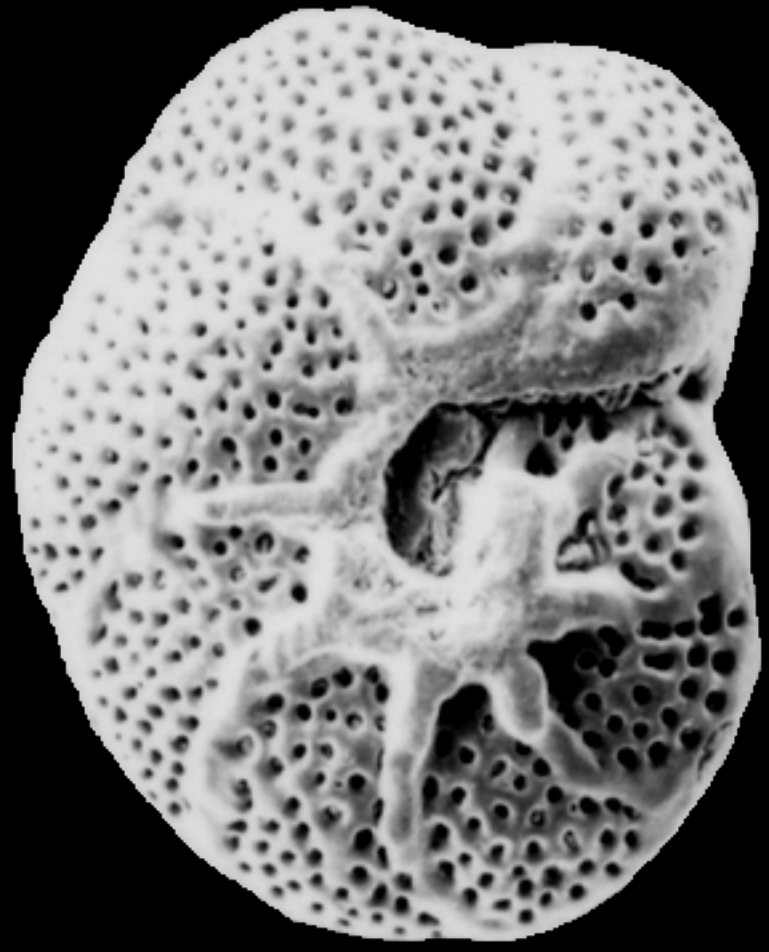




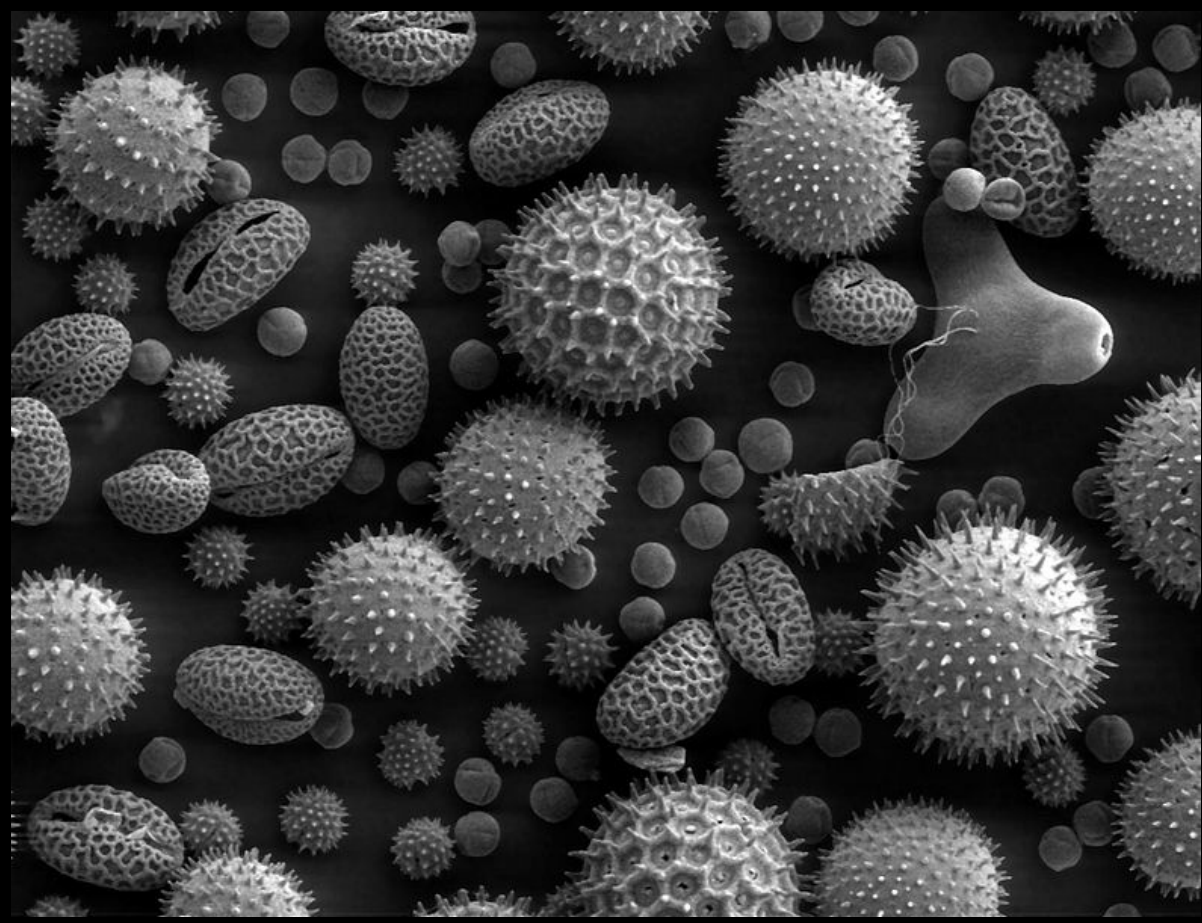
0.5cm

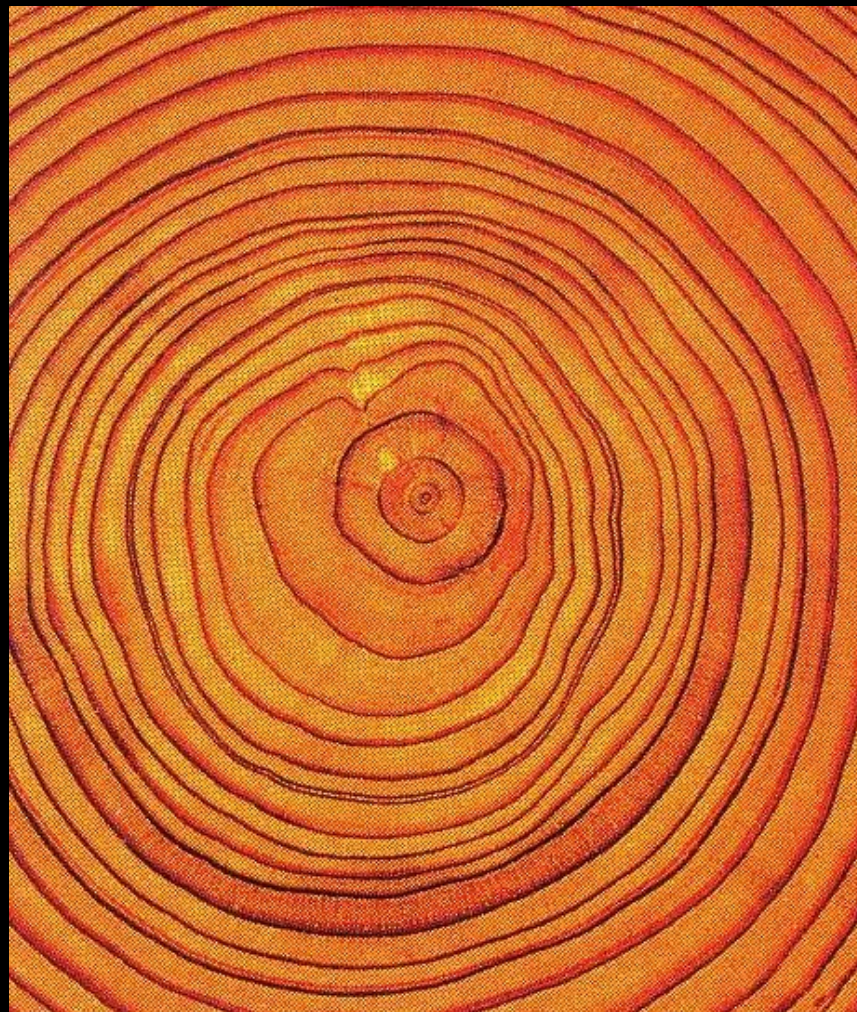






5 μm





Reconstructing past climate



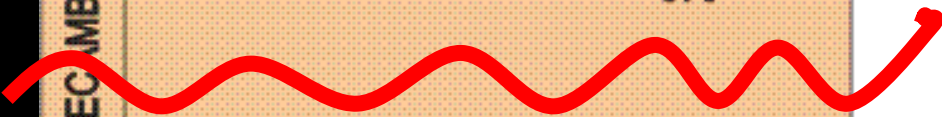
Talk outline:

A trip through geologic time

Take away points:

- Climate change through time
- What past climate change adds to the climate story
- What type of “archives” and data do we have

PHANEROZOIC	CENOZOIC	TERTIARY	QUATERNARY	0	HOLOCENE			
			NEOGENE	1.65	PLEISTOCENE			
			PALEOGENE	23.8	PLIOCENE			
	MESOZOIC	CRETACEOUS			65	MIOCENE		
						JURASSIC	144.8	OLIGOCENE
						TRIASSIC	200	EOCENE
		PALEOZOIC	PERMIAN	251	Millions of years ago (ma)	PALEOCENE		
			CARBONIFEROUS	300				
			DEVONIAN	355				
			SILURIAN	418				
ORDOVICIAN			441					
PRECAMBRIAN	CAMBRIAN	490						
	EDIACARAN	544						
				570				
				4000+				

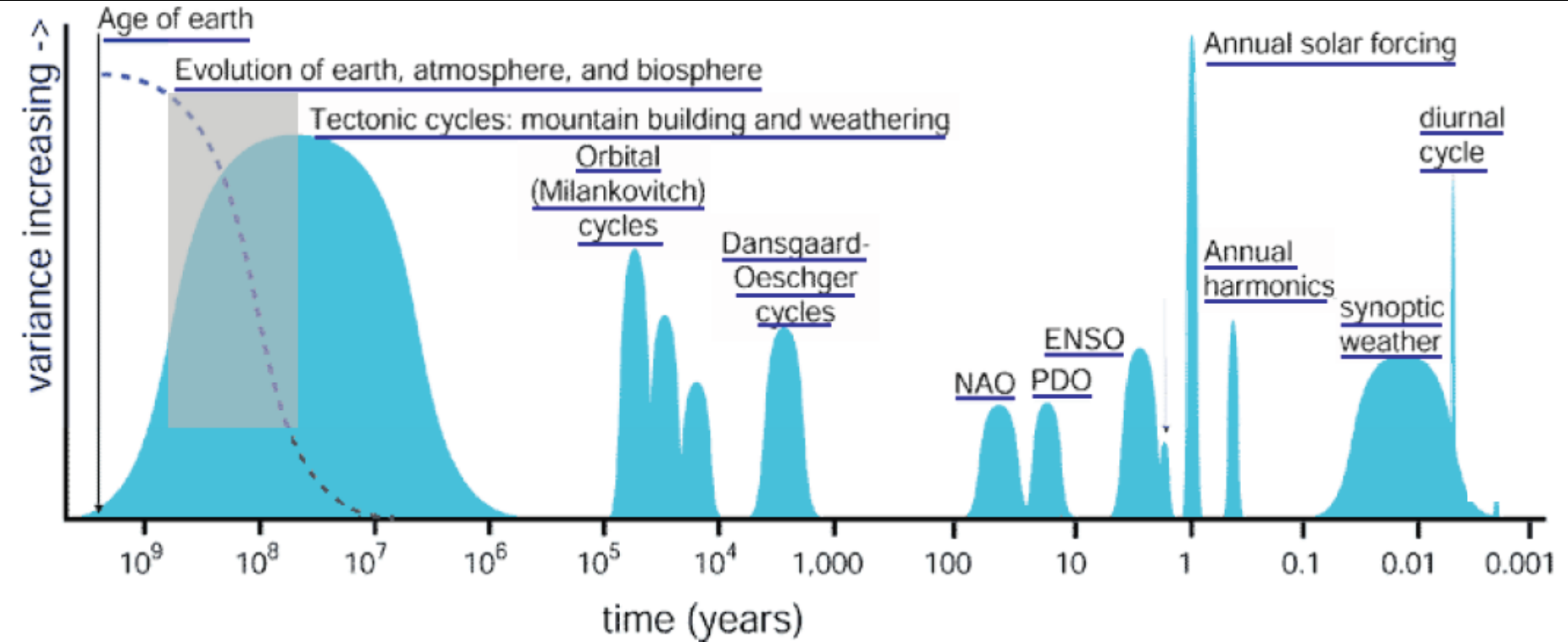




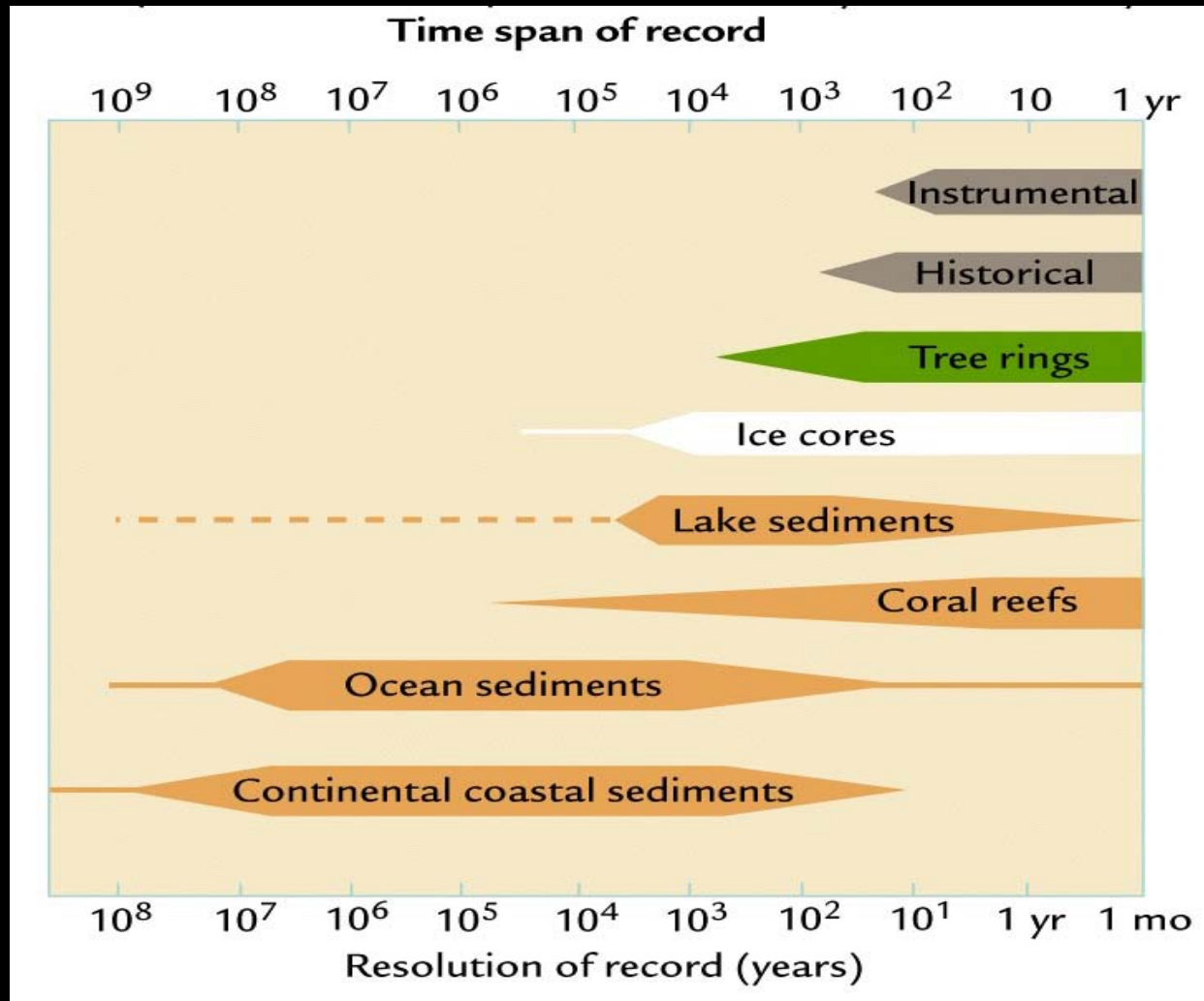
Causes of climate change: natural forcings

- Changes in plate tectonics and the related changes in carbon dioxide (100,000's to millions of years)
- Changes in the earth's orbit, "Milankovitch" cycles (10,000's to 100,000's years)
- Changes in the sun's strength (very short... to very long)

Timescales of climate variability



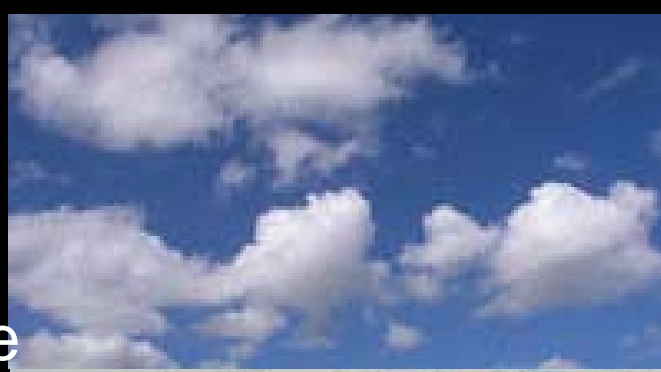
Climate archives: what records do we have?





Climate archives: what information do we need?

Atmosphere



Cryosphere



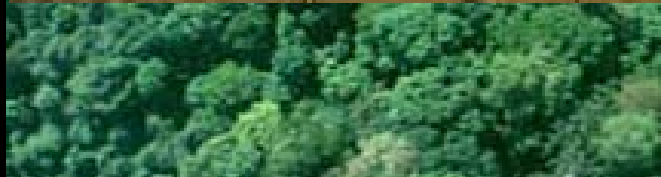
Hydrosphere



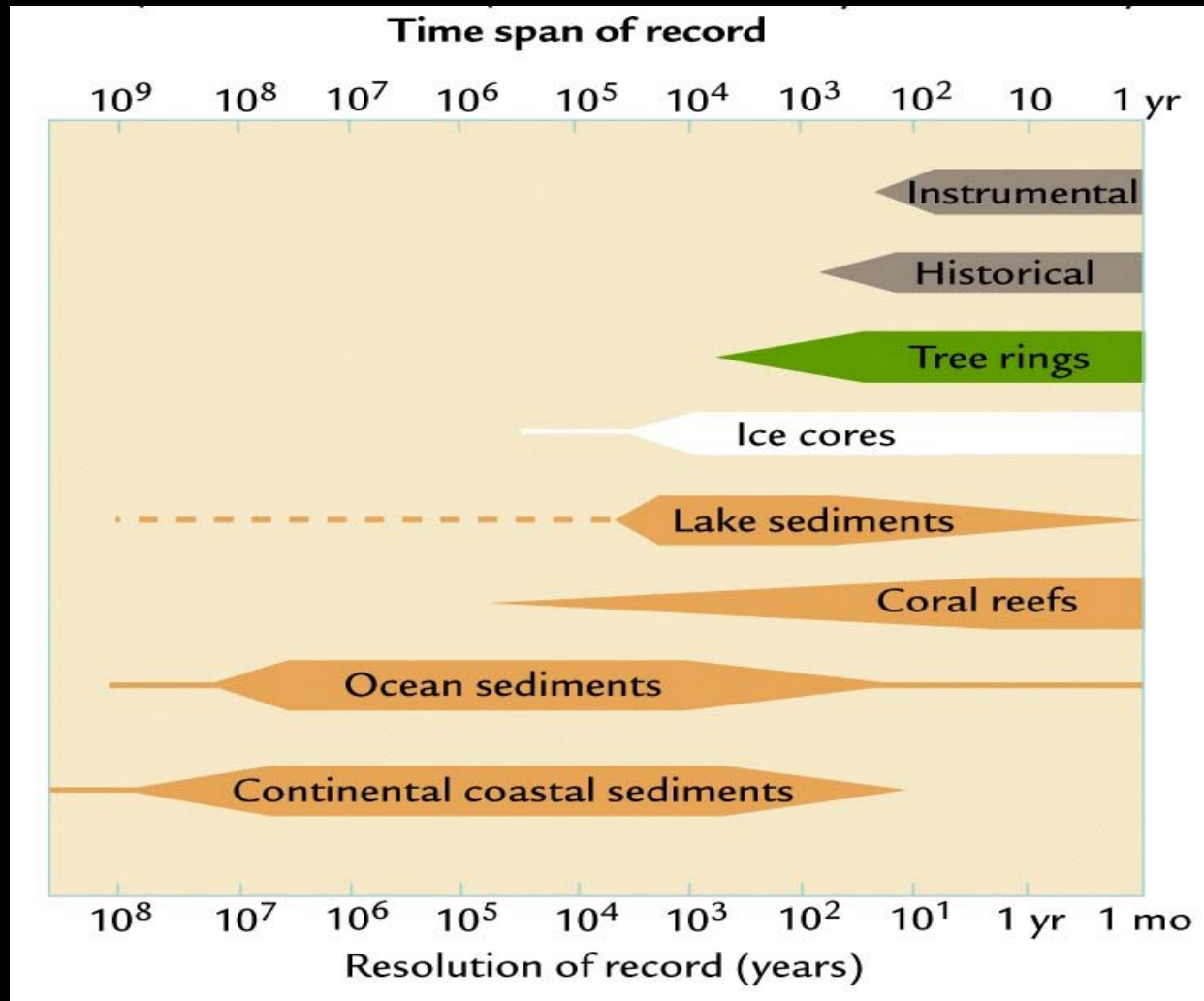
Land



Biosphere



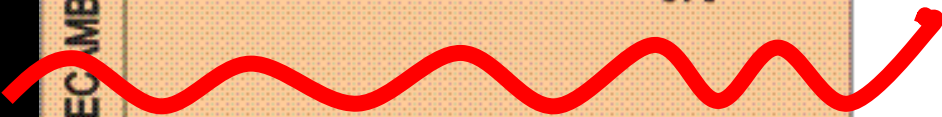
Climate archives: what records do we have?



