Geologic time and the last part of Metamorphic Rocks
The last part of the metamorphic notes is at the end of these notes

S=slide

S1 Geologic Time

S2 James Hutton (18^{th} century) recognized the how immense Earth's history is and the importance of time in geologic processes

A geologic scale was developed based on the sequence of relative dating principles
The discovery of radioactivity led to the ability to put fairly accurate dates on many geologic events

In 1869 John Wesley Powell (shown) led a trip down the Grand Canyon – 'book of geologic events' - millions of years of geologic of Earth history exposed in the cliffs. Later head of the USGS

S3 How do we measure time?

Astronomical observations
- lunar cycle
- solar cycle
- pulsars

Mechanical methods
- sun dial
- water clock
- clock
- watch

Some processes and time in years are shown here

S4 Historical methods of showing changes over time are shown by old maps like this of Wellfleet Bay, Cape Cod, Massachusetts made in 1887 and updated in 1988 (brown areas showing sand, silt and mud).

S5 Key Concepts
1.Know what relative dating means and how it is used to understand geologic time
2.Know the laws and principles
3.Correlation of rock layers
4.Fossils, types, preservation, and correlation
5.How radioactivity is used to determine the age of a rock
6.Know what the geologic time scale is and key divisions

S6 Relative Dating Principles

Relative dating- placing rocks in their proper sequence of formation

- cannot tell us how long ago something happened

- can tell us the order of events

S7 Law of Superposition
Nicolas Steno – 1636-1686, credited with being the first to recognize a sequence of events

In un-deformed sedimentary rocks the oldest rocks are on the bottom
-each bed or strata is younger than the one below – includes volcanic ash and lava flows

S8 Law of Superposition
(Grand Canyon images)

S9 Principle of Original Horizontality
Steno again
Sedimentary rocks are generally deposited in a horizontal position.
If the rock layer is flat then it has not been disturbed and has its original horizontality – not folded or inclined
If folded or inclined – must have moved there after deposition

S10 Principle of original horizontality - sediments are deposited in horizontal beds

Principle of superposition - beds on the bottom are older than the beds on the top

S11 Principle of Cross-Cutting Relationships
A fault or dike is younger than the rock that is affected

The fault or dike must have occurred after the sedimentary layer was deposited or after the igneous rock was emplaced or the rock was metamorphosed

S12 Inclusions
Inclusions are pieces of a rock unit that is included in another rock unit
The source rock for the pieces must be older than the rock that contains the pieces
The rock with the inclusions (pieces) is younger than the adjacent rock

S13 Two types of inclusions are shown here

1.The host fragments in the pluton

2.The igneous pieces in the sedimentary rock above

S14 Black rocks are un-melted pieces of the host rock in a pluton

S15 Magma intrudes the host rock – pieces of the host are incorporated into the magma, some host melts and some remains as xenoliths (pieces of the host rock).

S16 Uplift of the rock through mountain building processes
Weathering and erosion removes some of the host and igneous rock

S17 Sediments are deposited on top of the eroded surface and over time lithified.
Pieces of the older rock are inclusions in the sedimentary rock

S18 Unconformities
Conformable layers –deposited without interruption

Unconformities - missing time
    rock units are separated by either nondeposition or erosion
    uplift and erosion followed by subsidence and sedimentation

S19 Types of Unconformities
Angular unconformity – tilted or folded sedimentary rocks overlain by younger, flat-lying strata
Disconformity – strata (sedimentary layers) are flat on both sides of the unconformity - more common
Nonconformity – older igneous or metamorphic rock overlain by sedimentary rock – due to uplift and erosion

S20 Using Relative Dating Principles

S21 Correlation of Rock Layers
Correlation – matching rocks types from one place with rocks from another place
Over short distances can note a distinctive rock layer within a sequence of layers or by identifying distinctive or uncommon minerals

S22 Fossils
Fossils are the remains or traces of prehistoric life – in sediment and sedimentary rock

Paleontology – study of fossils

Types of fossils include parts of the organism through traces of the organism left in the sediment

S23 Petrified – 'turned to stone' small internal cavities and pores of the original structure are filled with precipitated minerals
Replacement is when the cell walls and other solid material is removed and replaced with mineral material

S24 Molds reflect the shape and surface markings of the organism and does not reveal any information about the internal structure. Casts are hollow spaces that were filled with mineral material.

