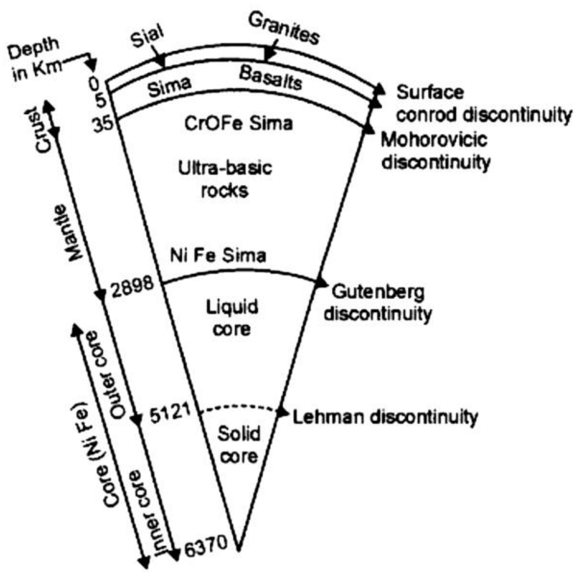
Petrology:

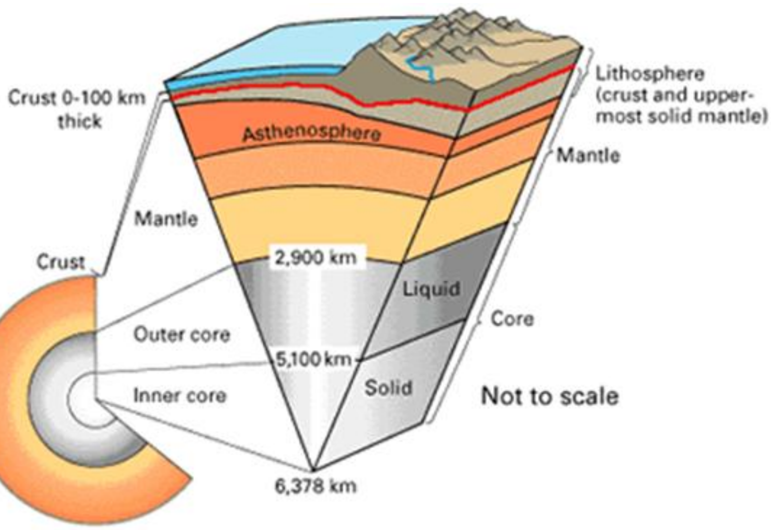
Petrology (from the Greek petra, "rock" and logos, "study") is the branch of geology that studies the origin, composition, distribution and structure of rocks.

Petrology utilizes the classical fields of mineralogy, petrography, optical mineralogy, and chemical analyses to describe the composition and texture of rocks. Modern petrologists also include the principles of geochemistry and geophysics through the studies of geochemical trends and cycles and the use of thermodynamic data and experiments to better understand the origins of rocks

Petrology is the earth study so shell structure of earth should be known.



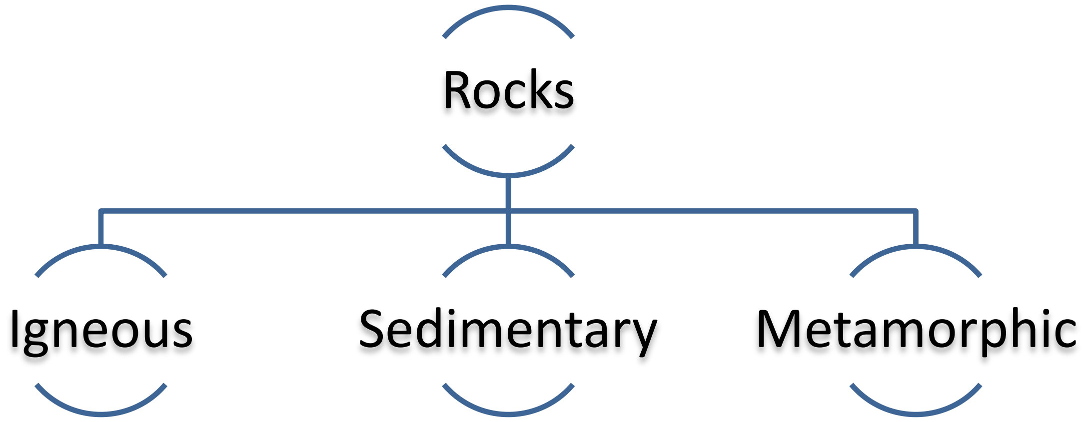
The interior of the Earth, like that of the other terrestrial planets, is divided into layers by their chemical or physical (rheological) properties, but unlike the other terrestrial planets, it has a distinct outer and inner core. The outer layer of the Earth is silicate solid crust, which is underlain by a highly viscous solid mantle. The crust is separated from the mantle by the Moho discontinuity (The Red Line in the fig. below), and the thickness of the crust varies: averaging 6 km under the oceans and 30–50 km on the continents. The crust and the cold, rigid, top of the upper mantle are collectively known as the lithosphere, and it is of the lithosphere that the tectonic plates are comprised. Beneath the lithosphere is the asthenosphere, a relatively low-viscosity layer on which the lithosphere rides. Important changes in crystal structure within the mantle occur at 410 and 660 kilometres below the surface, spanning a transition zone that separates the upper and lower mantle. Beneath the mantle, an extremely low viscosity liquid outer core lies above a solid inner core.



