Rocks Rock

- Rock Cycle
- Igneous Rocks
- Sedimentary Rocks
- Metamorphic Rocks

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Why are minerals & rocks important?

Geologic processes depend upon geologic materials

- volcanic eruptions
- earthquakes
- landslides
- erosion
- mountain building

A basic knowledge of Earth materials is essential to understanding geologic processes.

DEFINITIONS

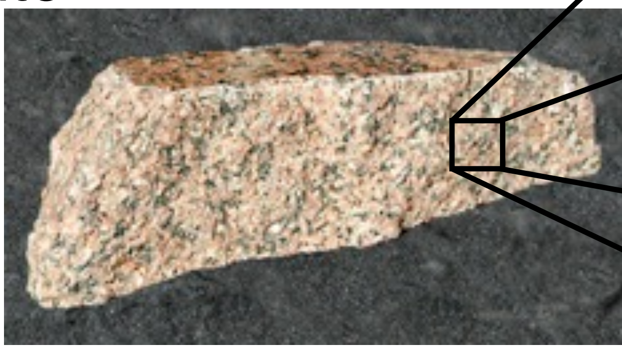
A *rock* is any solid mass of mineral (or mineral-like) matter that occurs naturally. A few rocks may be composed of only one mineral, but most are an aggregate of several minerals.

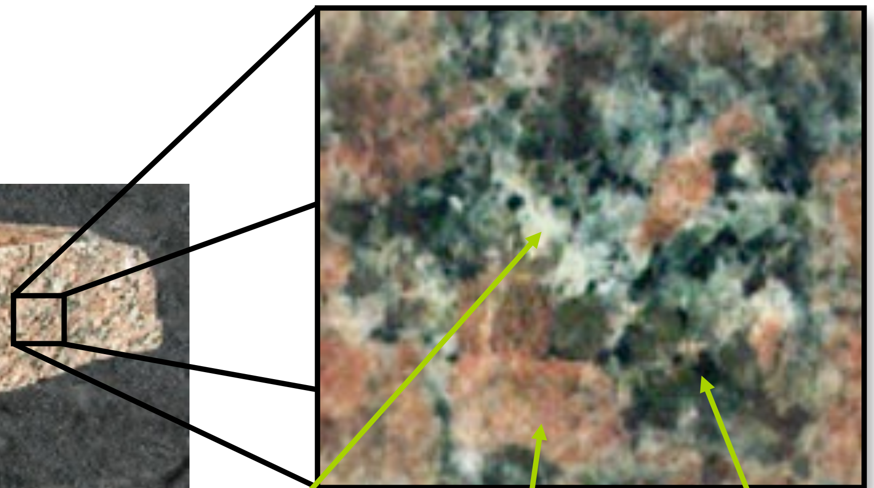
A *mineral* is any naturally occurring inorganic solid that possesses an orderly internal structure and a definite chemical composition.

1. naturally occurring (concrete, synthetic diamonds, etc. are excluded).
2. inorganic (teeth, seashells, trees, etc. are excluded)
3. solid (gases and liquids are excluded)
4. orderly internal structure (crystalline structure)
5. definite chemical composition

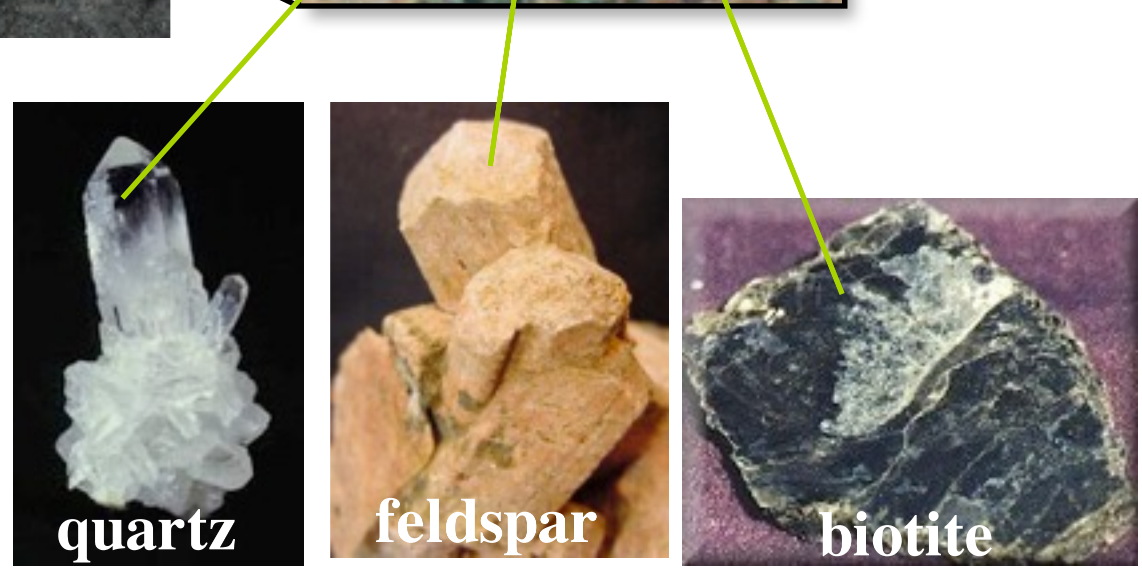
One way that rocks are characterized is by their mineral content. For example, the rock *granite* commonly contains the three minerals:

- quartz
- feldspar
- biotite





Luckily, most rocks are composed of a few common rock-forming minerals.



1. The Rock Cycle

Three basic rock types:

igneous - form from molten rock - magma/lava

sedimentary - form from sediment and chemical precipitation in seawater

metamorphic - form from other rocks that recrystallize (solid state) under higher pressures and/or temperatures.

