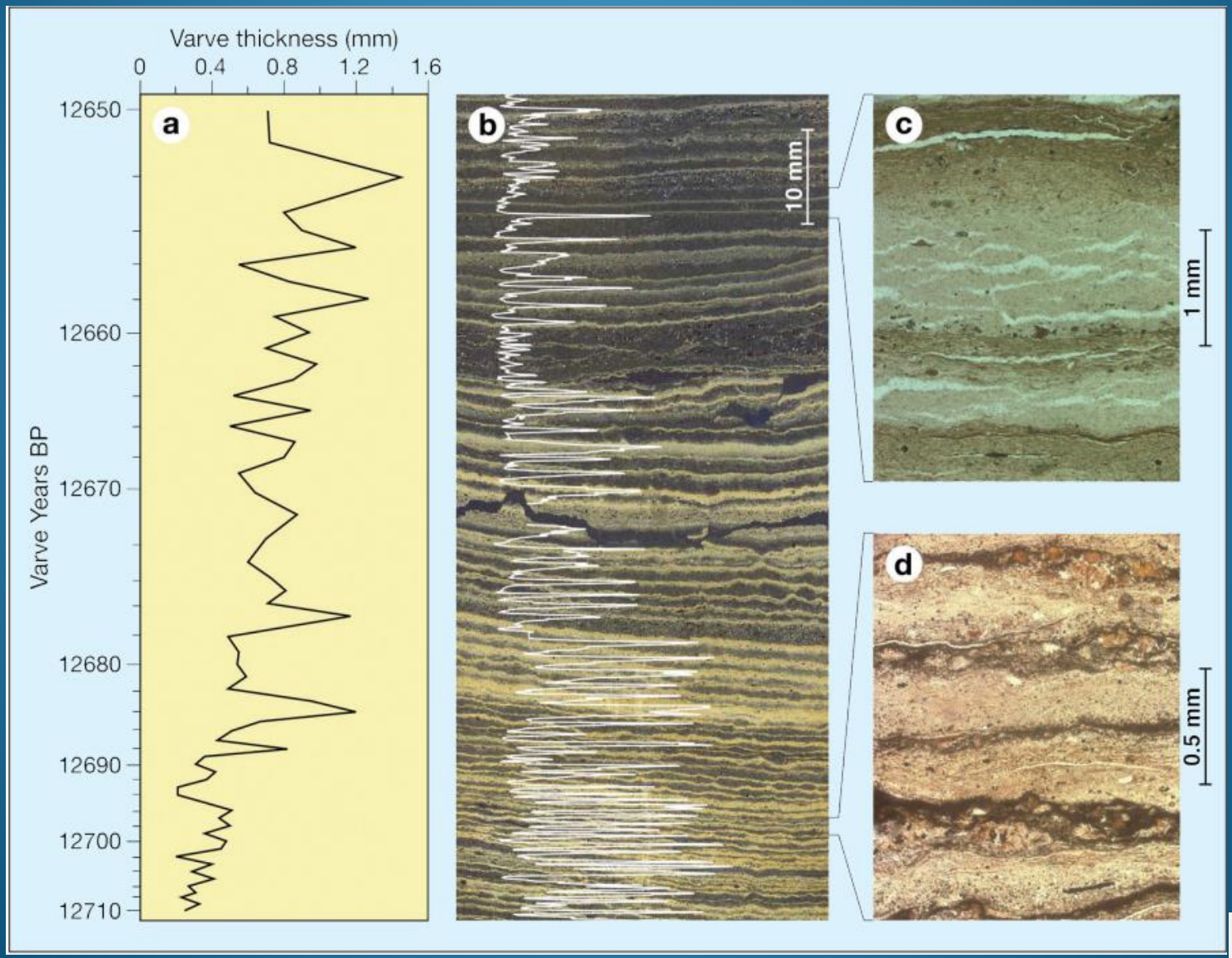
Lecture 12: Proxies of Paleoclimate I



Today's Learning Outcomes

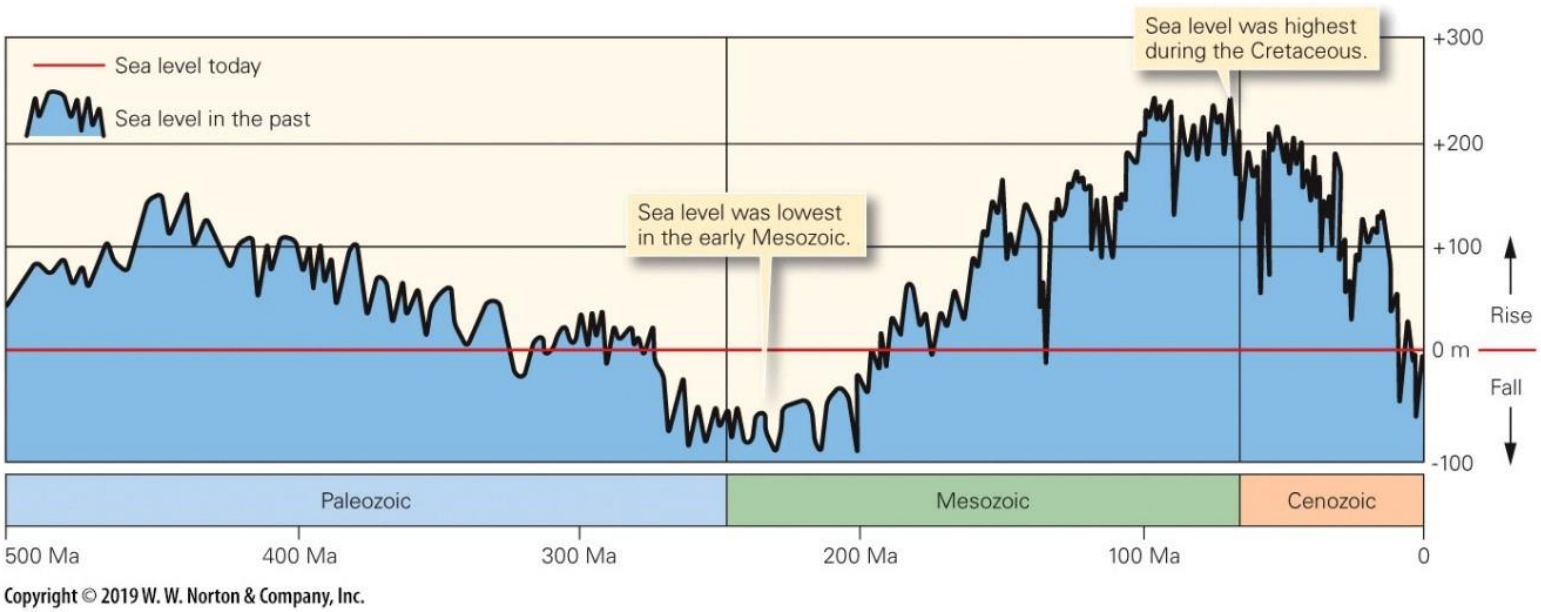
1. Be able to explain at least one way that understanding past climate helps our present understanding

2. Provide a definition of "paleoproxy"

3. Be able to explain the principles behind the four paleoproxies presented

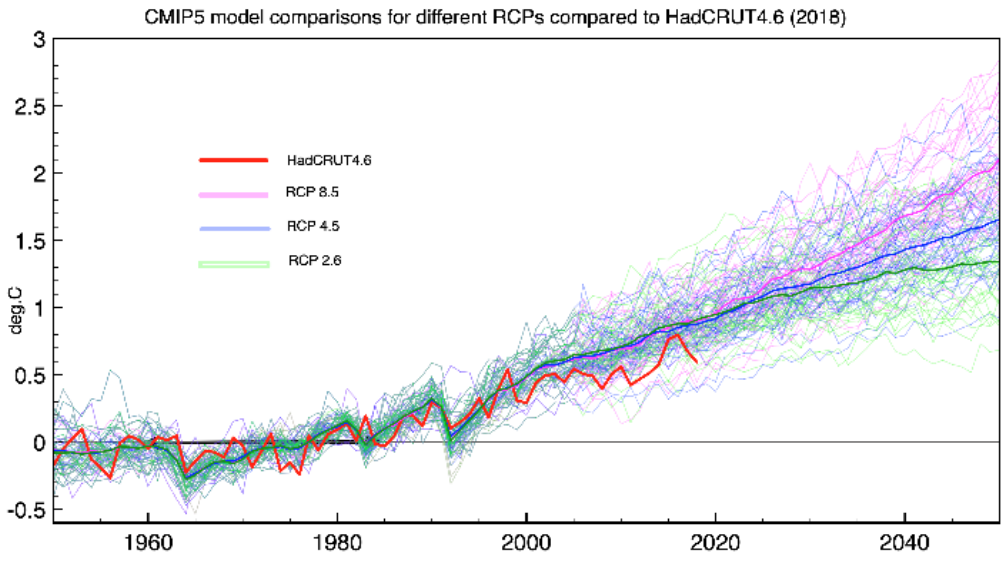
Why Look to the Past?

- It helps provide a baseline for our current climate
  - What is Earth's "normal" climate?
  - Are are we within a usual range of climate change or is the modern day truly unique in Earth's history?



Why Look to the Past?

- The Earth's climate record is incredibly long and thus provides much more data than the ~150 years we've been tracking it closely
  - Constrains the uncertainty of climate models looking into the future
  - Longer datasets = more rare events captured



Why Look to the Past?

