Lecture II
Climate Archives, Data,and Models

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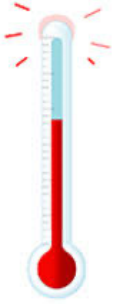
How do we know what we know about past climate?

Recorders of 'Natural climate experiments': Archives

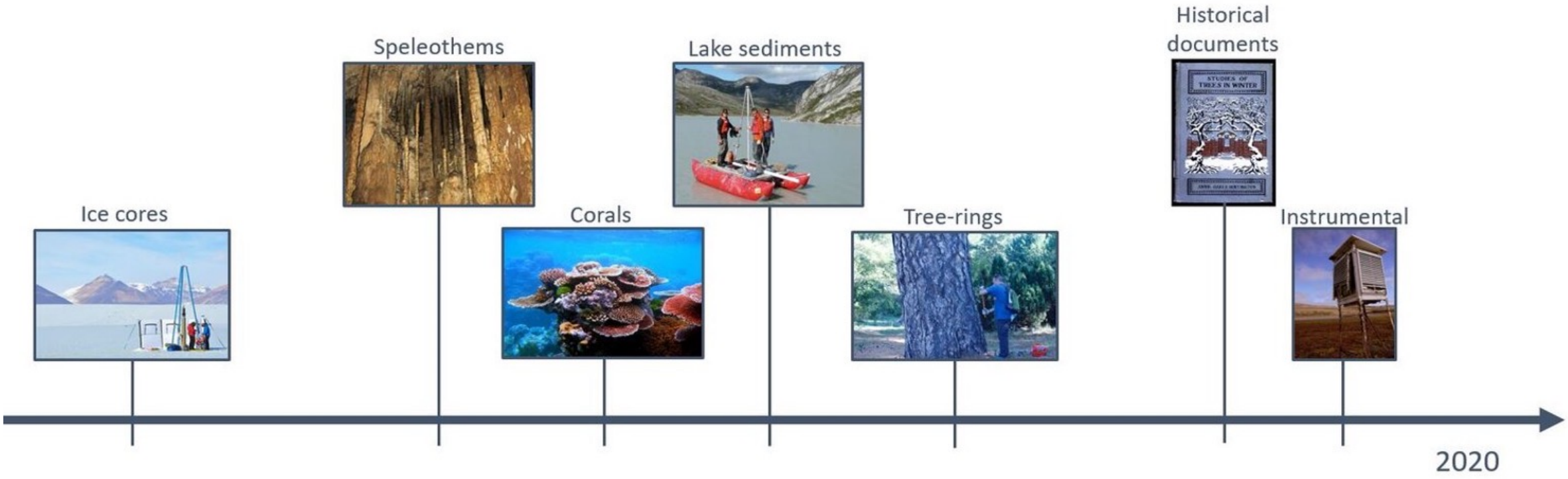
Historical records *Coral reefs* *Pollen* *Ice-cores* *Tree rings* *Carbonate caves*



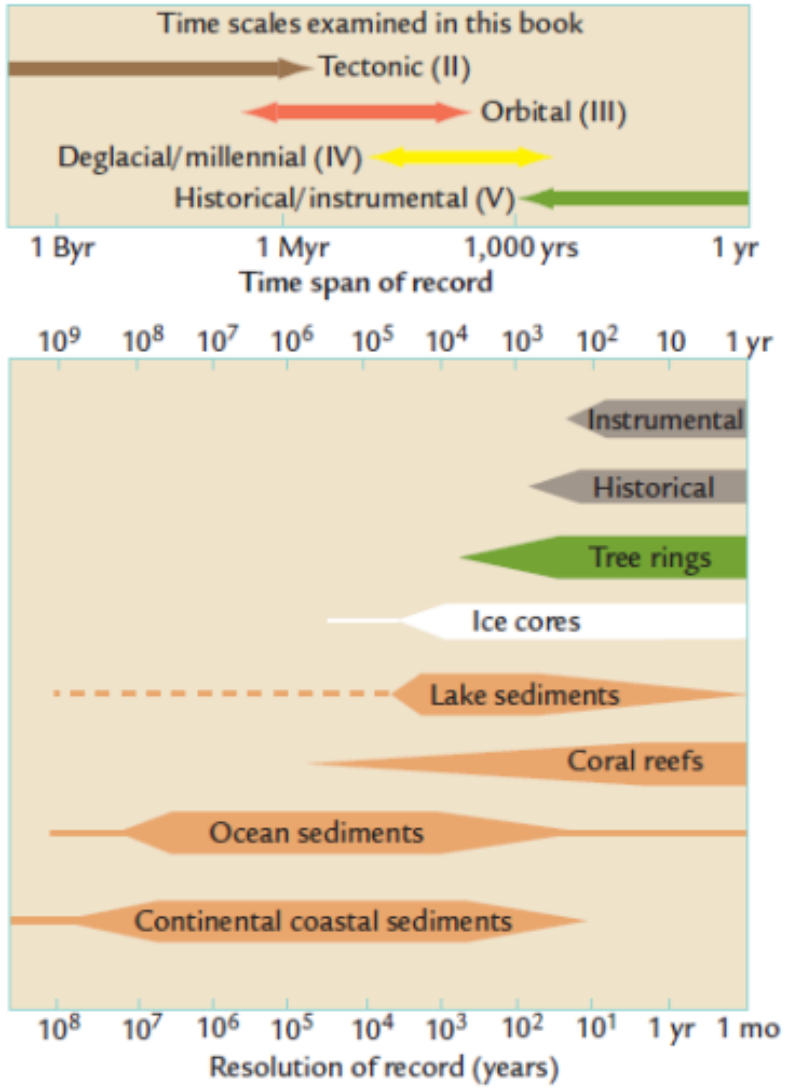
Proxy data are preserved physical characteristics of the environment

Paleoclimatology : study of past climates

Recorders of ‘Natural climate experiments’: Archives

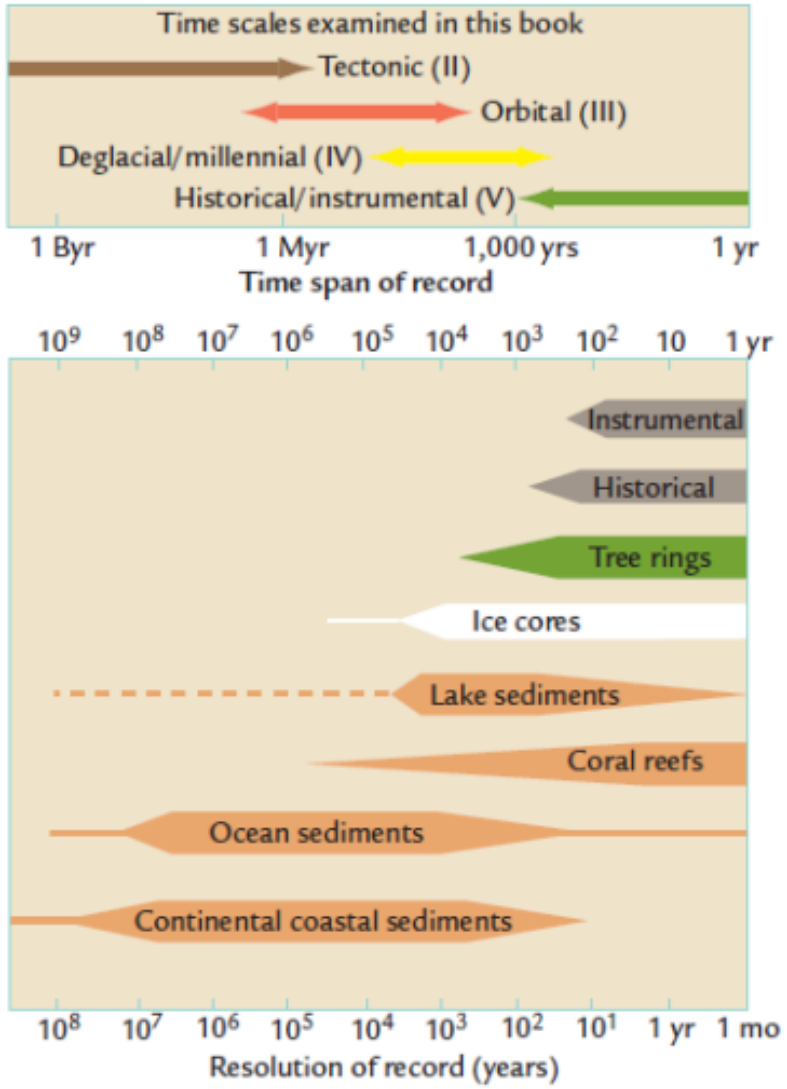


Direct climate information vs proxy records



- Direct measurements have limited timeframe to record the full range pf natural variability in the climate system
- Historical archives are qualitative and incomplete
- Proxy data: natural archives of longer term climate variability