The Rock Cycle

Let's consider the different processes that would alter and transform rocks

Igneous Processes

melting & crystallization

Sedimentary Processes

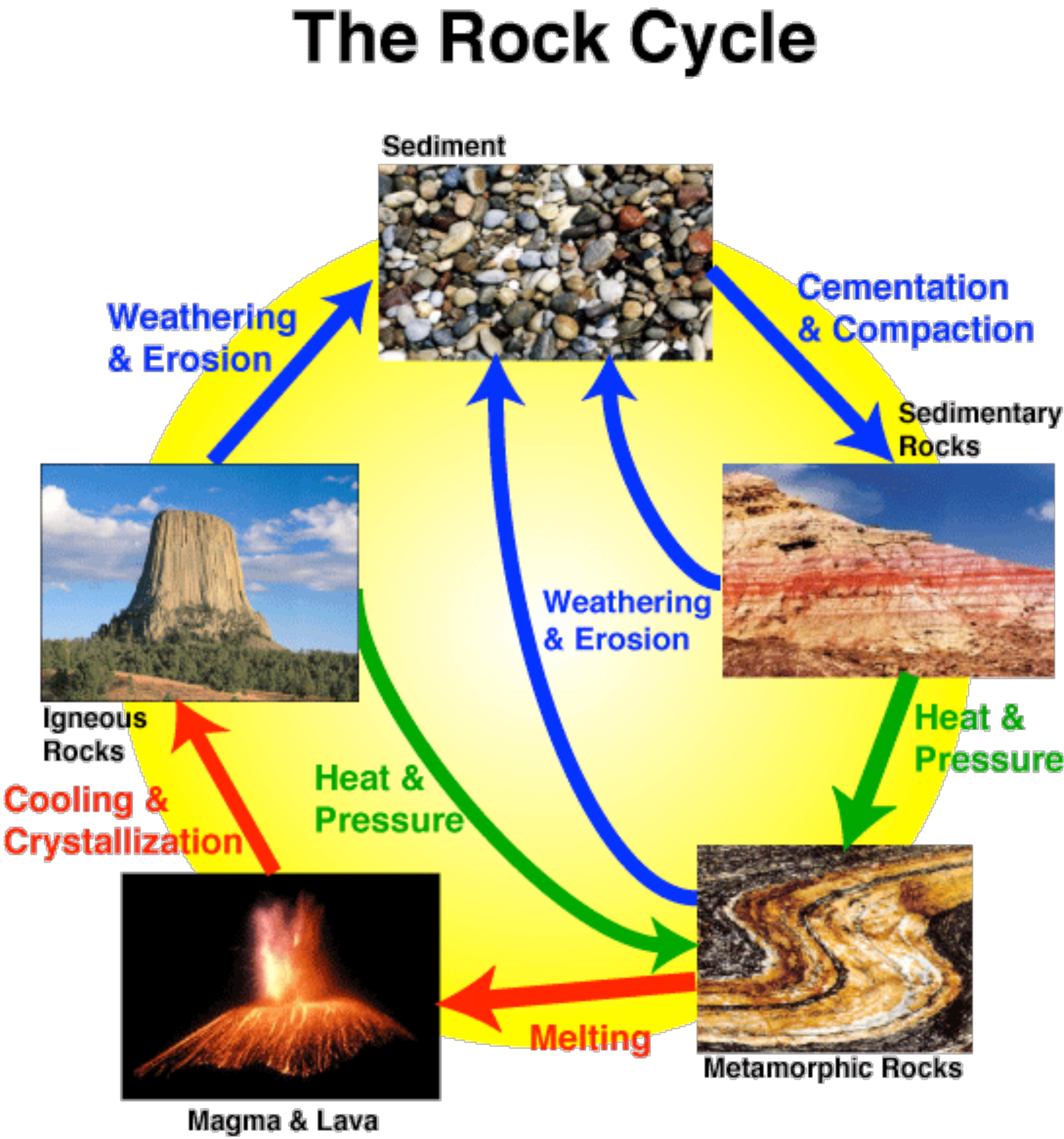
weathering (& erosion)

Metamorphic Processes

burial (heat & pressure)

This rock cycle diagram correlates changes to larger scale processes such as uplift.

In addition, this rock cycle diagram treats sediment and melt (magma or lava) as intermediate materials in the cycle.



2. Igneous Rocks

The word *igneous* comes from the latin word *ignis* which means fire.

Magma is completely or partly molten material.

Magma that reaches the surface is known as *lava*.

Once the magma has formed, it is less dense than the surrounding rocks and rises buoyantly towards the Earth's surface.

If the magma makes it to the Earth's surface, it may produce a spectacular volcanic eruption.

Igneous rocks that solidify at the surface are classified as *extrusive* or *volcanic*.

If the magma crystallized before it reaches the surface, it is classified as *intrusive* or *plutonic*.

Classification of Igneous Rocks

The classification of igneous rocks is based upon:

1. Composition (chemical and/or mineralogical) - the chemical composition of an igneous rock will be expressed by its *mineralogy* (i.e., what minerals are present).
2. Texture - describes the overall appearance of an igneous rock based on the size, shape and arrangement of its interlocking crystals.

Igneous Compositions

Igneous rocks are mainly composed of *silicate* minerals. The silicate minerals that form in a rock is primarily determined by the bulk chemical composition of the magma from which the rock crystallized.

Two major groups of silicate minerals:

- dark ferromagnesian minerals containing more Ca, Fe, Mg (olivine, pyroxene, amphibole, biotite) - *mafic*
- light minerals containing more silica, Na, K (feldspars, quartz, muscovite) - *felsic*

An igneous rock can be composed predominantly of dark or light silicate minerals — or various combinations of different minerals.

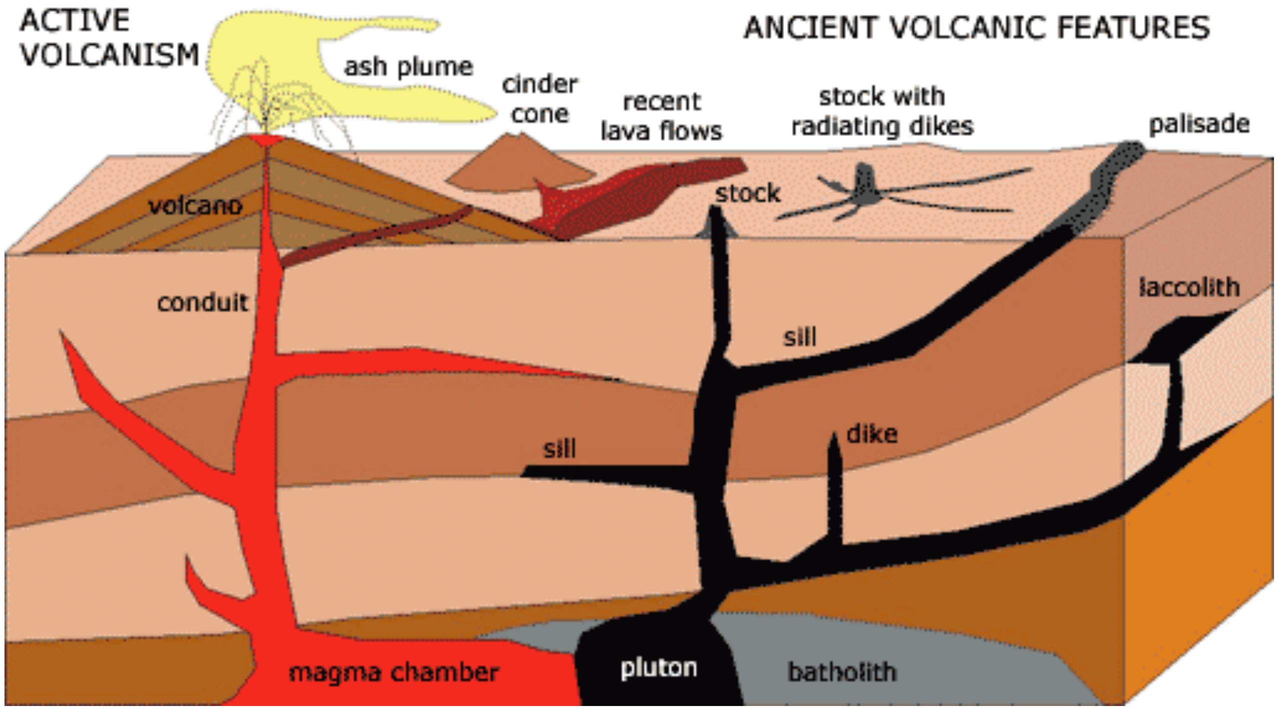
Composition of two familiar rocks:

granite is *felsic* and composed predominantly of light-colored minerals such as feldspar, quartz, (and dark biotite)

basalt is *mafic* and composed predominantly of dark silicates such as pyroxene, olivine (and feldspar)

Igneous Textures

The most important factor that contributes to the texture of an igneous rock is the cooling rate.



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In a lava flow (extrusive/volcanic), the lava cools quickly which results in the formation of smaller crystals.

Instantaneous cooling may result in the formation of glass (disordered solid).

A large igneous intrusive (plutonic) body located at depth may cool over a period of tens or hundreds of thousands of years.

This slow cooling rate promotes the formation of larger crystals.

Igneous Textures

The cooling rate of magma or lava results in a number of specific igneous textures.