- Life has also existed for a long time and how organisms and communities responded to past climate change events might help us to predict, prepare for, and mitigate those impacts today

Table 1. Past drivers of extinction in the ocean and current threats[a]

Time period[b]	Drivers and Threats[c]				
	Acidification[d]	Anoxia[e]	Warming	Cooling	Habitat Loss[f]
Ordovician-Silurian (~444 Ma)		○	○	●	●
Late Devonian* (Frasnian-Famennian; ~374 Ma)		●	○	●	●
End Permian* (~251 Ma)	●	●	●	○	●
Early Triassic (~245 Ma)	○	●	○	○	○
Triassic-Jurassic* (~202 Ma)	●		●		
Early Jurassic* (Pliensbachian-Toarcian; ~183 Ma)	●	●	●	●	
Aptian-Albian (~112 Ma)	●	●		○	○
Cenomanian–Turonian (~93.5 Ma)	●	●	○		
Cretaceous–Paleogene (~65.5 Ma)	●		○	●	○
Paleocene–Eocene Thermal Maximum* (~56 Ma)	●	○	●		
Eocene–Oligocene (~34 Ma)				●	○
Mid–Miocene Climatic Optimum (~14.7 Ma)			●		○
Historical (~10 Ka)			○		●
Modern	●	●	●		●

Proxies

- In the present we can track atmospheric levels of greenhouse gases, temperatures, sea level, and ice sheet volumes directly
- With a few exceptions none of these are preserved directly in the rock record so we have to rely of proxy measures
- A proxy is something that, in theory, closely tracks something else we cannot measure directly
  - Ex. Grades are a proxy for learning

We Use Proxies All the Time

- Where did I take a vacation? **Tropical oceanside (Pacific/Indian)**

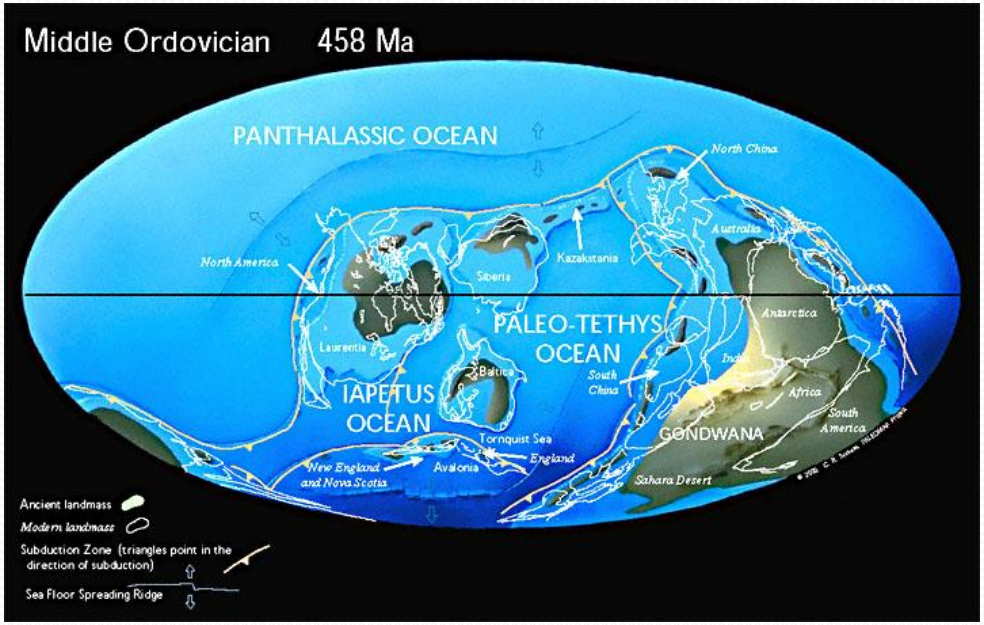
Coconut brought back:
tropical fruit,
oceanic dispersal

Tanlines: caused by exposure to UV radiation, probably not from a tanning bed given the sock line. Spending a lot of time in the sun in a place warm enough for shorts.

Paleoproxies

- Paleoproxies (paleo means “old/ancient”) are things preserved in rocks which we can measure and interpret as correlated to something we cannot measure but want to know

- <u>Paleoclimate</u> paleoproxies are features we can measure directly from the rock record which correlate to things like temperature, ice extent, etc. and allow us to reconstruct climate over time through Earth’s history



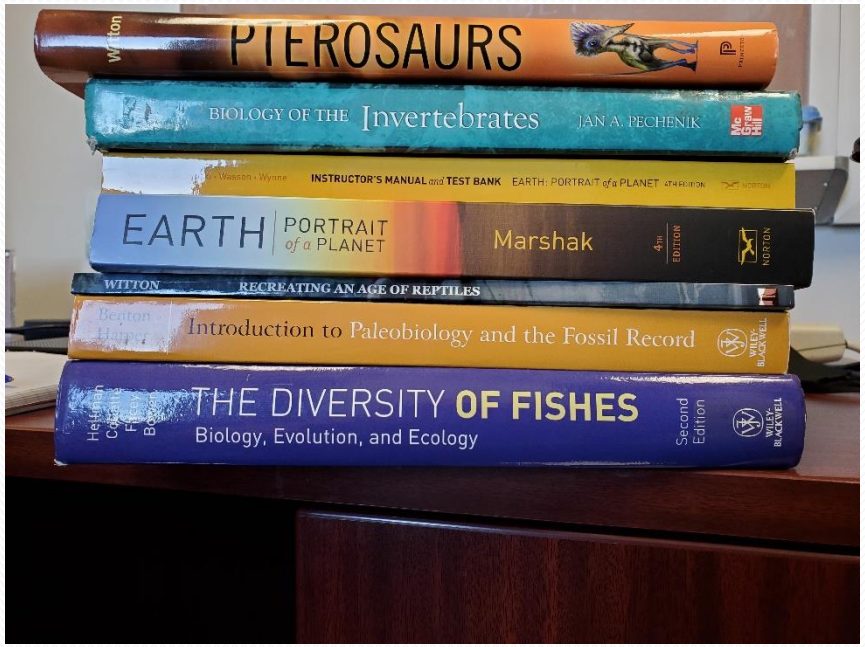
Eighteenmile Creek, Derby NY

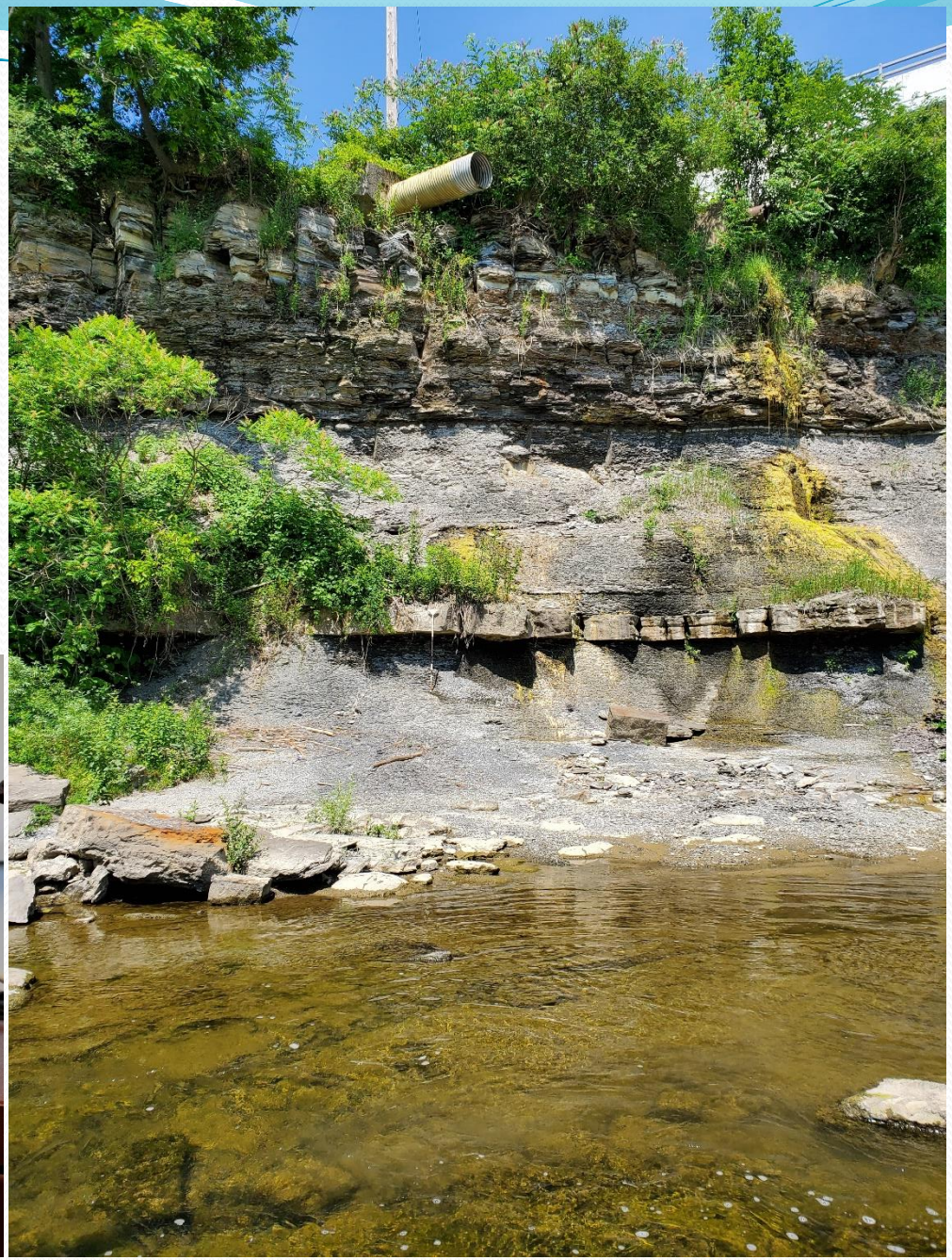
Paleoproxies

- Since these are proxies and **not** the direct signal they should always be interpreted carefully
- A single proxy should be viewed skeptically but many independent proxies all pointing to the same conclusion is more convincing
  - Doing well on one assignment does not mean you have mastered all the material yet
  - Doing well on all the assignments is a more reliable signal that you do understand the material
- Never actually prove anything, only infer with more confidence


Quick Foray into Stratigraphy

- Where are the oldest rocks?
- Which book did I put down first?