Rock:

In geology, rock or stone is a naturally occurring solid aggregate of minerals and/or mineraloids. The Earth's outer solid layer, the lithosphere, is made of rock.

Three majors groups of rocks are defined:



Igneous Rocks:

Igneous rock (derived from the Latin word ignis meaning fire) is formed through the cooling and solidification of magma or lava. Igneous rock may form with or without crystallization, either below the surface as intrusive (plutonic) rocks or on the surface as extrusive (volcanic) rocks. This magma can be derived from partial melts of pre-existing rocks in either a planet's mantle or crust. Typically, the melting is caused by one or more of three processes: an increase in temperature, a decrease in pressure, or a change in composition.

Geological significance:

Igneous and metamorphic rocks make up 90-95% of the top 16 km of the Earth's crust by volume. Igneous rocks are geologically important because,

- Their minerals and global chemistry give information about the composition of the mantle, from which some igneous rocks are extracted, and the temperature and pressure conditions that allowed this extraction, and/or of other pre-existing rock that melted;
- Their absolute ages can be obtained from various forms of radiometric dating and thus can be compared to adjacent geological strata, allowing a time sequence of events;
- Their features are usually characteristic of a specific tectonic environment, allowing tectonic reconstitutions;
- In some special circumstances they host important mineral deposits (ores): for example, tungsten, tin, and uranium are commonly associated with granites and diorites, whereas ores of chromium and platinum are commonly associated with gabbros.

Morphology and Setting (Formation):
In terms of modes of occurrence, igneous rocks can be either intrusive (plutonic), extrusive (volcanic) or hypabyssal.

Intrusive igneous rocks are formed from magma that cools and solidifies within the crust of a planet. Surrounded by pre-existing rock (called country rock), the magma cools slowly, and as a result these rocks are coarse grained. The mineral grains in such rocks can generally be identified with the naked eye. Intrusive rocks can also be classified according to the shape and size of the intrusive body and its relation to the other formations into which it intrudes. Typical intrusive formations are batholiths, stocks, laccoliths, sills and dikes.

Close-up of granite (an intrusive igneous rock) exposed in Chennai, India.

The central cores of major mountain ranges consist of intrusive igneous rocks, usually granite. When exposed by erosion, these cores (called batholiths) may occupy huge areas of the Earth's surface.

Coarse grained intrusive igneous rocks which form at depth within the crust are termed as abyssal; intrusive igneous rocks which form near the surface are termed hypabyssal.

Extrusive igneous rocks are formed at the crust's surface as a result of the partial melting of rocks within the mantle and crust. Extrusive Igneous rocks cool and solidify quicker than intrusive igneous rocks. Since the rocks cool very quickly, they are fine grained.

Basalt (an extrusive igneous rock in this case); light coloured tracks show the direction of lava flow.

The volume of extrusive rock erupted annually by volcanoes varies with plate tectonic setting. Extrusive rock is produced in the following proportions:

- divergent boundary[1]: 73%
- convergent boundary[2] (subduction zone): 15%
- hotspot[3]: 12%.

