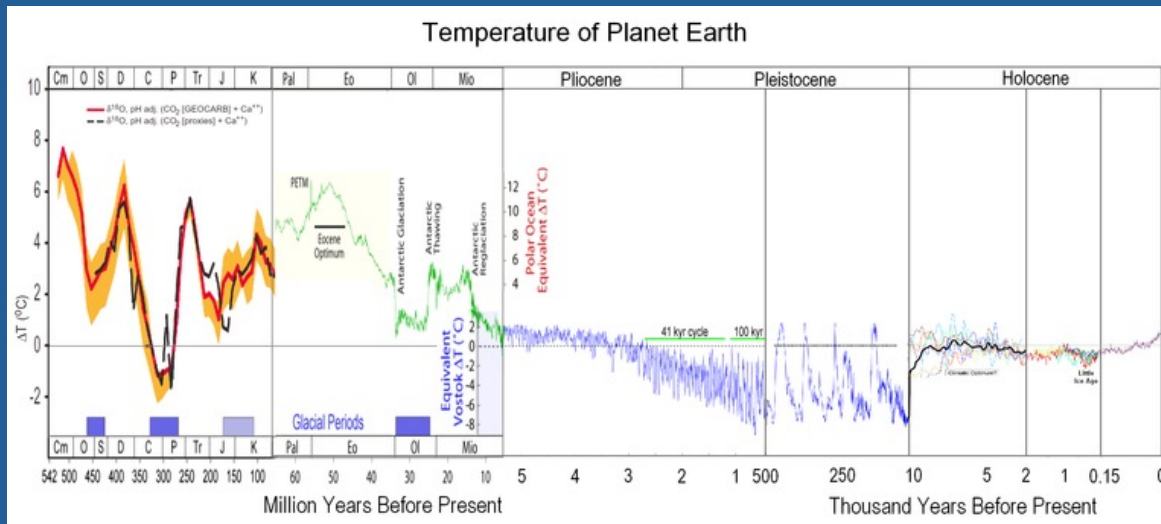


Climate Change

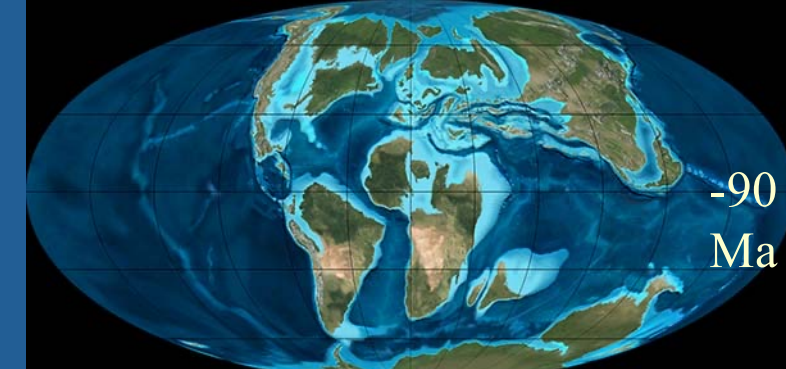
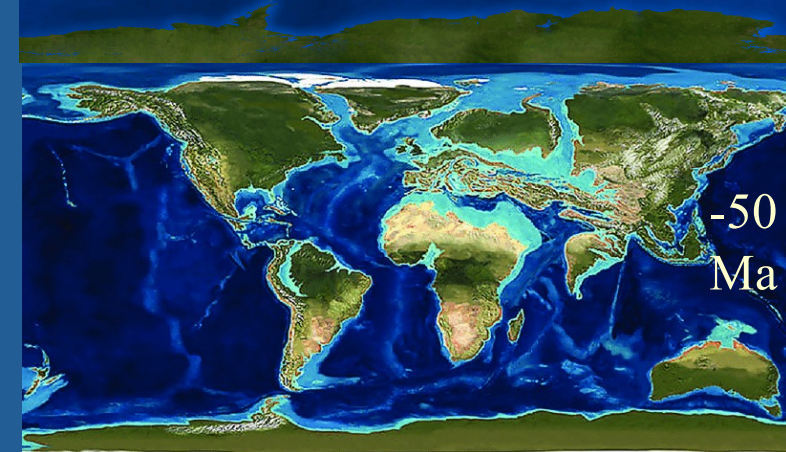
What can geology teach us about climate change past, present, & future?

Lecture 1: Climate Records



Presented by Nicole Myers

www.appreciatingearth.com/OLLI



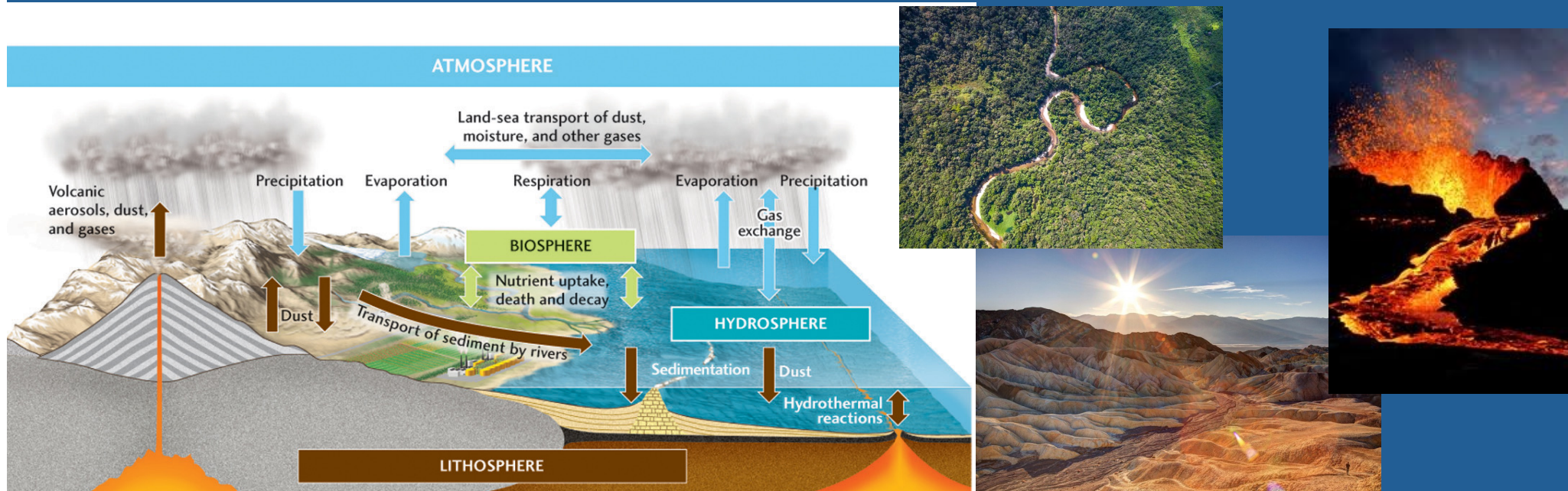
Climatology = Earth Systems Science

• Climate

- **long-term** (~30 years) characteristic atmospheric conditions of a given region
- derived from “Klima” (Greek) for slope = observed **temperature** patterns relative to latitude & elevation

• Environment

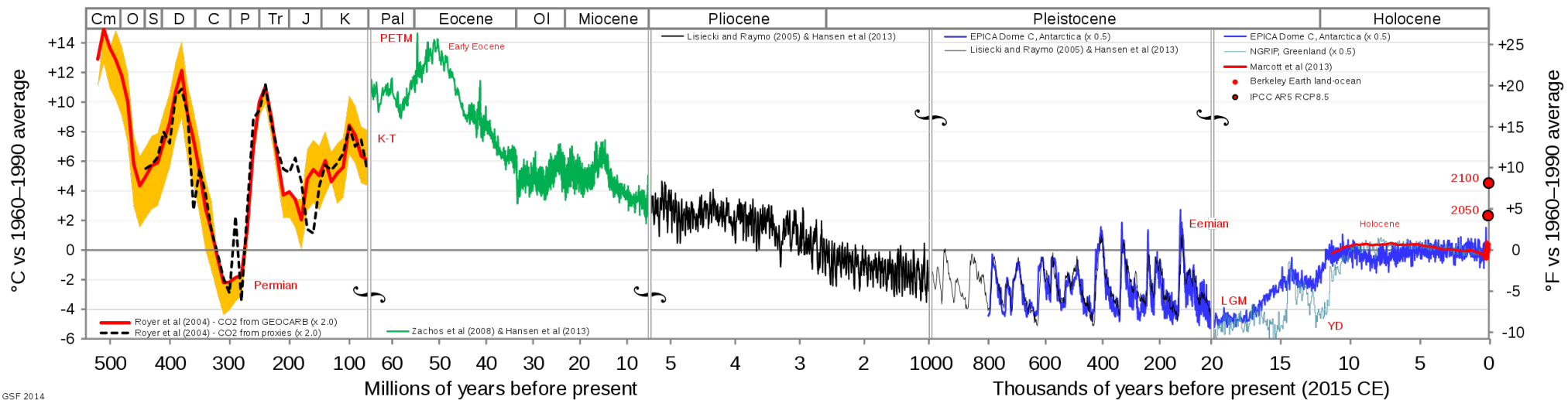
- combination of physical, chemical & biotic factors that act upon the ecosystem



