EENS 212	Petrology	Prof. Stephen A. Nelson
Introduction & Textures & Structures of Igneous Rocks		

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Petrology & Petrography

Petrology - The branch of geology dealing with the origin, occurrence, structure, and history of rocks.

Petrography - The branch of geology dealing with the description and systematic classification of rocks, especially by microscopic examination of thin sections. Petrography is a subfield of Petrology.

In this course, most of the lecture material falls under the field of Petrology, while much of the laboratory material falls in the field of Petrography.

Introduction to Igneous Rocks

An ***igneous rock*** is any crystalline or glassy rock that forms from cooling of a magma.

A ***magma*** consists mostly of liquid rock matter, but may contain crystals of various minerals, and may contain a gas phase that may be dissolved in the liquid or may be present as a separate gas phase.

Magma can cool to form an igneous rock either on the surface of the Earth - in which case it produces a ***volcanic*** or ***extrusive igneous rock***, or beneath the surface of the Earth, - in which case it produces a ***plutonic*** or ***intrusive igneous rock***.

Characteristics of Magma

Types of Magma

Types of magma are determined by chemical composition of the magma. Three general types are recognized, but we will look at other types later in the course:

1. ***Basaltic magma*** -- SiO_2 45-55 wt%, high in Fe, Mg, Ca, low in K, Na
2. ***Andesitic magma*** -- SiO_2 55-65 wt%, intermediate. in Fe, Mg, Ca, Na, K
3. ***Rhyolitic magma*** -- SiO_2 65-75%, low in Fe, Mg, Ca, high in K, Na

Gases in Magmas

At depth in the Earth nearly all magmas contain gas dissolved in the liquid, but the gas forms a separate vapor phase when pressure is decreased as magma rises toward the surface. This is similar to carbonated beverages which are bottled at high pressure. The high pressure keeps the gas in solution in the liquid, but when pressure is decreased, like when you open the can or bottle, the gas comes out of solution and forms a separate gas phase that you see as bubbles. Gas gives magmas their explosive character, because volume of gas expands as pressure is reduced. The composition of the gases in magma are:

- Mostly H_2O (water vapor) with some CO_2 (carbon dioxide)
- Minor amounts of Sulfur, Chlorine, and Fluorine gases

The amount of gas in a magma is also related to the chemical composition of the magma. Rhyolitic magmas usually have higher dissolved gas contents than basaltic magmas.

Temperature of Magmas

Temperature of magmas is difficult to measure (due to the danger involved), but laboratory measurement and limited field observation indicate that the eruption temperature of various magmas is as follows:

- Basaltic magma - 1000 to 1200^oC
- Andesitic magma - 800 to 1000^oC
- Rhyolitic magma - 650 to 800^oC.

Viscosity of Magmas

Viscosity is the resistance to flow (opposite of fluidity). Viscosity depends on primarily on the composition of the magma, and temperature.

- Higher SiO_2 (silica) content magmas have higher viscosity than lower SiO_2 content magmas (viscosity increases with increasing SiO_2 concentration in the magma).

- Lower temperature magmas have higher viscosity than higher temperature magmas (viscosity decreases with increasing temperature of the magma).

Thus, basaltic magmas tend to be fairly fluid (low viscosity), but their viscosity is still 10,000 to 100,0000 times more viscous than water. Rhyolitic magmas tend to have even higher viscosity, ranging between 1 million and 100 million times more viscous than water. (Note that solids, even though they appear solid have a viscosity, but it is very high, measured as trillions time the viscosity of water). Viscosity is an important property in determining the eruptive behavior of magmas.

Summary Table

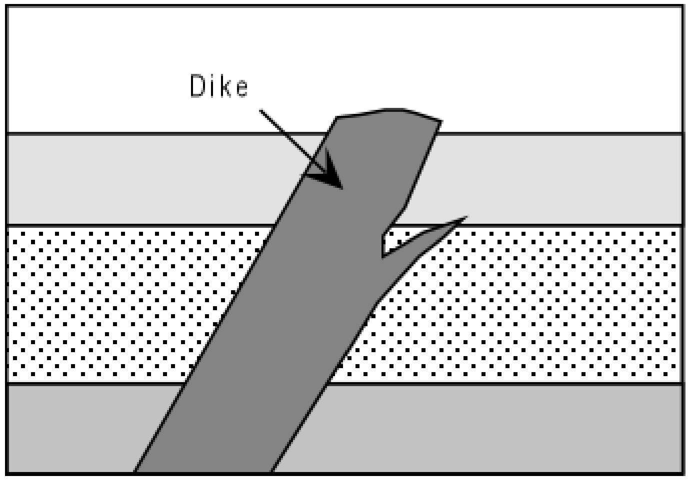
Magma Type	Solidified Rock	Chemical Composition	Temperature	Viscosity	Gas Content
Basaltic	Basalt	45-55 SiO_2 %, high in Fe, Mg, Ca, low in K, Na	1000 - 1200 ^oC	10 - 10^3 PaS	Low
Andesitic	Andesite	55-65 SiO_2 %, intermediate in Fe, Mg, Ca, Na, K	800 - 1000 ^oC	10^3 - 10^5 PaS	Intermediate
Rhyolitic	Rhyolite	65-75 SiO_2 %, low in Fe, Mg, Ca, high in K, Na.	650 - 800 ^oC	10^5 - 10^9 PaS	High

Plutonic (Intrusive) Igneous Rocks

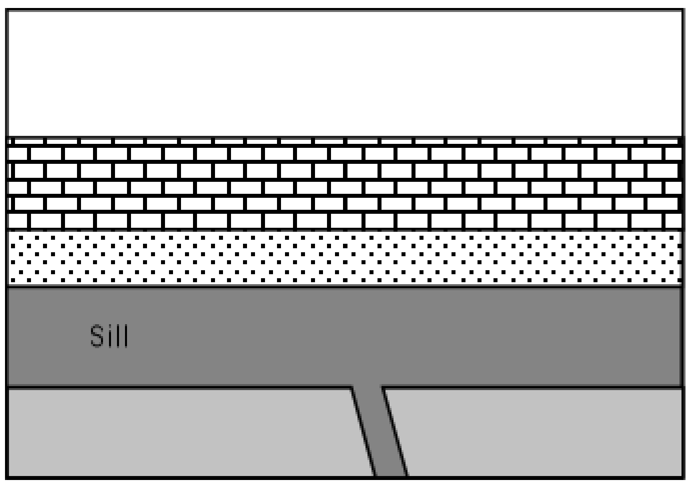
Hypabyssal Intrusions

Intrusions that intrude rocks at shallow levels of the crust are termed hypabyssal intrusions. Shallow generally refers to depths less than about 1 km. Hypabyssal intrusions always show sharp contact relations with the rocks that they intrude. Several types are found:

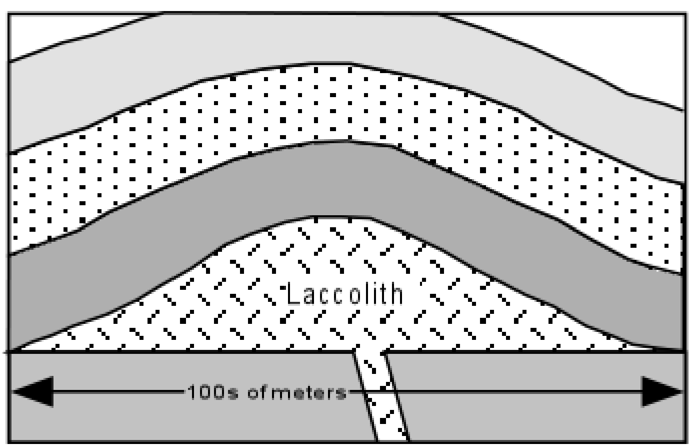
- **Dikes** are small (<20 m wide) shallow intrusions that show a discordant relationship to the rocks in which they intrude. Discordant means that they cut across preexisting structures. They may occur as isolated bodies or may occur as swarms of dikes emanating from a large intrusive body at depth.



- **Sills** are also small (<50 m thick) shallow intrusions that show a concordant relationship with the rocks that they intrude. Sills usually are fed by dikes, but these may not be exposed in the field.



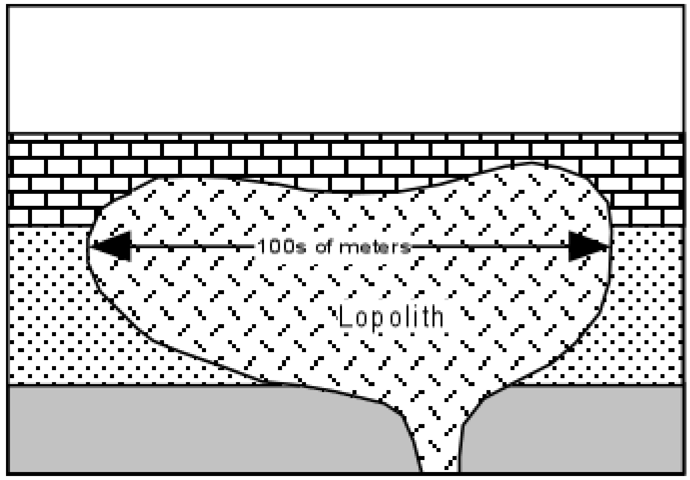
- **Laccoliths** are somewhat large intrusions that result in uplift and folding of the preexisting rocks above the intrusion. They are also concordant types of intrusions.



