Lecture 24: Millennial Changes: $\delta^{18}O$ in Ice Sheets

Ch. 14

Millennial Changes: $\delta^{18}O$ in Ice Sheets

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- What are millennial oscillations?

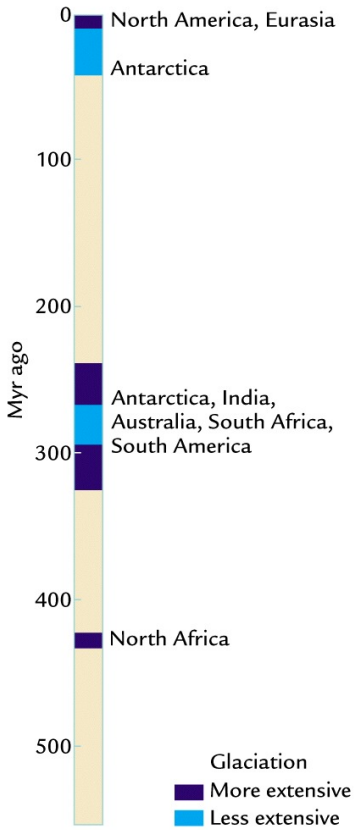
- How do millennial oscillation during interglacial compared to those during glacial periods?

- What evidence of millennial changes do we find in Greenland ice cores?

- How do the processes that control $\delta^{18}O$ changes measured in ice sheets differ from those measured in ocean cores?

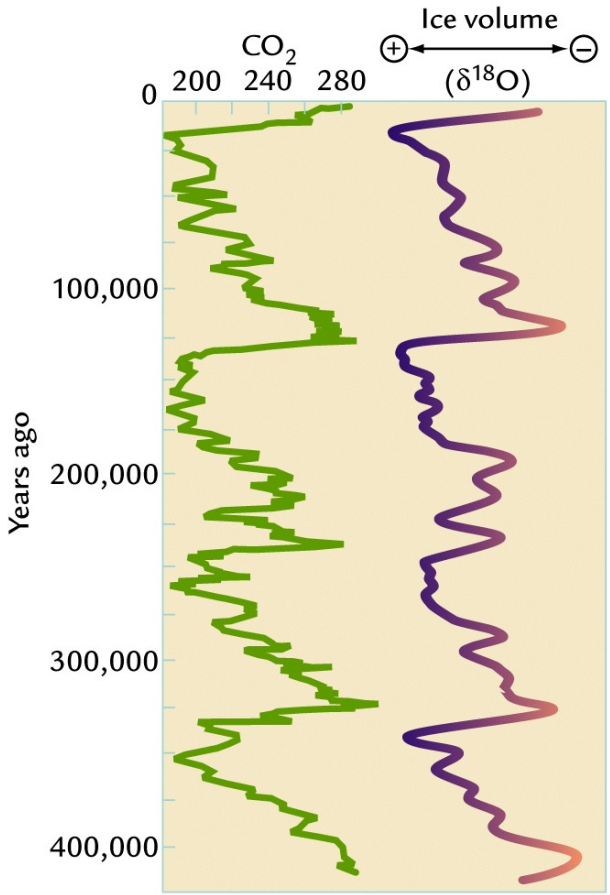
Climate Change at Different Time Scales

Tectonic-scale



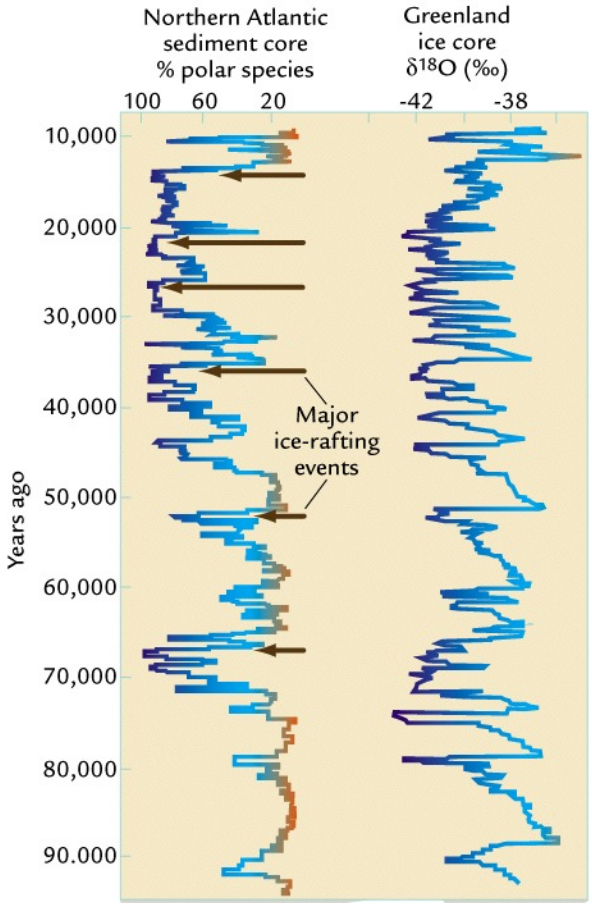
Hundreds of millions of years

Orbital-scale (Cycles)



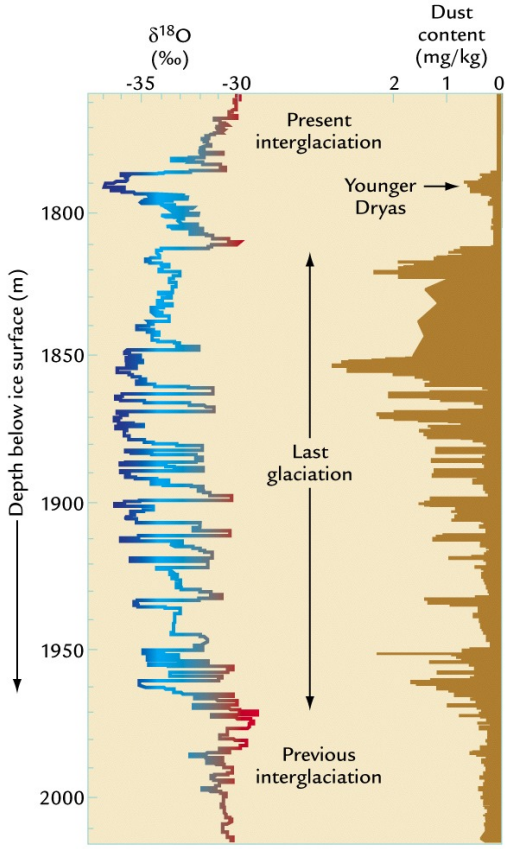
Tens to hundreds of thousands of years

Millennial-scale (Oscillations)

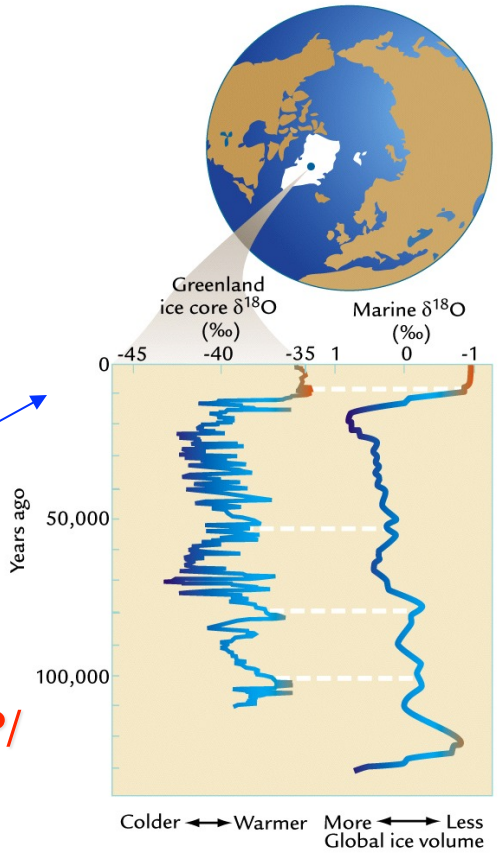


Thousands of years

Oscillations Recorded in Greenland Ice Cores



Ice core drilled in 1970s



Two long ice cores drilled on the summit of Greenland in 1990s (GISP/ GRIP sites)

