

Geol 104 Lecture 6  
Geologic Time

I. Early estimates of Earth's absolute age

A. Old Earth

1. Hutton recognized that the Earth must be very old
  - a. Principle of Uniformitarianism – the processes that acted to shape the Earth in the past are the same as those that operate today (“the present is the key to the past”)
  - b. If so, then the Earth must be very old – great amount of time needed for slow processes to produce what we observe today.
2. This opened the door for Darwin's Origin of Species and the Theory of Evolution

B. Theological clocks

1. Based on ‘divine’ texts – e.g. Genesis
2. Christian clocks
  - a. ~ 10,000 year old Earth
  - b. Ussher calculated earth began October 23, 4004 B.C.
    - used average length of generation & multiplied by # of generations in Genesis

C. ‘Uniformitarianism’ Clocks

1. Sediment Accumulation
  - a. age of Earth = thickness of all Earth's sediment / rate of sediment accumulation
  - b. Flaw: assumed constant sedimentation rate!
  - c. Flaw: gaps in sedimentary record caused by erosion (unconformities)
2. Salt Accumulation: John Joly, 100 m.y. old earth
  - a. assumed oceans initially filled with fresh water
  - b. assumed river input is source of salt in oceans
  - c. Calculated time required to reach current salinity
  - d. Flaw – river input is not constant supply
  - e. Flaw: removal of salt by pcpt. of evaporates
  - f. Flaw: Assume closed system by neglecting mantle input, hydrothermal exchange & subduction

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3. Cooling Rates: de Buffon (1700s, calculated 75,000 yr old Earth)
  - a. Assume early earth molten
  - b. How long to cool to today's temperature (assumes rate of heat loss & heat capacity)
4. Cooling Rates: Kelvin, 1846:  $20\text{-}30 \times 10^6$  yrs
  - a. assumed heat loss by conduction – missed convective heat loss of mantle!
  - b. used geothermal gradient! But missed heat production by decay!
  - c. problem with uniformitarianists who claimed earth must be much older.

## II. Radiogenic Decay – basis for absolute age dating

### A. Radioactive Decay: How does it work?

1. Some *isotopes* have energetically unstable nuclei.
  - Isotope means same place (on periodic chart), i.e. same element
2. The nuclear particles 'decay' or transform to another particle in order to reach a more stable nucleus (eventually).
  - a. In so doing, a particle is emitted (=radiation) and Heat is produced.
    - i. Major Source of Heat Production in Crust!
    - ii. **Parent isotope -> daughter isotope + particle + heat**
  - b. The rate of decay is constant (not dependant on environment)
    - Thus: number of daughters is dependant on number of parents and time!
3. Measuring Time:
  - a. See that the ratio of Parent to Daughter is a function of time!
    - this is the basis of radiometric dating (no details here)
  - b. The equation used is a line (called Isochron) and its slope is a function of time!
    - i. isochron is determined by measuring P/D in different minerals
    - ii. given measured P/D, can calculate age from the slope of the isochron
4. Common Dating Systems
  - a.  $^{87}\text{Rb}$ -  $^{87}\text{Sr}$ : 47 b.y. half-life
  - b.  $^{238}\text{U}$  –  $^{206}\text{Pb}$ : 4.5 b.y. half-life
  - c.  $^{235}\text{U}$  –  $^{207}\text{Pb}$ : 713 m.y. half-life
  - d.  $^{232}\text{Th}$  –  $^{208}\text{Pb}$ : 14.1 b.y. half-life
  - e.  $^{40}\text{K}$  –  $^{40}\text{Ar}$ : 1.3 b.y. half-life
  - f.  $^{14}\text{C}$  –  $^{14}\text{N}$ : 5730-year half-life

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5. Why can't all rocks be dated?
  - a. Can only date Metamorphic and Igneous rocks
    - i. minerals in these rocks record the time at which they cooled below their blocking temperature
      - blocking temp = temp below which mineral can't lose P and D isotopes
    - ii. Dating sedimentary rocks does not give the age of the rock!
  - b. Not all rocks contain radiogenic isotopes
  - c. Age of rock must be within magnitude of half-life
    - i.e., there must be enough parent and daughter isotopes in the rock to measure their ratio.
  - d. Some rocks contain 'heterogeneous' isotopes (i.e. accumulated from many sources) – or they were open systems (i.e. lost or gained Parent or Daughters)

C. Age of Earth

1. Oldest rocks on Earth = 4.03 Ga
  - a. this is not the age of the Earth
  - b. Early Earth was hot and temperatures > blocking temperature of minerals
  - c. Also, Tectonics resurfaces the Earth and very oldest rocks may not be preserved
2. Patterson, 1956 dated the earth at 4.55 Ga
  - a. Measured Pb isotopes in meteorites – Brilliant!
  - c. Compared to Pb isotopes in Marine sediment – Brilliant!
    - i. Homogenized sample of earth's Pb
    - ii. Coincident with meteorite isochron indicates age of earth at 4.55 Ga

D. Information gained from radiogenic isotopes

1. Age of earth from decay rates
2. Age of earth differentiation into composition layers (crust-mantle-lithosphere)
  - c. Formation of continents began at beginning of Earth history
3. Earth/mantle processes traced via isotopes with different distribution coefficients
  - a. Learn that the mantle is heterogeneous
  - b. Subducted and delaminated lithosphere
  - c. Primordial mantle