Geologic Time

PHANEROZOIC	CENOZOIC	QUATERNARY		0	HOLOCENE	
		TERTIARY	NEOGENE		1.65	PLEISTOCENE
			PALEOGENE		23.8	PLIOCENE MIOCENE
	MESOZOIC	CRETACEOUS		65	OLIGOCENE	
		JURASSIC		144.8	EOCENE	
		TRIASSIC		200	PALEOCENE	
		PALEOZOIC	PERMIAN		251	
			CARBONIFEROUS		300	
			DEVONIAN		355	
			SILURIAN		418	
			ORDOVICIAN		441	
	CAMBRIAN		490			
	EDIACARAN		544			
	PRECAMBRIAN			570		
		4000+				

Millions of years ago (ma)



Geologic Time: “Deep time problems”

- The Faint Young Sun (and climate homeostasis)
- Snowball Earth

PHANEROZOIC	CENOZOIC	QUATERNARY		0	HOLOCENE	
		TERTIARY	NEOGENE		1.65	PLEISTOCENE
			PALEOGENE		23.8	PLIOCENE MIOCENE OLIGOCENE EOCENE PALEOCENE
	MESOZOIC	CRETACEOUS		65	Millions of years ago (ma)	
		JURASSIC		144.8		
		TRIASSIC		200		
	PALEOZOIC	PERMIAN		251		
		CARBONIFEROUS		300		
		DEVONIAN		355		
		SILURIAN		418		
ORDOVICIAN		441				
PRECAMBRIAN	CAMBRIAN		490			
	EDIACARAN		544			
			570			
				4000+		

Geologic Time:
“Snow ball earth”

Setting the stage: “different boundary conditions”

- Neoproterozoic, 750 to 550 ma
(ma = million years ago)
- faint young sun, ~6% fainter
- more continents at low latitudes
- no multicellular life, no land plants:
precedes the Cambrian explosion

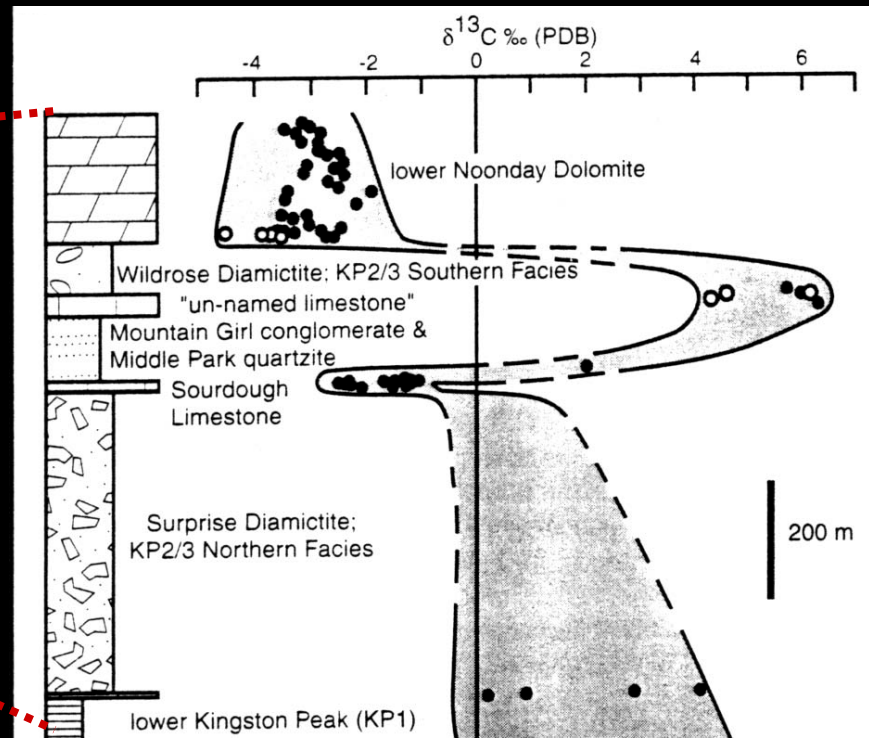
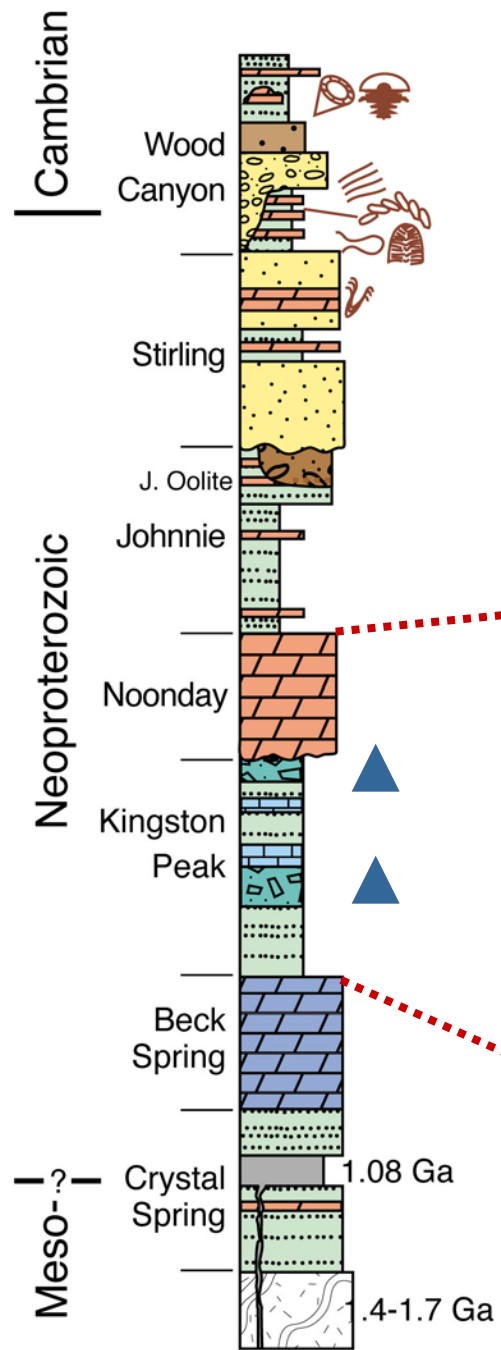
Geologic Time:
“Snow ball earth”

Paleo-data



Death Valley Rock record

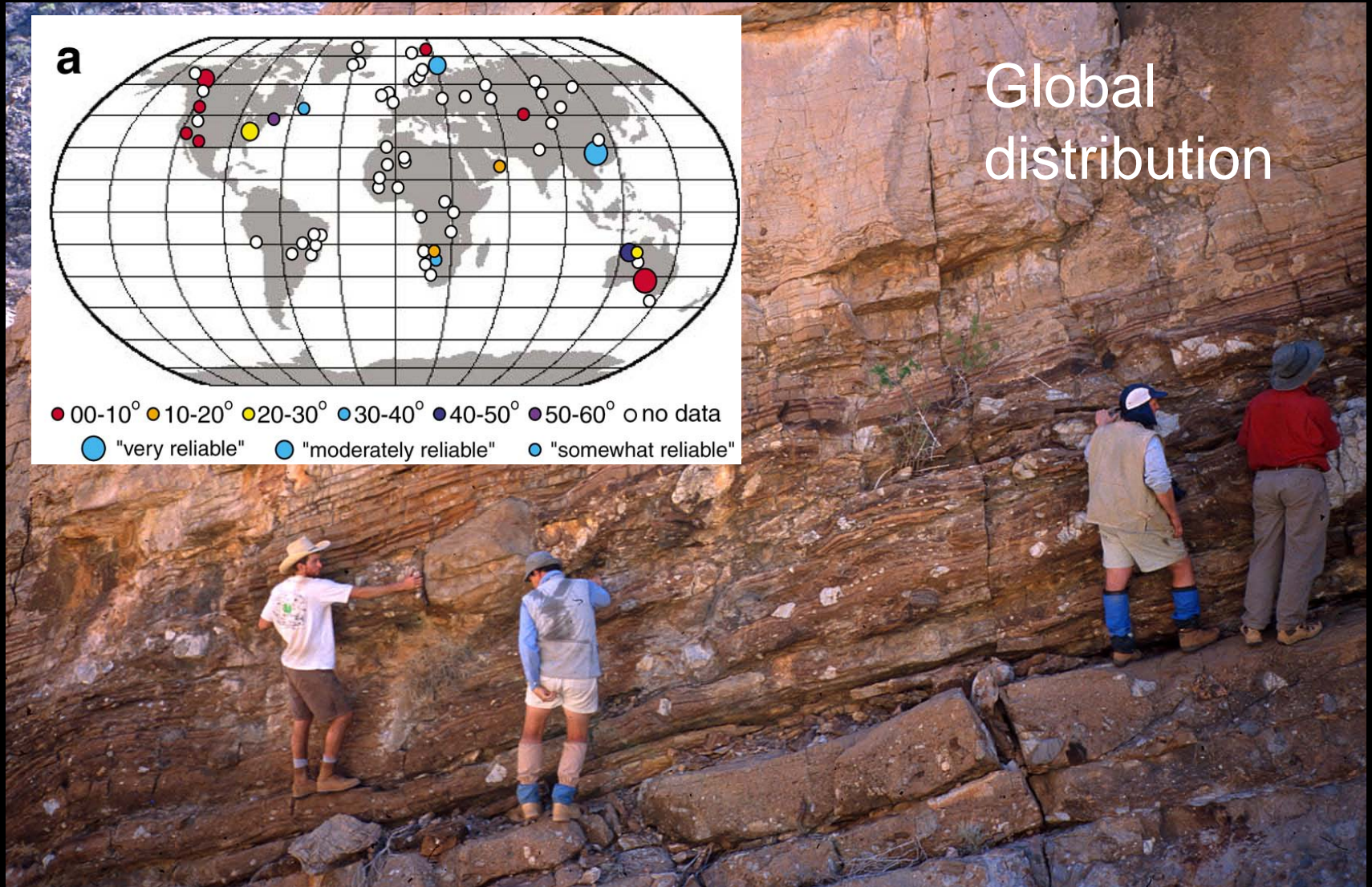
“2 diamictites, 2 excursions, 2 glaciation”



Prave, 1999

Geologic Time: "Snow ball earth"

Paleo-data



Geologic Time: “Deep time problems”

- Warm (“Equable”) climates

PHANEROZOIC	CENOZOIC	QUATERNARY		0	HOLOCENE	
		TERTIARY	NEOGENE		1.65	PLEISTOCENE
			PALEOGENE		23.8	PLIOCENE MIOCENE
	MESOZOIC	CRETACEOUS		65	OLIGOCENE	
		JURASSIC		144.8	EOCENE	
		TRIASSIC		200	PALEOCENE	
		PERMIAN		251		
		CARBONIFEROUS		300		
		DEVONIAN		355		
		SILURIAN		418		
ORDOVICIAN		441				
PALEOZOIC	CAMBRIAN		490			
	EDIACARAN		544			
PRECAMBRIAN			570			
			4000+			

Millions of years ago (ma)

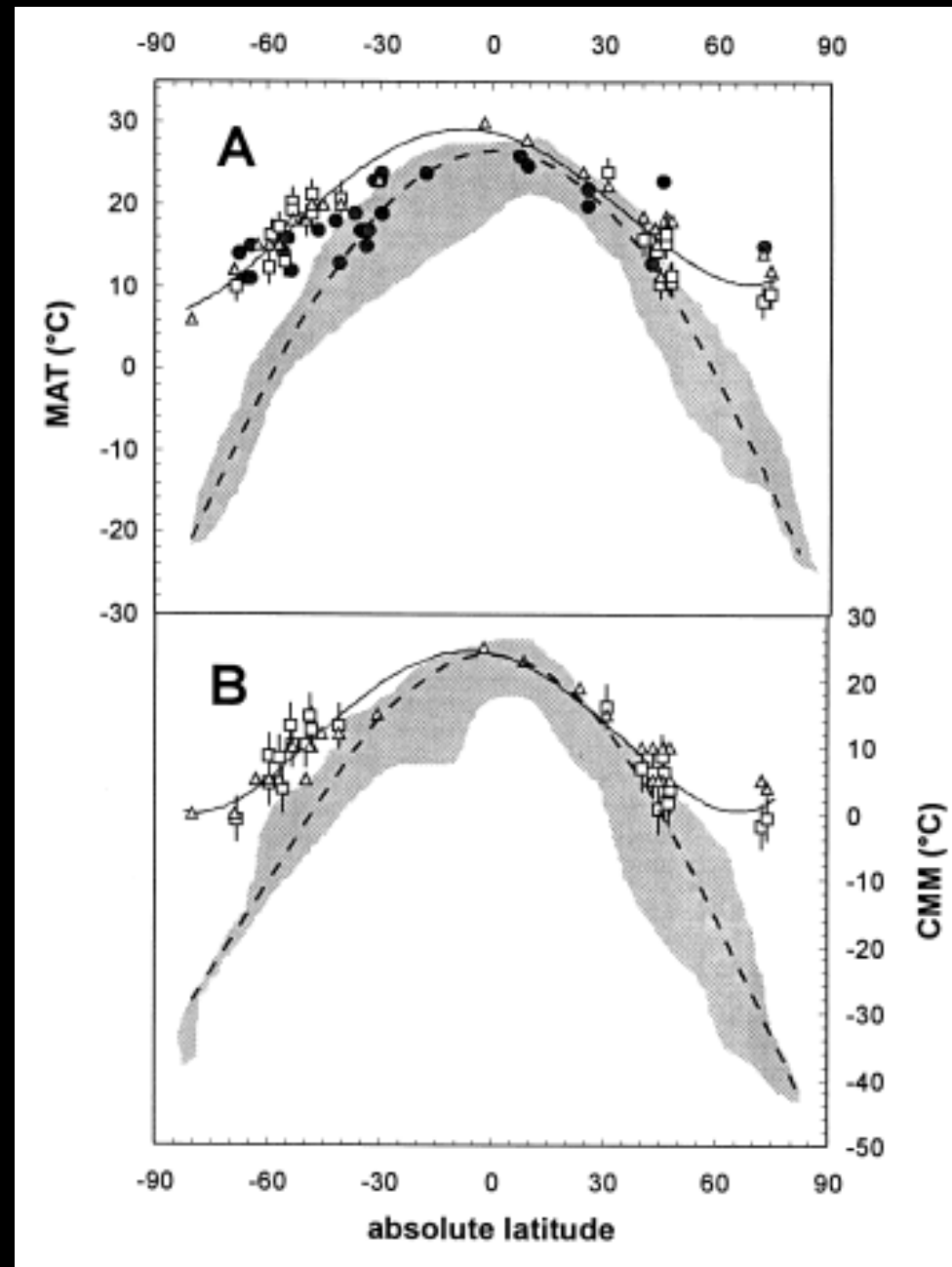
Geologic Time:
“Warm climates”

Setting the stage: “different boundary conditions”

- Paleozoic, Mesozoic, start of the Cenozoic
- Often modeling focuses on: Late Cretaceous and Early Paleogene (~100-35 MaYr)
- continents migrated so there are now polar continents

An example of an equable climate: Eocene Temperature

- - Modern land temp.
- - Eocene sea surface temp.
- △ - Eocene Model
- - Eocene Model

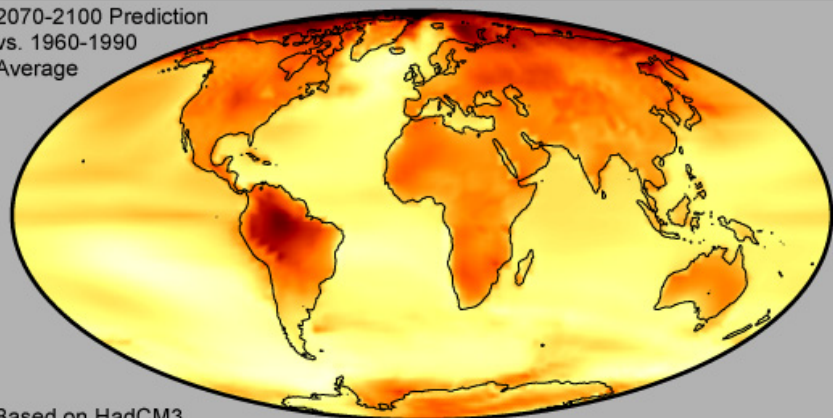


An example of an equable climate: Global warming?

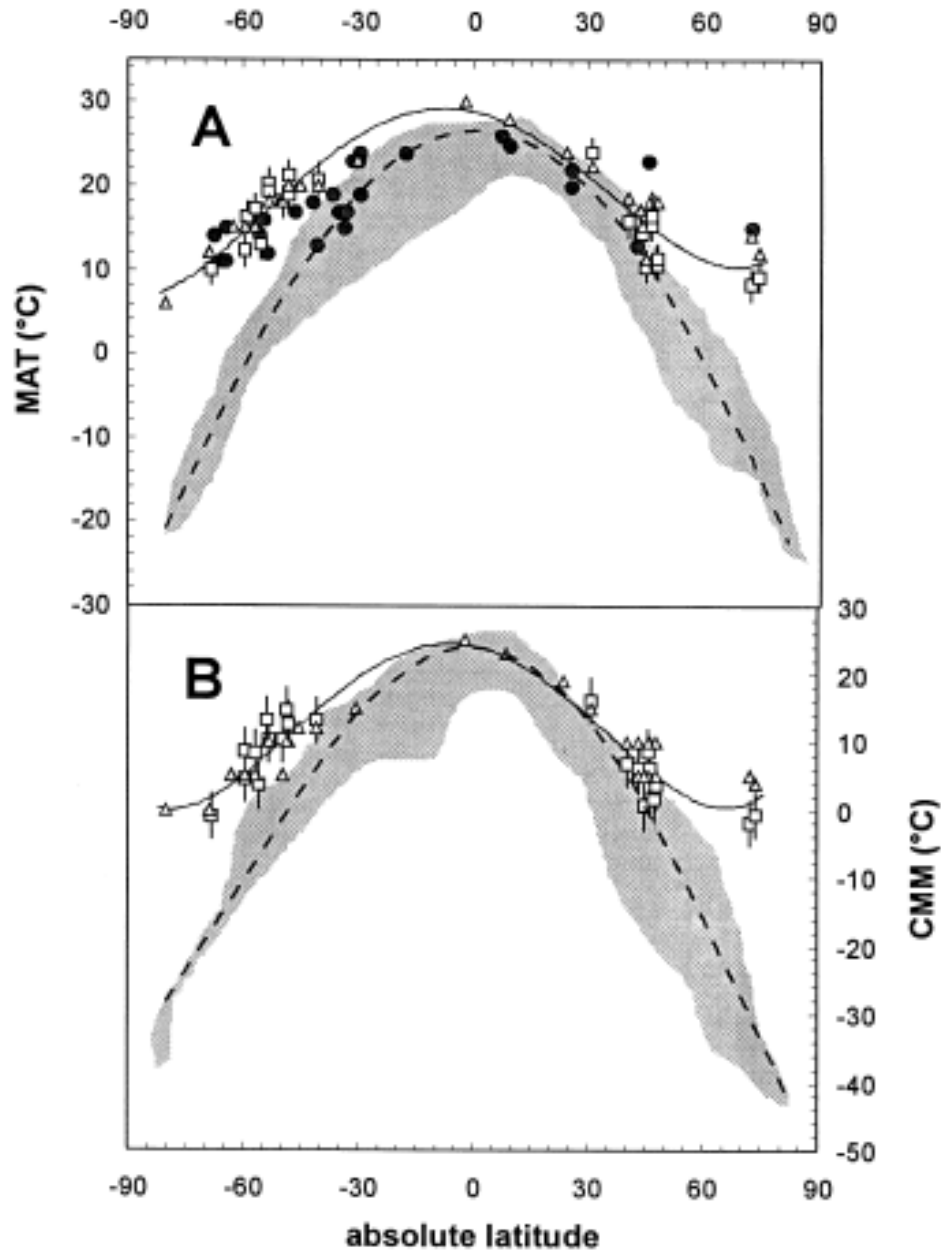
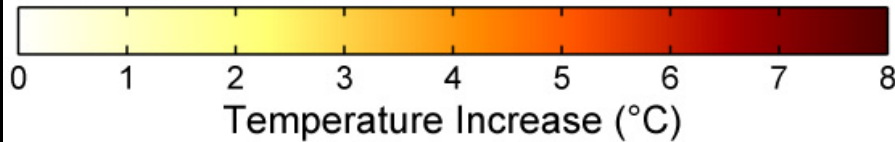
- - Modern land temp.
- - Eocene sea surface temp.
- △ - Eocene Model
- - Eocene Model

Global Warming Predictions

2070-2100 Prediction
vs. 1960-1990
Average



Based on HadCM3



[sorry no ref!]