Early studies in the 1970s

Focused on oxygen isotope ratios and dust

Rapid, large fluctuations mask slower orbital changes

Recent studies since early 1990s

Minimizing the ice flow impacts on deeper ice layers

Millennial oscillations throughout the last glaciation

Millennial Oscillations in Greenland Ice Cores

An Known Example

Younger Dryas

During the last deglacial period

~1500 years long

Abrupt beginning and ending

Millennial Oscillations

During glacial period

Dansgaard-Oeschger Cycles

Vary widely in spacing and amplitude

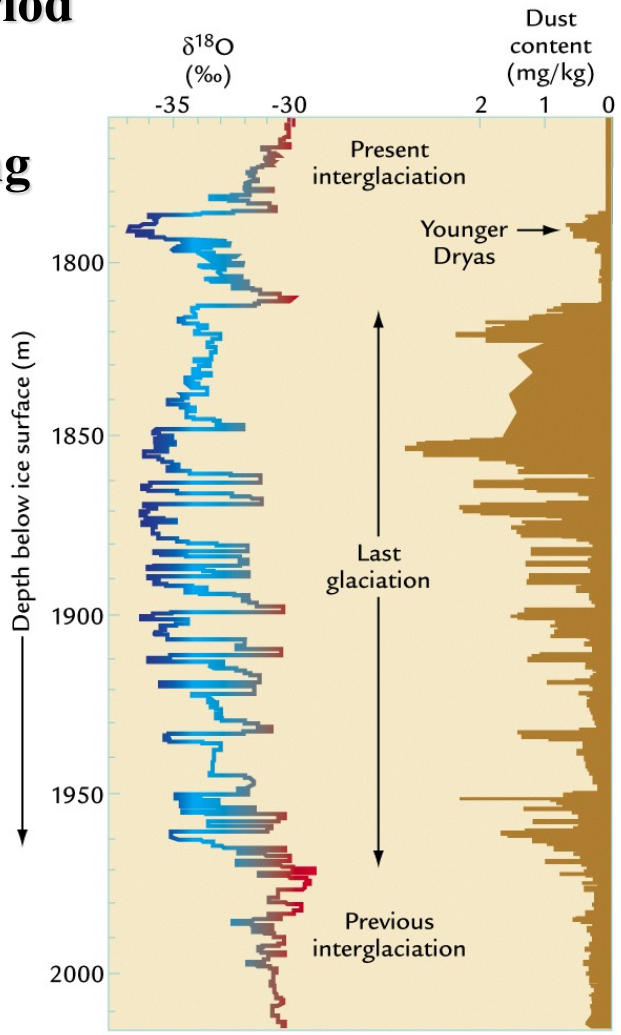
Average spacing: 1500 yrs

Large amplitude

During interglacial period

Small amplitude

Millennial-scale (Oscillations)



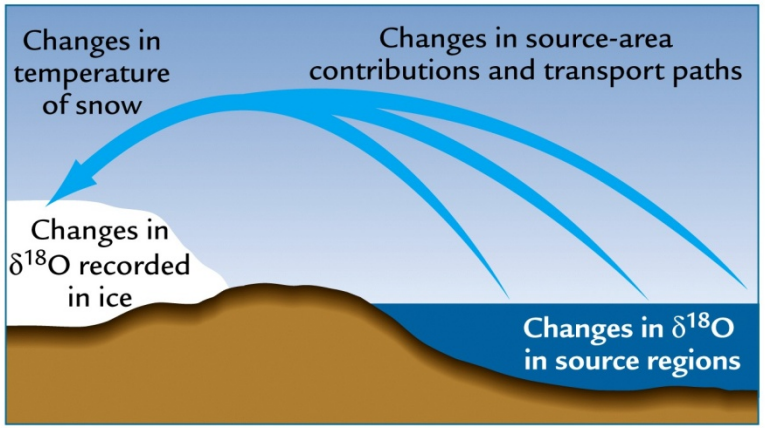
Thousands of years

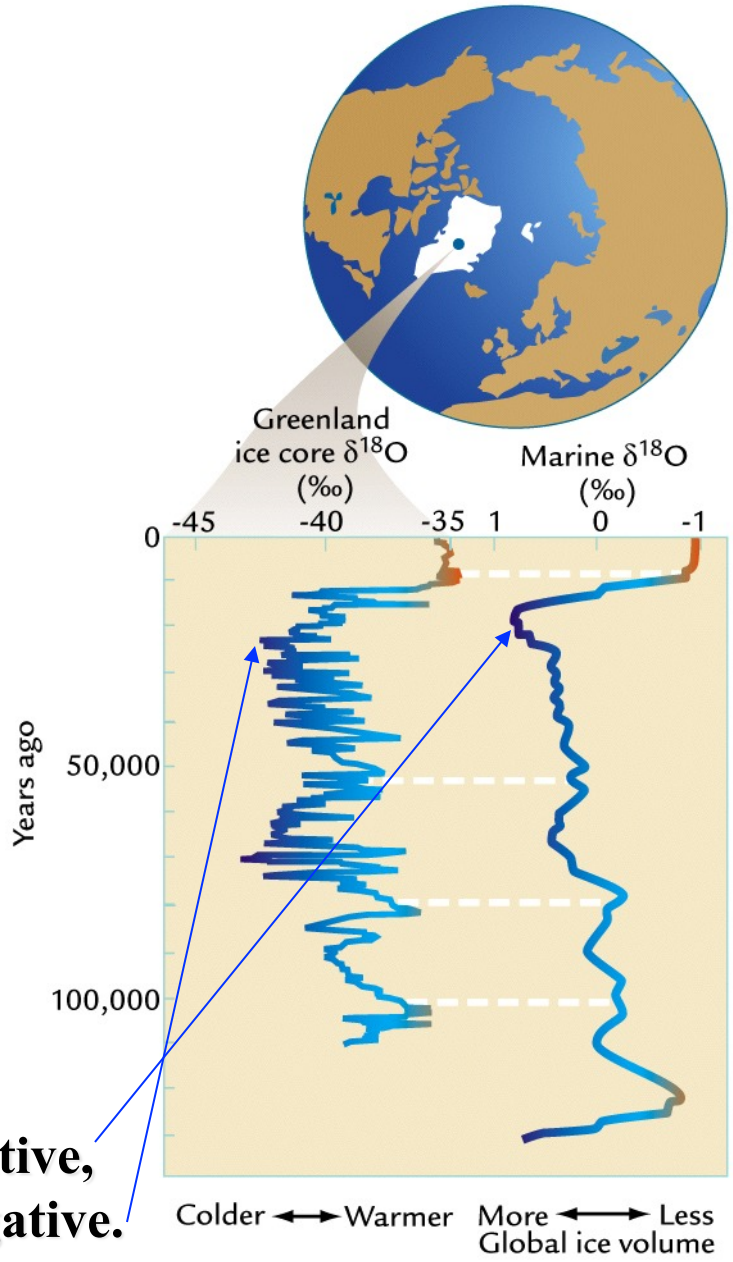
Oxygen Isotope Ratios ($\delta^{18}O$) in Ice and Ocean Cores

Ice Cores

$\delta^{18}O$ signals reflect several influences

- **Temperature of snowfall**
- **Source of moisture**
- **Transport paths**
- **Season of precipitation**





Ocean cores

$\delta^{18}O$ signals reflect two influences

- **Temperature of seawater**
- **Ice volume in continents**

Relationship

As marine $\delta^{18}O$ becomes more positive, $\delta^{18}O$ in ice cores becomes more negative.