Phaneritic texture results from slow cooling (plutonic) and is where all of the crystals in the rock are large enough to be seen with the naked eye.

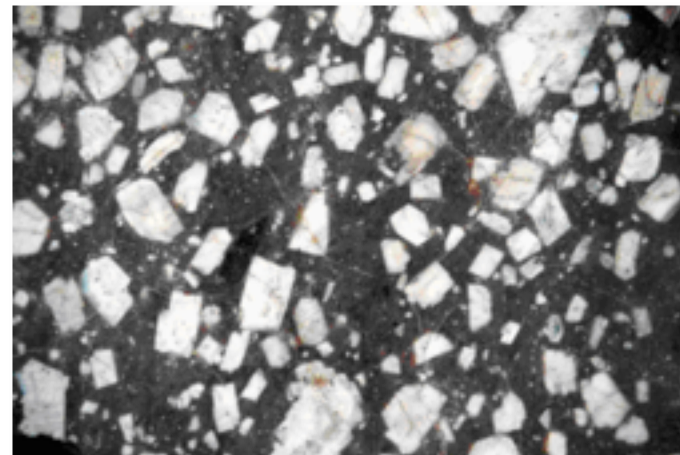
Aphanitic texture results from rapid cooling (volcanic) and is where the crystals are generally too small to be seen with the naked eye.

Glassy texture results from instantaneous cooling (volcanic) where glass forms rather than crystals.

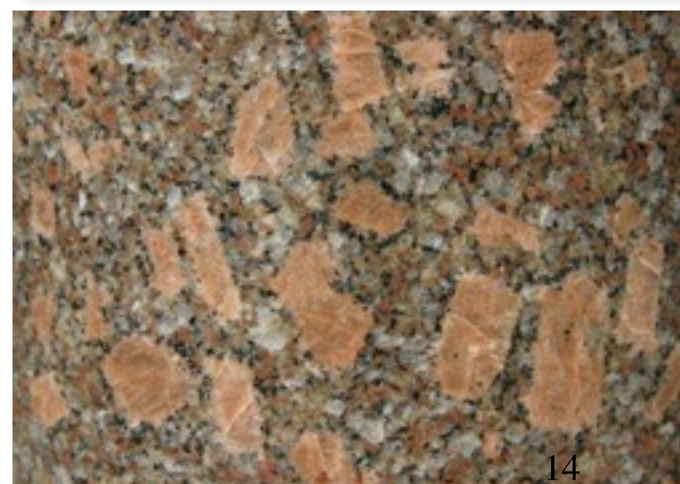
Note that the Greek root "phan" means to show.

Igneous Textures

More complex cooling of magma and lava may result in two or more distinct sizes of crystals called *porphyritic* texture. The large larger crystals are known as *phenocrysts*. The population of small crystals is known as the *groundmass*.



Porphyritic aphanitic texture is consists of visible *phenocrysts* and a groundmass with crystals that are two small to see with the naked eye (*aphanitic*).



Porphyritic phaneritic texture consists of *phenocrysts* surrounded by a groundmass composed of crystals that are large enough to see with the naked eye (*phaneritic*).

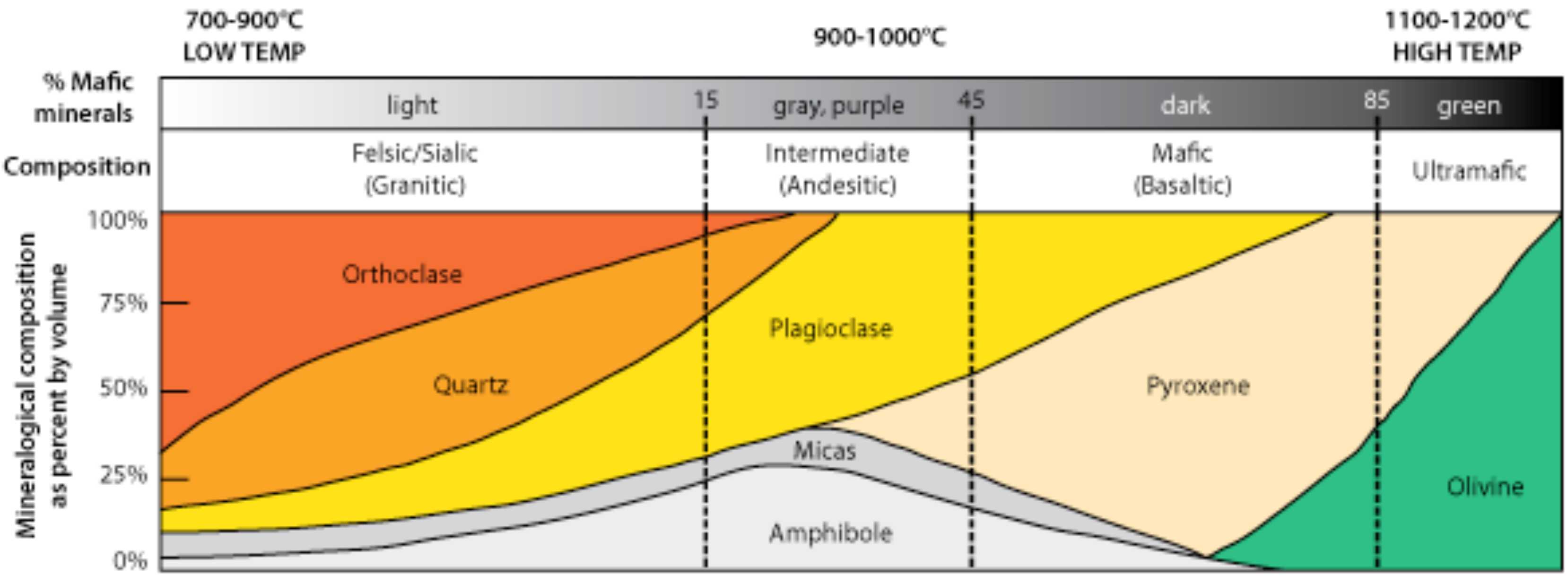
Common Igneous Rocks

← Igneous Texture →

← Igneous Chemistry →

Igneous Chemistry	Plutonic	Volcanic
Felsic - poor in Fe and Mg, rich in silica	granite	rhyolite
Intermediate - between felsic and mafic	diorite	andesite
Mafic - rich in Fe and Mg, poor in silica	gabbro	basalt
Ultramafic - very rich in Fe and Mg, poor in silica	peridotite	(komatiite)

Igneous Rock Mineralogy



Texture	Rock names			
Coarse-grained	Granite	Diorite	Gabbro	Peridotite
Fine-grained	Rhyolite	Andesite	Basalt	Uncommon (rarely encountered)
Pyroclastic	Rhyolite Tuff	Andesite Tuff	Basalt Tuff	
Glassy	Obsidian			
Vesicular	Pumice (like meringue)		Scoria	

Mineralogical Society of America

Igneous Rocks — Gabbro

Gabbro is an intrusive/plutonic igneous rock that contains crystals that are large enough to see with the naked eye - indicating that it formed from slow cooling.

Its dark color indicates that it formed from Fe- and Mg-rich (mafic) magma deep within the Earth.

It is composed of mostly dark minerals including a dark variety of feldspar.

Igneous Rocks — Basalt

Basalt is a volcanic igneous rock and has the same composition as gabbro. Since it is volcanic, it cooled much more rapidly and formed smaller crystals (generally aphanitic or very finely phaneritic in texture).

The seafloor is made of basalt and thus, it is the most common igneous rock on the Earths surface!

Basalt is the volcanic analog to gabbro.

