Climate Change

Initiation, processes, and effects

Goals

- What is climate change?
- How is it recorded/studied?
- What are the cause and effect relationships brought about by climate change?
- Some examples
- What it all means?

What is it?

- The climate change problem is related to changes in the concentration of the greenhouse gases (water vapor, CO2, CH4, N2O, and CFCs), which trap infrared radiation from the Earth's surface and thus cause the greenhouse effect.
- This effect is a natural phenomenon, which helps maintain a stable temperature and climate on Earth.

What is it cont.

- Human activities, such as fossil fuel combustion, deforestation, and some industrial processes have led to an increase in greenhouse gases concentration.
- Consequently, more infrared radiation has been captured in the atmosphere, which causes changes in the air temperature, precipitation patterns, sea-level rise, and melting of glaciers.

Climate forcing

- The primary factors that influence climate change are;

1. Tectonic processes
2. Earth-orbital changes
3. Changes in the strength of the Sun

Tectonic processes

- Defines the geography of the Earth's surface;
  - Mountain ranges
  - Ocean circulation
  - Atmospheric circulation

Earth-orbital changes

- Variations in the Earth’s orbit around the sun.
- Occurs over tens to hundreds of thousands of years
- Orbital variations change the amount of solar radiation received on Earth by season and by latitude

Milankovitch Cycles

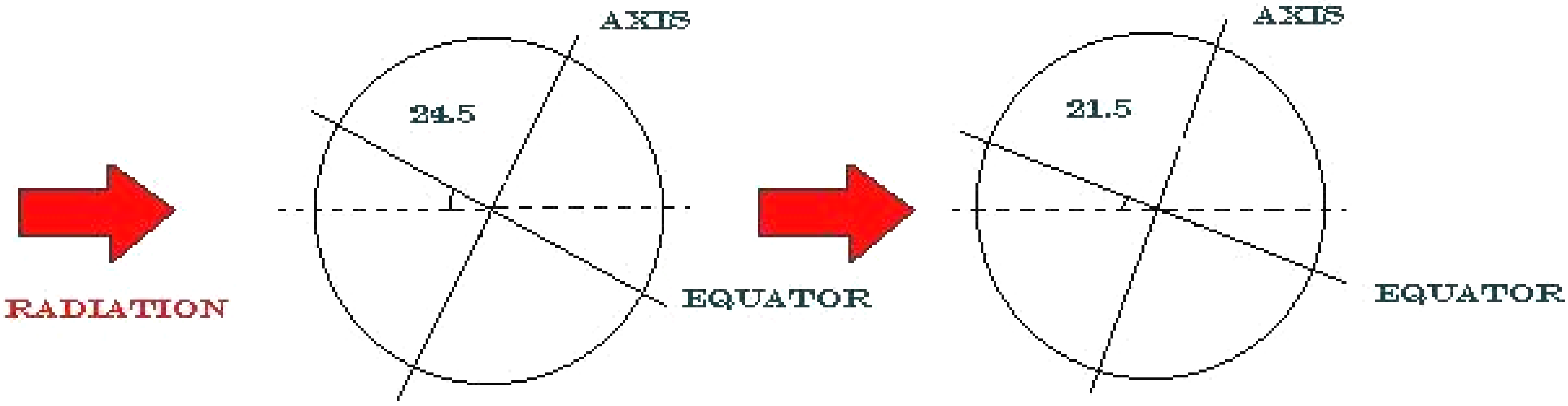
- Serbian mathematician Milutin Milankovitch (1920’s)
- Identified three cycles of different length;

1. Orbital eccentricity 100,000 yrs
2. Axial tilt (or obliquity) 41,000 yrs
3. Precession of the equinoxes 21,000 yrs

Milankovitch cont.

- The eccentricity cycle causes the Earth as a whole to receive different amounts of solar radiation.
- Tilt and precession work to redistribute in the different hemispheres

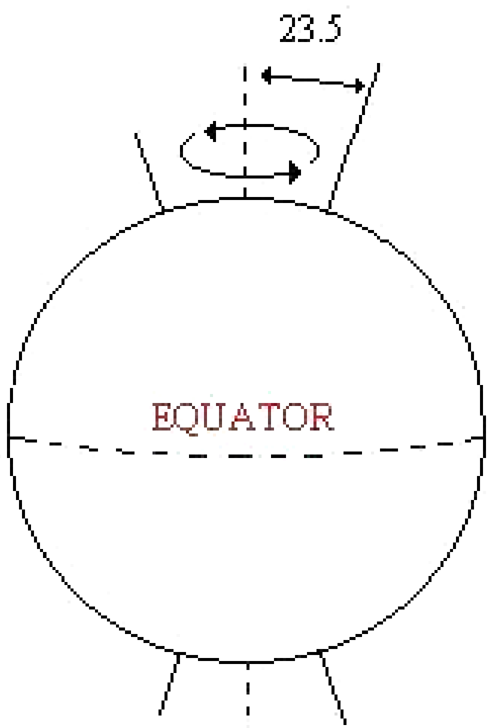
AXIAL TILT



PERIODICITY:

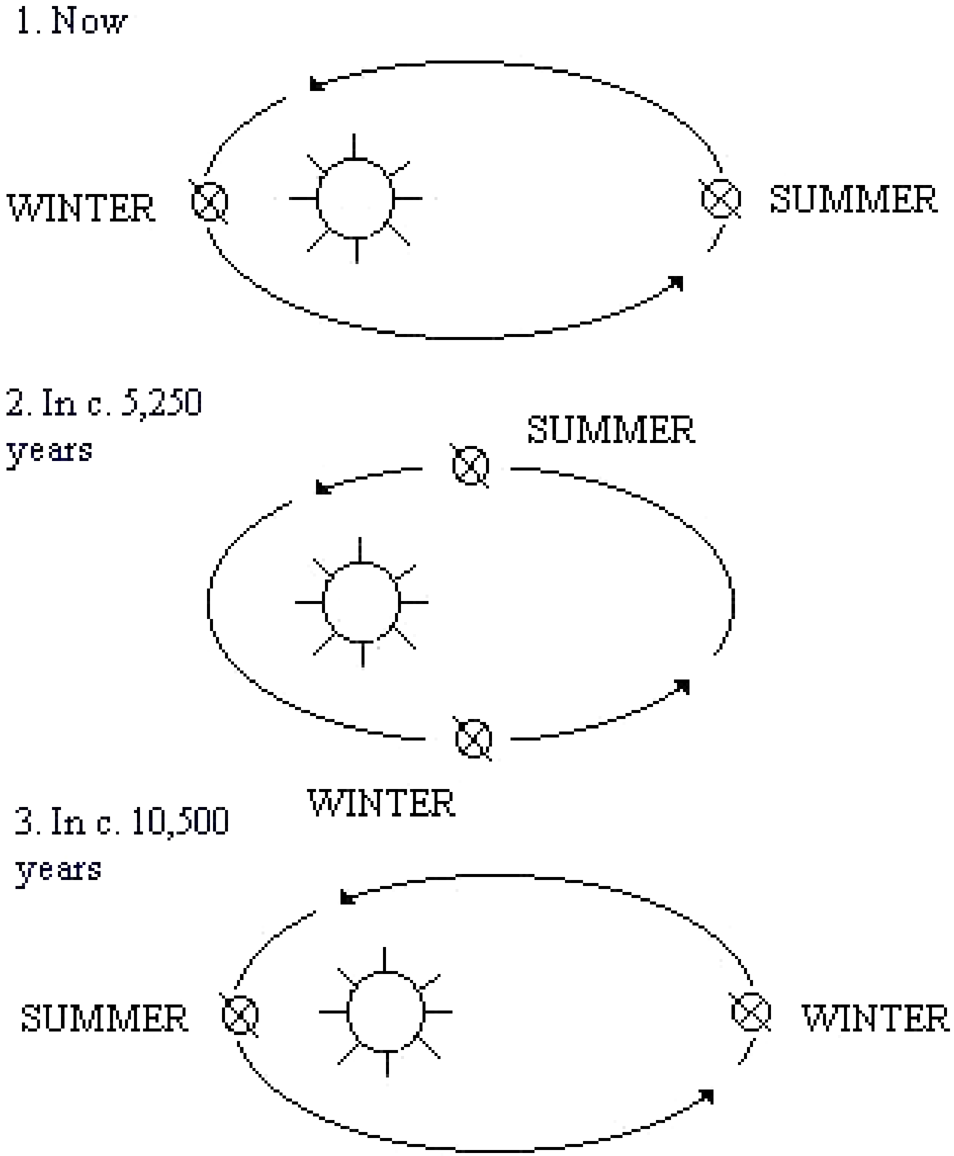
41,000 YEARS

PRECESSION

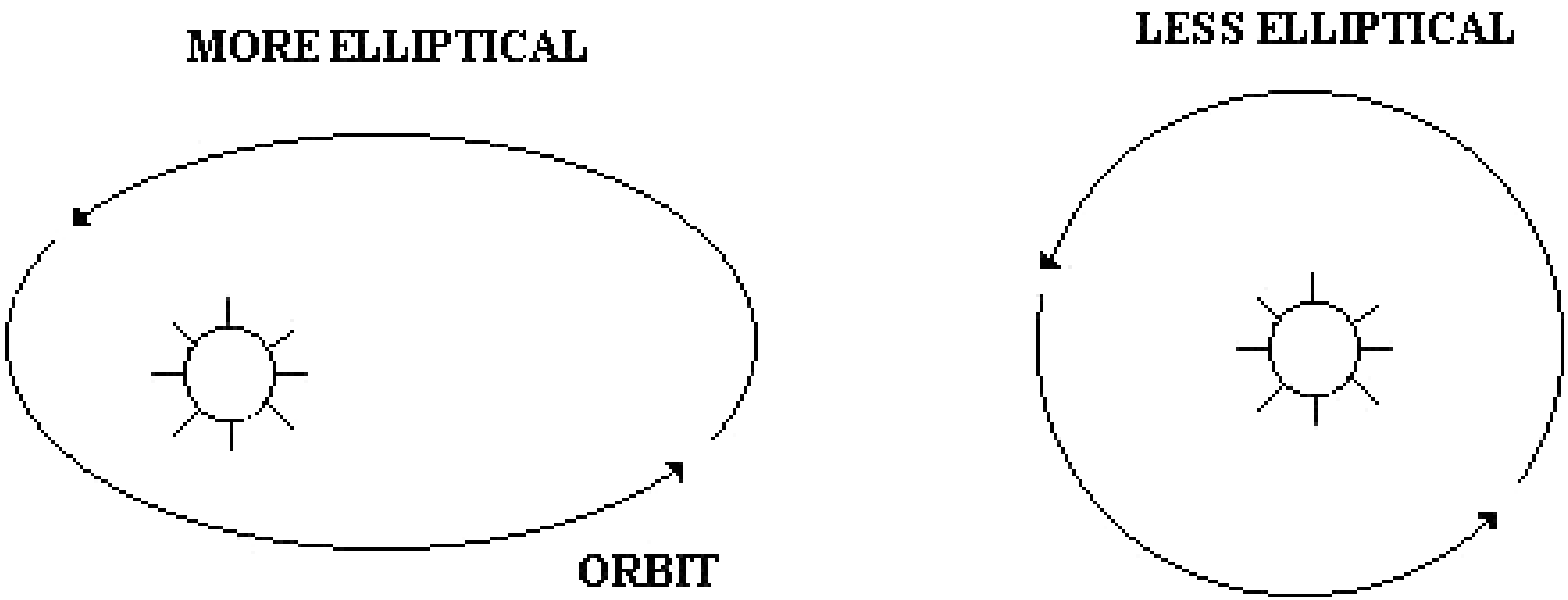


PERIODICITY:

C. 23,000 YEARS



ECCENTRICITY



PERIODICITY:

100,000 YEARS

Milankovitch cont.

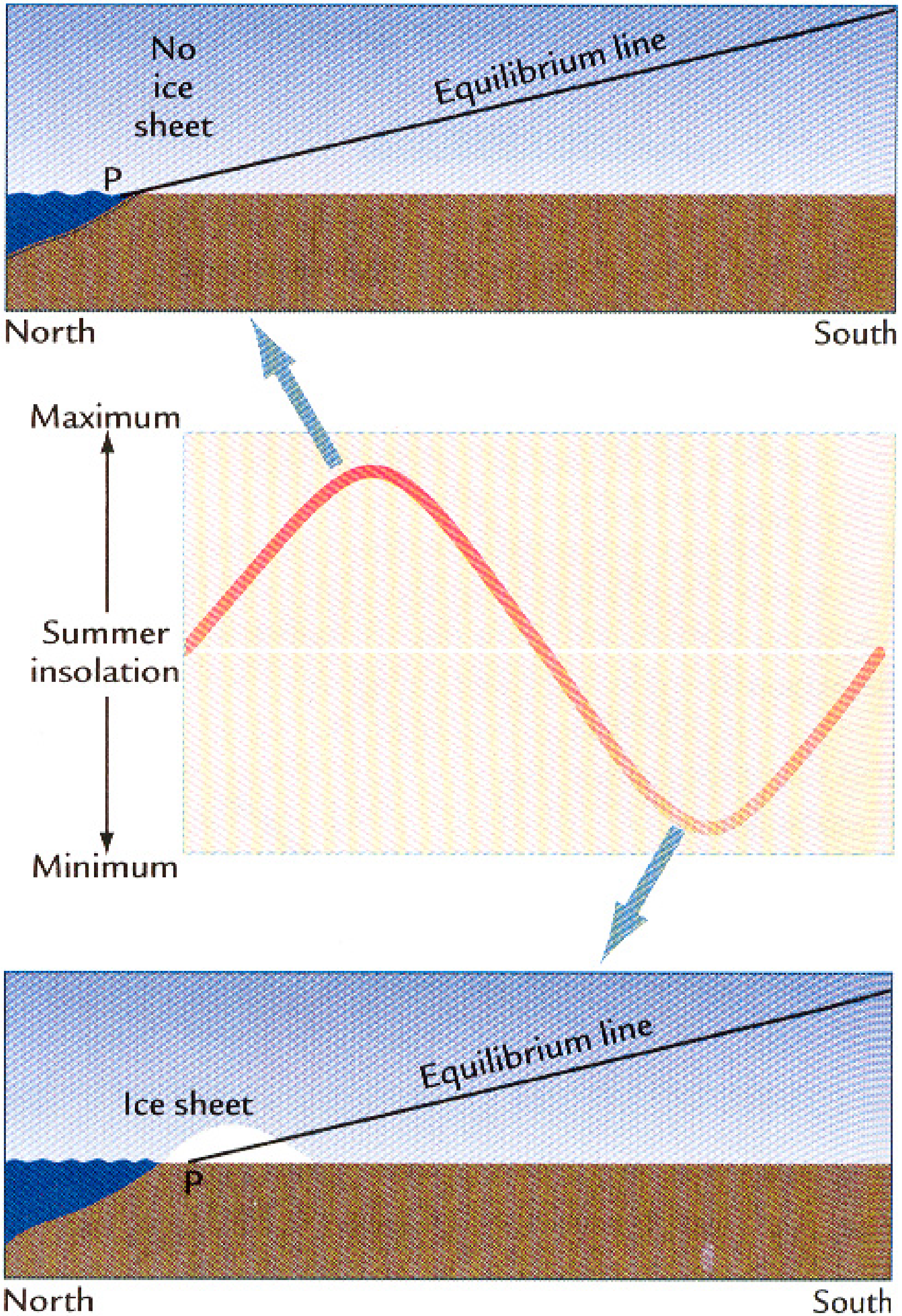
- Based on these principles it would seem, glacial phases would alternate between the Northern and Southern Hemisphere.
- Not so, E.g. the Last glacial maximum (LGM)
- According to this cycle we are in the latter part of an interglacial period, so in 25,000 yrs we may be in back in a glacial phase.