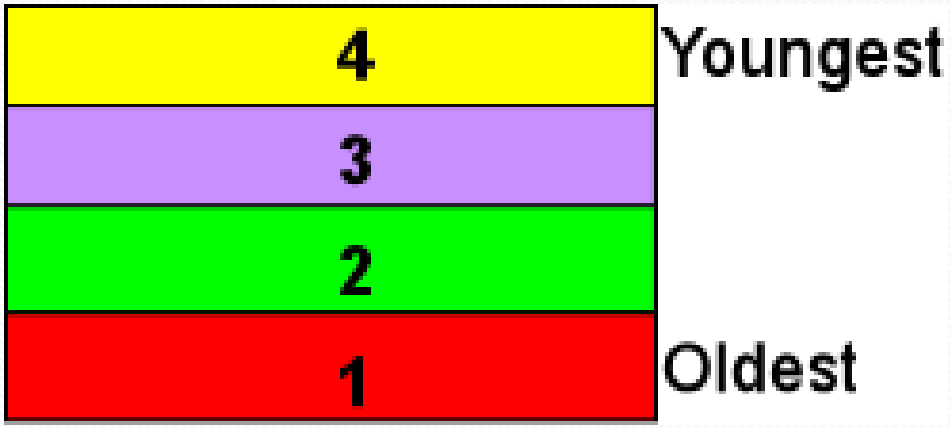


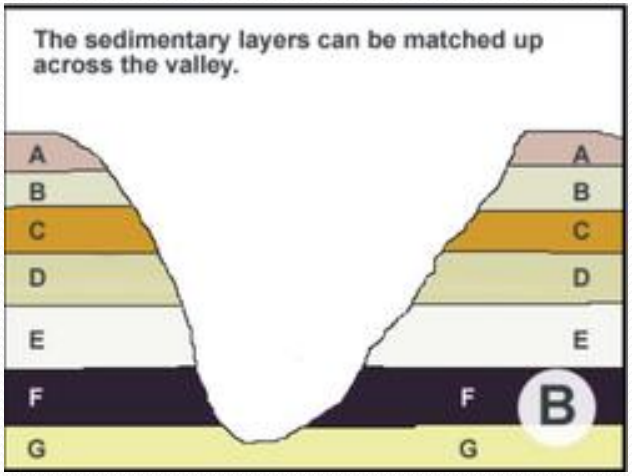


Sedimentary Rock Relationships

- Law of Original Horizontality: rock layers are laid down horizontally

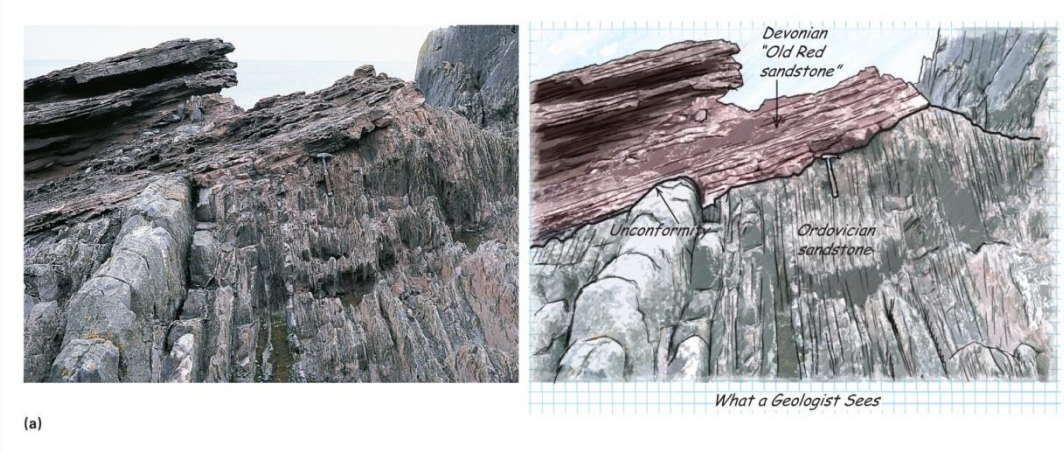
- Law of Superposition: layers toward the bottom of a rock sequence are older than those above them

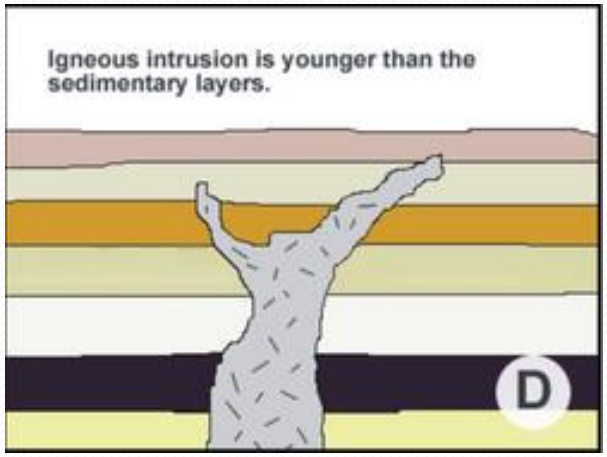




Sedimentary Rock Relationships

- Law of Cross-Cutting: events that cut across or deform a set of rocks must be younger than the rocks that are affected

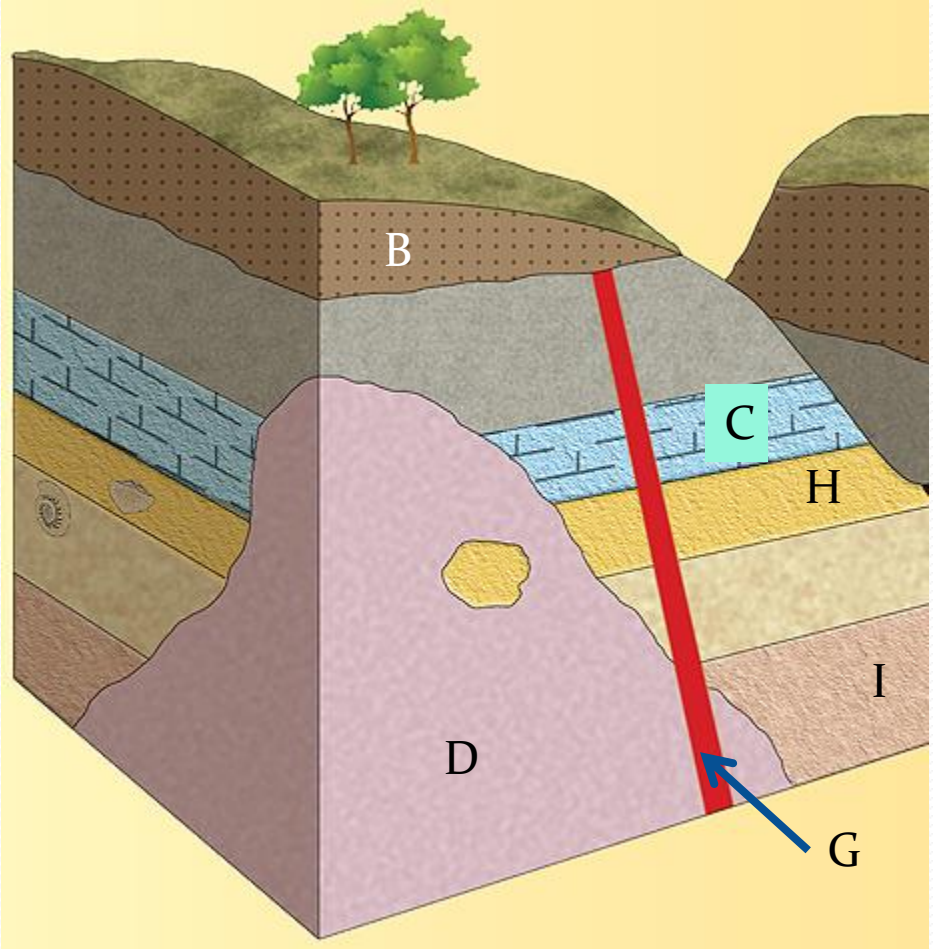




What is the Order of Events?

G is a dike, a vertical shaft of magma that cooled and froze to solid rock

D is pluton, a pool of magma that cooled and froze to solid rock



What is the Relative Order?

Youngest

B

G

D

A

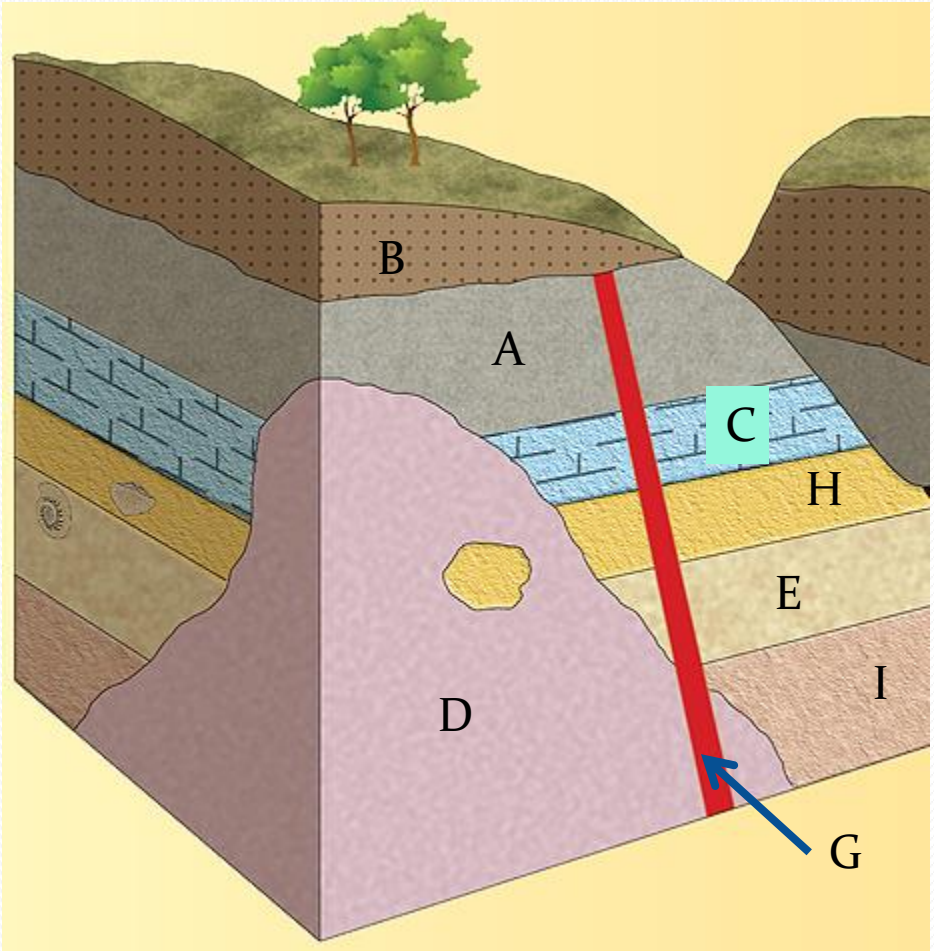
C

H

E

I

Oldest



Relative versus Absolute Time

- **Relative**: events are ordered into a sequence but the spacing between them is unknown
  - Order of Race Winners: Janice, Bob, Phil

