

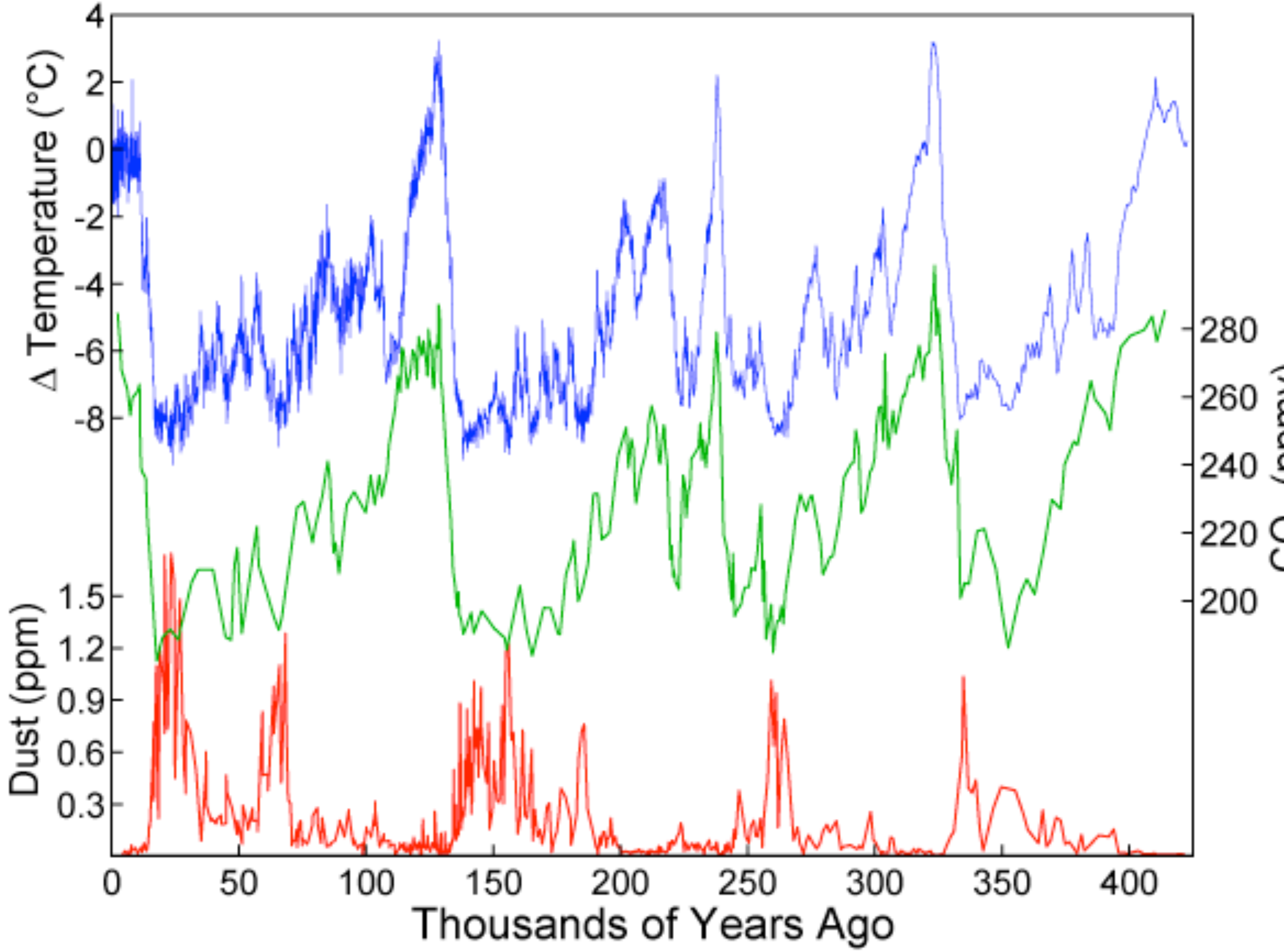
P-cycle response time is ~40,000 to 100,000 years



But Cd chemistry casts doubt on this idea…

Expansion of polar oceans?



