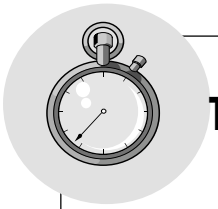
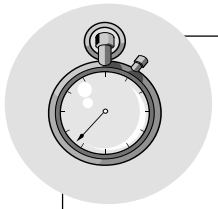
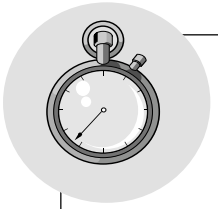


Time in Geology

- The age of objects can be determined if
  - a process of change can be identified that has a predictable (usually constant) rate
  - The starting condition is known and can be quantified
  - The current state can be accurately measured
- Brainstorm methods to estimate age of Earth
- Decay of unstable isotopes
  - ^{40}K, ^{14}C, ^{235}U, ^{238}U
- Cosmogenic isotopes

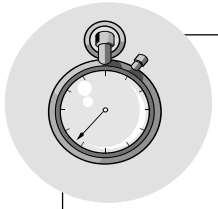


- Annual layers
- Relative Dating
- Magneto-stratigraphy
- Examples



Geologic Time
Lord Kelvin and the Age of Earth

- Assumptions:
  - Heat removed from Earth by conduction
  - No internal sources of Heat
  - "Known" initial (primordial) temperature
- Use Fourier's Theory of Thermal Conduction
  - Heat flow is proportional to the gradient in temperature
- Temperature gradient decreases with time as planet cools
  - Rapid increase with depth for young Earth
  - Less increase with depth for older Earth
- His result: Earth is 65 million years old



Geologic Time
Kelvin's Result

- Well, maybe some of the estimates are uncertain - Take some different guesses
- Maybe we can stretch the age to 100 - 400 my
- That was the absolute oldest Earth that physicists would allow geologists on the basis of 19th Century Physics
- What was missing?
  - Internal heat production
  - radioactive decay
  - Convective heat transport

Geologic Time
Isotopes

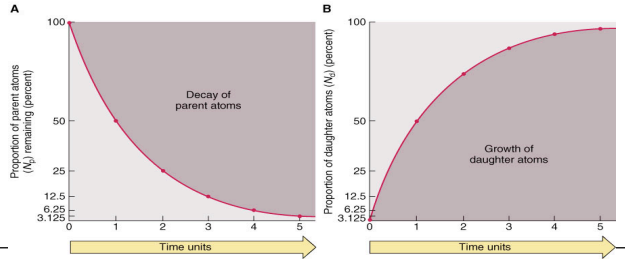
- ATOM: (Nucleus determines mass)

  Protons (atomic number)
  +
  Neutrons
  Mass Number → $^{40}_{19}K$

- Isotopes:
  Atoms having the same atomic number BUT different number of neutrons
- Radioactivity:
  - Unstable isotopes spontaneously transform to another nucleus
- Decay rates:
  - unique for each isotope
  - not a function of P or T or etc.

Geologic Time
Absolute Measurement via Radioactive Decay

- Parent is an Unstable Isotope
- Daughter is a Stable Isotope created by radioactive decay
- Rate of change of Parent to Daughter is proportional to amount of Parent:



Geologic Time
via Radioactive Decay The Assumptions

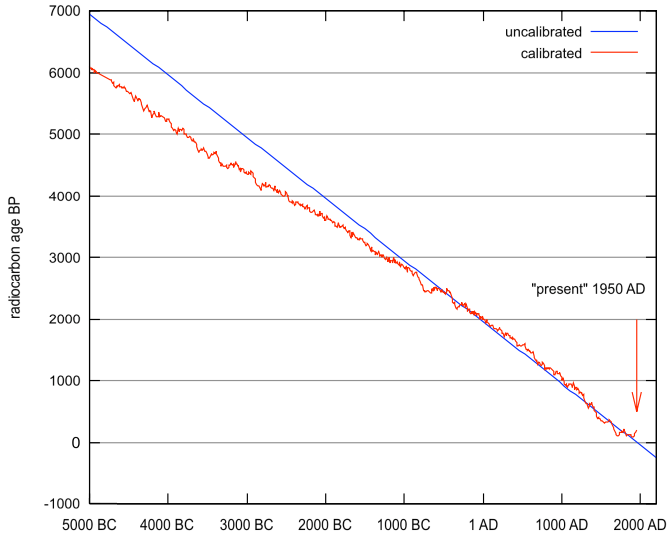
- The rock or mineral has neither gained nor lost either Parent or Daughter
  - It is a "Closed System"
- One must be able to determine the initial Daughter concentration
- The value of the decay constant must be accurately known
- Measurements of D and P must be accurate and representative of the rock or mineral to be dated