Magma which erupts from a volcano behaves according to its viscosity, determined by temperature, composition, and crystal content. High-temperature magma, most of which is basaltic in composition, behaves in a manner similar to thick oil and, as it cools, treacle[4]. Long, thin basalt flows with pahoehoe[5] surfaces are common. Intermediate composition magma such as andesite tends to form cinder cones of intermingled ash, tuff and lava, and may have viscosity similar to thick, cold molasses or even rubber when erupted. Felsic magma such as rhyolite is usually erupted at low temperature and is up to 10,000 times as viscous as basalt. Volcanoes with rhyolitic magma commonly erupt explosively, and rhyolitic lava flows typically are of limited extent and have steep margins, because the magma is so viscous.

Felsic and intermediate magmas that erupt often do so violently, with explosions driven by release of dissolved gases — typically water but also carbon dioxide. Explosively erupted pyroclastic material is called tephra and includes tuff, agglomerate and ignimbrite. Fine volcanic ash is also erupted and forms ash tuff deposits which can often cover vast areas.

Because lava cools and crystallizes rapidly, it is fine grained. If the cooling has been so rapid as to prevent the formation of even small crystals after extrusion, the resulting rock may be mostly glass (such as the rock obsidian). If the cooling of the lava happened slowly, the rocks would be coarse-grained.

Hypabyssal igneous rocks are formed at a depth in between the plutonic and volcanic rocks. These are formed due to cooling and resultant solidification of rising magma just beneath the earth surface. Hypabyssal rocks are less common than plutonic or volcanic rocks and often form dikes, sills, laccoliths, lopoliths, or phacoliths.

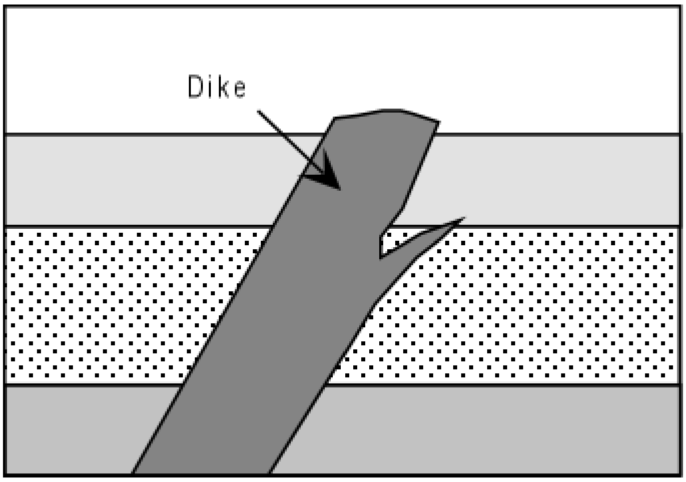
1- Divergent boundary -is a linear feature that exists between two tectonic plates that are moving away from each other. 2- Convergent boundary - is an actively deforming region where two (or more) tectonic plates or fragments of lithosphere move toward one another and collide. 3- Hot Spot –are the volcanic regions thought to be fed by underlying mantle that is anomalously hot compared with the mantle elsewhere. 4- treacle- syrup. 5- Pahoehoe - smooth, unbroken lava.

FORMS OF IGNEOUS ROCKS

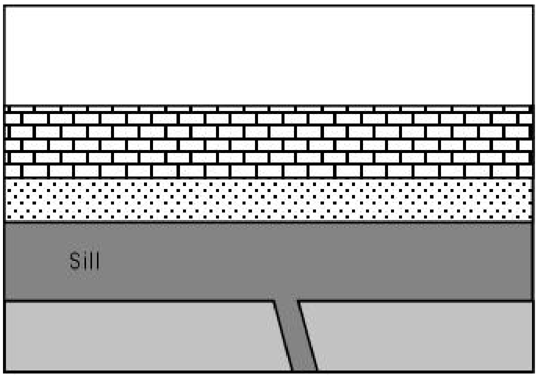
Intrusions that intrude rocks at shallow levels of the crust are termed hypabyssal intrusions. Shallow generally refers to depths less than about 1 km. Hypabyssal intrusions always show sharp contact relations with the rocks that they intrude. Several types are found:

