Topic 11: Earth Materials – Minerals, Rocks, and Mineral Resources

Topic 11 Section 1

Overview: mineral resources make possible over 95% of the products we use and enjoy today (including cars and computers). Fossil fuels still comprise much of our energy resources. Rocks make up the ground and solid surface of the Earth. Weathering and erosion form the landscape features we need (like soil) and enjoy (like sandy beaches and mountain trails).

Minerals

Minerals have characteristic physical and chemical properties (hardness, density, and color)

Mineral – a naturally occurring, inorganic, crystalline solid having a definite chemical composition

Minerals are not formed by people (synthetic rubies)

Minerals are not made by life forms (fossil fuels or pearls)

Minerals have a specific, repeating, arrangement of atoms called a *crystal structure*

- every mineral has a unique crystal structure
- x-ray diffraction can be used to identify crystal structures
- some minerals contain only one element
- minerals that contain more than one element have definite composition (integer ratios of each element in the compound)
- all minerals have unique properties that can be used for identification (see NYS ESRT page 16)

Relation of minerals to rocks

All minerals are rocks, not all rocks are minerals

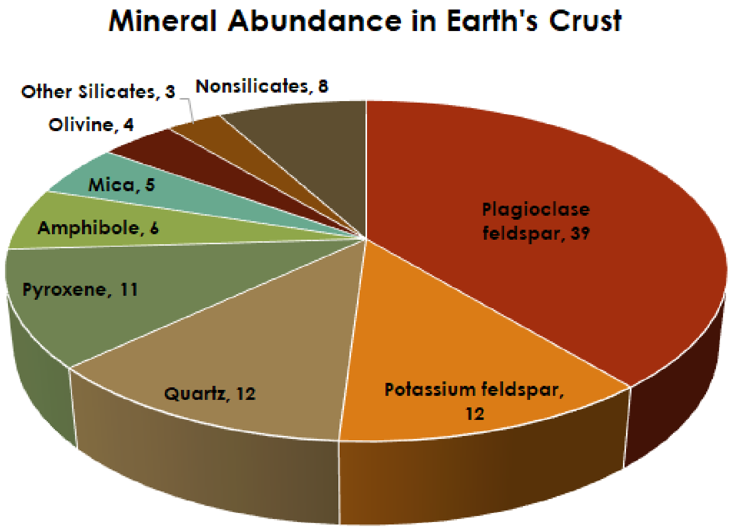
Rock – naturally formed solid that is part of the Earth (or any celestial body)

- a large percentage of rocks are composed of minerals
- glassy rocks are not minerals because the atoms in glasses are not arranged in a specific pattern
- many rocks are composed of more than one mineral
- single mineral rocks may not be minerals (they may be glasses, eg.)

Three schemes for rock identification:

- sedimentary (NYS ESRT page 7)
- metamorphic (NYS ESRT page 7)
- igneous (NYS ESRT page 6)

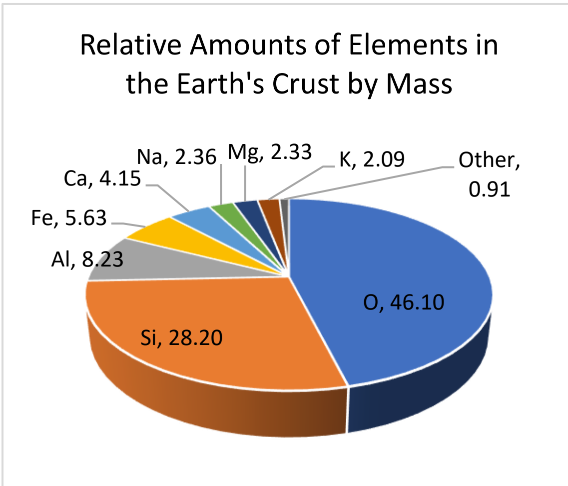
There are only 20 to 30 common minerals that form almost all rocks on the Earth