- **Absolute**: events are associated with specific dates and can be ordered based on those dates and the amount of time between them are know
  - Time of Race Winners: Janice (2:10), Bob (2:12), Phil (5:00)

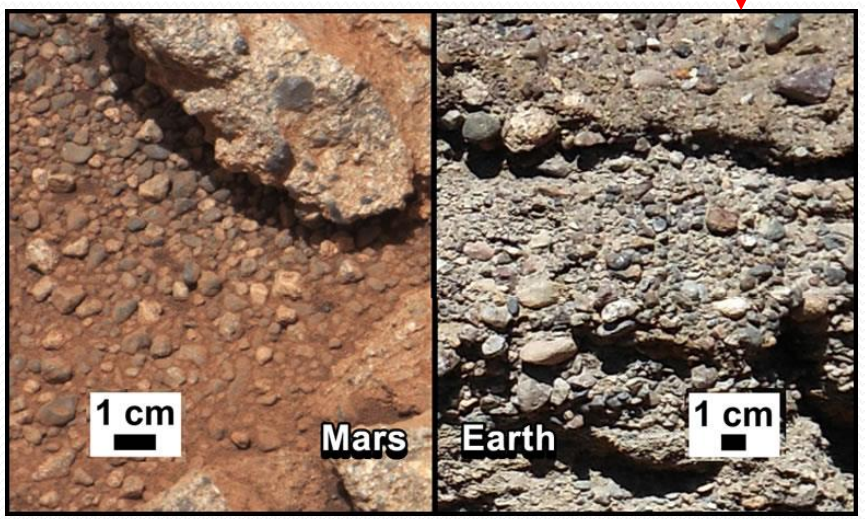
Paleoclimate Proxies

1. Depositional environment records of climate zones
2. Pollen records
3. Tree rings
4. Animals and plant forms
5. Isotopes [next lecture]

Proxy #1: Depositional Environments

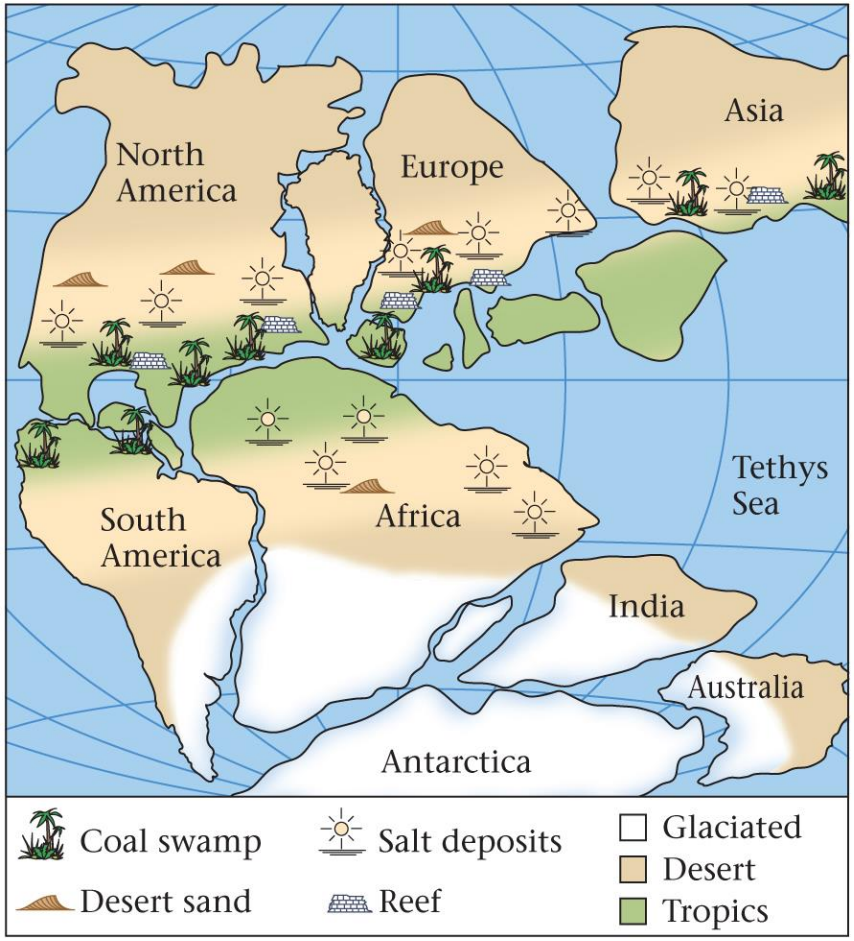
- Different climate regions leave different types of rock records behind

- If we assume the same basic principles that control climate today were true in the past (temperature highest at the equator, deserts at the Hadley-Ferrel Cell boundaries) then we can use the traces of environments expanding or contracting to map out ancient climate bands



Depositional Environments

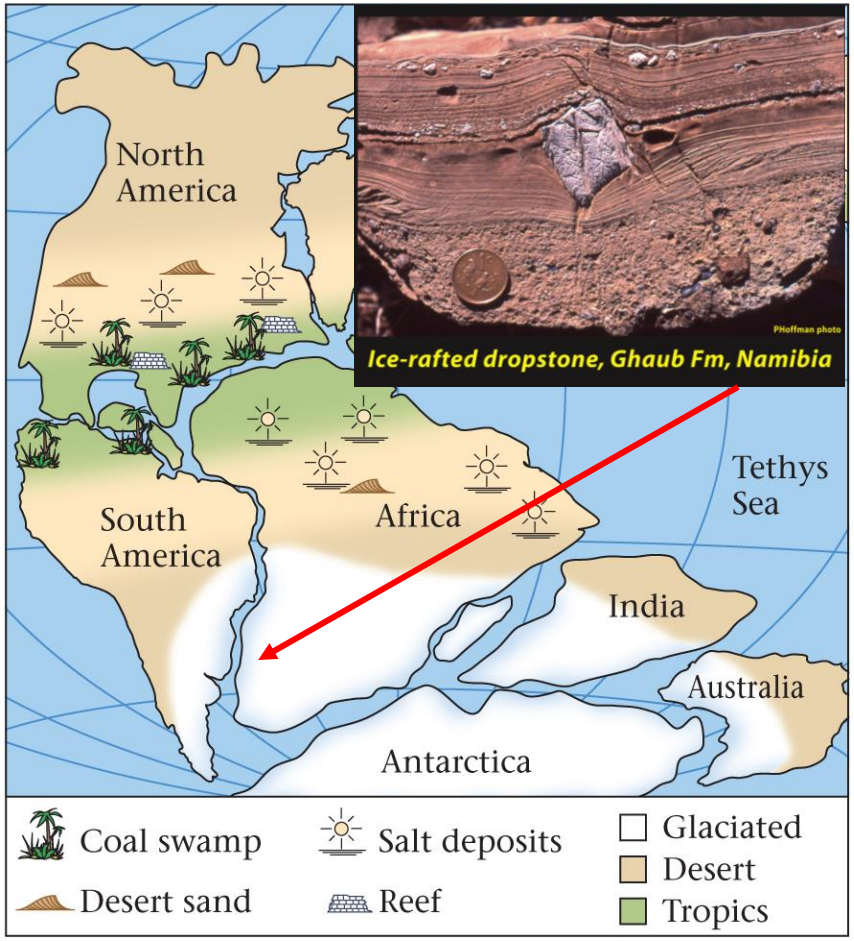
- Climates exist in distinct bands
  - Reefs/Coal swamps near equator
  - Deserts a bit away from the equator
  - Traces of glaciers at the poles



(b)

Depositional Environments

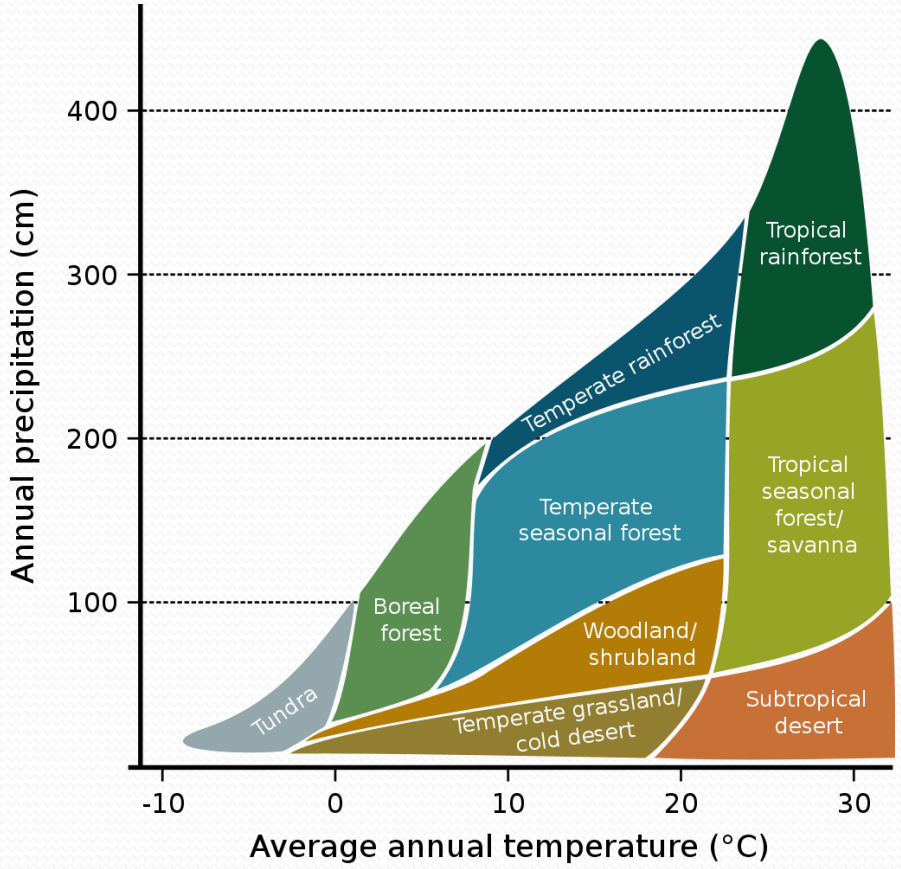
- Climates exist in distinct bands
  - Reefs/Coal swamps near equator
  - Deserts a bit away from the equator
  - Traces of glaciers at the poles (dropstones)