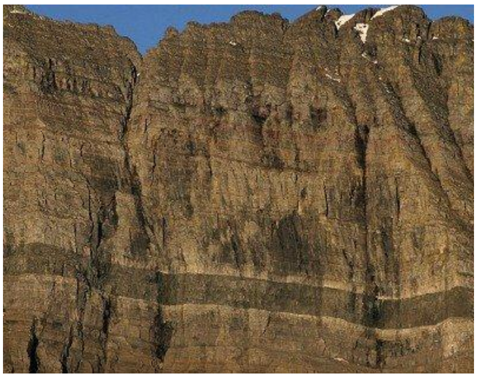
Dikes are small (<20 m wide) shallow intrusions that show a discordant relationship to the rocks in which they intrude. Discordant means that they cut across preexisting structures.

They may occur as isolated bodies or may occur as swarms of dikes emanating from a large intrusive body at depth.

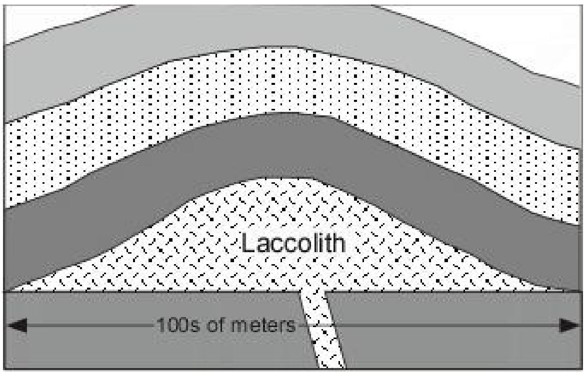


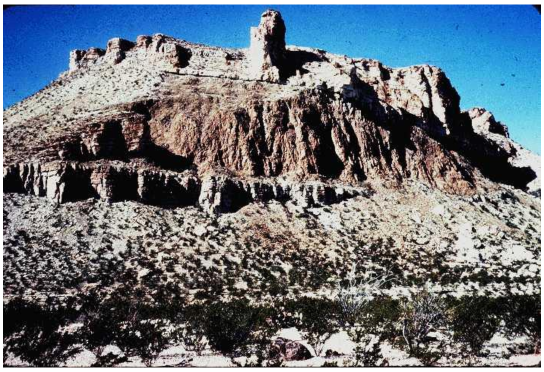
Sills are also small (<50 m thick) shallow intrusions that show a concordant relationship with the rocks that they intrude. Sills usually are fed by dikes, but these may not be exposed in the field.





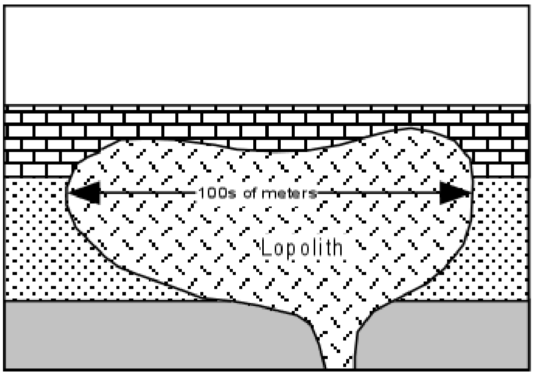
Laccoliths are somewhat large intrusions that result in uplift and folding of the preexisting rocks above the intrusion. They are also concordant types of intrusions.





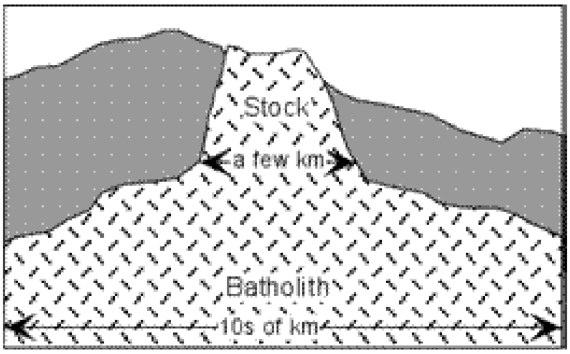
Plutons are generally much larger intrusive bodies that have intruded much deeper in the crust. Although they may show sharp contacts with the surrounding rocks into which they intruded, at deeper levels in the crust the contacts are often gradational.

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.