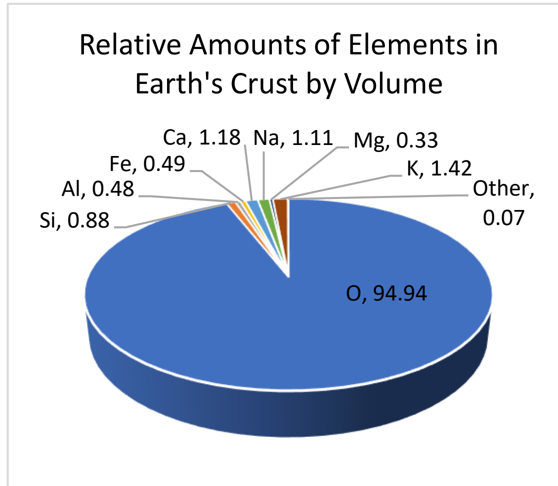


Element composition of Earth's crust

- 99% of Earth's crust is composed of only 8 of the 90 naturally occurring elements
- oxygen is the most abundant element by both mass and volume
- silicon is the second most abundant element by mass but potassium is the second most abundant element by volume

Relative amounts of elements in Earth's crust:





Mineral crystal structure

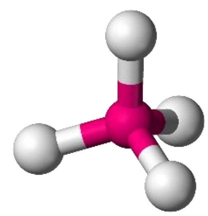
The arrangement of atoms that comprise a mineral, or its crystal structure, is responsible for many of the chemical and physical properties of that mineral

Most minerals are silicates that have various arrangements of a silicon-oxygen tetrahedron

The differing arrangements of this Si-O tetrahedron result in different breaking patterns

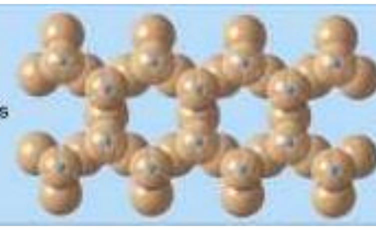
Fracture – random breaking with no smooth or planar surfaces

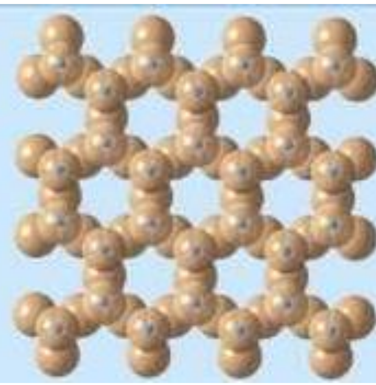
Cleavage – smooth breakage along internal crystal planes



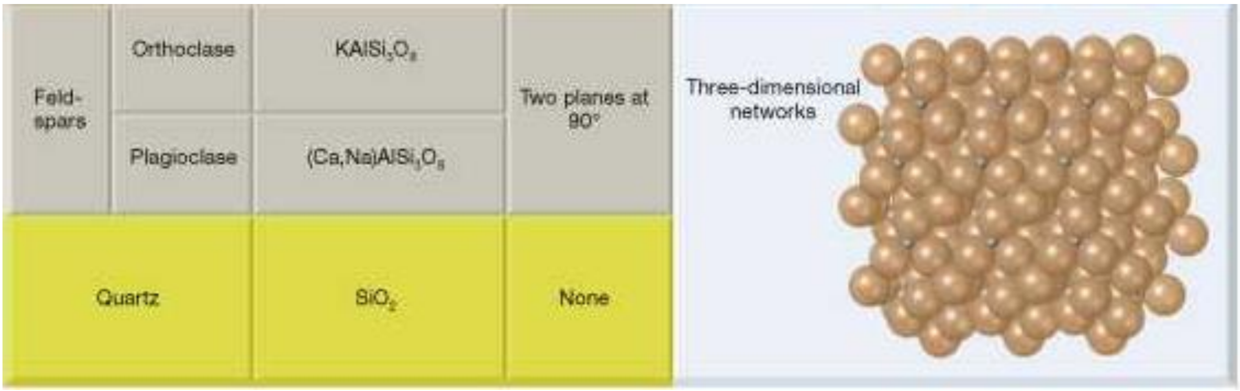
Mineral	Idealized Formula	Cleavage	Silicate Structure
Olivine	$(Mg, Fe)_2SiO_4$	None	Single tetrahedron 