(b)

Proxy #2: Pollen Records

- Most organisms, including plants, track their preferred environment
  - Pollen is a consistently abundant plant material
- Changes in the total and relative amounts of different pollens correlate with changes in climate
  - If we know the preferred climate of different plants we can infer the direction of change



Pollen Records

Wet and hot

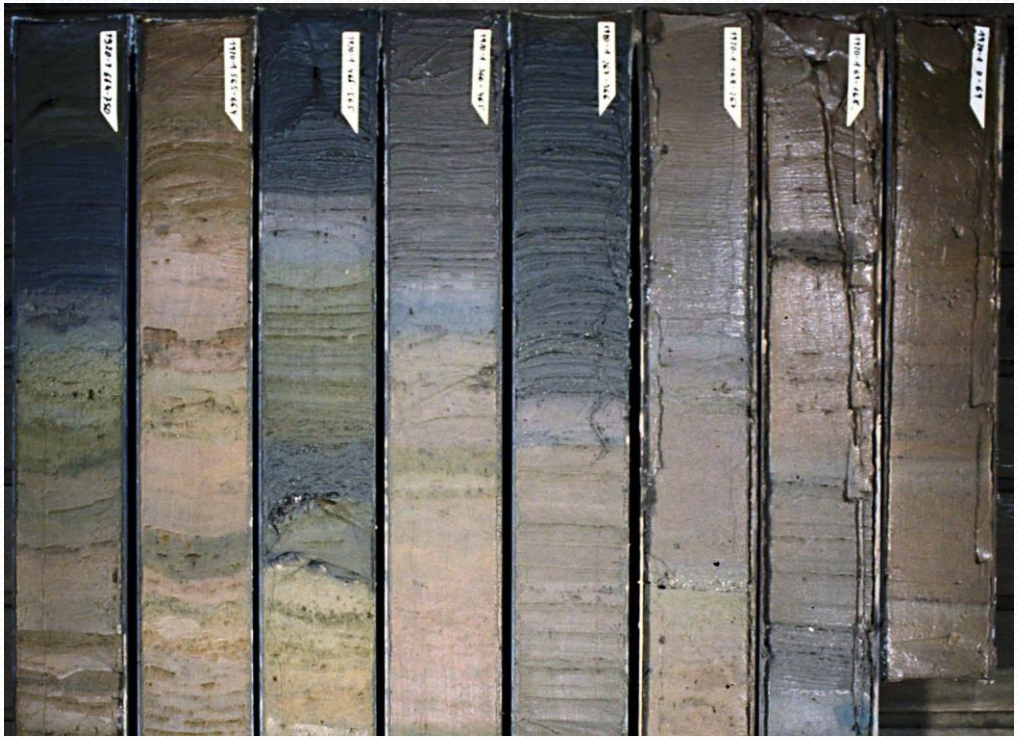
Honduran mahogany *Swietenia macrophylla*

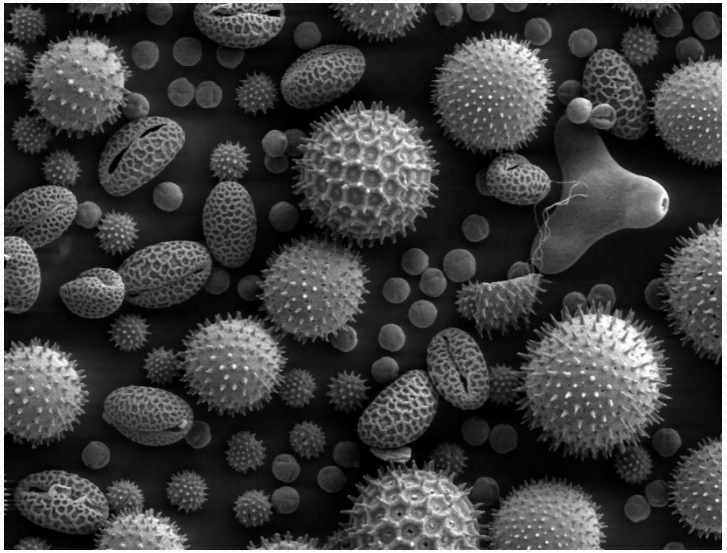
Dry and hot

Pinyon pine *Pinus edulis*

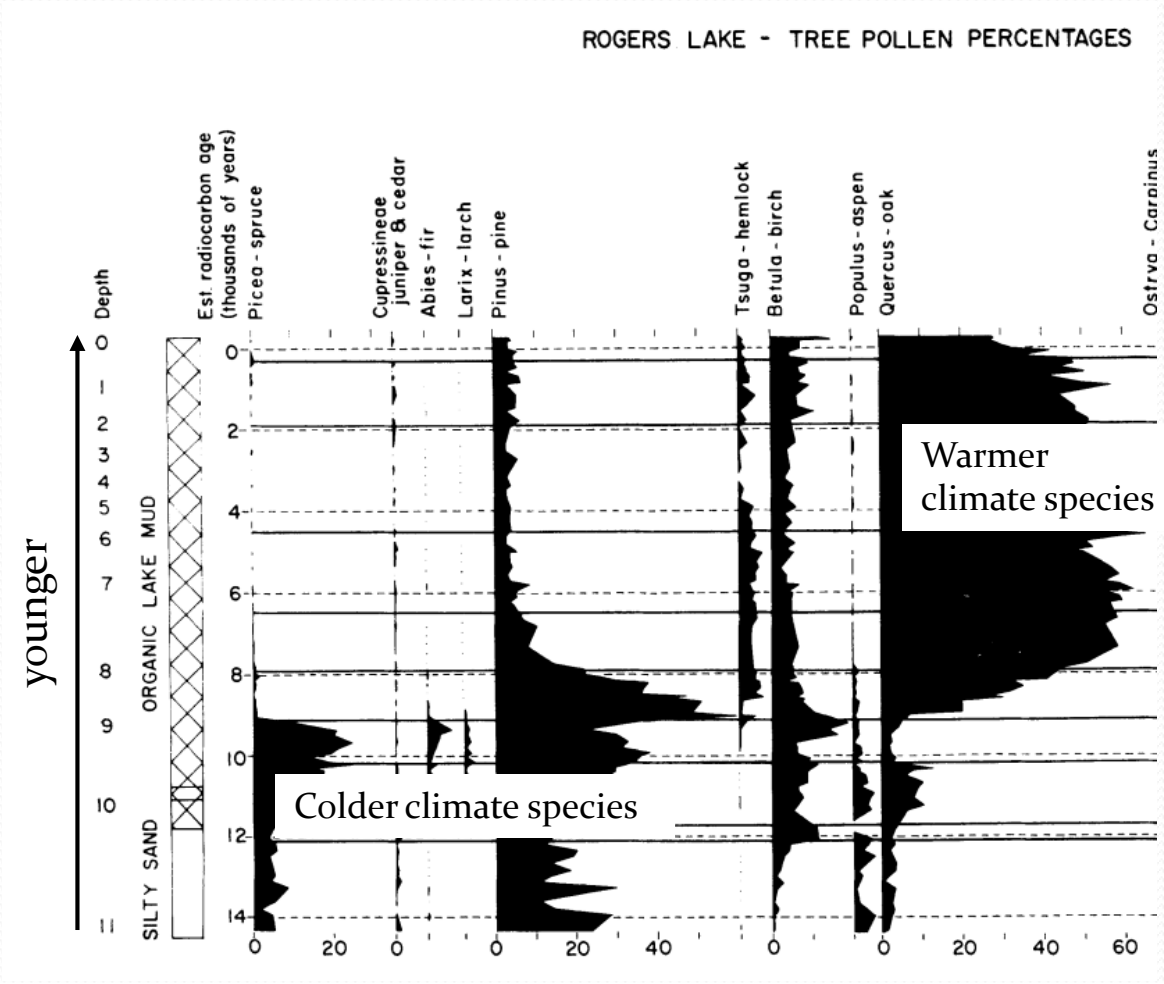
Pollen Record Sources

- One of the best settings for pollen records are lakes
  - Often have a very complete and detailed record
  - Layers can be dated by other techniques
  - Climate is inferred by the pollen types in each layer





Pollen Record Example



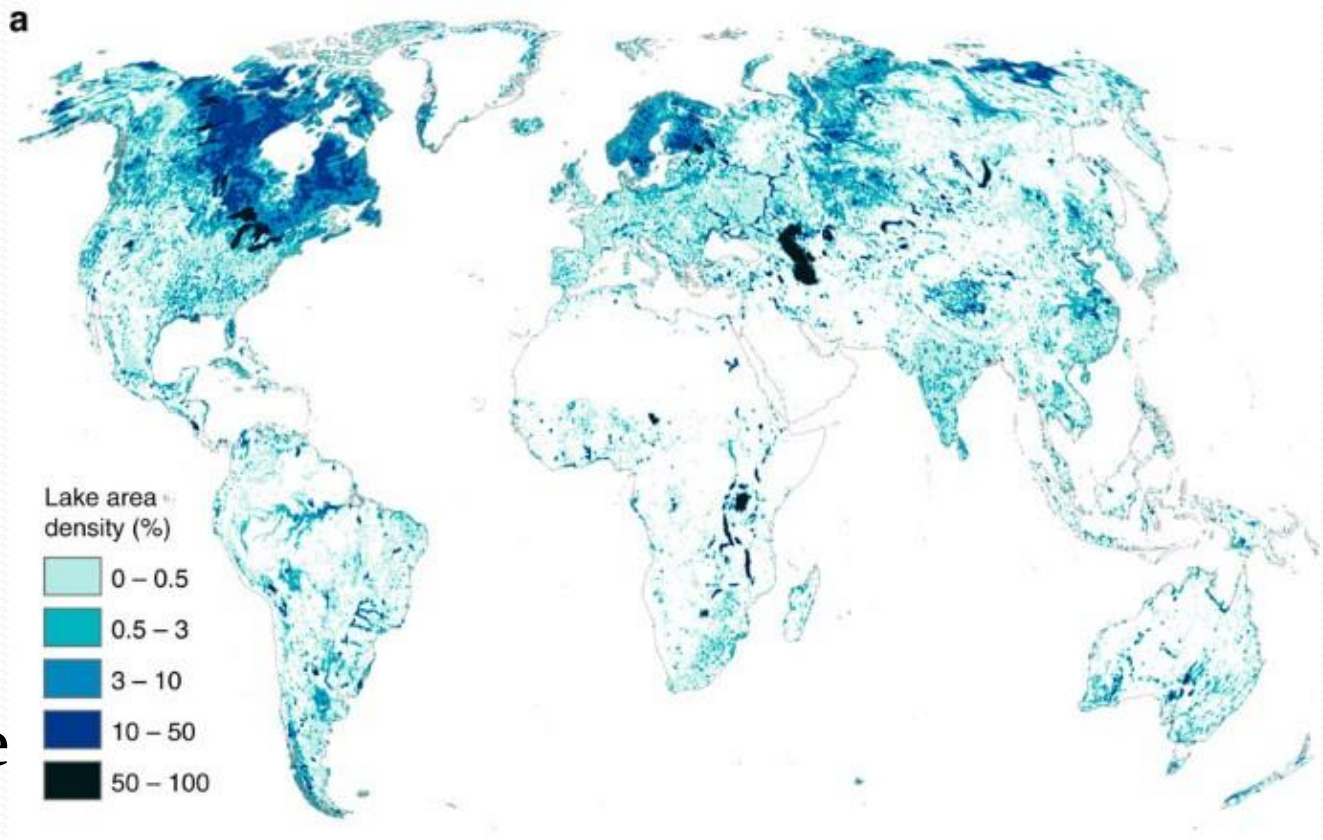
Rogers Lake records a warming trend (switch from pine-dominated to oak-dominated)