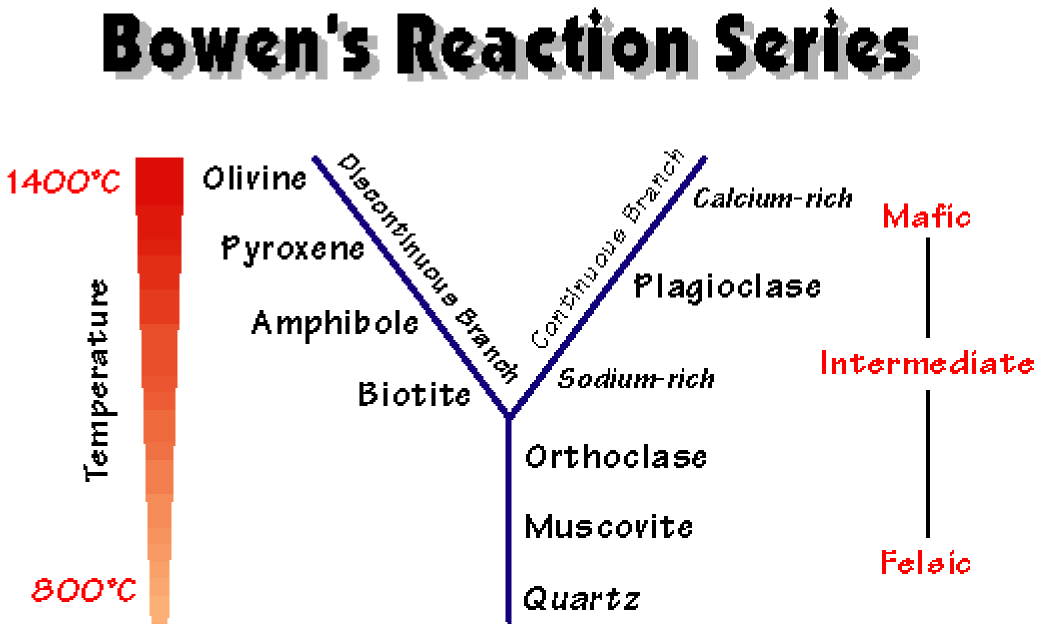
Batholiths are very large intrusive bodies, usually so large that there bottoms are rarely exposed. Sometimes they are composed of several smaller intrusions.

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.



BOWEN'S REACTION SERIES:

Bowen's Reaction Series which shows that the minerals in igneous rocks crystallize in an orderly sequence. Discontinuous Series so named because as temperature falls we change from one new mineral to another (Ex. olivine alters to pyroxene). Continuous Series, in which plagioclase feldspar merely changes composition from Ca-rich at high temperature to Na-rich at low temperature. Does not involve the formation of a new mineral, just a compositional change. This does not really help us understand why we have different igneous rocks, but it does seem to show that there is some order in nature. To more closely examine this order let's look only at the plagioclase feldspars. Why? Because plagioclase occurs in most igneous rocks. So if we can understand how and why feldspars form we may have some understanding about how different rocks form.



TEXTURES OF IGNEOUS ROCKS

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

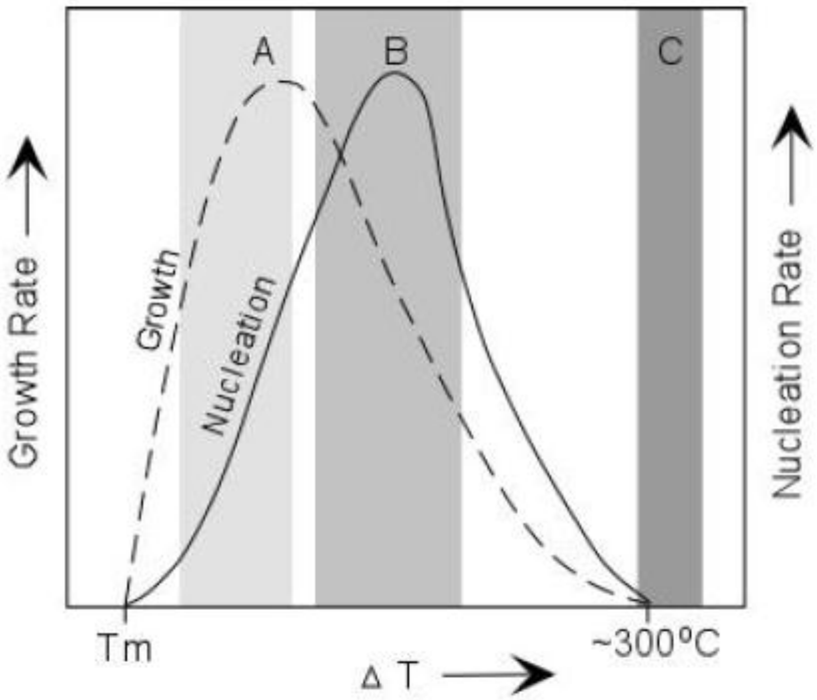
Other factors involved are:

- 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.