Direct climate information vs proxy records

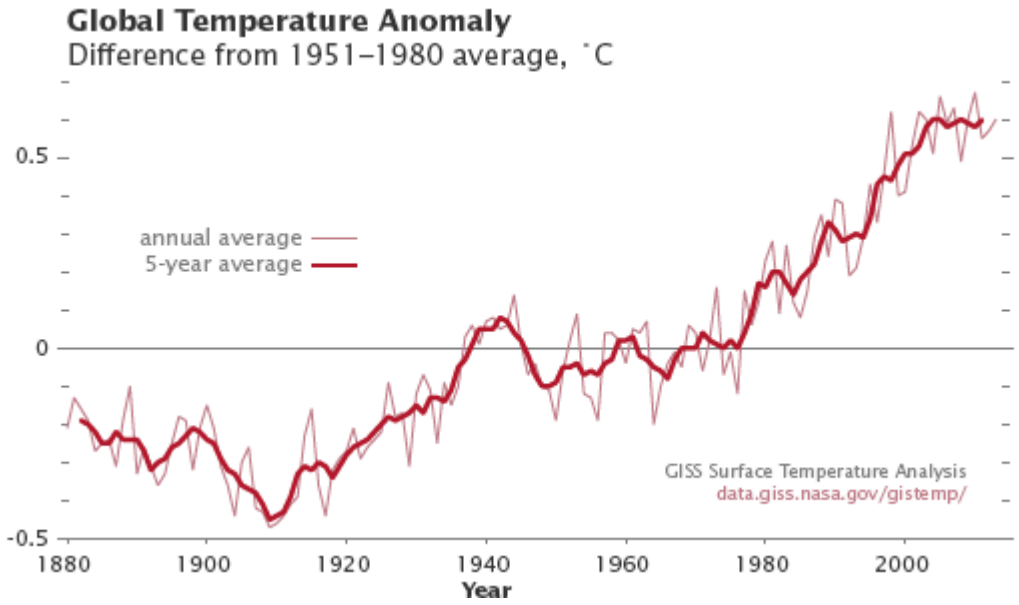


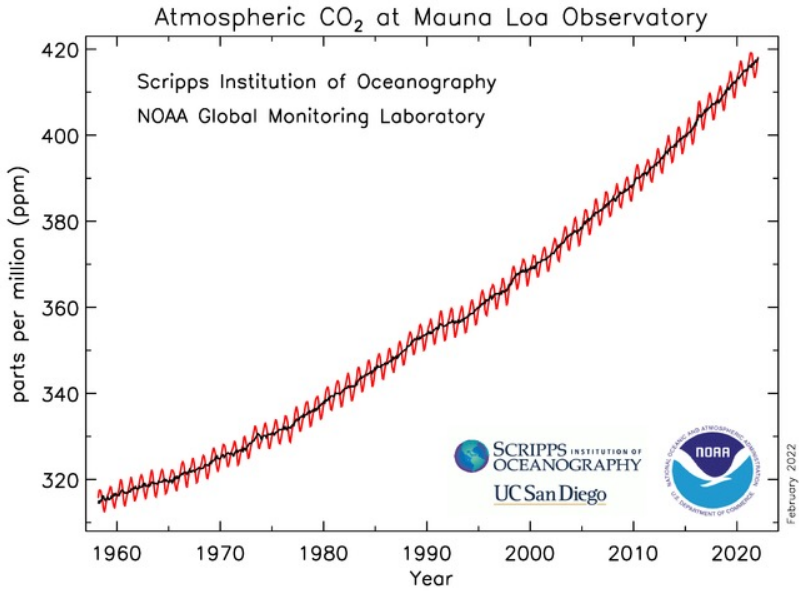
- Sediment archives (major climate archive for over 99% Earth's geological time)
- Ice cores
- Tree rings
- Corals
- Speleothems

Proxies

- Geological-geochemical proxies, which are measurements of mass movements of materials through the climate system, either as discrete (physical) particles or in dissolved (chemical) form.
- Biotic proxies: which are based on changes in composition of plant and animal groups,

Instrumental records





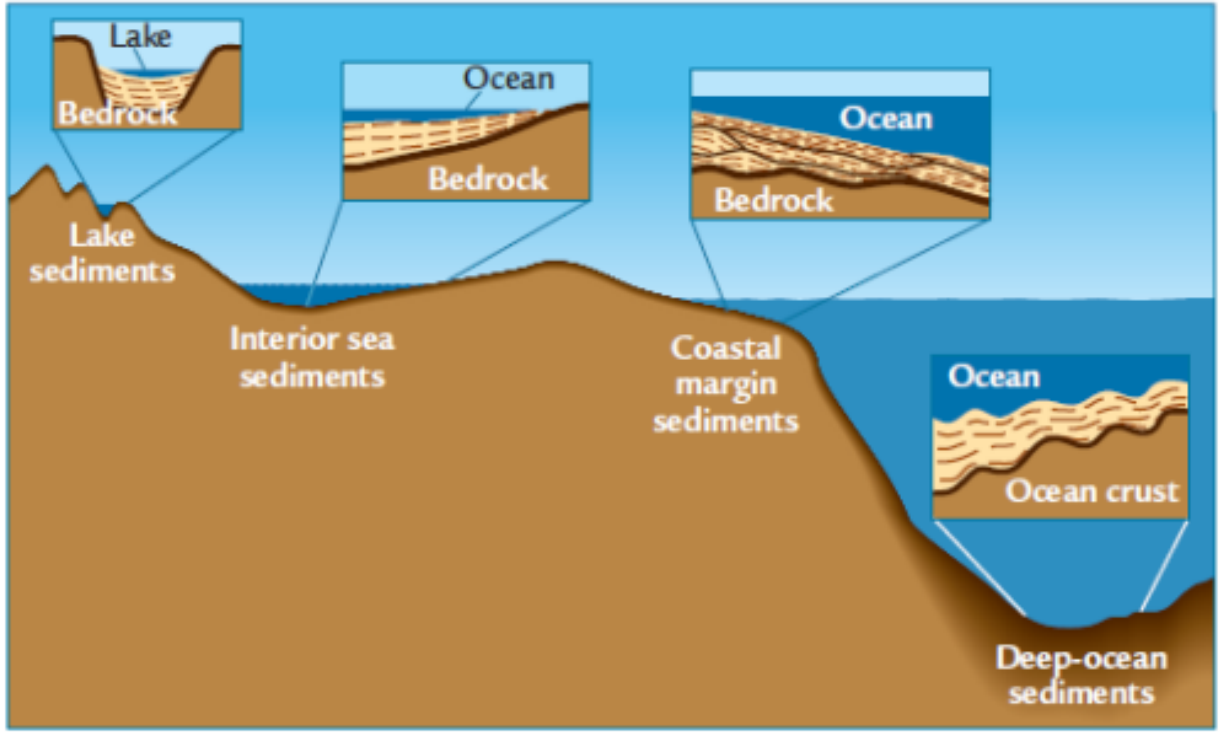
Direct climate information

Historical records

- Written accounts
  - El Niño events recorded from late 1500's
  - Crop harvest, migrations, spring blooms
  - Hurricane landfall
- Artwork
  - Snow/ice in temperate locations during Little Ice Age

Direct climate information

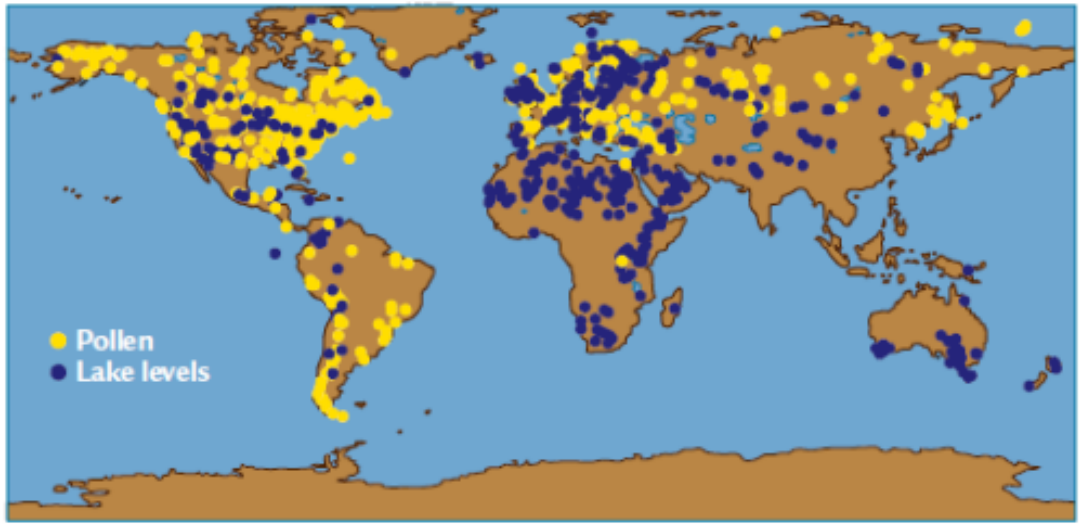
I. Sedimentary archives



- Rainfall and runoff it produces erode/weather the exposed rocks on the continents and transport the debris either physical (granular) and chemical (dissolved) forms.
- Most of the sediments are carried to the oceans, some deposited on quieter waters (eg. lakes), which eventually is carried to the ocean by long intervals of erosion and tectonic processes.