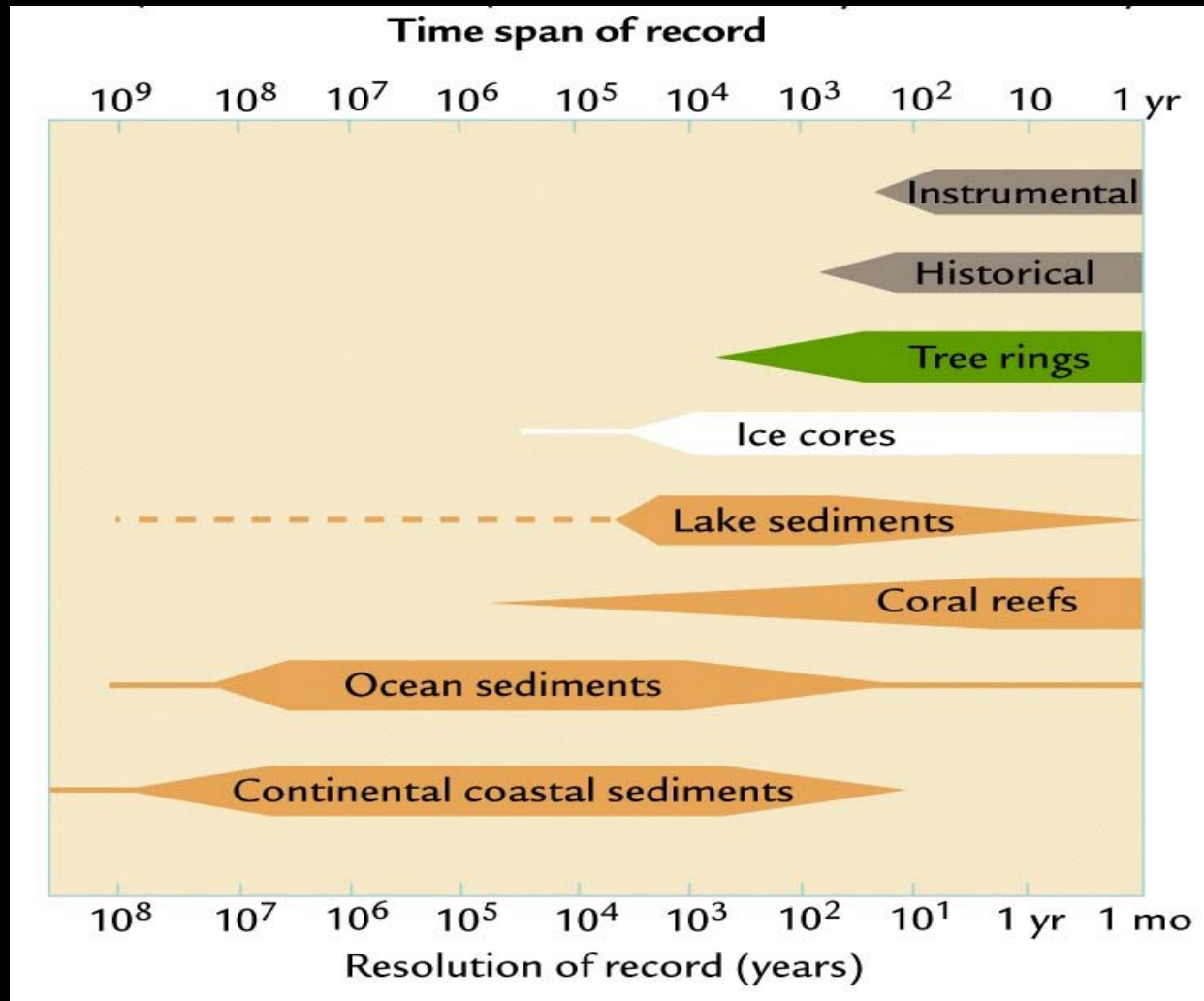
Geologic Time: “Cenozoic”

- Equable climates
- Tipping points
- Glacial cyclicity
- Abrupt climate

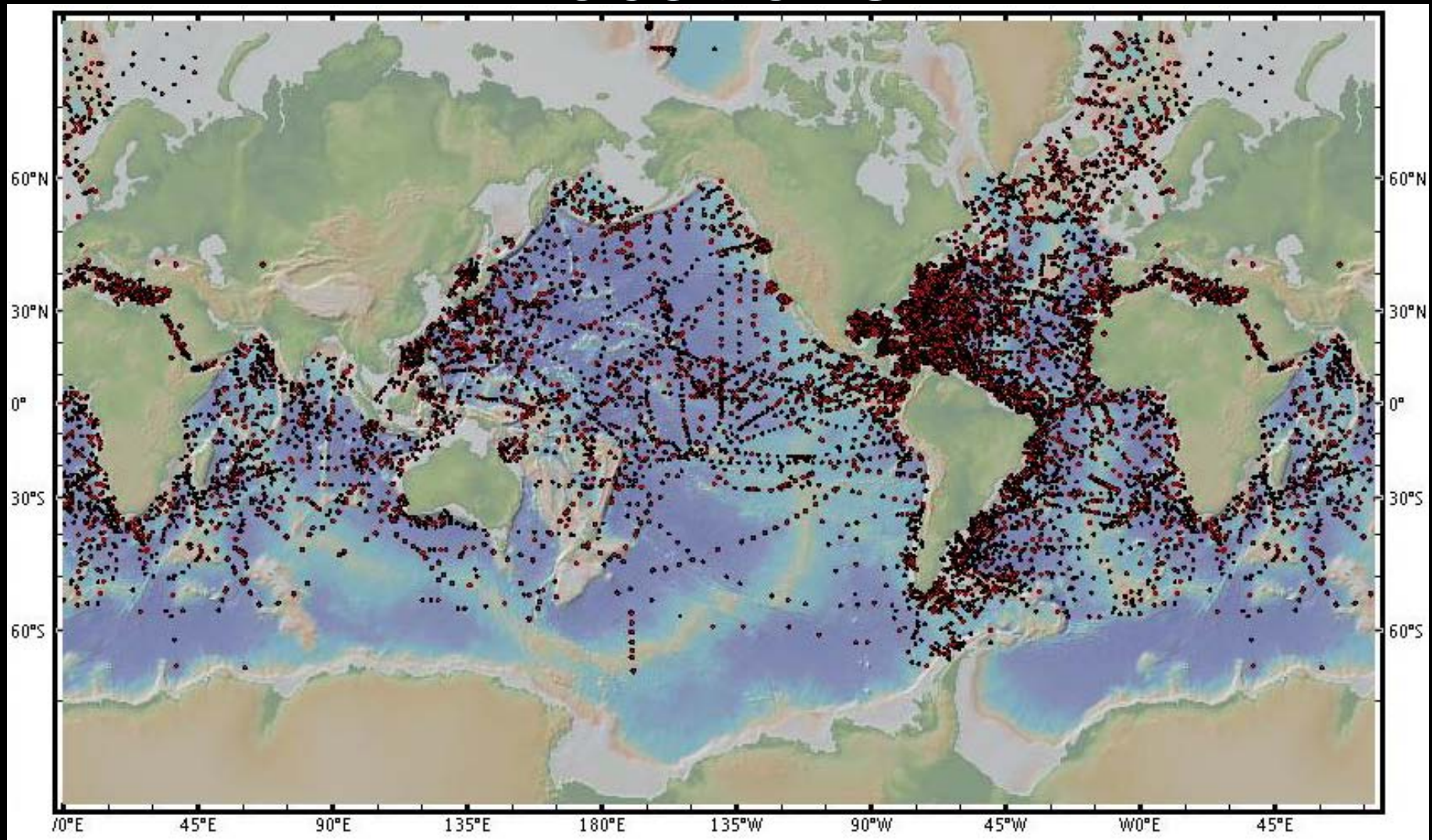
PHANEROZOIC	CENOZOIC	QUATERNARY	0	HOLOCENE	
		TERTIARY	NEOGENE	1.65	PLEISTOCENE
			PALEOGENE	23.8	PLIOCENE
	MESOZOIC	CRETACEOUS	65	MIOCENE	
				OLIGOCENE	
				EOCENE	
		PALEOZOIC	JURASSIC	144.8	PALEOCENE
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		EDACARAN	544		
			570		
			4000+		

Millions of years ago (ma)

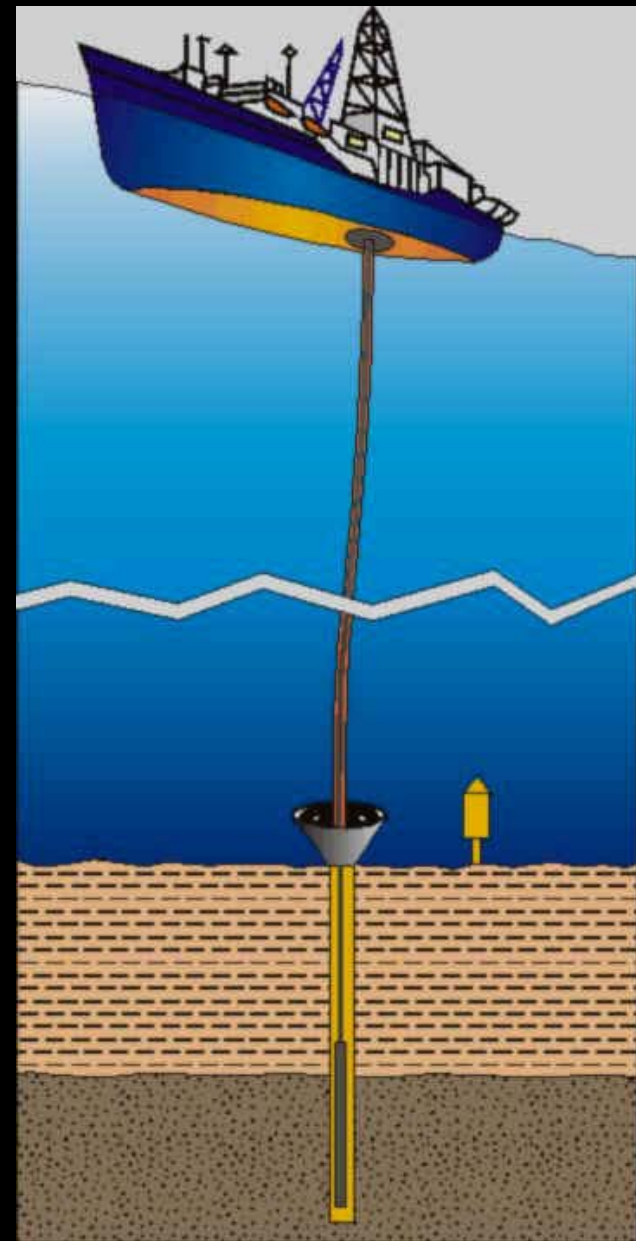
Climate archives: what records do we have?



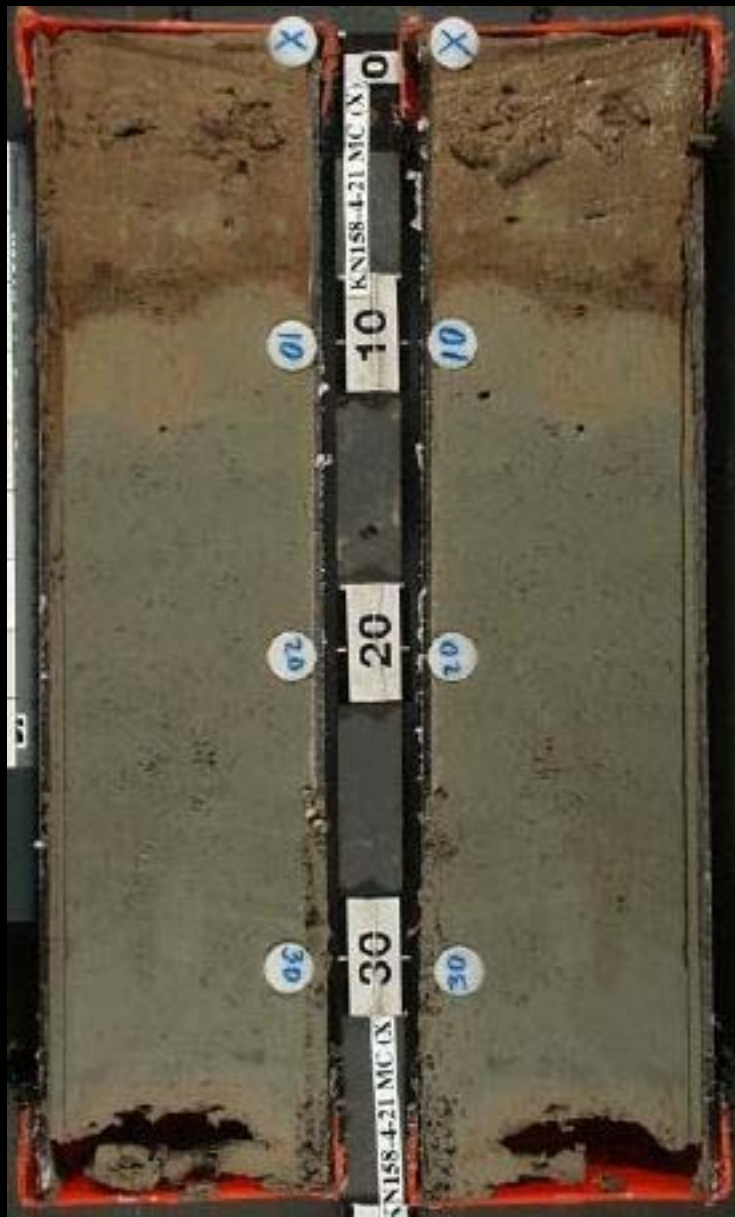
Ocean sediment-core locations



Ocean Drilling



Deep sea cores



younger



older

Ocean Plankton: live near surface

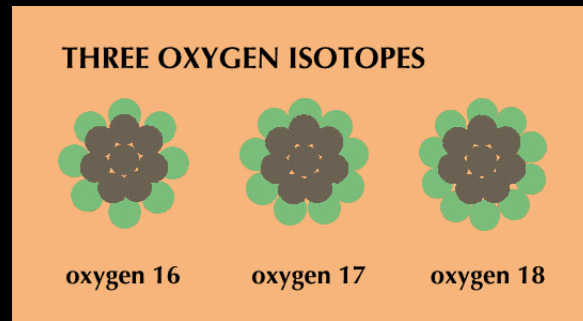


Foraminifera



Oxygen isotopes

Forams.

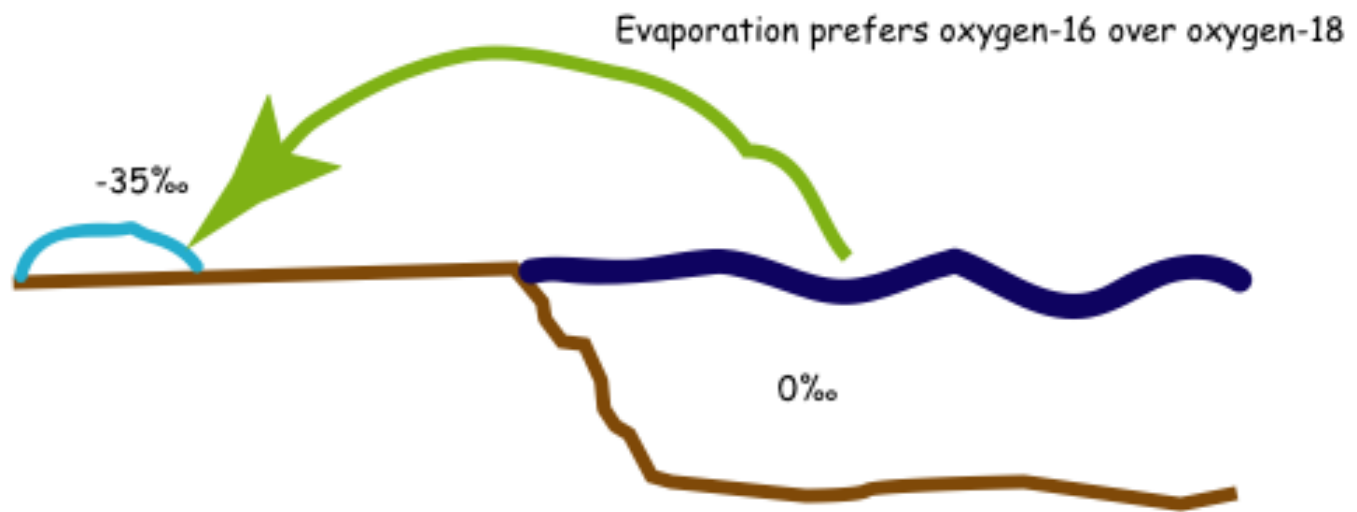


Drill

Die and Settle
To Bottom

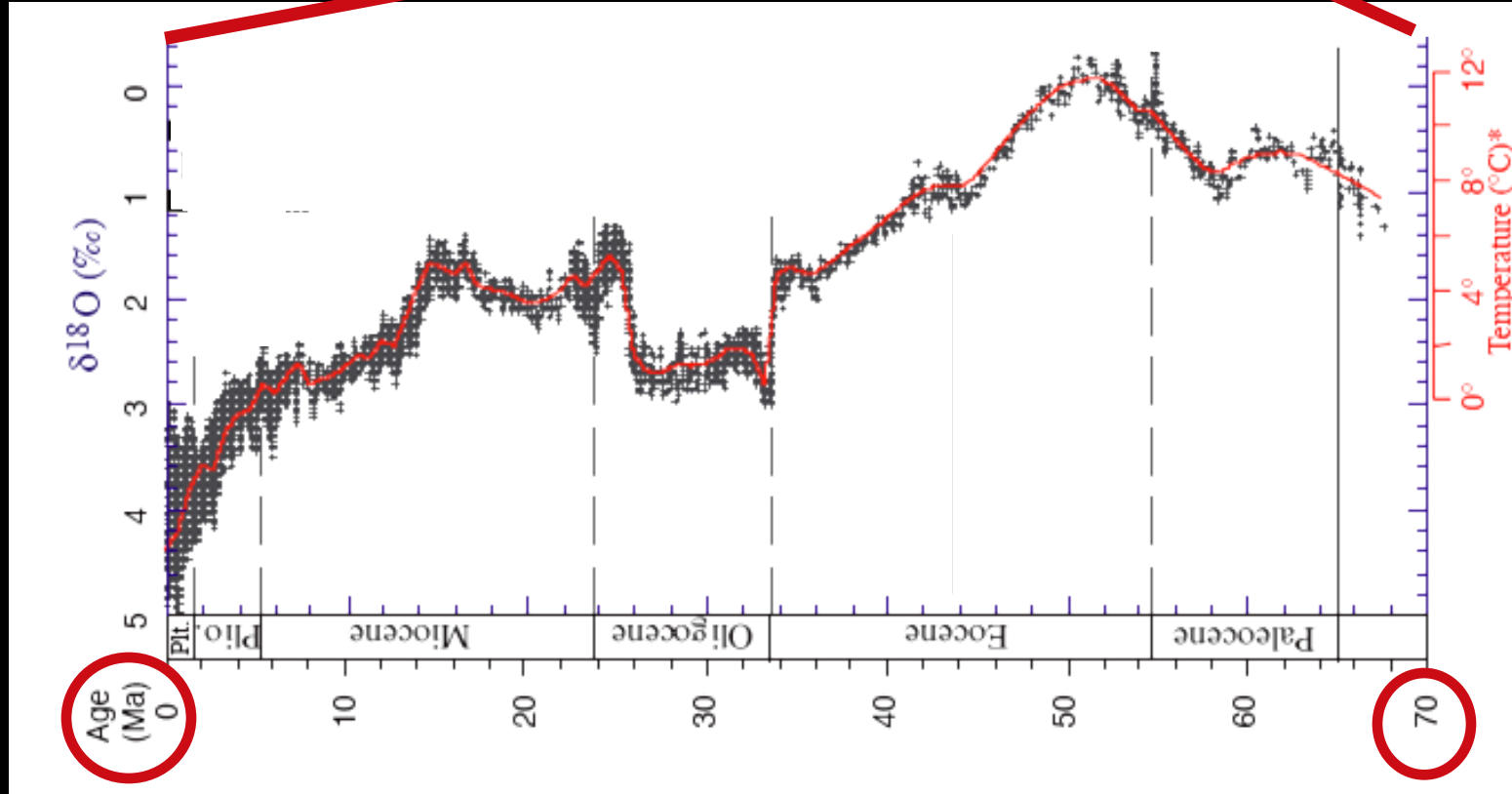
Mud!