Basalt is the most common volcanic rock on Earth and comes in a large number of varieties.

Basalt may erupt as a very fluid lava and form lava flows with fluid features (known as pahoehoe) or may the lava may be more viscous (known as aa).

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Brooklyn College Dept. of Earth & Environmental Sciences

Basalt commonly contains holes where gas bubbles escaped during the cooling and crystallization of the basalt. This variety of basalt is known as *vesicular basalt* or *scoria basalt*.

Igneous Rocks — Granite

Granite is an intrusive/plutonic igneous rock that contains crystals that are large enough to see with the naked eye - indicating that it formed from slow cooling.

It is composed of predominantly light-colored minerals such as quartz and feldspar (felsic composition) and commonly contains a dark mineral such as biotite or hornblende.

The color of granite ranges from pink to white (depending on the composition of the feldspar crystals).

Granite is similar to the average composition to the Earth's continental crust.

Igneous Rocks — Rhyolite

Rhyolite is a volcanic (fine-grain) igneous rock with a composition similar to granite (felsic). Since it is volcanic, it cooled much more rapidly than granite and formed smaller crystals (generally aphanitic or very finely phaneritic in texture).

It is usually buff, pink or gray in color.

Rhyolite is the volcanic analog to granite.

Igneous Rocks — Obsidian

Obsidian forms from the instantaneous quenching of a granitic (felsic) lava to form volcanic glass.

Although obsidian is commonly black, its chemical composition is more like that of granite (not basalt). The black color comes from tiny iron oxide crystals in the glassy matrix.

Igneous Rocks — Pumice

Pumice also forms from the instantaneous quenching of a granitic lava - very similar to obsidian. However, it is frothy because it contained a lot of dissolved gases that escaped during quenching.

Pumice is frothed-up glass and thus has a very low density - some samples float in water!

3. Sedimentary Rocks

The Earth's surface is a very dynamic environment!

Volcanic and other mountain building processes elevate portions of the Earth's surface, while opposing forces move material from high elevation to lower elevation.

Weathering is the physical breakdown and chemical alteration of rocks at or near the Earth's surface. Physical processes include changes in temperature and biologic activity.

Dirk Beyer (Wikimedia)

Erosion is the physical removal of material by mobile agents such as water, wind or ice.

Sedimentary Rocks

Mechanical and chemical weathering produce the raw materials for sedimentary rocks.

Sedimentary rocks only comprise ~5% of the Earth's crust — however, they are much more important than this percentage would imply.

Sedimentary rocks occur in the portion of Earth where we live.

Important source of resources:

- energy (coal, petroleum)
- water (storage of groundwater)
- minerals (gold, aluminum, lead/zinc,etc)

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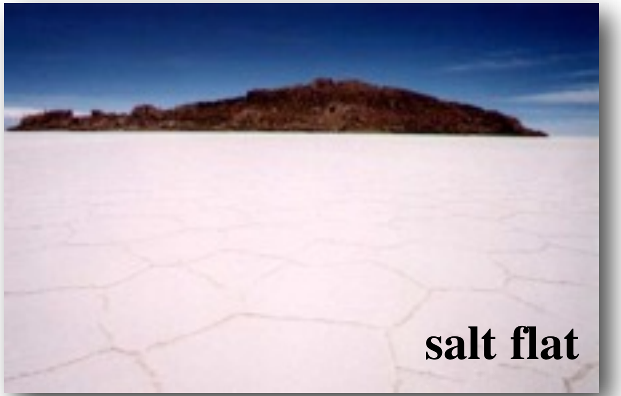
Types of Sedimentary Rocks

Weathering results in two types of products:

1. solid particles (sand grains, clay minerals, etc.)
2. dissolved constituents in water

This results in two fundamentally different types of sedimentary rocks:

1. *detrital (clastic) sedimentary rocks* - formed from transported solid particles (*detritus* or *clasts*).
2. *chemical sedimentary rocks* - formed by the precipitation of dissolved substances by either inorganic or biologic processes



Detrital Sedimentary Rocks

Quartz and clay minerals are the dominant constituents of detrital sedimentary rocks.

quartz - very resistant to weathering.

clay - product of chemical weathering of silicate minerals - very stable at the Earth's surface.

Feldspars, micas and other silicate minerals *may* occur in sedimentary rocks. Since these minerals are subject to chemical weathering (chemically unstable), their presence indicates that the sediment did not travel far.

Detrital Sedimentary Rocks

Sedimentary rocks are classified on the basis of *particle size, shape* and *composition*.

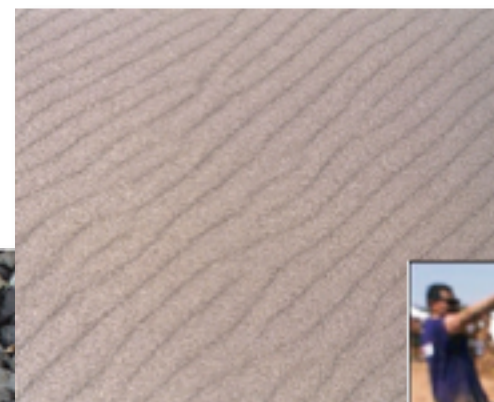
Sizes of particles can provide useful information about the environment of deposition:

- *Gravels* are found in high energy environments such as mountain streams and some beaches.
- *Sands* are found in intermediate energy environments such as beaches and river deposits.
- *Clays* are found in quiet environments such as lakes and the deep ocean.

Particle Size Classification for Detrital Sedimentary Rocks

Size Range (mm)	Particle Name	Sediment Name	Rock Name
>256 64 - 256 4 - 64 2 - 4	Boulder Cobble Pebble Granule	Gravel	Conglomerate or Breccia
1/16 - 2	Sand	Sand	Sandstone
1/256 - 1/16 <1/256	Silt Clay	Mud	Shale or Mudstone






Detrital Sedimentary Rocks - Shale

Shale is a fine grained detrital sedimentary rock composed of silt- and clay-sized particles (too small to see with the naked eye) and forms in quiet (low energy) aqueous environments.

Alignment of the plate-like clay particles permits shale to be split into layers.

Mudstone is similar to shale but does not split into layers.

Geological Society of London

Fossils are common in *shale* - the quiet depositional environment aids in the preservation of organisms.

Shale is the most common sedimentary rock and is forming in ocean basins and is found on continents in ancient sedimentary basins.


Colorado River Connected

Shale is becoming an important source of oil and natural gas with the development of hydraulic fracturing technologies to extract the energy resources.

Detrital Sedimentary Rocks — Sandstone

Sandstones are detrital rocks containing sand-sized particles that form in moderate energy environments. Quartz is the dominant mineral in sandstone - due to its durability. A well-sorted pure quartz sandstone with rounded grains indicates that it may be the result of a great deal of transport - maybe over several cycles.

- Pure quartz sand indicates a *distant* source for the sediment - other minerals are unstable and weather away.
- Sands containing other minerals indicate that they were deposited *near* the source of the sediment - minerals other than quartz (such as feldspars and hornblende) indicate are unstable in the sedimentary environment.

Detrital Sedimentary Rocks - Conglomerate and Breccia

These rocks consist of dominantly gravel-sized particles that form in high energy environments.

The particles are large enough to be identified as distinctive rock types which may indicate the source of sediment.

These are usually contain mud and sand as a matrix between the large particles.

Conglomerate - composed of rounded particles indicating some degree of transport (mountain stream, beaches).

Breccia - composed of angular fragments indicating that they did not travel far from their source (landslide, explosive hydrothermal activity, fault zones).