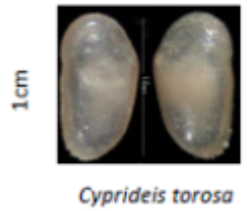
How far back in time can we reconstruct climate from ocean archives?
~170 Myr – ocean crust gets destroyed at convergent plate boundaries

Lake sediments



NPDC, Boulder

Lake varves

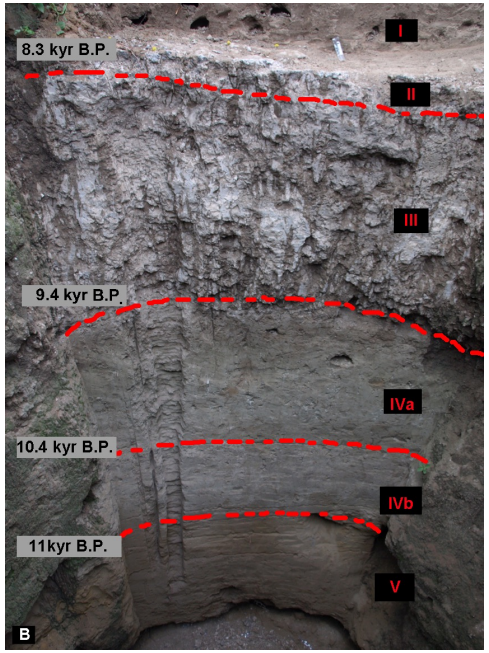


Cyprideis torosa

- Record terrestrial climate variations (temperature, precipitation).
- Varved sediments – annual banding caused by seasonal changes in productivity, sediment input
  - ➢ Summer – biological, organic rich
  - ➢ Winter – clastic runoff
- Ostracod shells chemistry – rainfall and temperature changes (Oxygen isotopes trace element composition)
- Pollen/C isotopes – vegetation changes

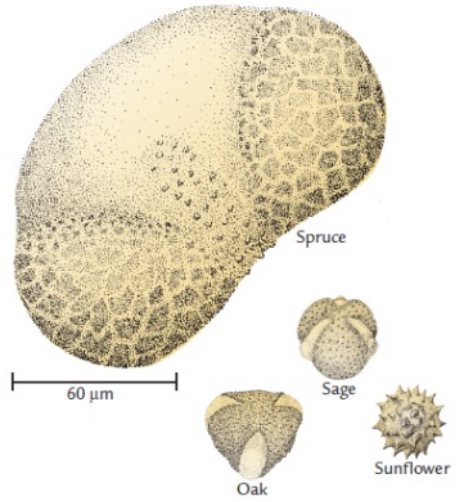
Lake and Ocean sedimentary archives

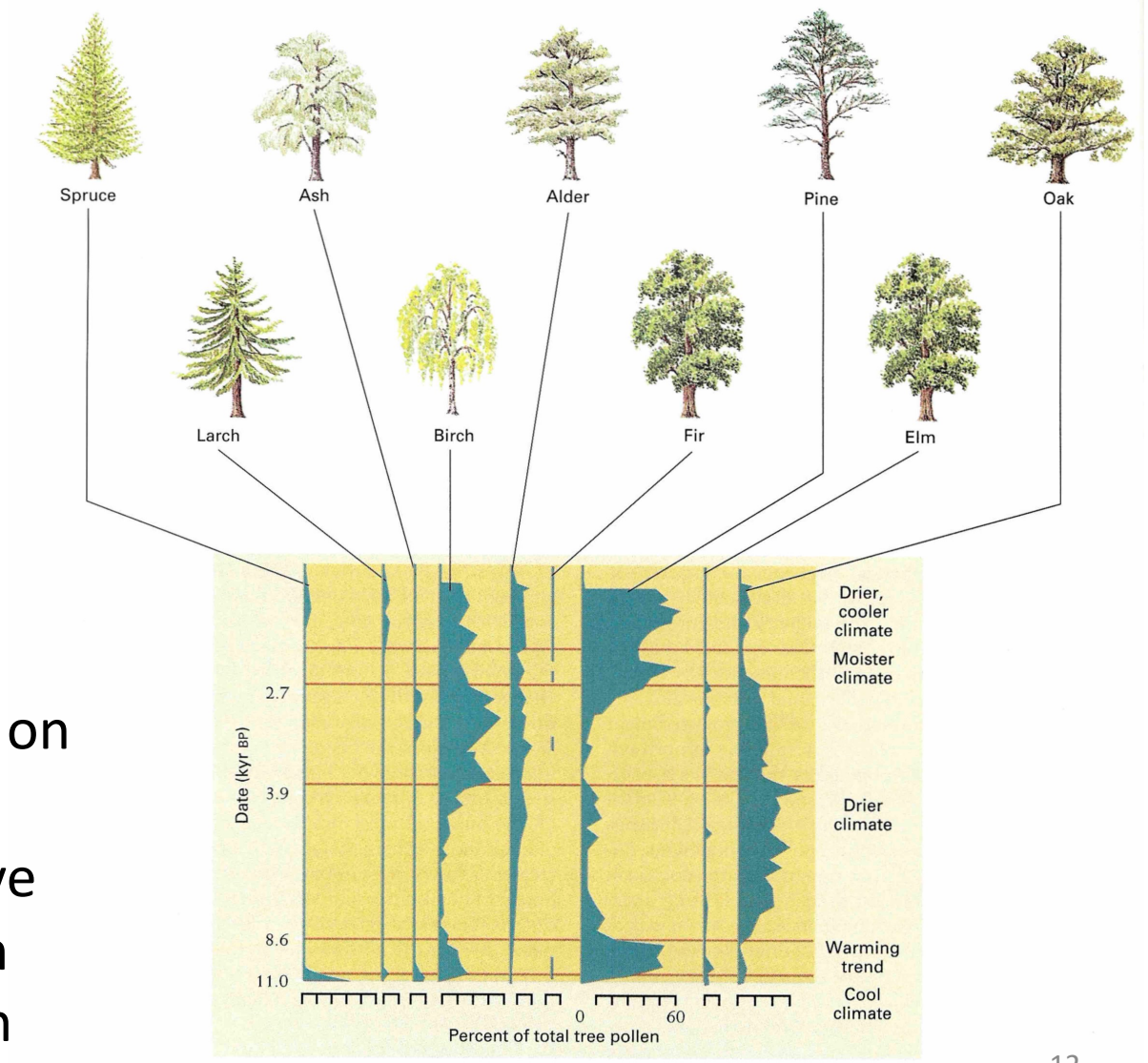
Sediment cores onboard the research ship



Lake sediment sampling from a cross sectional wall from a dug trench

Pollen analysis in terrestrial sediments





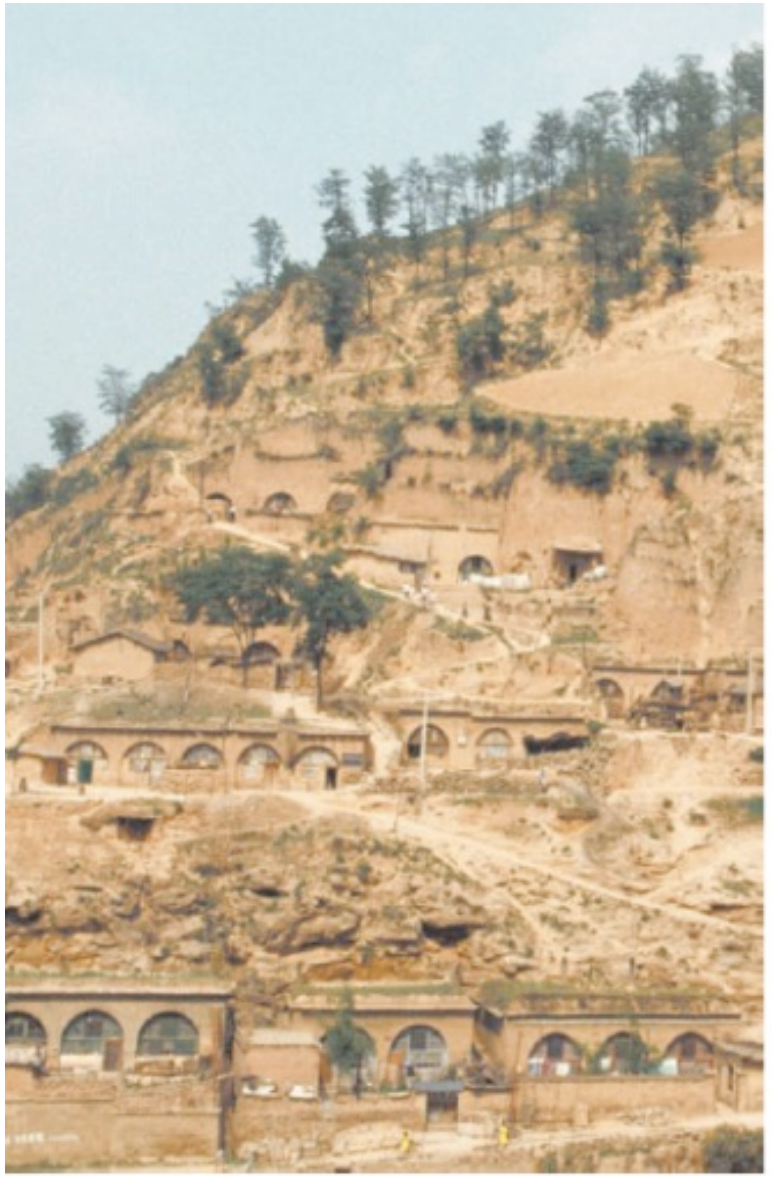
- A proxy indicator of climate on land
- Can be used to reconstruct past climates on tectonic timescales
- Presence of a single temperature sensitive form can indicate the climate e.g. Pagean climate from Palm vegetation in northern latitudes

