Geologic Time and Stratigraphic Correlation

Geology 200

Geology for Environmental Scientists
Relative Time

• Geologists first worked out the sequence of events recorded in the rock record using the principles of relative time:
  – original horizontality
  – original lateral continuity
  – superposition
  – fossil succession
  – cross-cutting and intrusive relationships
  – unconformities
Original Horizontality - Sediments usually form flat-lying deposits on the earth’s surface.
Original Horizontality - Sedimentary rocks are horizontal because the original sediments were horizontal.
Original Lateral Continuity: a logical extension of original horizontality. Individual beds are the same age along an outcrop.
Unconformities: They are significant in that they are indicators of missing time in the rock record.
(a) Layered sedimentary rocks

Nonconformity
- Metamorphic rock
- Igneous intrusive rock
- Younger sedimentary

(b) Angular unconformity
- Older, folded sedimentary rocks

(c) Disconformity
- Brachiopod (290 million years old)
- Trilobite (490 million years old)
Angular unconformity

Disconformity

Nonconformity
James Hutton, 18th Century founder of Geology
Siccar Point, Scotland, where Hutton discovered the meaning of unconformities.
Siccar Point, Scotland, June 2004
Angular Unconformity in the Grand Canyon between Proterozoic and Cambrian Rocks. 100s of million years (MY) are missing.
Nonconformity between metamorphic and sedimentary rocks in the Grand Canyon
Disconformity within Pennsylvanian age rocks, West Virginia. The disconformity shows an older topography. Maybe only 1000s of years are missing from the rock record.
Can you interpret the sequence of geologic events using superposition, intrusive relationships, and cross-cutting relationships?
What is the sequence of events?

Dike and Sill
What is the sequence of events?
These various principles were used to construct the Geologic Time Scale (p. 199 in Text), which was done without any knowledge of the number of years involved.
Fig. 8.8. The standard geologic time scale
Time Units of the Geologic Time Scale

• Time can be separated into “pure” time and “rock” time. Rock time is divided into time stratigraphic units. Pure time is divided into geochronologic units.

• Time stratigraphic units sometimes parallel formation boundaries, but often they cross formation boundaries.
Time Units

- Geochronologic
- Era
  - Period
    - Epoch
      - Age
- Devonian Period

- Time Stratigraphic
- (Erathem)
  - System
    - Series
      - Stage
- Devonian System
Rock Units, not a part of the Geologic Time Scale

- Sedimentary rocks are divided into formations.
- Formations can be divided into members.
- Formations can be combined into groups.
Rock Units, cont’d

• Formation name consists of two parts:
  – Geographic name
  – Lithology or simply Formation

• Examples:
  – Burlington Limestone
  – Waynesburg Sandstone
  – Juniata Formation (no dominant lithology)
Rock Units, cont’d

- Example of rock unit divisions:
  - Conemaugh Group: 2 formations
    - Casselman Formation
    - Glenshaw Fm.: several members
      - Ames Member
      - Harlem Coal Mbr.
      - Pittsburgh Red Shale Mbr.
The Grand Canyon of the Colorado River in Arizona. Sedimentary rocks are divided into formations, which can be combined into groups.
Absolute Time:
Geochronology

Radiometric Dating: the source of the dates on the Geologic Time Scale
Radiometric Dating

• Actually a simple technique.
• Only two measurements are needed:
  1. The parent:daughter ratio measured with a mass spectrometer.
  2. The decay constant measured by a scintillometer.
Basis of the Technique

• Radioactive elements “decay.” Decay occurs as an element changes to another element, e.g. uranium to lead.
• The parent element is radioactive, the daughter element is stable.
• The decay rate is constant.
What is Radioactivity?

- Radioactivity occurs when certain elements literally fall apart.
- Usually protons and neutrons are emitted by the nucleus.
- Sometimes an electron is emitted by the nucleus, which changes a neutron to a proton.
- Sometimes an electron is captured.
What causes radioactivity?

• Carbon-14 is produced by cosmic ray bombardment of Nitrogen-14 in the atmosphere.

