INTRODUCTION TO GEOLOGICAL PROCESS IN ILLINOIS

ROCKS & THE ROCK CYCLE

INTRODUCTION

The Earth's crust is made of rocks. A rock is defined as a solid aggregate of earth materials. This is an extremely broad definition because there are a wide variety of ways in which a rock may form. There are three rock types:

- **Igneous rock** forms from the solidification of molten rock.
- **Sedimentary rock** forms from the lithification (compaction and cementation) of sediment.
- **Metamorphic rock** forms from the alteration, while in the solid state, of existing rock due to heat, pressure, or both.

Geologists use the characteristics of rocks to determine their type, name, and origin. This lesson will focus on rock classification, rock formation, and the relationship between different rock types.

Rocks are often made of minerals but may also include organic materials and non-crystalline substances such as glass. The substances that compose a rock determine the rock's characteristics. Rocks are also the source of many of the earth's economically important resources based on the minerals and other substances of which they are composed.

ROCKS AND THE ROCK CYCLE

A description of how each of the rock types forms and the relationships of the rock types to each other are shown in the rock cycle.

Rock cycle diagrams:
http://www.washington.edu/uwired/outreach/teched/projects/web/rockteam/WebSite/rockcycle.htm.htm
http://www.cotf.edu/ete/modules/msese/earthsysflr/rock.html
http://academic.brooklyn.cuny.edu/geology/leveson/core/topics/rock_cycle/rock_cycle_diag.html

IGNEOUS ROCK

Igneous rocks form when molten rock cools and solidifies.

Volcanoes by Robert I. Tilling, U.S. Geological Survey: http://pubs.usgs.gov/gip/volc/

Formation of Molten Rock

Rocks melt when they are subjected to high temperatures; however, several other factors determine exactly how this takes place:

- *depth:* The farther beneath the Earth's surface a rock is located, the warmer the rock will be. The temperature increase (known as the geothermal gradient) is between 20 and 30 degrees centigrade per kilometer of depth.
- *pressure:* An increase in pressure will increase the temperature at which a rock will melt. Because pressure increases with depth, most of the rocks deep in the Earth's crust remain solid, even though the temperature is high.
- *volatile content:* The presence of volatiles (such as water) lowers the temperature at which a rock will melt; so, a wet rock will melt at a lower temperature than a dry one.
- *mineral content:* Each mineral has its own unique melting characteristics based on a combination of chemical composition, temperature, pressure, and water content.

Because a rock is usually made of several different minerals, sometimes only part of a rock will melt.

The conditions that cause rock to melt are an increase in depth, a reduction in pressure, the addition of water, or a combination of these. The composition of the molten rock will depend on the mineral content of the rock that melted. Molten rock is called magma when it is below the Earth's surface and lava when it is extruded onto the Earth's surface.

Igneous Rock Intrusion & Extrusion

Magma is less dense than rock and, because of its buoyancy, will rise toward the surface, intruding into the "country" rock already present. As the magma rises, it cools and may completely solidify below the surface. When this occurs, the igneous rock is called intrusive. If the magma makes it to the Earth's surface and is extruded as lava, it will cool and form extrusive igneous rock.

The largest type of igneous intrusion is the batholith. Smaller intrusions include the laccolith and sill, which are found between layers of sedimentary rock and dikes and pipes, which cut across the existing rocks.

Extrusion of igneous rocks is from a pipe, which produces a volcano, or from a dike, which produces a fissure eruption. The rocks produced by extrusive activity are lava flows and ash deposits.

Volcanoes at National Parks & Monuments in the U.S.
Hawai'i Volcanoes: http://www.nps.gov/havo/
Mt. St. Helens: http://www.fs.fed.us/gpnf/mshnvm/
Lassen Peak: http://www.nps.gov/lavo/index.htm
Mt. Rainier: http://www.nps.gov/mora/index.htm
Sunset Crater: http://www.nps.gov/sucr/index.htm
Crater Lake: http://www.nps.gov/crla/index.htm

Igneous Rock Texture

The texture of an igneous rock is primarily a description of the size of the rock's mineral crystal grains and is related to the manner and location in which the magma or lava solidified.

Phaneritic (coarse-grained): If all of the mineral crystals in an igneous rock are large enough to be seen without a microscope, the texture is phaneritic. The large crystal size indicates that the magma cooled below the Earth's surface at a slow rate, allowing large crystals to form. Phaneritic rocks are intrusive.