Ice volume changes the water composition

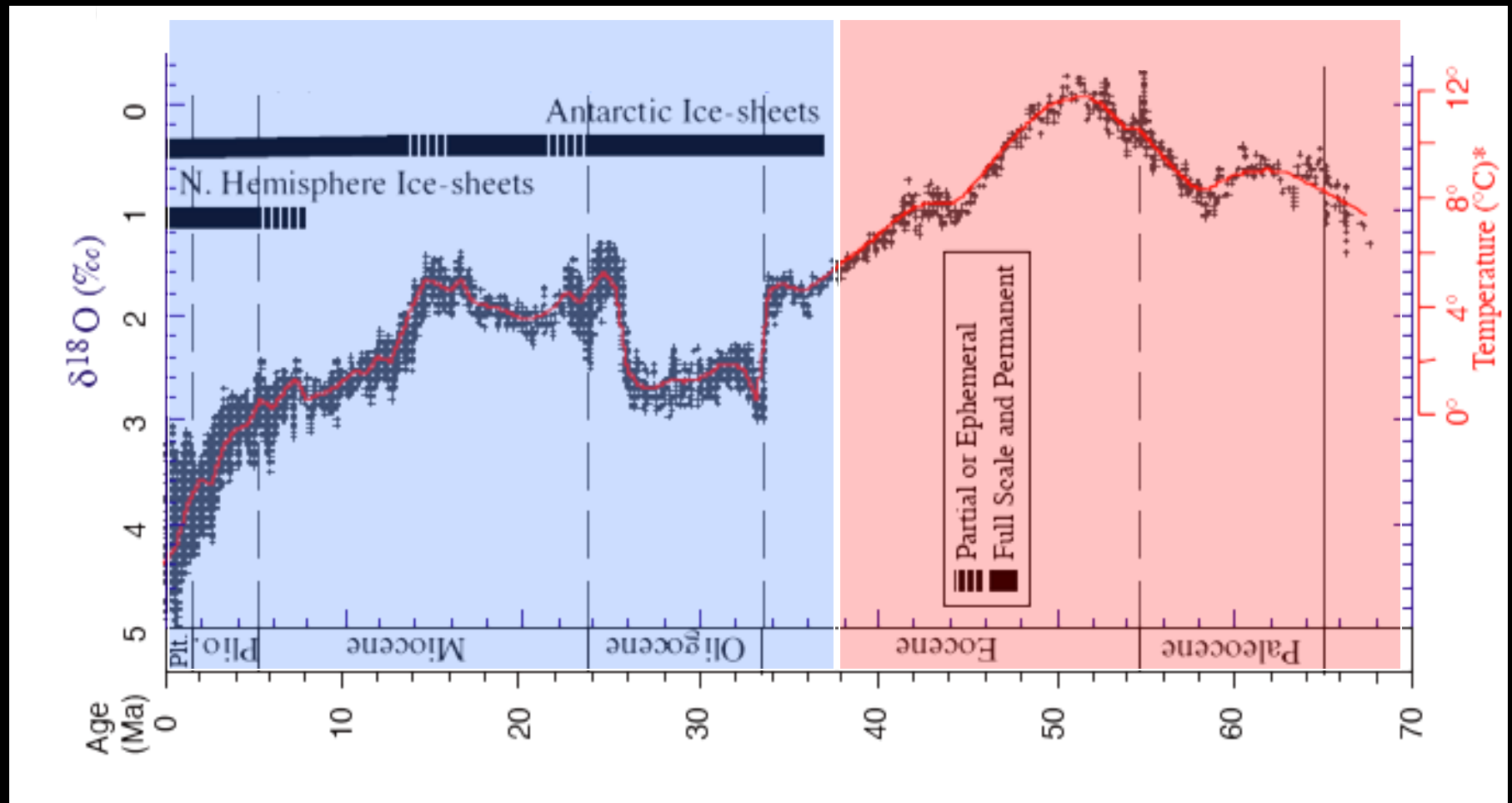


Climate data: A 65 million year (“Cenozoic”) environmental record from deep sea sediments

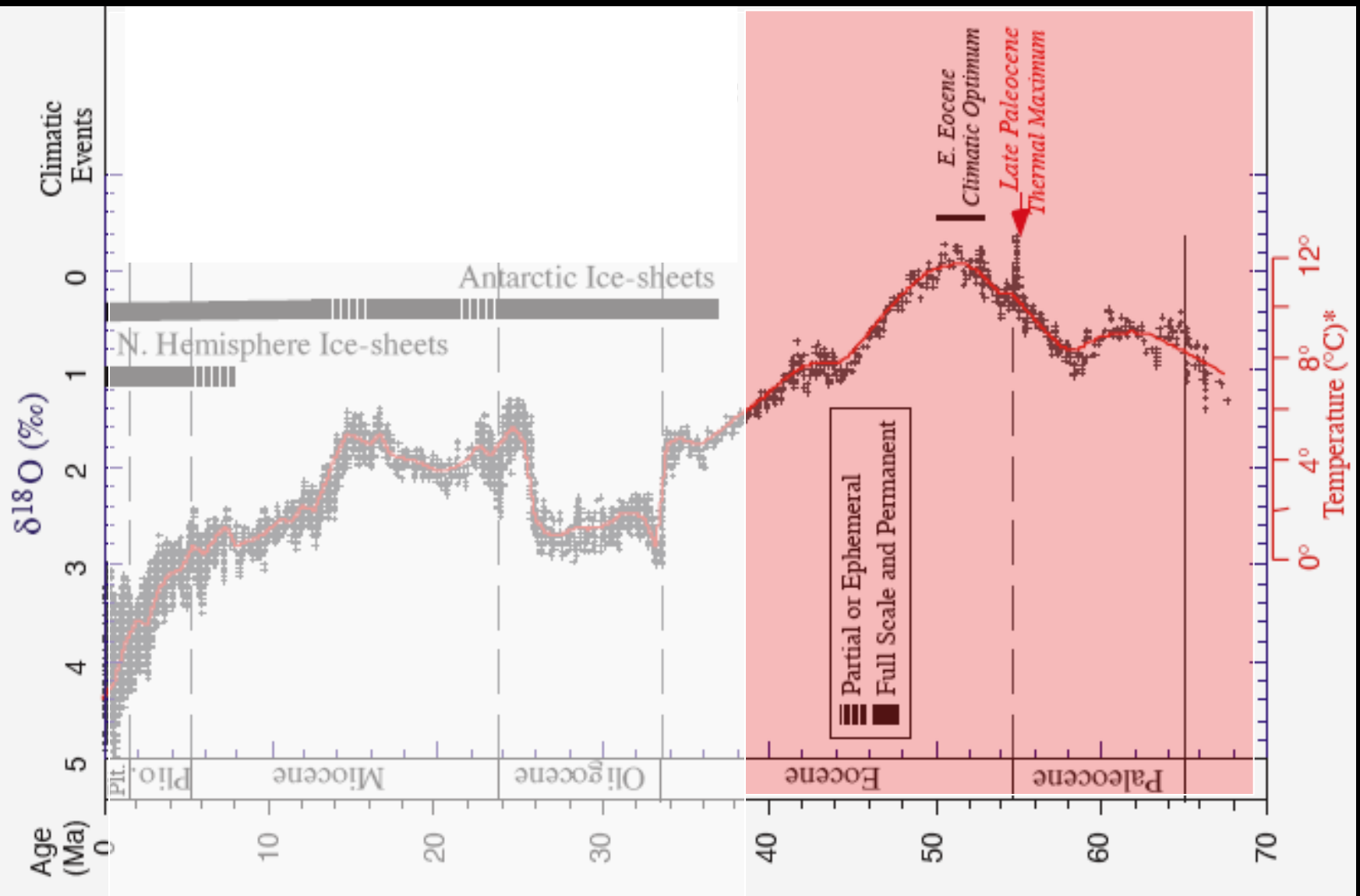
PHANEROZOIC	CENOZOIC	QUATERNARY	0
	MESOZOIC	NEOGENE	1.65
PALEOZOIC		PALEOGENE	23.8
PRECAMBRIAN	EDIIACARAN	544	544
		570	570
		490	490
		441	441
		ORDOVICIAN	441
		SILURIAN	418
		DEVONIAN	355
		CARBONIFEROUS	300
		PERMIAN	251
		TRIASSIC	200
JURASSIC	144.8		
CRETACEOUS	65		
		Millions of years ago (ma)	



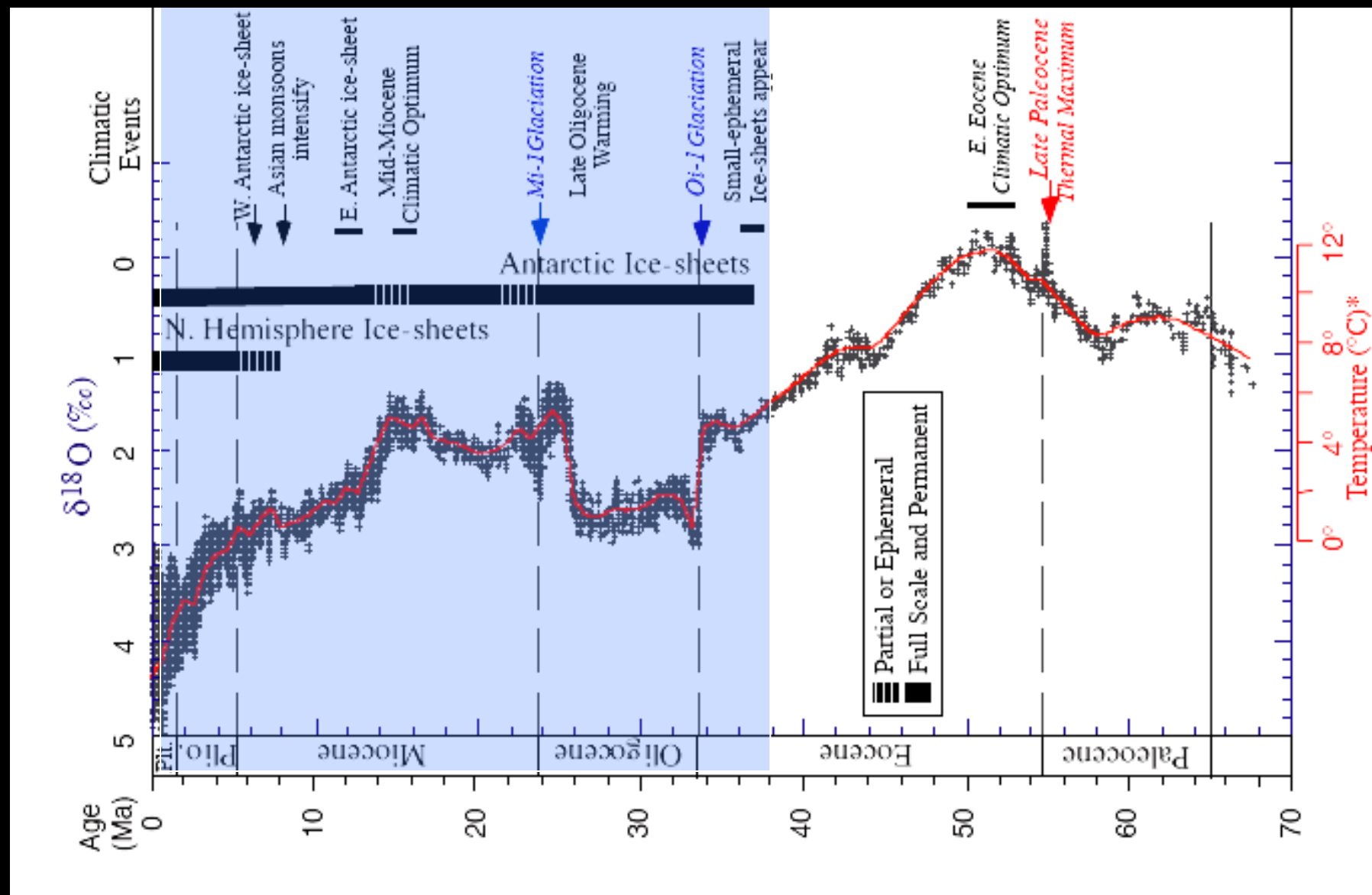
Climate data: A 65 million year (“Cenozoic”) environmental record from deep sea sediments



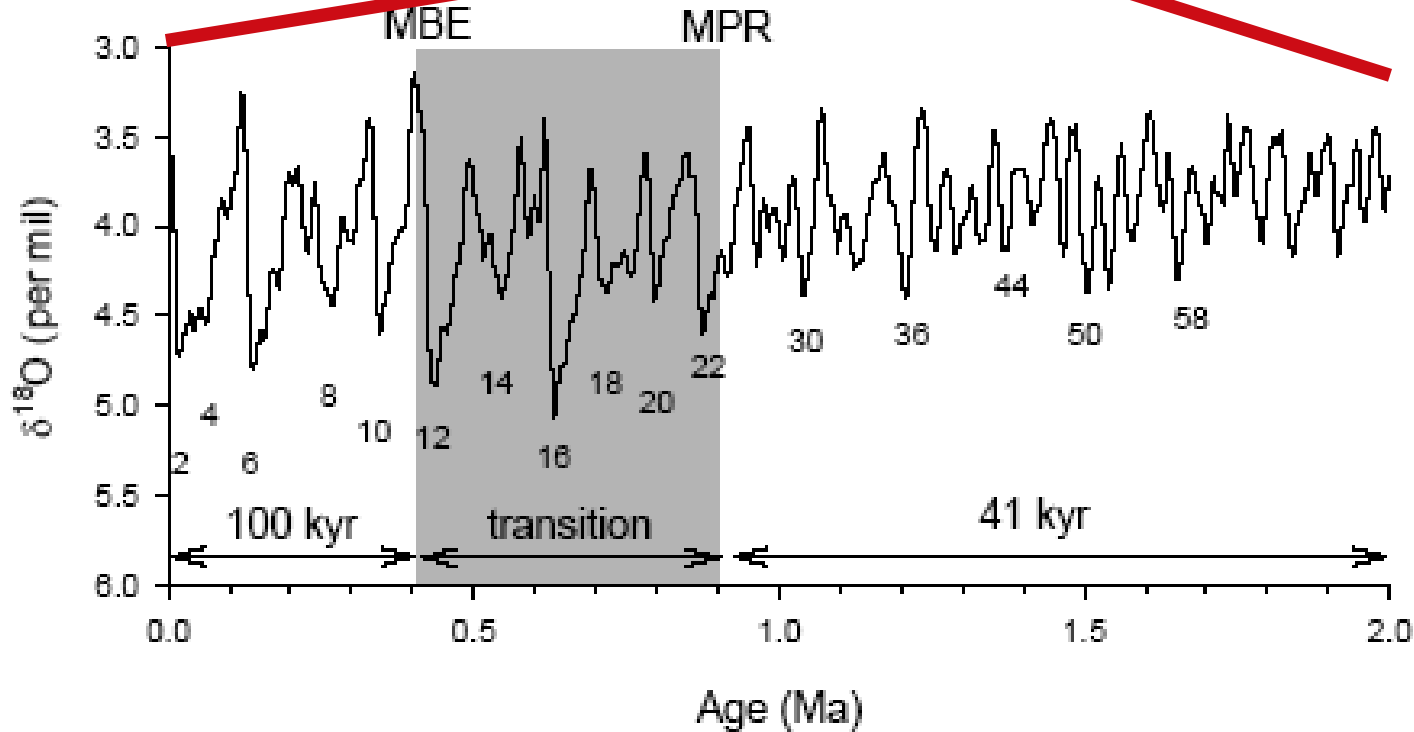
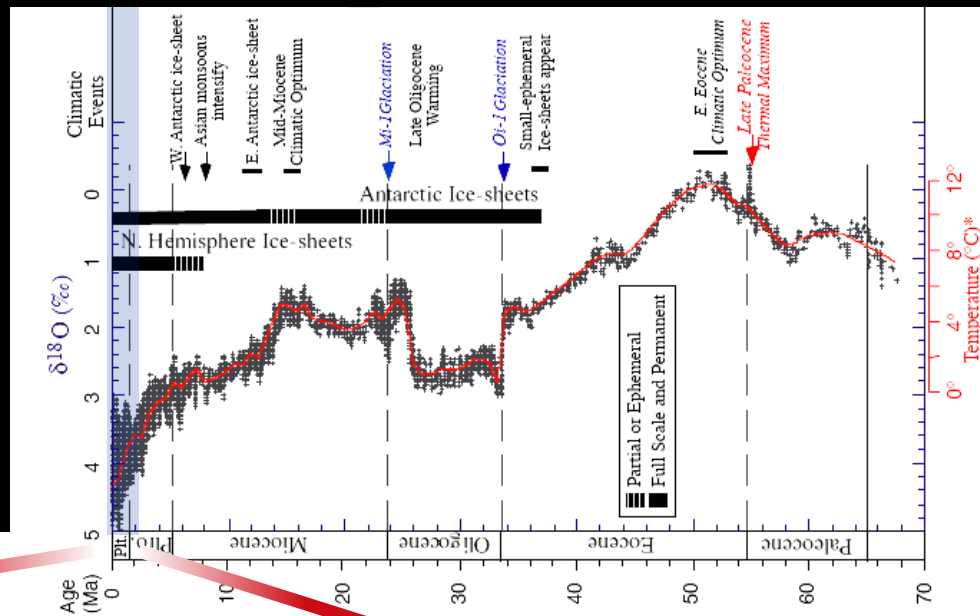
Climate data: A 65 million year (“Cenozoic”) environmental record from deep sea sediments



Climate data: A 65 million year (“Cenozoic”) environmental record from deep sea sediments



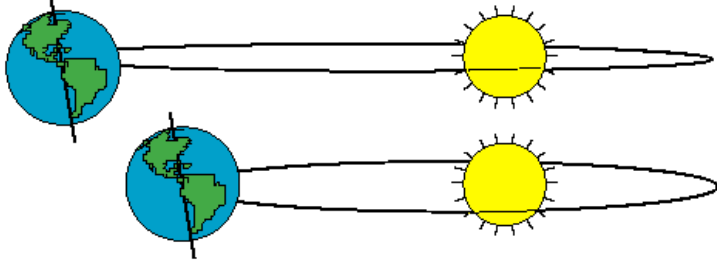
Glacial-interglacial cycles



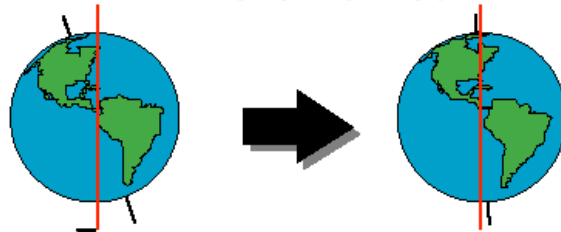
Glacial-interglacial cycles

- Earth orbitals

Eccentricity Cycle (100 k.y.)



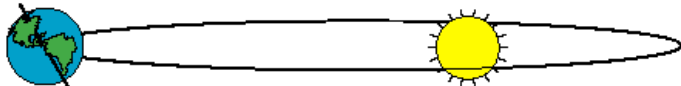
Obliquity Cycle (41 k.y.)