Plutons

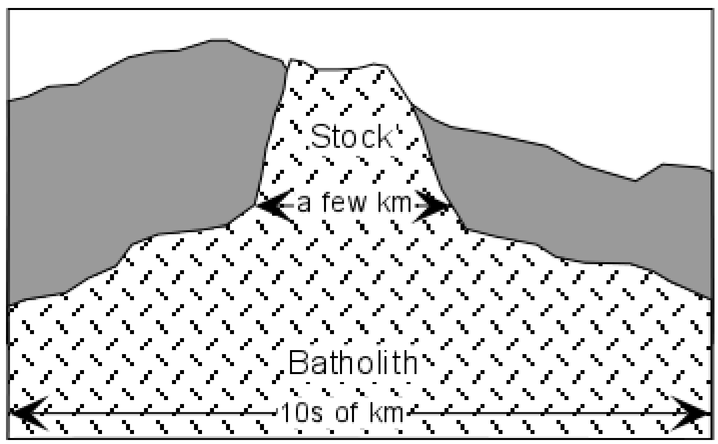
Plutons are generally much larger intrusive bodies that have intruded much deeper in the crust. Although they may show sharp contacts with the surrounding rocks into which they intruded, at deeper levels in the crust the contacts are often gradational.

- **Lopoliths** are relatively small plutons that usually show a concave downward upper surface. This shape may have resulted from the reduction in volume that occurs when magmas crystallize, with the weight of the overlying rocks causing collapse of into the space once occupied by the magma when it had a larger volume as a liquid.



- **Batholiths** are very large intrusive bodies, usually so large that there bottoms are rarely exposed. Sometimes they are composed of several smaller intrusions.

- **Stocks** are smaller bodies that are likely fed from deeper level batholiths. Stocks may have been feeders for volcanic eruptions, but because large amounts of erosion are required to expose a stock or batholith, the associated volcanic rocks are rarely exposed.



Volcanic (Extrusive) Igneous Rocks

Volcanic Eruptions

- In general, magmas that are generated deep within the Earth begin to rise because they are less dense than the surrounding solid rocks.

- As they rise they may encounter a depth or pressure where the dissolved gas no longer can be held in solution in the magma, and the gas begins to form a separate phase (i.e. it makes bubbles just like in a bottle of carbonated beverage when the pressure is reduced).

- When a gas bubble forms, it will also continue to grow in size as pressure is reduced and more of the gas comes out of solution. In other words, the gas bubbles begin to expand.

- If the liquid part of the magma has a low viscosity, then the gas can expand relatively easily. When the magma reaches the surface, the gas bubble will simply burst, the gas will easily expand to atmospheric pressure, and a non-explosive eruption will occur, usually as a lava flow (***Lava*** is the name we give to a magma on the surface of the Earth).

- If the liquid part of the magma has a high viscosity, then the gas will not be able to expand easily. Thus, pressure will build inside the gas bubble(s). When the magma reaches the surface, the gas bubbles will have a high pressure inside, which will cause them to burst explosively on reaching atmospheric pressure. This will cause an explosive volcanic eruption.

Explosive Eruptions

Explosive eruptions are favored by high gas content and high viscosity (andesitic to rhyolitic magmas).

- Explosive bursting of bubbles will fragment the magma into clots of liquid that will cool as they fall through the air. These solid particles become ***pyroclasts*** (meaning - hot fragments) and ***tephra*** or ***volcanic ash,*** which refer to sand- sized or smaller fragments.

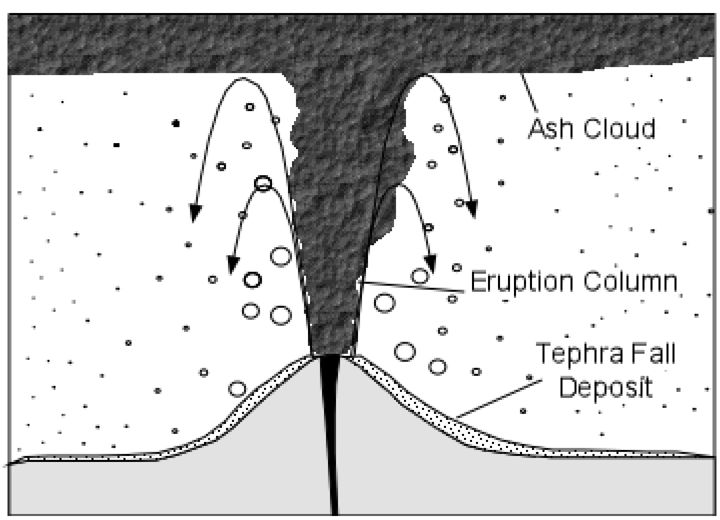
Tephra and Pyroclastic Rocks		
Average Particle Size (mm)	Unconsolidated Material (Tephra)	Pyroclastic Rock
>64	Bombs or Blocks	Agglomerate
2 - 64	Lapilli	Lapilli Tuff
<2	Ash	Ash Tuff

- ***Blocks*** are angular fragments that were solid when ejected.

- ***Bombs*** have an aerodynamic shape indicating they were liquid when ejected.

- Bombs and lapilli that consist mostly of gas bubbles (***vesicles***) result in a low density highly vesicular rock fragment called ***pumice***.

- Clouds of gas and tephra that rise above a volcano produce an ***eruption column*** that can rise up to 45 km into the atmosphere. Eventually the tephra in the eruption column will be picked up by the wind, carried for some distance, and then fall back to the surface as a ***tephra fall*** or ***ash fall***.



Textures of Igneous Rocks

The main factor that determines the texture of an igneous rock is the ***cooling rate*** (dT/dt)

Other factors involved are:

- The diffusion rate - the rate at which atoms or molecules can move (diffuse) through the liquid.

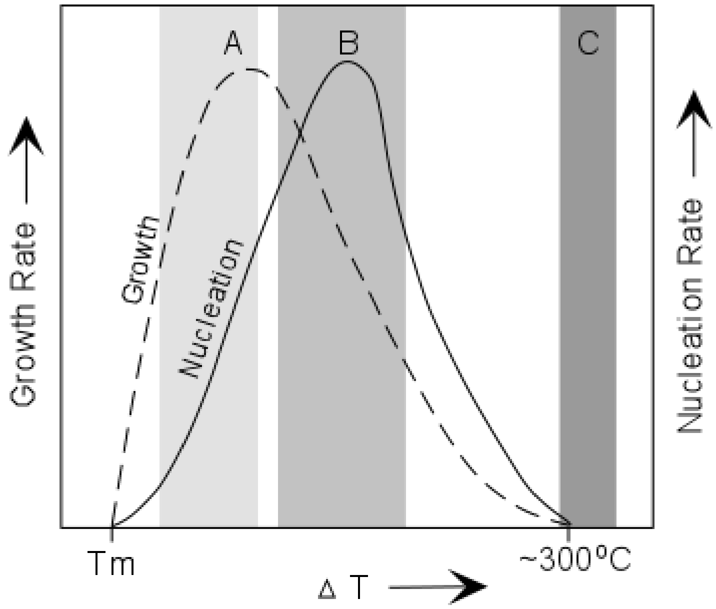
- The rate of nucleation of new crystals - the rate at which enough of the chemical constituents of a crystal can come together in one place without dissolving.

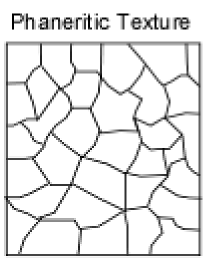
- The rate of growth of crystals - the rate at which new constituents can arrive at the surface of the growing crystal. This depends largely on the diffusion rate of the molecules of concern.

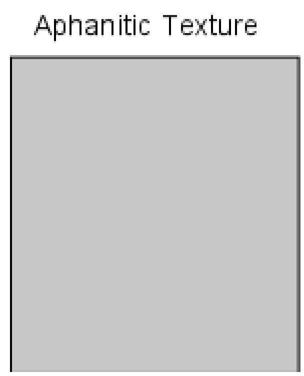
In order for a crystal to form in a magma enough of the chemical constituents that will make up the crystal must be at the same place at the same time to form a ***nucleus*** of the crystal. Once a nucleus forms, the chemical constituents must diffuse through the liquid to arrive at the surface of the growing crystal. The crystal can then grow until it runs into other crystals or the supply of chemical constituents is cut off.

All of these rates are strongly dependent on the temperature of the system. First, nucleation and growth cannot occur until temperatures are below the temperature at which equilibrium crystallization begins. Shown below are hypothetical nucleation and growth rate curves based on experiments in simple systems. Note that the rate of crystal growth and nucleation depends on how long the magma resides at a specified degree of undercooling ($\Delta T = T_m - T$), and thus the rate at which temperature is lowered below the the crystallization temperature. Three cases are shown.

1. For small degrees of undercooling (region A in the figure to the right) the nucleation rate will be low and the growth rate moderate. A few crystals will form and grow at a moderate rate until they run into each other. Because there are few nuclei, the crystals will be able to grow to relatively large size, and a coarse grained texture will result. This would be called a ***phaneritic texture***.



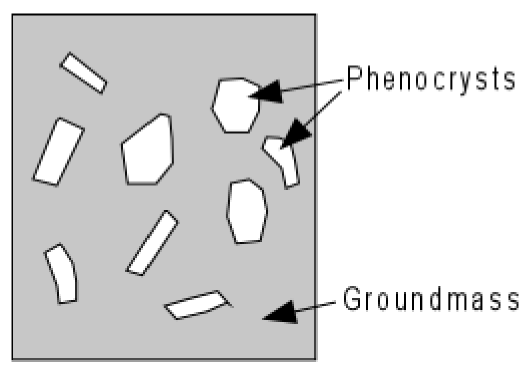




2. At larger degrees of undercooling, the nucleation rate will be high and the growth rate also high. This will result in many crystals all growing rapidly, but because there are so many crystals, they will run into each other before they have time to grow and the resulting texture will be a fine grained texture. If the size of the grains are so small that crystals cannot be distinguished with a handlens, the texture is said to be ***aphanitic***.