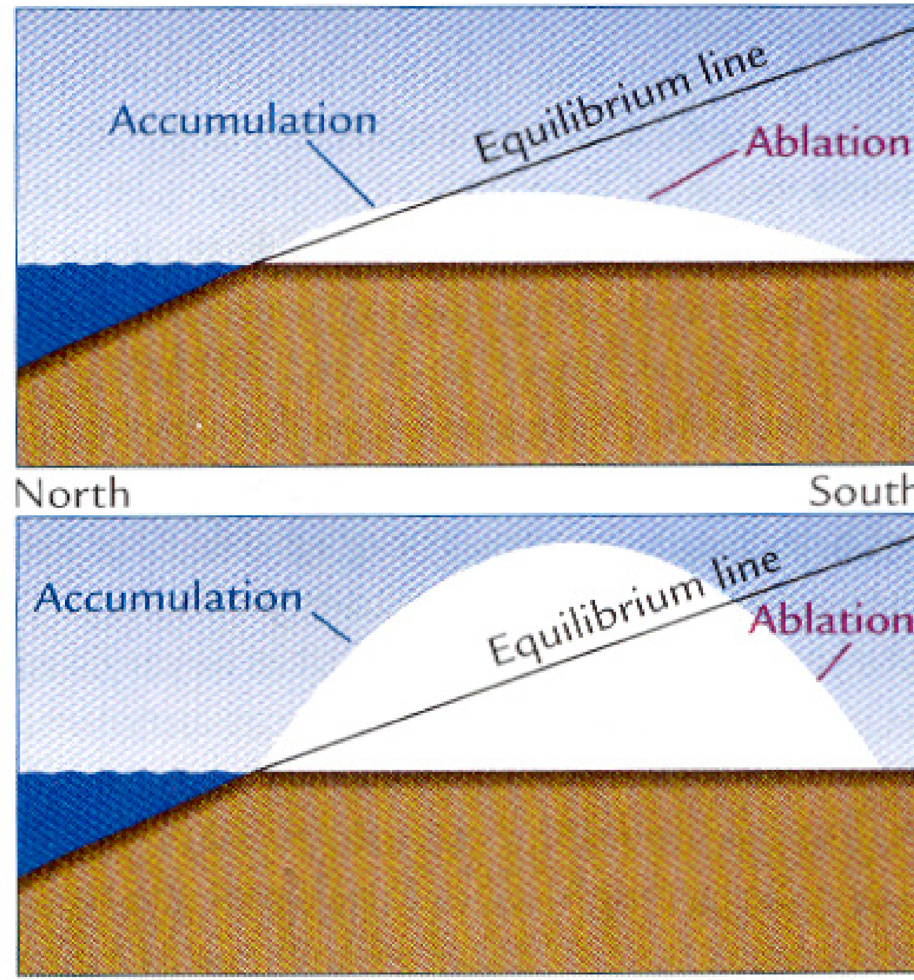
Are Milankovitch cycles the complete answer to the Glacial onset?

- This is Geology, nothing is ever that simple!
- Hayes et al. 1976, Milankovitch cycles ‘Earth’s Pacemaker’
- Contributing feedbacks work to regulate the Earth’s climate
  - – Linkages between ice, ocean, and atmosphere circulation
  - – Albedo

Feedbacks

- Linkages between ice, ocean, and climate (positive feedback)
- Albedo and ocean circulation (negative feedback)
- Greenhouse gas regulation

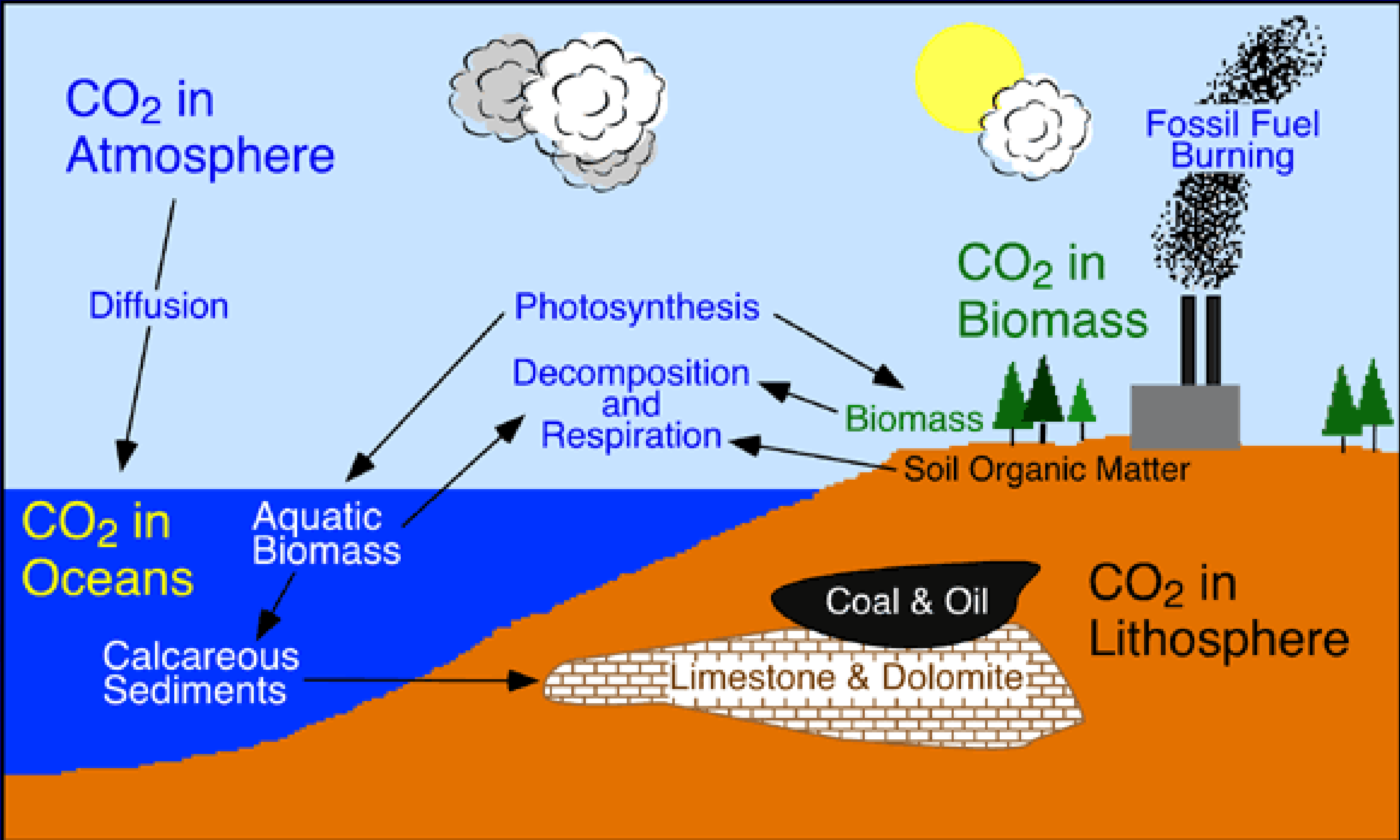

No
ice
sheet
Equilibrium line
P
North
South
Maximum
Summer
insolation
Minimum
Ice sheet
Equilibrium line
P
North
South


Accumulation
Equilibrium line
Ablation
North
South
Accumulation
Equilibrium line
Ablation

The Global Carbon Cycle

- The carbon cycle is a complex series of processes through which carbon atoms rotate between the living world, the atmosphere, oceans and the Earth's crust.
- In the carbon cycle there are various sinks, or stores, of carbon and processes by which the various sinks exchange carbon.

The Carbon Cycle



Carbon species

- Oxidized
  - CO_2, H_2CO_3, HCO_3, CO_3
- Reduced
  - Organic C and Methane CH_4

Reactions

- Abiotic
  - $CO_2 + H_2O = H_2CO_3 = H + HCO_3 = H + CO^{2-}_3$
  - Equilibrium depends on Temperature, Pressure, and Salinity
- Biotic

photosynthesis Increases pH

a. $CO2 + H2O + \text{nutrients} \rightleftharpoons \text{organic matter} + O_2$

Respiration

b. $Ca^{2+} + HCO_3 \longrightarrow CaCO_3$ Decreases pH

Missing carbon sink

- Balance:

Fossil fuel   Deforestation   Atmosphere   Ocean Uptake

$$5 + 2 \neq 3 + 2$$

Missing approximately 2 units of carbon,

Lets look for them!