Aphanitic (fine-grained): If all of the mineral crystals in an igneous rock are too small to be seen without a microscope, the texture is aphanitic. The small crystal size indicates that the magma or lava cooled near or on the Earth's surface at a quick rate, allowing only small crystals to form. Aphanitic rocks are extrusive.

Glassy: If no mineral crystals are present, the texture is glassy. The lack of crystals indicates that the lava cooled on the surface so quickly that crystals did not have time to form. Glassy rocks are extrusive.

Porphyritic: When two distinctly different crystal sizes are present, the texture is porphyritic. The two crystal sizes indicate that the magma or lava moved as it cooled; the larger crystals formed when the magma was deeper and the cooling rate was slower.

Porphyritic rocks are phaneritic-porphyritic (all crystals visible; intrusive) or aphanitic-porphyritic (some of the crystals visible, some not; extrusive).

Pegmatitic: When all of the crystals are larger than one centimeter, the texture is pegmatitic. The very large crystals form below the surface, late in the crystallization process, when the uncrystallized portion of the magma contains a large proportion of volatiles (including water). The volatiles interfere with the crystal formation process and the crystals that do form can become very large. Pegmatitic rocks are intrusive.

Vesicular: When the rock contains bubbles frozen in place during solidification, the texture is vesicular. The bubbles form when the pressure on lava is released as it is extruded onto the Earth's surface (in the same way bubbles form in a bottle of soda, when the lid is unsealed). The bubbles are frozen in place as the rock solidifies. Vesicular rocks are aphanitic-vesicular or glassy-vesicular. Vesicular rocks are extrusive.

Pyroclastic: When the rock is made of ash and other pieces of material thrown from a volcano, the texture is pyroclastic. Pyroclastic rocks have a texture that resembles detrital sedimentary rocks (discussed below), and are sometimes classified as sedimentary. Often, the ash will weld together because of the high temperature. Pyroclastic rocks are extrusive.

Igneous Rock Composition

The composition of an igneous rock is determined by the composition of the magma or lava from which it forms. In turn, the composition of magma or lava is determined by its source and what happens to it as it rises toward the Earth's surface (its history). The source of magma will be discussed in the lesson on Plate Tectonics. The history of a magma includes the loss of minerals that crystallize as the magma cools and the addition of new material from the surrounding rock, groundwater, and other magmas.

Igneous rocks may be divided into four compositional types: felsic, intermediate, mafic, and ultramafic. Each type has a common set of minerals. Based on the physical properties of those minerals (especially color), these compositions are fairly easy to distinguish.

Felsic: Felsic igneous rocks are made primarily of quartz (clear, white, pink), potassium feldspar (pink, white), and sodium plagioclase feldspar (white, light grey), with traces of muscovite and biotite mica (silvery and black) and hornblende (black). Felsic rocks are usually pink or light pink with small black specks.

Intermediate: Intermediate igneous rocks are made primarily of sodium plagioclase feldspar (white, light grey), calcium plagioclase feldspar (grey, dark grey), hornblende (black), and augite (black). Intermediate rocks are usually white and black (when phaneritic) or grey (when aphanitic).

Mafic: Mafic igneous rocks are made primarily of calcium plagioclase feldspar (grey, dark grey), hornblende (black), augite (black), and olivine (dark green). Mafic rocks are usually black.

Ultramafic: Ultramafic igneous rocks are made primarily of augite (black) and olivine (dark green) with traces of calcium plagioclase feldspar (grey, dark grey). Ultramafic rocks are usually dark green.

Igneous Rock Classification
Igneous rocks are classified using their texture and composition. The table below is a simplified version that places igneous rocks into broad categories useful to students, teachers, and amateur rock hunters. Geologists who study igneous rocks in detail use a more complex classification system in order to be more specific.

	Felsic	Intermediate	Mafic	Ultramafic
Phaneritic	GRANITE	DIORITE	GABBRO	PERIDOTITE
Aphanitic	RHYOLITE	ANDESITE	BASALT	
Glassy	OBSIDIAN			
	PUMICE (vesicular)			

The texture terms porphyritic, pegmatitic and vesicular may be used as adjectives to modify the rock names given above; rocks with a pyroclastic texture have the word "tuff" placed after the rock name. For example: a phaneritic, felsic igneous rock with all crystals larger than one centimeter would be a pegmatitic granite, and a mafic igneous rock with some mineral crystals large enough to see and some too small to see would be a porphyritic basalt.

Note that the names obsidian and pumice are used without respect to mineral composition. This is because glassy rocks contain no minerals.