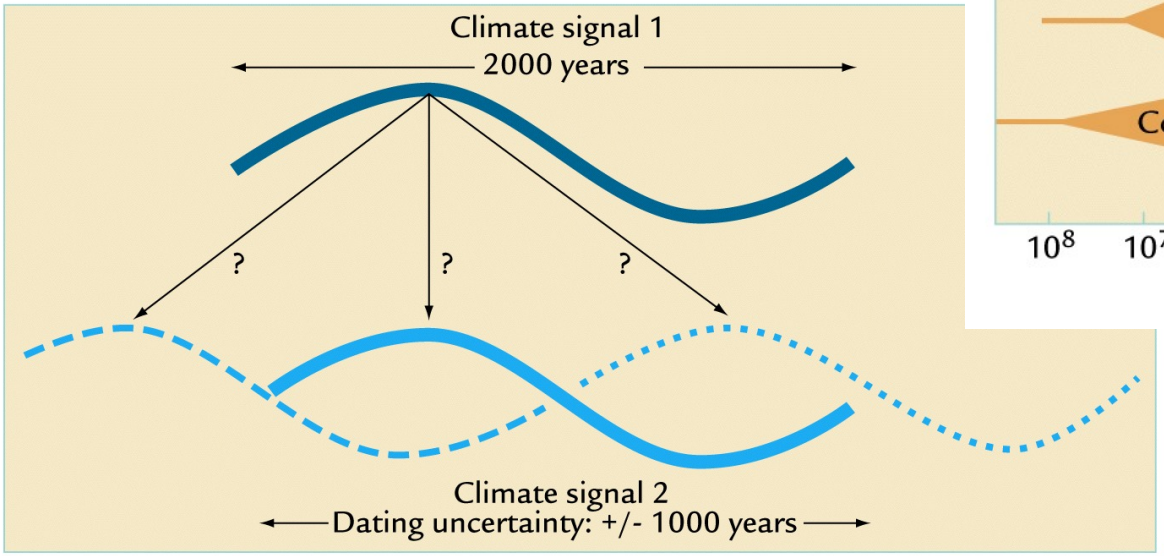
Detecting and Dating Millennial Oscillations in Regions Other Than Greenland (Ice)

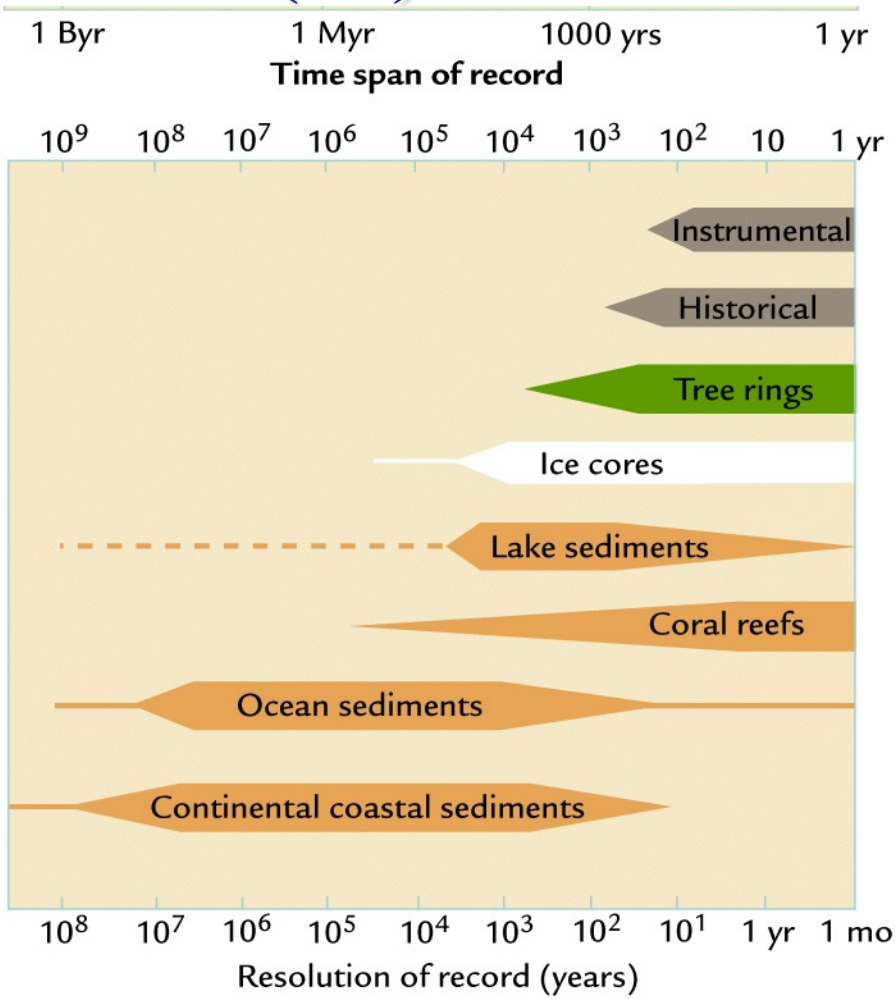
Ideal proxy data for millennial oscillations

Revealed annual changes
Dated back to the last glaciation and beyond

Uncertainties in dating millennial oscillations

^{14}C dating has errors of thousands of years, thus difficulty in telling leads and lags



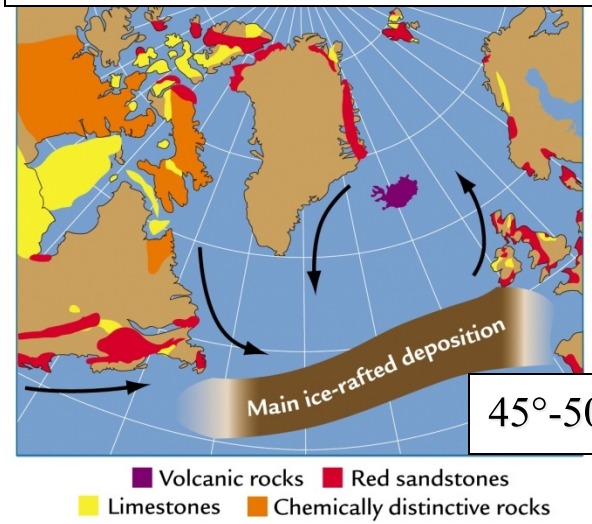


Oscillations Recorded in North Atlantic Sediments

The Atlantic Ocean is a good place to detect millennial changes.

