Topic 13: Interpreting Geologic History

Topic 13 Section 1

Overview: the composition, structure, position, and fossil content of Earth's rocks give evidence of Earth's geologic history. Scientists believe that the Earth is 4.2 billion years old. A bedrock map shows the rock types that underlie a region and the age of the bedrock.

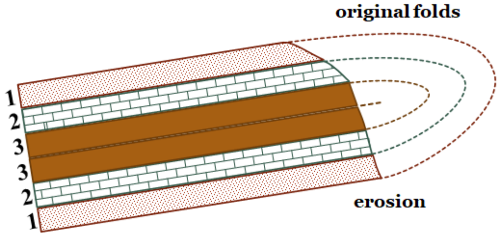
Relative dating of rocks and events

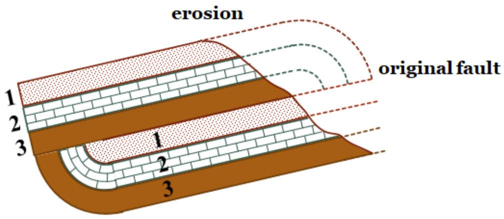
Relative dating determines the age of rocks or events compared to other rocks or events, usually in the same region

By comparison, absolute age refers to the age or rocks in years since their formation

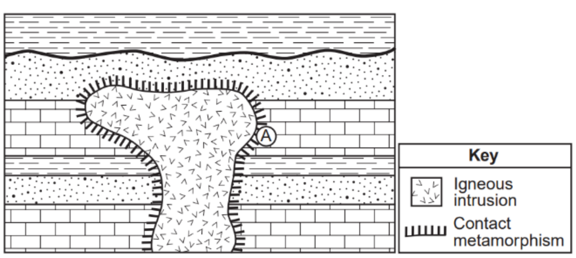
Description of methods used to determine relative age of rocks:

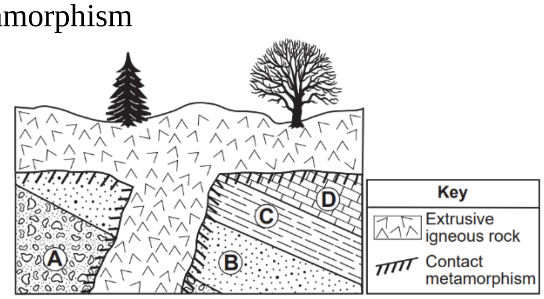
- Principle of Superposition – the bottom layer is the oldest, layers are progressively younger as you approach layers at the top
  - this is also true for extrusive igneous layers
  - this is not true for intrusive igneous layers
  - this is not true for folded layers, faulted layers, or overturned layers





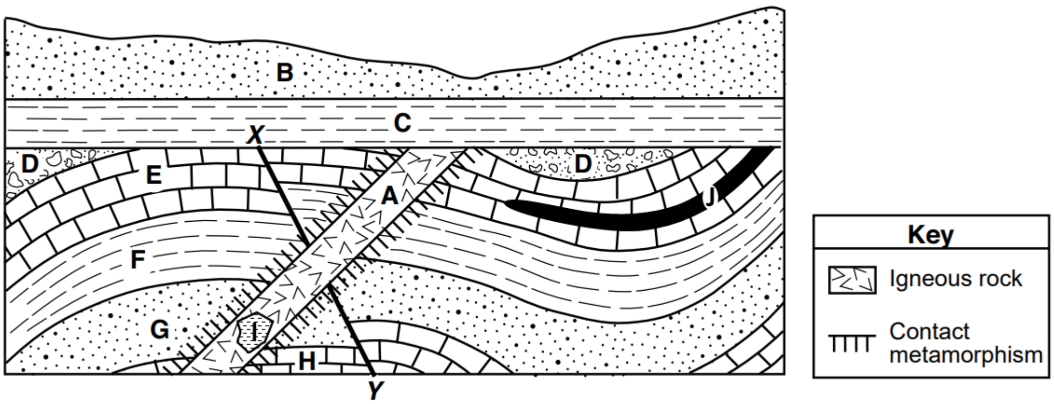
- Dating Intrusions, Extrusions, and Inclusions
  - intrusion – magma that squeezes between existing layers of rock then crystallizes
    - intrusions vary from a few cm to hundreds of km
    - intrusions are younger than rock they cut through
    - the heat of an intrusion causes contact metamorphism





  - extrusion – magma reaches the surface
    - extrusions include lava flows and volcanoes
    - extrusions are younger than rock beneath them but older than rock that forms above
    - extrusions show contact metamorphism only on the layer below