Climate Change: Time & Temperature

- Global climate change is constantly occurring (rate of change fluctuates) = long-term shifts in **temperature** & weather patterns
 - **Change**: to undergo a modification of (verb)
 - **Dynamic**: a process characterized by constant change
 - **Equilibrium**: a state of adjustment between opposing or divergent influences or elements

Temperature of Planet Earth

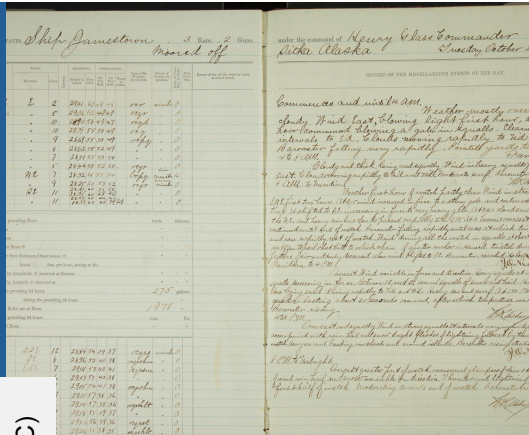


Climate Records

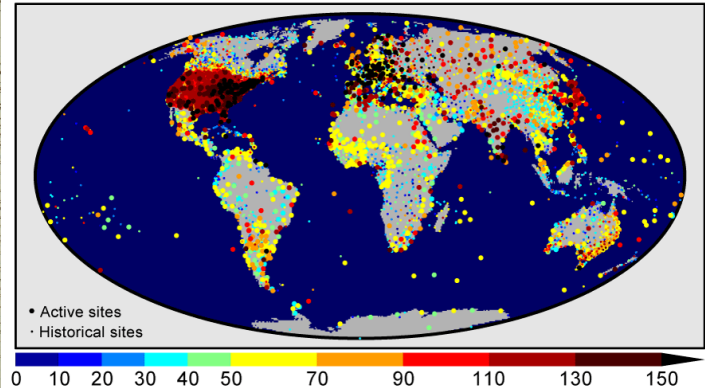
Instrumental Records

Historical Records

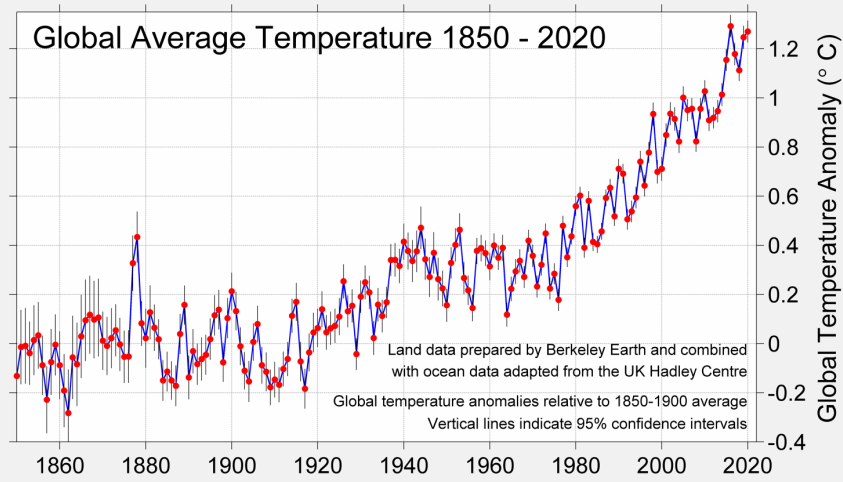
Paleo-Proxy Records



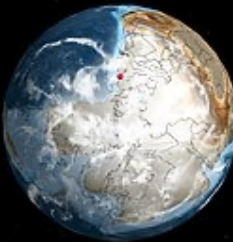
Global Climate Network Temperature Stations



Global Average Temperature 1850 - 2020



600 million years ago



500 million years ago



400 million years ago



300 million years ago



200 million years ago



100 million years ago



50 million years ago



20 million years ago

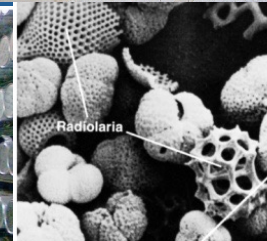


© dinosaurpictures

Paleo-Proxy Records & Paleoclimatology

Paleo-Proxy Record = Ancient Estimate Evidence

- Sediments = sedimentology & stratigraphy (marine, aquatic & terrestrial)
- Volcanic ash layers
- Radiometric dating
- **Paleothermometers** & isotope ratios
- Organic flora (plants: fossils + preserved + living)
- Organic fauna (animals: fossils + preserved + living)
- Palynology = pollen records
- Dendrology (tree rings) & fire history
- Soils & paleosols
- Boreholes
- Remnant landforms
- Caves & speleothems
- Ice Cores
- Geochronology: paleotectonics & paleogeography
- Paleomagnetism
- Paleoclimatology Modeling & Multi-Proxy Studies



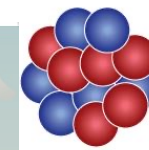
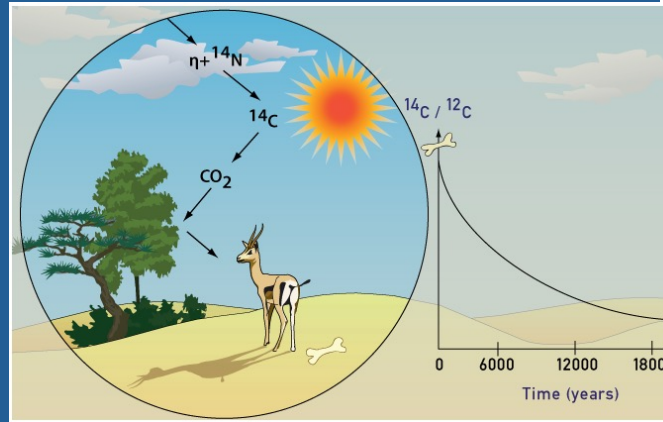
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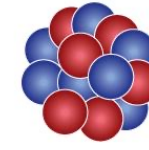
Measuring Time With Radiometric Dating

Atoms with unstable nucleus (radionuclides) undergo radioactive decay & ratio of parent atoms to daughter atom is a function of **time/age**