Age Dating
Potassium-Argon

- ^{40}K → ^{40}Ar (12%)
  ^{40}K → ^{40}Ca (88%)
- $T_{1/2}$ is 1.3 Billion Years!
- Ar is noble gas that is lost when crystal is heated :
  - $D_o = 0$
  - t_o is last time rock was hot
- ^{40}Ca is common Ca - not useful
- Useful range 100,000 yrs and up
- Useful for volcanic rocks, micas, amphiboles

Age Dating
Carbon -14

- cosmic particle + $^{14}N \longrightarrow {}^{14}C$
- $T_{1/2}$ = 5,730 yrs
- Carbon is well mixed in atmosphere
  - $^{14}C/^{12}C$ = constant
- Carbon in organisms is representative of atmosphere
- After death of organism, ^{14}C content decays if "closed system"
- Useful range 100 to 50,000 yrs
- Note problems



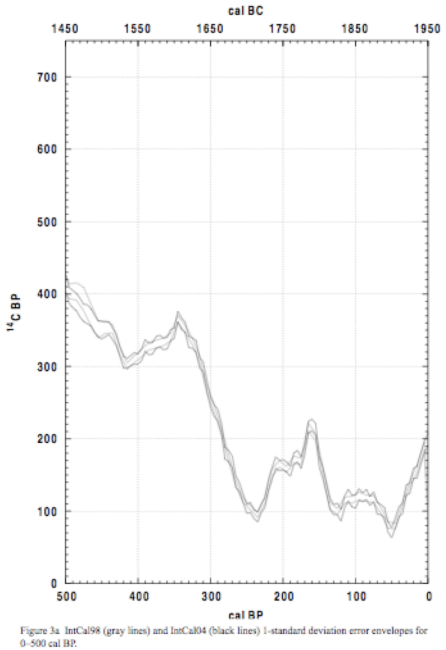


Figure 3a IntCal98 (gray lines) and IntCal04 (black lines) 1-standard deviation error envelopes for 0–500 cal BP.

Age Dating
Uranium - Lead and Age of Earth

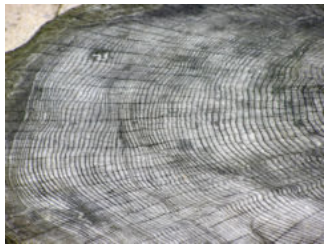
- $^{235}U \longrightarrow {}^{207}Pb + ..$ $T_{1/2}$ = 4.6 by
- $^{238}U \longrightarrow {}^{206}Pb + ..$ $T_{1/2}$ = 0.71 by
- ^{204}Pb has no unstable parent
  - constant amount
- Form set of equations in ratios of abundances
- Slope of line gives age of Earth (and meteorites)
- Age is 4.56 by!

Age Dating
Cosmogenic Isotopes

- Cosmic rays produce rare isotopes through collisions with elements in minerals at Earth's surface
- Examples: ^{10}Be, ^{36}Cl, ^{26}Al, ^{41}Ca, ^{129}I
- Concentration builds up with longer duration of exposure
- Can be used to date surfaces, measure erosion rates, trace groundwater, and more
- Relatively recent field of investigation

Age Dating
Annual layers

- tree rings
- varves
- ice layers



Age Dating
Relative Dating

- Lichen size
- Weathering

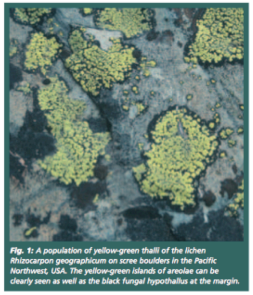


Fig. 1: A population of yellow-green thalli of the lichen Rhizocarpon geographicum on scree boulders in the Pacific Northwest, USA. The yellow-green islands of areolae can be clearly seen as well as the black fungal hypothallus at the margin.