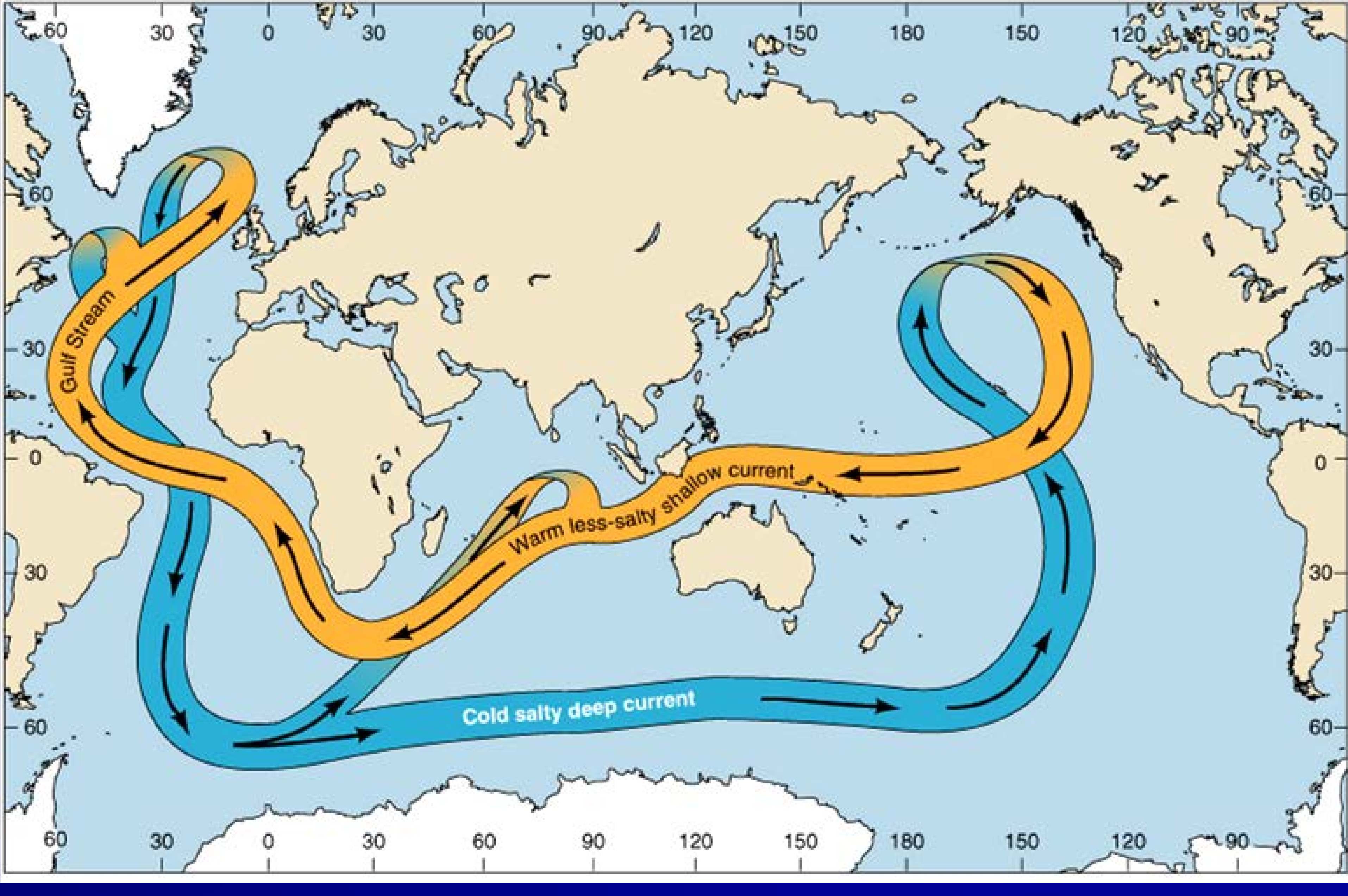
The Physical Realm

- C dissolved in water
  1. Pressure: High P stores the most carbon;
  2. Temperature: Low T, stores most carbon
  3. Salinaty: Low Na stores most carbon

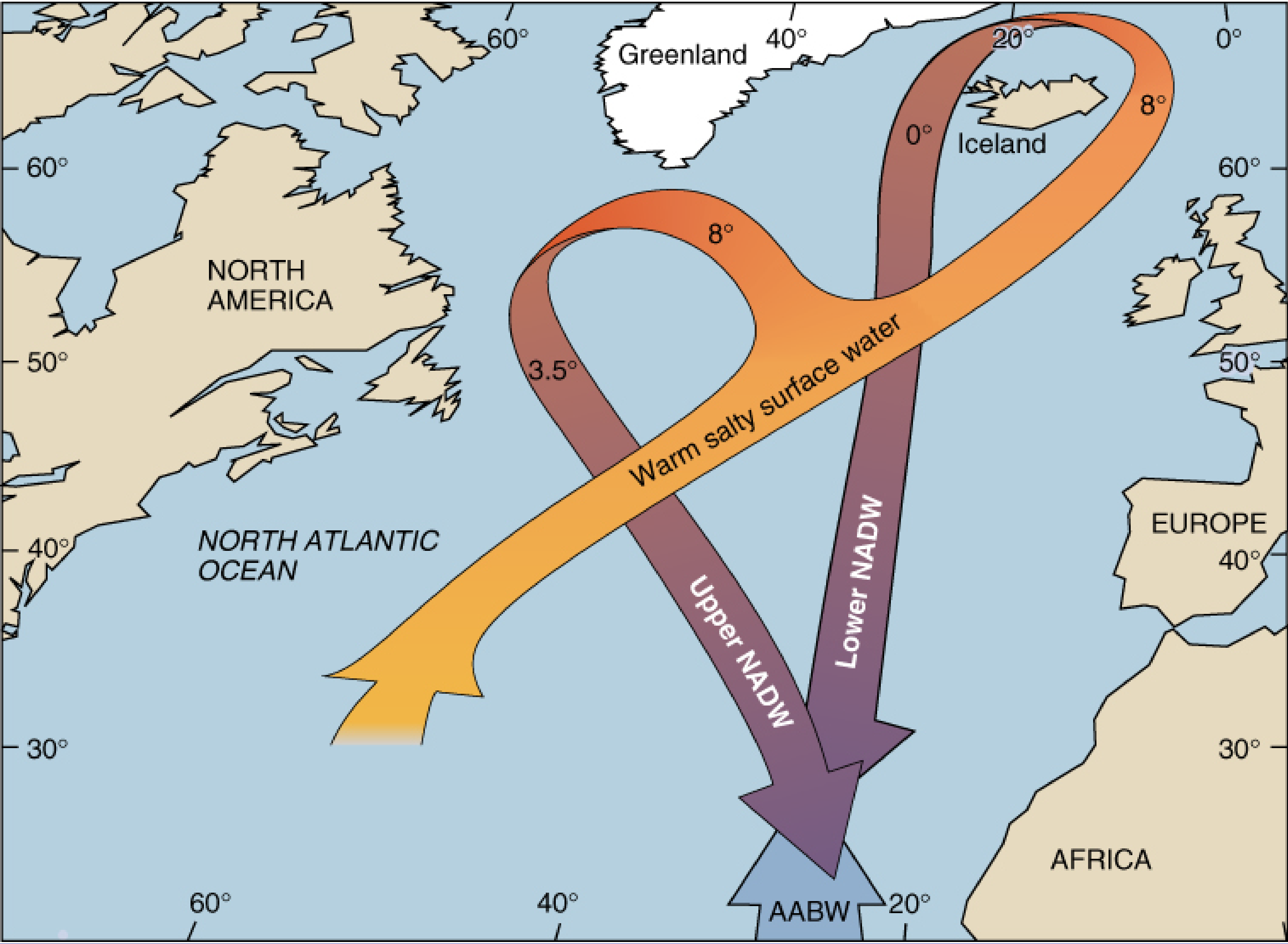
- Ocean
  1. High pressure, deep basins, is the largest reservoir for carbon
  2. Cold regions, polar areas, a great place to store carbon

CO_2 Regulation

- CO_2 enters cold deep ocean via High latitude pressure sinks.
- But it will only come back out again as the cold water mixes back to the surface to warm.
- Or will it?
- The atmosphere contains only ½ of the CO_2 released so far.