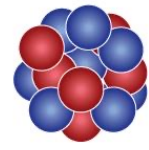
- Rocks
- Organisms



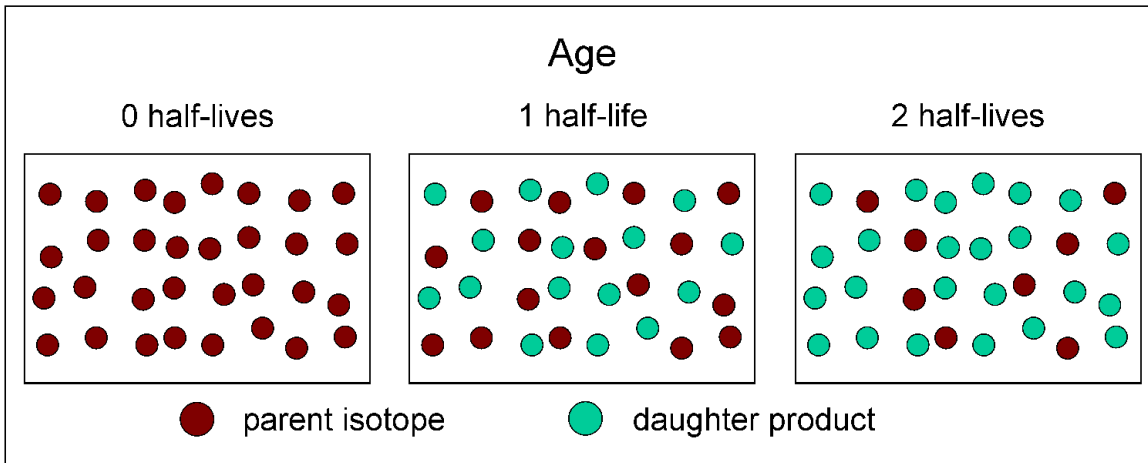
carbon-12
98.9%
6 protons
6 neutrons



carbon-13
1.1%
6 protons
7 neutrons



carbon-14
<0.1%
6 protons
8 neutrons

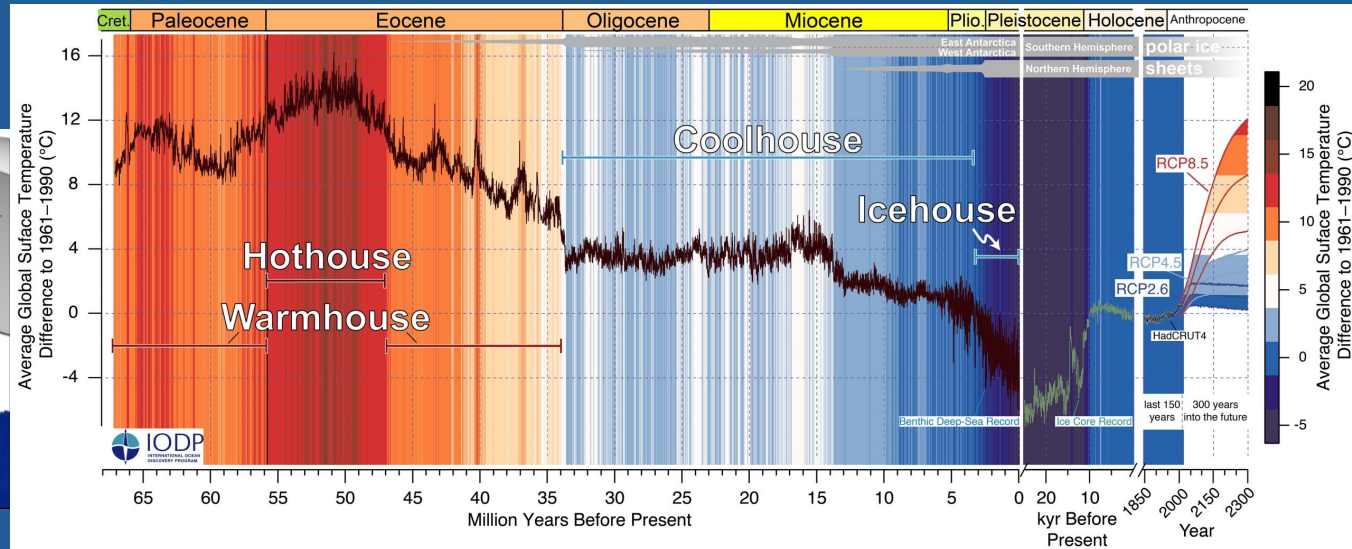
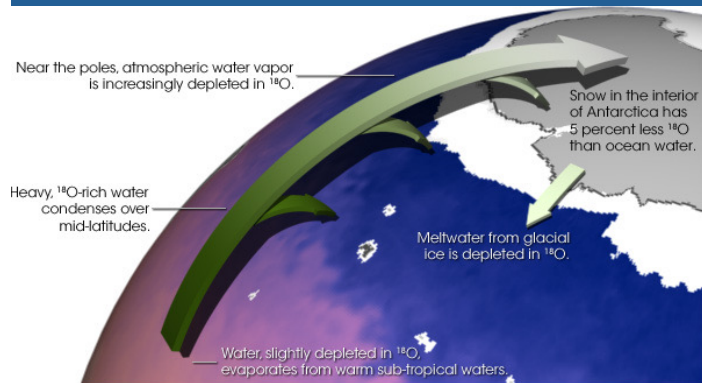
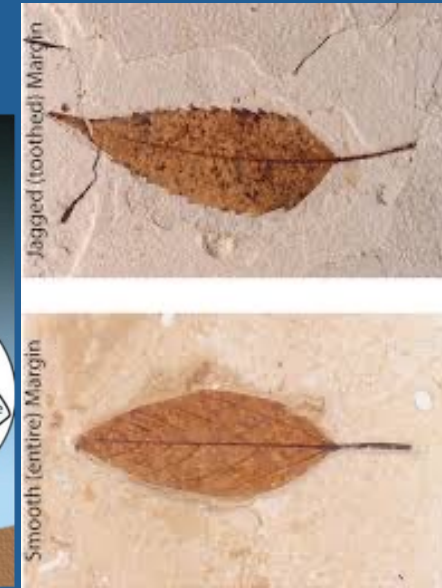
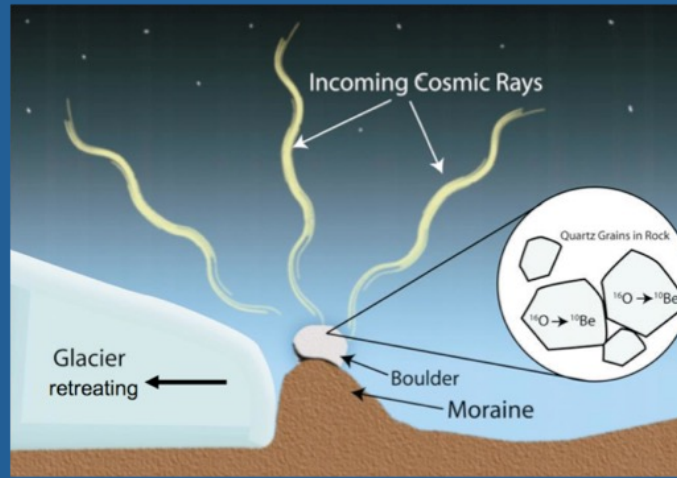


Isotope		Half-life of parent (years)	Useful range (years)
Parent	Daughter		
Carbon 14	Nitrogen 14	5,730	100 - 30,000
Potassium 40	Argon 40	1.3 billion	100,000 - 4.5 billion
Rubidium 87	Strontium 87	47 billion	10 million - 4.5 billion
Uranium 238	Lead 206	4.5 billion	10 million - 4.6 billion
Uranium 235	Lead 207	710 million	10 million - 4.6 billion

Paleothermometers & Isotope Ratios

Paleothermometry uses natural variation (fractionation) of atoms & ecosystems to estimate **temperature** variations

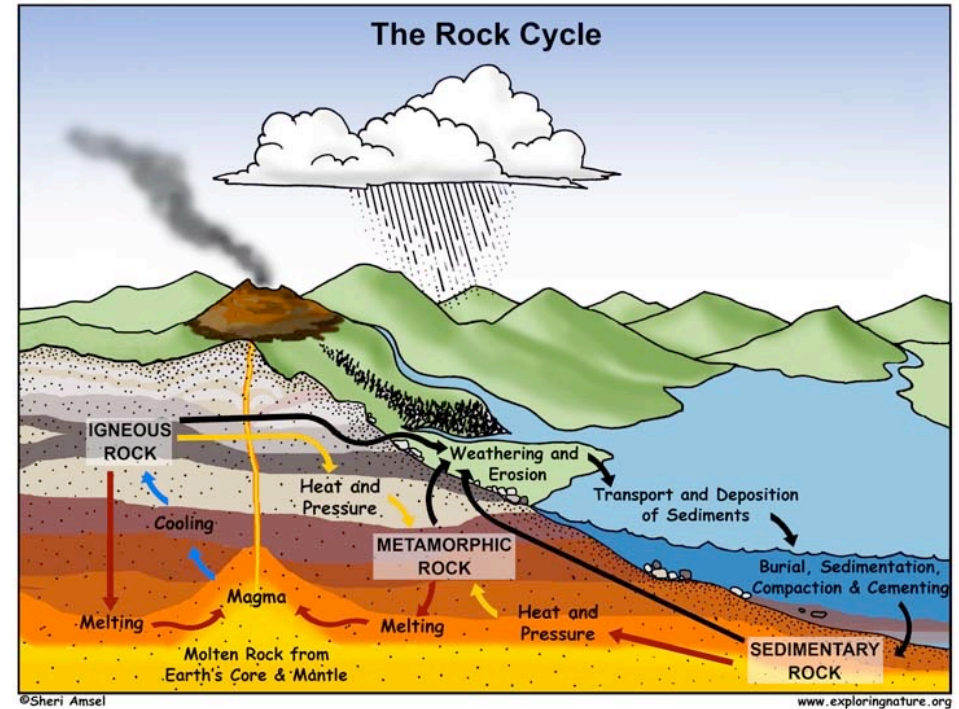
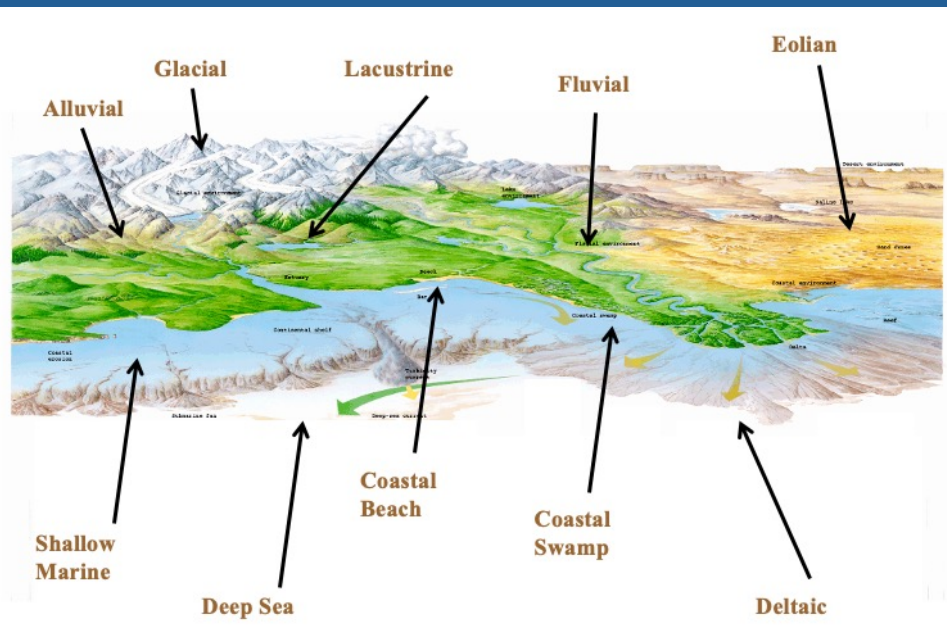
- **Materials:** rocks, ice, air, water, plants, animals, fossils
- **Surface UV exposure dating**
- **Lichenometry dating**
- **Leaf Physiognomy**



Sedimentology & Stratigraphy

Sedimentary rocks form layers on the surface of the Earth in unique depositional environments