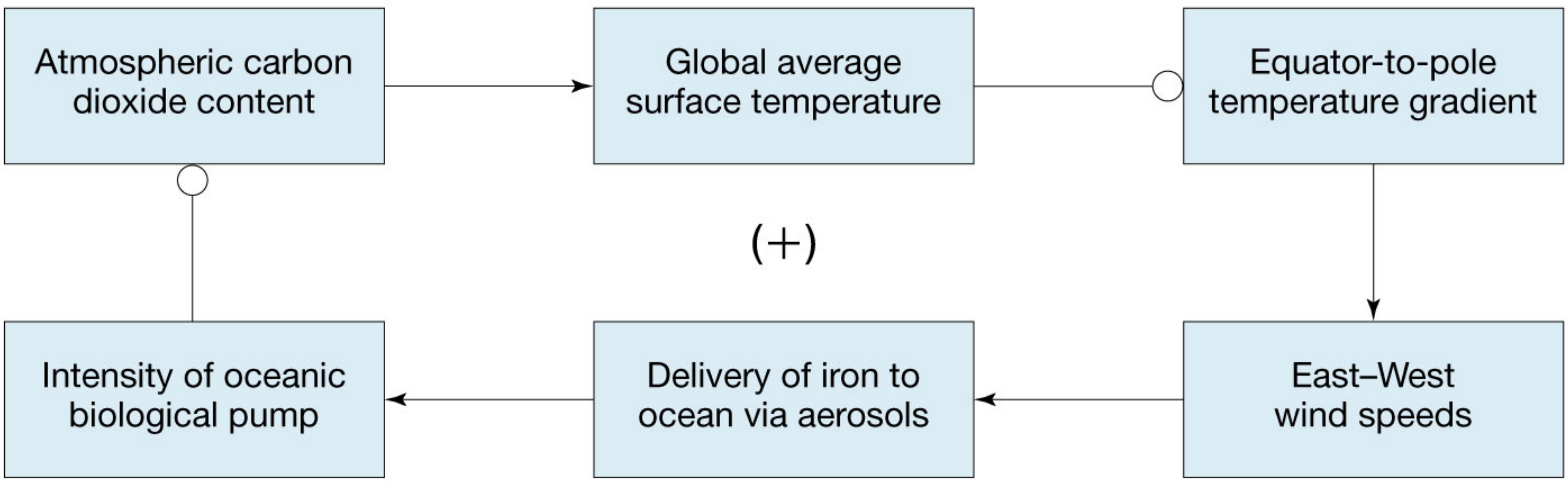


Petit J.R. et al. (1999). , Nature, 399: 429-436.

Iron Fertilization Hypothesis

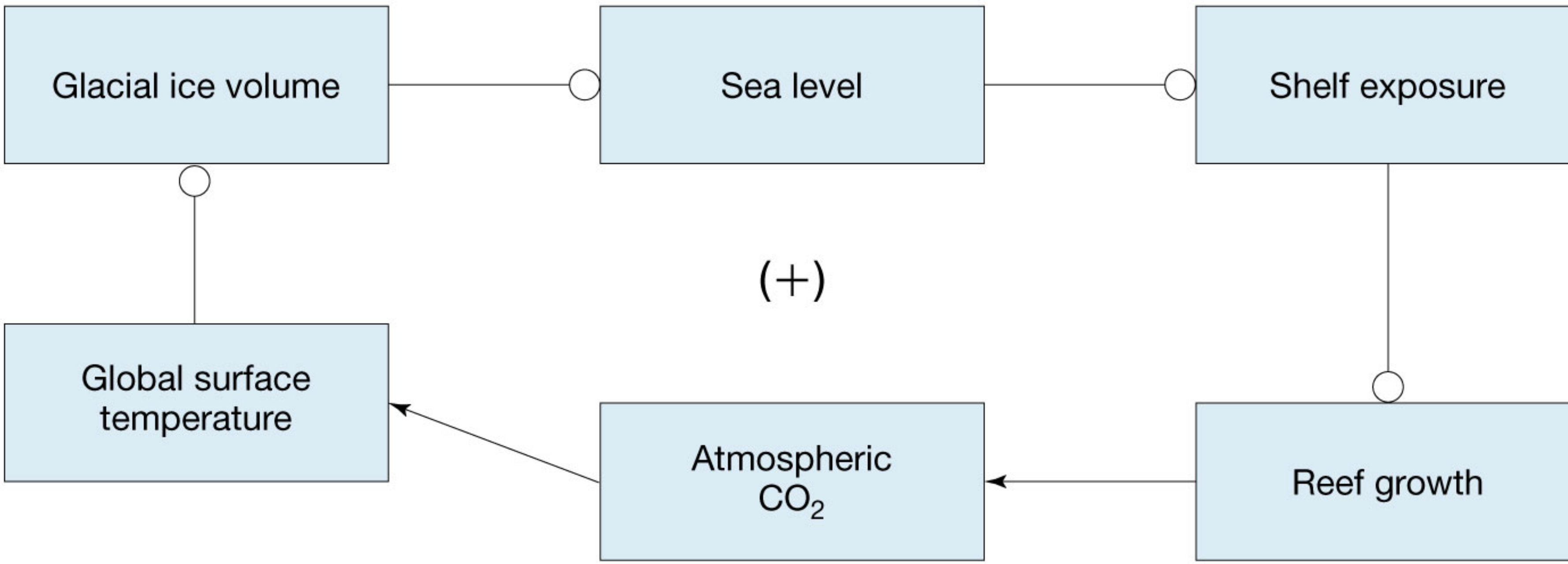
- Fe (iron) is often the limiting nutrient in the open oceans - other nutrients are not used because there is not enough iron
- Fe is part of hemoglobin, but also of key proteins in photosynthesis
- Major source to oceans is wind-blown dust - which was greater during glacial times (loess)
- Marine sediments support this idea
- Fertilize oceans with Fe?