3. At high degrees of undercooling, both the growth rate and nucleation rate will be low. Thus few crystals will form and they will not grow to any large size. The resulting texture will be glassy, with a few tiny crystals called microlites. A completely glassy texture is called ***holohyaline texture***.

Two stages of cooling, i.e. slow cooling to grow a few large crystals, followed by rapid cooling to grow many smaller crystals could result in a ***porphyritic texture***, a texture with two or more distinct sizes of grains. Single stage cooling can also produce a porphyritic texture. In a porphyritic texture, the larger grains are called ***phenocrysts*** and the material surrounding the the phenocrysts is called ***groundmass*** or ***matrix***



In a rock with a phaneritic texture, where all grains are about the same size, we use the grain size ranges shown to the right to describe the texture:

<1 mm	fine grained
1 - 5 mm	medium grained
5 - 3 cm	coarse grained
> 3 cm	very coarse grained

In a rock with a porphyritic texture, we use the above table to define the grain size of the groundmass or matrix, and this table to describe the phenocrysts:

0.03 - 0.3 mm	microphenocrysts
0.3 - 5 mm	phenocrysts
> 5 mm	megaphenocrysts

Another aspect of texture, particularly in medium to coarse grained rocks is referred to as fabric. ***Fabric*** refers to the mutual relationship between the grains. Three types of fabric are commonly referred to:

1. If most of the grains are ***euhedral*** - that is they are bounded by well-formed crystal faces. The fabric is said to be ***idomorphic granular***.

2. If most of the grains are ***subhedral*** - that is they bounded by only a few well-formed crystal faces, the fabric is said to be ***hypidiomorphic granular***.

3. If most of the grains are ***anhedral*** - that is they are generally not bounded by crystal faces, the fabric is said to be ***allotriomorphic granular***.

If the grains have particularly descriptive shapes, then it is essential to describe the individual grains. Some common grain shapes are:

- *Tabular* - a term used to describe grains with rectangular tablet shapes.

- *Equant* - a term used to describe grains that have all of their boundaries of approximately equal length.

- *Fibrous* - a term used to describe grains that occur as long fibers.

- *Acicular* - a term used to describe grains that occur as long, slender crystals.

- *Prismatic* - a term used to describe grains that show an abundance of prism faces.

Other terms may apply to certain situations and should be noted if found in a rock.

- *Vesicular* - if the rock contains numerous holes that were once occupied by a gas phase, then this term is added to the textural description of the rock.

- *Glomeroporphyritic* - if phenocrysts are found to occur as clusters of crystals, then the rock should be described as glomeroporphyritic instead of porphyritic.

- *Amygdular* - if vesicles have been filled with material (usually calcite, chalcedonay, or quartz, then the term amygdular should be added to the textural description of the rock. An amygdule is defined as a refilled vesicle.

- *Pumiceous* - if vesicles are so abundant that they make up over 50% of the rock and the rock has a density less than 1 (i.e. it would float in water), then the rock is pumiceous.

- *Scoraceous*- if vesicles are so abundant that they make up over 50% of the rock and the rock has a density greater than 1, then the rock is said to be scoraceous.

- *Graphic* - a texture consisting of intergrowths of quartz and alkali feldspar wherein the orientation of the quartz grains resembles cuneiform writing. This texture is most commonly observed in pegmatites.

- *Spherulitic* - a texture commonly found in glassy rhyolites wherein spherical intergrowths of radiating quartz and feldspar replace glass as a result of devitrification.

- *Obicular* - a texture usually restricted to coarser grained rocks that consists of concentrically banded spheres wherein the bands consist of alternating light colored and dark colored minerals.

Other textures that may be evident on microscopic examination of igneous rocks are as follows:

- *Myrmekitic texture* - an intergrowth of quartz and plagioclase that shows small wormlike bodies of quartz enclosed in plagioclase. This texture is found in granites.

- *Ophitic texture* - laths of plagioclase in a coarse grained matrix of pyroxene crystals, wherein the plagioclase is totally surrounded by pyroxene grains. This texture is common in diabases and gabbros.

- *Subophitic texture* - similar to ophitic texture wherein the plagioclase grains are not completely enclosed in a matrix of pyroxene grains.

- *Poikilitic texture* - smaller grains of one mineral are completely enclosed in large, optically continuous grains of another mineral.

- *Intergranular texture* - a texture in which the angular interstices between plagioclase grains are occupied by grains of ferromagnesium minerals such as olivine, pyroxene, or iron titanium oxides.

- *Intersertal texture* - a texture similar to intergranular texture except that the interstices between plagioclase grains are occupied by glass or cryptocrystalline material.

- *Hyaloophitic texture* - a texture similar to ophitic texture except that glass completely surrounds the plagioclase laths.

- *Hyalopilitic texture* - a texture wherein microlites of plagioclase are more abundant than groundmass, and the groundmass consists of glass which occupies the tiny interstices between plagioclase grains.

- *Trachytic texture* - a texture wherein plagioclase grains show a preferred orientation due to flowage, and the interstices between plagioclase grains are occupied by glass or cryptocrystalline material.

- *Coronas or reaction rims* - often times reaction rims or coronas surround individual crystals as a result of the crystal becoming unstable and reacting with its surrounding crystals or melt. If such rims are present on crystals they should be noted in the textural description.

- *Patchy zoning* - This sometimes occurs in plagioclase crystals where irregularly shaped patches of the crystal show different compositions as evidenced by going extinct at angles different from other zones in the crystal.

- *Oscillatory zoning* - This sometimes occurs in plagioclase grains wherein concentric zones around the grain show thin zones of different composition as evidenced by extinction phenomena.

- *Moth eaten texture* (also called *sieve texture*)- This sometimes occurs in plagioclase wherein individual plagioclase grains show an abundance of glassy inclusions.

- *Perthitic texture* - Exsolution lamellae of albite occurring in orthoclase or microcline.

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Types of Metamorphism		

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Metamorphism is defined as follows:

> **The mineralogical and structural adjustment of solid rocks to physical and chemical conditions that have been imposed at depths below the near surface zones of weathering and diagenesis and which differ from conditions under which the rocks in question originated.**

The word "***Metamorphism***" comes from the Greek: meta = change, morph = form, so metamorphism means to change form. In geology this refers to the changes in mineral assemblage and texture that result from subjecting a rock to conditions such pressures, temperatures, and chemical environments different from those under which the rock originally formed.

- Note that ***Diagenesis*** is also a change in form that occurs in sedimentary rocks. In geology, however, we restrict diagenetic processes to those which occur at temperatures below 200^{o}C and pressures below about 300 MPa (MPa stands for Mega Pascals), this is equivalent to about 3 kilobars of pressure (1kb = 100 MPa).

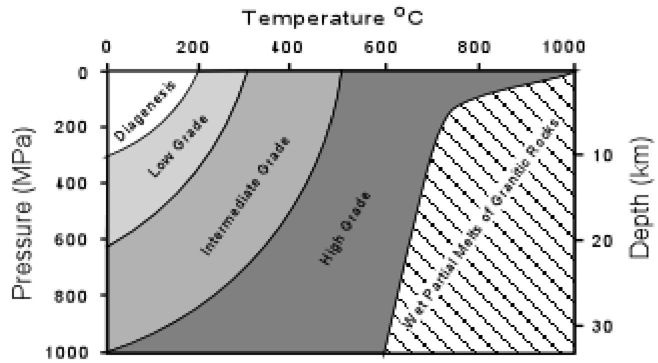
- Metamorphism, therefore occurs at temperatures and pressures higher than 200^{o}C and 300 MPa. Rocks can be subjected to these higher temperatures and pressures as they are buried deeper in the Earth. Such burial usually takes place as a result of tectonic processes such as continental collisions or subduction.

- The upper limit of metamorphism occurs at the pressure and temperature where melting of the rock in question begins. Once melting begins, the process changes to an igneous process rather than a metamorphic process.

Grade of Metamorphism

As the temperature and/or pressure increases on a body of rock we say the rock undergoes ***prograde metamorphism*** or that the grade of metamorphism increases. ***Metamorphic grade*** is a general term for describing the relative temperature and pressure conditions under which metamorphic rocks form.

- Low-grade metamorphism takes place at temperatures between about 200 to 320^oC, and relatively low pressure. Low grade metamorphic rocks are generally characterized by an abundance of hydrous minerals. With increasing grade of metamorphism, the hydrous minerals begin to react with other minerals and/or break down to less hydrous minerals.



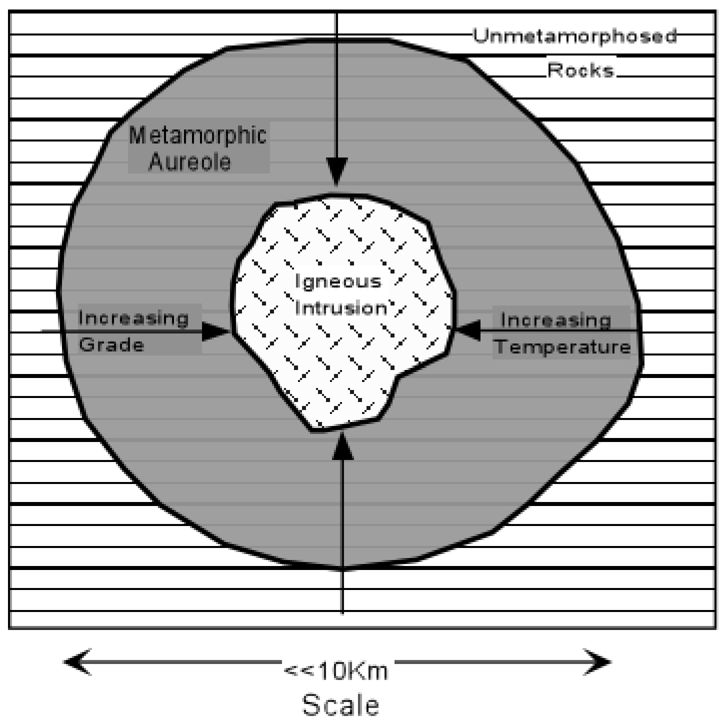
- High-grade metamorphism takes place at temperatures greater than 320^oC and relatively high pressure. As grade of metamorphism increases, hydrous minerals become less hydrous, by losing H_2O, and non-hydrous minerals become more common.