II. Relative Age -Most rocks cannot be dated. But, we can determine their age relative to another rock

A. 'Definition':

1. Relative age places an event/rock unit in a sequence of events.
  - Remember: Rocks are produced during geologic events, so when you determine relative ages, you are really determining sequences of events.
2. Examples: I am younger than my brother – sequence of events (births) and ages

B. Principles of relative age dating

1. Principle of Original Horizontality: Steno (1600's)
  - a. Sediments are deposited in horizontal sheets
  - b. Lavas too
  - c. Thus, inclined or folded beds are disturbed.
2. Principle of Superposition: Steno (1600's)
  - a. Older layers on bottom
  - b. Layer cake model
  - c. Assumes no disruption of layers (faulting etc.)
3. Principle of Original Continuity
  - a. Sediments or lavas ('beds') accumulate in continuous sheets
  - b. Thus, can infer they continue across eroded regions
4. Principle of Cross-Cutting Relationships
  - a. Faults cut pre-existing (older) rocks
  - b. Igneous rocks intrude (or extrude onto) older rocks.
5. Principle of inclusions:
  - a. If a rock contains fragments of another rock, the fragments are older.
  - b. Examples: rip-up clasts, xenoliths etc.
6. Principle of Faunal Succession (William Smith in late 1700's) (**draw**)
  - a. Smith surveyed canals for coal transport – industrial revolution.
  - b. Noticed
    - ii. Fossils occur in groups (assemblages)

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- iii. Fossil organisms succeed one another in definite order
- c. Correlation of Fossil assemblages
  - i. Group rocks units from separate regions based on fossil assemblage
  - ii. Place Relative age on units recognizing that loss of fossil = extinction
- d. Extinction (Baron Georges Cuvier – early 1800's, Father of Catastrophism)
  - i. Worked in Paris Basin (Cenozoic)
  - ii. Noticed 7 distinct terrestrial fossil organism
    - Each disappeared from strata prior to succeeding fossil ('pair')
    - Each 'pair' separated by marine fauna
  - iii. Postulated: Cataclysmic event (flood) caused extinction
    - Did not accept evolution (after his time)
    - Rather, thought that 'latter' organism migrated to fill niche

C. Unconformities = Gaps in rock record = Gaps in time

- 1. Hutton's unconformity (Siccar Point)
  - a. Inclined sediments
    - i. Must have been horizontal at one point
    - ii. Then tilted **and** eroded
  - b. Red sandstone and conglomerate then deposited
  - c. Contact between Old Red SS and gray shales = angular unconformity
- 2. Other two unconformities
  - a. Nonconformity: sediment on igneous/metamorphic rocks (erosion surface between)
  - b. Disconformity: Sediment on sediment (horizontal) separated by erosion surface
  - c. Unconformities imply uplift and erosion prior to resumption of sedimentation

D. Correlations of rock units

- 1. Correlation
  - a. Determine age relationships in rocks exposed in different places.
  - b. Using principles of relative age dating (and unconformities)

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2. Examples:
  - a. Across grand canyon (simple continuity & Lithologic correlation)
  - b. Grand Canyon correlated w/Las Vegas (150 km West) = fossil correlation
3. Correlating rocks globally results in Geologic Column (time scale)

IV. Geologic Time Scale and Life on Earth:

A. Geologic Time Scale

1. Construct from
  - a. Geologic Column (relative dating/correlations of Earth's rocks)
  - b. Absolute age dating of rocks in the time scale (appropriate composition)
2. Boundaries between divisions (eons, eras, epochs etc.) determined by major events
  - a. E.g.: Proterozoic – Cambrian boundary
    - Cambrian explosion of life (543 m.y.)
  - b. Cretaceous - Tertiary (65 m.y.) Mass extinction of dinosaurs

B. History of life on Earth:

1. Precambrian = ~90% of Earth History
  - a. Archean
    - 3,800 m.y first record of primitive life (prokaryotes: bacteria, algae etc. dominate for 3 b.y.)
  - b. Proterozoic – simple life forms (bacteria, Vendian etc.)
2. Phanerozoic (visible life)
  - a. Cambrian 543 m.y.
    - i. Boom, life takes off with shelled invertebrates
    - ii. 505 m.y. First Fish:
  - b. Silurian
    - i. 400 m.y. ago first insects
    - ii. 440 m.y. ago First land plants
  - c. Devonian
    - 370 m.y. first sharks
  - d. Permian

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- i. Dinosaurs arrive and dominate through Cretaceous
- ii. 245 m.y. Permian-Triassic >95% of life on earth became extinct.
  - Cause: unknown
  - Supercontinent of Pangaea
  - Possible causes: restriction of environments (single continent), change in sea level, change in climate (favored) with change in CO<sub>2</sub>
- iii. 221 m.y. first mammals (Triassic)
- f. 65 m.y. Cretaceous-Tertiary;
  - i. Extinction of last dinosaurs, ammonites, others
  - ii. Likely boloid impact.
- g. Tertiary ~60 m.y. Marine mammals (whales, dolphin, seals etc.)
- h. Humans begin to develop in Holocene (10,000 years ago)