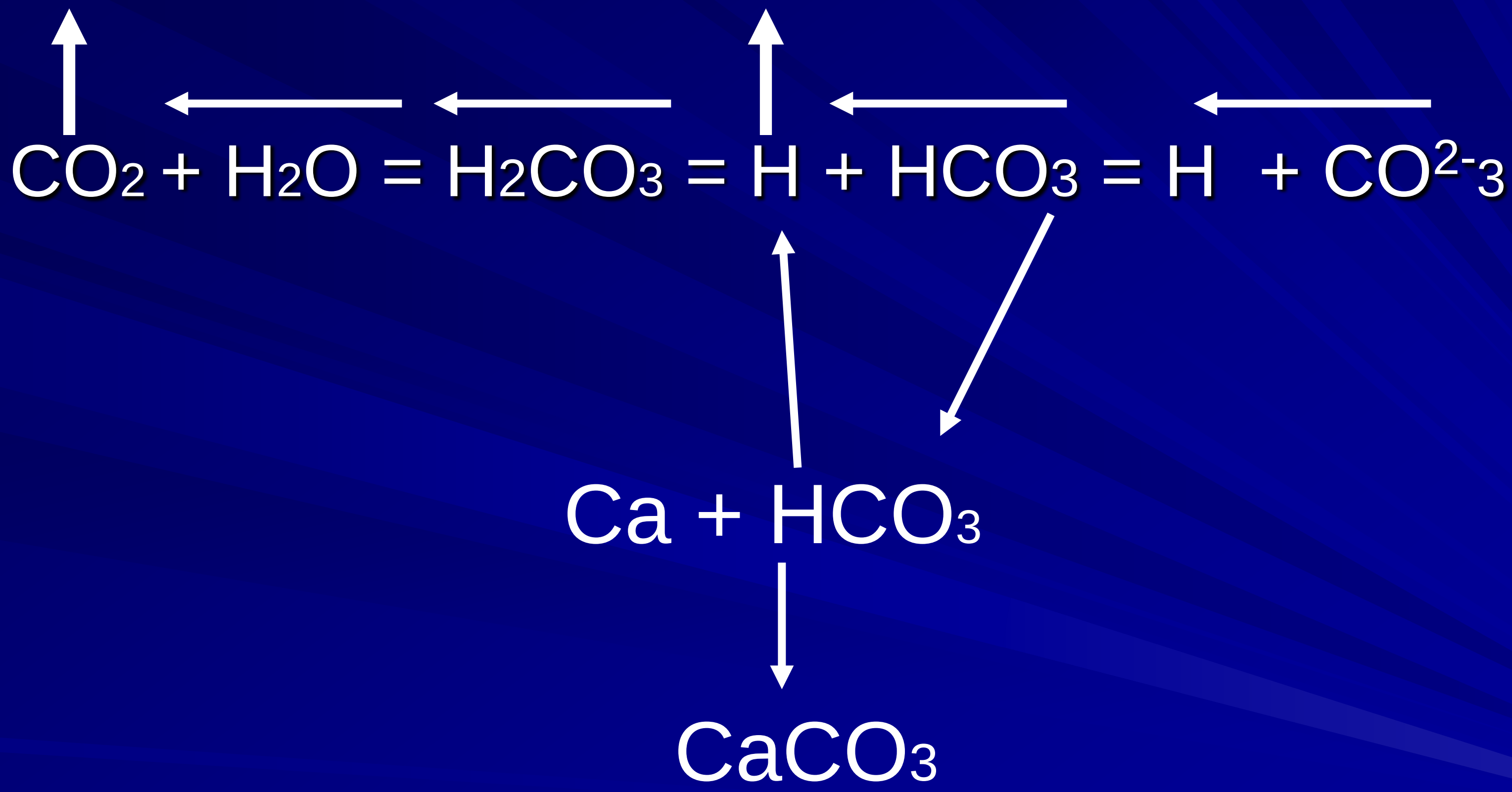
60
30
0
30
60
90
120
150
180
150
120
90
Gulf Stream
Warm less-salty shallow current
Cold salty deep current



Greenland
Iceland
NORTH AMERICA
NORTH ATLANTIC OCEAN
EUROPE
AFRICA
Warm salty surface water
Upper NADW
Lower NADW
AABW
8°
0°
3.5°
8°
60°
40°
20°
0°
60°
50°
40°
30°
60°
50°
40°
30°
60°
40°
20°

Carbonate reactions

End result
release of CO_2



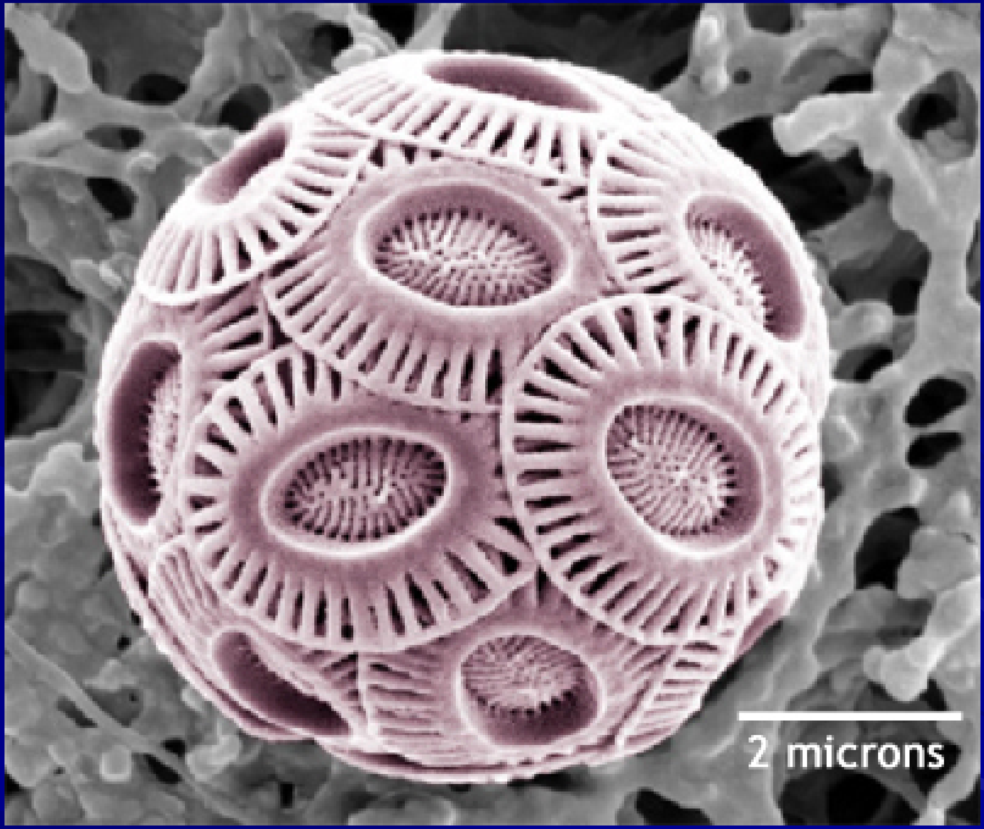
Equilibrium reactions drive CO_3 to the left

The Biological Realm

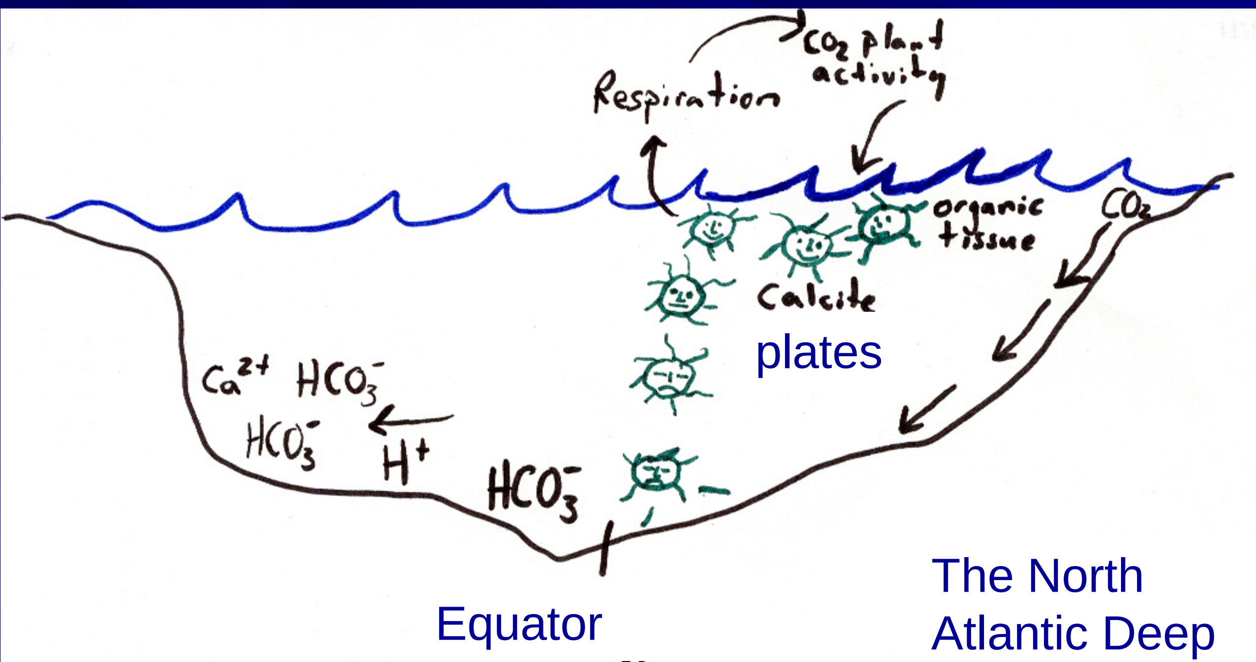
- Ocean
- Terrestrial landscape

The Ocean

- **Coccolithophore**, single-celled plants that use carbon to produce calcite body plates.



