

STRATIGRAPHY

The study of layered rocks; their arrangement and history.

Classification and description of layered rocks = **Lithostratigraphy**

- based on the type of rock
- e.g., limestone, sandstone, shale, conglomerate

GEOLOGIC TIME

How can we use stratification to determine relative time?

(i.e., establish a sequence of geological events)

Nicolaus Steno's three axioms for interpreting stratified rocks:

1. principle of superposition
oldest strata lie at the bottom
2. principle of original horizontality
all strata were horizontal, or near-horizontal, when they were deposited
3. principle of original lateral continuity
strata originally accumulated across unbroken flat expanses

- beds thin laterally or end abruptly at edge of depositional basin
- erosion disrupts the original continuity (*e.g., a river*)

Other physical ways we can establish the relative sequence of geologic events:

4. cross-cutting relationships

faults and igneous intrusions are younger than the rocks they cut

5. inclusions

pieces of rock, including gravel or pebbles, incorporated into another rock are older than the host rock

Principles 1-5 apply to rocks in contact with one another or in close proximity,

- 1. How do we relate sequences of geologic events recorded in rocks that are widely separated from one another?*
- 2. How do we determine the relative age of a sequence of sedimentary rocks?*

Paleontology

Fossils provide a means to establish relative ages in rocks that are far apart
fossils also provide a basis for stratigraphy independent of rock type (= biostratigraphy)

William "Strata" Smith and Georges Cuvier:

principle of faunal succession

similar to principle of superposition

- distinguished rocks on basis of fossil content
- each assemblage of fossils represents a particular age
- evolution and extinction of organisms

a framework for stratigraphic classification based on **relative time** rather than rock type

= ***chronostratigraphy***

recognition of major stratigraphic units based on fossils

= ***geologic systems****

**led to the development of the geologic time scale*

What types of fossil organisms would be most useful for establishing the relative age of a rock unit?

- **rapid and wide dispersal**
*planktonic (floating) or nektonic (swimming);
or planktonic larval stage of benthic species*
- **geologically short-lived**
narrow stratigraphic range
- **easily preserved**
- **easily distinguished**
- **abundant enough to be found easily**
- **occurs in numerous environments**
("facies")

"index fossils", "guide fossils"
species used to define biostratigraphic zones

Fossil Zone = interval of strata characterized by a distinctive index fossil or assemblage of species

correlation based on fossil zones assumes *synchronicity*

Shelly fossils became abundant at a level called the **Cambrian age**,
older rocks lacking shelly fossils = "Precambrian"

Precambrian time is formally divided:

Hadean Eon (~4600 Ma to ~4000 Ma)
early Earth history without a preserved rock record

Archean Eon (~4000 Ma to ~2500 Ma)

Proterozoic Eon (~2500 Ma to 543 Ma)

Time since the appearance of shelly fossils:

Phanerozoic Eon (543 Ma to present)

"*Eon*" = largest formal unit of geologic time

"*Ma*" = mega-annums or millions of years

Phanerozoic time is subdivided into 3 Eras:

Paleozoic Era (543 Ma to 245 Ma)

"interval of old life"

Mesozoic Era (245 Ma to 65 Ma)

"interval of middle life" or "age of dinosaurs"

Cenozoic Era (65 Ma to present)

"age of modern life" or "age of mammals"

*the Eras of the Phanerozoic are separated by ***mass extinctions*** in the biota: *end-Permian and end-Cretaceous extinction events*

Each Era is subdivided into Geologic Periods

- Cambrian is the oldest Period of Phanerozoic Eon and Paleozoic Era
- Permian is the youngest Period of the Paleozoic Era
- Cretaceous is the youngest Period of the Mesozoic Era

Geologic Time Units: Time-Rock Units:

Era

Erathem

Period

System

Epoch

Series

Age

Stage

Geochronology

Chronostratigraphy

Geologic Systems

rock sequences with their contained fossils

= chronostratigraphic units ('time-rock units')

each of the Systems has a Type Locality and Type Section, and many Systems are also defined on the basis of a Boundary Stratotype; these serve as objective standards for correlation to other parts of the world

Geologic Periods

geologic time during which rocks of a System are deposited

= geochronologic units ('geologic time units')

relates to absolute age (in Ma), compared with relative age

THE GEOLOGIC TIME SCALE

- did not evolve from a master plan
- geologists from many countries working independently and in different basins and mountain ranges
- recognized natural breaks or changes in the rock record (lithology & fossils)
- represents the **synthesis** of the relative sequence of those changes that have shaped Earth history

Radioactivity and Absolute Age

'relative age'

- *superposition and cross-cutting relationships*
- *fossils*

'absolute age'

- *radiometric dating*

What is radioactive decay?

Many kinds of atoms in nature are unstable, they change spontaneously by radioactive decay *decay to lower energy level and new element*

What is an atom?

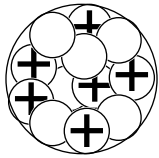
- the smallest particles of an element
nucleus (protons + neutrons) with orbiting electrons
- # protons = **atomic number** (an element)
- # protons + # neutrons = **atomic mass**

What is an isotope?

- same # protons (= same element)
- different # of neutrons
□ *different atomic mass*

Why are some isotopes radioactive?