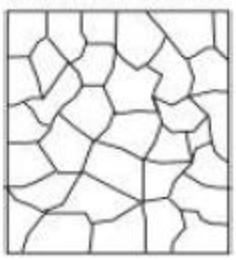
In order for a crystal to form in magma enough of the chemical constituents that will make up the crystal must be at the same place at the same time to form a nucleus of the crystal. Once a nucleus forms, the chemical constituents must diffuse through the liquid to arrive at the surface of the growing 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 crystallization temperature. Three cases are shown.

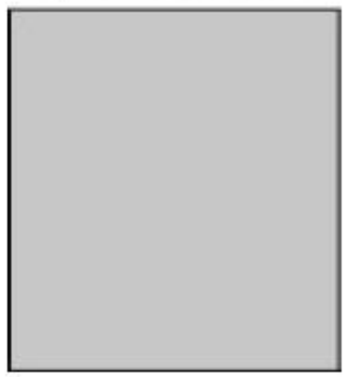
1. For small degrees of undercooling (region A in the figure below) the nucleation rate will be low and the growth rate moderate. A few crystals will form and grow at a moderate rate until they run into each other. Because there are few nuclei, the crystals will be able to grow to relatively large size,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



Phaneritic Texture



Aphanitic Texture

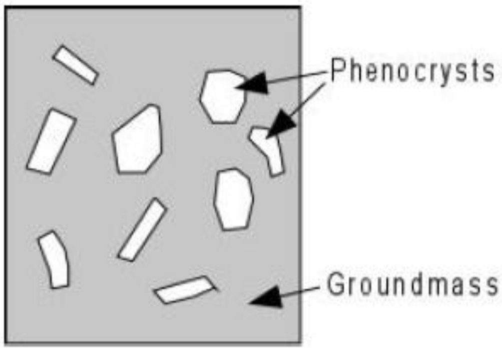


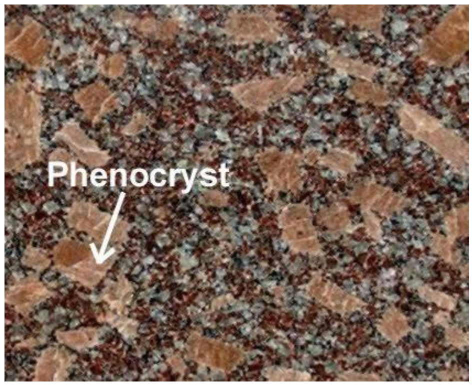
2. At larger degrees of undercooling, the nucleation rate will be high and the growth rate also high. This will result in many crystals all growing rapidly, but because there are so many crystals, they will run into each other before they have time to grow and the resulting texture will be a fine grained texture. If the

sizes of the grains are so small that crystals cannot be distinguished with a hand lens, 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 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 below 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 the table below is 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 ground mass, 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 time's 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.

Sedimentary rocks:

Sedimentary rocks are types of rock that are formed by the deposition of material at the Earth's surface and within bodies of water. Sedimentation is the collective name for, the processes that cause mineral and/or organic particles (detritus) to settle and accumulate or minerals to precipitate from a solution.

Particles that form a sedimentary rock by accumulating are called sediment. Before being deposited, sediment was formed by weathering and erosion in a source area, and then transported to the place of deposition by water, wind, ice, mass movement or glaciers which are called agents of denudation.