• All other radioactive elements were produced by supernova explosions before our solar system formed. This is called explosive nucleosynthesis.
Common Radioactive Elements, Parents and Daughters

- Carbon-14, $^{14}\text{C}$ → Nitrogen-14, $^{14}\text{N}$
- Uranium-235, $^{235}\text{U}$ → Lead-207, $^{207}\text{Pb}$
- Potassium-40, $^{40}\text{K}$ → Argon-40, $^{40}\text{Ar}$
- Uranium-238, $^{238}\text{U}$ → Lead-206, $^{206}\text{Pb}$
- Rubidium-87, $^{87}\text{Rb}$ → Strontium-87, $^{87}\text{Sr}$
Basis of the Technique

• As the parent element decays, its amount decreases while the amount of the daughter element increases. This gives us a ratio of parent:daughter elements.

• The decay rate is geometric rather than linear. Unaffected by heat or pressure.
Key Term

• Half-Life: the amount of time for half the atoms of a radioactive element to decay. Doesn’t matter how many atoms started, half will decay.
A mineral sample containing radioactive atoms, which decay into daughter atoms.

Percentage of radioactive and daughter atoms in the mineral.

Percentage remaining

100  50  0

1/2 remain  1/4 remain  1/8 remain

Percentage of radioactive atoms remaining

Age in half-lives

0  1  2  3  4  5  6
Radioactive Decay

Half Lives

Percent Nuclide

Parent
Daughter

0 2 4 6 8 10

0 20 40 60 80 100
On a log scale, geometric depletion plots as a straight line.
Radioactive decay for an isotope that has a decay constant of 2% a year (2.0x10^{-2}). The half life is 35 years.

Radioactive Decay, $\lambda = 0.02$/yr
Radioactive decay is the opposite of geometric growth by compound interest. At 2% interest the money doubles every 35 years.
Half-Lives

- Counting half-lives:
- Half-lives: 1  2  3  4
- Parent  : 1/2, 1/4, 1/8, 1/16, etc.
- Daughter : 1/2, 3/4, 7/8, 15/16, etc.
- P:D Ratio: 1:1, 1:3, 1:7, 1:15
Measuring Half-Lives

- Ratios of 1:3, 1:7, 1:15, etc. are for whole half lives, but any ratios can be measured; e.g. 1:4.2, or 8.6:1
The Decay Constant, $\lambda$

- The rate of decay is called the decay constant. It determines the half-life of a radioactive element.
- The decay constant is unique for each radioactive element.
- Measured with a scintillimeter.
The Decay Constant, $\lambda$

- Some values of the decay constant:
  - $^{14}\text{C}$: $1.21 \times 10^{-4}$ atoms per year
  - $^{235}\text{U}$: $9.72 \times 10^{-10}$ atoms per year
  - $^{40}\text{K}$: $5.34 \times 10^{-10}$ atoms per year
Calculating a Radiometric Date

- \( t = \frac{\ln (P+D)}{P} \)

\( \lambda \)

- What is the half life of Carbon-14?
- \( t = \frac{(\ln ((1+1)/1))}{1.21 \times 10^{-4}} \)
- \( t = \frac{(\ln 2)}{1.21 \times 10^{-4}} \)
- \( t = 5,728 \) years
Some Half Lives

- Carbon-14: 5,728 years
- Uranium-235: 713 MY
- Potassium-40: 1.3 BY
- Uranium-238: 4.5 BY
- Rubidium-87: 48.8 BY
Setting the Radiometric Clock

• When an igneous melt crystallizes, parent and daughter elements are chemically separated into different crystals.

• Further radioactive decay keeps the parent and daughter elements in the same crystal.
Setting the Radiometric Clock

• Individual crystals of the same mineral are dated to give the age of crystallization or cooling. Examples include zircon, muscovite, and biotite.

• Note that whole rock analysis would not give the age of cooling.
Setting the Radiometric Clock

- Carbon-14 is different in that it occurs in organic remains rather than in rocks.
- Clock is set when an organism dies.
- Carbon-14 is absorbed by all living organisms from the atmosphere or the food they eat.
- Useful for about 10 half lives, or only about 57,000 years.
Fig. 8.12. Carbon-14 radiometric clock

Space

Atmosphere

Neutron

Cosmic ray collides with atom in atmosphere and produces energetic neutron

Neutron collides with $^{14}\text{N}$ nitrogen atom

Radioactive $^{14}\text{C}$ Carbon produced

Carbon reacts with oxygen

CO$_2$ molecule with $^{14}\text{C}$

Absorbed by plants

Dissolves in water

Layers rich in organic carbon

Amount of $^{14}\text{C}$

0 y

5730 y

11,460 y

17,190 y

22,920 y

$^{14}\text{C}$ in dead plants and animals gradually decays to $^{14}\text{N}$
Cosmic Radiation

Cosmic rays enter the earth's atmosphere and collide with an atom, creating an energetic neutron.