SEDIMENTARY ROCK
Sedimentary rocks form when sediments are lithified. Each sedimentary rock reflects the processes that produced it. The environment in which a sedimentary rock was deposited can be interpreted by careful examination of the sedimentary rock.

Sedimentary Rock Formation
Sediments are formed when preexisting rocks are weathered. There are two types of weathering:

> *Physical weathering* is the mechanical disintegration of rock. Physical weathering produces smaller pieces of rock such as gravel, sand and silt. Gravel and larger sized-pieces are smaller versions of the original rock and usually contain a variety of minerals, while sand and silt-sized particles are usually composed of a single mineral type.
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> *Chemical weathering* is the chemical disintegration of rock. Chemical weathering produces clay minerals and dissolved ions in solution. The clay minerals form when silicate minerals such as micas and feldspars lose some of their chemical components and gain part of a water molecule.

Once created, sediments are classified as detrital or chemical; unfortunately, the definitions of these terms do not align exactly with the weathering processes that produce them.

> *Detrital sediments* are solid particles in the water and thus include clay, a product of chemical weathering, with gravel, sand, and silt, products of physical weathering.
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> *Chemical sediments* derive from the dissolved ions, such as calcium and sodium, in solution. The ions may form minerals and precipitate directly from the water, or they

may be extracted from the water by living organisms for use in shells or other body parts. The latter example produces what may be called "biochemical" sediment.

Weathered particles are eroded, transported, and deposited by wind, water, and ice. Once deposited, the sediment may be buried or picked up and moved again. The final resting place of a sediment is its environment of deposition.

Environments of Deposition

The environment of deposition can be interpreted by carefully examining the rock and comparing it to places where sediments are being deposited today.

Sediment type: Gravel, sand, silt, clay, mineral precipitates, and biological materials are all deposited in different places. Gravel is deposited in river channels; sand is deposited along rivers, on beaches and in deserts; clay is deposited in lakes and bays; minerals precipitate in closed lakes and bays; and biological materials collect along coral reefs and in swamps. These are examples of just a few environments where sediments are deposited.

Sedimentary structures: Sand dunes, mud cracks, and ripples are all preserved in sediments and reflect the conditions under which they were deposited.

Fossils: Living organisms leave traces of their existence in deposits of sediments including shells, bones, trails, and burrows. These fossils can be used to interpret the environment; for example, fish, clams, and trees all live in different environments. Because the conditions under which igneous and metamorphic rocks form are not conducive to life, fossils are limited to sedimentary rocks. (If a rock contains a fossil, it is sedimentary!)

Environments of deposition will be described in greater detail in the lesson on interpreting geologic history.

Lithification

The final step in the sedimentary rock forming process is lithification. When sediments are buried, they are compressed by the pressure of the overlying material. The compression compacts the sediments and forces out most of the air and water. Dissolved ions in the water may crystallize to form cement which holds the sediments together. The amount of cement will determine how strongly the sediments are bonded together. Cementing minerals can be added, altered, or removed by groundwater long after a sedimentary rock is initially lithified.

Sedimentary Rock Classification

Sedimentary rocks are classified according to sediment type (detrital or chemical) and then named based on the composition and characteristics of the sediments.

Detrital Sedimentary Rocks are made from detrital sediments (gravel, sand, silt, and clay). Their names are based on the size of the sediment grains and are modified based on the composition and characteristics of the sediments.

sediment size	sediment characteristics	rock name	environment of deposition
Gravel	gravel is rounded	conglomerate	river bed glacier
	gravel is angular	breccia	alluvial fan
Sand	sand is > 90% quartz	quartz sandstone	beach desert
	sand is mixture of quartz & feldspar	arkose sandstone	river bed alluvial fan
	sand is mixture of many types of minerals and clay	greywacke sandstone	river bed river delta
silt	silt (may be in thin layers)	siltstone	river flood plain river delta continental shelf
clay	clay in thick layers or not layered	claystone	river flood plain continental shelf
	clay in thin, brittle layers	shale	river flood plain continental shelf

Chemical Sedimentary Rocks are made from mineral precipitates and biological materials. They are named based on their mineral (or chemical) content and the names may be modified based on the characteristics of the sediments.