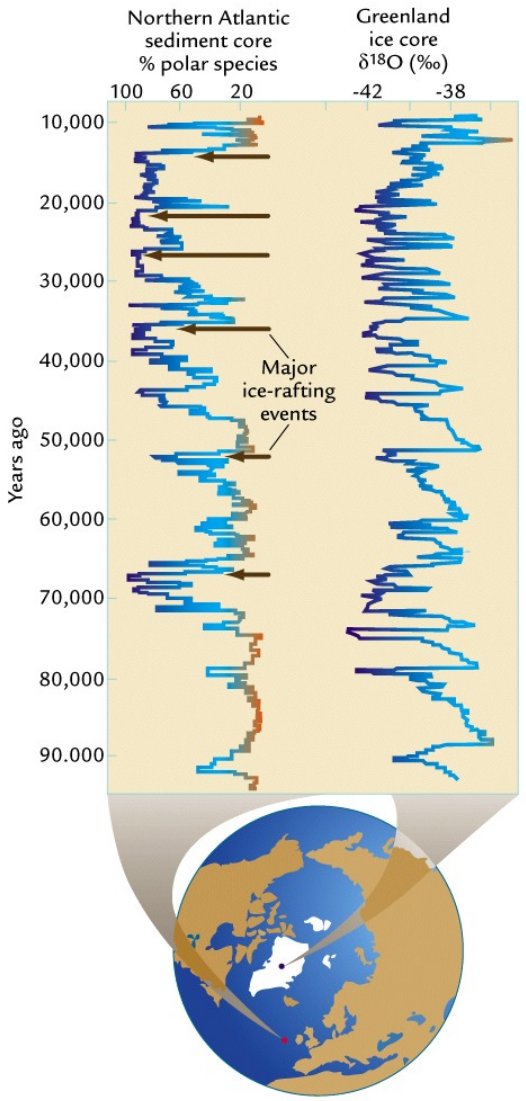
High deposition rates
Foraminifera and ice-rafted debris stay in place

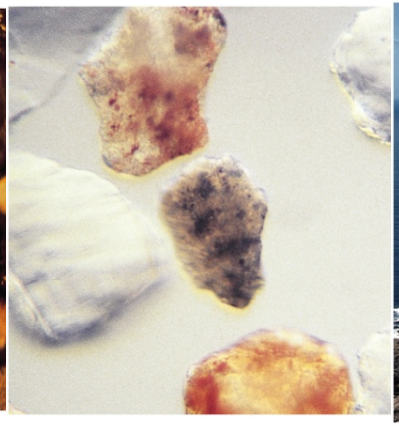
Sources of ice-rafted debris



Heinrich events:

ice-rafting events occurred when climate had been cooling for several millennia, followed by rapid warming.

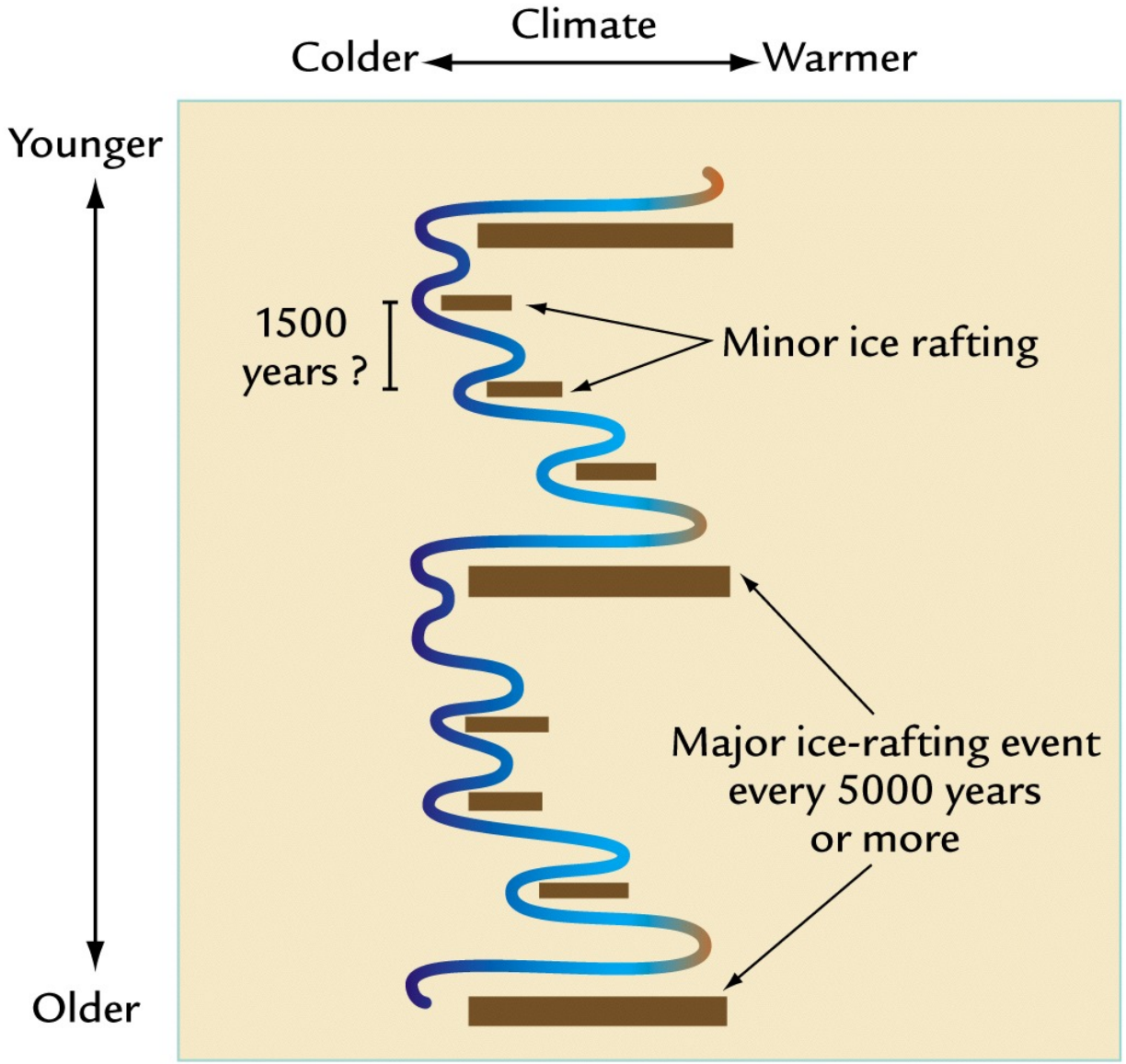




More negative $\delta^{18}O$ in Greenland ice core, the colder air, the colder ocean water, the more icebergs, the more ice-rafted debris, and the more polar plankton.

Millennial-scale North Atlantic Cycles? (Stochastic Resonance)

1. 1500-yr "true" cycle of minor ice rafting (resonance = cyclic behavior)
2. Gradual cooling
3. Reaching a threshold
4. Triggering a major ice rafting (n×1500, i.e., 3000, 4500, 6000, 7500, 9000; stochastic = random)

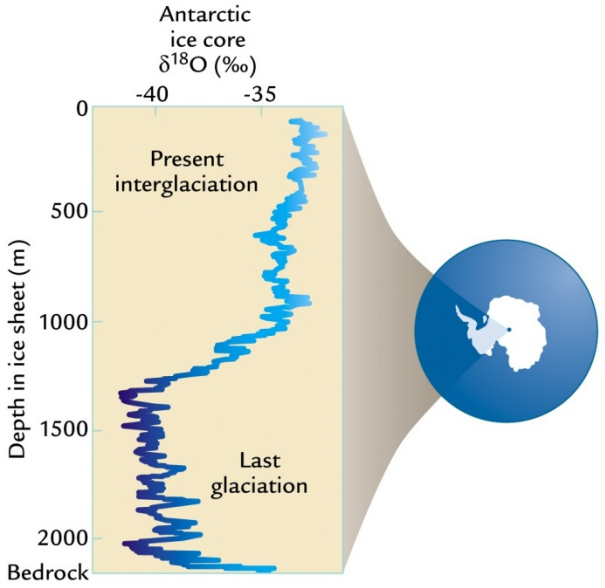


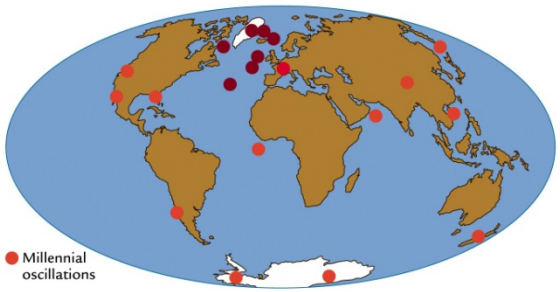
Where Else Did Millennial Oscillations Occur?