Loess sediments

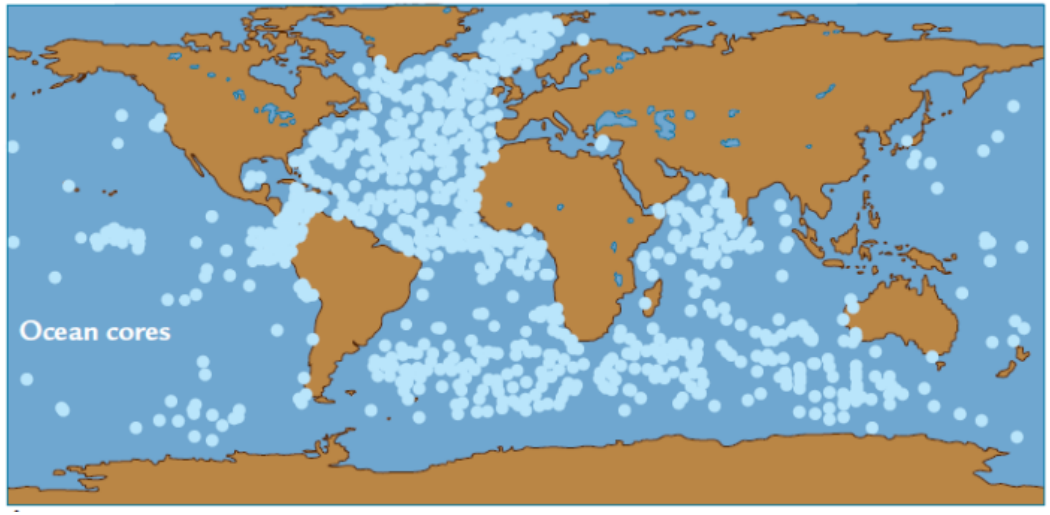
- Coarse (silt-sized) wind blown sediment sequences called loess.
- China has some excellent loess repositories of the last 3 million years.
- Grain size analysis of the entire exposed section of the loess deposition indicator of glacial-interglacial climate changes.

Soil – fine grain size (wetter period)

Loess sediment – coarse , wind blown (dry period)



Ocean archives



NPDC, Boulder

IODP - International Ocean Discovery Program

Geological and geochemical data

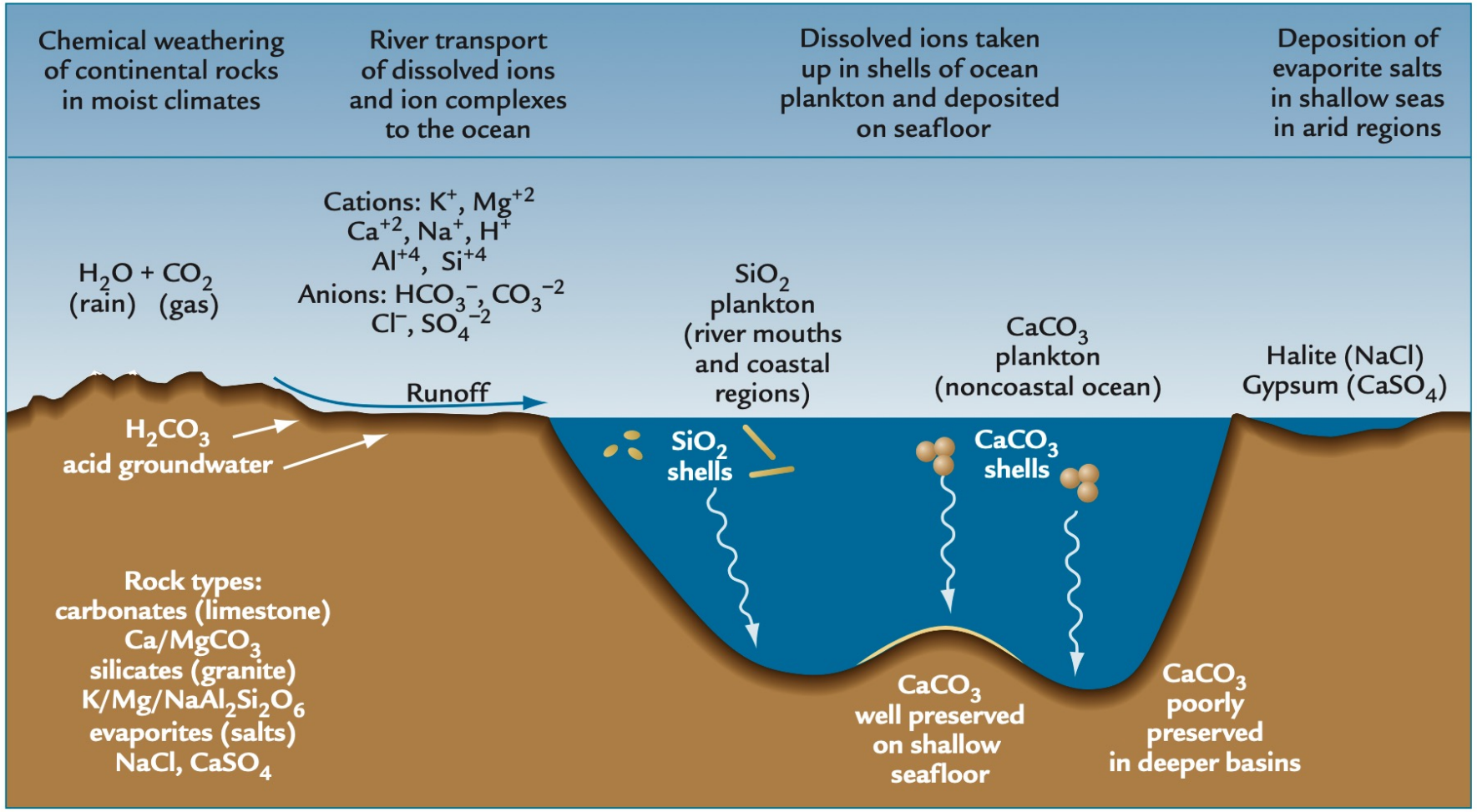
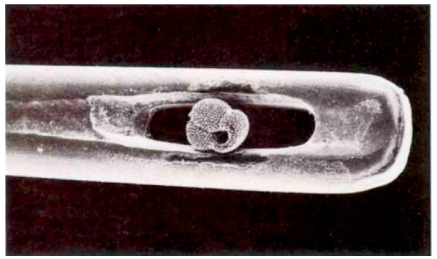