mineral composition	characteristics	rock name	environment of deposition
calcite (effervesces rapidly in weak acid)	calcite crystals are microscopic	micrite limestone	continental shelf
	calcite crystals are visible	crystalline limestone	continental shelf
	calcite crystals are in banded layers	travertine limestone	cave
	calcite in small spheres	oolitic limestone	shallow tropical lagoon
	poorly cemented microscopic shells	chalk limestone	abyssal plain continental shelf
	visible shells and shell fragments, poorly cemented	coquina limestone	continental shelf organic reef
	visible shells and shell fragments, well cemented	fossiliferous limestone	continental shelf organic reef
dolomite (effervesces slowly in acid)	similar to limestone, tan color	micritic, crystalline, oolitic or fossiliferous dolostone	commonly forms when magnesium replaces calcium in limestone
gypsum	clear, grey, reddish grey; hardness = 1	rock gypsum	enclosed bay or lake

halite	clear, grey; salty taste; hardness = 2.5	rock salt	enclosed bay or lake
quartz	wide variety of colors; hardness = 7	chert	abyssal plain deposit of microscopic shells; replacement of calcite by groundwater
organic carbon	dull to shiny black; rubs off on hands	coal	swamp

More on sedimentary rocks: http://www.physicalgeography.net/fundamentals/10f.html

METAMORPHIC ROCK

Metamorphic rocks form when rocks are subjected to high pressure and or temperature. Each metamorphic rock reflects the composition of the original rock as well as the conditions that produced it. The source rock and the metamorphic environment can be interpreted by careful examination of the metamorphic rock.

Metamorphosis of a rock occurs when high pressure and/or high temperature causes the minerals in a rock to reform and grow. Metamorphosis happens because some minerals are not stable at high pressure or temperature and the chemical elements within those minerals rearrange into a more stable form. Metamorphosis occurs in a solid state with the aid of water which helps ions move from one location to another.

Metamorphic Environments

There are four types of metamorphism:

> *Contact metamorphism* occurs when magma comes into contact with existing rock. The heat of the molten rock bakes the surrounding rock creating a zone of metamorphic rock around the igneous intrusion. Because rock does not conduct heat very well, the zone of rock "baked" by the magma rarely extends more than a few feet from the intrusion; however, rocks farther away may be altered by hot water associated with the intrusion.
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> *Fault zone metamorphism* occurs along faults. The intense pressure can cause rocks on both sides of the fault to break and can then force them back together as a "fault breccia" which looks very similar to the sedimentary rock breccia.
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> *Regional metamorphism* occurs when a large region of the earth's crust is subjected to heat and pressure. The heat and pressure may be caused by deep burial or the collision of two tectonic plates. This type of metamorphism will be discussed further in lessons on plate tectonics and geologic history.
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> *Impact metamorphism* occurs when a large celestial object such as a meteor strikes the earth. The impact causes a brief period of intense heat and pressure. This type of metamorphism covers a very small area, although the impact can throw small metamorphosed crystals into the atmosphere where they can be scattered over a very large area.

Each metamorphic environment produces a unique set of characteristics in a metamorphic rock. These characteristics are reflected in the resulting rock's texture and grade.

Metamorphic Texture
Metamorphic rocks are separated into two texture groups.

> **Foliated metamorphic rocks** show the alignment of visible minerals or break along parallel planes due to the alignment of minerals too small to see. Foliation is created when new minerals form and grow perpendicular to the direction of greatest pressure. This alignment is most clearly visible in minerals such as muscovite and biotite mica, hornblende, and augite, all of which have elongated crystalline structures. The type of foliation exhibited by a metamorphic rock depends on the amount of change the rock has undergone, which will be discussed below in the section on metamorphic grade. Foliated texture occurs as a result of regional metamorphism.
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> **Non-foliated metamorphic rocks** form when the pressure on a rock is not directional, when there is little or no pressure involved, or when the rock is made entirely of minerals that do not have elongated crystalline structures. Contact metamorphic rocks are not foliated because they are formed due to heat. Regional metamorphic rocks that form from quartz sandstone, limestone, or coal are not foliated because they have chemical compositions that do not allow the formation of minerals with elongated crystalline structures such as micas, hornblende, and augite.