- inclusions – pieces of older rock that are picked up by magma or lava flow
  - some inclusions may melt and become part of the magma or lava
  - cooler magma or lava may have un-melted inclusions (which will show contact metamorphism



- Dating Rock Features and Cross-Cutting Relationships
  Intrusions (A), faults (X-Y), joints (near vertical lines in E), and veins (J) are types of cross-cutting relationships
  - a rock is older than any fault, joint, tilting, or fold
  - sediments are older than the rock but cement is younger than the rock
  - individual mineral crystals in igneous rock have different ages
    - larger, better developed crystals are generally older than smaller crystals
  - veins are younger than the surrounding rock

Topic 13 Section 2

Correlation

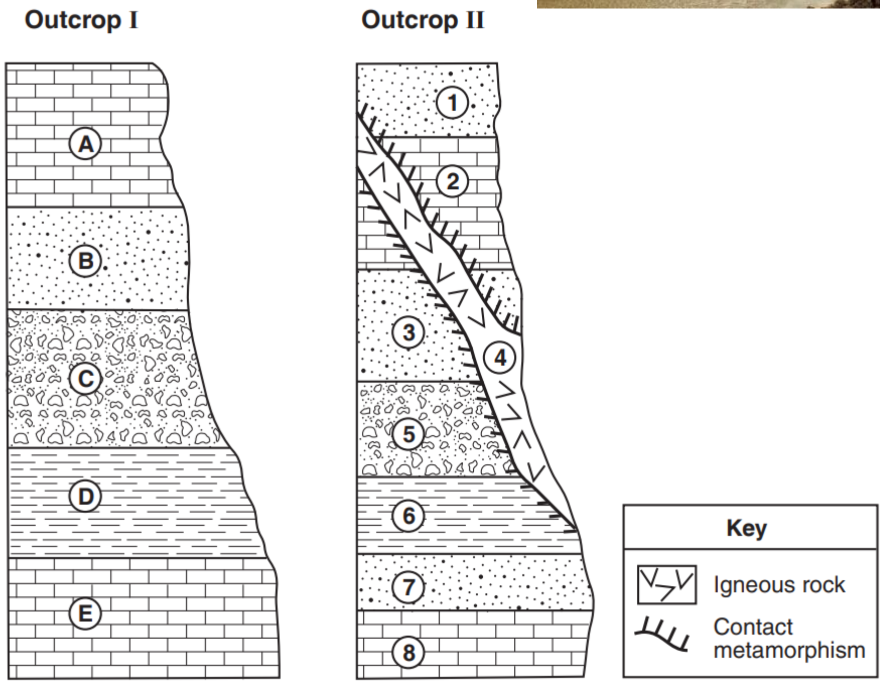
- makes it possible to show that rocks in different locations are the same age
- makes it possible to infer the sequence of geological events
- is useful in finding certain mineral resources (like coal)

Correlation can be established by:

- exposed bedrock
  - opposite banks of river cut or road cut outcroppings
  - accomplished by directly observing continuity of rock layers
  - direct observation is especially easy in arid regions (little vegetation)

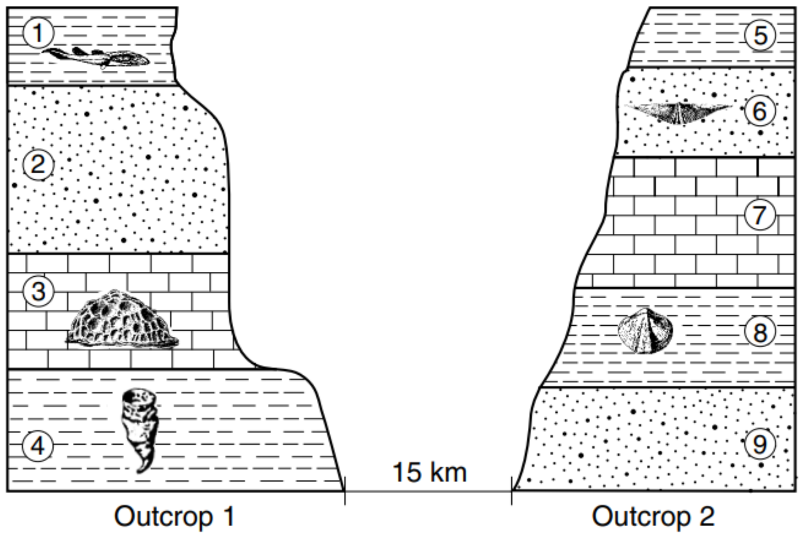
  Example: note the similar layers on both sides of the canyon

- similarities in rocks
  - when rocks are separated, tentative correlations can be made by similarities in mineral composition
  - only valid over short distances and even then this method is only tentative



Example: by correlation, it can be inferred that layer 7 is missing in Outcrop I

- use of index fossils
  - considered to be one of the best methods of correlation
    - fossils – remains or evidence of former living things (bones, shells, footprints, DNA)
      - rarely found in igneous rock due to melting and destruction of evidence
      - almost always found in sedimentary rocks
    - index fossils – require two conditions be met:
      - life form must have lived over a wide geographic area
      - must have existed only a relatively short period of time



Example: Which layers formed during the same geologic time period?