- Grain size, chemistry, textures & structures (environment & source & history)
- Fossils = ecosystems

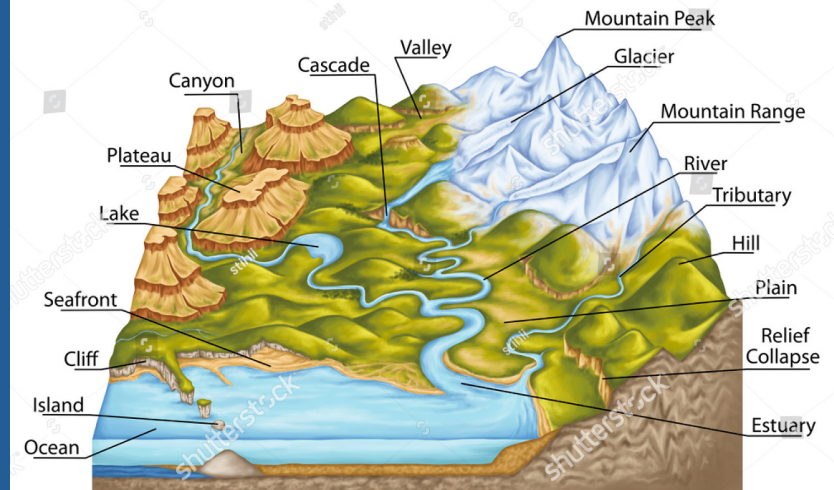
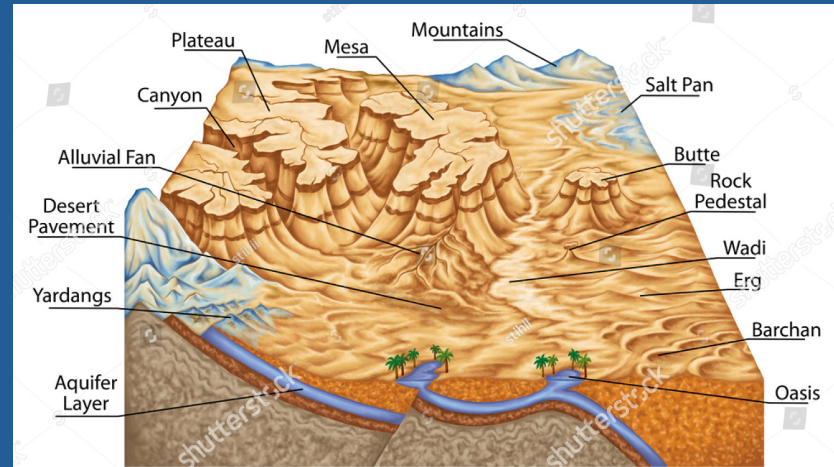
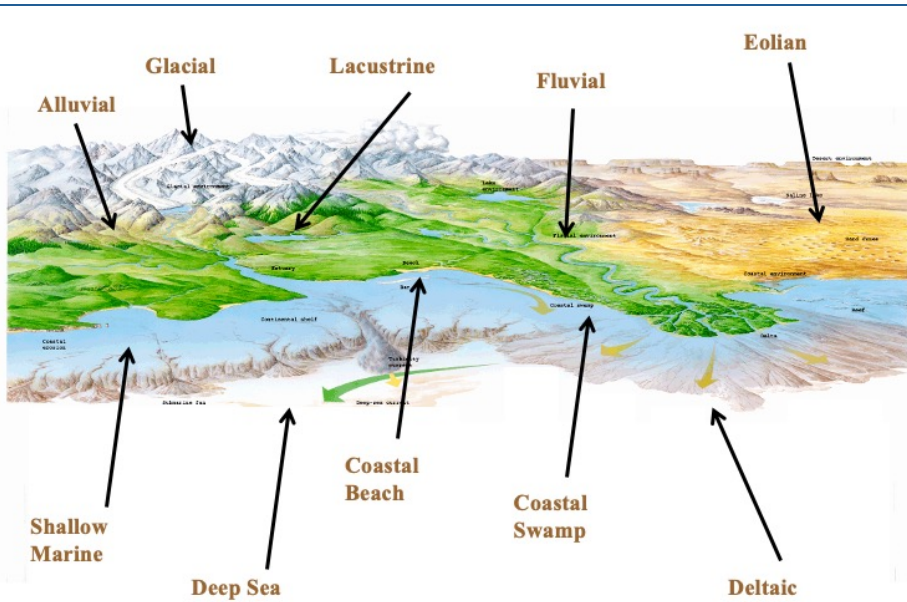


Remnant Landforms

Surface rocks carved by:

- Air
- Water
- Ice
- Rock

Due to plate tectonics & climate



Break!

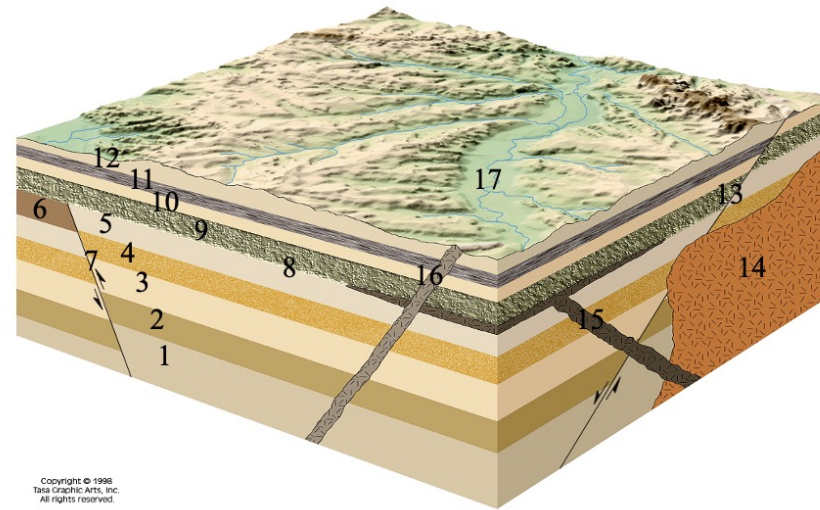
Video link:

<https://www.youtube.com/watch?v=Q1OreyX0-fw>

Sediment Cores

Drill & sample Earth layers to observe order of surface conditions change

- **Cover:** Sediments & sedimentary rocks form on Earth's surface (~5% vol. of Earth's outer 10mi)
- **Marine, terrestrial & aquatic**
- Fossils (surface environments)
- Uplift & erosion
- Volcanism

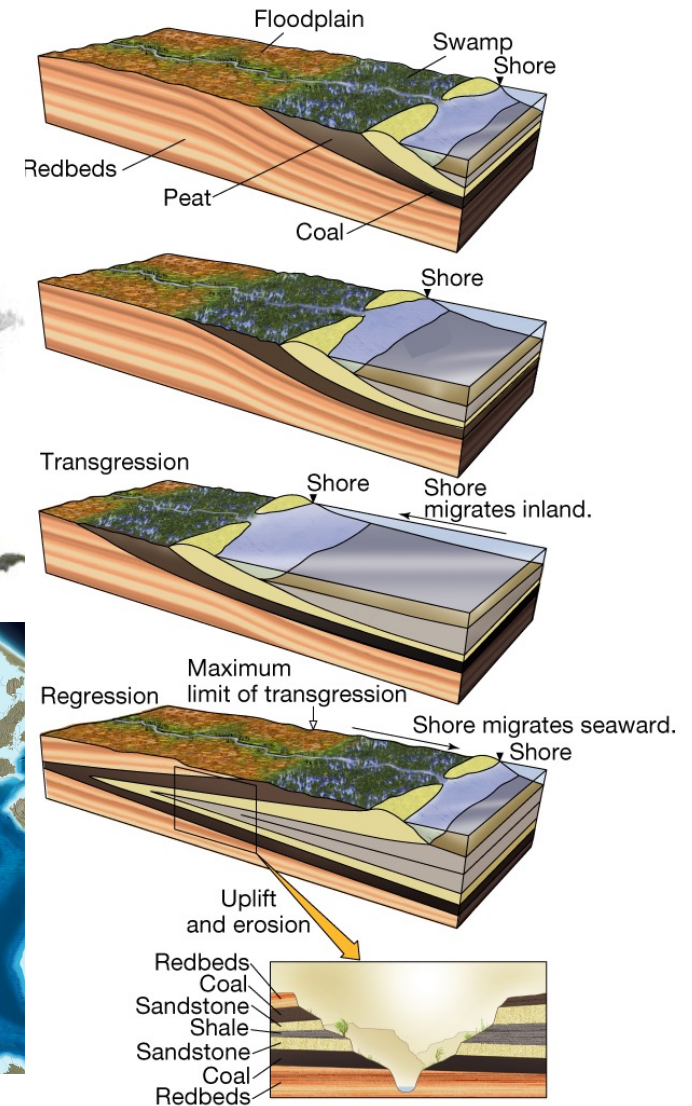
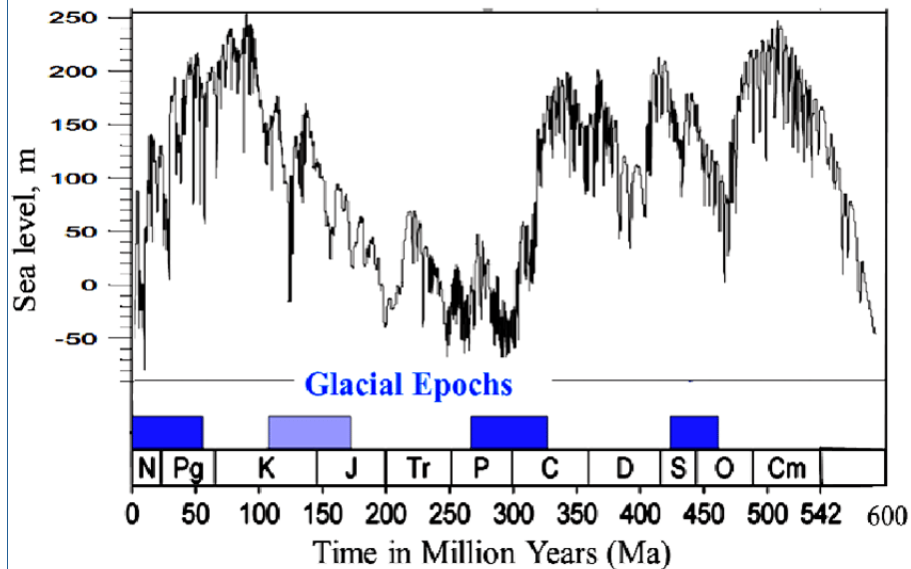