Chemical Sedimentary Rocks

Chemical sedimentary rocks are derived from material that is carried in solution to lakes and seas.

Precipitation occurs in two ways:

1. *Inorganic processes* such as evaporation can produce chemical sediments. (ex. evaporites, dripstone, travertine, etc.)

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2. *Biologic processes* (forming shells) results in chemical sediment. Organisms die and collect on the seafloor (ex. coral, chalk, etc.).

Chemical Sedimentary Rocks — Limestone

Limestone is the most common chemical sedimentary rock & is composed chiefly of the mineral calcite (reacts to acid).

Limestone is a very diverse rock and has a very wide range of occurrences ranging from coral reefs to chalk to cave formations

Some limestones straddle the line between detrital and chemical sedimentary rocks. Many contain detrital and biogenic (shell) particles as well as being the product of precipitation from seawater.

MO Dept. of Natural Resources

Limestone commonly contains fossils of marine organisms.

Lithification

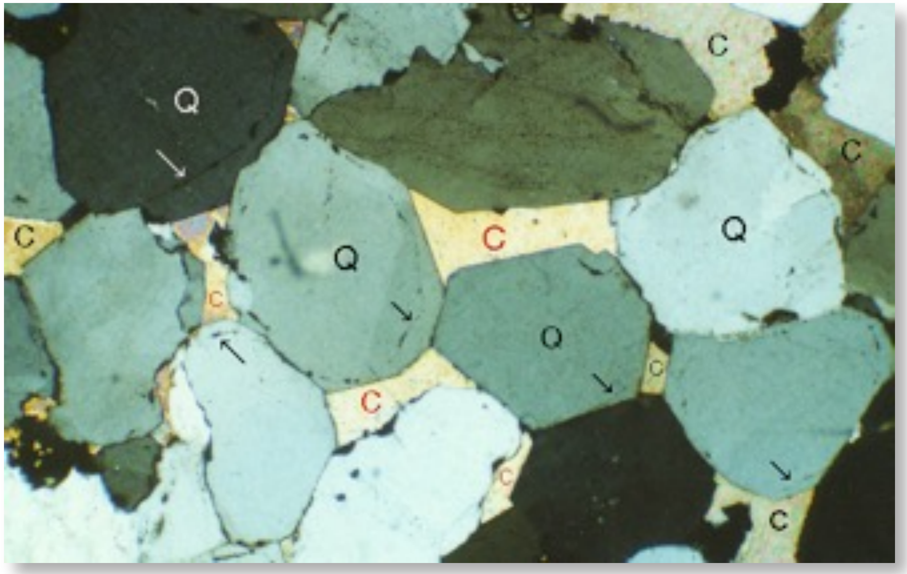
Lithification is the process by which unconsolidated sediment is transformed into solid sedimentary rock.

Two process are important in *lithification*:

1. *compaction* — as sediments accumulate through time, the weight of overlying material compresses/compacts the deeper sediment.

2. *cementation* — cementing materials are carried in solution by water percolating through the pore spaces between particles. Calcite, silica, and hematite are common cementing agents.

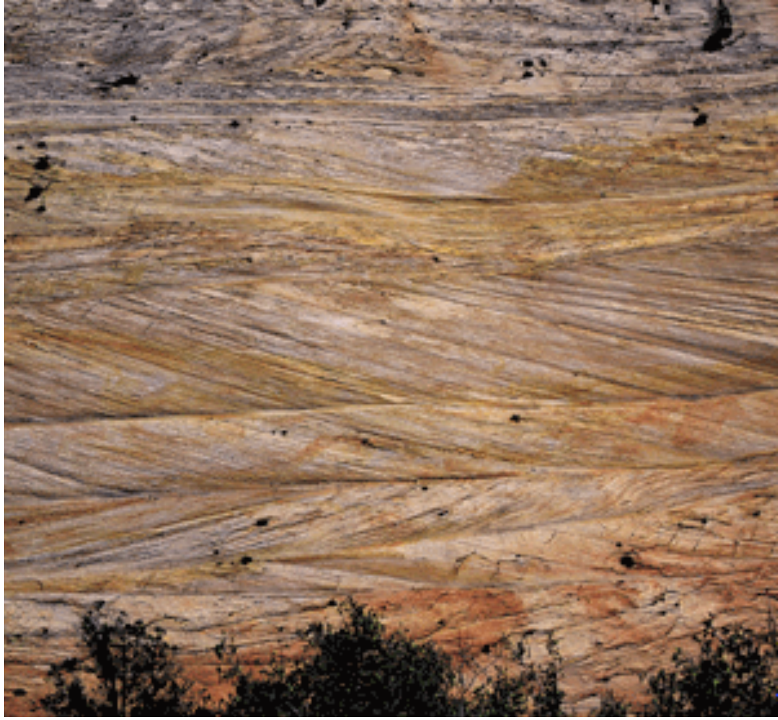
The photo shows a sandstone with quartz (Q) grains cemented by calcite (C) in thin section.



Features of Sedimentary Rocks

Sediments display a variety of different structures that allow us to determine some of the environmental parameters in a depositional environment.

The photo to the right shows *cross-bedding* which is characteristic of sand dunes, deltas, etc.



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Fossils are common in sedimentary rocks and provide a record of the environment/ecosystem.

Sedimentary Structures

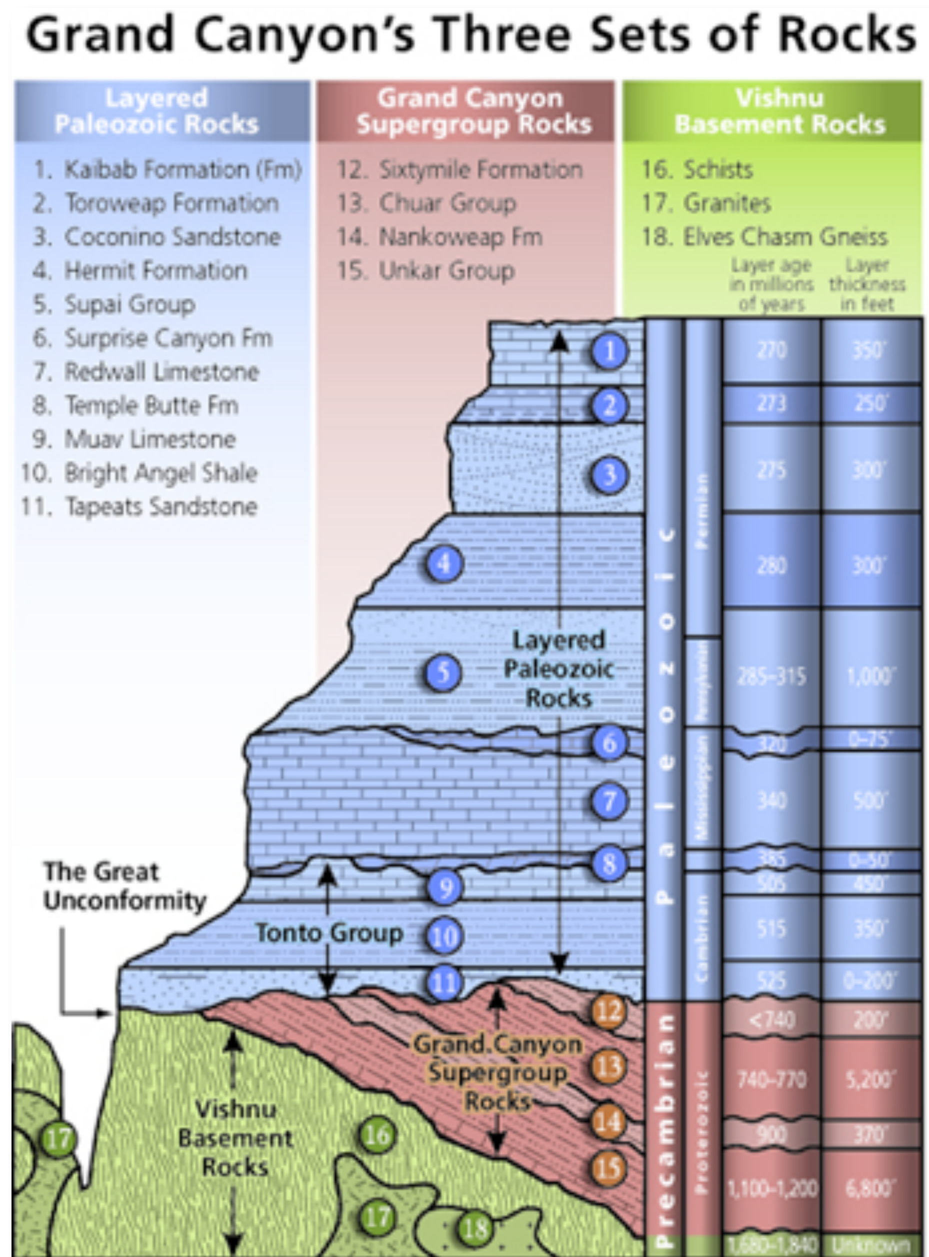
Ripple marks are small waves of sand that develop on a surface and may be preserved in a sedimentary rock during *lithification*.