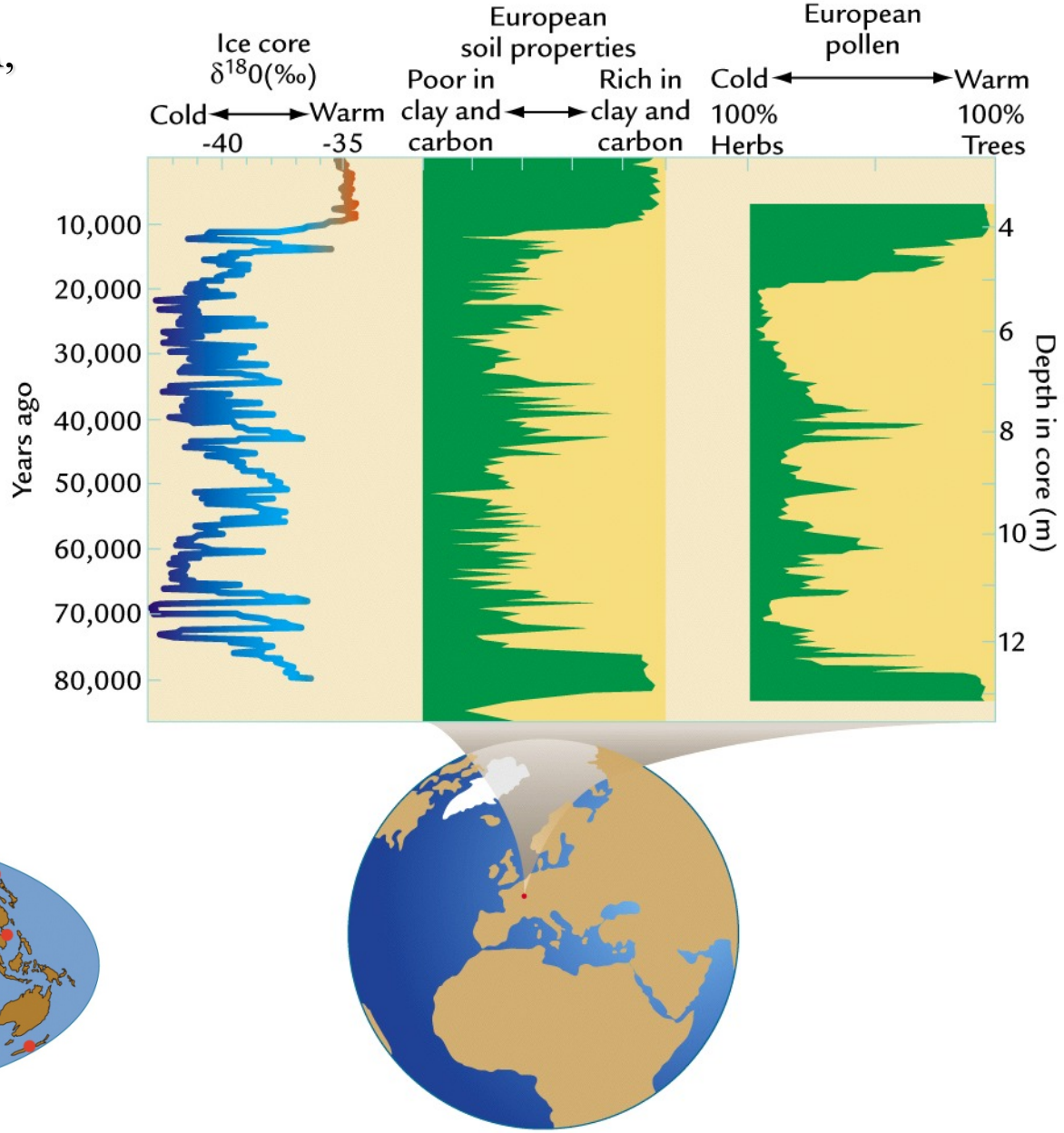
Worldwide

N.H. Midlatitude Europe, Asia, USA,
N.H. Tropics, Equatorial Atlantic
South American Andes

New Zealand, Antarctica







Millennial Oscillations During the Last 8000 Years

Millennial oscillations were evident when N.H. ice sheets were large.

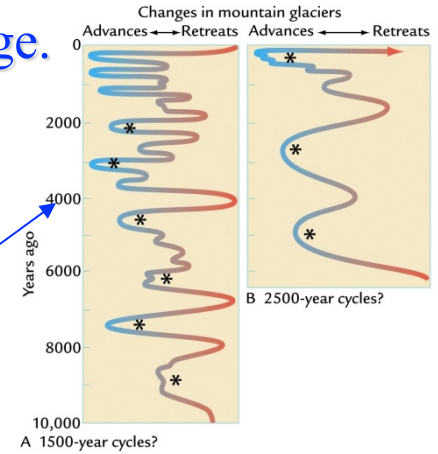
Millennial oscillations were small or absent during the interglacial.

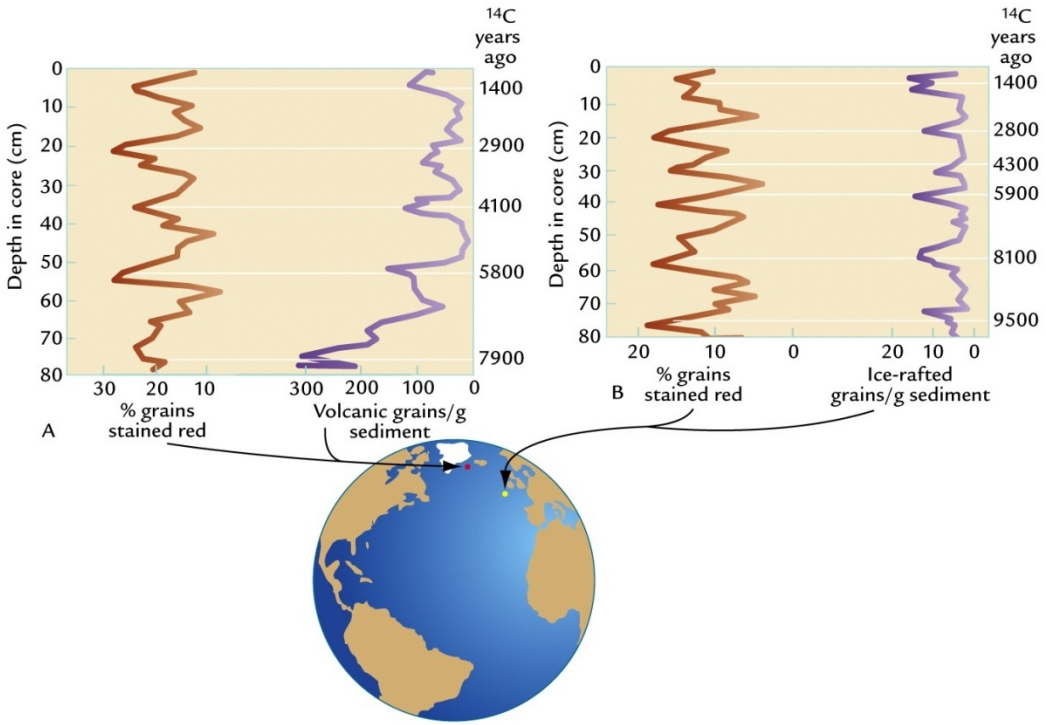
No major episodes of ice rafting or plankton reduction