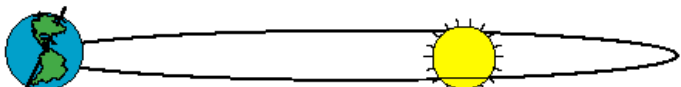
Normal to Ecliptic

©Scott Rutherford (1997)

Precession of the Equinoxes (19 and 23 k.y.)



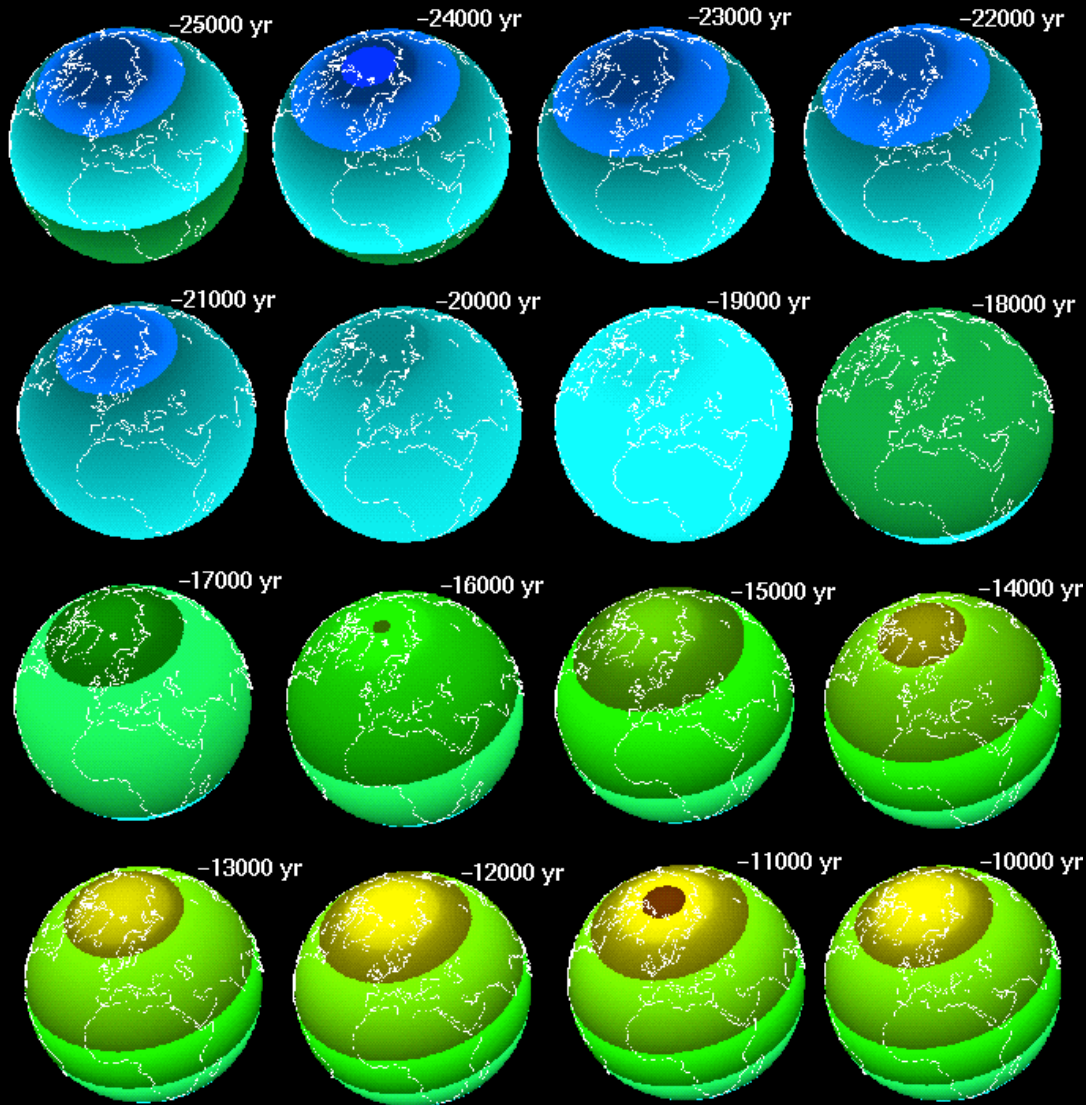
Northern Hemisphere tilted away from the sun at aphelion.



Northern hemisphere tilted toward the sun at aphelion.

Visualization of Milankovitch Climate Change Theory

Glacial-interglacial cycles



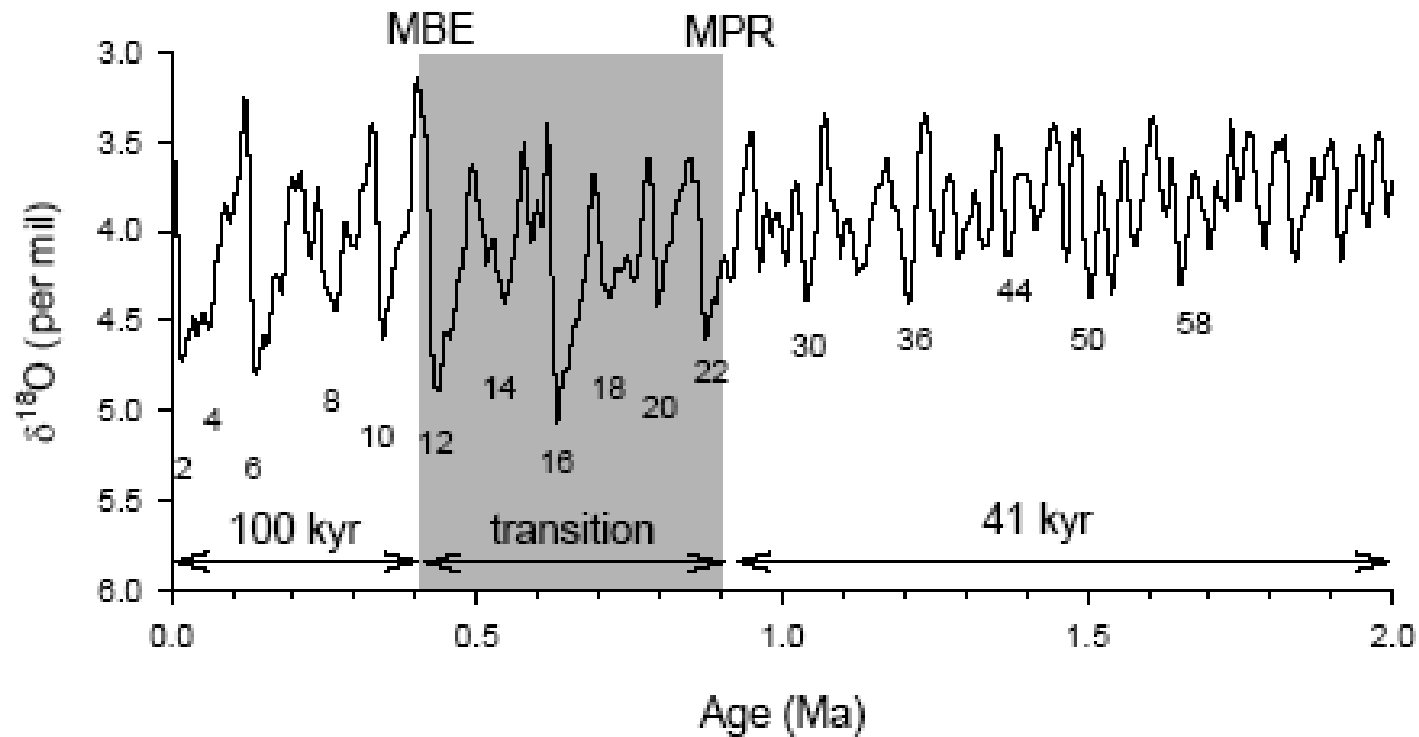
Reproduction is permitted with proper attribution: ASU Depts of Geography & Computer Science, 1996

Daily Total Solar Radiation (MJ m^{-2})
June Solstice

Reproduction is permitted with proper attribution: ASU Depts of Geography & Computer Science, 1996



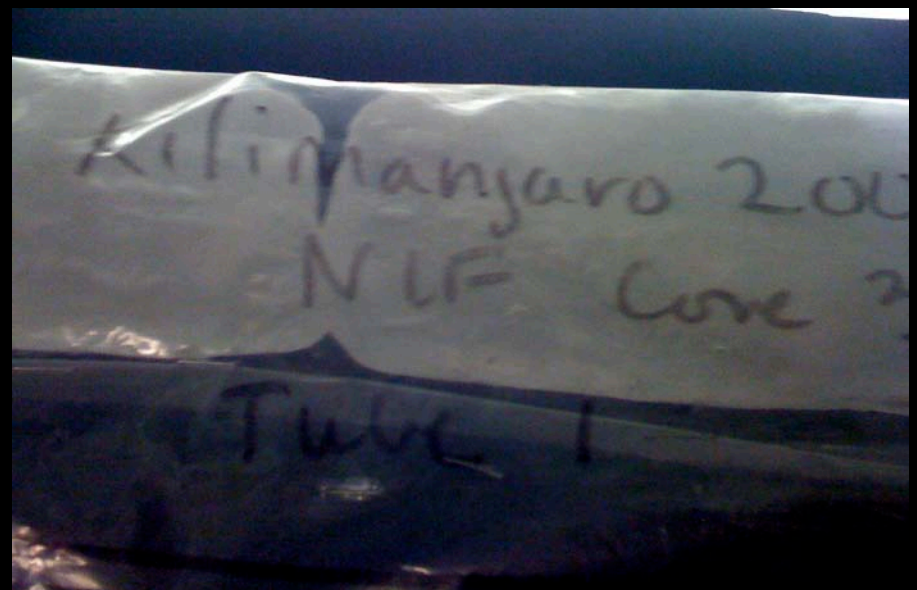
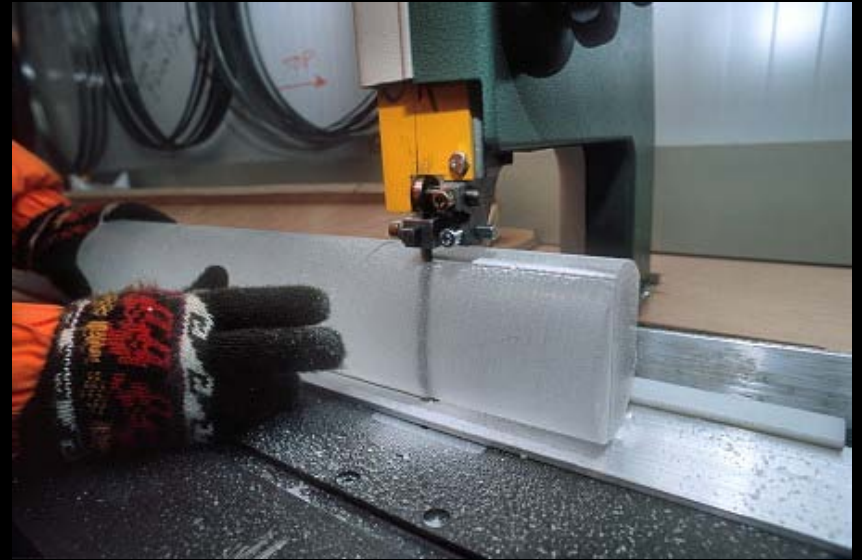
Glacial-interglacial cycles



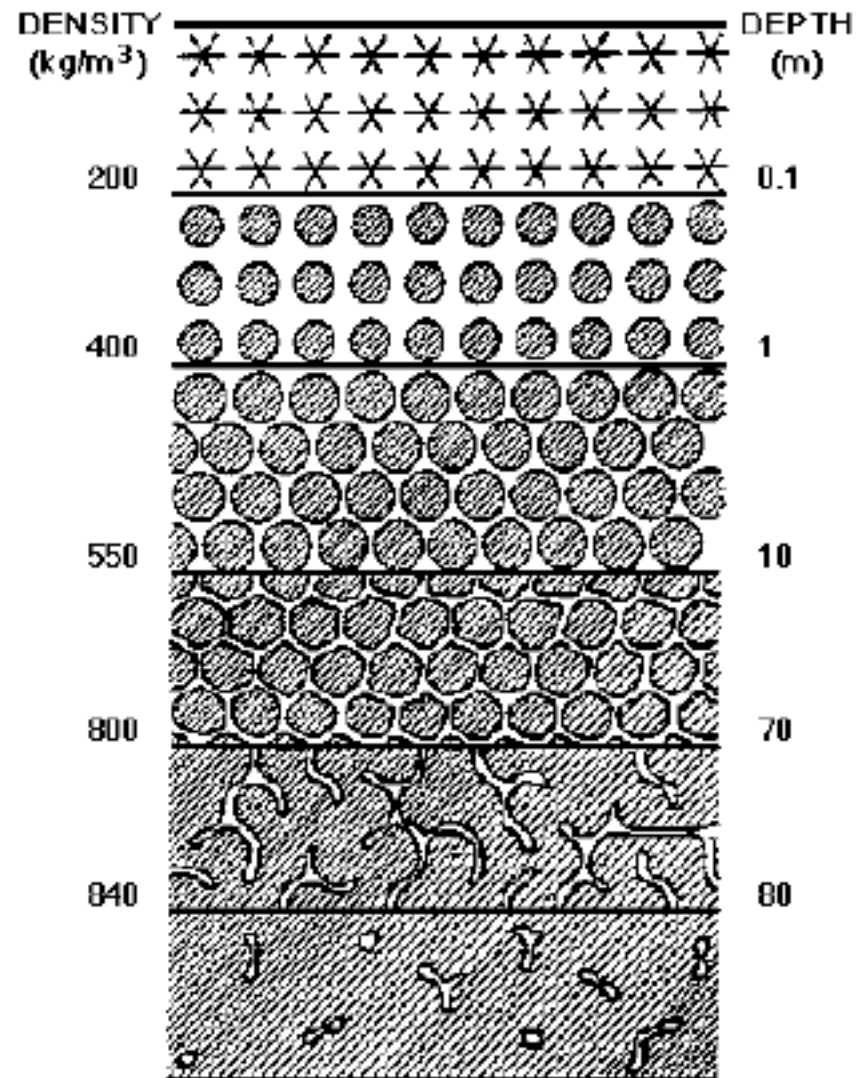
Glacial climate in ice cores



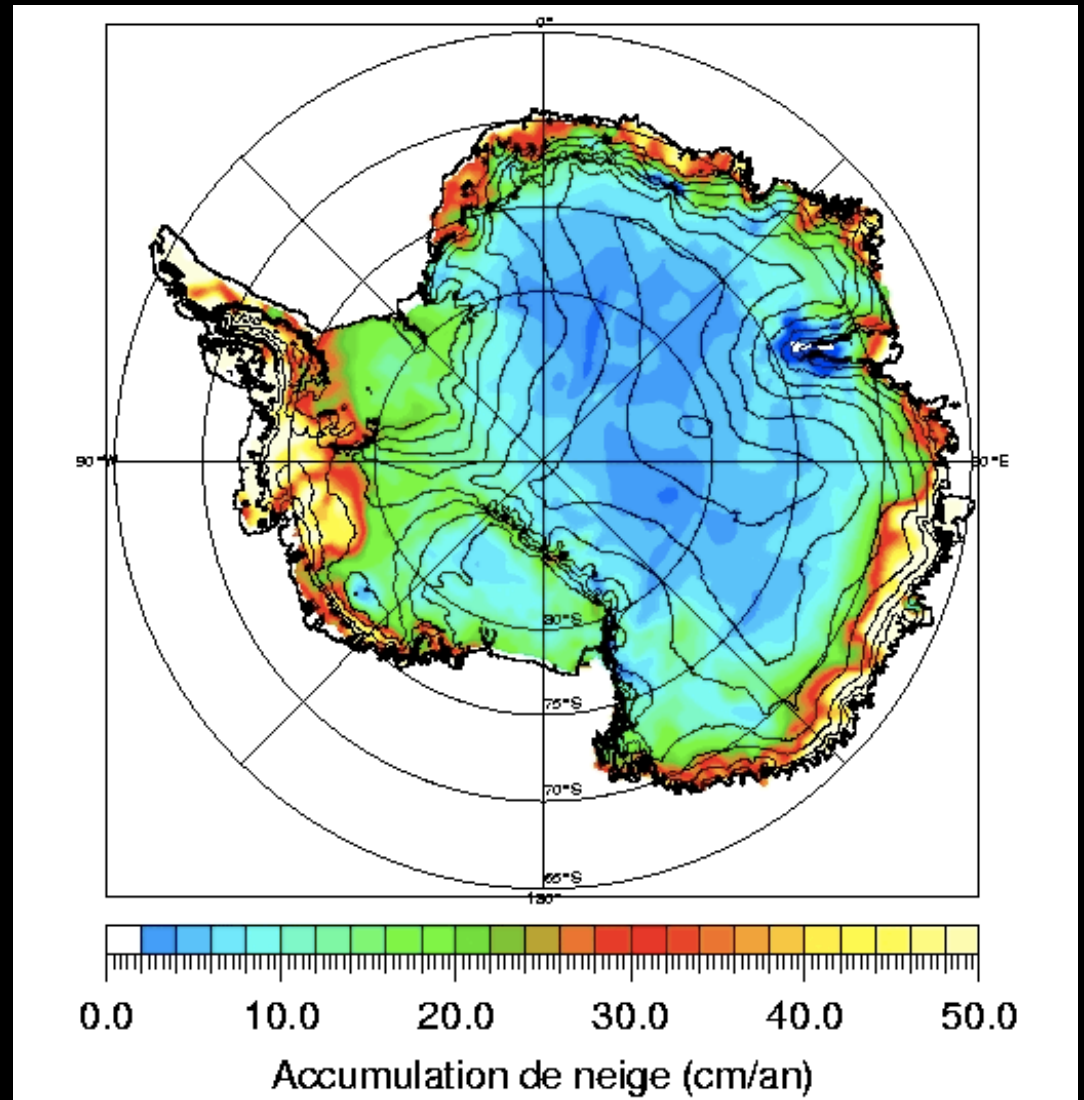
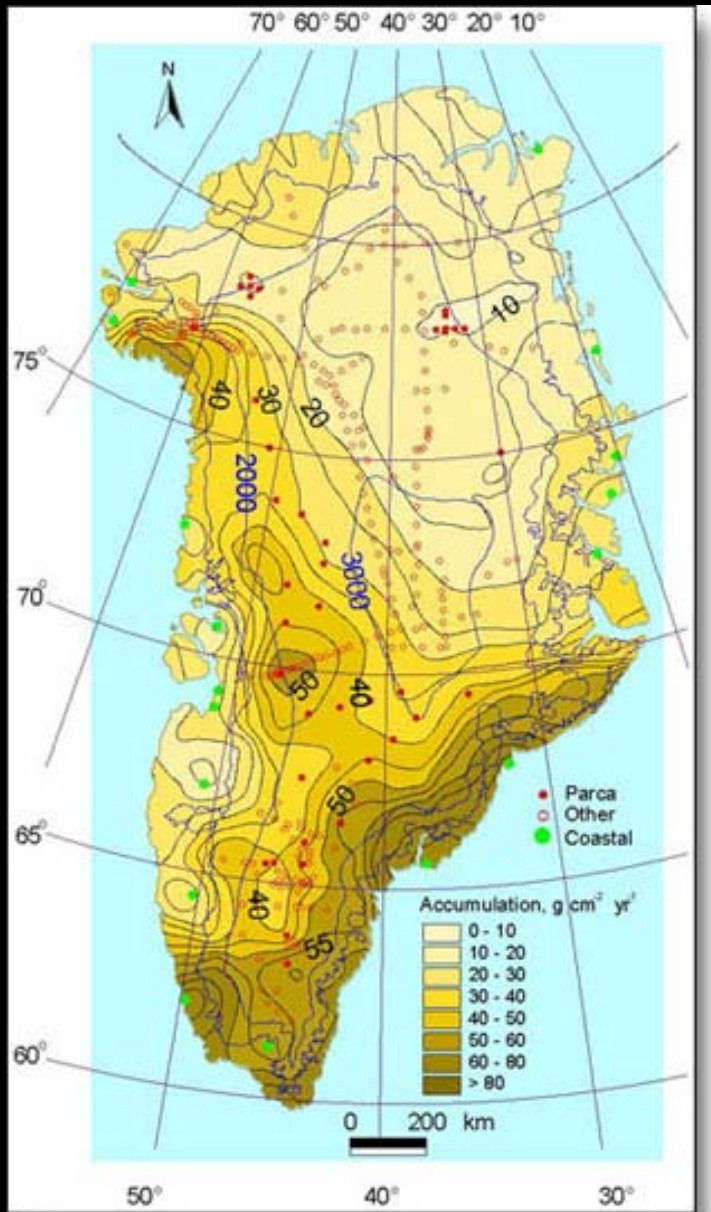
Drilling into the ice



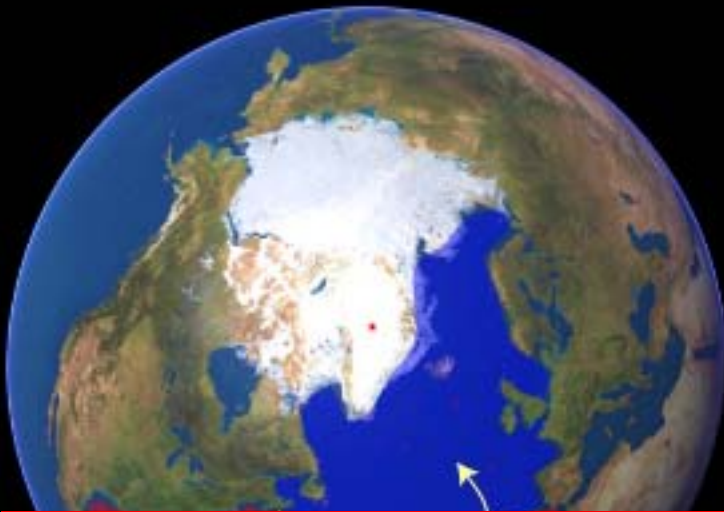
Air trapped as bubbles...