Pyroxene group (Augite)	$(Mg,Fe)SiO_3$	Two planes at right angles	Single chains 


Amphibole group (Hornblende)	$Ca_2(Fe,Mg)_5Si_8O_{22}(OH)_2$	Two planes at 60° and 120°	Double chains 


Micas	Biotite	$K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$	One plane	Sheets 
	Muscovite	$KAl_2(AlSi_3O_{10})(OH)_2$		





Feld-spars	Orthoclase	$KAlSi_3O_8$	Two planes at 90°	Three-dimensional networks
	Plagioclase	$(Ca,Na)AlSi_3O_8$		
Quartz		SiO_2	None	

Mineral formation:
- Crystallization – precipitation of halite by evaporation
- Recrystallization – metamorphic transformation of limestone to marble

Mineral properties and identification
- Based on chemical and physical properties
  - Two most important things that determine chemical and physical properties:
    - crystal structure
    - composition
  - X-ray diffraction is the most accurate method to identify minerals
    - diffractometers are too big
    - diffractometers are too expensive to be practical
  - Identification in the field is done by observing mineral characteristics
    - Refer to Physical Setting/Earth Science Reference Tables – 2011 edition, page 16
    - color – although obvious, color alone is usually not useful because:
      - many minerals have similar color, many are clear and colorless
      - small impurities changes the color of a single mineral (ruby and sapphire)
    - streak – the color of finely crushed powder on a white or black ceramic tile
      - streak color is more consistent than mineral color
    - luster – the shine or reflection from an unweathered mineral surface
      - nonmetallic – most minerals have nonmetallic luster
      - metallic – pyrite, galena, native metals
    - hardness – resistance to scratching, usually measured on the Mohs scale
      - minerals that scratch glass are hard, those that do not are soft
    - density – a non-destructive test (unlike hardness and streak)
      - minerology often uses specific gravity instead of density
      - specific gravity compares density to the density of water so it is unitless

- cleavage – breaking to form smooth, parallel surfaces
  - minerals that do not exhibit cleave break in uneven zones called *fracture*
    fracture can be irregular, fibrous, or chonchoidal
  - some minerals exhibit both cleavage and fracture on difference sides or faces
- crystal structure – not to be confused with molecular structure or molecular crystal structure although crystal structure is a result of molecular structure
  - minerals exhibit crystal structure outwardly only when mineral grains have room to grow freely
  - minerals with different internal crystal structure can exhibit the same outward crystal form
  - the same mineral can exhibit multiple outward crystal forms
- other properties can also be used such as:
  - the chemical reaction of marble or limestone with acid to form CO_2
  - dolomite only reacts with HCl if the dolomite is powdered first
  - thin pieces of muscovite and biotite mica are translucent and flexible
  - other properties can be found on Properties of Common Minerals, ESRT page 16
  - note the distinguishing characteristics of calcite and dolomite on ESRT page 16
  - note the distinguishing characteristics of calcite and dolomite on ESRT page 16

Topic 11 Section 2

Rocks

A rock is any naturally formed solid either on Earth or anywhere in the universe

Please note that:

- rocks do not have to have a crystal structure
- all minerals are rocks, not all rocks are minerals – most rocks contain many minerals
- rocks can be formed naturally by living organisms – amber and corals, e.g.
- some rocks are a single mineral but are *glassy* or have no crystal structure

Rocks fall into three types:

- sedimentary – the accumulation of sediments
- igneous – natural lava or magma cools and hardens
- metamorphic – pre-existing rock is changed by heat and pressure without melting

Sedimentary rocks

Formed from sediments of pre-existing and weathered rocks or organic materials by various processes at or near the surface of the Earth