Types of Metamorphism

Contact Metamorphism

Contact metamorphism occurs adjacent to igneous intrusions and results from high temperatures associated with the igneous intrusion**.**

Since only a small area surrounding the intrusion is heated by the magma, metamorphism is restricted to the zone surrounding the intrusion, called a ***metamorphic*** or ***contact aureole***. Outside of the contact aureole, the rocks are not affected by the intrusive event. The grade of metamorphism increases in all directions toward the intrusion. Because the temperature contrast between the surrounding rock and the intruded magma is larger at shallow levels in the crust where pressure is low, contact metamorphism is often referred to as high temperature, low pressure metamorphism. The rock produced is often a fine-grained rock that shows no foliation, called a ***hornfels***.



Regional Metamorphism

Regional metamorphism occurs over large areas and generally does not show any relationship to igneous bodies. Most regional metamorphism is accompanied by deformation under non-hydrostatic or differential stress conditions. Thus, regional metamorphism usually results in forming metamorphic rocks that are strongly foliated, such as slates, schists, and gniesses. The differential stress usually results from tectonic forces that produce compressional stresses in the rocks, such as when two continental masses collide. Thus, regionally metamorphosed rocks occur in the cores of fold/thrust mountain belts or in eroded mountain ranges. Compressive stresses result in folding of rock and thickening of the crust, which tends to push rocks to deeper levels where they are subjected to higher temperatures and pressures.

Cataclastic Metamorphism

Cataclastic metamorphism occurs as a result of mechanical deformation, like when two bodies of rock slide past one another along a fault zone. Heat is generated by the friction of sliding along such a shear zone, and the rocks tend to be mechanically deformed, being crushed and pulverized, due to the shearing. Cataclastic metamorphism is not very common and is restricted to a narrow zone along which the shearing occurred.

Hydrothermal Metamorphism

Rocks that are altered at high temperatures and moderate pressures by hydrothermal fluids are hydrothermally metamorphosed. This is common in basaltic rocks that generally lack hydrous minerals. The hydrothermal metamorphism results in alteration to such Mg-Fe rich hydrous minerals as talc, chlorite, serpentine, actinolite, tremolite, zeolites, and clay minerals. Rich ore deposits are often formed as a result of hydrothermal metamorphism.

Burial Metamorphism

When sedimentary rocks are buried to depths of several hundred meters, temperatures greater than $300^{o}C$ may develop in the absence of differential stress. New minerals grow, but the rock does not appear to be metamorphosed. The main minerals produced are often the Zeolites. Burial metamorphism overlaps, to some extent, with diagenesis, and grades into regional metamorphism as temperature and pressure increase.

Shock Metamorphism (Impact Metamorphism)

When an extraterrestrial body, such as a meteorite or comet impacts with the Earth or if there is a very large volcanic explosion, ultrahigh pressures can be generated in the impacted rock. These ultrahigh pressures can produce minerals that are only stable at very high pressure, such as the SiO_2 polymorphs coesite and stishovite. In addition they can produce textures known as shock lamellae in mineral grains, and such textures as shatter cones in the impacted rock.

Classification of Metamorphic Rocks

Classification of metamorphic rocks is based on mineral assemblage, texture, protolith, and bulk chemical composition of the rock. Each of these will be discussed in turn, then we will summarize how metamorphic rocks are classified.

Texture

In metamorphic rocks individual minerals may or may not be bounded by crystal faces. Those that are bounded by their own crystal faces are termed ***idioblastic***. Those that show none of their own crystal faces are termed ***xenoblastic***. From examination of metamorphic rocks, it has been found that metamorphic minerals can be listed in a generalized sequence, known as the ***crystalloblastic series***, listing minerals in order of their tendency to be idioblastic. In the series, each mineral tends to develop idioblastic surfaces against any mineral that occurs lower in the series. This series is listed below:

- rutile, sphene, magnetite
- tourmaline kyanite, staurolite, garnet, andalusite
- epidote, zoisite, lawsonite, forsterite
- pyroxenes, amphiboles, wollastonite
- micas, chlorites, talc, stilpnomelane, prehnite
- dolomite, calcite
- scapolite, cordierite, feldspars
- quartz

This series can, in a rather general way, enable us to determine the origin of a given rock. For example a rock that shows euhedral plagioclase crystals in contact with anhedral amphibole, likely had an igneous protolith, since a metamorphic rock with the same minerals would be expected to show euhedral amphibole in contact with anhedral plagioclase.

Another aspect of the crystalloblastic series is that minerals high on the list tend to form ***porphyroblasts*** (the metamorphic equivalent of phenocrysts), although K-feldspar (a mineral that occurs lower in the list) may also form porphyroblasts. Porphyroblasts are often riddled with inclusions of other minerals that were enveloped during growth of the porphyroblast. These are said to have a ***poikioblastic texture***.

Most metamorphic textures involve foliation. Foliation is generally caused by a preferred orientation of sheet silicates. If a rock has a slatey cleavage as its foliation, it is termed a ***slate***, if it has a phyllitic foliation, it is termed a ***phyllite***, if it has a shistose foliation, it is termed a ***schist***. A rock that shows a banded texture without a distinct foliation is termed a ***gneiss***. All of these could be porphyroblastic (i.e. could contain porhyroblasts).

A rock that shows no foliation is called a ***hornfels*** if the grain size is small, and a ***granulite***, if the grain size is large and individual minerals can be easily distinguished with a hand lens.

Protolith

Protolith refers to the original rock, prior to metamorphism. In low grade metamorphic rocks, original textures are often preserved allowing one to determine the likely protolith. As the grade of metamorphism increases, original textures are replaced with metamorphic textures and other clues, such as bulk chemical composition of the rock, are used to determine the protolith.

Bulk Chemical Composition

The mineral assemblage that develops in a metamorphic rock is dependent on

- The pressure and temperature reached during metamorphism
- The composition of any fluid phase present during metamorphism, and
- The bulk chemical composition of the rock.

Just like in igneous rocks, minerals can only form if the necessary chemical constituents are present in the rock (i.e. the concept of silica saturation and alumina saturation applies to metamorphic rocks as well). Based on the mineral assemblage present in the rock one can often estimate the approximate bulk chemical composition of the rock. Some terms that describe this general bulk chemical composition are as follows:

- ***Pelitic***. These rocks are derivatives of aluminous sedimentary rocks like shales and mudrocks. Because of their high concentrations of alumina they are recognized by an abundance of aluminous minerals, like clay minerals, micas, kyanite, sillimanite, andalusite, and garnet.
- ***Quartzo-Feldspathic.*** Rocks that originally contained mostly quartz and feldspar like granitic rocks and arkosic sandstones will also contain an abundance of quartz and feldspar as metamorphic rocks, since these minerals are stable over a wide range of temperature and pressure. Those that exhibit mostly quartz and feldspar with only minor

amounts of aluminous minerals are termed quartzo-feldspathic.

- ***Calcareous.*** Calcareous rocks are calcium rich. They are usually derivatives of carbonate rocks, although they contain other minerals that result from reaction of the carbonates with associated siliceous detrital minerals that were present in the rock. At low grades of metamorphism calcareous rocks are recognized by their abundance of carbonate minerals like calcite and dolomite. With increasing grade of metamorphism these are replaced by minerals like brucite, phlogopite (Mg-rich biotite), chlorite, and tremolite. At even higher grades anhydrous minerals like diopside, forsterite, wollastonite, grossularite, and calcic plagioclase.

- ***Basic.*** Just like in igneous rocks, the general term basic refers to low silica content. Basic metamorphic rocks are generally derivatives of basic igneous rocks like basalts and gabbros. They have an abundance of Fe-Mg minerals like biotite, chlorite, and hornblende, as well as calcic minerals like plagioclase and epidote.

- ***Magnesian.*** Rocks that are rich in Mg with relatively less Fe, are termed magnesian. Such rocks would contain Mg-rich minerals like serpentine, brucite, talc, dolomite, and tremolite. In general, such rocks usually have an ultrabasic protolith, like peridotite, dunite, or pyroxenite.

- ***Ferriginous.*** Rocks that are rich in Fe with little Mg are termed ferriginous. Such rocks could be derivatives of Fe-rich cherts or ironstones. They are characterized by an abundance of Fe-rich minerals like greenalite (Fe-rich serpentine), minnesotaite (Fe-rich talc), ferroactinolite, ferrocummingtonite, hematite, and magnetite at low grades, and ferrosilite, fayalite, ferrohedenbergite, and almandine garnet at higher grades.

- ***Manganiferrous.*** Rocks that are characterized by the presence of Mn-rich minerals are termed manganiferrous. They are characterized by such minerals as Stilpnomelane and spessartine.

Classification

Classification of metamorphic rocks depends on what is visible in the rock and its degree of metamorphism. Note that classification is generally loose and practical such that names can be adapted to describe the rock in the most satisfactory way that conveys the important characteristics. Three kinds of criteria are normally employed. These are:

1. Mineralogical - The most distinguishing minerals are used as a prefix to a textural term. Thus, a schist containing biotite, garnet, quartz, and feldspar, would be called a biotite-garnet schist. A gneiss containing hornblende, pyroxene, quartz, and feldspar would be called a hornblende-pyroxene gneiss. A schist containing porphyroblasts of K-feldspar would be called a K-spar porphyroblastic schist.