Fe-fertilization feedback:



Coral Reef Feedback:

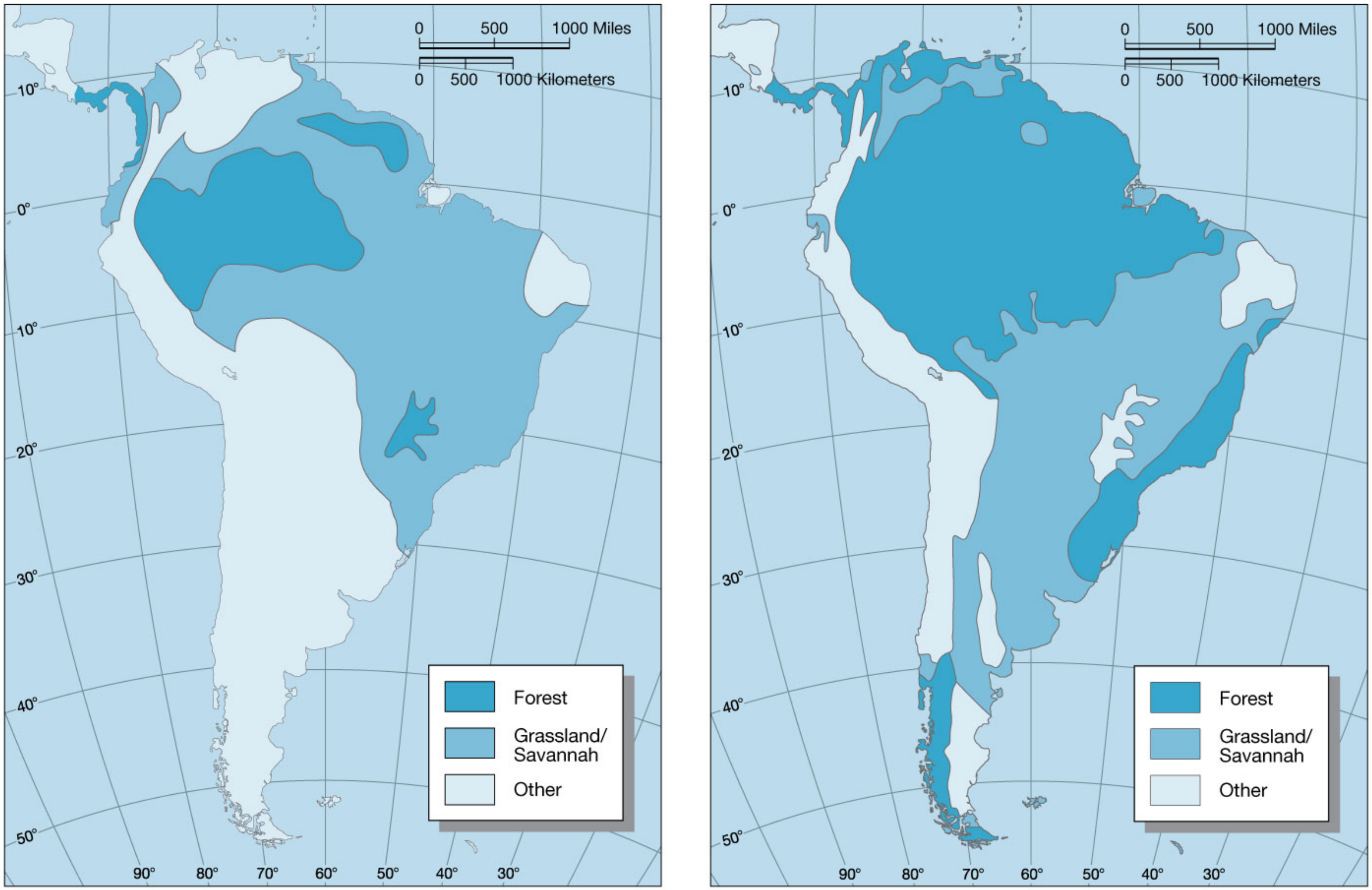
$$Ca^{2+} + 2HCO_3^- \text{ --> } CaCO_3 + CO_2 + H_2O$$



(Reef growth is source of CO_2 to atmosphere over the short term)

Fig. 14-16

(-) Feedback from vegetation:



(a) Reconstructed vegetation cover, 18 k.y. ago

(b) Present-day "potential" vegetation cover.

Vegetation Feedback:

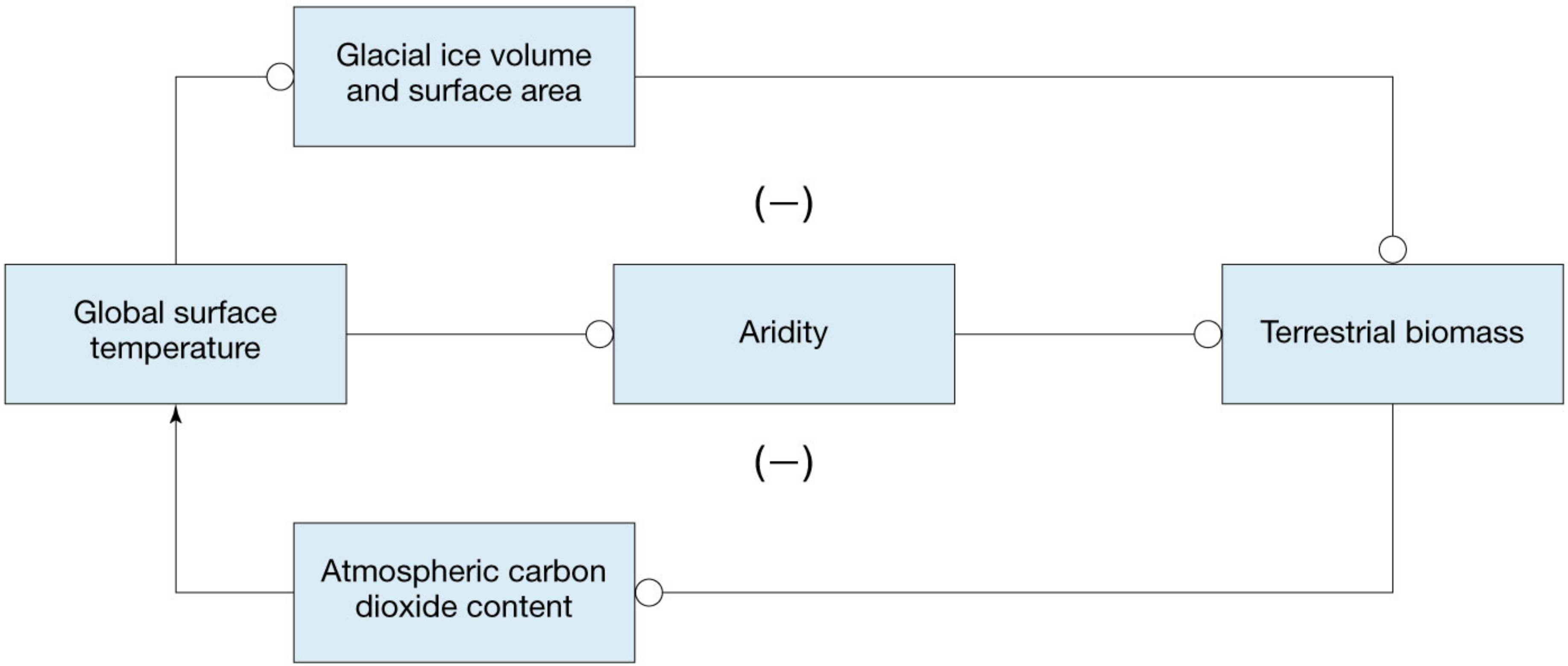
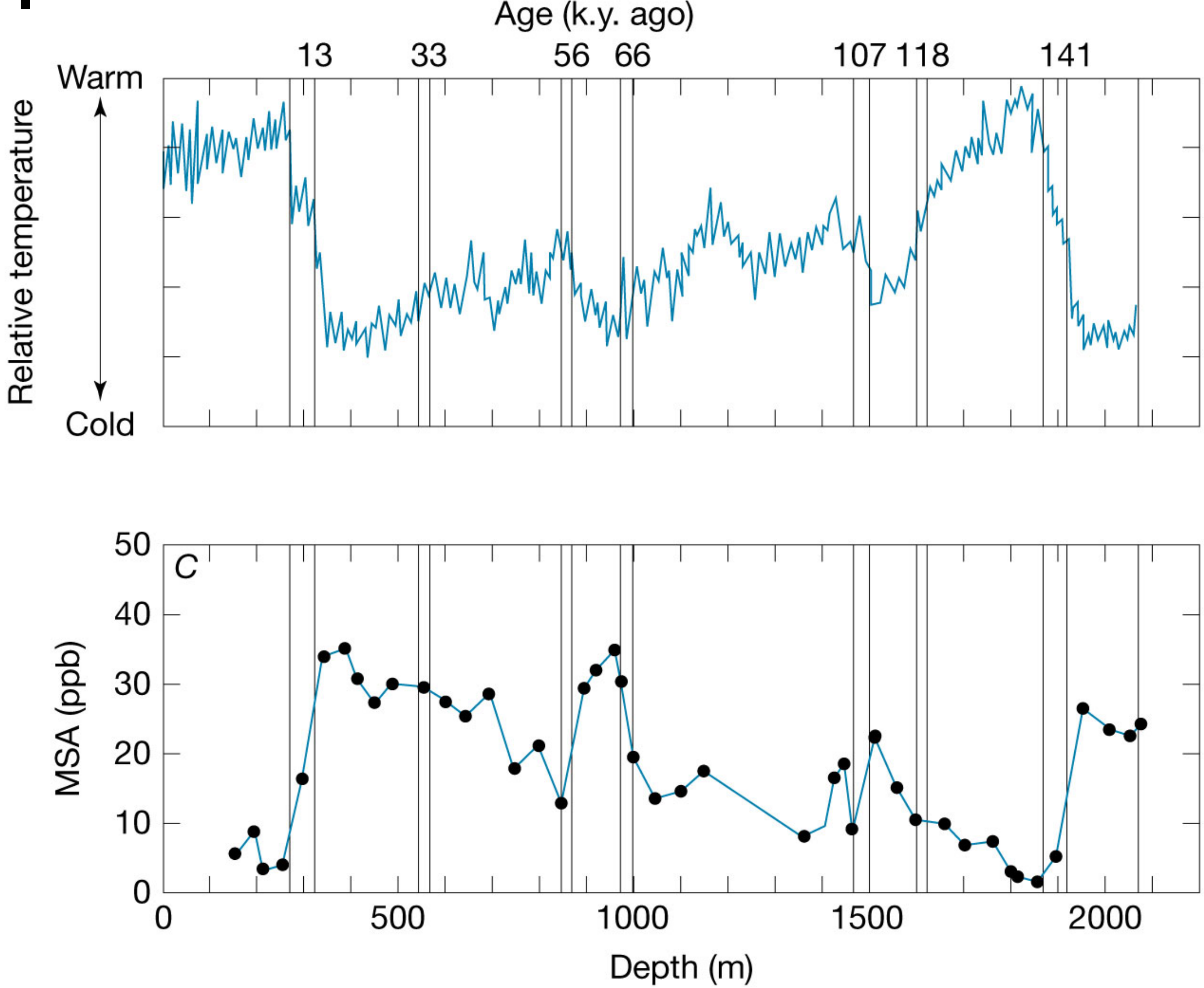