Margaret B. Davis

Bias in Lake Distribution

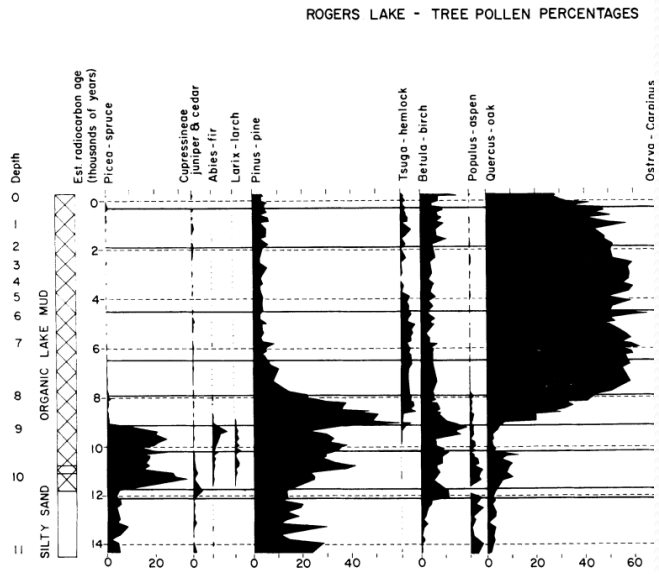
- Lakes are short-lived geologically and most around today were formed by the action or retreat of glaciers

- Most lakes are in the global north leading to a bias in the spatial coverage of this technique



Pollen Records Limitations

- Can infer back 10,000+ years, until the initial formation of the lake
  - Sediments generally do not survive glaciation, so some practical limits

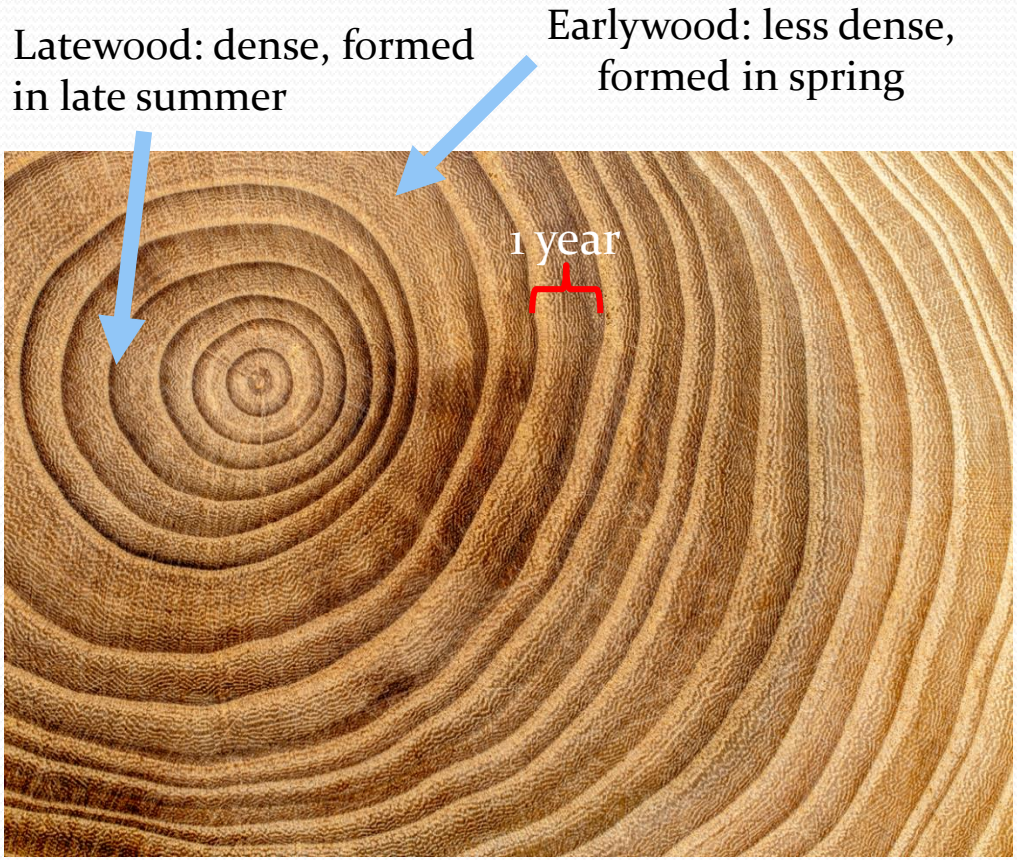


- Fine temporal resolution
  - But pollen changes can lag climate change, because species take time to migrate

- Changes can be due to precipitation, temperature changes, or both, so cannot give a 100% conclusive picture of climate

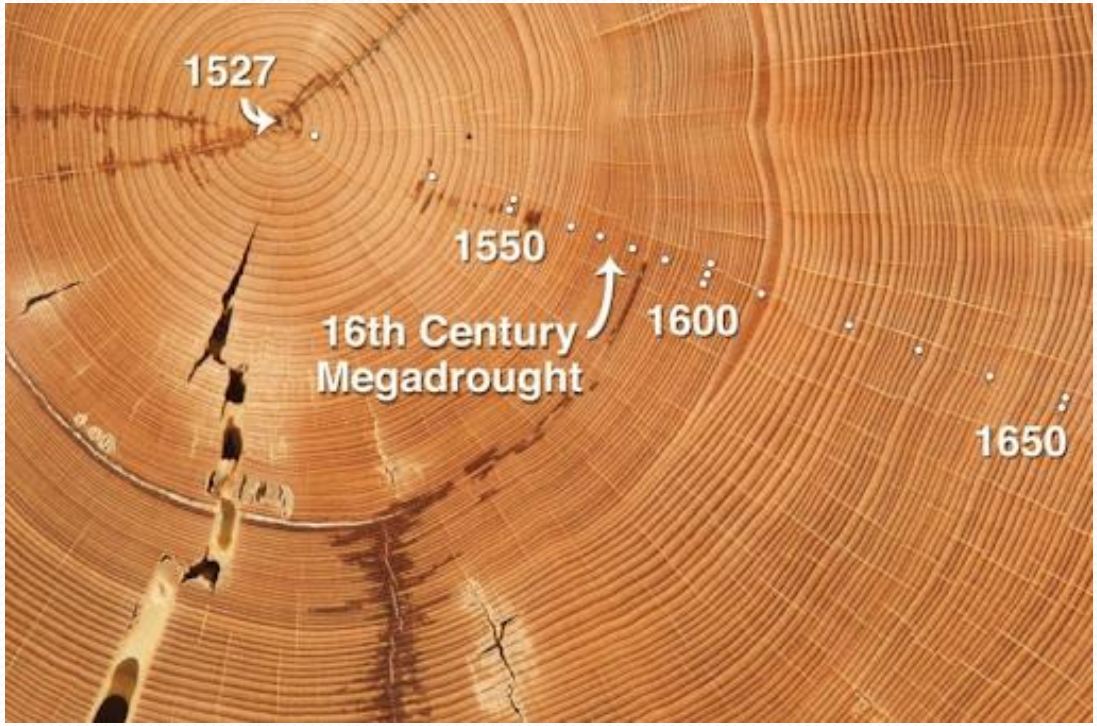
Proxy #3: Tree Rings

- Trees in temperate climates make annual rings as they grow
- Wide bands indicate fast growth under optimal conditions (spring) and narrow bands are poor growing conditions (late summer)



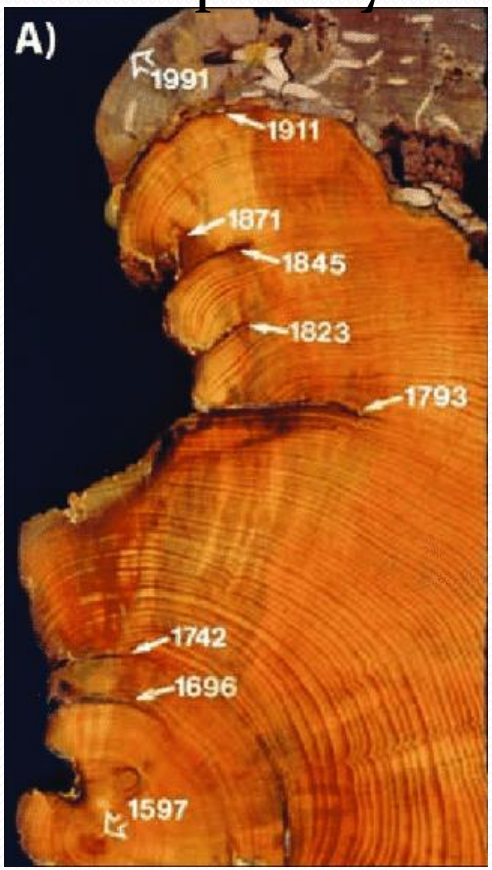
Tree Rings

- If the death date of a tree is known can count backwards on the rings to figure out what year each ring corresponds to
  - Band width is used as proxy for optimal versus poor climate conditions for the tree species being examined