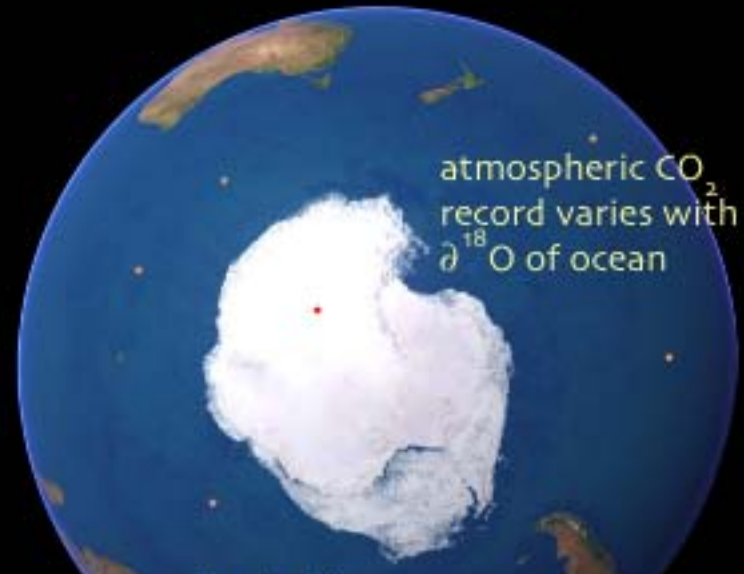
Snow Accumulation Rates



How does this manifest in the climate records?

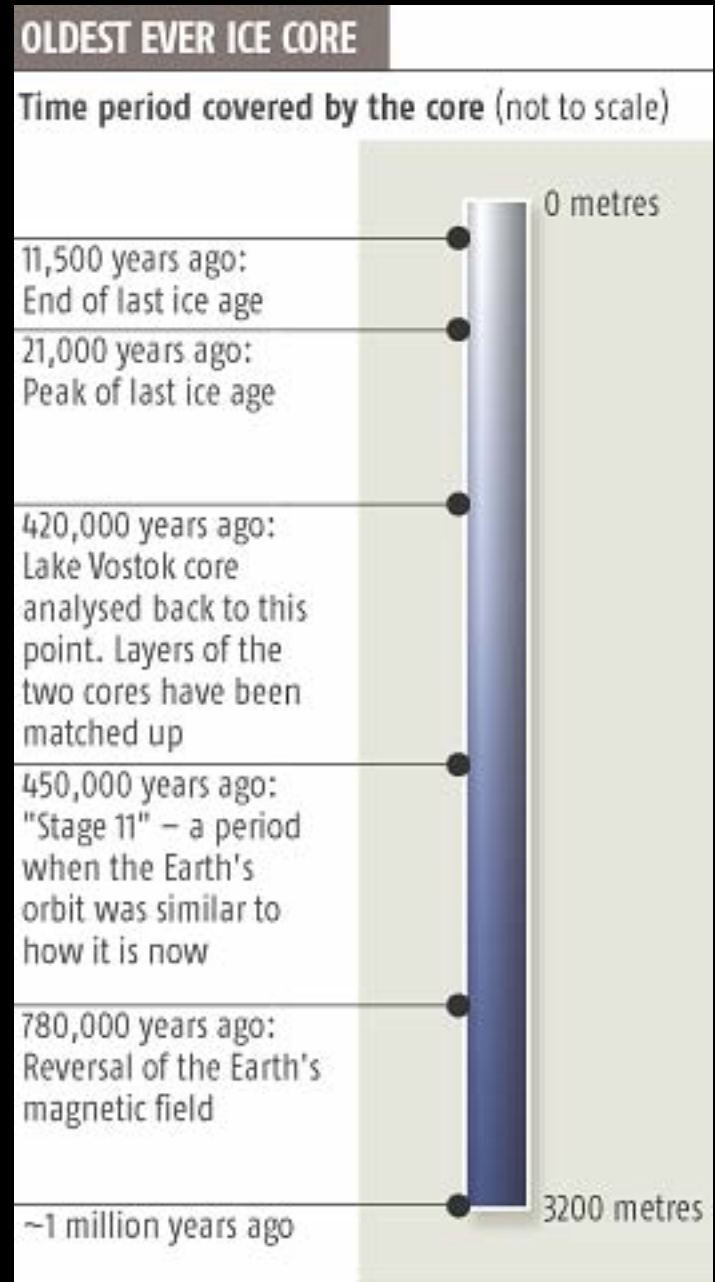


North Pole:
Shorter, high resolution
records

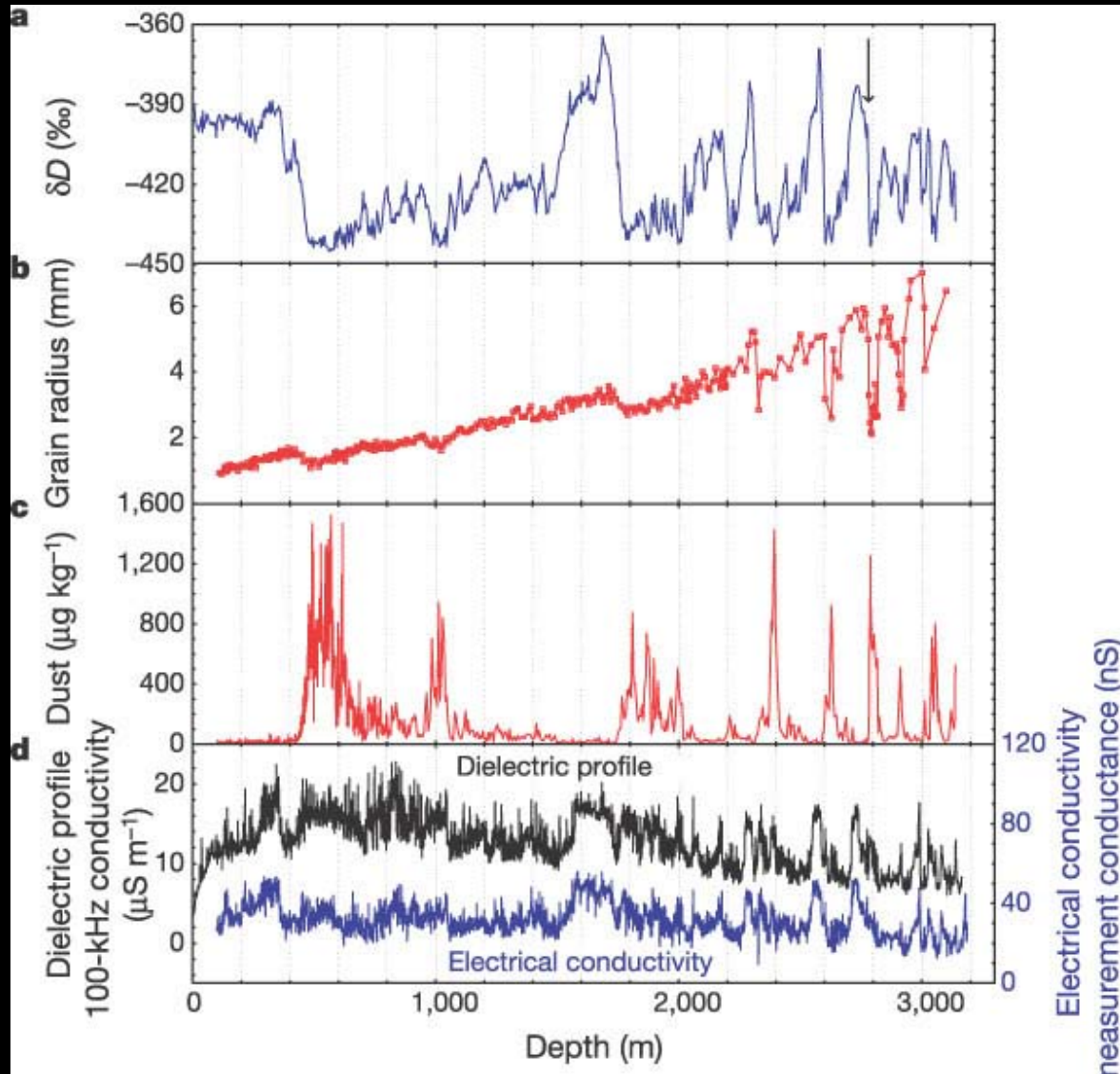


South Pole:
Longer, low resolution
records

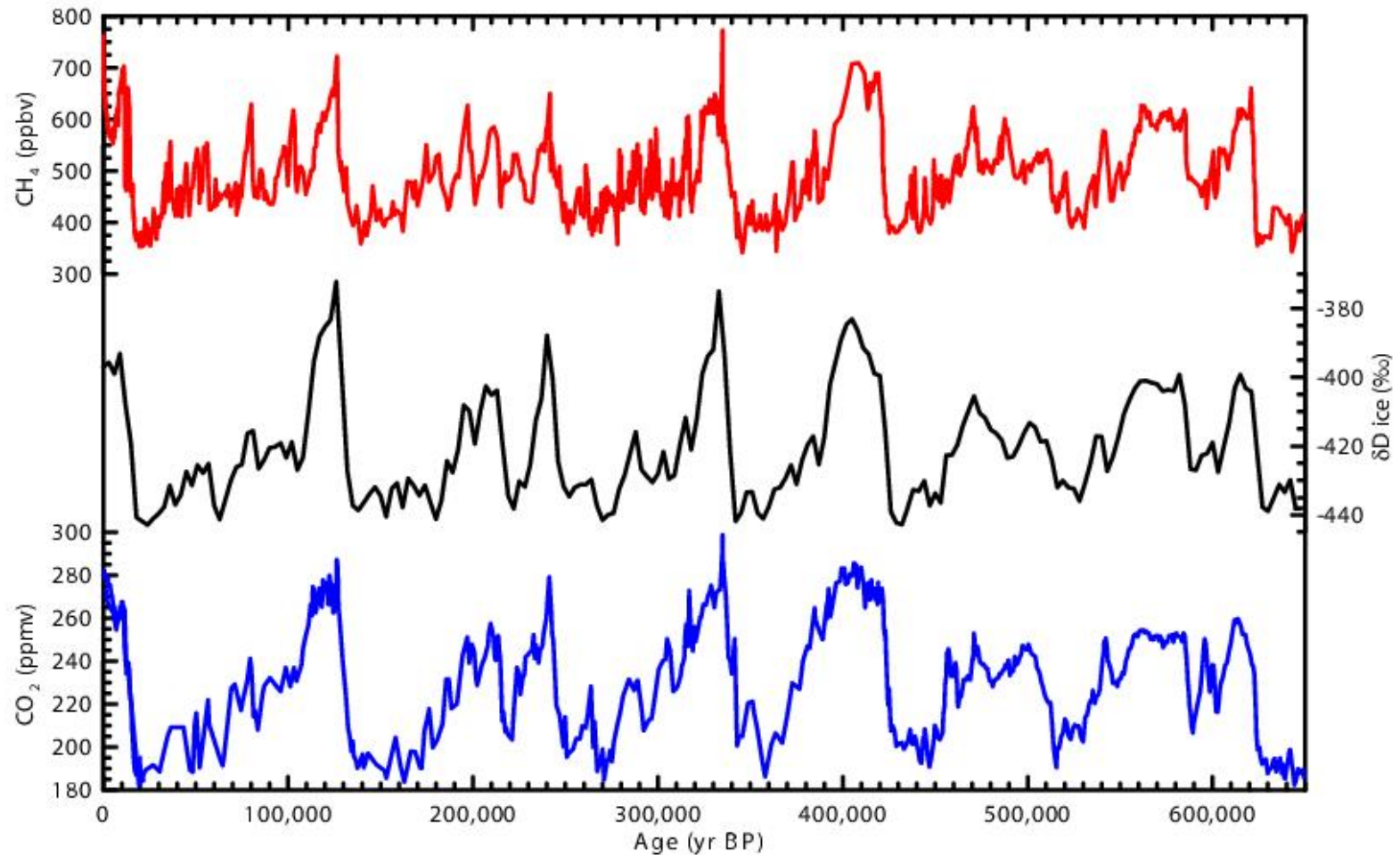
“EPICA”... the oldest ice core records so far



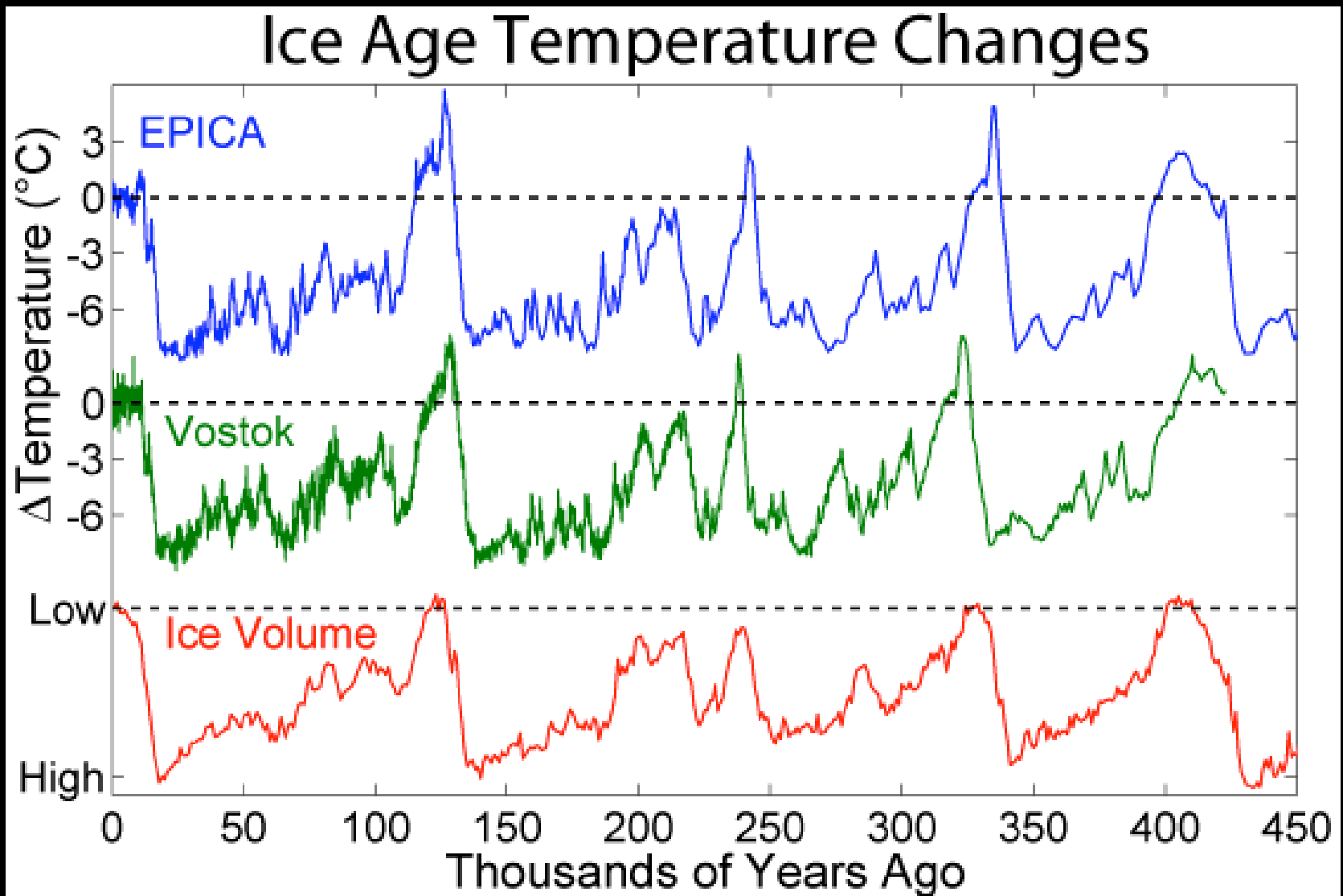
Epica... the raw records



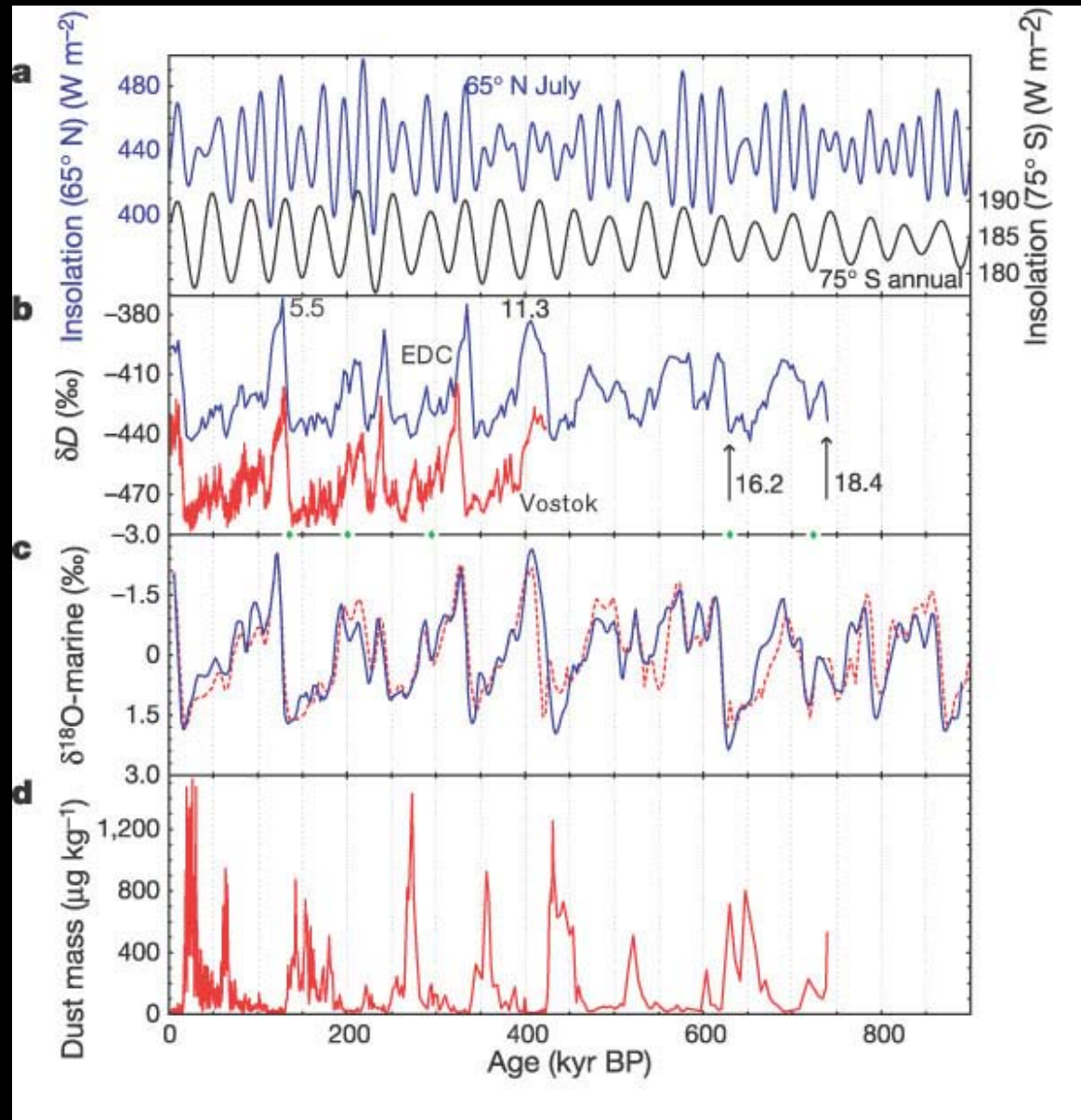
Atmospheric gases...