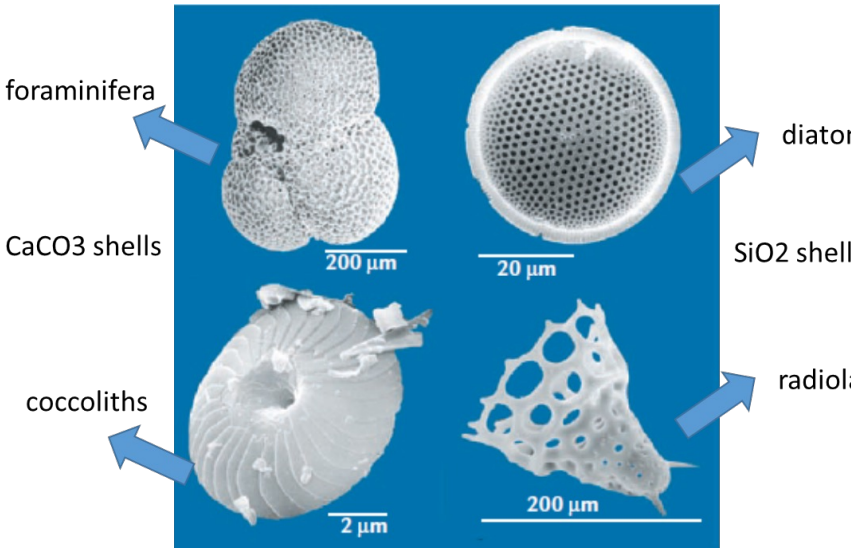
FIGURE 3-17

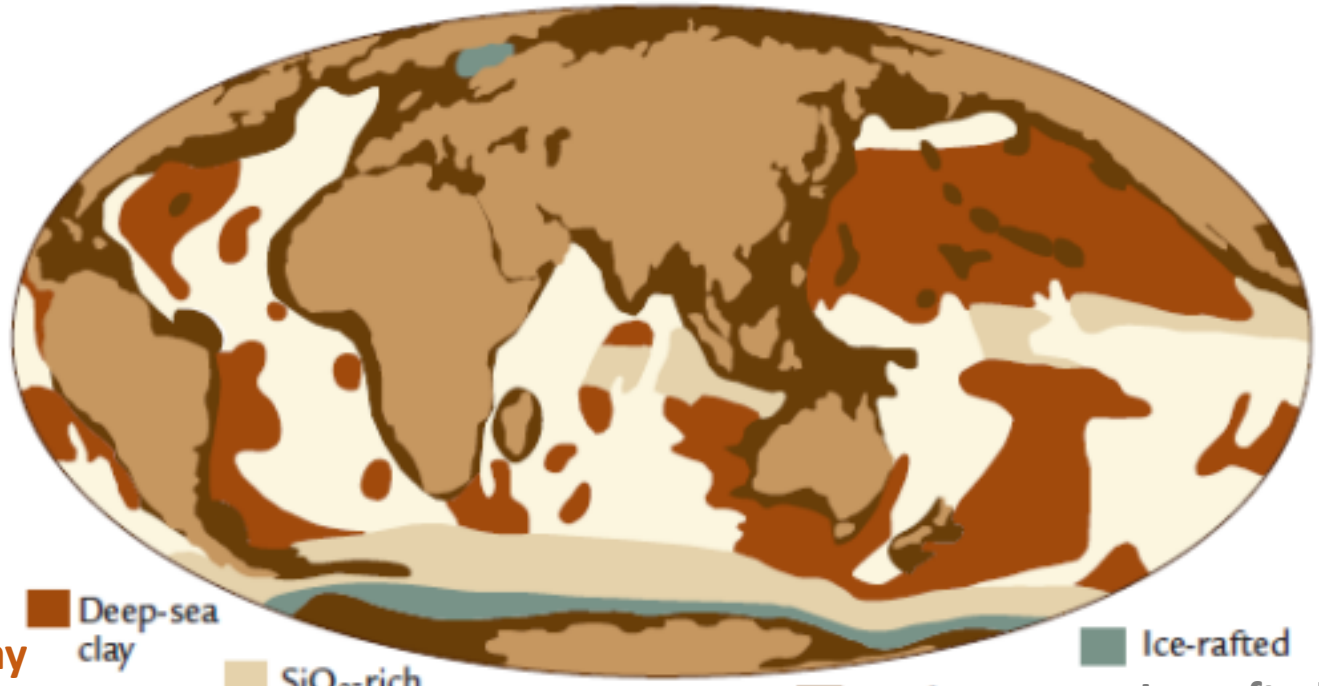
Chemical weathering, transport, and deposition

Chemical weathering slowly attacks rocks on land and sends dissolved ions into rivers for transport to the ocean. Ocean plankton incorporate some of the dissolved ions in their shells, which fall to the seafloor and form part of the geologic record. Some dissolved ions are also deposited in shallow salty evaporating pools on continental margins where the climate is dry.

Ocean archives







Deep sea clay are windblown deposited far from the continents

SiO2 in productive areas

CaCO3 rich sediments in high rises and ridges (~3.5km water depth – WHY THIS DEPTH?)

Debris from land

Ice rafted in polar areas

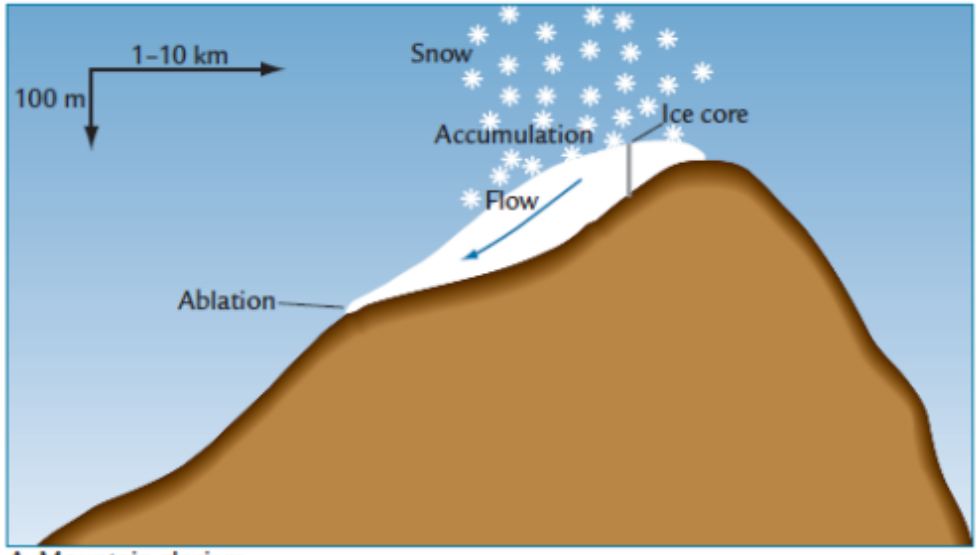
Plankton: a proxy indicator of climate in the ocean

Four types of shelled remains of plankton are common in ocean sediments:

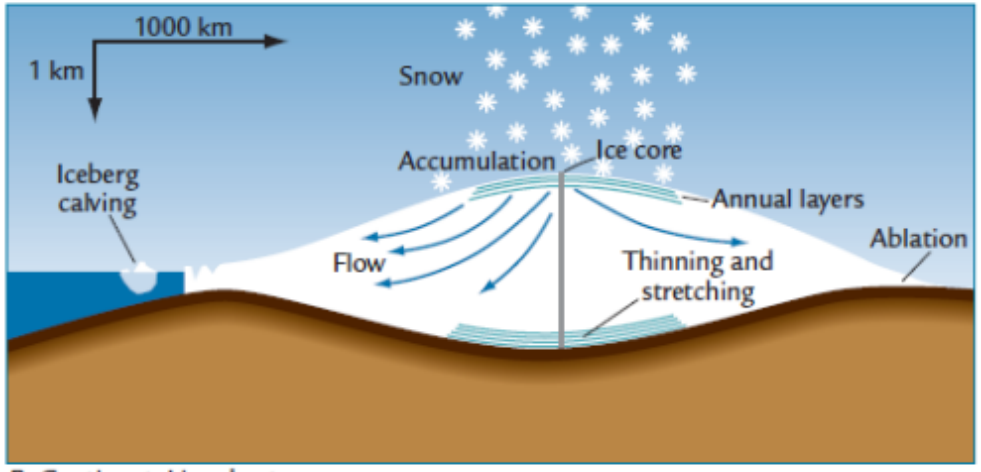
1. CaCO3 shells are represented by sand-sized planktic foraminifera (upper left) and small clay-sized coccoliths (lower left);
2. SiO2 shells include silt-sized diatoms (upper right) and sand-sized radiolaria (lower right).

For comparison, small grains of sand are 60 µm or larger in diameter.

Ice archives



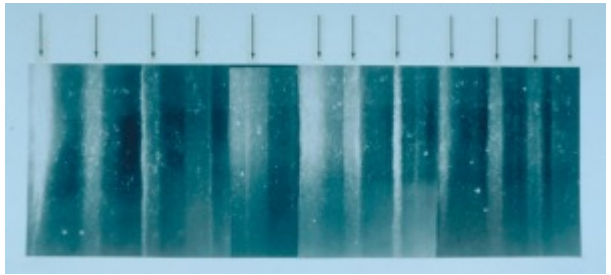
A Mountain glaciers



B Continental ice sheets

Located on high latitudes and altitudes

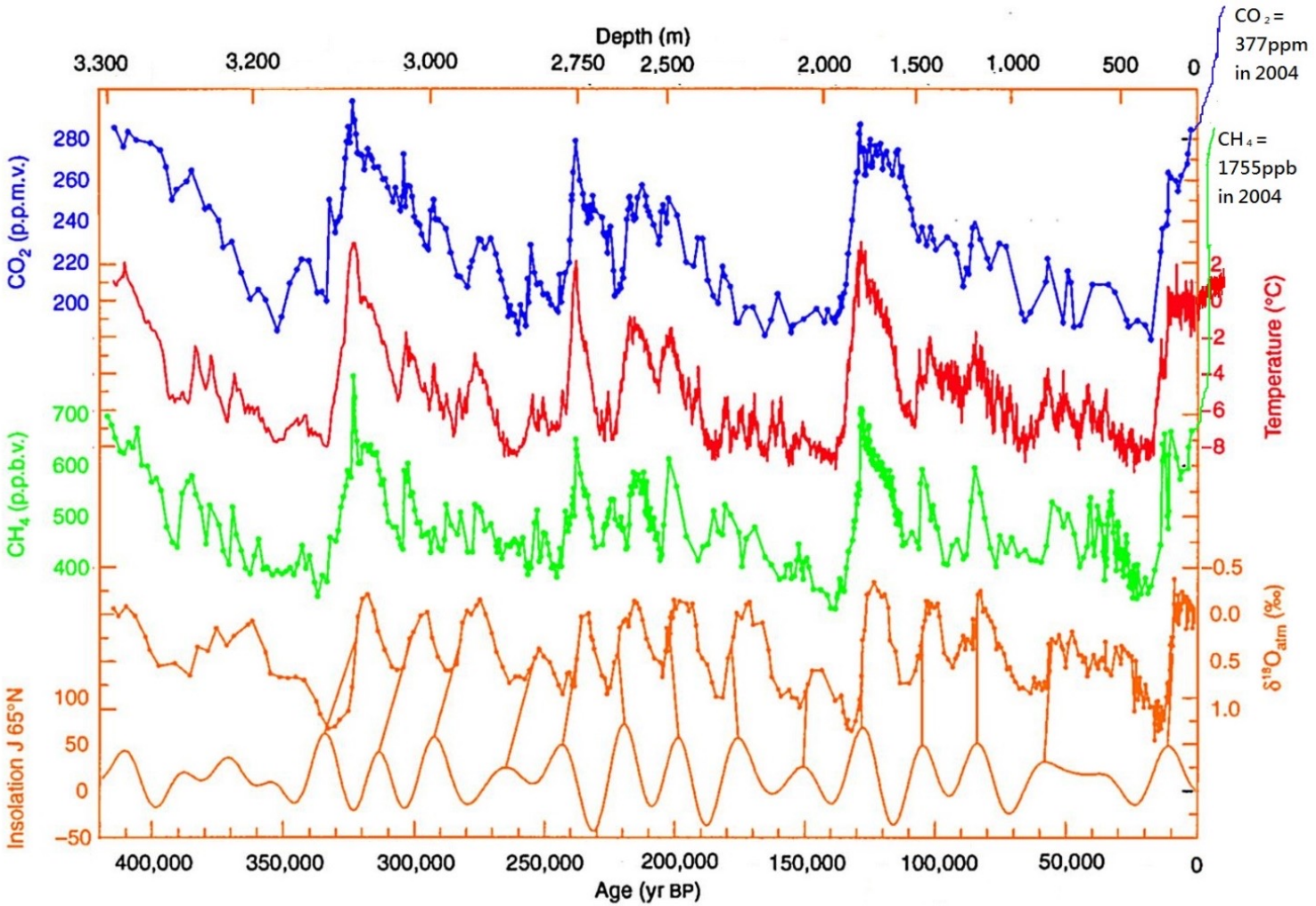
- H_2O in ice – Oxygen isotopes –temp, precipitation
- Dust amount – global dryness, wind
- Air bubbles – Actual samples of trapped air to determine past concentrations of gases such as CO2, CH4
- Layers in the ice