Placing Carbon deep in the ocean. (an E.g.)



1. Coccolithophore accumulate on the sea floor;

2. The body plate decay under a weak acid

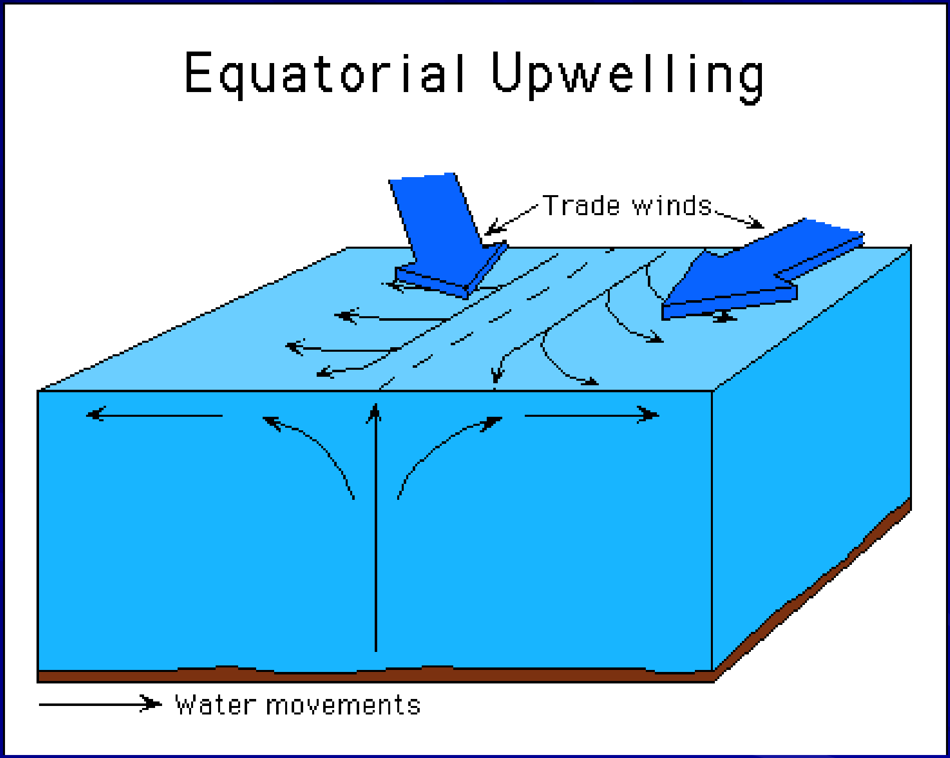
$H + CaCO_3 = HCO_3 + H^+$

3. As oxidation occurs carbon dioxide will be released

This process increase the concentration of HCO_3 in the deep ocean.

How does Carbon get back to the surface?

- At the Equator, ocean circulation and the correolis effect pulls the surface current apart, creating an upwelling process that brings water from the deep ocean up.



Upwelling

- The upwelling cold water will warm with increased solar radiation causing a degassing of the water, releasing CO_2 in to the atmosphere again.

Carbon cycle and the Earth’s Oceans

- What will likely happen if global warming, heats up the poles like we think it will?

The probable chain of events.

- What we know, basic ocean circulation (water) looses heat at high latitudes producing deep ocean currents that suck CO_2 from the atmosphere and create HCO_3 accumulation.
- The deep ocean stores approximately 90 percent of the Global Carbon.

- If polar water continues to warm its density gradients will lessen;
- This will decrease deep ocean current velocities and slow the whole ocean/atmosphere system down;
- Thus, less CO_2 will go into the oceans, less will be stored, and less will exit near the equator.

Key consequences

- The oceans will cease to be a factor in CO_2 regulation (No more CO_2 sponge)

1. The deep oceans will remain cold but will be isolated from the main stream circulation;
2. Eventually the deep oceans will warm as temps increase and will vertically mix with the warmer surface water releasing a lot of CO_2 in to the atmosphere;
3. Creating a positive feedback of increasing atmospheric temperatures. (This is BAD!)

More GeoChemical Cycles!

- If this were a climate change course we would go much more in depth of not only the carbon cycle but the Phosphorous and Nitrogen cycles as well.

Records of past climate change

- Ice cores
- Lake cores
- Deep sea cores
- Pollen and plant macrofossils
- Speleothems
- Paleosols
- Geoarchaeology

Vocabulary idea

- Climate archives contain many indicators of past climate referred to as climate <u>proxies</u> (meaning “substitute”).

1st a Crash/Refresher course on Isotopic Geochemistry

- O^{18}/O^{16} 18-Heavy/few : 16-light/abundent
- Geological thermometer
- Measured from
  - – planktonic foraminifera
  - – speleothems
  - – ice
  - – snail shells
  - – coral
  - – sediment

Foraminifera

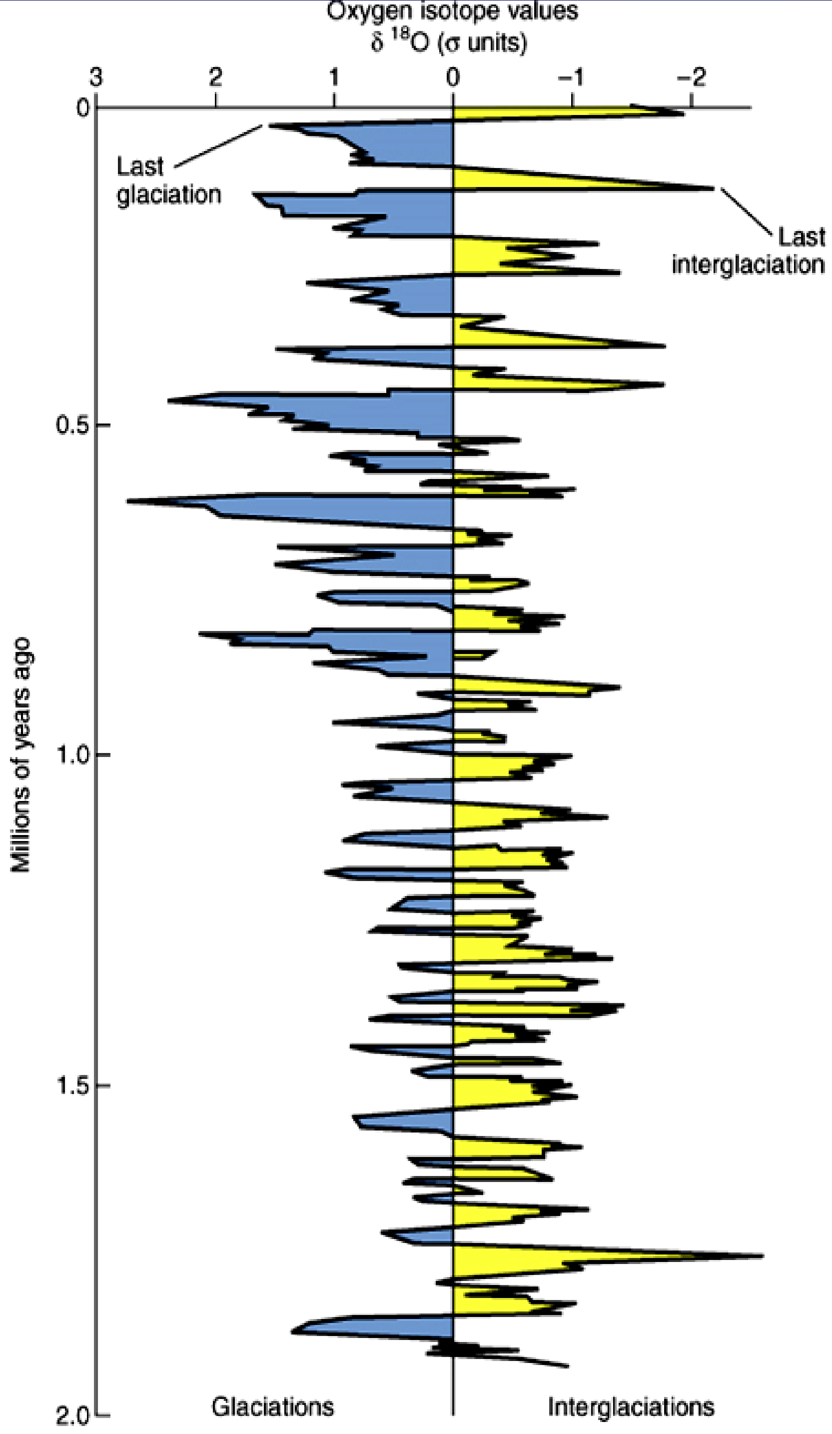
The Oxygen isotope record

- The O^{18}/O^{16} or $\partial^{18}O$ ratio varies with temperature.
- Used to classify the Quaternary ice ages into episodes of warmer and colder climate or the growth and decay of ice sheets.