Page 9 of ESRT: U in 4 and Y in 8 are the same age and the rock is shale in both layers
V in 3 is older than Z in 6 and Z in 6 is older than R in 1.
The age of layer 7 is between Y in 8 and Z in 6 both by superposition and index fossils.

- volcanic ash and meteorite deposits
  - both volcanic ash and meteorite ejecta are shot far into the air and settle over large geographic regions in very thin layers with mineral contents that are easy to identify
    - these criteria meet those required of index materials
  - a large asteroid that hit the Yucatan peninsula 65 million years ago spread a thin layer of iridium (a very rare element on Earth) over much of Earth's surface
    - this event is the probable cause of the extinction of the dinosaurs

Topic 13 Section 3

Geologic History From the Rock Record

Fossils in rock layers help establish the relative age of those layers

- some life forms only existed for short periods of time
- some life forms existed for very long periods of time

Geologic time scale

Mainly on the basis of changing fossil evidence, geologists have divided geologic time into

- eons longest span of time
- eras
- periods
- epochs shortest span of time

When using pages 8 and 9 (Geologic History of New York State) in the ESRT, remember to open your tables up so you can see both pages at once – the periods and epochs span across both pages

Also note that the Era section expands the last 1.3 billion years of time so it takes up most of the pages

Also note that eras, periods, and epochs do not span equal amounts of time

- the Precambrian is a very long eon which accounts for 88% of all geologic time
  - Precambrian fossils are very rare
    - they are very small and have no hard body parts
    - they buried so deep that they have either melted or been metamorphosed

Unconformities

Unconformities – buried, eroded surfaces

- imply that at some time in the past, the surface was uplifted and eroded
- are evidence that part of the geologic history is missing
- there is often a loss of parallelism above and below the unconformity
  - strata below the unconformity were lifted, then sinking occurred followed by added sedimentary layers which are horizontal and parallel
- unconformities usually correlate with a time of orogeny
- unconformities where older strata are folded and eroded are fairly easy to identify but unconformities in parallel layers can be difficult to identify without fossils that can show a large gap in the time scale

Uniformity of process

Uniformity of process – a basic principle of geology that assumes geological processes of the past occur in the same manner geological processes occur today – the present is the key to the past

Example: A geologist in a tropical area finds a conglomerate layer that exhibits unsorted material with sub-rounded samples having parallel scratches. The geologist infers that this layer is the result of a glacier at some time in the past.

Uniformity of process not only assumes that present observations help us understand the past, but also assume that present observations may help us predict future events

Topic 13 Section 4

Absolute Dating of Rocks Using Radioactive Decay

Correlation gives relative age of rocks and events

Absolute dating is accomplished using radioactive decay methods

Isotopes and radioactive decay

Element – atoms with the same number of protons in the nucleus

Isotopes – atoms with the same number of protons (i.e., atoms of the same element) with different numbers of neutrons (i.e., having different masses)

The nuclei of some isotopes are stable while others are unstable and will spontaneously emit particles and energy as they *decay* to form a different isotope or element

- sometimes the product of nuclear decay or fission is also unstable and will also decay
- eventually, the *decay series* will form a stable isotope that will stop the chain

Uranium-238, U-238 or $^{238}_{92}U$, is the most important radioisotope used to date rocks

- U-238 begins a radioactive series that ends at the stable isotope Pb-206

Half-life – the time required for half the atoms of a radioactive sample to decay

- radioactive decay is a random event
- if large numbers of atoms, say 1 billion are present, the time required for 500 million atoms to decay, the first half of the atoms, will be equal to the time required for the next 250 million atoms, half of the remaining atoms, to decay
- each radioisotope has a unique half-life

Table showing the decay pathway and half-life of radioisotopes important to Earth science

Radioactive Decay Data

RADIOACTIVE ISOTOPE	DISINTEGRATION	HALF-LIFE (years)
Carbon-14	$^{14}C \rightarrow {}^{14}N$	5.7×10^3
Potassium-40	$^{40}K \rightarrow {}^{40}Ar$, $^{40}K \rightarrow {}^{40}Ca$	1.3×10^9
Uranium-238	$^{238}U \rightarrow {}^{206}Pb$	4.5×10^9
Rubidium-87	$^{87}Rb \rightarrow {}^{87}Sr$	4.9×10^{10}

Physical Setting/Earth Science Reference Tables – 2011 Edition

- carbon-14 is important for dating wood
- uranium-238 is important for dating rocks

Radioactive dating

Using the ratio of the parent (original) isotope and the daughter (decay result) isotope to calculate the time that has passed

How old is a piece of wood in which the amount of carbon-14 remaining is 12.5% of the carbon-14 found in living wood?