Ice archives

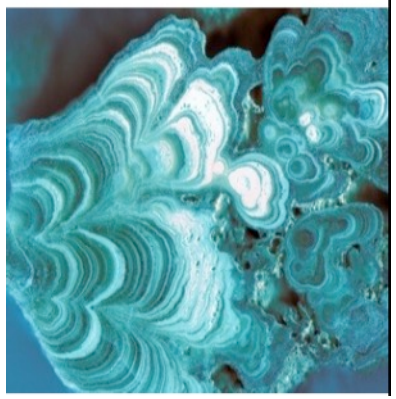
- Ice recovered from the Antarctic ice sheet now dates back to 800,000 years, and ice from the Greenland ice sheet dates to just beyond 125,000 years.

Vostok ice core record in East Antarctica

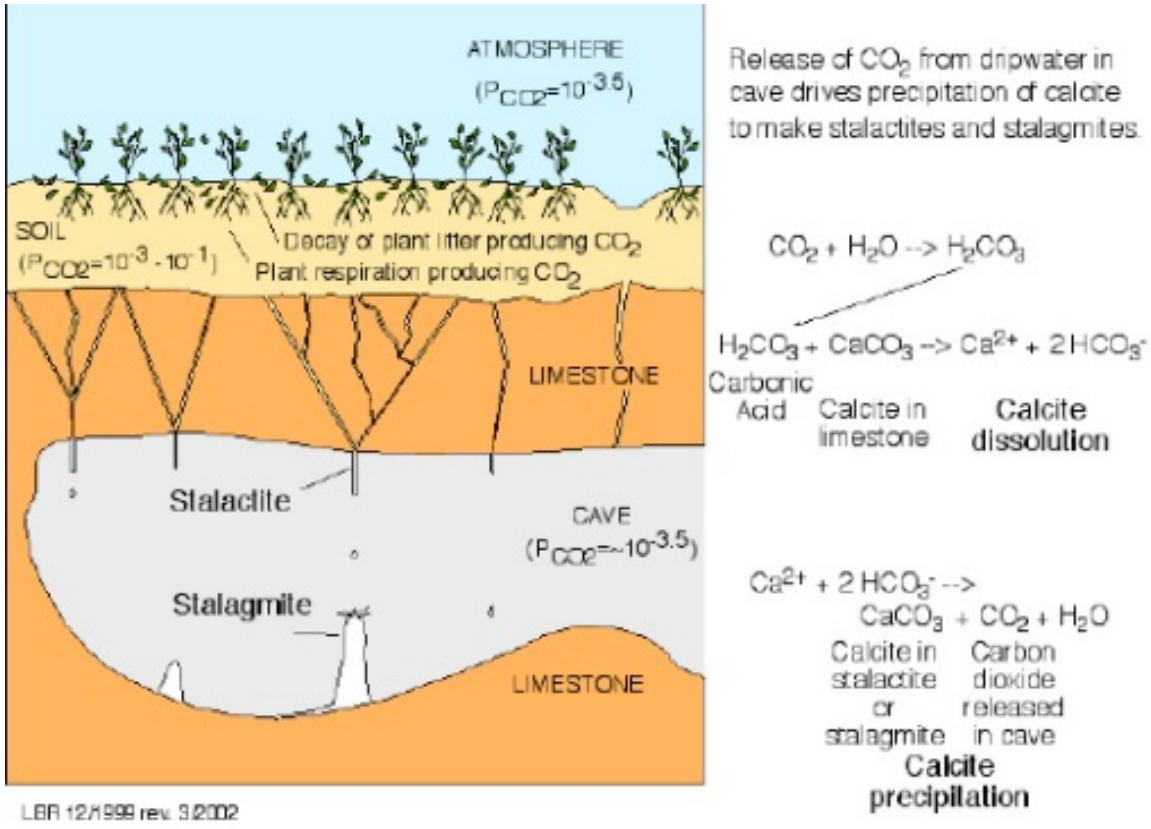


Speleothems

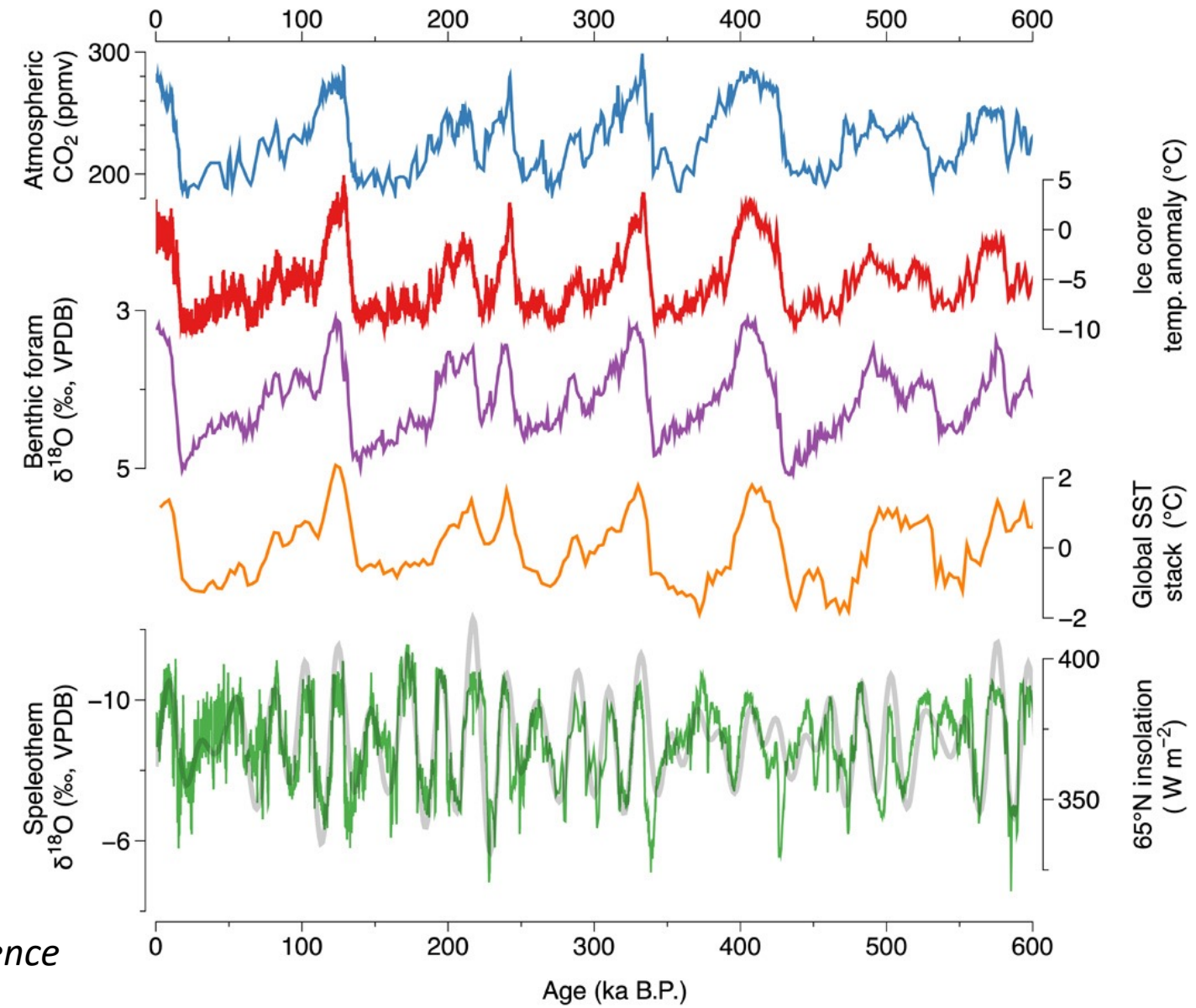
Calcium carbonate cave deposits – Stalagmites and Stalactites



d18O of speleothems is a reflection of the groundwater d18O and ultimately the d18O of the rainfall in the region