Mud cracks indicates that sediments went through cycles of wet and dry. They may be preserved in the sedimentary rock.

Depositional Environment and Facies

Sedimentary rocks indicate the type of environment in which they formed.

For example, the Paleozoic sediments in the Grand Canyon range from shales to sandstones to limestones. Thus, we can use the type of sedimentary rock to infer how the depositional environment changed with time.



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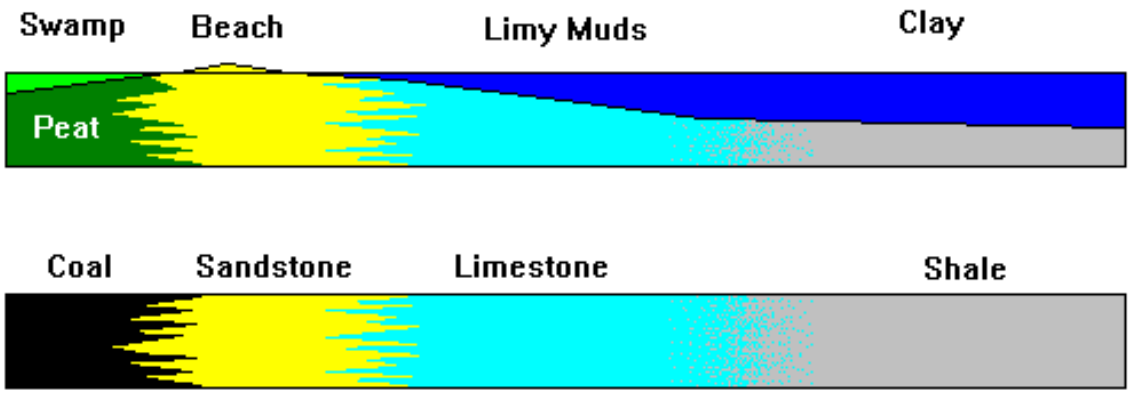
Depositional Environment and Facies

In addition, different sedimentary environments occur over a broad area at the same time. The term *facies* is used to describe these sets of sedimentary rocks that grade from one into another.



Steven Dutch UWGB

For example, sand and conglomerate may accumulate in a beach environment (high energy) while finer muds are deposited in quieter offshore waters. In some environments, calcareous (limestone) sediments may accumulate where land-derived sediments are scarce. Different sediments are accumulating adjacent to one another at the same time.

4. Metamorphic Rocks

Metamorphic rocks form as igneous, sedimentary or even other metamorphic rocks are changed due to an increase in temperature and/or pressure. The increase in pressure and temperature usually occurs as the rock is buried deeper in the Earth.

Temperature increases in the crust ~20-30°/km (geothermal gradient)

Pressure increases with depth ~280 bar/km (geobaric gradient)

Metamorphism occurs incrementally, from slight change (known as low-grade metamorphism) to dramatic change (high-grade metamorphism) from the *parent rock*. Metamorphic rocks change without melting (solid state reactions).

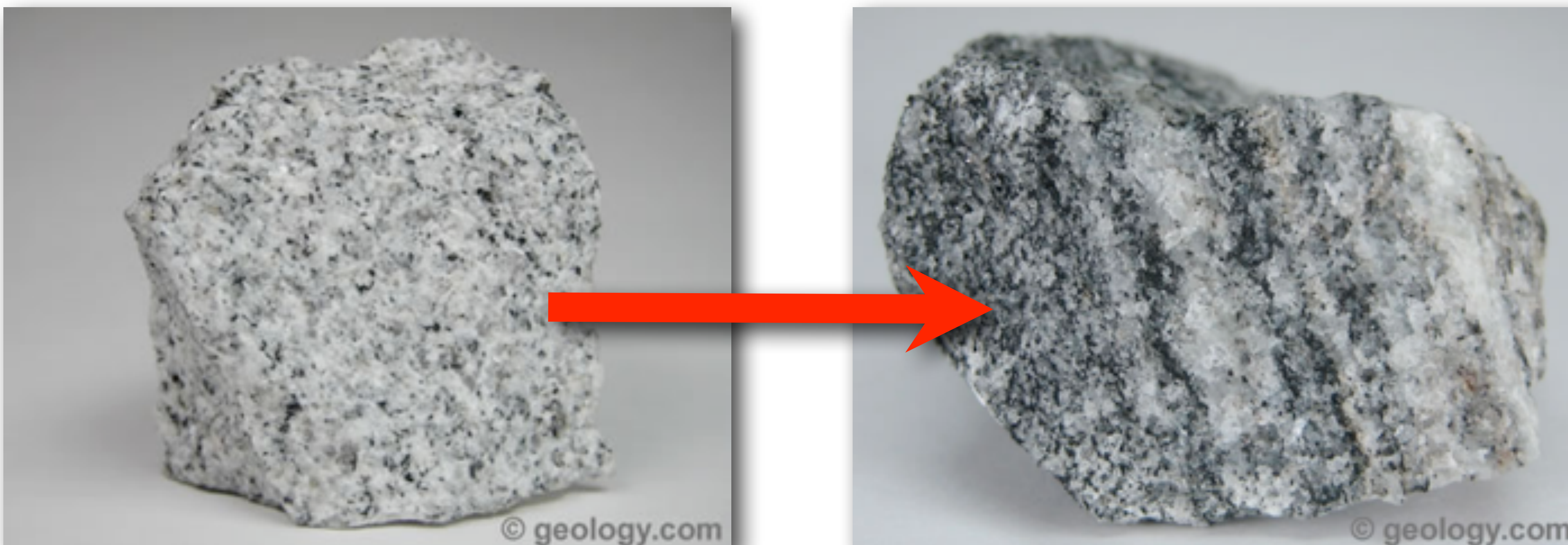
The *parent rock* is the original rock before metamorphism.

Metamorphism causes changes in rocks, including increased density, growth of larger crystals, reorientation of grains into layers or bands, and the formation of new minerals.

