

## Chapter 11 (Geologic Time)

Knowing the chronology of events is crucial for interpreting geologic history. One of the early figures in geology, James Hutton, observed of geologic time that there is "No vestige of a beginning, no prospect of an end". Since Hutton's time (18th century) we have learned quite precisely that the beginning (at least for the earth) was 4.55 Ga (Ga stands for Giga annum or a billion [ $10^9$ ] years). But long before the age of the earth was known, geologists had worked out a time scale that covered about the past 550 Ma (Ma stands for Mega annum or a million [ $10^6$ ] years). They did this using the principles of relative time.

### Stratigraphic principles and relative time

- Laws of original horizontality, superposition, lateral continuity

- Unconformities

- Rock stratigraphic units

- Time stratigraphic units

  - Fossils and faunal succession

- Geologic time scale

  - Extinctions and major developments in Phanerozoic

  - see <http://www.ucmp.berkeley.edu/> for additional information on this

### Quantitative time

- Radioactivity: the concept of half life

- Important types of radioactive decay

- Practical applications: the isochron

- Determining the ages of rocks: what is being dated?

Anchoring the timescale - putting ages on events in rock record

## Relative Dating

Two Laws of Stratigraphy  
Superposition  
Original Horizontality  
Unconformities

## Stratigraphic classification

Rock-stratigraphic units

*formation* = strata that are sufficiently distinct from underlying and overlying units that they can be mapped over large area (based on material properties)

not particularly good since often not synchronous

Time-stratigraphic record

Faunal succession

= assemblages of plants and animals follow or succeed each other in time in a predictable manner

Correlation = determination of equivalence of time- or rock-stratigraphic units

temporal markers

ash beds

magnetic reversals

isotopic stratigraphy

e.g. oxygen isotopes

seawater Sr

## Geologic Timescale

Eons, Eras, Periods, Epochs

Hadean (>4.0 Ga) - Greek for "beneath the Earth"

Archean (2.5-4.0 Ga)- Greek for "ancient"

reducing atmosphere of methane and ammonia, oxygen 1% of present value

3.5 Ga - oldest bacteria microfossils

Proterozoic (0.545-2.5) - "earlier life"

1.8 Ga oxygen levels reached 15% of present value and rising  
evidence for higher oxygen contents  
Fe oxides in paleosols, red beds

Vendian (650-540)

soft bodied organisms



Phanerozoic (545 Ma - 0) "visible life"

Paleozoic "early animals" 545-245

bracketed by two of the most important events in animal life

Cambrian explosion - within few m.y. almost all living phyla developed

Permian extinction - wiped out 90% of all marine species

Mesozoic "middle animals" 245-65

Cretaceous-Tertiary extinction

Cenozoic

sometimes called age of mammals (but a bit of a misnomer)

flowering plants, insects, birds, teleost fish

*Camels Often Sit Down Carefully. Perhaps Their Joints Creak. Possibly Early Oiling Might Prevent Permanent Rheumatism.*

## Radioactive decay

relative ages from fossils can give quite good relative age resolution (~200 ky)

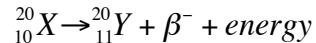
Bequerel (1896) discovered radioactivity in U

Rutherford (1905) first radiometric date using U mineral

Radioactive decay = spontaneous decay of unstable parent to daughter

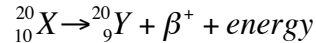
## Decay types

### 1) beta decay (n ->> p)

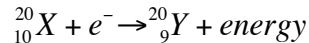


e.g.  ${}^{40}\text{K} \rightarrow {}^{40}\text{Ca}$ ,  ${}^{87}\text{Rb} \rightarrow {}^{87}\text{Sr}$ ,  ${}^{14}\text{C} \rightarrow {}^{14}\text{N}$

### 2) positron emission (p ->> n)

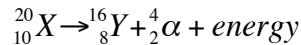


### 3) e capture (p ->> n)



e.g.  ${}^{40}\text{K} \rightarrow {}^{40}\text{Ar}$

### 4) alpha decay



e.g. U series elements

### 5) gamma ray emission

n,p unchanged

## Concept of half life

$$N = N_0 e^{-\lambda t}$$

where  $\lambda$  is the decay constant [ $\text{time}^{-1}$ ]

NB: unaffected by changes in chemical/physical environment

simple derivation of half life = time for 1/2 of parent to decay to daughter

$$\frac{N}{N_0} = 0.5 = e^{-\lambda t}$$

$$\ln(0.5) = -\lambda t$$

$$-.693 = -\lambda t$$

$$t = \frac{\lambda}{.693}$$

illustrate decay of parent and buildup of daughter

maximum useful - 7 half lives

## Half lives of some useful radioactive systems

system	half life	useful range	materials used
${}^{238}\text{U} \rightarrow {}^{206}\text{Pb}$	4.5 Gyr	> 10 m.y.	zircon, uraninite
${}^{40}\text{K} \rightarrow {}^{40}\text{Ar}$	1.3 Gyr	> 50 kyr.	muscovite, biotite, Hb, whole rocks
${}^{87}\text{Rb} \rightarrow {}^{87}\text{Sr}$	47 Gyr	> 10 m.y.	muscovite, biotite, Kspar
${}^{14}\text{C} \rightarrow {}^{14}\text{N}$	5730 yr	100-50 kyr	wood (organics), shells

## Practical application for dating - the isochron

- 1) In general no way to determine  $N_0$  (at time 0)  
what can be measured is the amount of daughter and amount of parent remaining  
 $N_0 = D + N$

$$N = N_0 e^{-\lambda t}$$

$$N = (D + N) e^{-\lambda t}$$

$$N e^{\lambda t} = D + N$$

$$N(e^{\lambda t} - 1) = D$$

- 2) Problem of initial daughter present in rock (use  $^{87}\text{Sr}$  example)

$$^{87}\text{Sr} = ^{87}\text{Rb}(e^{\lambda t} - 1) + ^{87}\text{Sr}_0$$

- 3) Practical measurement using isotope ratios  
in practice it's difficult to measure number of atoms  
mass spec - measure isotope ratio (using stable isotope in denominator)
- 4) Isochron to estimate initial ratio

$$\frac{^{87}\text{Sr}}{^{86}\text{Sr}} = \frac{^{87}\text{Rb}}{^{86}\text{Sr}}(e^{\lambda t} - 1) + \left(\frac{^{87}\text{Sr}}{^{86}\text{Sr}}\right)_0$$

note similarity with equation of straight line

how does this help?

igneous rock with various mineral phases

Rb partitions differently into some mineral phases

sketch isochron plot

## What makes a good radiometric clock?

- 1) resistant to changes in temperature and pressure  
parent and daughter not mobile (e.g. problem with K mobility in K/Ar)  
must be a closed system
- 2) need to be able to determine amount of initial daughter product  
isochron
- 3) well determined decay constants
- 4) automatically starting  
closure temperatures  
e.g. K/Ar system - Hb closure at  $450^\circ\text{C}$   
U/Pb zircons closure at  $800-900^\circ\text{C}$
- 5) multiple systems

## What event is being dated in a rock?

igneous and metamorphic rocks

time at which rocks cooled below closure temperature

sedimentary rocks

dates of formation of pre-existing ig or met rocks

special case of rapid erosion to put limits on sedimentary age

better methods of dating sediments

interlayered marker beds (ashes)

independent time markers (e.g. magstrat, isotope stratigraphy)