2. Chemical - If the general chemical composition can be determined from the mineral assemblage, then a chemical name can be employed. For example a schist with a lot of quartz and feldspar and some garnet and muscovite would be called a garnet-muscovite quartzo-feldspathic schist. A schist consisting mostly of talc would be called a talc-magnesian schist.

3. Protolithic - If a rock has undergone only slight metamorphism such that its original texture can still be observed then the rock is given a name based on its original name, with the prefix meta- applied. For example: metabasalt, metagraywacke, meta-andesite, metagranite.

In addition to these conventions, certain non-foliated rocks with specific chemical compositions and/or mineral assemblages are given specific names. These are as follows:

- ***Amphibolites***: These are medium to coarse grained, dark colored rocks whose principal minerals are hornblende and plagioclase. They result from metamorphism of basic igneous rocks. Foliation is highly variable, but when present the term schist can be appended to the name (i.e. amphibolite schist).

- ***Marbles***: These are rocks composed mostly of calcite, and less commonly of dolomite. They result from metamorphism of limestones and dolostones. Some foliation may be present if the marble contains micas.

- ***Eclogites***: These are medium to coarse grained consisting mostly of garnet and green clinopyroxene called omphacite, that result from high grade metamorphism of basic igneous rocks. Eclogites usually do not show foliation.

- ***Quartzites:*** Quartz arenites and chert both are composed mostly of SiO_2. Since quartz is stable over a wide range of pressures and temperatures, metamorphism of quartz arenites and cherts will result only in the recrystallization of quartz forming a hard rock with interlocking crystals of quartz. Such a rock is called a quartzite.

- ***Serpentinites:*** Serpentinites are rocks that consist mostly of serpentine. These form by hydrothermal metamorphism of ultrabasic igneous rocks.

- ***Soapstones:*** Soapstones are rocks that contain an abundance of talc, which gives the rock a greasy feel, similar to that of soap. Talc is an Mg-rich mineral, and thus soapstones from ultrabasic igneous protoliths, like peridotites, dunites, and pyroxenites, usually by hydrothermal alteration.

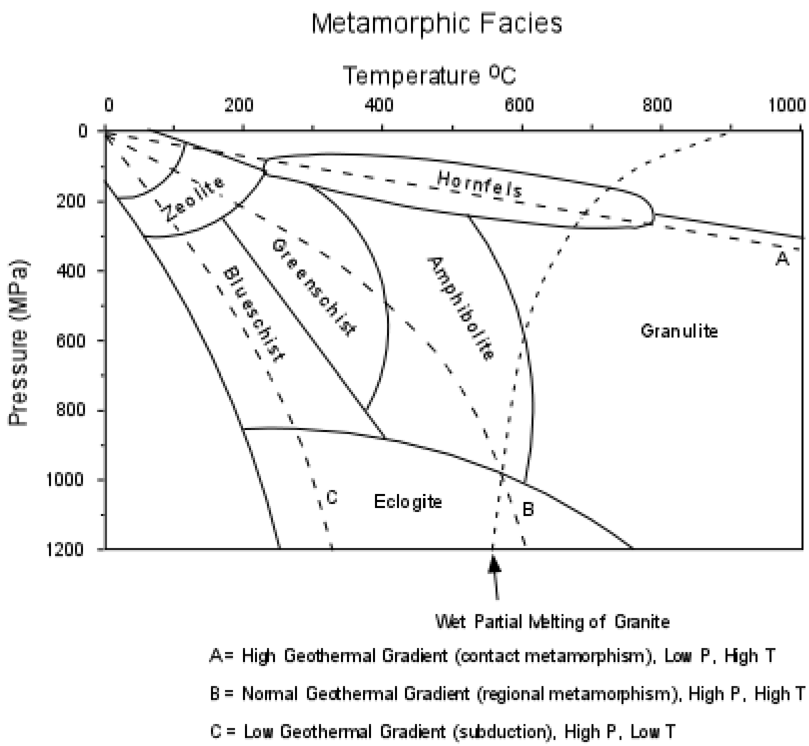
- ***Skarns:*** Skarns are rocks that originate from contact metamorphism of limestones or dolostones, and show evidence of having exchanged constituents with the intruding magma. Thus, skarns are generally composed of minerals like calcite and dolomite, from the original carbonate rock, but contain abundant calcium and magnesium silicate minerals like andradite, grossularite, epidote, vesuvianite, diopside, and wollastonite that form by reaction of the original carbonate minerals with silica from the magma. The chemical exchange is that takes place is called ***metasomatism.***

- ***Mylonites:*** Mylonites are cataclastic metamorphic rocks that are produced along shear zones deep in the crust. They are usually fine-grained, sometimes glassy, that are streaky or layered, with the layers and streaks having been drawn out by ductile shear.

Metamorphic Facies

In general, metamorphic rocks do not drastically change chemical composition during metamorphism, except in the special case where metasomatism is involved (such as in the production of skarns, as discussed above). The changes in mineral assemblages are due to changes in the temperature and pressure conditions of metamorphism. Thus, the mineral assemblages that are observed must be an indication of the temperature and pressure environment that the rock was subjected to. This pressure and temperature environment is referred to as ***Metamorphic Facies.*** (This is similar to the concept of sedimentary facies, in that a sedimentary facies is also a set of environmental conditions present during deposition). The sequence of metamorphic facies observed in any metamorphic terrain, depends on the geothermal gradient that was present during metamorphism.

A high geothermal gradient such as the one labeled "A" , might be present around an igneous intrusion, and would result in metamorphic rocks belonging to the hornfels facies. Under a normal to high geothermal gradient, such as "B", rocks would progress from zeolite facies to greenschist, amphibolite, and eclogite facies as the grade of metamorphism (or depth of burial) increased. If a low geothermal gradient was present, such the one labeled "C" in the diagram, then rocks would progress from zeolite facies to blueschist facies to eclogite facies.



Thus, if we know the facies of metamorphic rocks in the region, we can determine what the geothermal gradient must have been like at the time the metamorphism occurred. This relationship between geothermal gradient and metamorphism will be the central theme of our discussion of metamorphism.

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EENS 212	Petrology
Prof. Stephen A. Nelson	Tulane University
Metamorphic Rock Textures	

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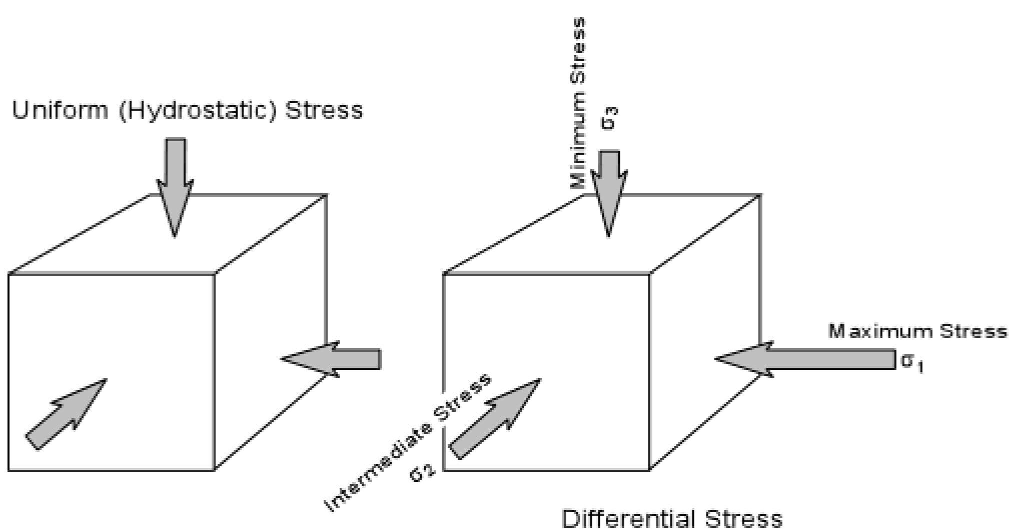
Metamorphic rocks exhibit a variety of textures. These can range from textures similar to the original protolith at low grades of metamorphism, to textures that are purely produced during metamorphism and leave the rock with little resemblance to the original protolith. Textural features of metamorphic rocks have been discussed in the previous lecture. Here, we concentrate on the development of foliation, one of the most common purely metamorphic textures, and on the processes involved in forming compositional layering commonly observed in metamorphic rocks.

Foliation

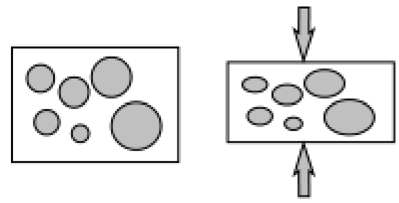
Foliation is defined as a pervasive planar structure that results from the nearly parallel alignment of sheet silicate minerals and/or compositional and mineralogical layering in the rock. Most foliation is caused by the preferred orientation of phylosilicates, like clay minerals, micas, and chlorite. Preferred orientation develops as a result of non-hydrostatic or ***differential stress*** acting on the rock (also called ***deviatoric stress***). We here review the differences between hydrostatic and differential stress.

Stress and Preferred Orientation

Pressure increases with depth of burial, thus, both pressure and temperature will vary with depth in the Earth. Pressure is defined as a force acting equally from all directions. It is a type of ***stress***, called ***hydrostatic stress*** or ***uniform stress.*** If the stress is not equal from all directions, then the stress is called a ***differential stress.*** Normally geologists talk about stress as compressional stress. Thus, if a differential stress is acting on the rock, the direction along which the maximum principal stress acts is called σ_1, the minimum principal stress is called σ_3, and the intermediate principal stress direction is called σ_2. Note that extensional stress would act along the direction of minimum principal stress.