Sedimentary Record of Shorelines

The edge of land & sea is dynamic

- Glaciation & sea level
- Longshore current direction
- Sea level: transgression ↑ & regression ↓

Sea Level Fluctuations



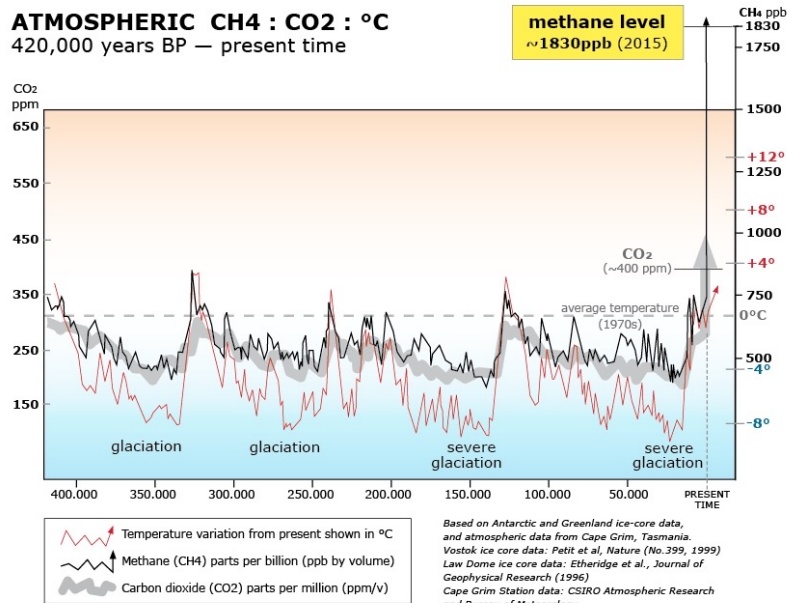
Organic Carbon Rocks: Life & Temperature

Carbon Sinks: atmosphere, oceans, flora, fauna, rocks, sediments, soil, fossil fuels (peat coal, oil & natural gas), volcanic gases

- **↑**carbon in atmosphere & oceans = **↑**temperatures
 - High atmospheric CO₂ → extensive limestone formation
- **↑**carbon in organisms, rocks, fossil fuels = **↓**Temps