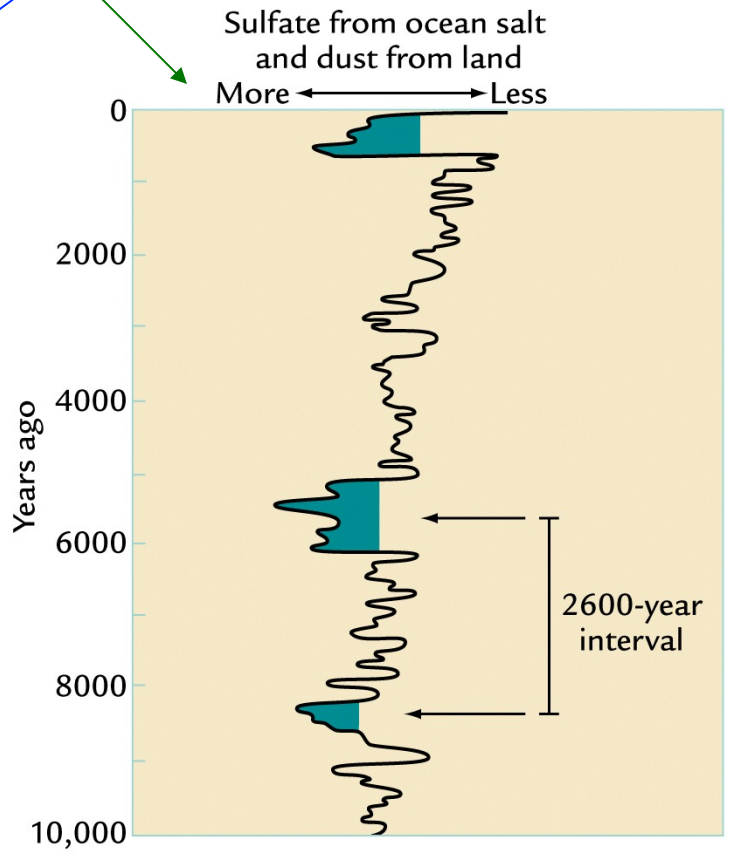
Small fluctuations exist in the Greenland dust amount.

The only large N.H. ice sheet left is the one in Greenland, from which a small number of icebergs can break off.

Advances and retreats of mountain glaciers.







Causes of Millennial Changes

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- What initiates these oscillations?
- How are they transmitted to those parts of the climate system where they have been observed?
- Why are they stronger during glaciations than during interglaciations?
- Why would the climate system oscillate in such a way?

- H1. The natural oscillations inherent in the internal behavior of northern hemisphere ice sheets.
- H2. The result of internal interactions among several parts of the climate system.
- H3. A response to solar variations external to the climate system.

Processes Within Ice Sheets

Ice sheets as a whole

Very slow response
Many thousands of years

Ice sheets margins

Faster changes

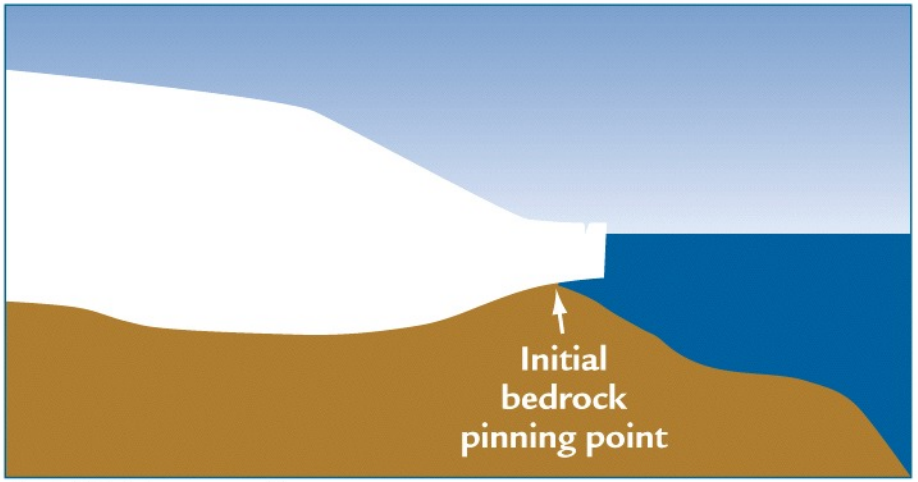
Thinner on lands underlying soft sediments or along the oceans

Heat from below

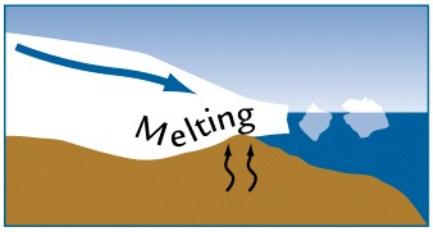
Depression of bedrock
Sea level change
(10-15m)

Limitations:

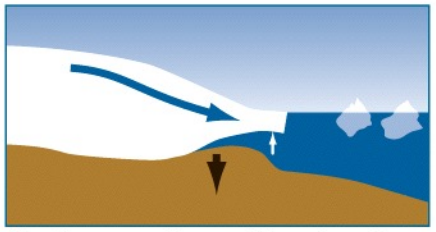
Affect only larger millennial oscillations