S25 Carbonization is when delicate organisms, such as leaves or insects, are covered with fine sediments that are compressed forcing out all liquid and gaseous components leaving a carbon residue.

S26 Impressions are common fossils that can show details of the organism

S27 Amber is the hardened resin of ancient trees that may contain trapped insects or small organisms.

S28 Tracks – animal footprints made in soft sediment that was later lithified

S29 Indirect examples of prehistoric life
Burrows – tubes in sediment, wood, or rock made by an animal. The holes later become filled with mineral mater and preserved
Coprolites – fossil dung and stomach contents
Gastroliths – polished stomach stones used in the grinding of food by some extinct reptiles

S30 Fossil Preservation
Very few organisms that lived in the past have been preserved as fossils
Two conditions needed to preserve are:
  rapid burial
  possession of hard parts
Traces of soft-bodied organisms exist but are not common

S31 Fossils and Correlation
William Smith – English engineer and canal builder – noticed that strata could be indentified by the fossils and the fossils were different above and below the layer
Principle of fossil succession – *Fossil organisms succeed one another in a definite and determinable order, and therefore any time period can be recognized by its fossil content.*

S32 Index Fossils
Fossils that are widespread geographically and are limited to a short time span of geologic time
Presence of these fossils provides a method to match rocks of the same age

S33 Groups of fossils can be used when the rock does not contain an index fossil.

S34 Fossils can also provide information about the past environment
  thick shells are needed to withstand pounding waves and thin shells probably indicate deeper and calmer offshore water

Water temperature can be inferred based on where similar organism live today – corals in warm water today means likely warm water environment in the past

S35 Radioactivity
Basic atomic structure – proton, neutron, and electron – isotope –different mass number
Uranium has 92 protons – atomic number = 92, neutrons vary so it has 3 isotopes U-234, U-235, and U-238 all look the same and have same chemical reactions
Radioactivity – in some isotopes the nuclei are unstable and spontaneously break apart (decay), process is radioactivity

S36 Three parts of an atom
Atomic number = # of protons in nucleus

Protons + neutrons = mass number

Isotope = element with different # of neutrons -> different mass number

S37 Types of radioactivity
Alpha particle = 2 protons and 2 neutrons ->from emission mass number drops by 4, atomic number by 2

Beta particle, an electron is given off from the nucleus -> because a neutron is a proton and electron the atomic number increases by 1

Electron capture by nucleus -> electron combines with proton to form neutron atomic number decreases by 1

S38 Half-life
The time required for one-half of the nuclei in a sample to decay

The isotope that is unstable is called the parent and the atom that is produced from the decay is the daughter

S39 Radiometric Dating
Percentage of radioactive atoms that decay in one half-life remains 50% but the actual number of atoms that decay decreases and the number of daughter atoms produced increases

Five radioactive isotopes are used in dating ancient rocks

S40 Potassium-Argon
Analytical techniques make it possible to measure small amounts

used in part because of the minerals with K (potassium)- micas and feldspars

Clock starts when mineral forms from melt

Sources of errors – must remain a closed system – no addition or loss of parent or daughter due to processes other than radioactivity

Argon is a gas and leave the mineral easily

Heating a sample can reset the radioactive clock due to changes in parent/daughter composition

S41 Carbon-14 Dating
Used for recent events – half-life is only 5,730 years – can only be used for events to 70,000 years ago
Carbon 14 is produced in the upper atmosphere (cosmic ray bombardment)
While an organism is alive the carbon 14 is constantly replaced – dating when it died – only used for organic material