Fig 3: A growth curve of the lichen Rhizocarpon geographicum from southeast Iceland determined by lichenometry. The non-linear form of the curve is a notable feature of lichen growth curves from many sites around the globe.

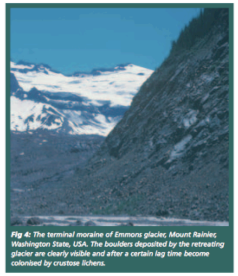
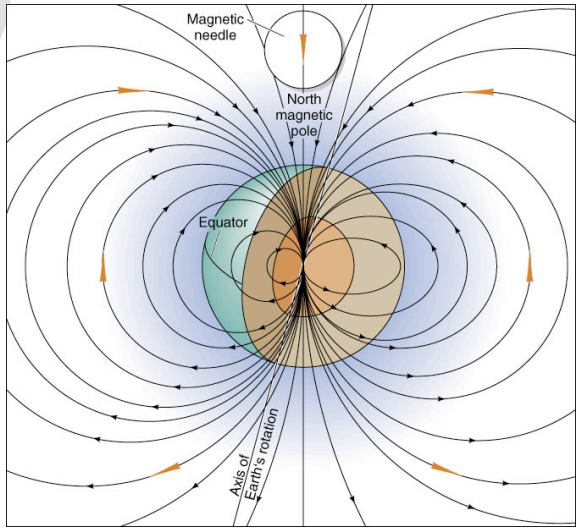


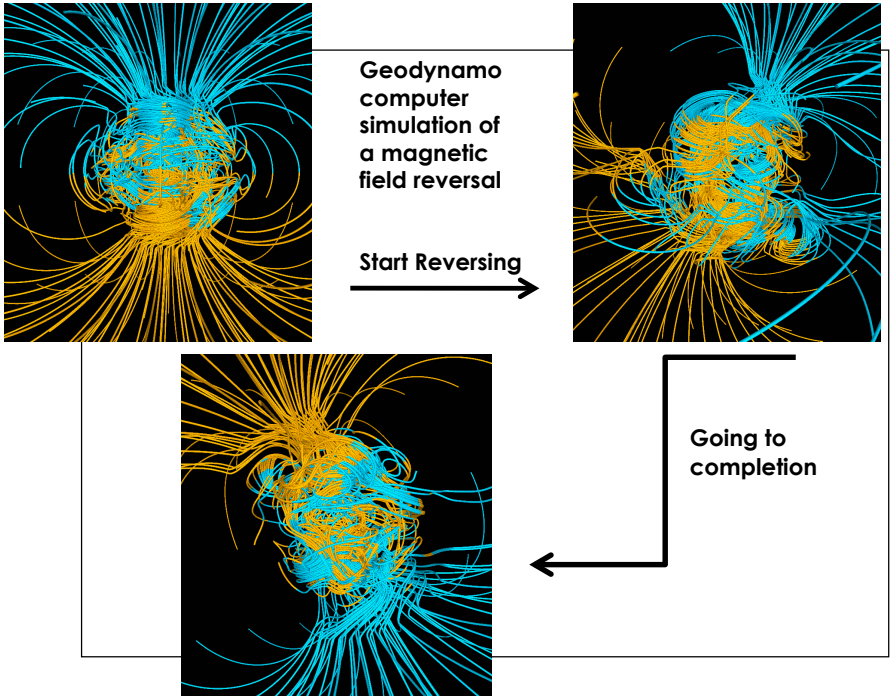
Fig 4: The terminal moraine of Emmons glacier, Mount Rainier, Washington State, USA. The boulders deposited by the retreating glacier are clearly visible and after a certain lag time become colonised by crustose lichens.