Chinese speleothem vs global records



Antarctica surface temperatures

Southern china speleothem

Note the 23kyr precessional cycle

Liu et al., 2020 Science

Other climate archives

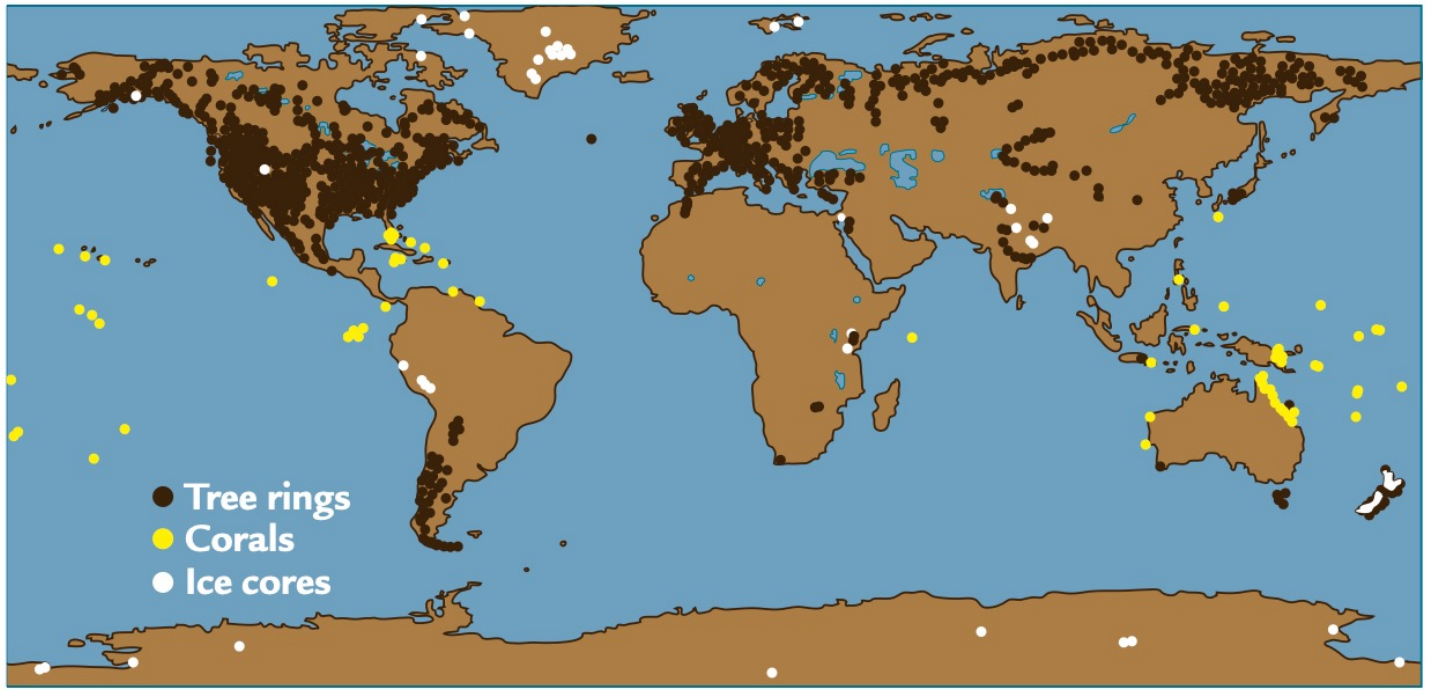


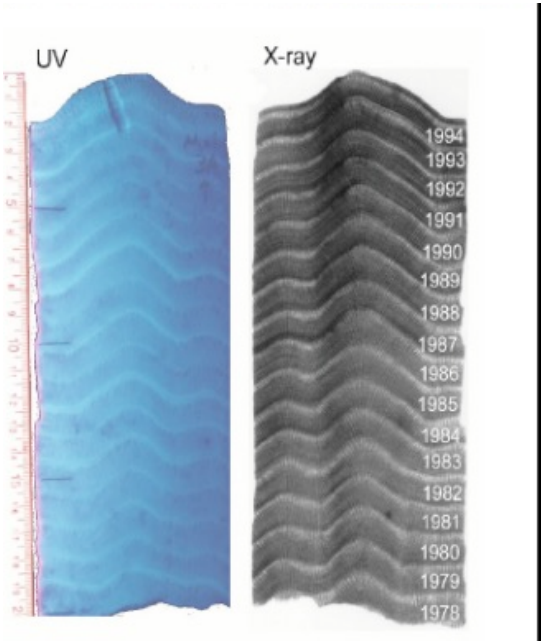
FIGURE 3-6

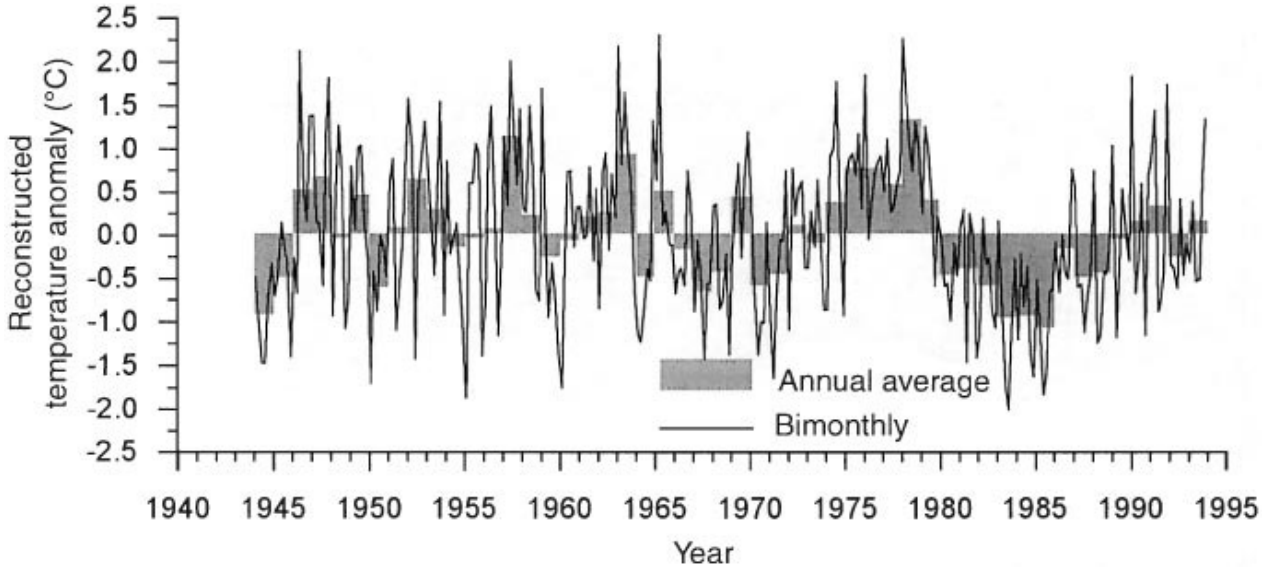
Ice cores, corals, and tree rings

Ice cores, corals, and tree rings are archives of climate change in more recent Earth history. (NATIONAL PALEOCLIMATE DATA CENTER, NGDC, BOULDER, CO.)

Corals

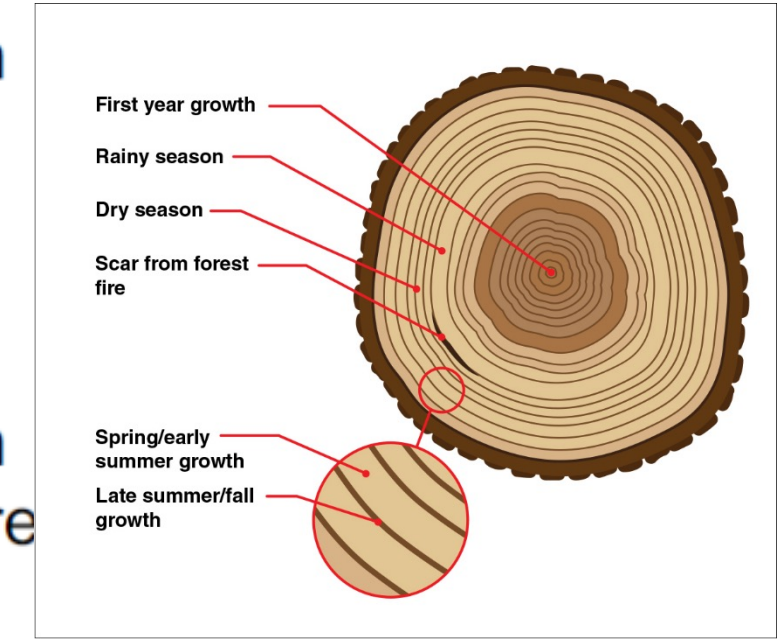
- Skeletons made of aragonite ($CaCO_3$)
- Dated using annual density band U-Th, ^{14}C
- Recorders of tropical sea surface conditions:
  Temperature, Salinity
- Oxygen Isotopes record a combination of temp and salinity
- Strontium/Calcium (Sr/Ca) records mainly temperature