When the neutron collides with a nitrogen atom, a nitrogen-14 (seven protons, seven neutrons) atom turns into a carbon-14 atom.

Neutron capture

Nitrogen 14

Carbon 14

Plants absorb carbon dioxide and incorporate carbon-14 through photosynthesis.

Animals and people eat plants and take in carbon-14.

Following death and burial, wood and bones lose C-14 as it changes to N-14 by beta decay.

Beta decay

Carbon 14

Nitrogen 14

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Materials dated using the Carbon-14 method

Charcoal, wood, twigs and seeds.
Bone.
Marine, estuarine and riverine shell.
Leather.
Peat.
Coprolites.
Soil.
Pollen.
Hair.
Pottery.
Wall paintings and rock art works.
Avian eggshell.
Corals and foraminifera.
Speleothems.
Blood residues.
Textiles and fabrics.
Paper and parchment.
Fish remains.
Insect remains.
Resins and glues.
Antler and horn.
Water.
Calibrating the Geologic Time Scale

- Radiometric dates from igneous rocks can be used to indirectly date sedimentary rocks and their fossils. Principles such as superposition and cross-cutting relationships come into play.
- Thousands of radiometric dates have been obtained.
Lava flow 1
80 MY old

Layer?
What we want to date

Cretaceous fossils

Lava flow 2
90 MY old

821
Lava flow 1
200,000 years old

80 MY old

Layer?
What we want to date

Cretaceous fossils

Lava flow 2
90 MY old
Examples of conodonts, the teeth of primitive chordates
The conodont animal from the Mississippian of Scotland
Age of the Earth: 4.6 BY

- The oldest rocks found on earth are 4.0 BY from NW Canada.
- 4.3 BY detrital zircons have been found in younger sandstones in Australia.
- Meteorites and moon rocks are 4.6 BY.
- Rocks older than 4.0 BY on earth have apparently been destroyed by weathering and plate tectonics.
4.40 BY zircon grain from Australia, found in 3 BY sandstone
Stratigraphic Correlation
The Grand Canyon of the Colorado River
in Arizona
Fig. 5.1. Layered sedimentary rocks exposed in the Grand Canyon, AZ
Stratigraphic correlation between Grand Canyon, Zion, and Bryce Canyon national parks allows construction of a composite stratigraphic column.
Stratigraphic correlation between Grand Canyon, Zion, and Bryce Canyon national parks allows construction of a composite stratigraphic column.
Zion Canyon National Park, Jurassic Sedimentary Rocks
Jurassic Navaho Sandstone, Zion National Park, wind-blown cross-bedding.
Bryce Canyon, Utah, Cretaceous sedimentary rocks
Correlation

• Determination of the equivalence of bodies of rock at different locations. There are two kinds of correlation:
  • Lithostratigraphic - matching up continuous formations.
  • Chronostratigraphic - matching up rocks of the same age. Usually done with fossils using biostratigraphy.
Correlation

- Over short distances, lithostratigraphic correlation is the same as chronostratigraphic correlation.
- Over medium distances, they are not the same.
- Over long distances, only chronostratigraphic correlation can be used.
Original Lateral Continuity: permits lithostratigraphic correlation
Lithostratigraphic and Chronostratigraphic Relationships
Sedimentary Facies
Modern Barrier Island

Sedimentary Facies in the subsurface

Lewis Shale

Parkman Ss

Cody Shale
Simple Lithostratigraphic Correlation: Facies Boundaries, not Time Lines
Grand Canyon Stratigraphy
Cambrian strata of the Grand Canyon: Tapeats Ss., Bright Angel Sh., and Muav Ls. Note the two time lines from biostratigraphy.
Correlated Bed contacts
Detailed lithostratigraphic correlation of the Cambrian strata of the Grand Canyon. Note the facies interfingering. (Stanley, Fig. 6.5)
Cambrian strata of the Grand Canyon: Note the two time lines from biostratigraphy.

- Interfingering of strata due to shifting of facies during deposition
- Bright Angel Shale
- Trilobite zone of Middle Cambrian age
- Tapeats Sandstone
- Trilobite zone of Early Cambrian age
- Unconformity

Time lines established by biostratigraphy
Depositional Model for the Cambrian strata of the Grand Canyon: Tapeats Ss., Bright Angel Sh., and Muav Ls.
Transgression, regression, and stratigraphic cycles. Fig. 5.26