Clastic sedimentary rocks – formed from solid fragments of weathered rocks or sediments (called clasts) that are held together by cementation and/or compaction

- cementation – loss of water causes precipitation of minerals that glue the clasts together
- compaction – crustal movement or the weight of overlying water or sediments compresses clasts reducing pore space and water causing rock formation
    - shale and bituminous coal form by compaction only but most clastic rock forms by a combination of compaction and cementation
- chemical action – liquid water on Earth’s surface always contains dissolved minerals
    - when dissolved minerals precipitate out of the water, they form a mass of intergrown or interconnected crystals of one or more minerals called *chemical sedimentary rock* or an *evaporite*
    - precipitation can result from evaporation, saturation, or changes in temperature
- organic processes – when life forms withdraw dissolved minerals, it is termed chemical, not mineral, precipitation – examples include shells and corals
    - such rocks are termed *bioclastic sedimentary rock*

Characteristics of sedimentary rocks

Features that distinguish sedimentary rocks from igneous and metamorphic rocks are:

- most sedimentary rocks are clastic
- most clasts are rounded due to running water, wind, or ocean currents
- the clasts are often sorted into a small range of sizes due to horizontal sorting
- organic sedimentary rock often contains *fossils*
- strata or bedding are one of the most characteristic features of sedimentary rocks
- inclusions – mud cracks or rain drop impressions indicate formation at the surface while ripple marks may indicate sand dune or ocean bottom formation
- chemical sedimentary rocks are not clastic, but are formed by interconnected crytals

Identifying sedimentary rocks

The more common clastic sedimentary rocks are identified on the basis of the sediments of which they are composed

Texture (grain size) is the main factor used for identification and classification

Sand sized grains comprise sandstone

Silt sized grains comprise siltstone, etc., refer to ESRT at the top of page 7

Rounded sediments larger than sand form *conglomerates*

Angular sediments larger than sand form *breccia*

Nonclastic sedimentary rocks are predominantly composed of a single mineral and are treated as minerals

Bioclastic limestone will fizz on exposure to acids

Powdered dolostone will also react with acid to form CO_2 gas bubbles

Limestone can be crystalline or bioclastic

Coal is bioclastic

Igneous rocks

Form when natural, molten (liquid) rock-forming material cools and turns into a solid

Liquid rock beneath the surface is called *magma*

When magma reaches Earth's surface, it is called *lava*

Intrusive igneous rock – sometimes called *plutonic* igneous rock – solidifies beneath the surface of the Earth

- forms bodies called *intrusions* that range from finger size to the size of a state
- intrusions cool slowly
- intrusive rock has large or coarse crystal sizes

Extrusive igneous rock – sometimes called *volcanic* igneous rock – solidifies on the surface of the Earth

- forms bodies called *extrusions*, the most common extrusions are volcanoes and lava flows
- extrusions cool quickly
- extrusive rock is fine grained or has small crystal sizes, sometimes so small that it is not even crystalline but is called *glassy* instead

Mineral texture depends on:

- crystal size
- presence of glass
- presence of rounded pores called *vescicles*

The features comprising texture are controlled by:

- cooling time
  - fewer silicates (SiO_2) increases cooling time
  - more water increases cooling time
  - higher temperature increases cooling time
  - higher pressure increases cooling time