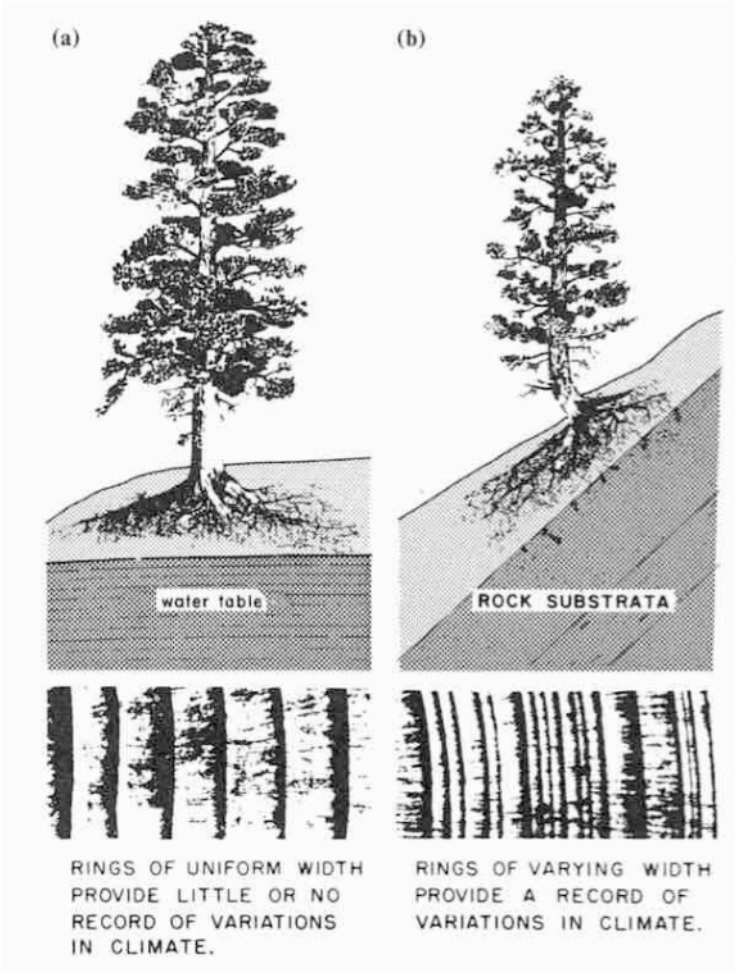




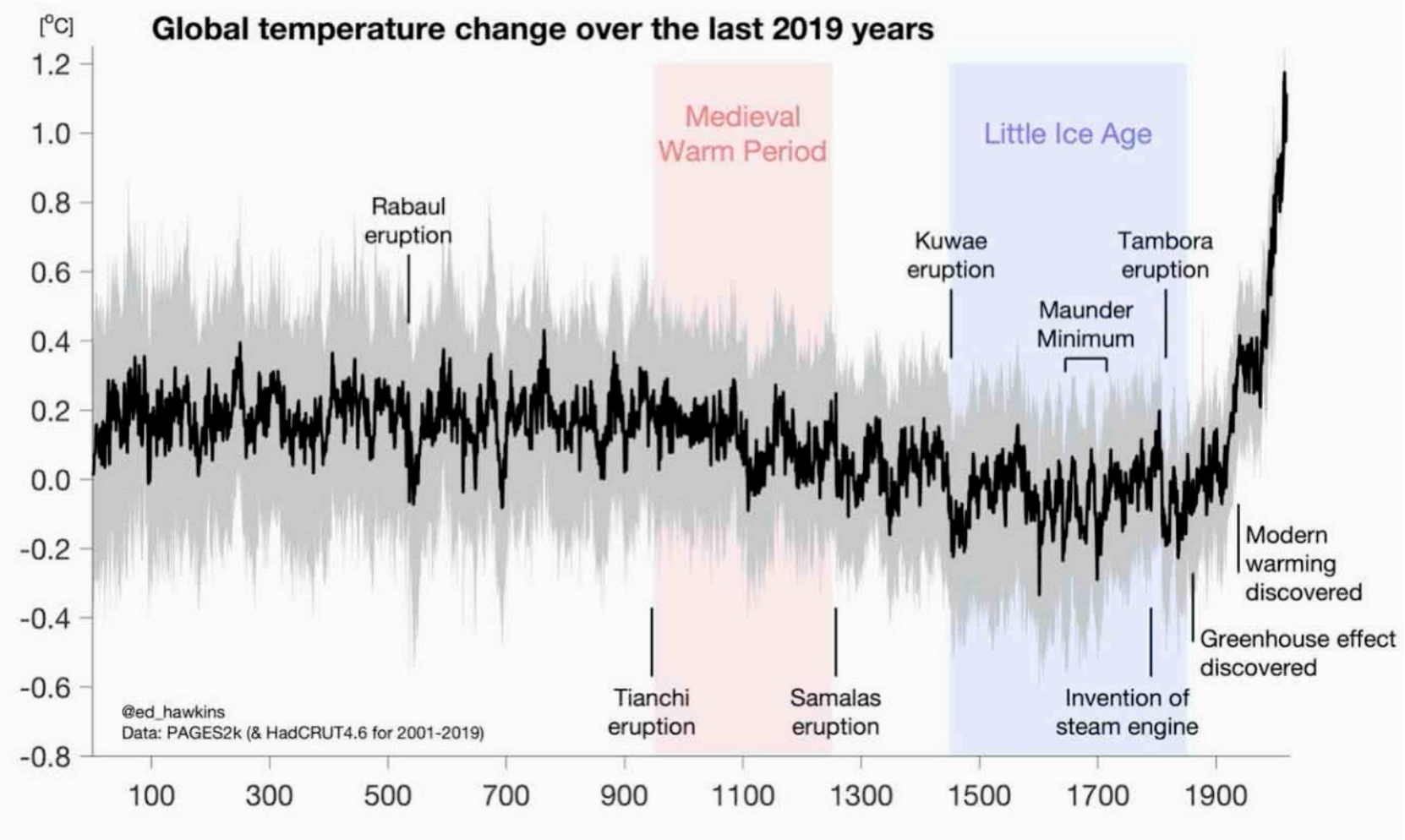
Tree rings

- Predominantly temperate (mid-latitudes)
- Dated using radiocarbon
- Thick bands during growing season, thin bands during cold/dry months
- Varying widths of growth bands reflect temperature or precipitation





Global temperature change over two millennia



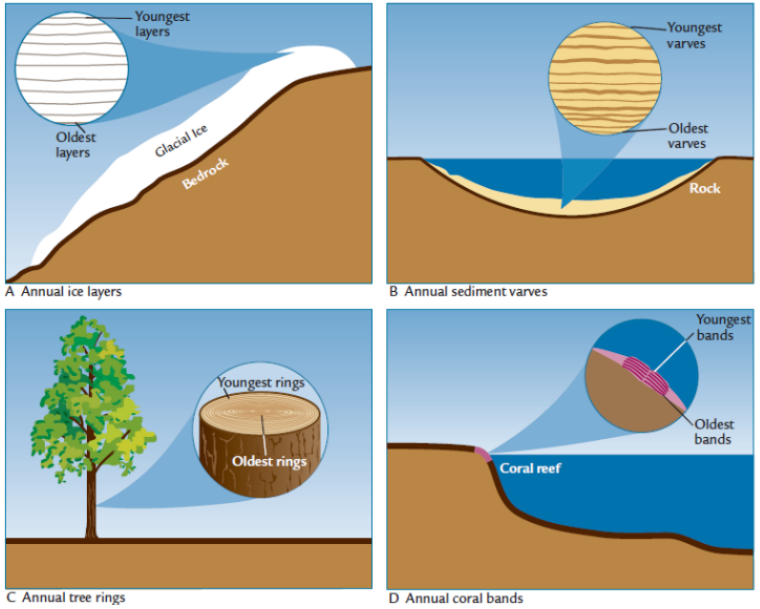
How do we date these proxy records?

Table 3-1 Radioactive Decay Used to Date Climate Records

Parent isotope	Daughter isotope	Half-life	Useful for ages:	Useful for dating:
Rubidium-87 (^{87}Rb)	Strontium-87 (^{87}Sr)	47 Byr	100 Myr	Granites
Uranium-238 (^{238}U)	Lead-206 (^{206}Pb)	4.5 Byr	>100 Myr	Many rocks
Uranium-235 (^{235}U)	Lead-207 (^{207}Pb)	0.7 Byr	>100 Myr	Many rocks
Potassium-40 (^{40}K)	Argon-40 (^{40}Ar)	1.3 Byr	>100,000 years	Basalts
Thorium 230 (^{230}Th)	Radon-226* (^{226}Ra)	75,000 years	<400,000 years	Corals
Carbon-14 (^{14}C)	Nitrogen-14* (^{14}N)	5,780 years	<50,000 years	Anything that contains carbon

*Daughter in this case is a gas that has escaped and cannot be measured.

Counting annual layers



Correlating records with orbital cycles – 'tuning'

- Timing is accurately known from astronomical calculations and physical processes like cyclical growth and decay of high-latitude ice-sheets and monsoon variations in low-latitudes
- Absolute dating covering many Myr

Confluence of disciplines – Paleoclimatology