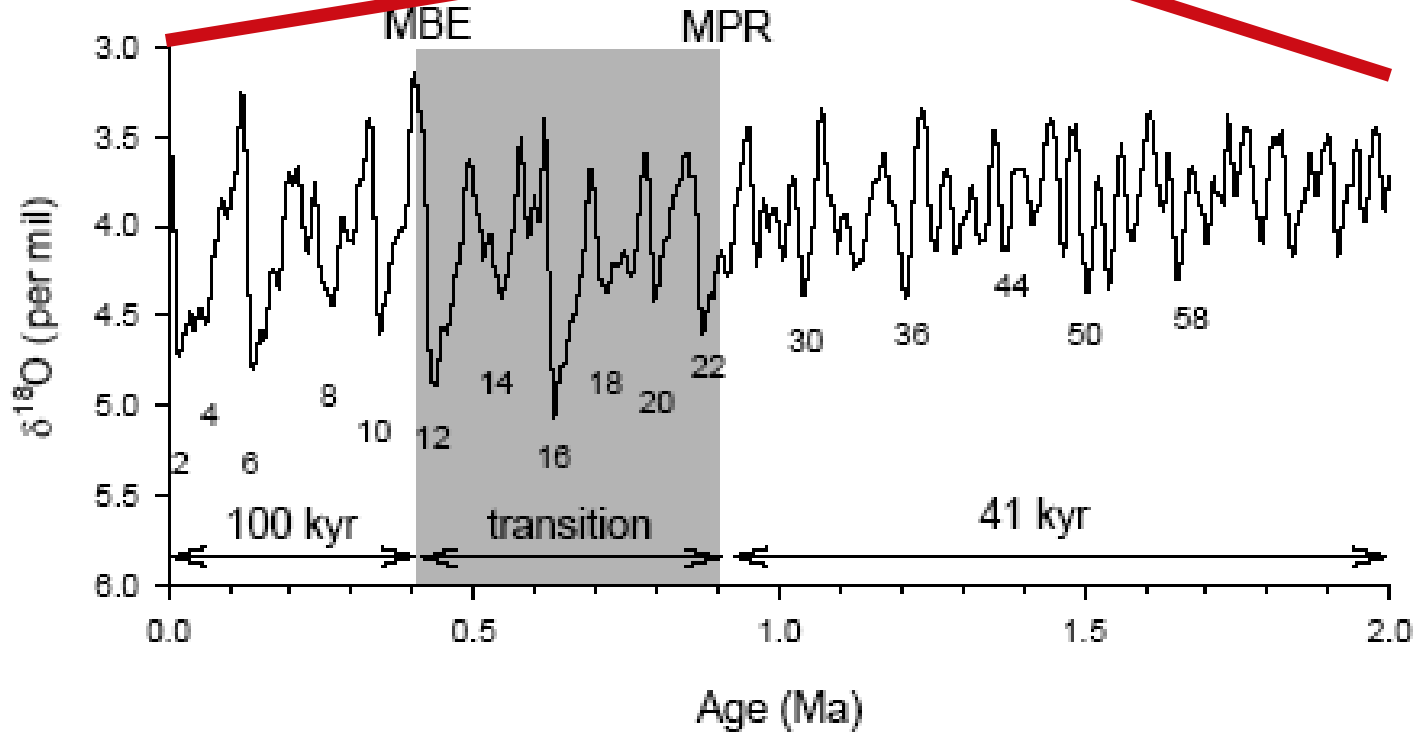
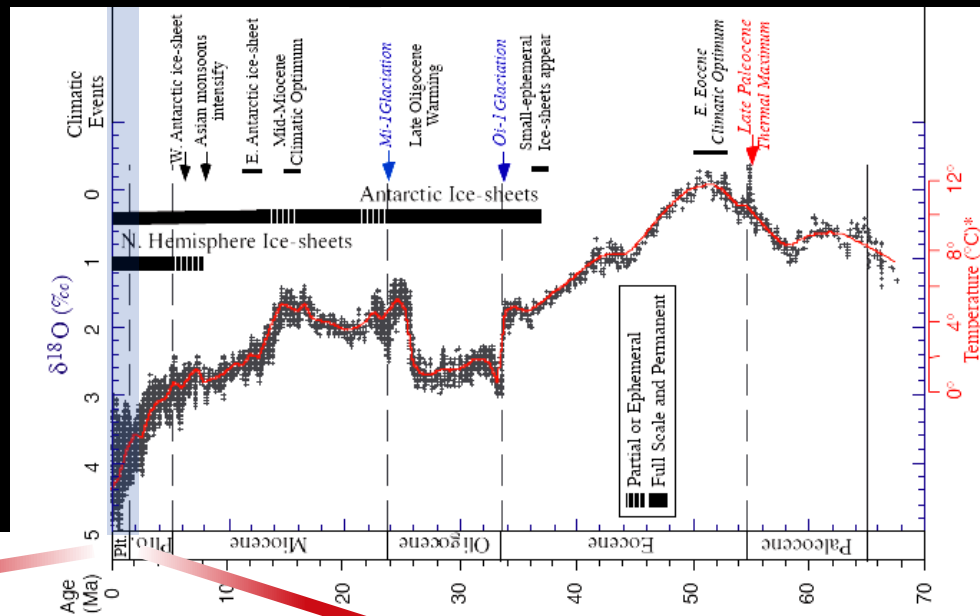
Air temperature and glaciers



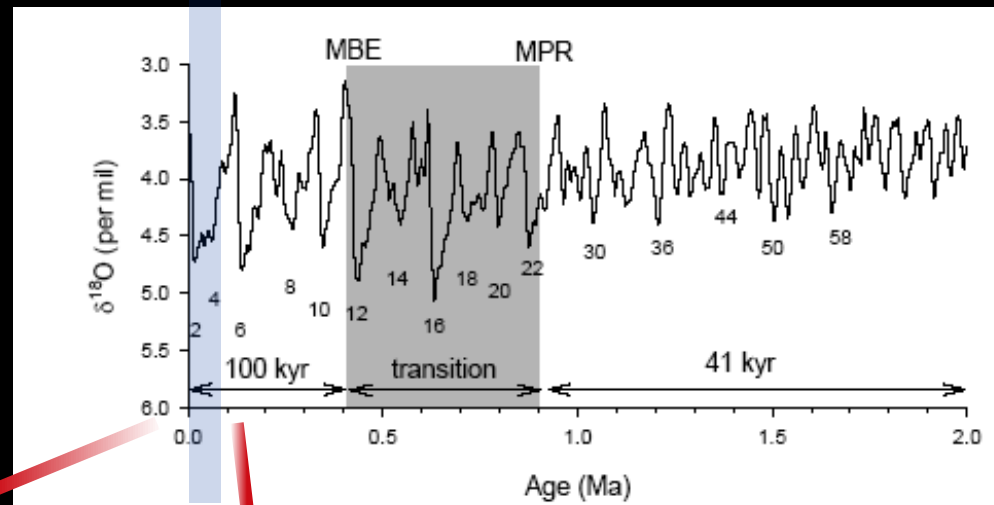
Comparison of climate records



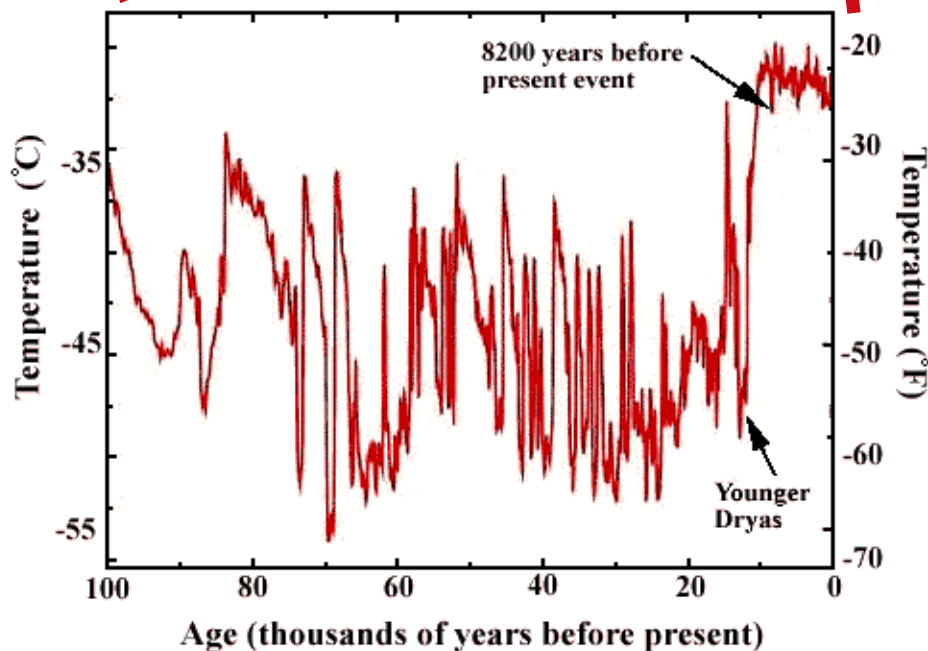
Glacial-interglacial cycles



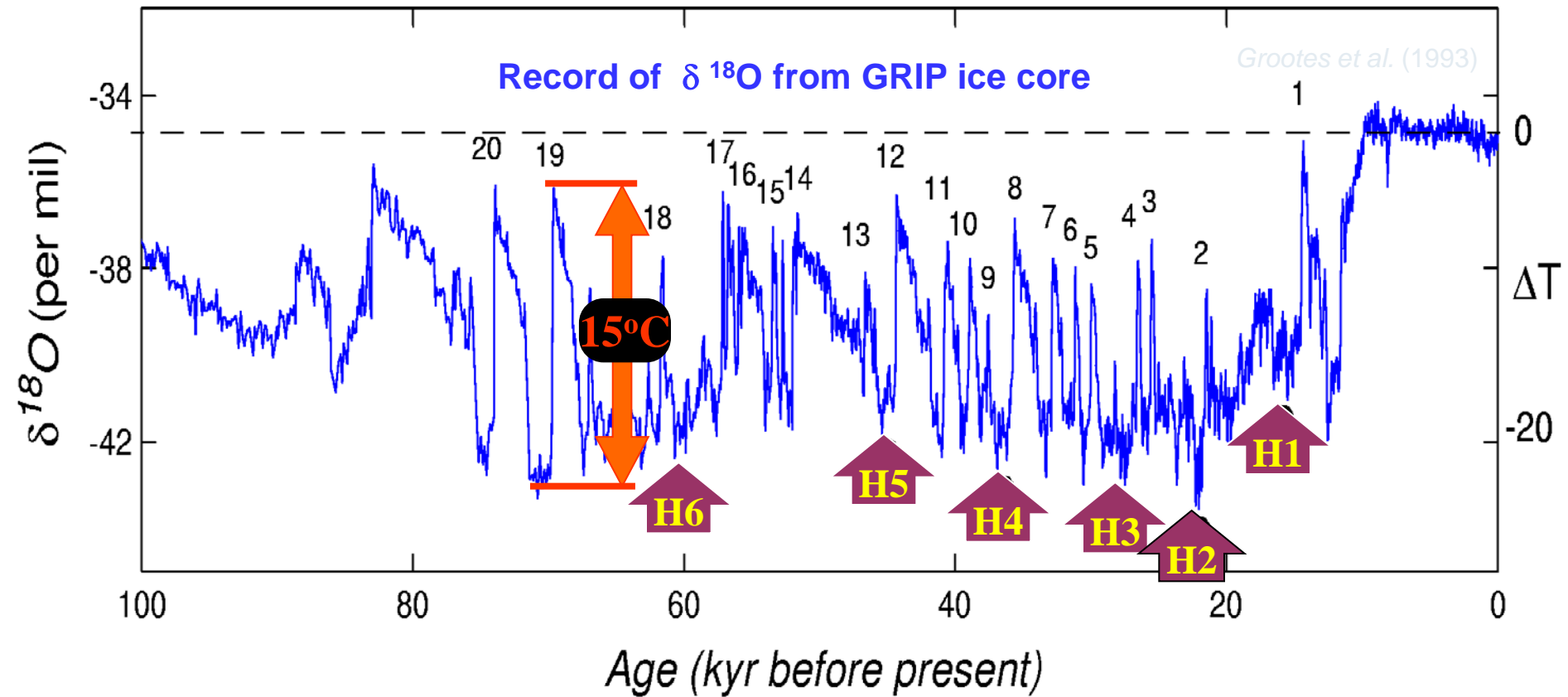
Abrupt climate oscillations



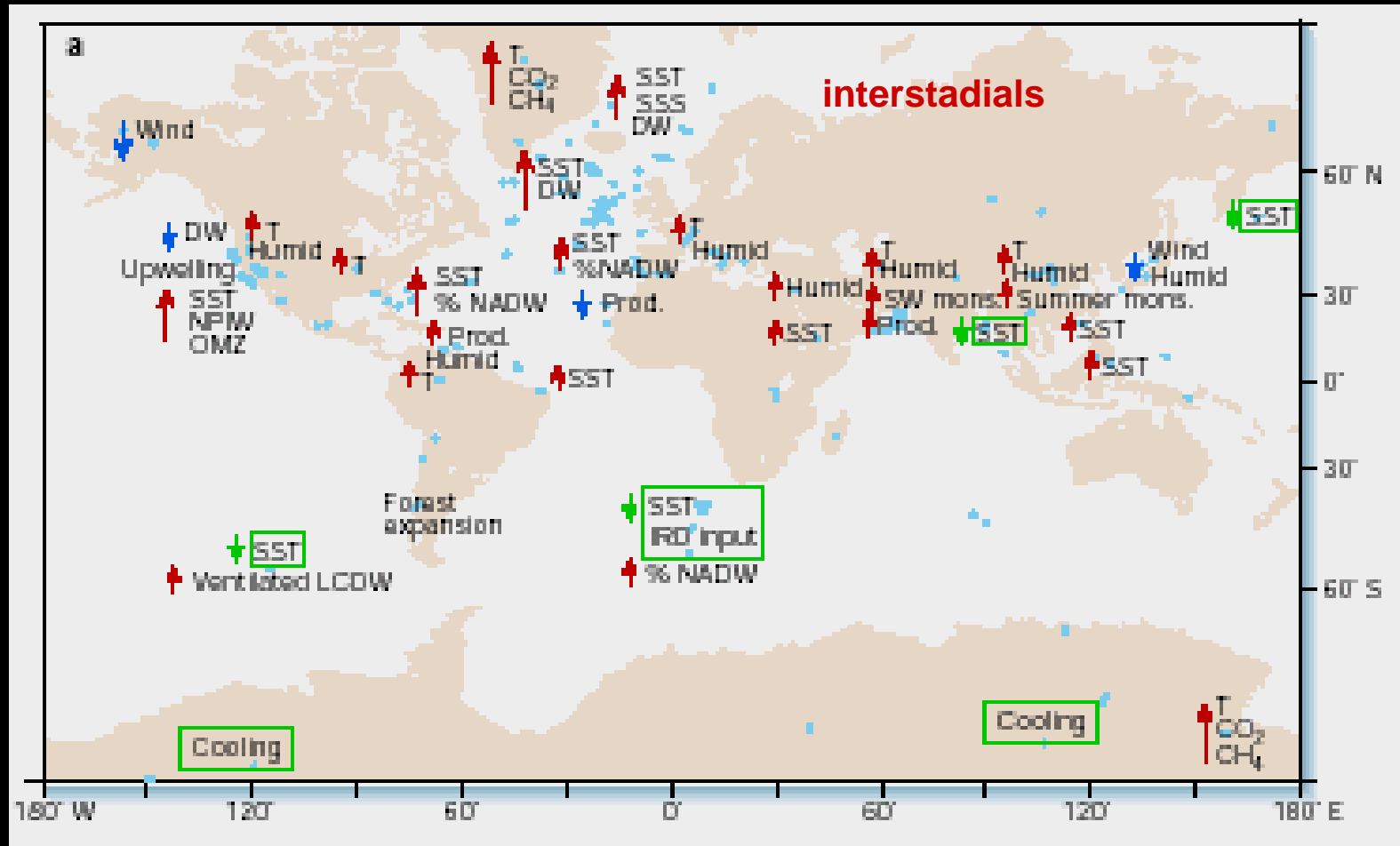
Temperatures in Greenland over the past 100,000 years



Abrupt climate change recorded in greenland...

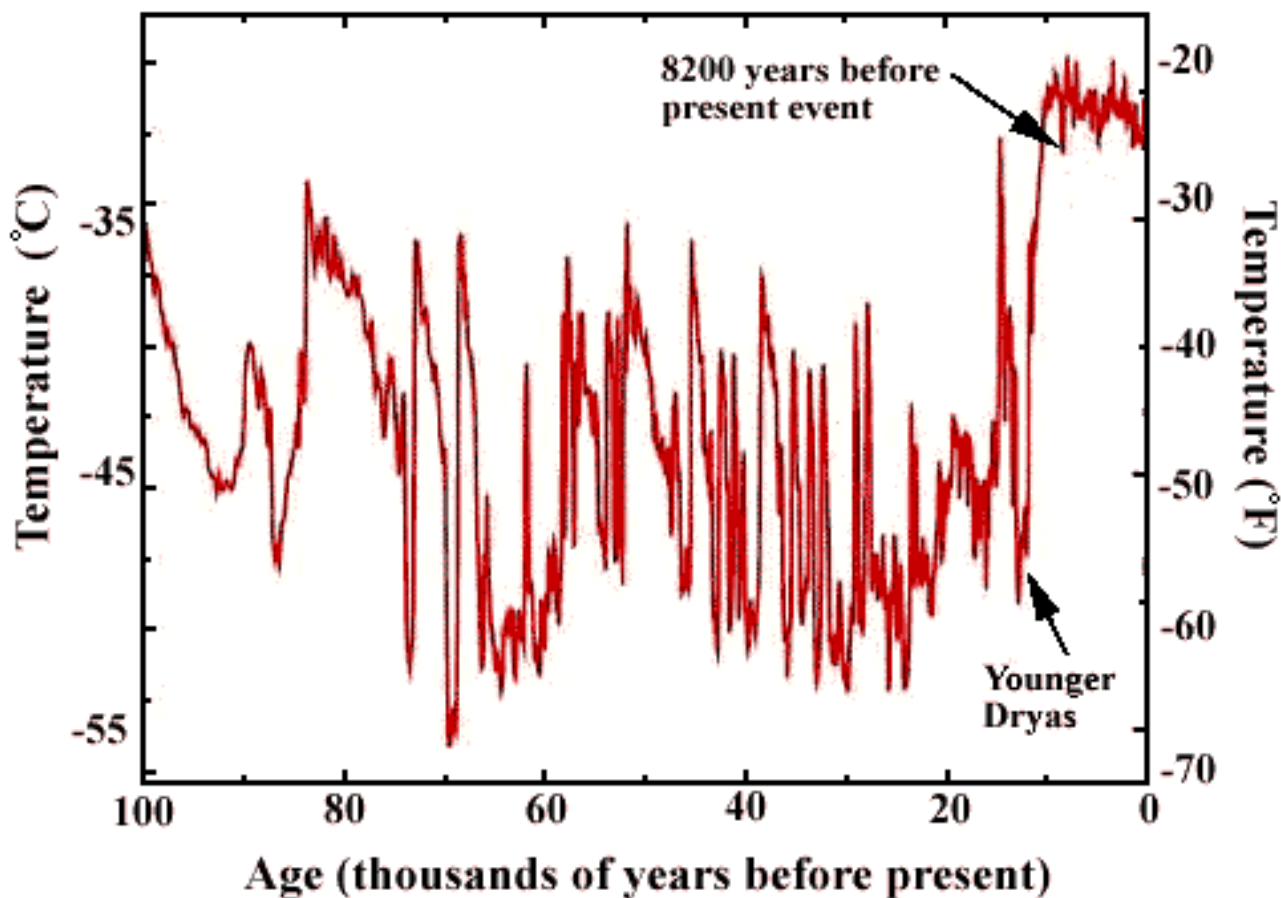


Where else?