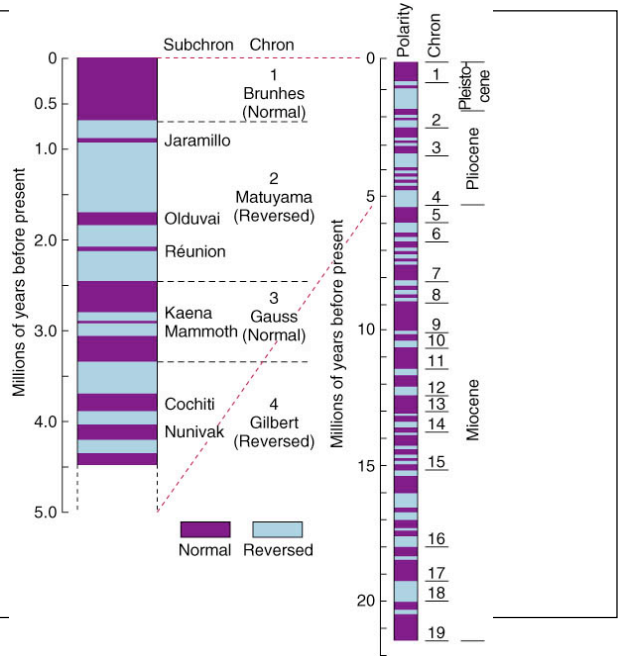
Armstrong, Microbiologist, 2004

Age Dating
Magneto-Stratigraphy

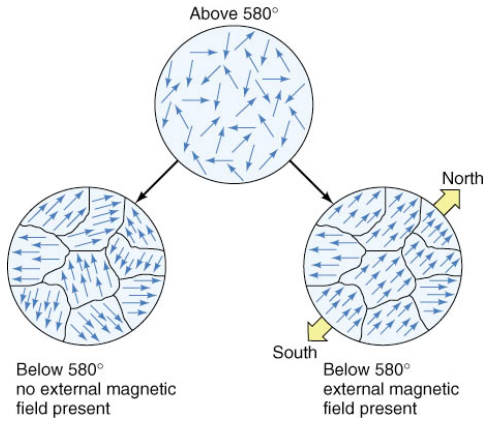
- Earth's magnetic field reverses direction apperiodically
- Cooling igneous rocks preserve a record of the direction of Earth's field
- Sediments also preserve magnetic field direction at time of deposition





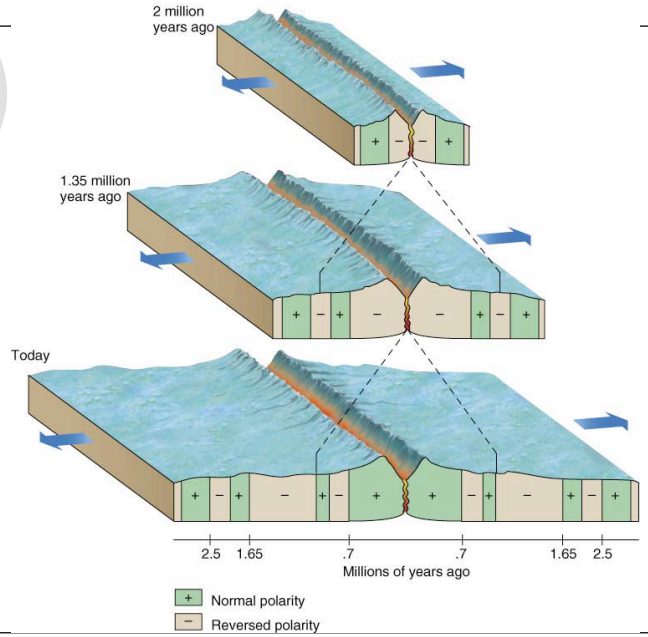


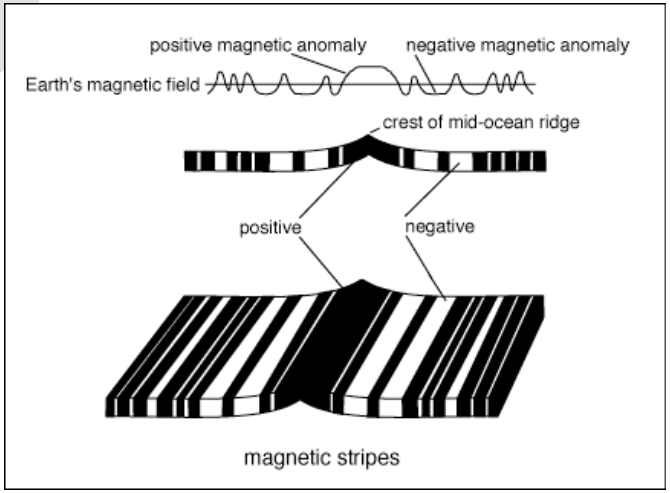
Thermal Remnant Magnetization (TRM)