S42 Upper atmosphere bombardment
Decay upon death of organism by Beta emission

S43 Importance of Radiometric Dating
Radiometric dating methods have been used to determine past events in Earth's history
Oldest rocks – 3.5 billion years
Oldest mineral is a zircon – 4.3 billion years found in a sedimentary rock implying the source rock was older

S44 Tree Rings to Date the Recent Past
Trees in temperate regions add a new layer of wood under the bark
Characteristics of ring reflect environmental conditions
Favorable conditions – wide ring, unfavorable- narrow ring
Trees growing in same region at same time and similar patterns
Single growth ring added every year

S45 If the year a tree is cut is known – count the rings to determine age – can be used to determine change in landscape

Compare ring patterns in an area – cross dating

S46 Structure of the Time Scale
Geologic history with units of varying magnitudes
Eons – greatest expanses of time
Eras – bounded by significant worldwide changes in life forms
Periods – lesser changes in life forms

S47 Difficulties in Dating the Geologic Time Scale
Not all rocks can be dated by radiometric methods
Sedimentary rocks generally can not be dated by radiometric methods but the ages of the minerals or pre-existing rock, volcanic, igneous, or metamorphic rock in the area can be dated and the age of the sedimentary rock inferred

S48
When do the clocks begin?

Measurements are of the time the minerals were formed or the organism died for carbon 14.
Igneous = when the mineral crystallized
Metamorphic = when the mineral reformed
Sedimentary = generally no
Fossils in sedimentary = when died

Continuation of metamorphic notes
S48
Hydrothermal metamorphism

S49
Hydrothermal metamorphism of a calcareous siltstone: metasomatic alteration (to amphibole, pyroxene, and garnet) along fractures that transmitted the fluids.

S50
Black-smokers along mid-ocean ridges

S51
Metamorphic Environment
Burial or Subduction Zone
Thick accumulations of sedimentary strata in a subsiding basin
Confining pressure and geothermal heat cause low grade metamorphism
Rocks carried to depth in subduction zones – differential stress

S52
Metamorphic Environment
Regional Metamorphism
Associated with mountain building
Occurs where plates are deformed along convergent margins
Crust is thickened
Regional metamorphism typically results from large-scale lateral crustal compression like mountain-building.

S53

Cataclastic metamorphism -- mylonite

1. Occurrence
   a. Along faults
   b. Occurs where strain-rates are very high
   c. Temperature & Pressure variable

S54
Mylonite, metamorphosed from a granite by high pressure due to fault shearing. Great Slave Lake shear zone, NW Territories, Canada.

S55
Other Metamorphic Environments
Impact metamorphism or shock metamorphism
Meteorites impact the Earth's surface – energy is released upon impact as heat and shock waves pass through the surrounding rock
Rock is pulverized and may be melted – dense form of quartz called coesite produced and tiny diamonds

S56
Metamorphic Zones
Textural variations –coarsening of grain size when parent rock is clay or shale
    slate – phyllite- schist – gneiss
Index minerals and metamorphic grade
    parent rock is shale – chlorite – biotite – garnet- staurolite – sillimanite (index minerals)
Migmatites – highest grade – partially melted

S57
Index minerals associated with the metamorphism of shales from low- to high-grade.
S58
Regional metamorphism of a shale showing the various metamorphic zones based on index minerals.

S59
Diagram showing the temperature and pressure conditions at which three index minerals composed of Al_2SiO_4 occur.
Geothermometers and geobarameters

S60
Metamorphic facies grouped according to the temperatures and pressures at which they form.

S61
Pressure-temperature pathway for a rock body undergoing metamorphism along a subduction zone

S62

Key Concepts

1. Driving mechanisms of metamorphism – temperature, pressure, and chemically active fluids

2. Metamorphic textures – foliated (slate, schistosity, gneissic) and nonfoliated

3. Rock classification

4. Metamorphic environments – contact or thermal, hydrothermal, burial and subduction zone, regional, cataclastic, and impact

5. Metamorphic zones - textural variations and index minerals and grade