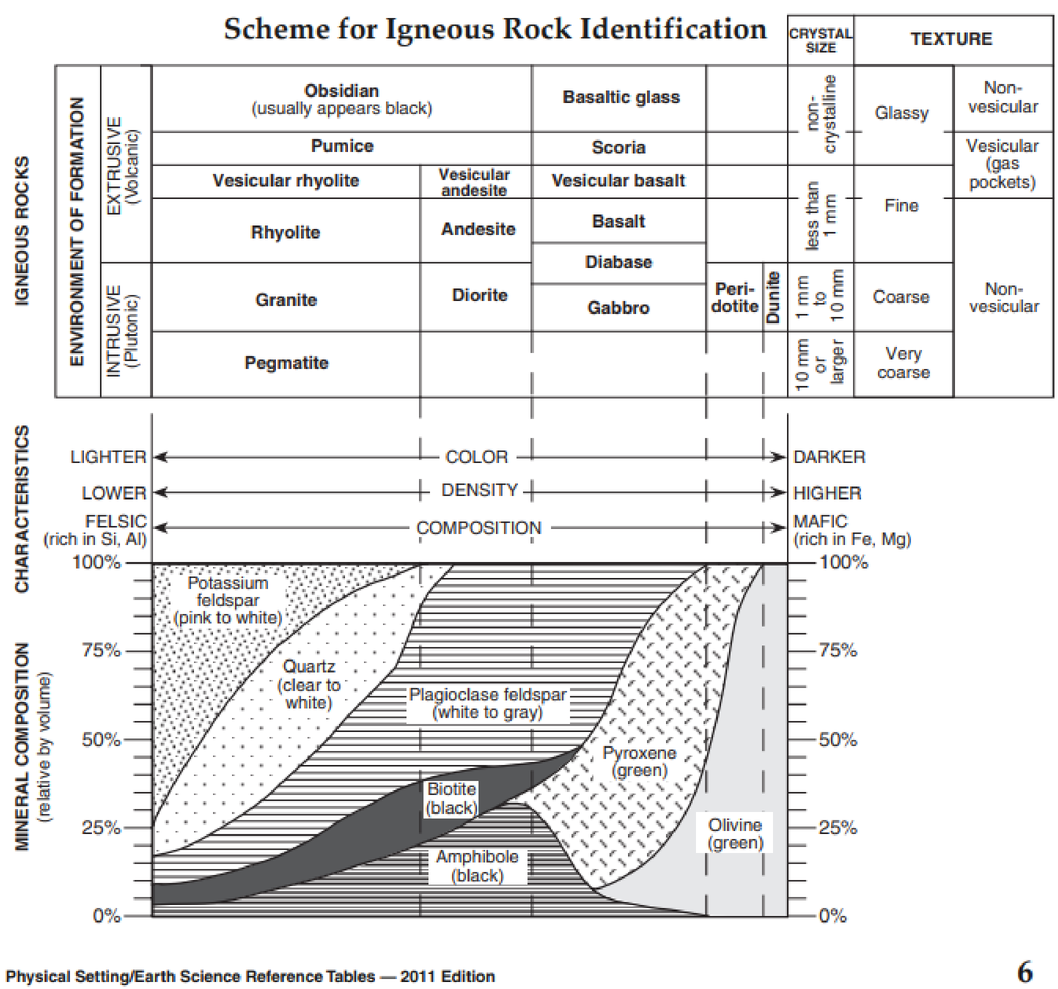
Identifying igneous rocks

Igneous rock identification is largely based on:

- Texture (crystal size)
  - very coarse (10 mm or larger)
  - coarse (1 mm to 10 mm)
  - fine (less than 1 mm) } vesicular (gas pockets)
  - glassy (non crystalline) } non-vesicular
- percent mineral composition
  - match percent crystal types on the surface with chart below
  - for fine minerals, use a microscope and match percent crystal types
  - if microscopes are not available, use density and color

Note that all the rocks on the chart below are:

- tetrahedral silicates
- density ranges from 2.7 g/cm^3 for felsic minerals (left) to 3.4 g/cm^3 for mafic minerals on the right [see densities on Inferred Properties of Earth's Interior, ESRT, page 10: 2.7 g/cm^3 for continental crust to 3.4 g/cm^3 just above the stiffer mantle]



Metamorphic rocks

Form from changes in previously existing rocks due to heat, pressure, or mineral fluids without weathering or melting

- such changes usually occur deep within the lithosphere
- changes caused by metamorphism often include:
  - less porosity
  - higher density
  - larger crystal size
  - foliation – exhibit layering

Formation of metamorphic rocks

Parent rocks are usually recrystallized:

- increases size of mineral crystals or rock clasts
- changes mineral composition without melting

High heat and pressure deep in the lithosphere allows atoms to move small distances and rearrange without true melting

Types of metamorphism:

- contact metamorphism – older rocks contact magma (intrusive) or lava (extrusive)
  - contact metamorphism results in a progression from igneous to metamorphic rock
  - hornfel, marbles, and quartzites often form
  - contact metamorphism has heat but little pressure so foliation rarely occurs
- regional metamorphism – usually the result of collisions of tectonic plates
  - mountain building often results, so metamorphism usually occurs at greater depths
  - resulting metamorphic rocks are often highly folded and faulted
  - contact metamorphism has heat but little pressure so foliation rarely occurs

Textures of metamorphic rocks

Foliated – layering of two types of crystals usually as a result of regional metamorphism

Three types of foliation:

- slate – fine grained foliation, breaks into smooth layers, crystals too small to see (phyllite is similar to slate but has a shiny surface)
- schist – medium grained foliation, grains just visible, high mica content
- gneiss – coarse grained foliation, minerals easy to see

Nonfoliated – composed of interconnected mineral crystals from contact metamorphism

Two single-mineral crystalline metamorphic rocks are:

- quartzite – formed from pure quartz sandstone
- marble – from parent dolostone or limestone

Identification of metamorphic rocks

Metamorphic rocks are identified based on composition and texture

Identification of foliated rocks is based mostly on texture

How to identify slate, phyllite, schist, and gneiss is given above

Identification of nonfoliated rocks is usually based on composition

METAMORPHIC ROCK IDENTIFICATION KEY				
Distinctive Properties	**Grain Size**	**Parent Rock**	**Texture**	**Rock Name**
Excellent rock cleavage, smooth dull surfaces	Very fine	Shale, or siltstone		Slate
Breaks along wavy surfaces, glossy sheen	Fine	Shale, slate, or siltstone		Phyllite
Micas dominate, breaks along scaly foliation	Medium to Coarse	Shale, slate, phyllite, or siltstone		Schist
Compositional banding due to segregation of dark and light minerals	Medium to Coarse	Shale, schist, granite, or volcanic rocks		Gneiss
Interlocking calcite or dolomite crystals nearly the same size, soft, reacts to HCl	Medium to coarse	Limestone, dolostone		Marble
Fused quartz grains, massive, very hard	Medium to coarse	Quartz sandstone		Quartzite
Round or stretched pebbles that have a preferred orientation	Coarse-grained	Quartz-rich conglomerate		Metaconglomerate
Shiny black rock that may exhibit conchoidal fracture	Fine	Bituminous coal		Anthracite
Usually, dark massive rock with dull luster	Fine	Any rock type		Hornfels
Very fine grained, typically dull with a greenish color, may contain asbestos fibers	Fine	Mafic or ultramafic rocks		Serpentinite

Foliated

Nonfoliated

Environment of Rock Formation

The type of environment in which a rock formed can be inferred from its structure, composition, and texture

Examples:

- large, thick areas of rock salt are found in western NYS
  - inference – there was once a large salty sea in what is now western NYS
- northern Adirondack Mountains in NYS show bent and twisted rock structures
  - inference – the region experienced mountain building period(s)
- rock fragments in a clastic sedimentary rock are sharp and angular
  - inference – the rock formed near where weathering produced the fragments
- igneous rock from a lava flow has many large mineral crystals mixed with small crystals
  - inference – some of the magma cooled below the surface (to form the large mineral crystals) before the lava erupted onto Earth's surface (forming small crystals)

The Rock Cycle

The rock cycle is a model that shows that all three rock types (igneous, sedimentary, and metamorphic) are interrelated