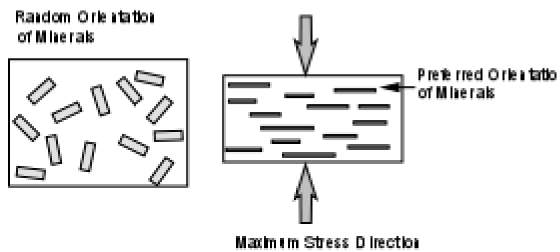


If differential stress is present during metamorphism, it can have a profound effect on the texture of the rock.



- Rounded grains can become flattened in the direction of maximum compressional stress.

- Minerals that crystallize or grow in the differential stress field may develop a preferred orientation. Sheet silicates and minerals that have an elongated habit will grow with their sheets or direction of elongation orientated perpendicular to the direction of maximum stress.

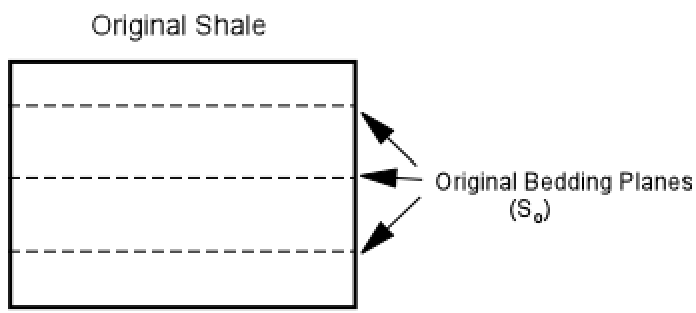


This is because growth of such minerals is easier along directions parallel to sheets, or along the direction of elongation and thus will grow along σ_3 or σ_2, perpendicular to σ_1.

Since most phyllosilicates are aluminous minerals, aluminous (pelitic) rocks like shales, generally develop a foliation as the result of metamorphism in a differential stress field.

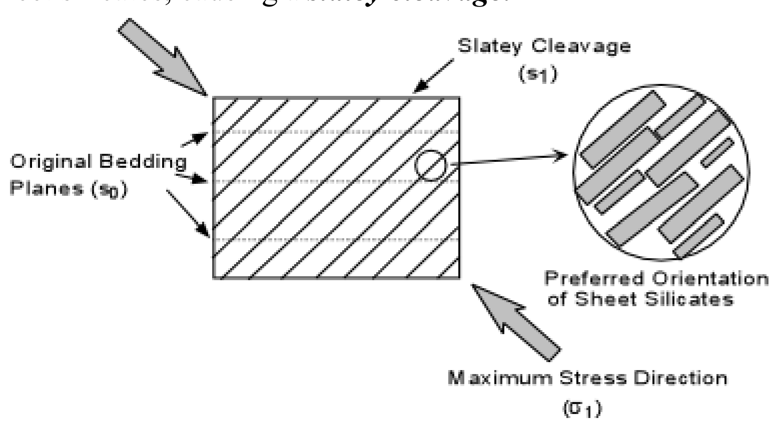
Example - metamorphism of a shale (made up initially of clay minerals and quartz)

Shales have fissility that is caused by the preferred orientation of clay minerals with their {001} planes orientated parallel to bedding. Metamorphic petrologists and structural geologists refer to the original bedding surface as S_0.

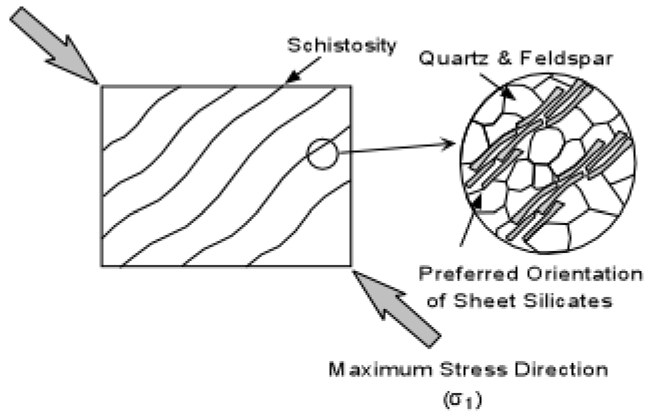


- ***Slate*** Slates form at low metamorphic grade by the growth of fine grained chlorite and clay minerals. The preferred orientation of these sheet silicates causes the rock to easily break planes parallel to the sheet silicates, causing a ***slatey cleavage.***

Note that in the case shown here, the maximum principle stress is oriented at an angle to the original bedding planes so that the slatey cleavage develops at an angle to the original bedding. The foliation or surface produced by this deformation is referred to S_1.

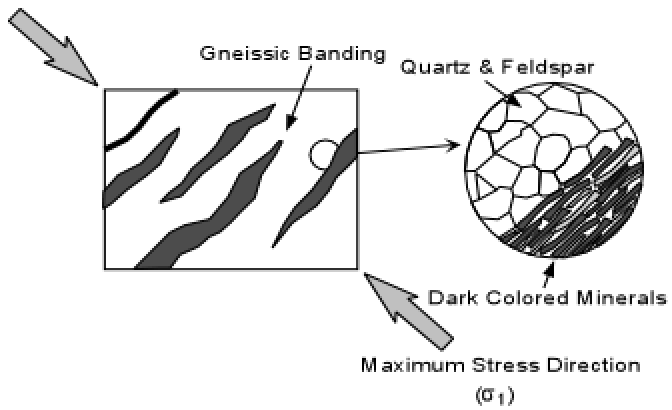


- ***Schist*** - The size of the mineral grains tends to enlarge with increasing grade of metamorphism. Eventually the rock develops a near planar foliation caused by the preferred orientation of sheet silicates (mainly biotite and muscovite). Quartz and feldspar grains, however show no preferred orientation. The irregular planar foliation at this stage is called ***schistosity***

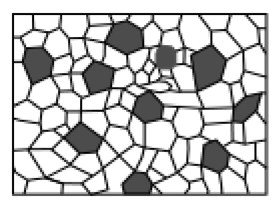


- ***Gneiss*** As metamorphic grade increases, the sheet silicates become unstable and dark colored minerals like hornblende and pyroxene start to grow.

  These dark colored minerals tend to become segregated into distinct bands through the rock (this process is called metamorphic differentiation), giving the rock a ***gneissic banding***. Because the dark colored minerals tend to form elongated crystals, rather than sheet-like crystals, they still have a preferred orientation with their long directions perpendicular to the maximum differential stress.



- ***Granulite*** - At the highest grades of metamorphism most of the hydrous minerals and sheet silicates become unstable and thus there are few minerals present that would show a preferred orientation. The resulting rock will have a granulitic texture that is similar to a phaneritic texture in igneous rocks.

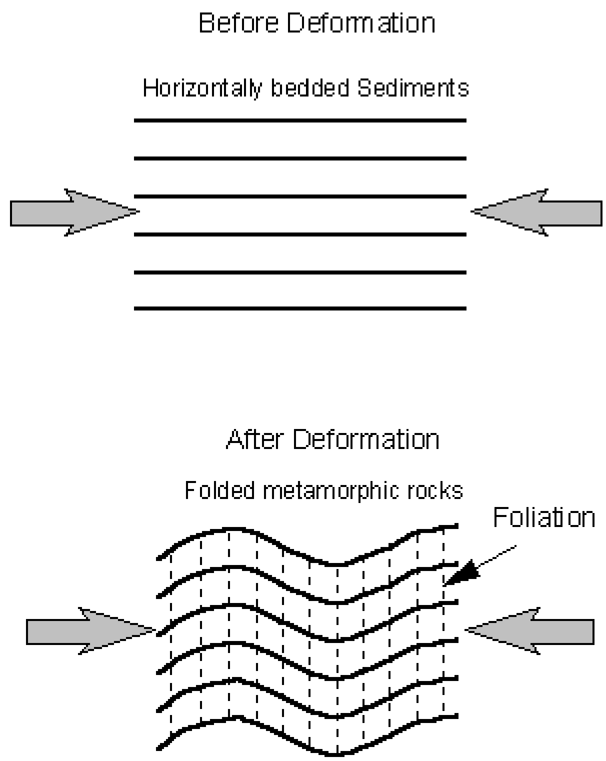


In general, the grain size of metamorphic rocks tends to increase with increasing grade of metamorphism, as seen in the progression form fine grained shales to coarser (but still fine) grained slates, to coarser grained schists and gneisses.

Metamorphism and Deformation

Most regionally metamorphosed rocks (at least those that eventually get exposed at the Earth's surface) are metamorphosed during deformational events. Since deformation involves the application of differential stress, the textures that develop in metamorphic rocks reflect the mode of deformation, and foliations or slatey cleavage that develop during metamorphism reflect the deformational mode and are part of the deformational structures.

The deformation involved in the formation of fold-thrust mountain belts generally involves compressional stresses. The result of compressional stress acting on rocks that behave in a ductile manner (ductile behavior is favored by higher temperature, higher confining stress [pressure] and low strain rates) is the folding of rocks. Original bedding is folded into a series of anticlines and synclines with fold axes perpendicular to the direction of maximum compressional stress. These folds can vary in their scale from centimeters to several kilometers between hinges. Note that since the axial planes are oriented perpendicular to the maximum compressional stress direction, slatey cleavage or foliation should also develop along these directions. Thus, slatey cleavage or foliation is often seen to be parallel to the axial planes of folds, and is sometimes referred to axial plane cleavage or foliation.