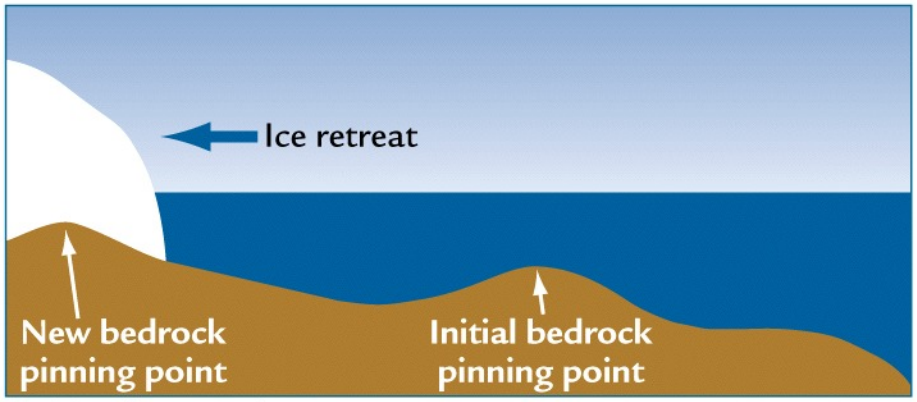


A Initial ice margin



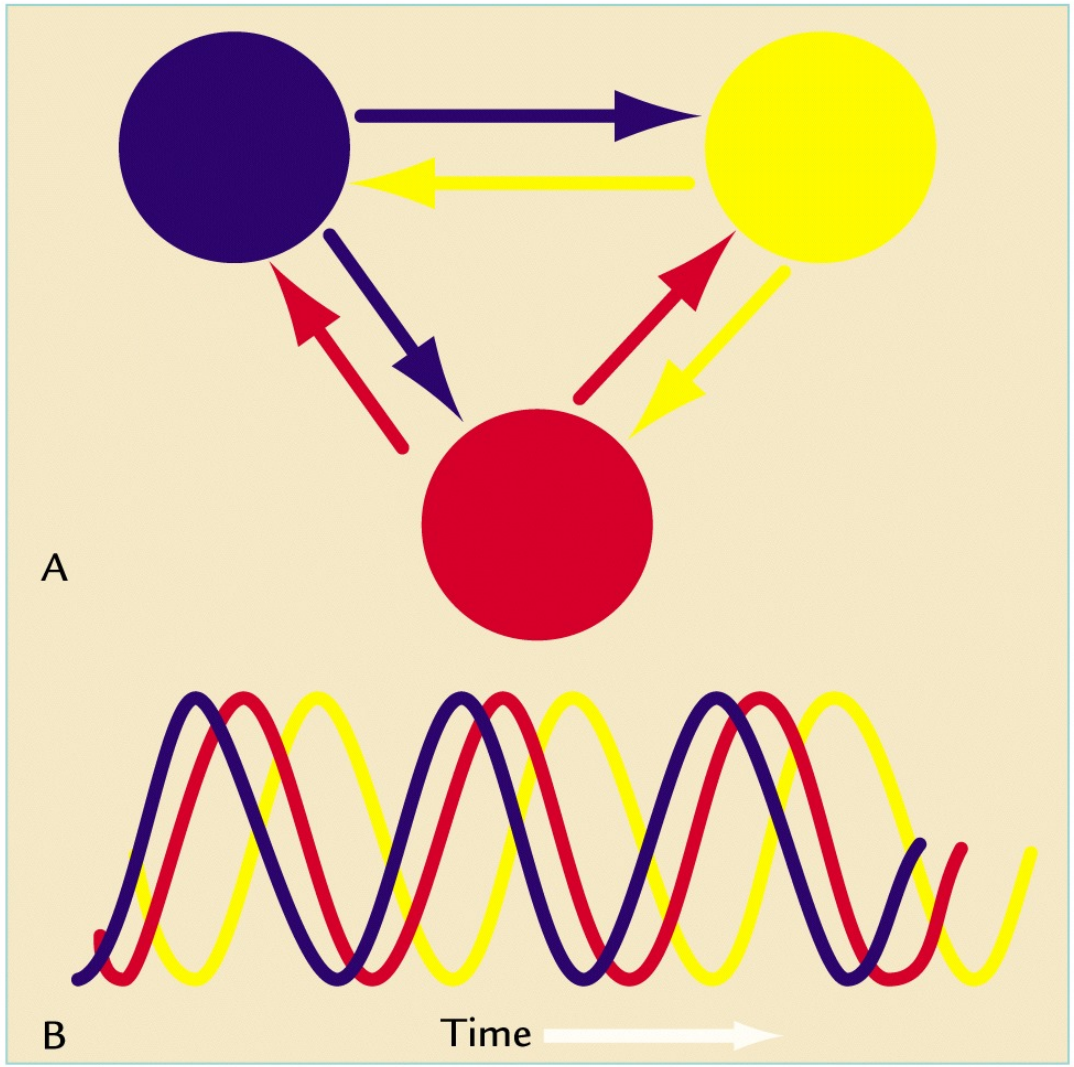
B Heat from below


C Depression of bedrock



D New ice margin

Interactions Within the Climate System



Key components of the climate system: ice sheets, surface ocean, deep ocean

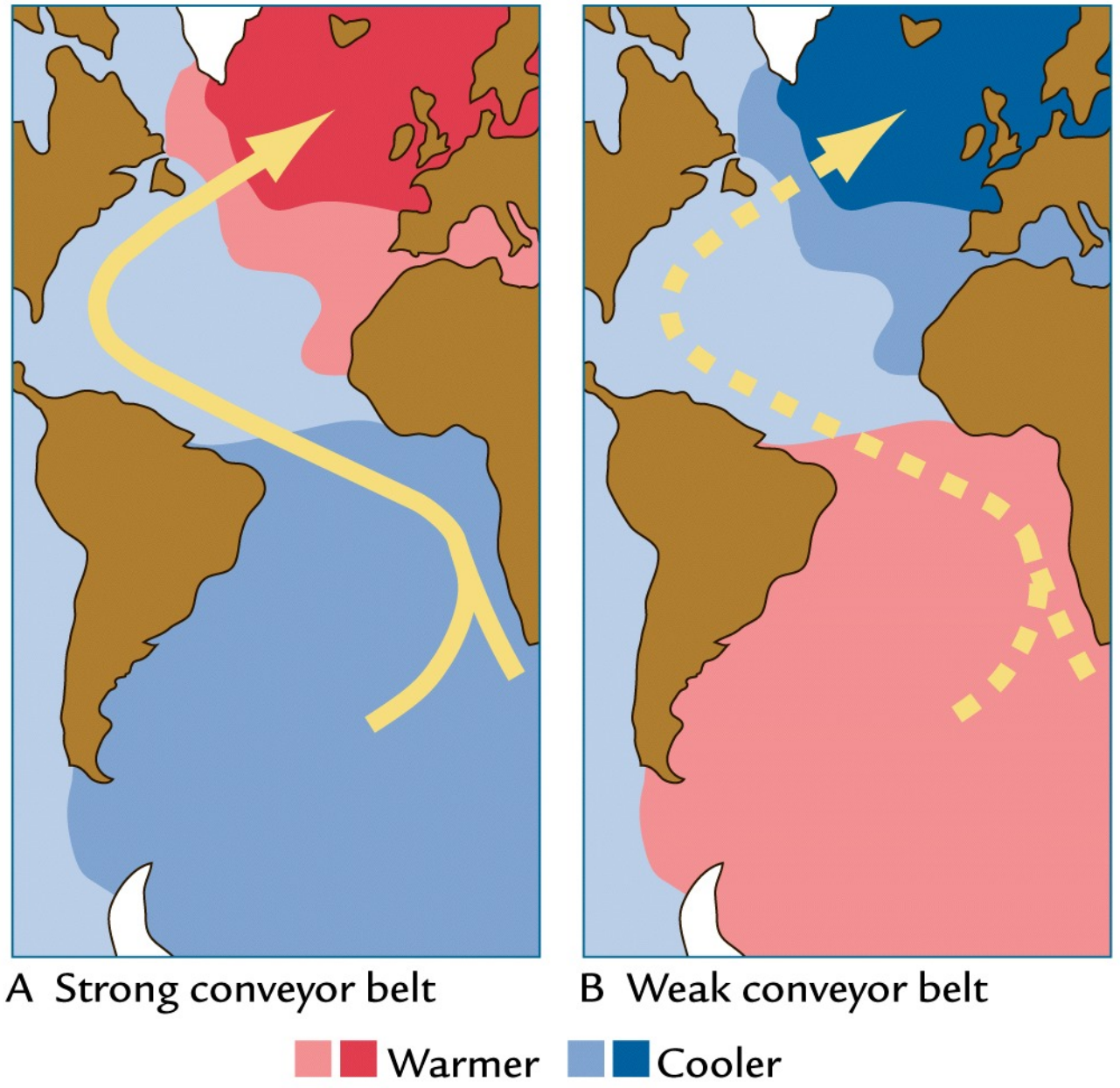
Ice sheets → meltwater runoff → salinity of surface ocean → formation of deep water

Opposite Hemispheric Responses Caused by the Conveyor Belt

Conveyor belt strong: North Atlantic warm but southern hemisphere cool

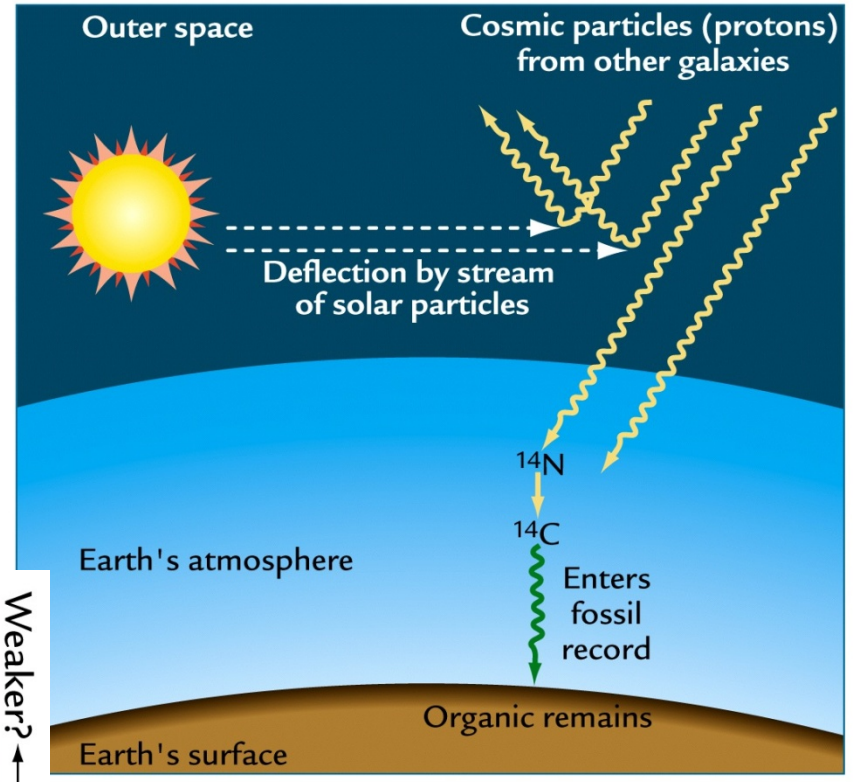
When it is weak, the temperature responses are reversed.