12.5% = 0.125 = 1/8 = ½ × ½ × ½ or 3 half-lives

3 half-lives × 5.7×10^3 years/half-life = 1.71×10^4 years or 17 100 years

After five half-lives, the amount of parent material will be 1/32 or 0.03125 or 3.125%

Noise (background radiation) and statistical errors prevent using more than five half-lives, so the effective limit for carbon-14 is just over 5 × 5700 years = 28 500 years or about 30 000 years

Topic 13 Section 5

Evolution of Earth and Life

Variations in fossils and environments

- most fossils are found in sedimentary rock
- formation of fossils is a rare event
- most fossilized life forms are now extinct
- the percentage of sedimentary rock studied for fossils is very low

Conclusion: most life forms from the past have not been identified

Example: uniformity of process and the discovery of coral fossils in Devonian rocks of the Allegheny Plateau in Western NYS

Today, corals grow in warm, shallow ocean water, therefore NYS was once at the bottom of a shallow ocean and was closer to the equator – comparing the data on page 9 of the ESRT shows that NYS was closer to the equator in the Devonian period 360 mya

Environment, evolution, and plate tectonics

Movement of plates over geologic time explains changes in environments of landmasses

Plate convergence causes mountain formation, e.g., the Himalayas

Rapid rise of magma at a mid-oceanic ridge explains rise of ocean levels that covers land

Environmental evolution and rock types

Hot, humid climate in the Carboniferous Period and swamps led to coal deposits today

Hot, dry environments in the Silurian Period led to drying of oceans with the formation of salt and gypsum deposits in NYS today

Fossils and the evolution of life

Species – a group of organisms which are similar enough to breen and produce fertile young

- a species will exhibit variations
- graphing a trait's variation will usually produce a bell curve

The theory of evolution is based on the assumptions that:

- changes in environment may favor a certain variation in a species
- over time, members with unfavorable variations will become extinct
- genetic coding for favorable variations is passed on
- over time, members with favorable genetic coding may no longer be able to interbreed with earlier varieties of a species thereby forming a new species

Evidence in the fossil record indicates that evolutionary changes such as those above do not occur at the same rate – very rapid changes are known as *punctuated evolution*

Rapid evolution of life after an impact event

There is evidence that a large asteroid hit the Yucatan Peninsula at the end of the Mesozoic Era (with similar evidence of similar events at the ends of the Triassic, Permian, and Devonian Periods)

Large strikes like this would cause:

- extensive fires reducing vegetation supplies
- dust in the atmosphere lasting 10-20 years reducing insolation causing cold temperatures and loss of photosynthesis – the basis of food supply
- these changes would have favored small mammals (warm blooded with fur)

Early evolution on Earth

Inferences about Earth's early history (see ESRT, Geologic History of NYS, pages 8 and 9)

- radioactive dating of rocks on the Earth and Moon indicate an age of 4.6 billion years
- frequent impact events and radioactive decay during Earth's formation caused melting
- materials and elements separated by density – more dense material in the core, lighter silicates formed early crust, early gases largely escaped into space
- eventually, solid crust with tectonic movement resulted, evidence indicates 4.2 bya – outgassing from volcanic activity formed a second atmosphere, H_2O, CO_2, and N_2
- with more cooling, water precipitation formed oceans – sedimentary rocks more than 4 billion years old give evidence of early oceans – single celled organisms occur and the oceans begin to become salty, the result of chemical weathering
- 3.5 billion years ago, stromatolites (algae and bacterial colonies) used CO_2 and formed free O_2 – the atmosphere changed from mostly CO_2 to N_2 and O_2
- increased O_2 caused the formation of reddish Fe_2O_3 (iron oxide) covering the Earth with red rust much like the surface of Mars between 3.5 and 2.8 billion years ago
- 2.8 billion years ago, iron was mostly all oxidized and O_2 levels in the atmosphere began to rise – ozone layer probably formed at this time
- in the Precambrian Era, multi-celled life forms appear with very little fossil evidence (soft bodies) – in early Cambrian Period (Paleozoic Era), life forms developed hard body parts with much more fossil evidence and ancestors that resemble modern life forms