Metamorphic Grade
The metamorphic process produces gradational change; as a rock is subjected to increasing pressure and/or temperature, the rock and the minerals in it slowly change form. A metamorphic rock that has been subjected to low pressure and temperature will appear similar to its original form. A metamorphic rock that has been subjected to very high pressure and temperature will look nothing like its original form. The amount of change a metamorphic rock has undergone is referred to as its metamorphic grade. The metamorphic grade can be determined by examining:

> *Mineral grain size* As a rock is metamorphosed, new minerals form and grow. The greater the pressure and temperature, the larger the new crystals become. As the crystals form and grow, they will gradually destroy the features of the original rock.
>
> *Index minerals* Many minerals form and are stable at a narrow range of pressure and temperature; if these conditions are exceeded, the mineral's component elements will reform into a new mineral that is stable at the new pressure and temperature. Index minerals have relatively narrow ranges of stability and are made of elements commonly found in many rocks. Examples of index minerals are (from low to high grade): chlorite, muscovite mica, biotite mica, garnet, staurolite, sillimanite.
>
> *Foliation type* As the rock and its minerals change, so does the type of foliation. At low pressures and temperatures, the mineral crystals are too small to see and the foliation can be seen only because the aligned minerals cause the rock to break in sheets (slaty foliation). In a medium grade metamorphic rock, the minerals are large enough to see and often include the micas that form in sheets (schistose foliation). In a high-grade metamorphic rock, the micas are no longer present and the rock begins to resemble an intrusive igneous rock with some of the darker crystals aligned in a tiger-stripe pattern (gneissic foliation).

At very high pressures and temperatures, the rock may begin to melt. Not all of the minerals melt under the same conditions, so the change from metamorphic rock to magma is gradual. If the process stops and the pressure and temperature decrease, the resulting rock will be part metamorphic and part igneous. This highest possible metamorphic grade is called a migmatite.

Metamorphic Rock Classification

Foliated metamorphic rocks are classified by the type of foliation and the mineral content.

type of foliation	**description**	**rock name**	**source**
slaty	minerals too small to see dull surface rings when struck *low grade*	slate	regional metamorphism of shale
	minerals too small to see silky, shiny surface *low to medium grade*	phyllite	regional metamorphism of shale
schistose	minerals large enough to identify *low to medium grade*	schist*	regional metamorphism of various sedimentary & igneous rocks
gneissic	minerals large enough to see similar to phaneritic igneous dark minerals in tiger-stripes *high grade*	gneiss**	regional metamorphism of various sedimentary & igneous rocks
	contains thin layers of igneous rock between bands of gneiss *very high grade*	migmatite	regional metamorphism of various sedimentary & igneous rocks

* The name of a schist is modified with the names of the minerals observed in the rock; for example, a schist containing biotite and garnet would be a "biotite-garnet schist."
** The name of a gneiss can be modified with the name of the igneous rock with a similar mineral content; for example, a gneiss with a felsic composition would be a "granite gneiss."

Non-Foliated metamorphic rocks are classified based on mineral (or chemical) content.

mineral composition	**description**	**rock name**	**source rock**
calcite	various colors (usually light) crystals visible effervesces in acid *variable grade*	marble	regional metamorphism of limestone
quartz	various colors crystals visible scratches glass *variable grade*	quartzite	regional metamorphism of quartz sandstone
carbon	shiny black light *variable grade*	anthracite	regional metamorphism of coal

talc	very soft various colors (often green or grey) *low grade*	soapstone	regional metamorphism of peridotite
chlorite	very soft dark green *low grade*	greenstone	regional metamorphism of mafic igneous rock
various (crystals too small to identify	crystals not visible dark brown or black *low grade*	hornfels	contact metamorphism of various rock types

More on metamorphic rocks: http://www.physicalgeography.net/fundamentals/10g.html

ILLINOIS STATE PARKS AND NATURAL AREAS OF NOTE FOR THEIR SEDIMENTARY ROCK EXPOSURES

Apple River Canyon (limestone, dolostone, and shale)
Buffalo Rock (coal, sandstone, clay)
Castle Rock (sandstone)
Dixon Springs (limestone, shale, sandstone)
Ferne Clyffe (sandstone)
Franklin Creek (sandstone and dolostone)
Fults Hill Prairie (limestone)
Giant City (sandstone)
Kankakee River (dolostone)
Lowden Miller (sandstone)
Matthessien (sandstone, dolostone, limestone, shale)
Mazonia-Braidwood (clay and many fossils)
Mississippi Palisades (limestone)
Mississippi River Area (limestone)
Pere Marquette (limestone)
Piney Creek Ravine (sandstone)
Randolph County (limestone)
Ray Norbut (limestone)
Rock Cut (dolostone)
Siloam Springs (limestone)
Starved Rock (sandstone)
Stephen A. Forbes (sandstone and siltstone)
Trail of Tears (limestone and chert)
Tunnel Hill Trail (sandstone, limestone, shale)
White Pines Forest (limestone)