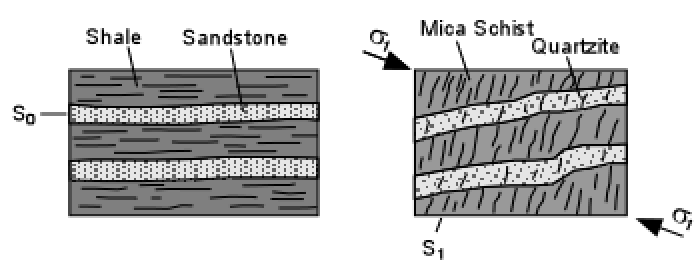


Metamorphic Differentiation

As discussed above, gneisses, and to some extent schists, show compositional banding or layering, usually evident as alternating somewhat discontinuous bands or layers of dark colored ferromagnesian minerals and lighter colored quartzo-feldspathic layers. The development of such compositional layering or banding is referred to as ***metamorphic differentiation.*** Throughout the history of metamorphic petrology, several mechanisms have been proposed to explain metamorphic differentiation.

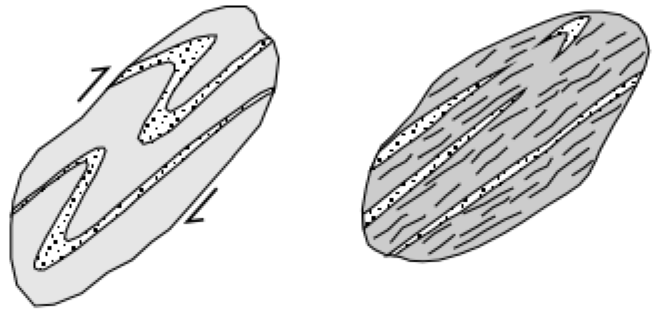
1. **Preservation of Original Compositional Layering.** In some rocks the compositional layering may not represent metamorphic differentiation at all, but instead could simply be the result of original bedding. For example, during the early stages of metamorphism and deformation of interbedded sandstones and shales the compositional layering could be preserved even if the maximum compressional stress direction were at an angle to the original bedding.

   In such a case, a foliation might develop in the shale layers due to the recrystallization of clay minerals or the crystallization of other sheet silicates with a preferred orientation controlled by the maximum stress direction.

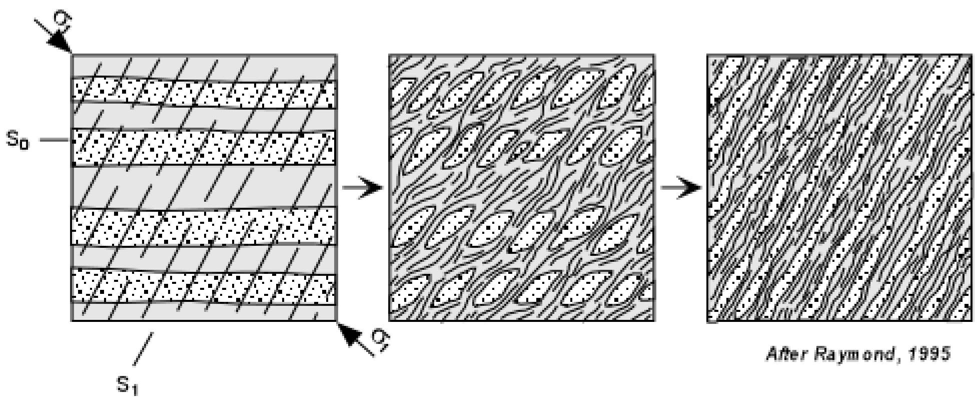
   Here, it would be easy to determine that the compositional layers represented original bedding because the foliation would cut across the compositional layering.

In highly deformed rocks that have undergone both folding and shearing, it may be more difficult to determine that the compositional layering represents original bedding. As shearing stretches the bedding, individual folded beds may be stretched out and broken to that the original folds are not easily seen.

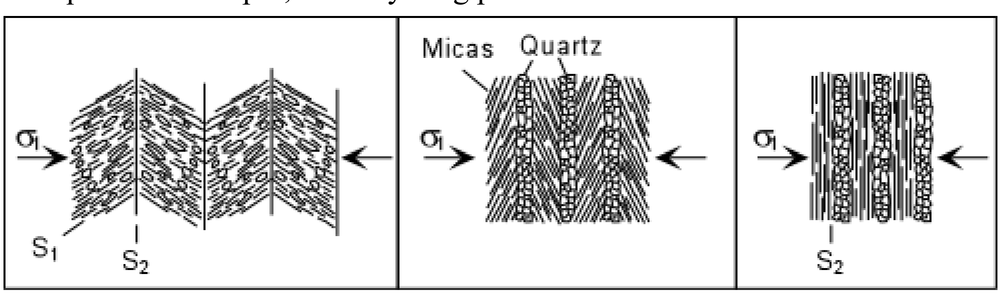


Similarly, if the rock had been injected by dikes or sills prior to metamorphism, these contrasting compositional bands, not necessarily parallel to the original bedding, could be preserved in the metamorphic rock.

2. **Transposition of Original Bedding.** Original compositional layering a rock could also become transposed to a new orientation during metamorphism. The diagram below shows how this could occur. In the initial stages a new foliation begins to develop in the rock as a result of compressional stress at some angle to the original bedding. As the minerals that form this foliation grow, they begin to break up the original beds into small pods. As the pods are compressed and extended, partly by recrystallization, they could eventually intersect again to form new compositional bands parallel to the new foliation.

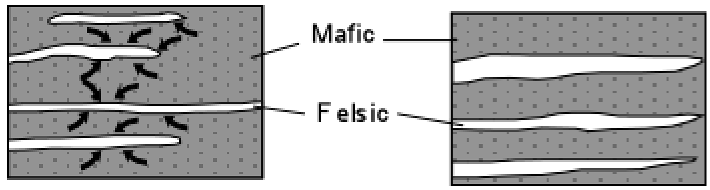


3. **Solution and Re-precipitation.** In fine grained metamorphic rocks small scale folds, called kink bands, often develop in the rock as the result of application of compressional stress. A new foliation begins to develop along the axial planes of the folds. Quartz and feldspar may dissolve as a result of pressure solution and be reprecipitated at the hinges of the folds where the pressure is lower. As the new foliation begins to align itself perpendicular to σ_1, the end result would be alternating bands of micas or sheet silicates and quartz or feldspar, with layering parallel to the new foliation.



4. **Preferential Nucleation.** Fluids present during metamorphism have the ability to dissolve minerals and transport ions from one place in the rock to another.

   Thus felsic minerals could be dissolved from one part of the rock and preferentially nucleate and grow in another part of the rock to produce discontinuous layers of alternating mafic and felsic compositions.



5. **Migmatization**. As discussed previously, migmatites are small pods and lenses that occur in high grade metamorphic terranes that may represent melts of the surrounding metamorphic rocks. Injection of the these melts into pods and layers in the rock could also produce the discontinuous banding often seen in high grade metamorphic rocks. The process would be similar to that described in 4, above, except that it would involve partially melting the original rock to produce a felsic melt, which would then migrate and crystallize in pods and layers in the metamorphic rock. Further deformation of the rock could then stretch and fold such layers so that they may no longer by recognizable as migmatites.

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EENS 1110	Physical Geology
Tulane University	Prof. Stephen A. Nelson

Sediment and Sedimentary Rocks

This page last updated on 28-Apr-2018

Sedimentary Rocks

Rivers, oceans, winds, and rain runoff all have the ability to carry the particles washed off of eroding rocks. Such material, called ***detritus***, consists of fragments of rocks and minerals. When the energy of the transporting current is not strong enough to carry these particles, the particles drop out in the process of ***sedimentation***. This type of sedimentary deposition is referred to as ***clastic sedimentation***. Another type of sedimentary deposition occurs when material is dissolved in water, and chemically precipitates from the water. This type of sedimentation is referred to as ***chemical sedimentation***. A third process can occur, wherein living organisms extract ions dissolved in water to make such things as shells and bones. This type of sedimentation is called ***biochemical sedimentation.*** The accumulation of plant matter, such as at the bottom of a swamp, is referred to as ***organic sedimentation.*** Thus, there are 4 major types of sedimentary rocks: ***Clastic Sedimentary Rocks***, ***Chemical Sedimentary Rocks***, ***Biochemical Sedimentary Rocks***, and ***Organic Sedimentary Rocks***.

Clastic Sediments and Sedimentary Rocks

The formation of a clastic sediment and sedimentary rocks involves five processes:

1. ***Weathering*** - The first step is transforming solid rock into smaller fragments or dissolved ions by physical and chemical weathering as discussed in the last lecture.
2. ***Erosion*** - Erosion is actually many processes which act together to lower the surface of the earth. In terms of producing sediment, erosion begins the transportation process by moving the weathered products from their original location. This can take place by gravity (massmovement events like landslides or rock falls), by running water. by wind, or by moving ice. Erosion overlaps with transportation.
3. ***Transportation*** - Sediment can be transported by sliding down slopes, being picked up by the wind, or by being carried by running water in streams, rivers, or ocean currents. The distance the sediment is transported and the energy of the transporting medium all leave clues in the final sediment that tell us something about the mode of transportation.
4. ***Deposition*** - Sediment is deposited when the energy of the transporting medium becomes too low to continue the transport process. In other words, if the velocity of the transporting medium becomes too low to transport sediment, the sediment will fall out and become deposited. The final sediment thus reflects the energy of the transporting medium.
5. ***Lithification (Diagenesis)*** - Lithification is the process that turns sediment into rock. The first stage of the process is compaction. Compaction occurs as the weight of the overlying material increases. Compaction forces the grains closer together, reducing pore space and eliminating some of the contained water. Some of this water may carry mineral components in solution, and these constituents may later precipitate as new minerals in the pore spaces. This causes cementation, which will then start to bind the individual particles together.

Classification - Clastic sedimentary particles and sedimentary rocks are classified in terms of grain size and shape, among other factors.