Fig. 14-17

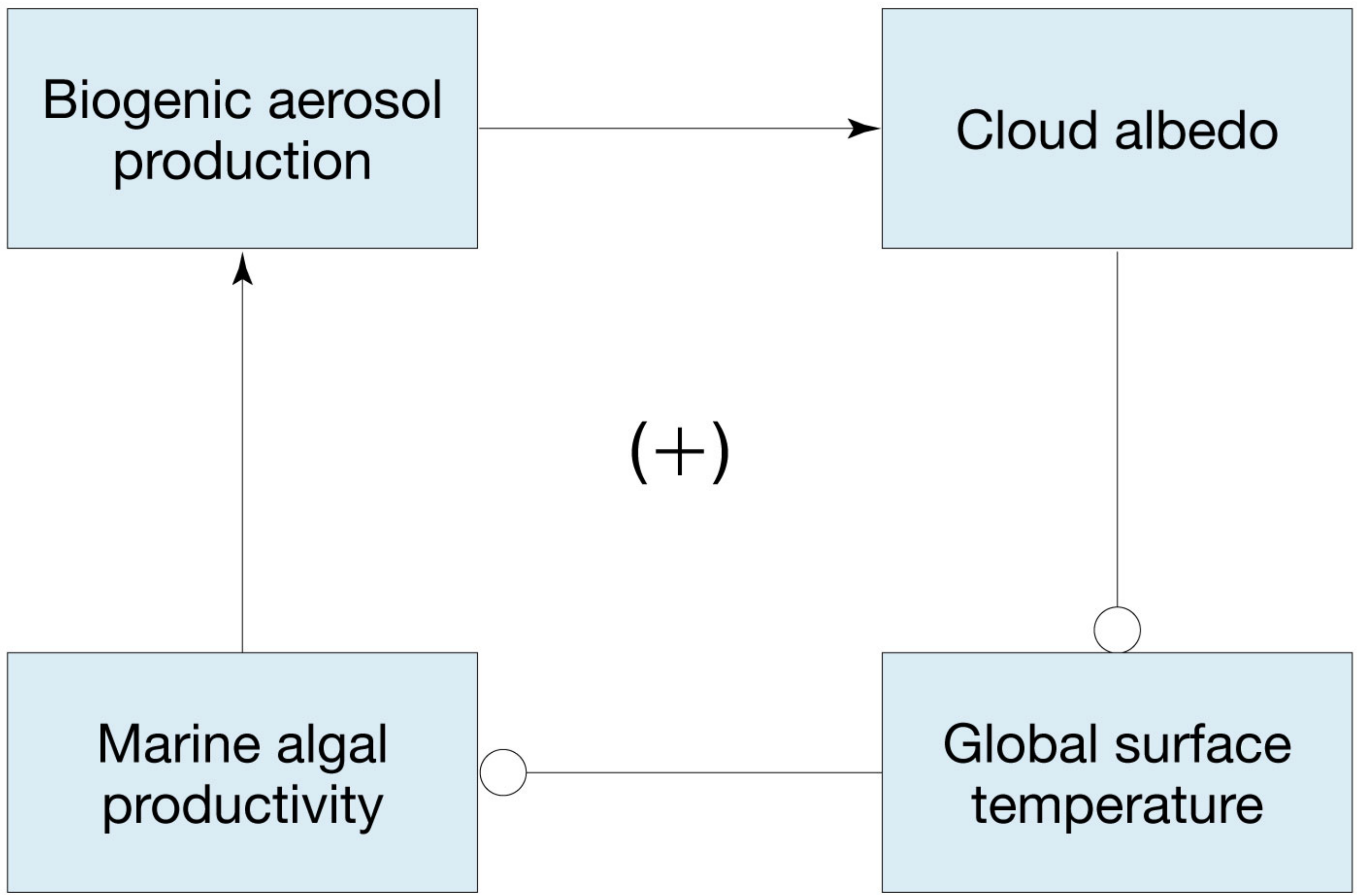
Methane sulfonic acid (MSA)

- Marine algae produce dimethyl sulfide (DMS)
- DMS escapes to atmosphere, where it is oxidized to MSA or SO_2
- Aerosol particles form, increasing condensation nuclei for cloud formation
- MSA preserved in ice as tracer - more marine biological productivity during glaciation!