Too many neutrons can create instability in the nucleus (i.e., exceed the stable size)



stable size
of C nucleus
6 protons and
6 (^{12}C) or 7 (^{13}C)
neutrons; not
stable w/8 (^{14}C)

Each type of radionuclide:

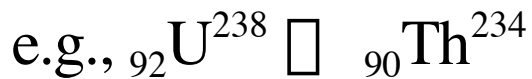
1. one mode of decay*
2. unique rate of decay*
 - independent of heat and pressure
 - unaffected by oxidation or reduction

**decay is a process of the nucleus only, not orbiting electrons*

1. Modes of decay

Alpha decay

nucleus emits an alpha particle consisting of 2 protons + 2 neutrons



Beta decay

nucleus emits a negatively charged particle (a neutron is transformed into a proton)



Electron capture

nucleus captures an electron from one of its orbiting shells (a proton is transformed into a neutron)

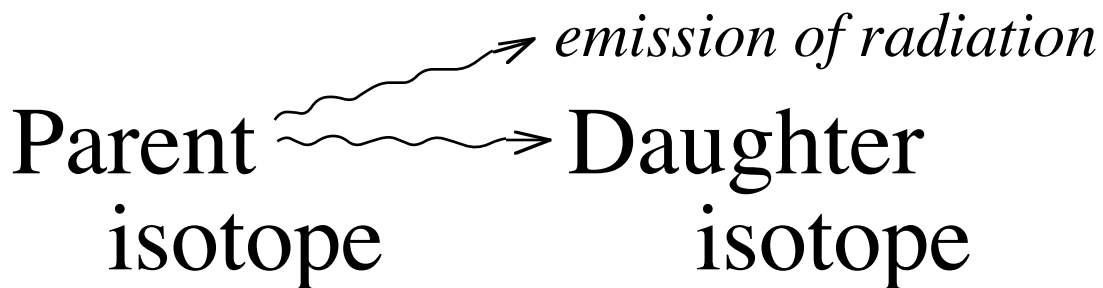


2. Rates of decay

radioactive decay occurs at a constant exponential rate*

***half-life** = time required for half the radioactive atoms to decay

*unique rate for each radionuclide



- decay constants have been determined experimentally
- measure ratio of D/P to calculate age*
= Radiometric Age

**use a Mass Spectrometer*

Assumptions:

1. mineral grains have remained closed
*neither parent nor daughter atoms have been added
or removed other than by radioactive decay*
2. no atoms of radiogenic daughter were
present when the mineral crystallized

Radiometric Dating Methods

Rb⁸⁷ - Sr⁸⁷: $t_{1/2} = 48.8$ b.y.

- Rb is trace element in many igneous & metamorphic rocks (e.g., **biotite, muscovite, K-feldspar, granitic whole rock**)

K⁴⁰ - Ar⁴⁰: $t_{1/2} = 1251$ m.y.

- K is minor element in felsic to intermediate igneous rocks (e.g., **biotite, muscovite, hornblende, K-feldspar, volcanic "whole rock", bentonite** = altered volcanic ash)
- also **glauconite** (authigenic, green clay mineral found in marine sediments)
- Ar is a noble gas and is typically lost during metamorphism (geol. clock is "reset")

U²³⁸ - Pb²⁰⁶: $t_{1/2} = 4470$ m.y.

U²³⁵ - Pb²⁰⁷: $t_{1/2} = 704$ m.y.

- most useful mineral: **zircon**, found in low concentrations in ign. & met. rocks
- also **sphene, apatite**

- **fission-track dating**: decay yields tracks in crystal lattice; enlarge tracks with acid etching; count tracks under microscope; irradiate mineral to complete decay process; count tracks again; ratio of natural tracks to lab tracks = age of mineral
- U^{234} - Th^{230} can be used to date $CaCO_3$ shells (e.g., **corals**) <300kyr (v. short half-life of U^{234})

C^{14} - N^{14} : $t_{1/2} = 5730$ yrs.

- can
- **wood, charcoal, cloth, bone, water, animal tissue**

In summary:

- radioactive decay is the only process in geology that operates at steady, statistically predictable rates
- measuring the products of radioactive decay (daughter isotopes) trapped in the crystal structure of minerals* is used to calculate the numerical age ("absolute age") of geological events

mostly minerals from igneous and metamorphic rocks (i.e., **crystalline rocks)*

exceptions; sedimentary rocks can be radiometrically dated if they contain:

- volcanic ash (bentonite), or
- glauconite*

**K-rich clay mineral that forms in some marine environments*

The Geologic Systems (Periods) of the Phanerozoic Eon are defined by what criteria?

- sedimentary rocks and their contained **fossils**

What materials are used for radiometric age dating?

- mostly mineral grains of **igneous** and **metamorphic** rocks

Why wouldn't you want to date a feldspar grain in a sandstone?

- sand grains are **detrital**; the ages would record the origin of the feldspar grain, not its accumulation in the sedimentary record

So, how has the Geologic Time Scale been constructed?

1. igneous rocks bracketing sedimentary rocks

- sediments accumulating on igneous or metamorphic "basement"
(yields maximum age for the strata)
- sedimentary rocks intruded by igneous dikes or sills
(yields minimum age for the strata)

2. sedimentary rocks interbedded with volcanic rocks

- lava flows
- ash fall deposits ("bentonites")

3. marine sedimentary rocks containing authigenic glauconite