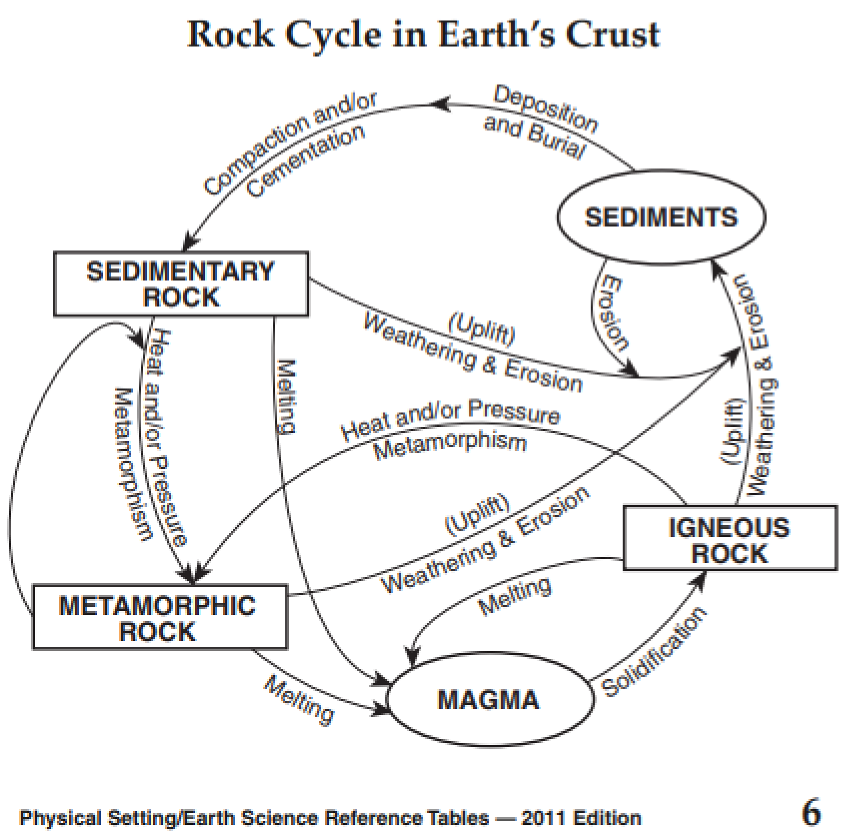
Any rock can change into any other rock type

There is no preferred direction or length of time in the rock cycle

There is often no exact point of separation between rock types

Contact metamorphism shows gradual change from igneous to metamorphic to parent rock

Energy input from Earth's interior, insolation, impacting meteorites, or gravity drive the rock cycle



Topic 11 Section 3

Mineral resources

Many natural resources are renewable – trees, water, energy from the sun, fish, and oxygen

Mineral resources are nonrenewable – minerals, rocks, and fossil fuels

Many rocks are useful because of their characteristics

- slate is impermeable and cleaves on foliations making good chalkboards and roofing
- basalt and diabase resist crushing and are used as roadbeds and under train tracks
- coal releases a lot of energy when burned
- pumice has a lot of pore space so it is low density and used as insulation
- granite and quartzite are nonporous so they weather slowly and are used for buildings

Rock properties and land usage

- limestone and dolostone weather to produce nonacidic soils but form caves and sinkholes
- shale erodes easily and quickly forming low rolling landscapes that make roads and buildings easier to construct
- gneiss and granite do not compress or flow under stress and make good bedrock for tall buildings (NYC)

Mineral properties and human usage

- piezoelectric properties of quartz causes it to vibrate under pressure – used for watches
- hard minerals are used for jewelry and sandpapers – diamonds corundum, garnet, etc.
- graphite is soft and has a black streak – used in pencil leads
- talc is soft with one dimensional cleavage – used as baby powder
- hematite has a red color – used for cave paintings, cosmetics, and red paints
- other uses are given on the ESRT Properties of Common Minerals

Global distribution of mineral deposits

Many important elements used in the US are not found in the US

Population growth and demand from other countries make obtaining minerals more competitive

Fossil fuels

Petroleum, natural gas, coal, and oil shale result from the compaction of organic sediments

Reserves of these fossil fuels in the US are dwindling fast