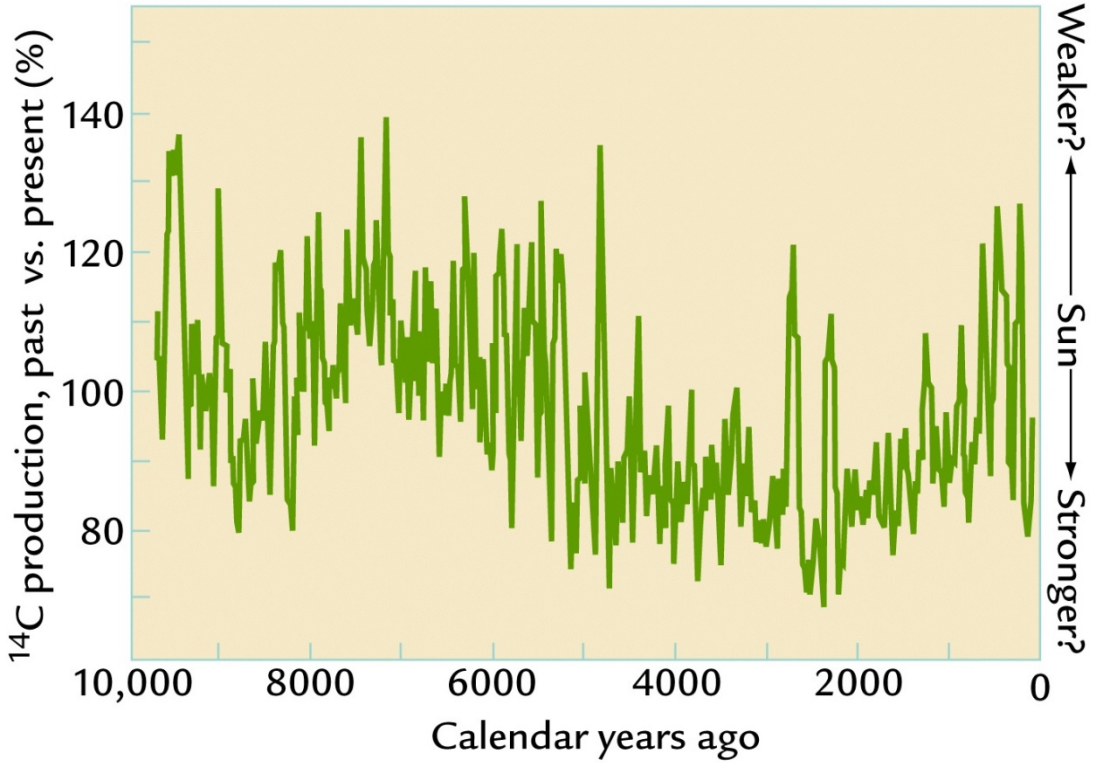
The bipolar seesaw pattern



Causes External to the Climate System: Solar Variability

1. Weaker magnetic field → weaker solar shielding → more bombardment by cosmic particles → faster production of ^{14}C
2. 420-year cycle; weak 2100-year cycle
3. No 1500-year cycle

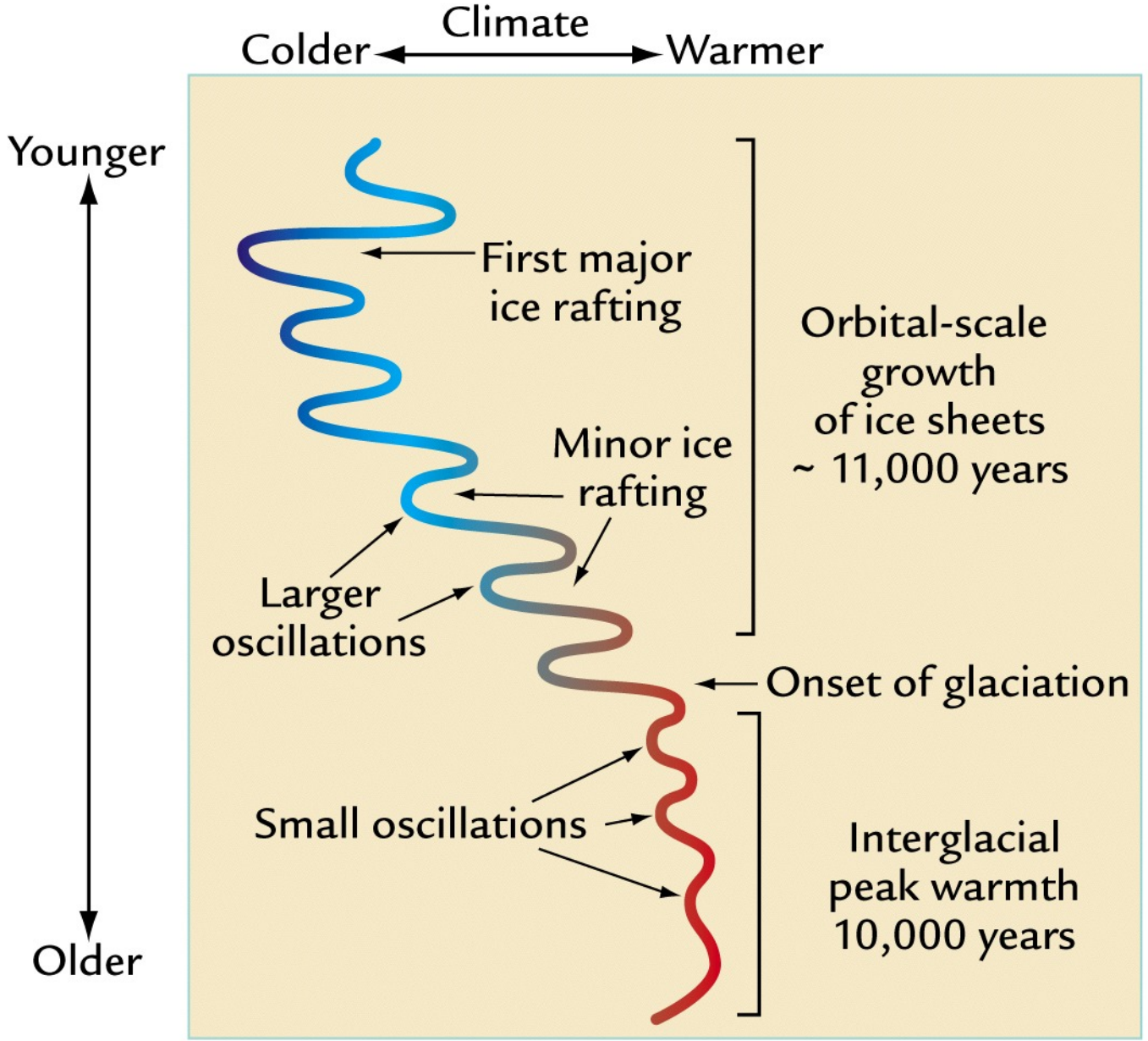




Implications of Millennial Oscillations for Future Climate

Would natural oscillations cause climate to warm or to cool in future decades?

How would Greenland and Antarctic ice sheets melting affect climate?



Summary-Discussion:

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