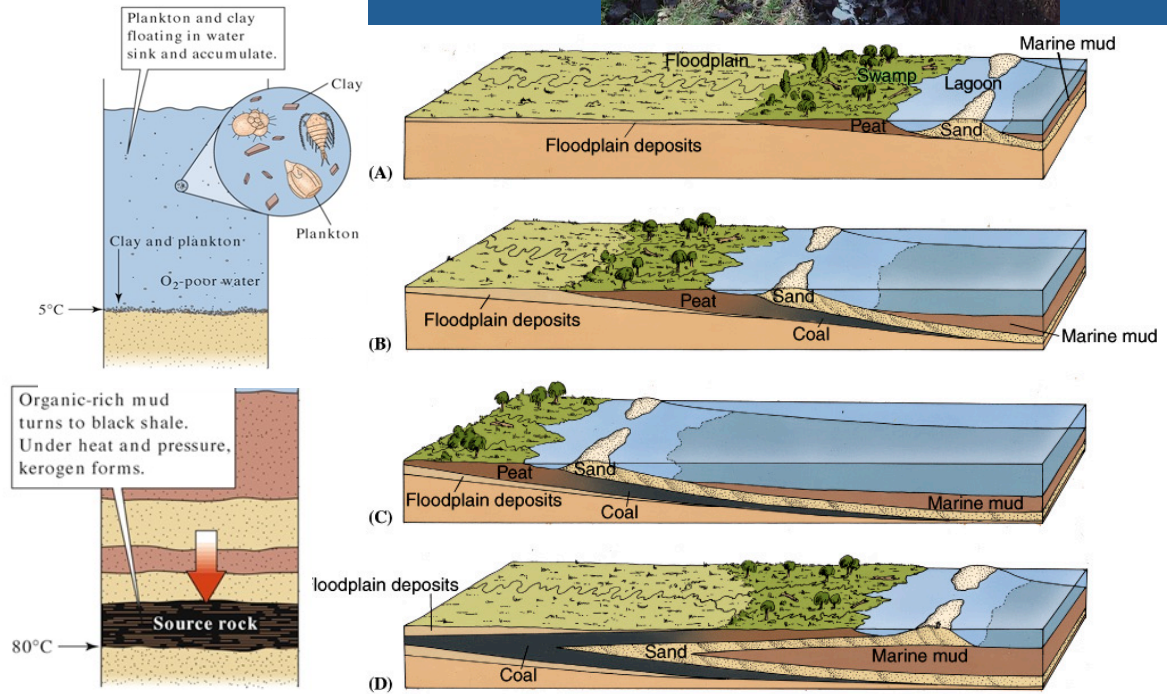


ATMOSPHERIC CH₄ : CO₂ : °C
420,000 years BP — present time



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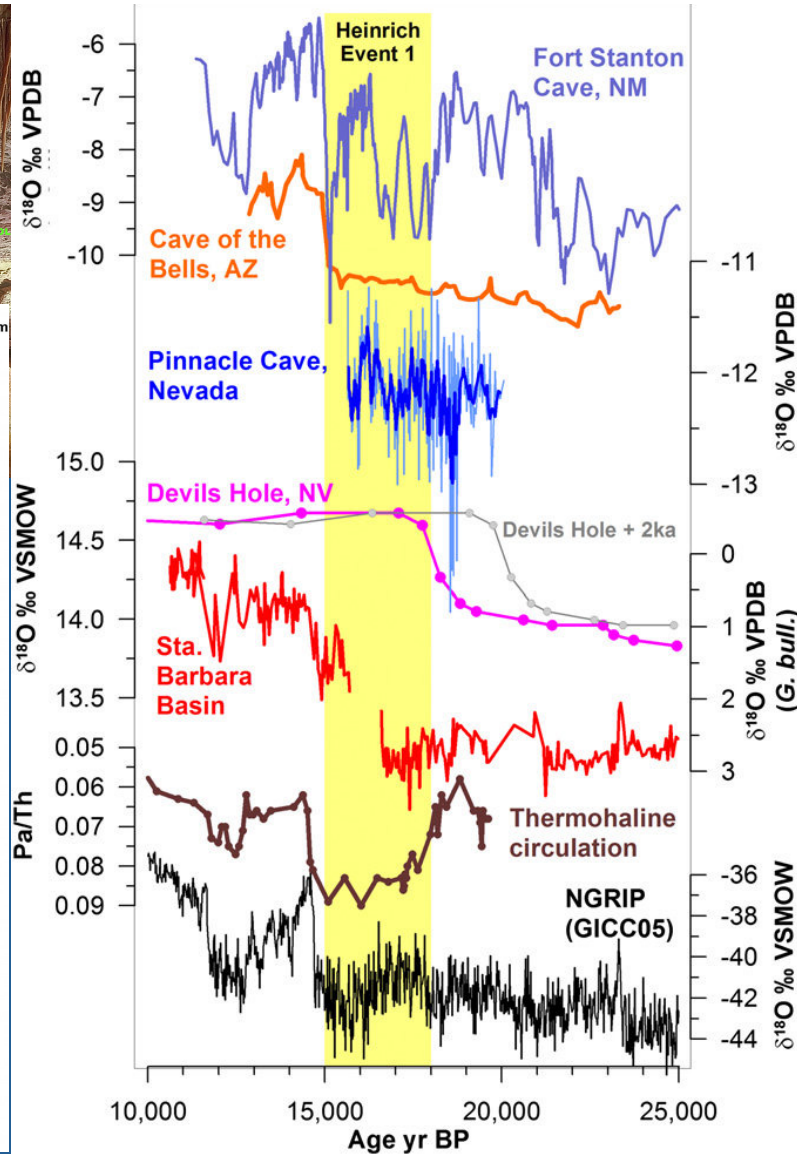
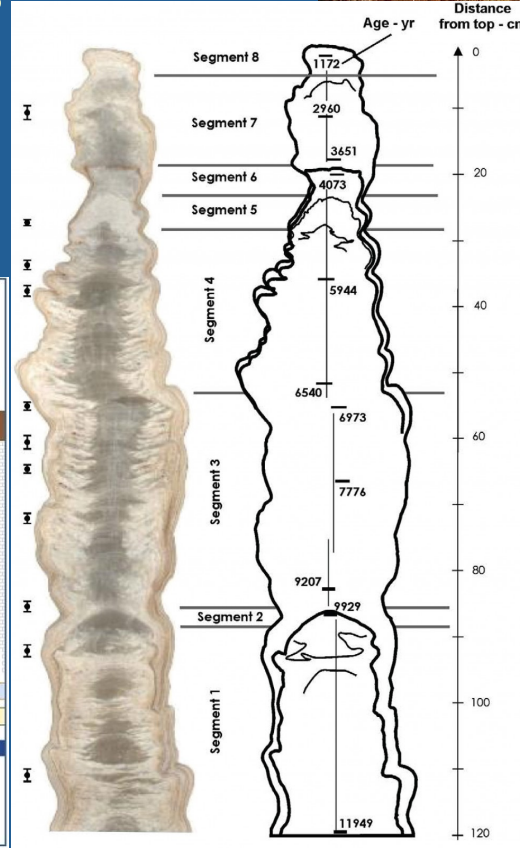
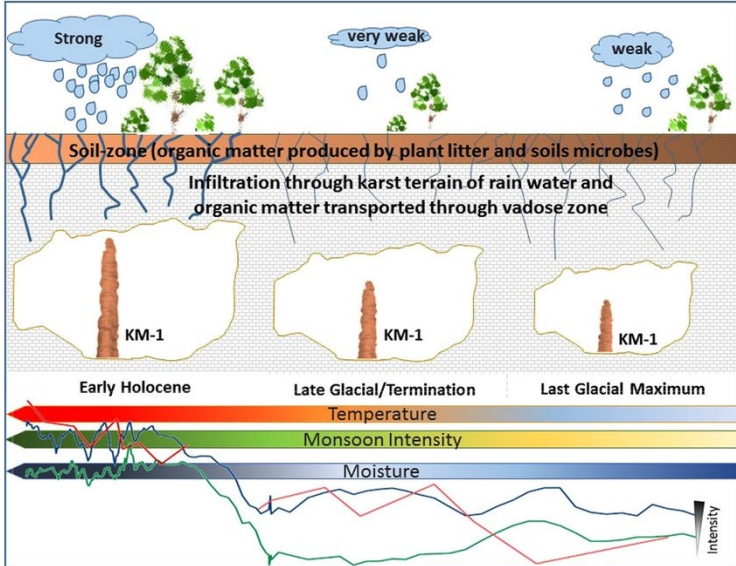
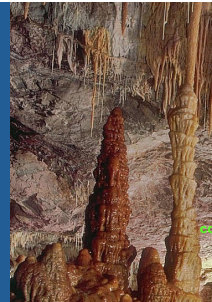
Based on Antarctic and Greenland ice-core data, and atmospheric data from Cape Grim, Tasmania. Vostok ice core data: Petit et al, Nature (No.399, 1999) Law Dome ice core data: Etheridge et al., Journal of Geophysical Research (1996) Cape Grim Station data: CSIRO Atmospheric Research and Bureau of Meteorology °C between 160,000 and 420,000 years BP from IPCC.



Caves & Speleothems

Limestone (CaCO_3) dissolves & deposits, protected from chaotic surface conditions

- Radiometric dating of layers
- Paleothermometers
- Precipitation estimate
- Global cryosphere



Ice Cores

Drill & sample glacier & ice cap layers to observe order of surface & atmospheric conditions change

- Paleothermometers (H₂O isotopes, electrical conductivity, atmospheric chemistry)
- Terrestrial dust (wind)
- Volcanic ash & gases

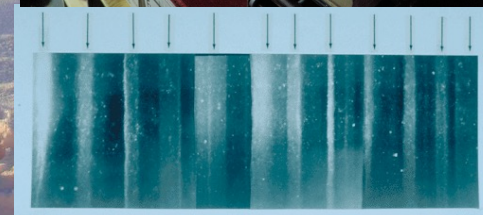
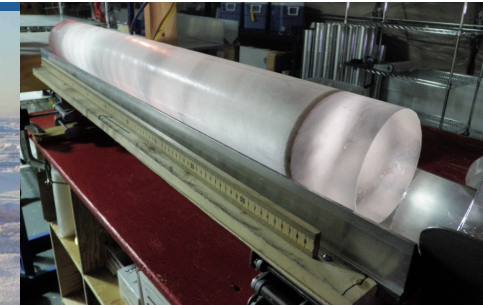
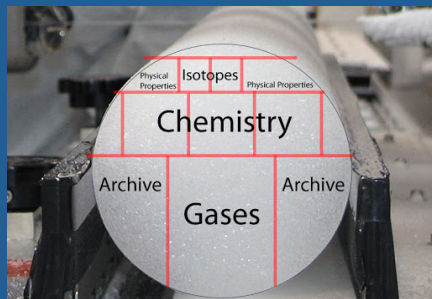
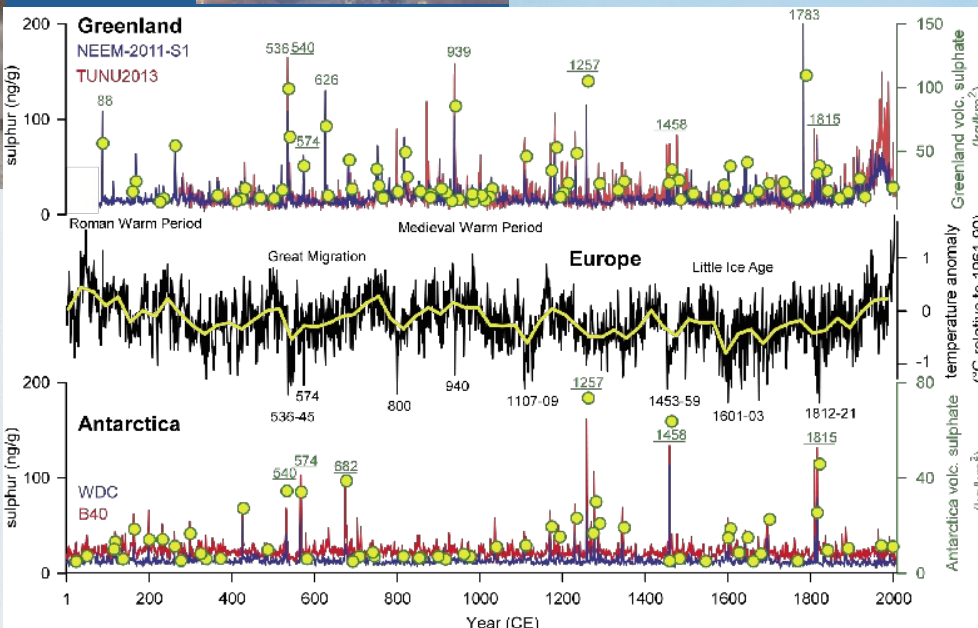
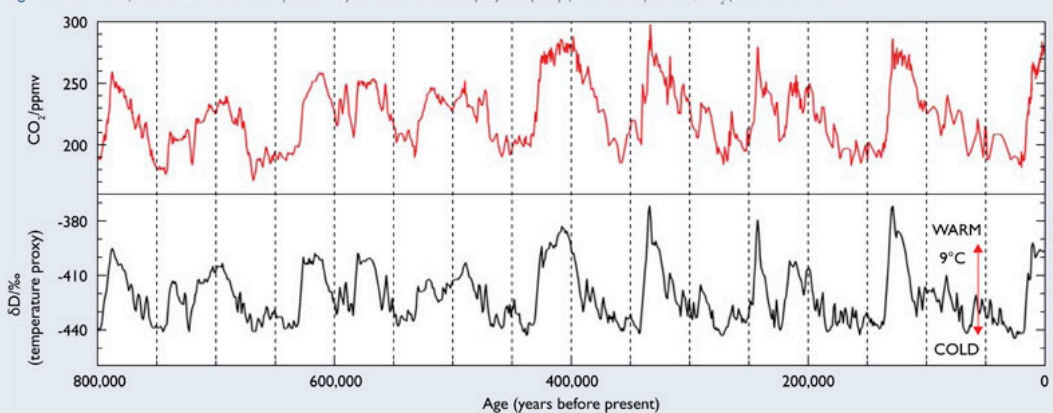