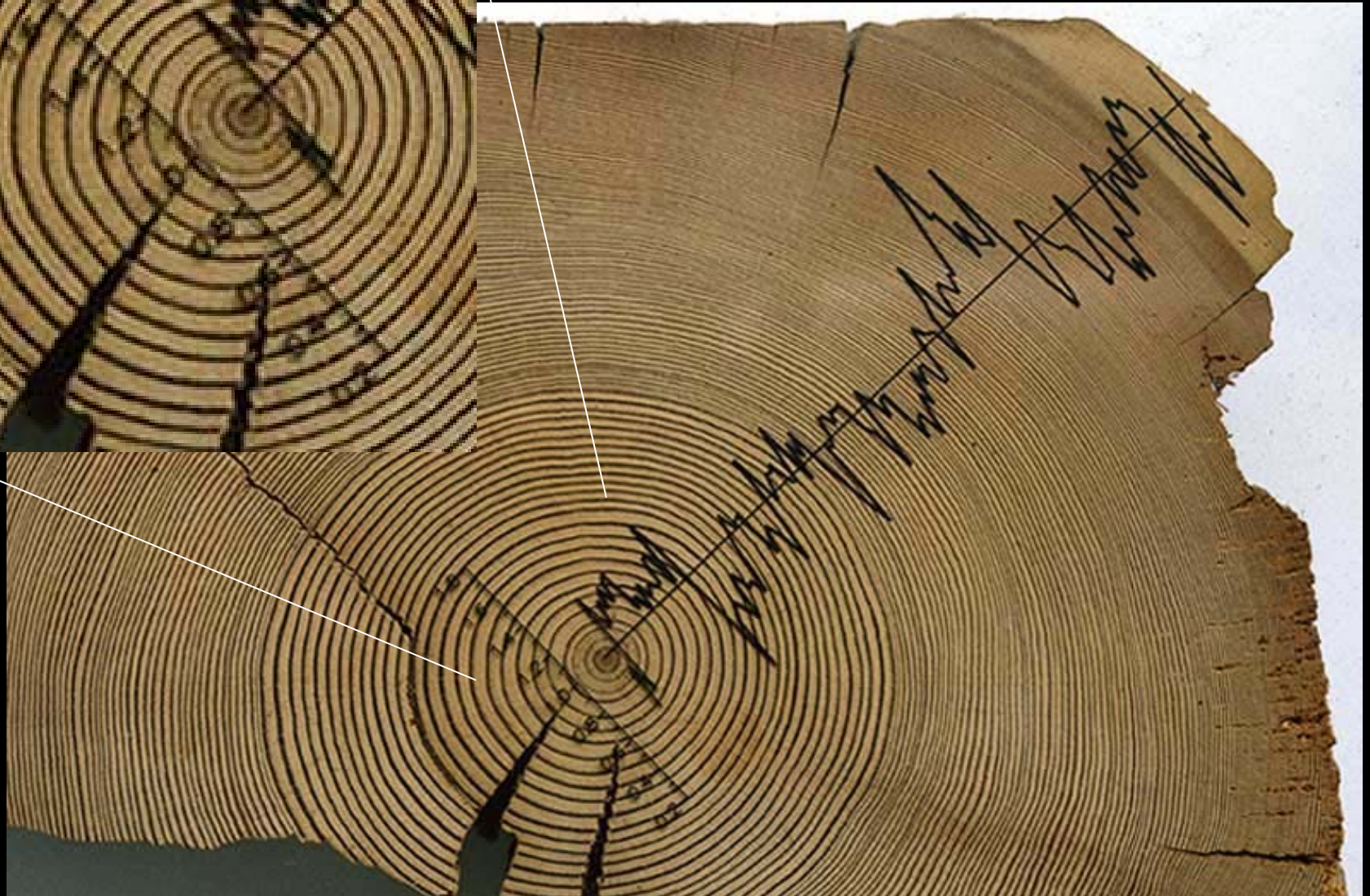


Abrupt events recorded in ice cores

Temperatures in Greenland over the past 100,000 years



A record of temperature change....



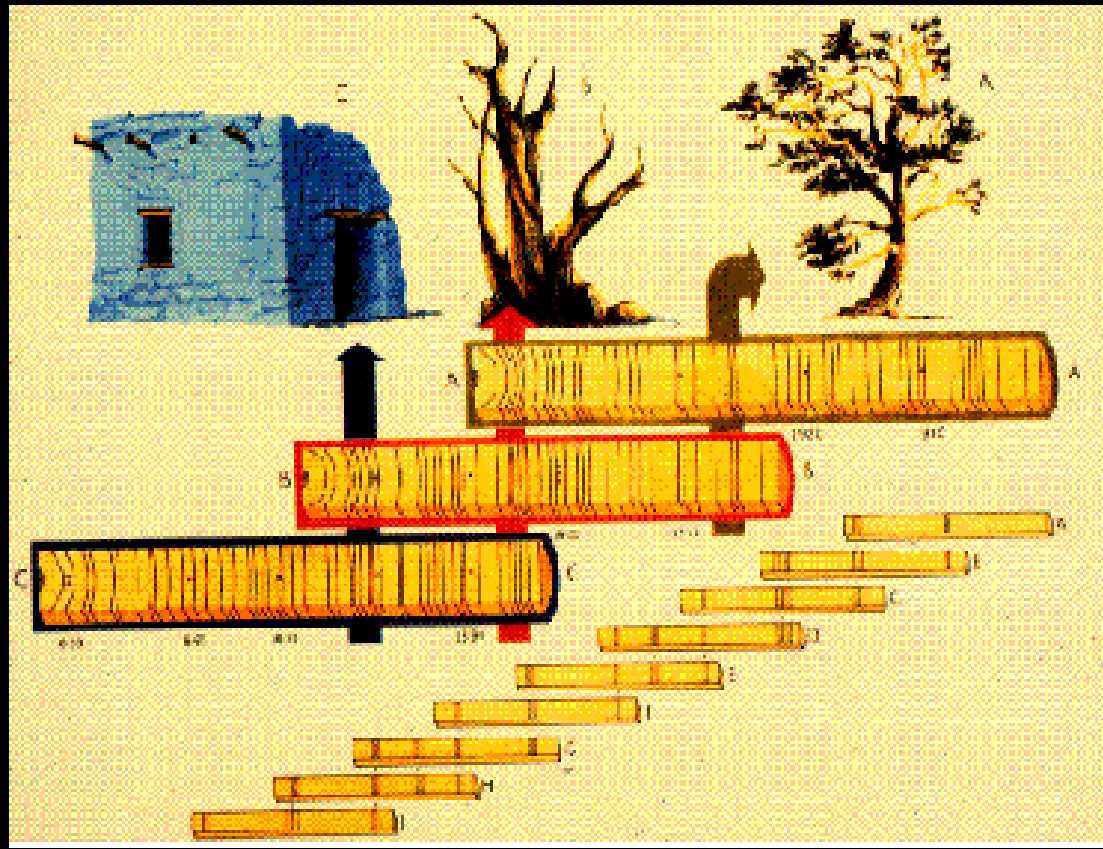
Trees that get really old....

- Intermountain bristlecone pine **4,844 yrs**
- Alerce **3,620**
- Giant sequoia **3,300**
- Rocky Mountain bristlecone pine **2,425**
- Coast redwood **2,200**
- Foxtail pine **2,110**
- Rocky Mountain juniper **1,889**
- Limber pine **1,670**
- Alaska yellow-cedar **1,636**
- Baldcypress **1,622**
- Western juniper **1,288**
- Douglas-fir **1,275**
- Himalayan Hemlock **1,011**

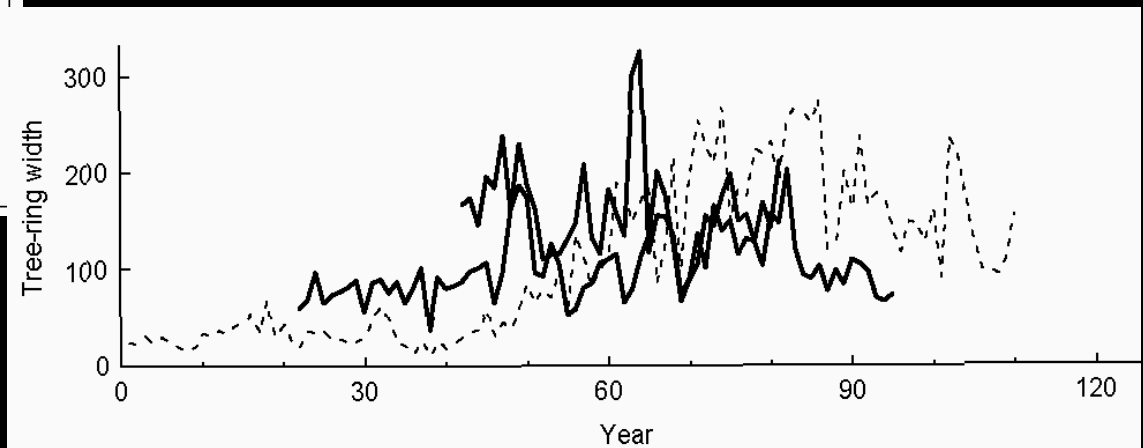
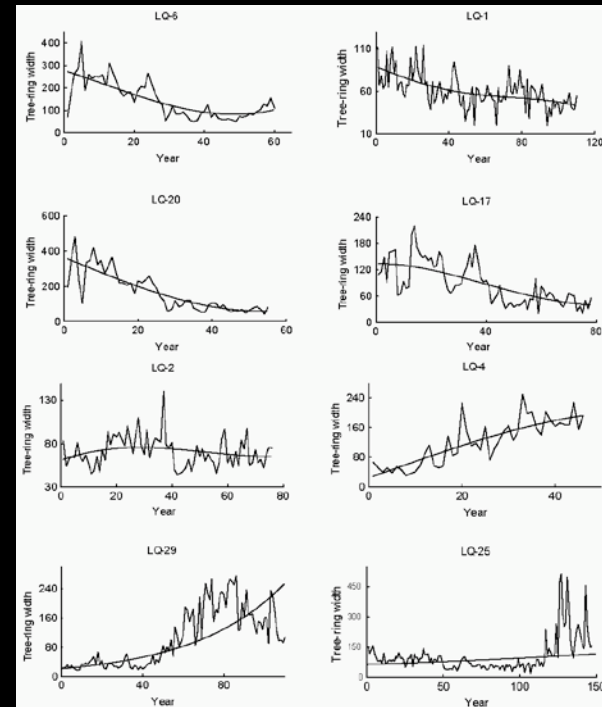
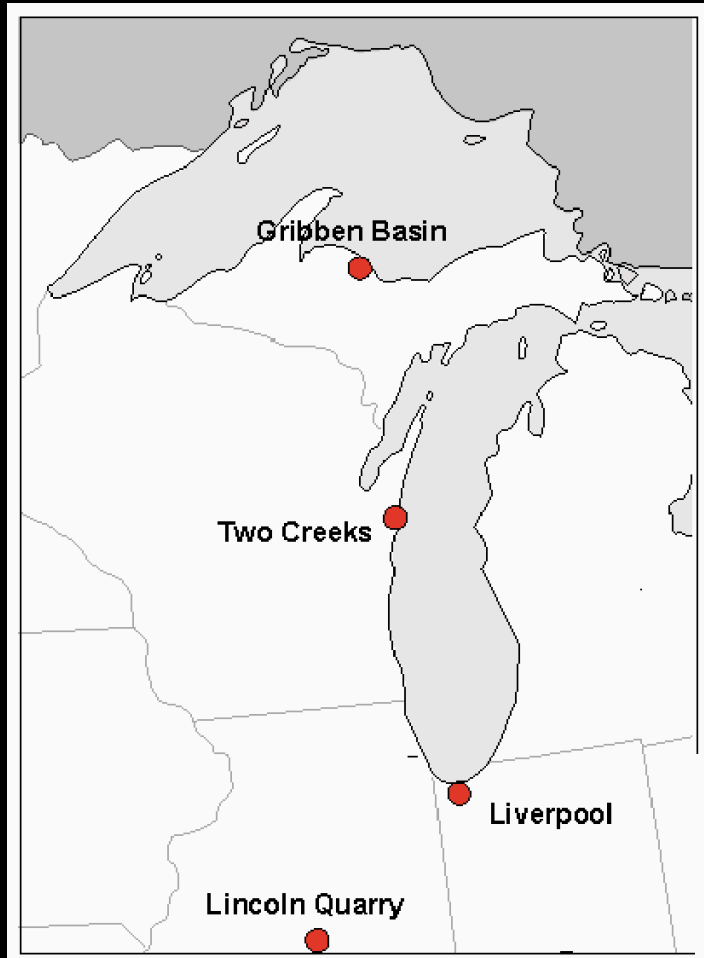


How do we go older?

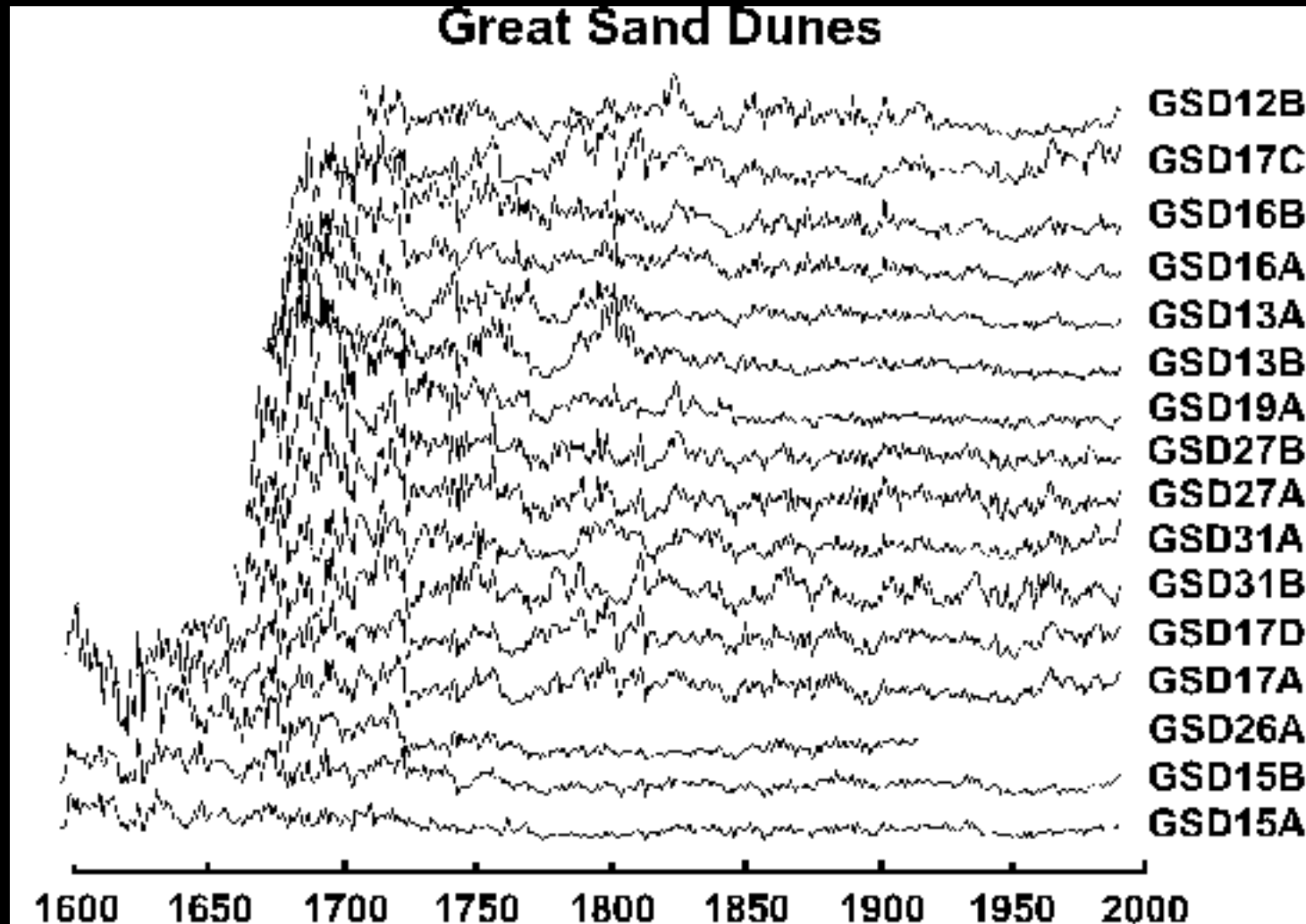
Correlation and Crossdating



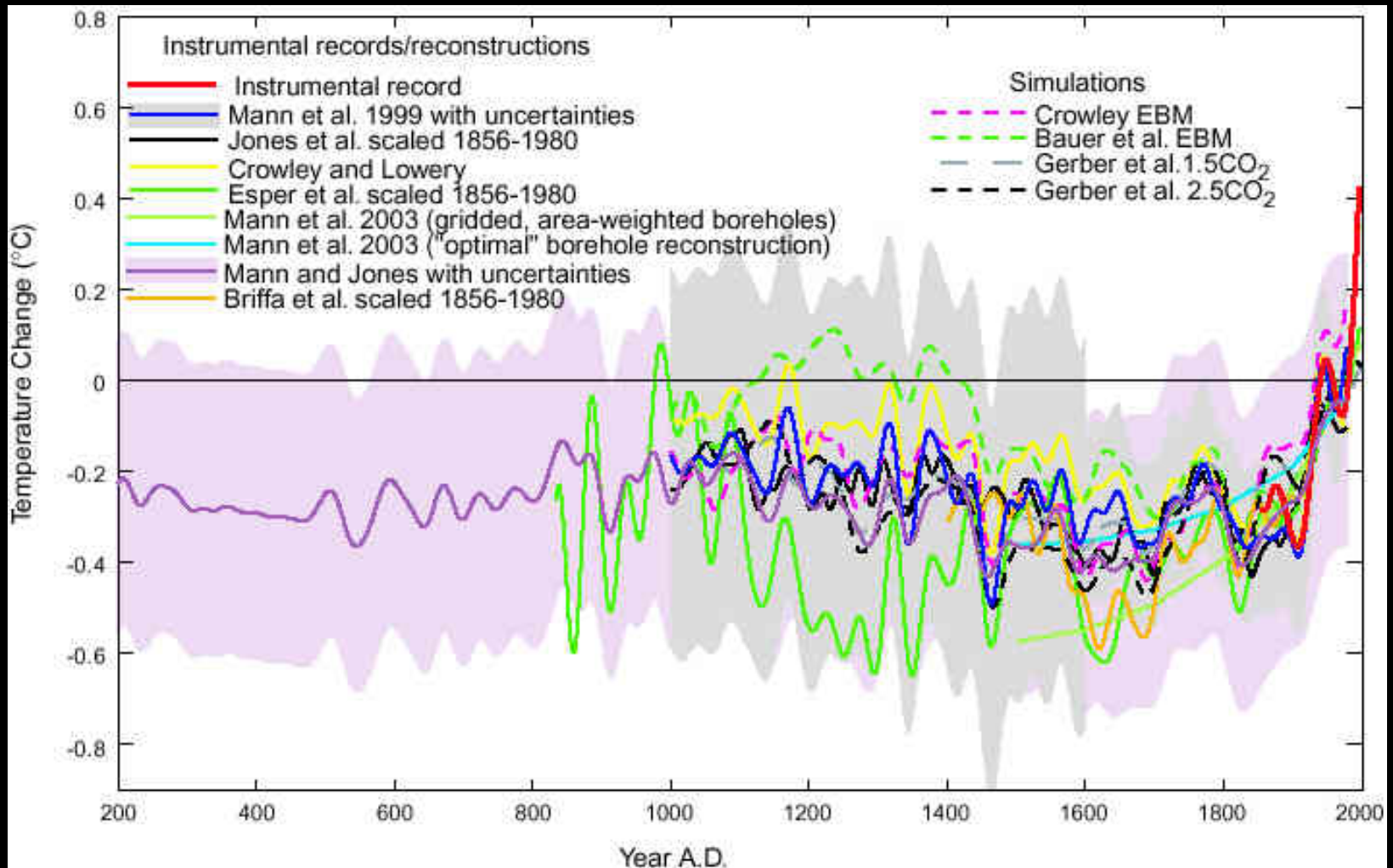
Correlation and Crossdating



some principles applied in dendro studies.. 'replication'



Reconstructing temperature change... the controversy



Talk outline:

A trip through geologic time

Take away points:

- Climate change through time
- What past climate change adds to the climate story
- What type of “archives” and data do we have

PHANEROZOIC	CENOZOIC	TERTIARY	QUATERNARY	0	HOLOCENE			
			NEOGENE	1.65	PLEISTOCENE			
			PALEOGENE	23.8	PLIOCENE			
	MESOZOIC	CRETACEOUS			65	MIOCENE		
						JURASSIC	144.8	OLIGOCENE
						TRIASSIC	200	EOCENE
		PALEOZOIC	PERMIAN	251	Millions of years ago (ma)	PALEOCENE		
			CARBONIFEROUS	300				
			DEVONIAN	355				
			SILURIAN	418				
ORDOVICIAN			441					
PRECAMBRIAN	CAMBRIAN	490						
	EDIACARAN	544						
		570						
		4000+						