What happens

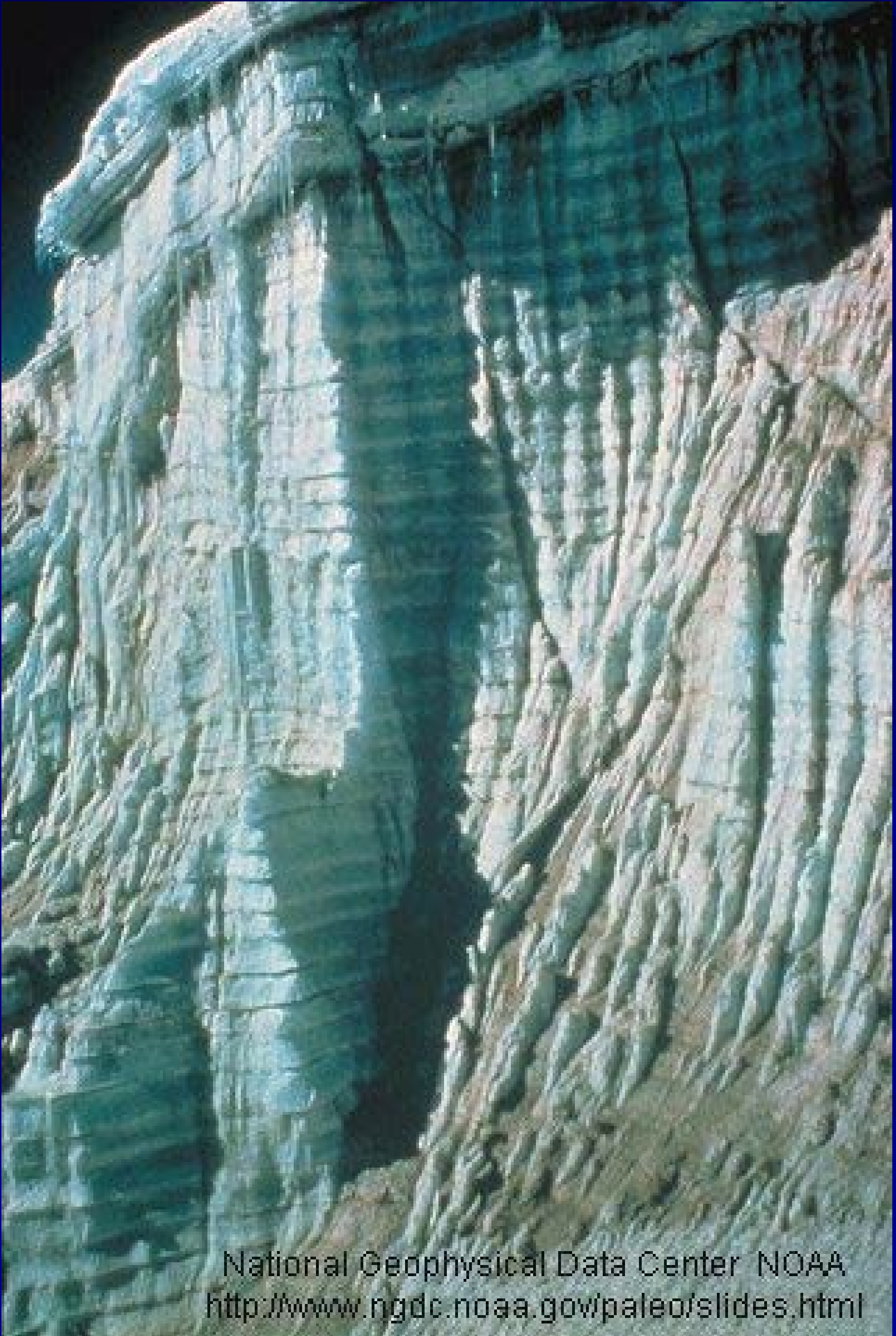
1. Growing glaciers and ice sheets lock up ‘light’ (O^{16}) water in the form of ice.
2. This leaves the ‘heavier’ (O^{18}) concentrated in the ocean.
3. So during ‘cold’ periods of ice growth the worlds oceans are depleted in O^{16} and enriched in O^{18} .