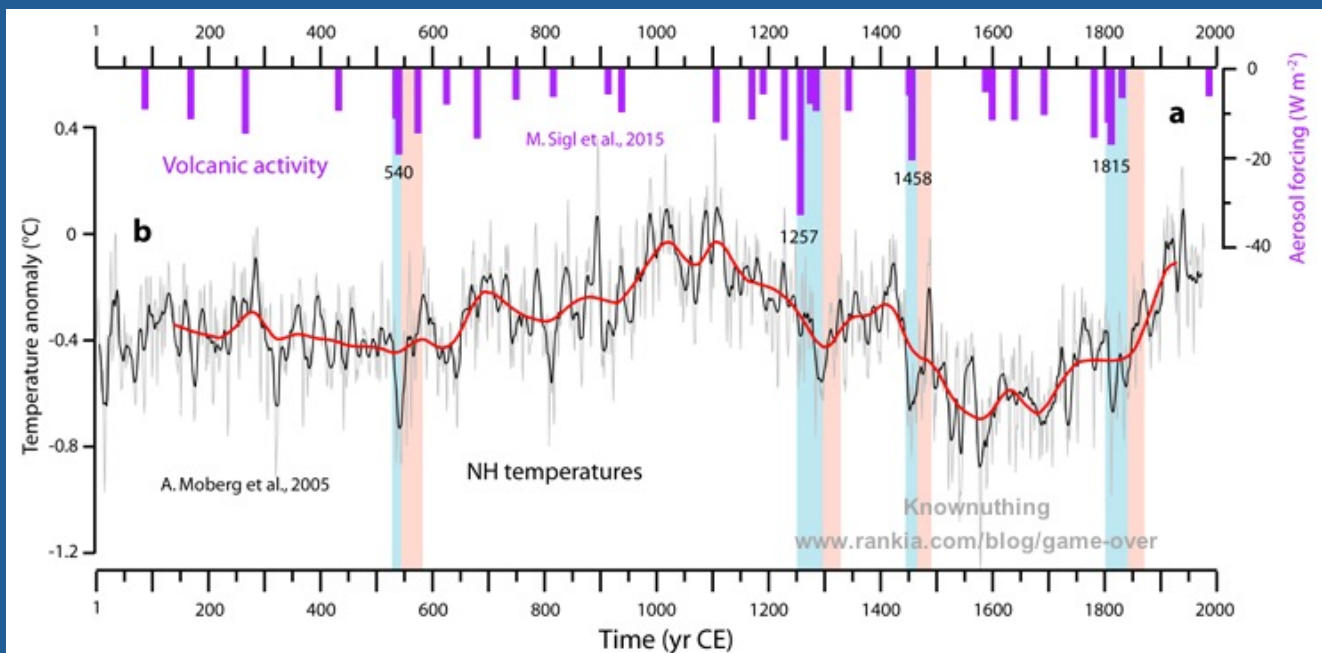
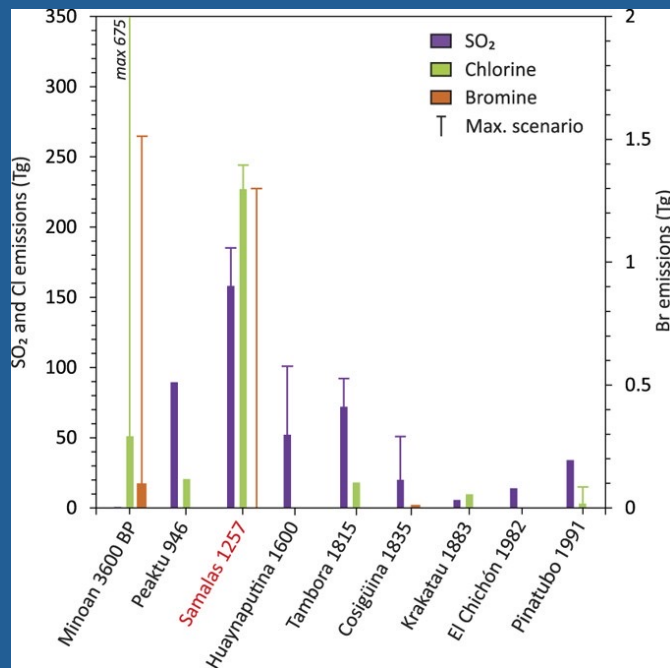
Fig. 3: Ice core data from the EPICA Dome C (Antarctica) ice core: deuterium (δD) is a proxy for local temperature; CO₂ from the ice core air⁵⁴⁾



Volcanic Ash Layers

Causes immediate atmospheric cooling & produces CO₂

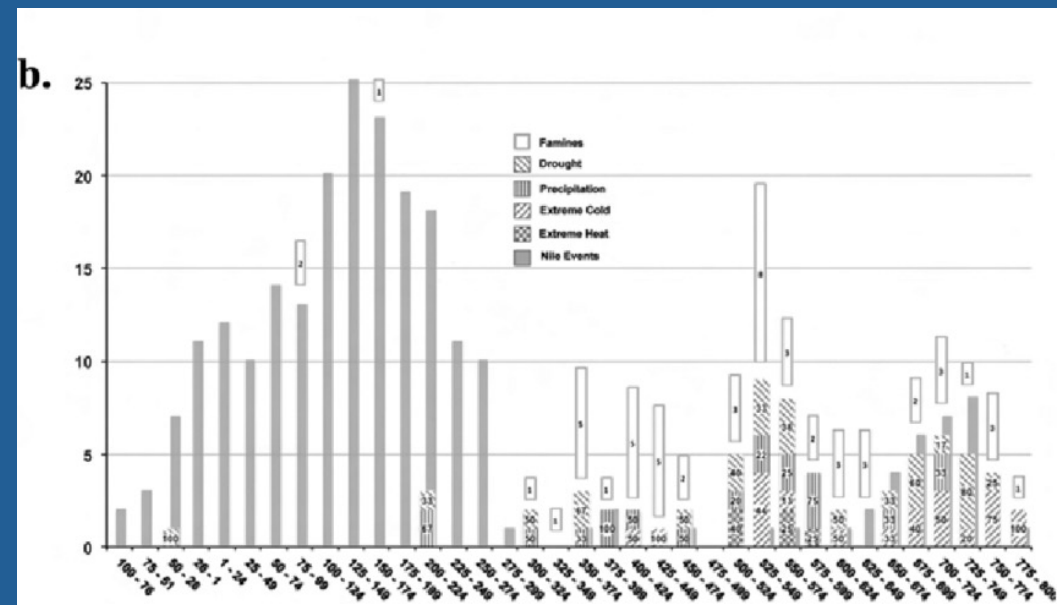
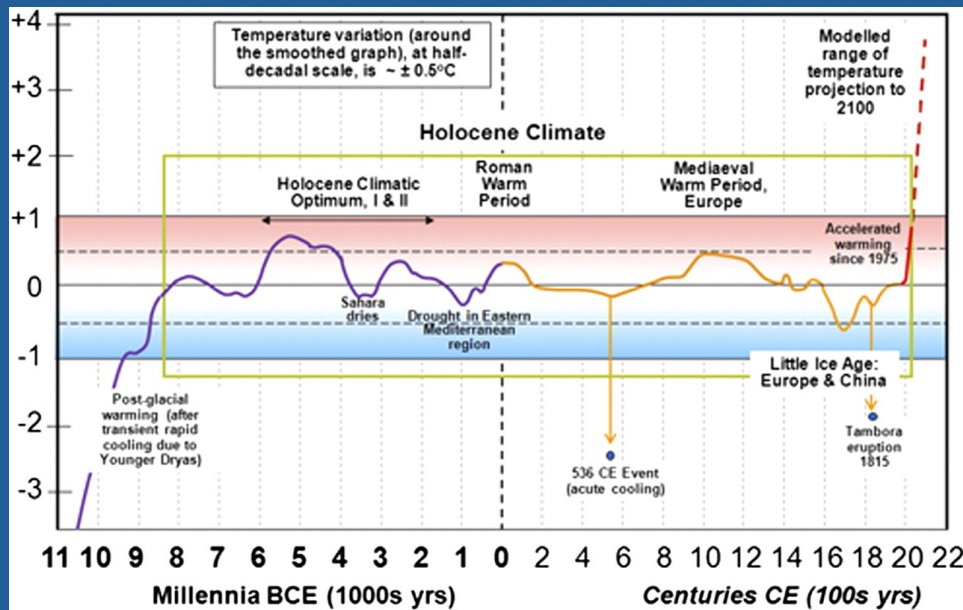
- Radiometrically dated to date of eruption
- Each eruption = unique ash & gas chemistry
- Recorded in sedimentary layers, peat, ice cores, & speleothems
- **Correlates with:** decrease tree growth, agricultural failure, onset of epidemics, unusually cold summers, changing weather patterns



Historical Records: Weather Observations

Provide timelines of drought, famine, cold, heat, agricultural bounty, & populations

- Written history ~5,500 years ago
- Church records, ship logs, diaries, media, harbor ice free dates, agricultural records, maps art, literature, etc.
- Local history (stories, tales, oral history, lore, sagas, chronicles)