Correspondence between temperature and MSA in ice cores

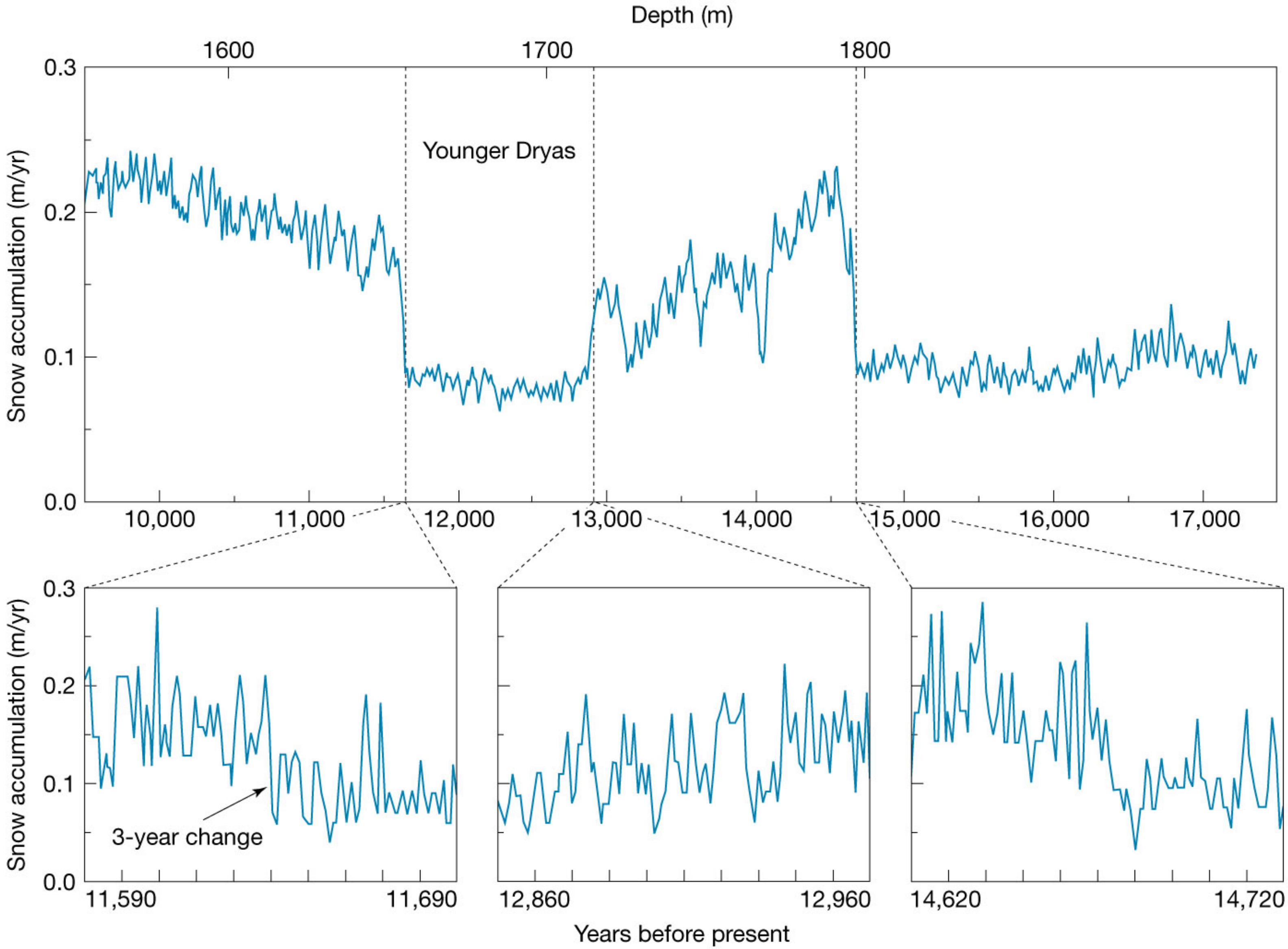


Aerosol Feedback:

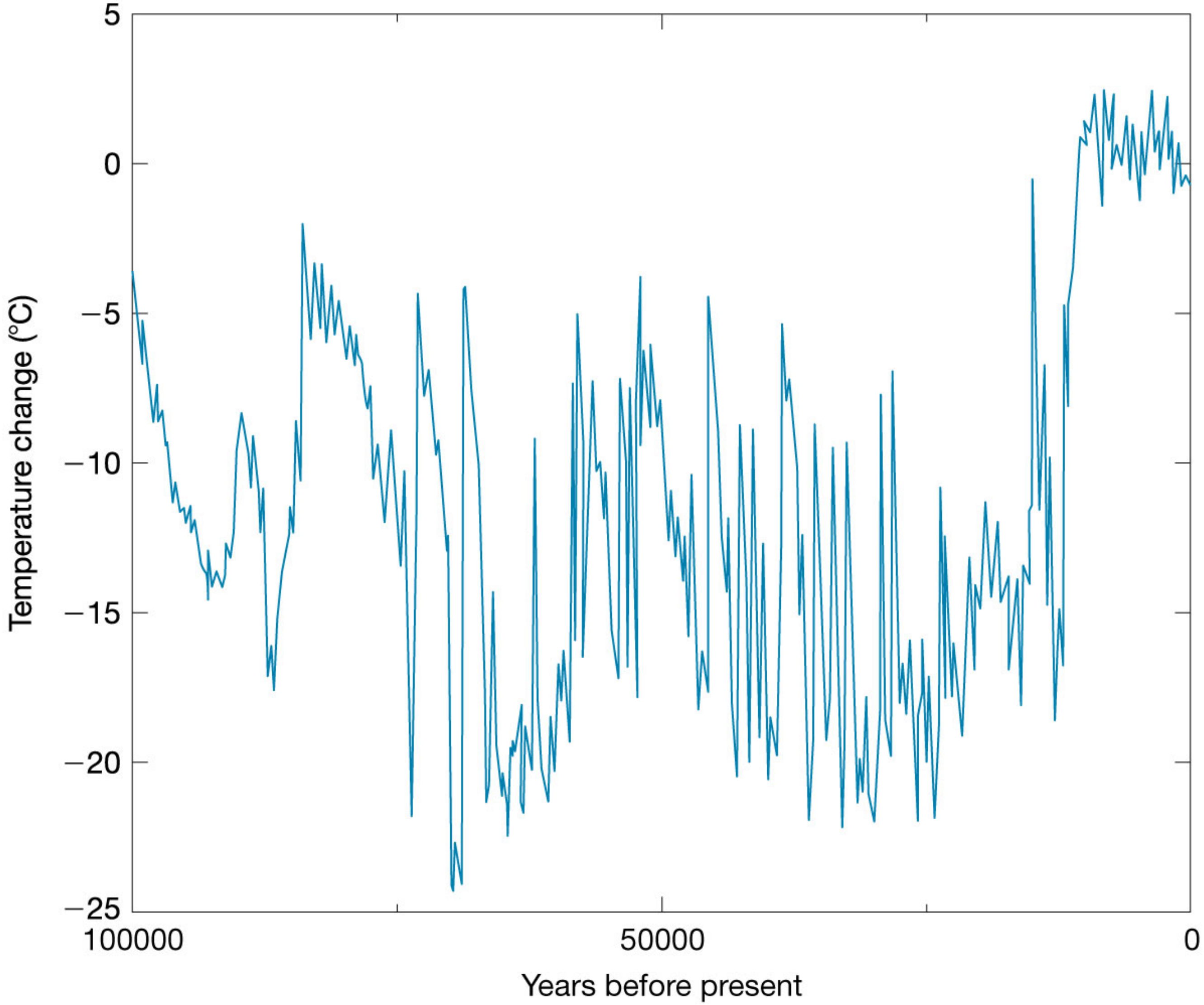


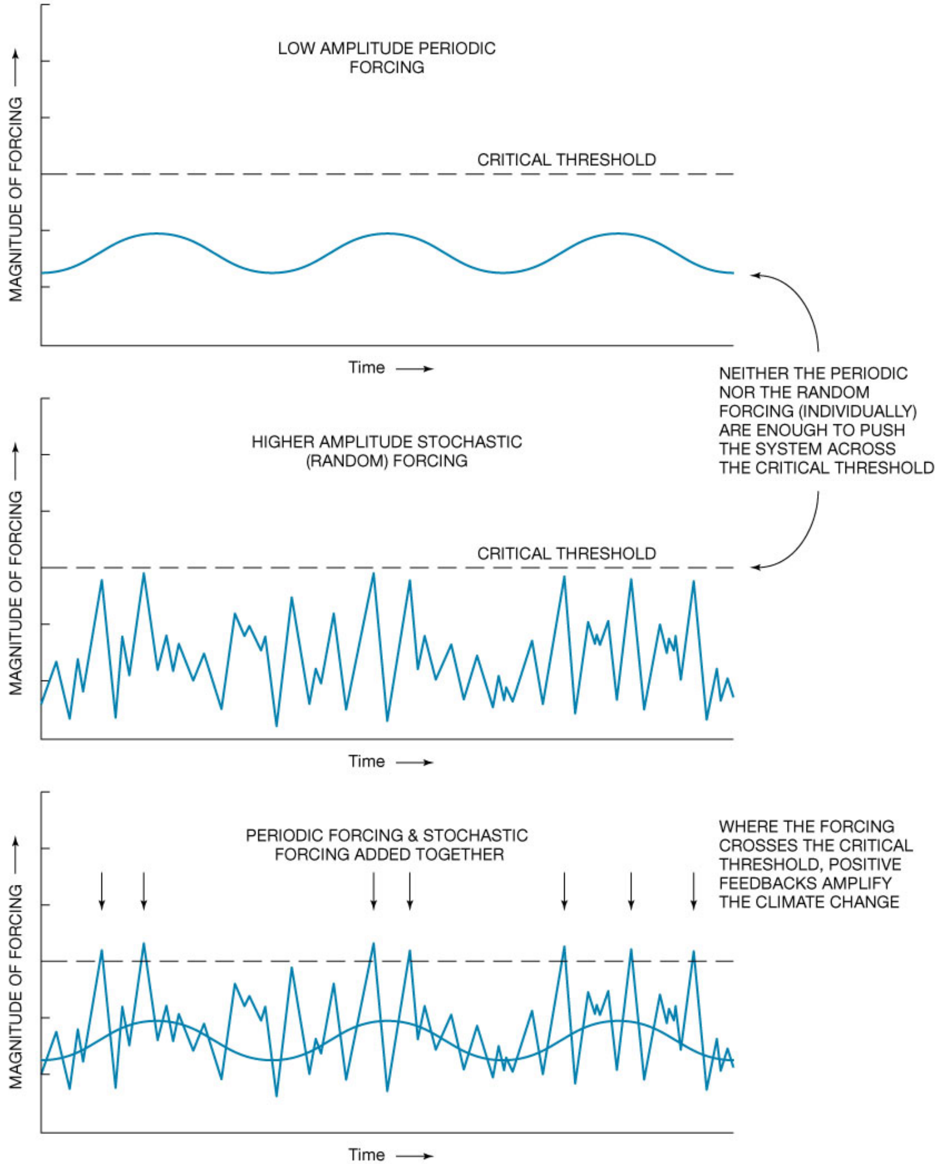
Factors in pleistocene glaciations:

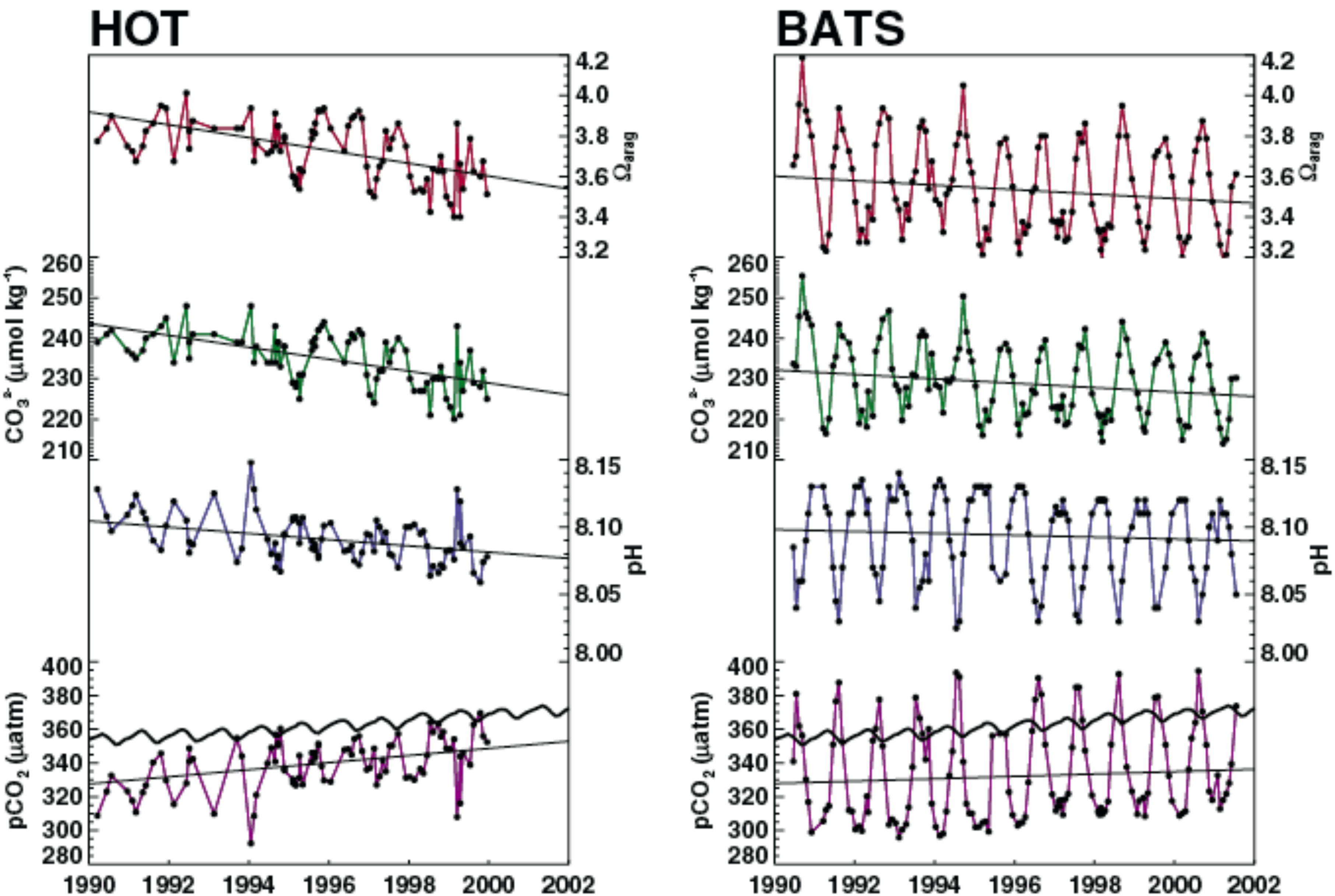
- Orbital Mechanics and sunlight to high latitudes (tropics don't vary much)
- Need amplification of such cycles with feedback systems!
- Biological pump: Shelf, Fe, Coral, MSA
- Negative vegetation feedback
- Others?


Depth (m)
1600
1700
1800
Younger Dryas
Snow accumulation (m/yr)
0.3
0.2
0.1
0.0
10,000
11,000
12,000
13,000
14,000
15,000
16,000
17,000
3-year change
11,590
11,690
12,860
12,960
14,620
14,720
Years before present

Temperature history in central Greenland




MAGNITUDE OF FORCING
LOW AMPLITUDE PERIODIC FORCING
CRITICAL THRESHOLD
Time
NEITHER THE PERIODIC NOR THE RANDOM FORCING (INDIVIDUALLY) ARE ENOUGH TO PUSH THE SYSTEM ACROSS THE CRITICAL THRESHOLD
MAGNITUDE OF FORCING
HIGHER AMPLITUDE STOCHASTIC (RANDOM) FORCING
CRITICAL THRESHOLD
Time
MAGNITUDE OF FORCING
PERIODIC FORCING & STOCHASTIC FORCING ADDED TOGETHER
WHERE THE FORCING CROSSES THE CRITICAL THRESHOLD, POSITIVE FEEDBACKS AMPLIFY THE CLIMATE CHANGE
Time



HOT
BATS
4.2
4.0
3.8
3.6
3.4
3.2
Ω_{arag}
260
250
240
230
220
210
CO_3^{2-} (µmol kg^{-1})
8.15
8.10
8.05
8.00
pH
400
380
360
340
320
300
280
pCO_2 (µatm)
1990
1992
1994
1996
1998
2000
2002