Name of Particle	Size Range	Loose Sediment	Consolidated Rock
Boulder	>256 mm	Gravel	Conglomerate or Breccia (depends on rounding)
Cobble	64 - 256 mm	Gravel	
Pebble	2 - 64 mm	Gravel	
Sand	1/16 - 2mm	Sand	Sandstone
Silt	1/256 - 1/16 mm	Silt	Siltstone
Clay	<1/256 mm	Clay	Claystone, mudstone, and shale

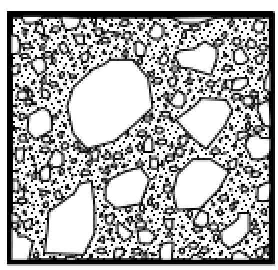
In general, the coarser sediment gets left behind by the transportation process. Thus, coarse sediment is usually found closer to its source and fine grained sediment is found farther from the source.

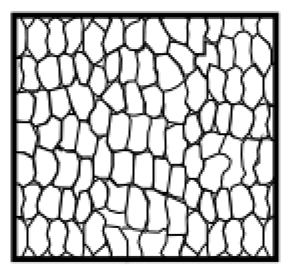
Textures of Clastic Sedimentary Rocks

When sediment is transported and deposited, it leaves clues to the mode of transport and deposition. For example, if the mode of transport is by sliding down a slope, the deposits that result are generally chaotic in nature, and show a wide variety of particle sizes. Grain size and the interrelationship between grains gives the resulting sediment texture. Thus, we can use the texture of the resulting deposits to give us clues to the mode of transport and deposition.

***Sorting* -** The degree of uniformity of grain size. Particles become sorted on the basis of density, because of the energy of the transporting medium. High energy currents can carry larger fragments. As the energy decreases, heavier particles are deposited and lighter fragments continue to be transported. This results in sorting due to density.

If the particles have the same density, then the heavier particles will also be larger, so the sorting will take place on the basis of size. We can classify this size sorting on a relative basis - well sorted to poorly sorted. Sorting gives clues to the energy conditions of the transporting medium from which the sediment was deposited.


Poorly Sorted Sediment


Well Sorted Sediment

Examples

- Beach deposits and wind blown deposits generally show good sorting because the energy of the transporting medium is usually constant.
- Stream deposits are usually poorly sorted because the energy (velocity) in a stream varies with position in the stream and time.

ROUNDNESS AND SPHERICITY

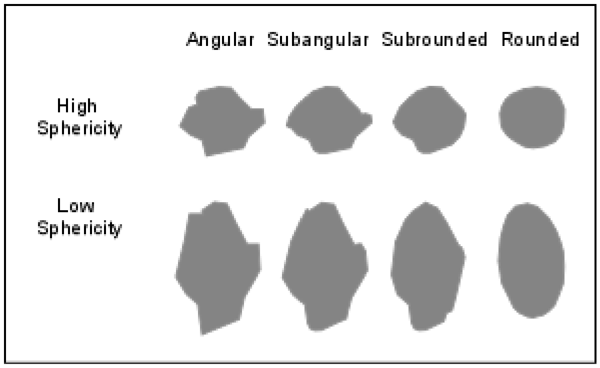
I. Introduction

Roundness and sphericity have proven to be useful properties of particles (greater than sand size) when investigating the transport and deposition of sedimentary material. In this laboratory you will determine the roundness and sphericity of a number of sedimentary particles and will investigate the relationship between these two properties of particles.

Roundness refers to the sharpness of the corners and edges of a grain. Roundness was defined by Wadell (1932) as the ratio of the average radius of curvature of the corners to the radius of the largest inscribed circle. Since it is quite time consuming to measure roundness, the common method of estimating roundness is to visually compare grains of unknown roundness with standard images of grains of known roundness.

Sphericity measures the degree to which a particle approaches a spherical shape. It was defined by Wadell (1932) as the ratio between the diameter of a sphere with the same volume as the particle and the diameter of the circumscribed sphere. The sphericity of a particle is usually determined by measuring the three linear dimensions of the particle (longest (L), intermediate (I) and shortest (S) diameters).

Rounding - During the transportation process, grains may be reduced in size due to abrasion. Random abrasion results in the eventual rounding off of the sharp corners and edges of grains. Thus, rounding of grains gives us clues to the amount of time a sediment has been in the transportation cycle. Rounding is classified on relative terms as well.



Sediment Maturity

Sediment Maturity refers to the length of time that the sediment has been in the sedimentary cycle. Texturally mature sediment is sediment that is well rounded, (as rounding increases with transport distance and time) and well sorted (as sorting gets better as larger clasts are left behind and smaller clasts are carried away. Because the weathering processes continues during sediment transport, mineral grains that are unstable near the surface become less common as the distance of transport or time in the cycle increases. Thus compositionally mature sediment is composed of only the most stable minerals.

For example a poorly sediment containing glassy angular volcanic fragments, olivine crystals and plagioclase is texturally immature because the fragments are angular, indicating they have not been transported very far and the sediment is poorly sorted, indicating that little time has been involved in separating larger fragments from smaller fragments. It is compositionally immature because it contains unstable glass along with minerals that are not very stable near the surface - olivine and plagioclase.

On the other hand a well sorted beach sand consisting mainly of well rounded quartz grains is texturally mature because the grains are rounded, indicating a long time in the transportation cycle, and the sediment is well sorted, also indicative of the long time required to separate the coarser grained material and finer grained material from the sand. The beach sand is compositionally mature because it is made up only of quartz which is very stable at the earth's surface.

Types of Clastic Sedimentary Rocks

We next look at various clastic sedimentary rocks that result from lithification of sediment.

Conglomerates and Breccias

Conglomerate and Breccia are rocks that contain an abundance of coarse grained clasts (pebbles, cobbles, or boulders). In a conglomerate, the coarse grained clasts are well rounded, indicating that they spent considerable time in the transportation process and were ultimately deposited in a high energy environment capable of carrying the large clasts. In a breccia, the coarse grained clasts are very angular, indicating the the clasts spent little time in the transportation cycle.

Sandstones

A Sandstone is made of sand-sized particles and forms in many different depositional settings. Texture and composition permit historic interpretation of the transport and depositional cycle and sometimes allows determination of the source. Quartz is, by far, the dominant mineral in sandstones. Still there are other varieties. A Quartz arenite – is nearly 100% quartz grains. An Arkose contains abundant feldspar. In a lithic sandstone, the grains are mostly small rock fragments. A Wacke is a sandstone that contains more than 15% mud (silt and clay sized grains).. Sandstones are one of the most common types of sedimentary rocks.

Mudrocks

Mudrocks are made of fine grained clasts (silt and clay sized) . A siltstone is one variety that consists of silt-sized fragments. A shale is composed of clay sized particles and is a rock that tends to break into thin flat fragments (See figure 7.6e in your text). A mudstone is similar to a shale, but does not break into thin flat fragments. Organic-rich shales are the source of petroleum.

Fine grained clastics are deposited in non-agitated water, calm water, where there is little energy to continue to transport the small grains. Thus mudrocks form in deep water ocean basins and lakes.

Biochemical and Organic Sediments and Sedimentary Rocks

Biochemical and Organic sediments and sedimentary rocks are those derived from living organisms. When the organism dies, the remains can accumulate to become sediment or sedimentary rock. Among the types of rock produced by this process are:

Biochemical Limestone **-** calcite ($CaCO_3$) is precipitated by organisms usually to form a shell or other skeletal structure. Accumulation of these skeletal remains results in a limestone. Sometimes the fossilized remains of the organism are preserved in the rock, other times recrystallization during lithification has destroyed the remains. Limestones are very common sedimentary rocks.

Biochemical Chert **-** Tiny silica secreting planktonic organism like Radiolaria and Diatoms can accumulate on the sea floor and recrystallize during lithification to form biochemical chert. The recrystallization results in a hard rock that is usually seen as thin beds (see figure 7.8a in your test).

Diatomite **-** When diatoms accumulate and do not undergo recrystallization, they form a white rock called diatomite as seen in the White Cliffs of Dover (see figure 7.22b in your text).

Coal **-** Coal is an organic rock made from organic carbon that is the remains of fossil plant matter. It accumulates in lush tropical wetland settings and requires deposition in absence of Oxygen. It is high in carbon and can easily be burned to obtain energy.

Chemical Sediments and Sedimentary Rocks

Dissolved ions released into water by the weathering process are carried in streams or groundwater. Eventually these dissolved ions end in up in the ocean, explaining why sea water is salty. When water evaporates or the concentration of the ions get too high as a result of some other process, the ions recombine by chemical precipitation to form minerals that can accumulate to become chemical sediments and chemical sedimentary rocks. Among these are:

Evaporites - formed by evaporation of sea water or lake water. Produces halite (salt) and gypsum deposits by chemical precipitation as concentration of solids increases due to water loss by evaporation. This can occur in lakes that have no outlets (like the Great Salt Lake) or restricted ocean basins, like has happened in the Mediterranean Sea or the Gulf of Mexico in the past.

Travertine - Groundwater containing dissolve Calcium and bicarbonate ions can precipitate calcite to form a chemically precipitated limestone, called travertine. This can occur in lakes, hot springs, and caves.
Dolostones - Limestone that have been chemically modified by Mg-rich fluids flowing through the rock are converted to dolostones. $CaCO_3$ is recrystallized to a new mineral dolomite $CaMg(CO_3)_2$.

***Chemical Cherts* -** Groundwater flowing through rock can precipitate SiO_2 to replace minerals that were present. This produces a non-biogenic chert. There are many varsities of such chert that are given different names depending on their attributes, For example:

Flint – Black or gray from organic matter.
Jasper – Red or yellow from Fe oxides.
Petrified wood – Wood grain preserved by silica.
Agate – Concentrically layered rings