These changes may be grouped into two broad categories:

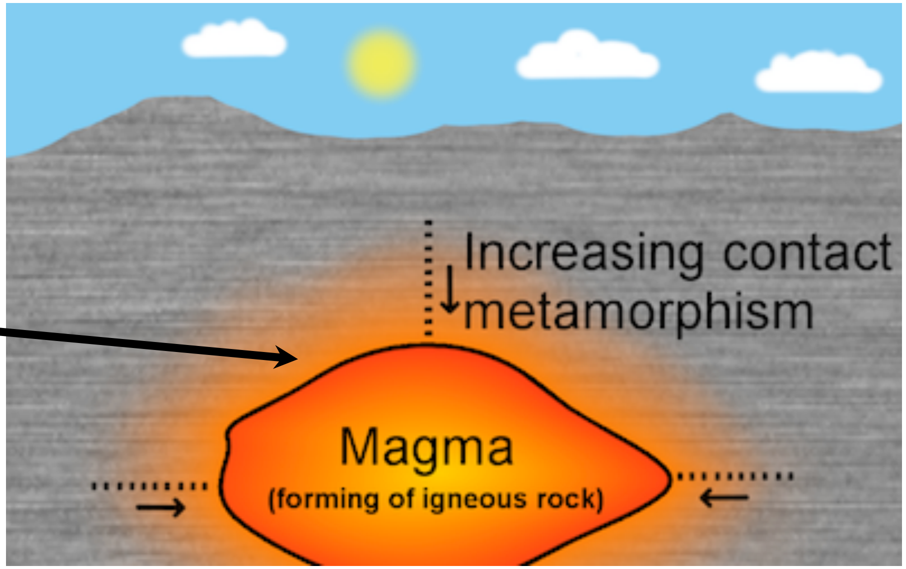
1. textural changes
2. mineralogic changes (composition)

In addition, on a larger scale, the forces that cause metamorphism may also deform (fold and shear) rocks.



The most common geologic settings for metamorphism are:

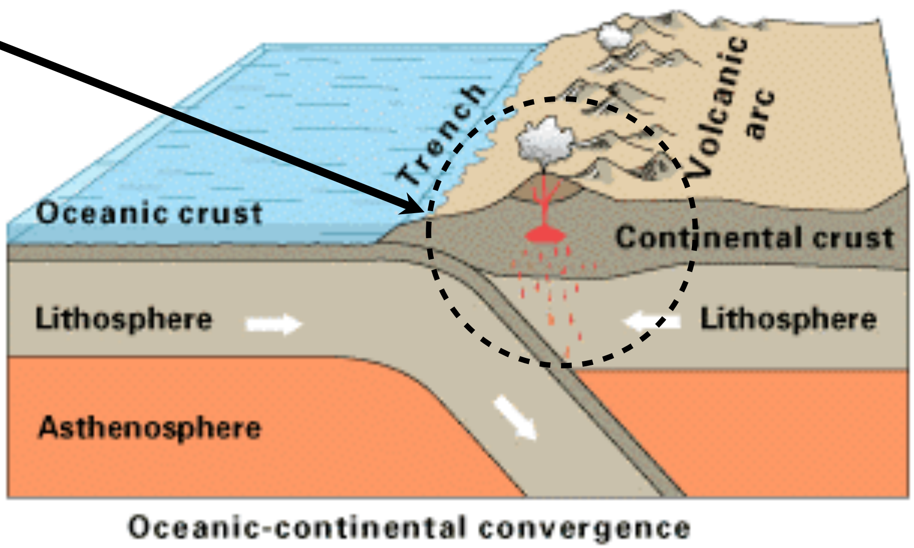
1. *Contact (thermal) metamorphism* occur in rocks when they are intruded by hot magma - "bake" the surrounding rock- it is a relatively small event.



Wikimedia: Jasmin Ros

2. *Regional metamorphism* occurs when large-scale deformation occurs in rocks when they are subjected to higher pressure and temperatures during "mountain building" processes.

Pearson



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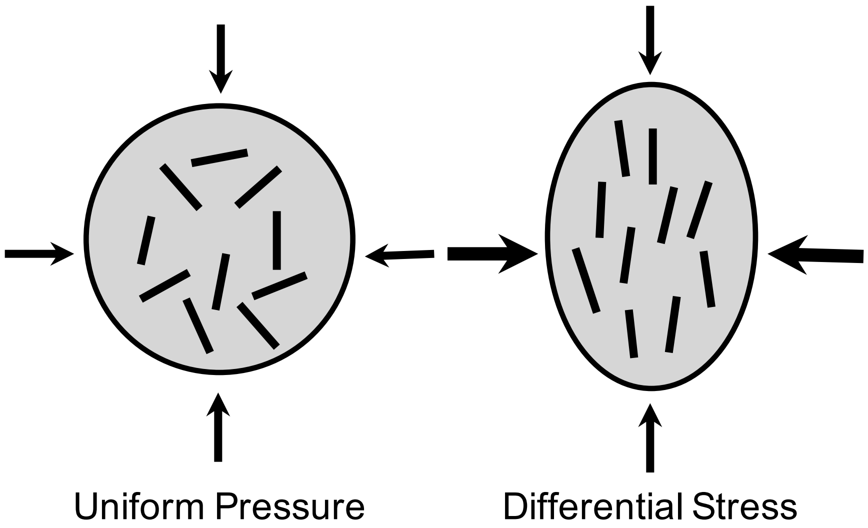
Textural Changes in Metamorphic Rocks

During metamorphism, rocks may develop *foliation* where mineral grains realign and recrystallize (solid state) *perpendicular* to stress.

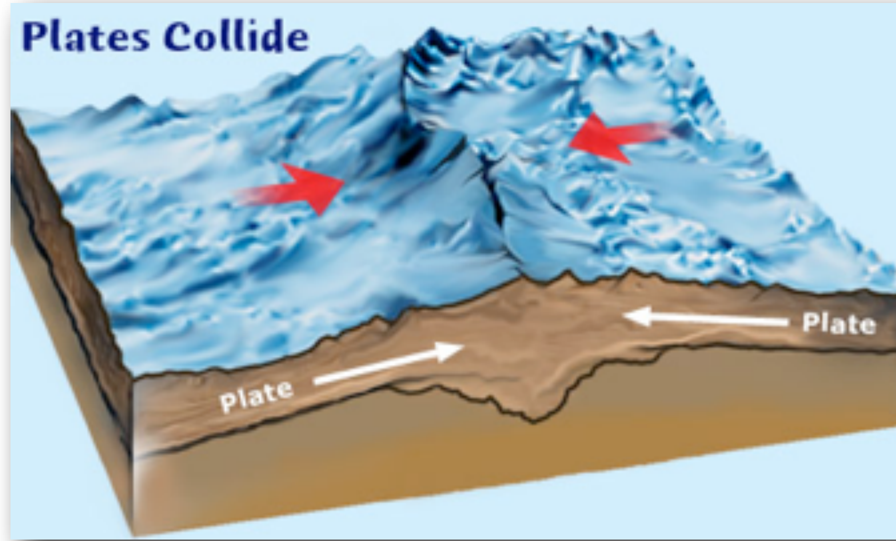
The development of *foliation* is common during *regional metamorphism* where stress is greater in one direction than in the others.



Some metamorphic rocks are *nonfoliated* - they do not develop a parallel alignment of mineral grains. *Nonfoliated* rocks are common with contact metamorphism where rocks are heated by an igneous magma but are not subjected to high increases in pressure.

Common Metamorphic Rocks: Foliated Rocks

Let's consider the progressive metamorphism of a shale (or mudstone) during a regional metamorphic event (mountain building).