$\partial^{18}O$ curve

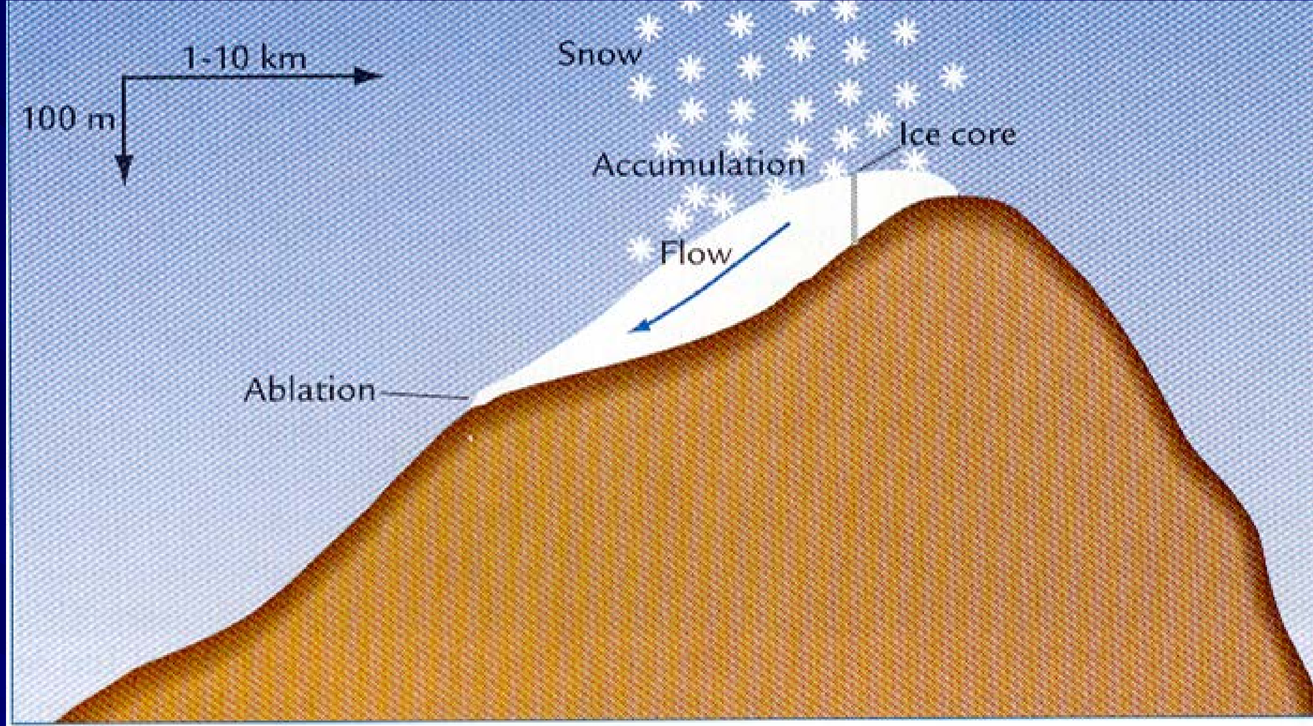


Ice cores

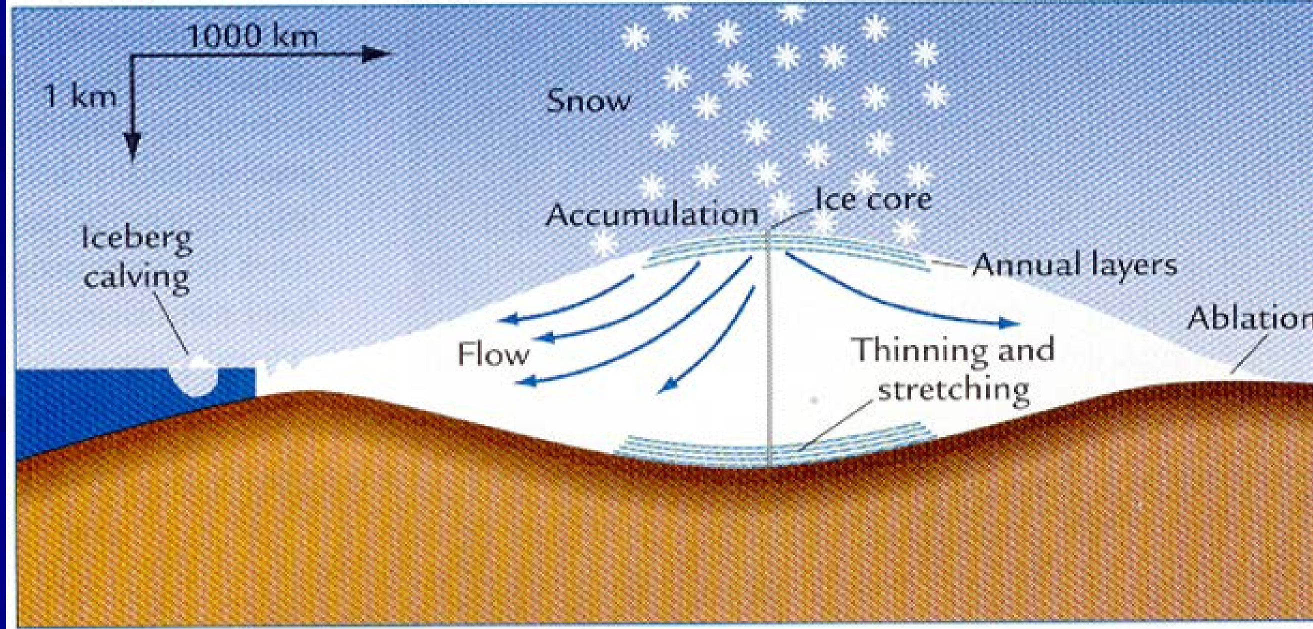
- Location
  - Polar
  - High-mountain regions
- Longest record, Russian Antarctic core site (Vostok) extends back through several full glacial-interglacial cycles.
- Key benefit, as snow accumulates and is compressed into ice it traps air (paleo) that can be analyzed for methane CH_4 and carbon dioxide CO_2 levels (greenhouse gas)



1. Annual snow accumulation layers
2. Thick at the surface, compressed and thin with depth
3. Provide a ready made time scale to investigate climate change



A Mountain glaciers



B Continental ice sheets

Sedimentary assemblages

- Sedimentary assemblages are the major climatic archive for 99% of geologic time.
  - Lake sediment
  - Interior sea sediment
  - Coastal margin sediment
  - Deep ocean sediment

Sedimentary assemblages

- A complete stratigraphic record may contain climatic records dating back millions of years (170 m.y. max)
- Uninterrupted stratigraphic records are relatively rare
  - – Erosion, (wave, wind, etc.)
    - High vs. low energy environments
  - – Tectonic activity
  - – Sea level changes

Sedimentary assemblages

- Low energy environments that receive cyclical to uniform sedimentation are excellent sources of paleoclimatic data.
- The Deep Sea
  - Ocean Drilling Project (ODP)
- Large Lakes
  - Lake Tanganyika; Lake Bosumtwi Africa
  - Lago di Monticchio, southern Italy
- Loess
  - Nebraska, Iowa, Illinois
  - China

Biotic data

- Vertebrate/invertebrate fossils
  - – Beetles, NDSU Allen Ashworth
- Plant fossils
  - – Pollen
  - – macrofossils

Pollen

- Produce by vegetation
- Distributed by wind
- Deposited with sediment
- Influence most by
  - Climate
  - Human activity

Pollen

- Well preserved in oxygen poor lakes
- Vegetative types are indicative of particular climates.
  - For example, warmer climates during the Cretaceous are partially inferred from the presence of palm-like trees at high northern latitudes
  - Reconstructing past vegetative cover

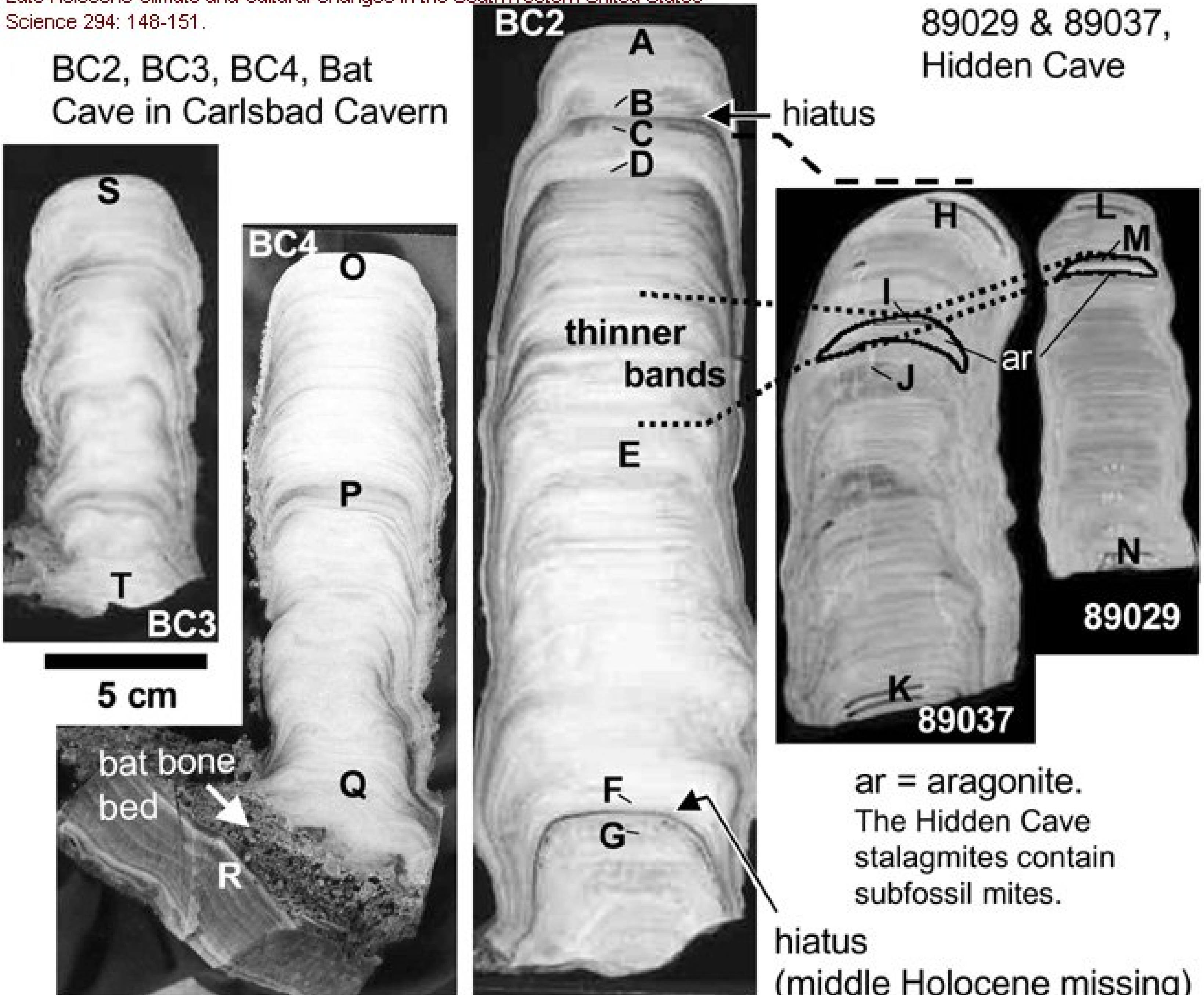
Plant Macrofossils

- The larger remains of vegetation that are not likely to be transported far from their point of origin
  - Cones
  - Seeds
  - leaves

Speleothems

- Stalactites and Stalagmites, in Karst terrains
- Contain geochemical evidence of past climates

Polyak, Asmerom 2001.
Late Holocene Climate and Cultural Changes in the Southwestern United States
Science 294: 148-151.



Paleosols

Paleosols

- Known facts
- Soils,
  - require a stable landscape
  - form under specific environmental conditions
- Humans tend to live on stable landscapes.

- Therefore, by investigating recent (the past 2.2 million years) soil developments
  - It is possible to discover what it was like (climate) to live in a particular place at a particular time.
- Paleosols contribute to, Paleoenvironmental Reconstructions

Geoarchaeology

Includes the study of sediment that is associated with a human context.

Differentiating human vs. climate based changes is a challenging endeavor.