Practical Application

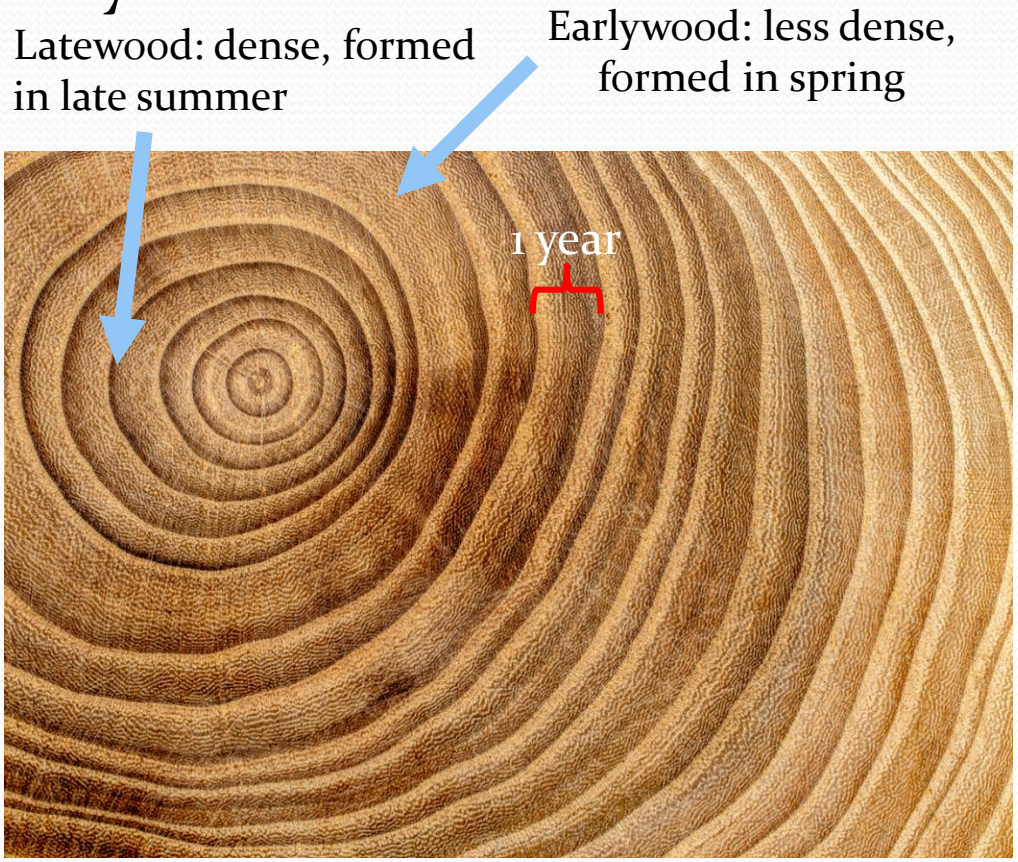
- How will fire risk change with a changing climate?
  - We can calculate frequency of wildfires in the past by dating burn scars



Tree Rings Limitations

- Very high temporal resolution
  - Limited to 5000 years at the absolute maximum, but widespread data for <1000 years BP
- Some confounding factors
  - shading, insect outbreaks, etc.
- Not available for humid tropics
  - Trees rot and are not preserved

Soil respiration rates very high!



Paleoproxy #4: Animal and Plant Morphology

- Some animals and plants have features which are strongly controlled by climate conditions

- If we know how a feature correlates with climate conditions today and we find a fossil with that feature we can use it to estimate the climate at the time the organism was alive
  - Ex. body size

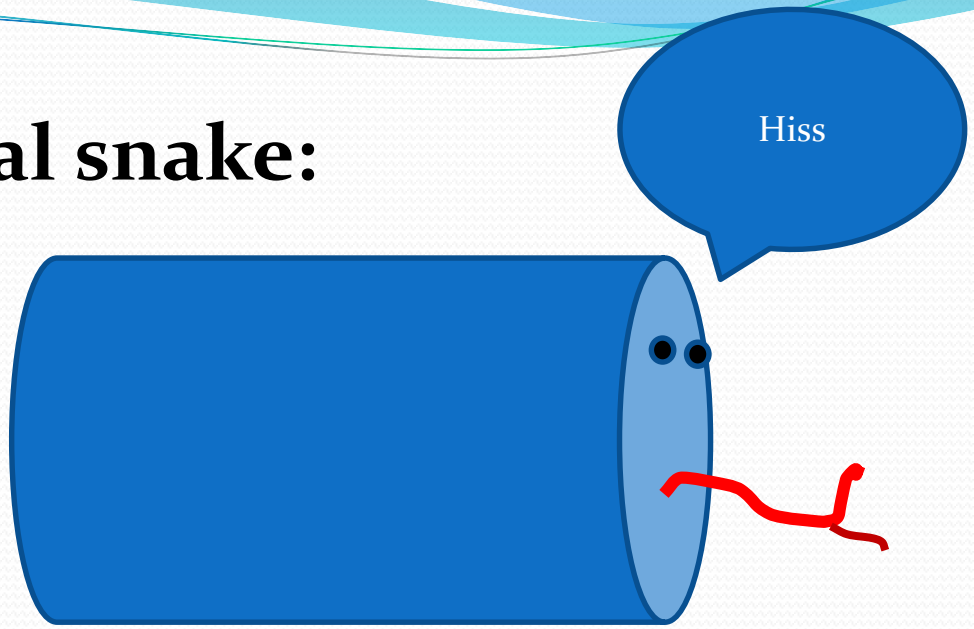
Body Size Limits in Cold-blooded Animals

Eastern Indigo snake, only found in FL, GA, AL

Snakes are *poikilotherms* – a fancy word that means that they use their behavior to maintain their body temperature to a desired range

They maintain their temperature by sunning themselves, absorbing energy from the external environment

Consider a cylindrical snake:

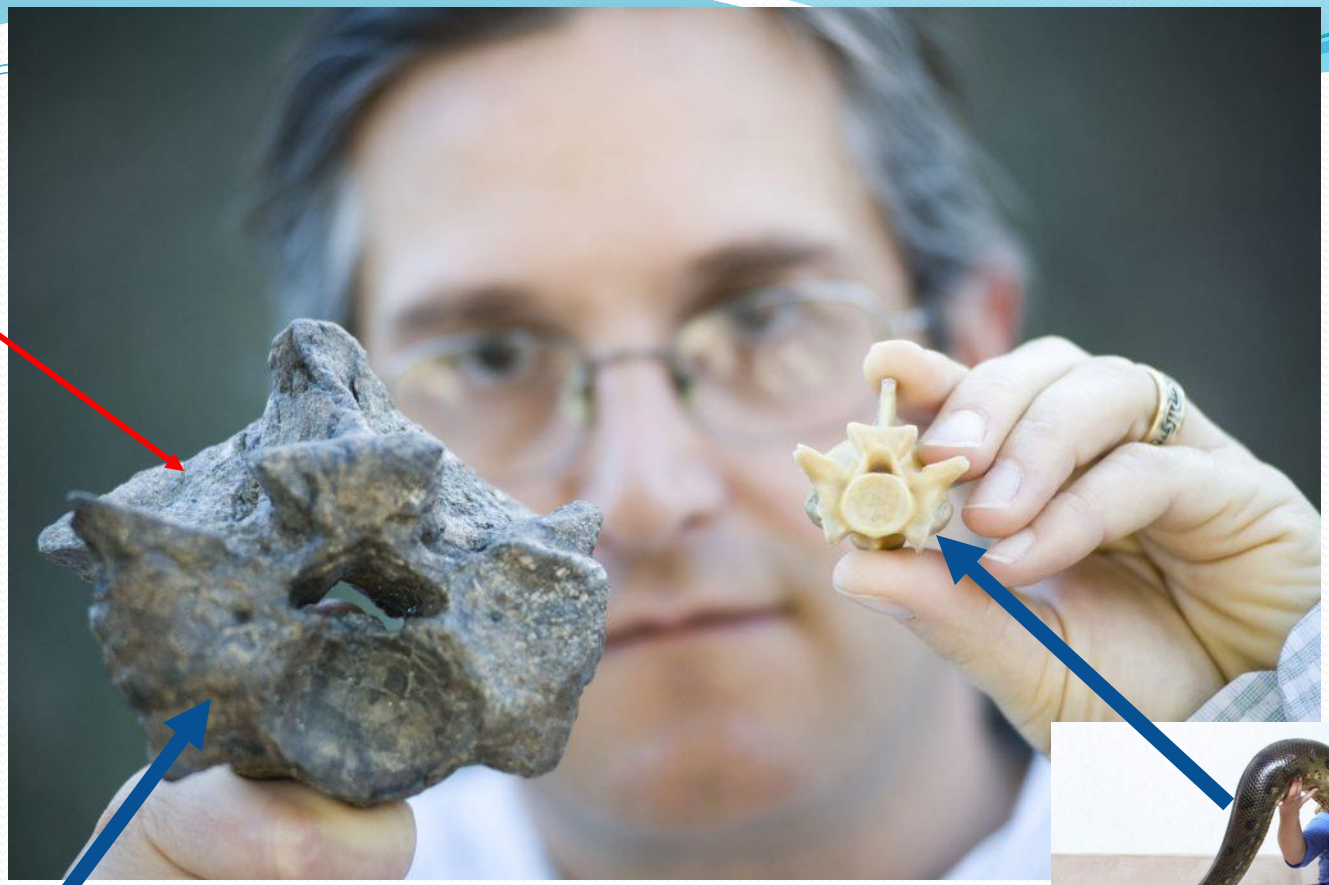


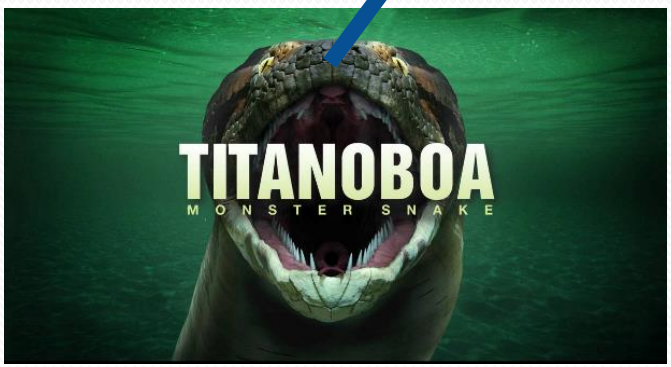
Surface area = amount of heat-receiving surface = $L\pi 2r$

Volume = total amount of snake to heat = $L\pi r^2$

- As snakes get larger, surface area decreases relative to volume
- **Reason**: Surface area is a function of radius but volume is a function of the SQUARE of radius. So larger snakes need a hotter climate to heat their volume.