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Shale

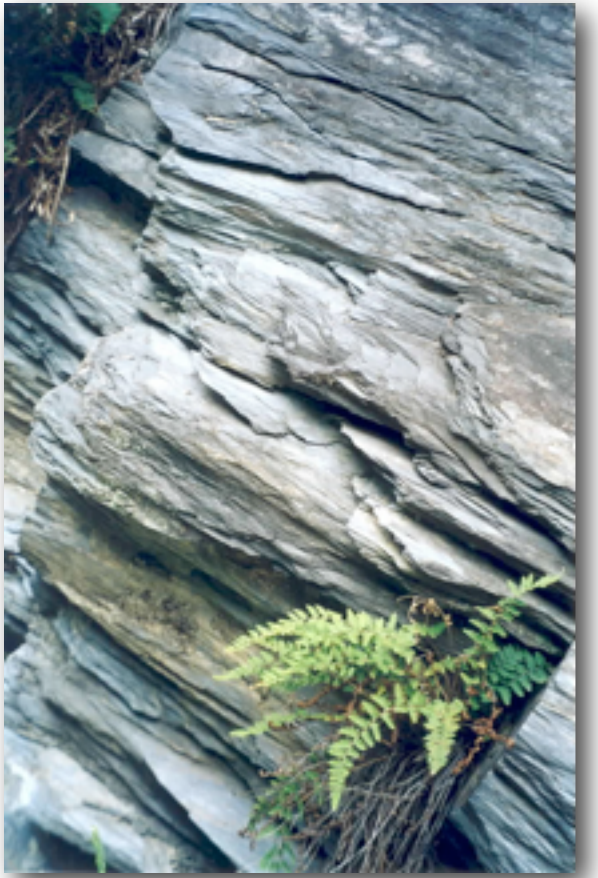
Remember that *shale* is a fine grained detrital sedimentary rock composed of silt- and clay-sized particles (too small to see with the naked eye) and is the most common sedimentary rock.

Progressive metamorphism: slate → phyllite → schist → gneiss

Progressive metamorphism generally results in rocks that are increasingly coarse in texture (larger crystals).

Common Metamorphic Rocks: Foliated Rocks

Slate is the first distinctive metamorphic rock to form. It is low-grade (relatively low pressure and temperature), very fine grained foliated rock composed of microscopic grains of mica.



Slate has excellent rock cleavage.
The foliation in slate is *not* related to the foliation in shale. The foliation in slate forms perpendicular to the greatest stress.

Common Metamorphic Rocks: Foliated Rocks

Low to moderate-grade metamorphism of shale results in *phyllite*.

Phyllite is a foliated metamorphic rock that is similar to slate. In phyllite, the mica crystals (although generally too small to see with the naked eye) are large enough to give *phyllite* sheen (reflects light).

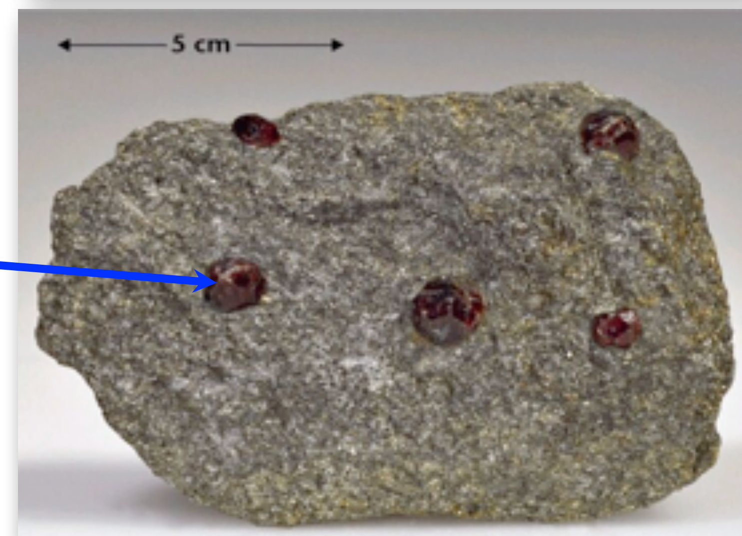
Progressive metamorphism: slate → phyllite → schist → gneiss

Common Metamorphic Rocks: Foliated Rocks

The next step in the progressive metamorphism of shale is schist.

Schist is a moderate- to high-grade foliated rock where the platy minerals (micas) (>50%) are large enough to see with the naked eye.

Phyllite may contain larger accessory minerals such as garnet.



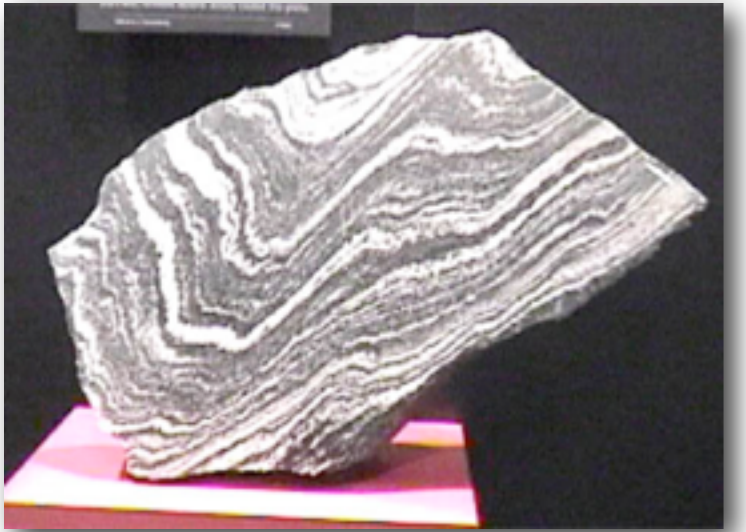
Progressive metamorphism: slate → phyllite → schist → gneiss

Common Metamorphic Rocks: Foliated Rocks

Gneiss high-grade foliated metamorphic rock where the minerals have segregated into bands of light and dark minerals (gneissic banding).

Gneiss may or may not possess rock cleavage.

It is common to find folds in the bands of minerals in gneiss.



Progressive metamorphism: slate → phyllite → schist → gneiss

Nonfoliated Textures

Nonfoliated metamorphic rocks typically form in contact metamorphic environments.

Not all metamorphic rocks will developed foliated texture due to the absence of platy minerals. However, the size of the crystals increases with increased metamorphic grade.

Marble is a nonfoliated metamorphic rock that is commonly composed of the mineral calcite (reacts to acid). The parent rock of *marble* is limestone.

Marble is commonly used as a decorative stone.

Nonfoliated Textures

Quartzite is a nonfoliated metamorphic rock that is composed of quartz.

The parent rock of *quartzite* is sandstone. It is very hard and chemically resistant.

Quartzite may appear to look similar to marble but can be by its extreme hardness since it is composed of fused quartz grains. In addition, *marble* will commonly react with acid.

Common Metamorphic Rocks

Rock Name	grade	Texture	Grain Size	Comments	Parent Rock
Slate	↓	foliated	Very fine	Rock cleavage	Shale or mudstone
Phyllite	↓	foliated	Fine	Wavy rock cleavage; glossy	Slate
Schist	↓	foliated	Medium to Coarse	Mica minerals & scaly foliation	Phyllite
Gneiss	↓	foliated	Medium to Coarse	Banding	Schist
Quartzite		non-foliated	Medium to Coarse	Massive & very hard	Quartz sandstone
Marble		non-foliated	Fine to Medium	Granular	Limestone