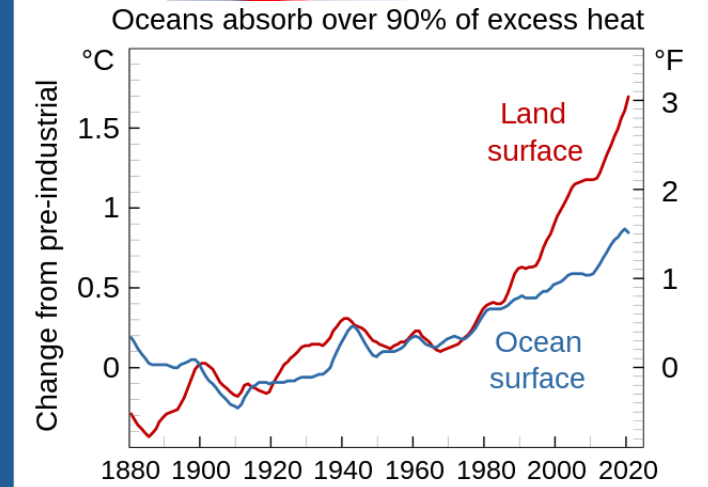
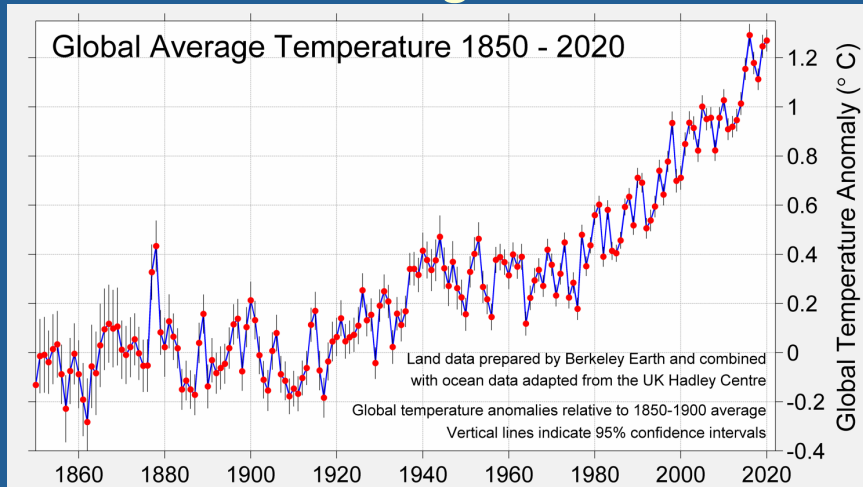
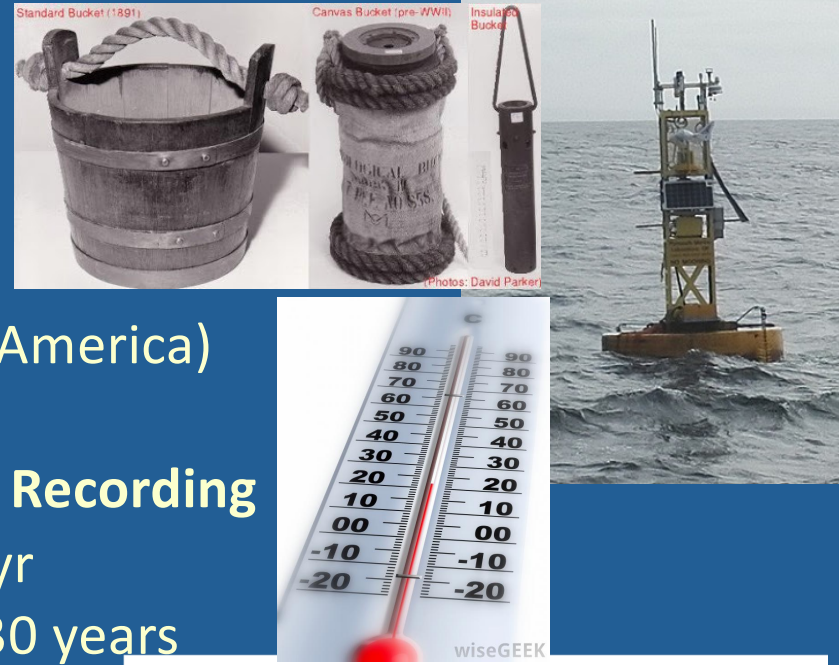
Temperature Measurements

Invention of the thermometer = Instrument

- 1654 Central Europe first thermometer
- Late 1700s Sea surface temperatures (SST)
- 1850 Modern weather records (Europe & N. America)
- 1880 Global temperature record begins

Global Historical Climatological Network Official Recording Stations 30yr. service requirement @ ≥ 182 days/yr

- Climate Normal = average over most recent 30 years



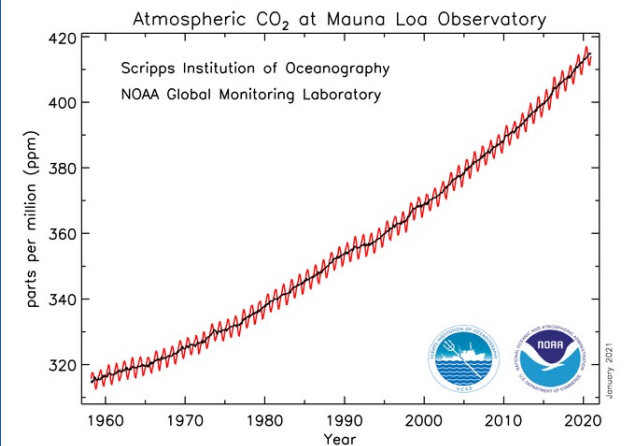
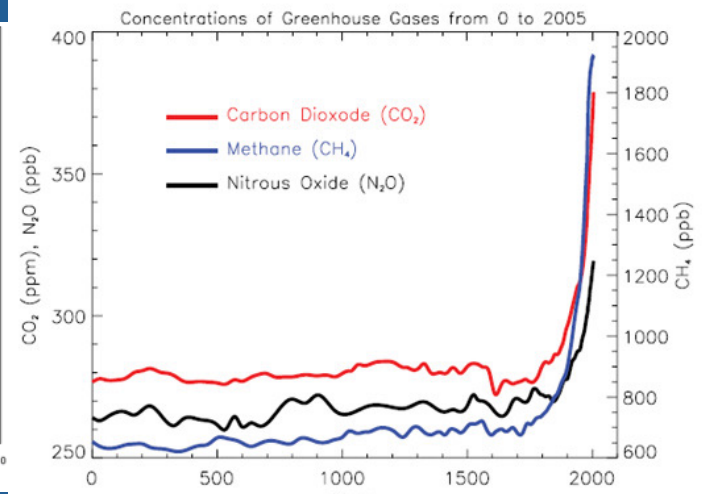
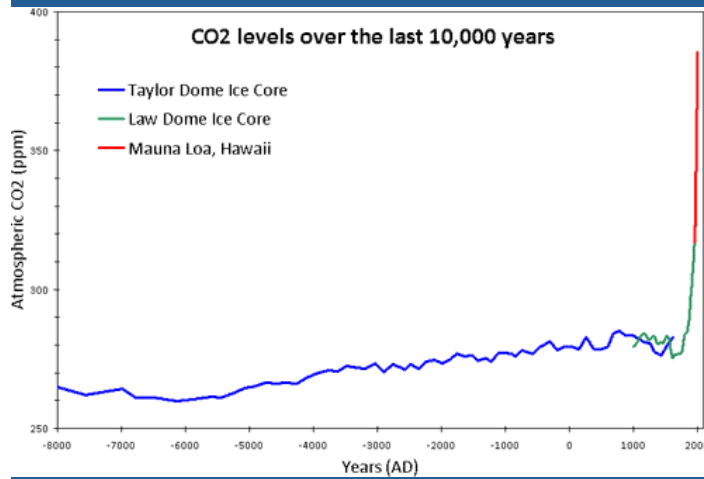
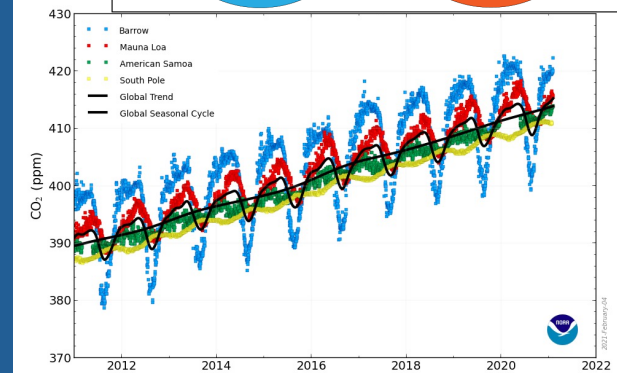
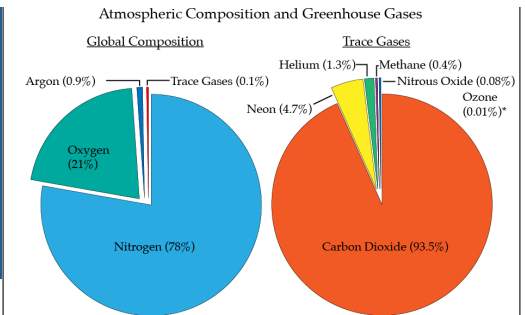
Atmospheric Composition Measurements

Atmospheric composition & greenhouse gases: photosynthesis, respiration, volcanism & weathering

- Greenhouse gases absorb **infrared heat** (Tyndall 1859)
- Only 4 Global Monitoring Baseline Observatories (Mauna Loa 1958)
- Keeling Curve (1976)

Video link:

<https://www.youtube.com/watch?v=x1SgmFa0r04>



Climatology = Instrumental + Historical + Paleo-Proxy Records

Climatology models generally agree with each other

- **Atmosphere & Ocean Temperatures:** rising rapidly+out of equilibrium with geosphere+biosphere
- **RCCs:** rapid climate change events are not rare & faster is associated with higher extinction rates
- *How will Earth's spheres & systems change to achieve a new equilibrium with the warmer atmospheric & ocean conditions, & how fast?*