Vertebra

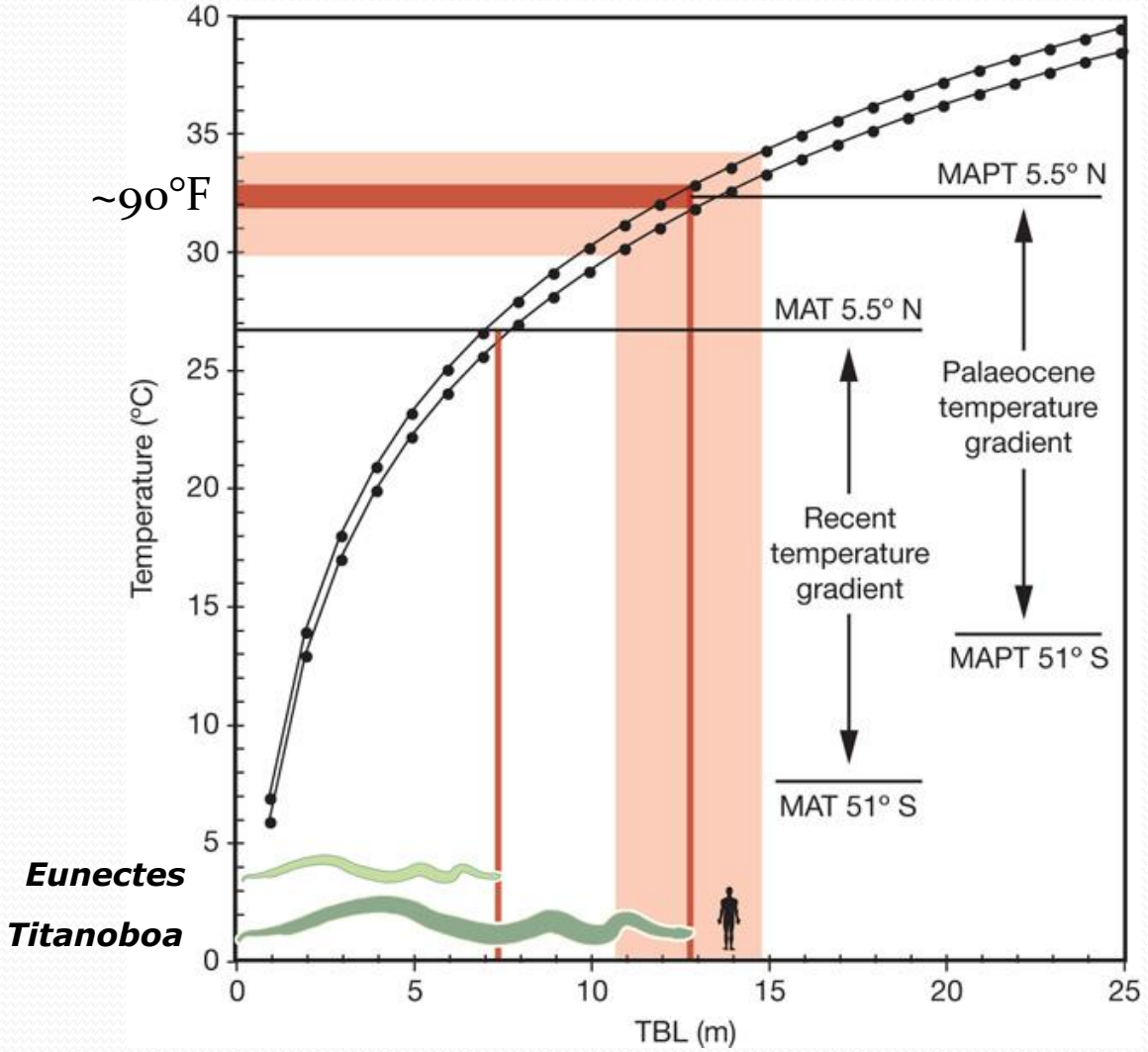




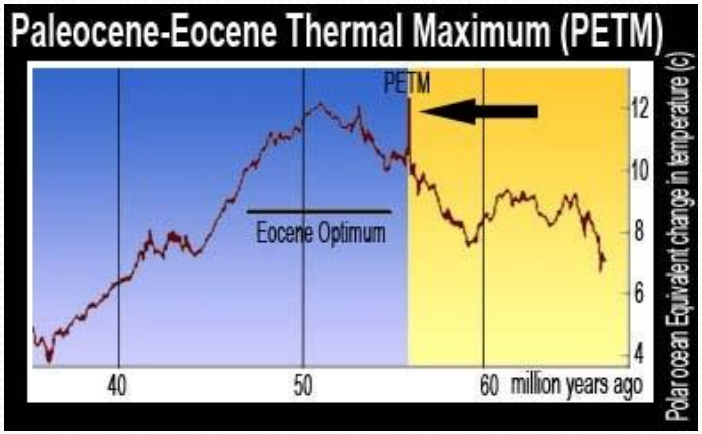
Titanoboa, from 60mya in South America
Estimated body length of 42-45 ft long

Eunectes, green anaconda
Largest extant snake

Estimating Past Temperature Snakes



Since we can measure the size of modern snakes and their local climate's temperature we can build a correlation between the two (chart at left) and then extend the correlation to the size of *Titanoboa* to estimate what temperature it would need to survive (i.e. minimum temperature)

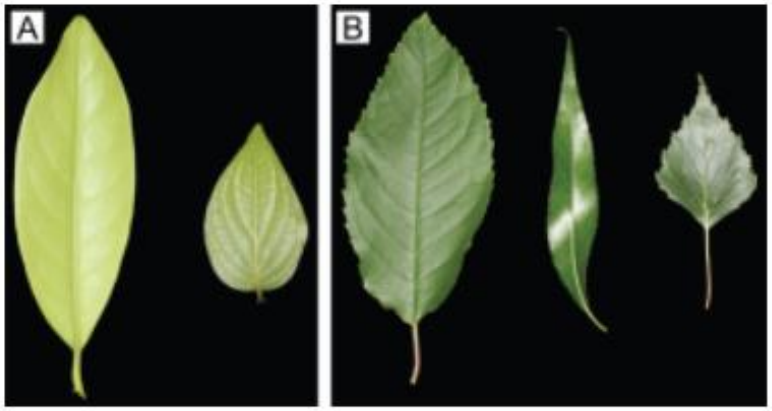


Body Size Limits in Warm-blooded Animals

- In strict endotherms (="warm-blooded") larger animals have to worry about overheating so the largest individuals give a maximum temperature

Plants Are Useful Proxies too!

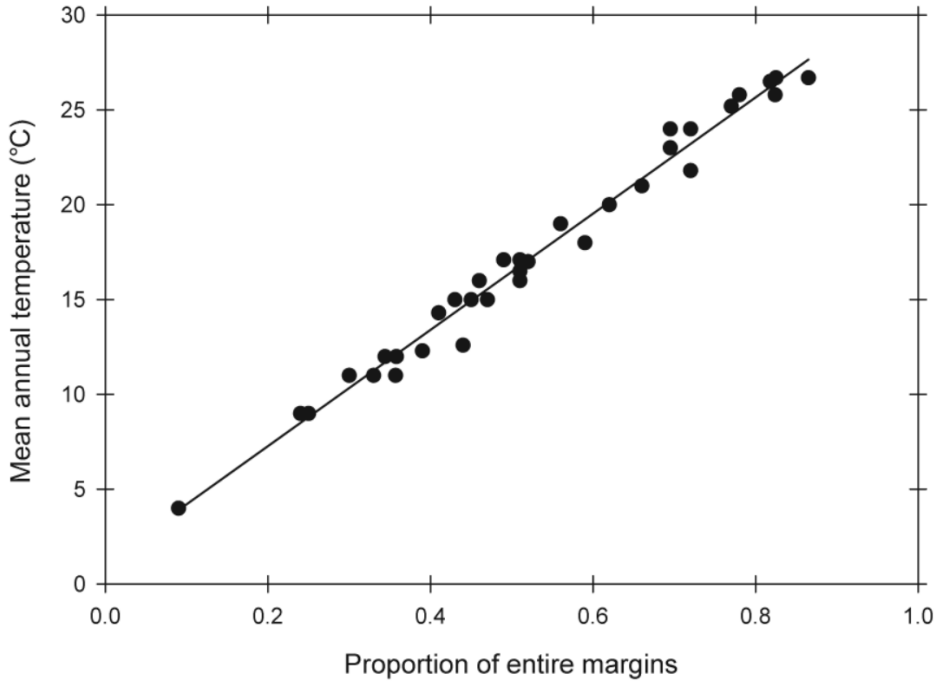
- Serrated leaf margins help a plant kickstart growth and are found more commonly in low-temperature settings (also high moisture)



Smooth edges a.k.a. entire margins

Jagged edges a.k.a. Serrate margins

Can project modern pattern onto fossil leaves



Smooth edged leaves are more prevalent in warmer environments

Animal and Plant Morphology Limitations

- Organisms have been around a long time but…
  - species typically do not last very long and are not found everywhere on Earth
- Relies on a feature being consistently correlated with climate over millions of years
- Most convincing when there is a direct and clear physiological basis for a correlation

Today's Learning Outcomes

1. Be able to explain at least one way that understanding past climate helps our present understanding

2. Provide a definition of "paleoproxy"

3. Be able to explain the principles behind the four paleoproxies presented