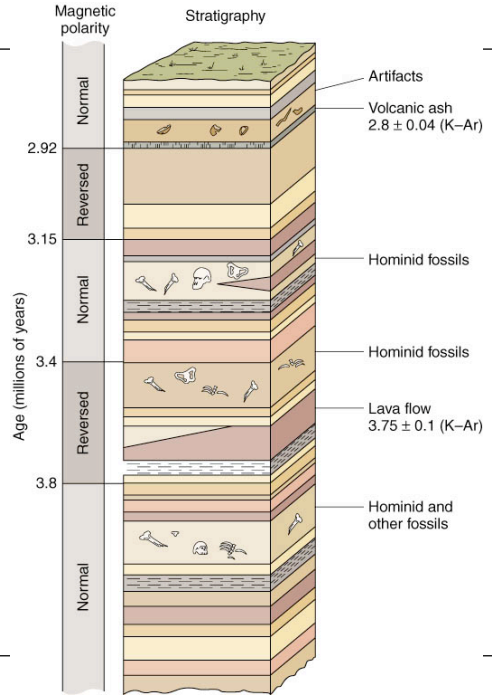


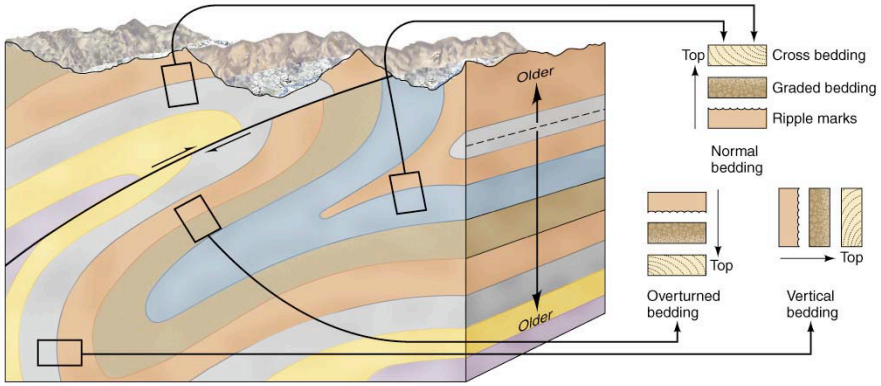
Depositional Remnant Magnetization (DRM)

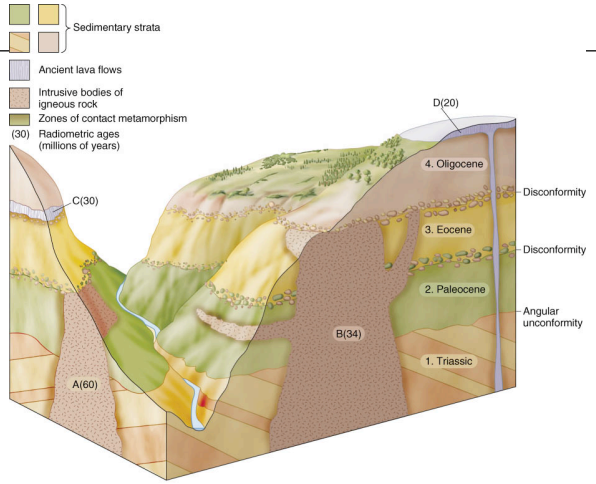
- Small magnetic mineral grains suspended in calm water are aligned with Earth's magnetic field
- As they settle on the bottom, they maintain alignment
- The sedimentary rock thus has a weak magnetization parallel to Earth's field at the time of deposition











Stratum	Age (millions of years)	Interpretation
4	<34 (younger than B) <30 (younger than C) >20 (older than D)	Age lies between 20 and 30 million years
3	<60 (younger than A) >34 (older than B) >30 (older than C)	Age lies between 34 and 60 million years
2 1	>60 (older than A) >60 (older than A)	Age of both is greater than 60 million years