Middle Triassic marginal marine sequence of siltstones (below) and limestones (above)

The sedimentary rock cover of the continents of the Earth's crust is extensive, but the total contribution of sedimentary rocks is estimated to be only 8% of the total volume of the crust. Sedimentary rocks are only a thin veneer over a crust consisting mainly of igneous and metamorphic rocks. Sedimentary rocks are deposited in layers as strata, forming a structure called bedding. The study of sedimentary rocks and rock strata provides information about the subsurface that is useful for civil engineering, for example in the construction of roads, houses, tunnels, canals or other constructions. Sedimentary rocks are also important sources of natural resources like coal, fossil fuels, drinking water or ores.

Classification:

Based on the processes responsible for their formation, sedimentary rocks can be subdivided into four groups: clastic sedimentary rocks, biochemical (or biogenic) sedimentary rocks, chemical sedimentary rocks and a fourth category for "other" sedimentary rocks formed by impacts, volcanism, and other minor processes.

Clastic sedimentary rocks:

Clastic sedimentary rocks are composed of silicate minerals and rock fragments that were transported by moving fluids (as bed load, suspended load, or by sediment gravity flows) and were deposited when these fluids came to rest. Clastic rocks are composed largely of quartz, feldspar, rock (lithic) fragments, clay minerals, and mica; numerous other minerals may be present as accessories and may be important locally.

Clastic sediment, and thus clastic sedimentary rocks, are subdivided according to the dominant particle size (diameter). Most geologists use the Udden-Wentworth grain size scale and divide unconsolidated sediment into three fractions: gravel (>2 mm diameter), sand (0.0625 (1/16) to 2 mm diameter), and mud (clay is <0.0039 mm (1/256) and silt is between 0.0625 and 0.0039 mm). The classification of clastic sedimentary rocks parallels this scheme; conglomerates and breccias are made mostly of gravel, sandstones are made mostly of sand, and mudrocks are made mostly of mud. This tripartite subdivision is mirrored by the broad categories of rudites, arenites, and lutites, respectively, in older literature.

Subdivision of these three broad categories is based on differences in clast shape (conglomerates and breccias), composition (sandstones), grain size and/or texture (mudrocks).

Conglomerates and breccias

Conglomerates are dominantly composed of rounded gravel and breccias are composed of dominantly angular gravel.

Conglomerate breccia

Sandstones

Sandstone classification schemes vary widely, but most geologists have adopted the Dott scheme, which uses the relative abundance of quartz, feldspar, and lithic framework grains and the abundance of muddy matrix between these larger grains.

Composition of framework grains

The relative abundance of sand-sized framework grains determines the first word in a sandstone name. For naming purposes, the abundance of framework grains is normalized to quartz, feldspar, and lithic fragments formed from other rocks. These are the three most abundant components of sandstones; all other minerals are considered accessories and not used in the naming of the rock, regardless of abundance.

Quartz sandstones have >90% quartz grains

Feldspathic sandstones have <90% quartz grains and more feldspar grains than lithic grains

Lithic sandstones have <90% quartz grains and more lithic grains than feldspar grains

Abundance of muddy matrix between sand grains

When sand-sized particles are deposited, the space between the sand grains either remains open or is filled with mud (silt and/or clay sized particle).

"Clean" sandstones with open pore space (that may later be filled with cement) are called arenites

Muddy sandstones with abundant (>10%) muddy matrix are called wackes.

Mudrocks are sedimentary rocks composed of at least 50% silt- and clay-sized particles. These relatively fine-grained particles are commonly transported as suspended particles by turbulent flow in water or air, and deposited as the flow calms and the particles settle out of suspension.

Unstratified Mudrock

Stratified Mud Rock

Most authors presently use the term "mudrock" to refer to all rocks composed dominantly of mud. Mudrocks can be divided into

- Siltstones (composed dominantly of silt-sized particles)
- Mudstones (subequal mixture of silt- and clay-sized particles) and
- Claystones (composed mostly of clay-sized particles).

Most authors use "shale" as a term for a fissile[1] mudrock (regardless of grain size), although some older literature uses the term "shale" as a synonym for mudrock.

Biochemical sedimentary rocks are created when organisms use materials dissolved in air or water to build their tissue. For example, most types of limestone are formed from the calcareous skeletons of organisms such as corals, mollusks, and foraminifera. Coal which forms as plants remove carbon from the atmosphere and

1- Fissile-Fissility refers to the property of rocks to split along planes of weakness into thin sheets.

combine with other elements to build their tissue. Deposits of chert formed from the accumulation of siliceous skeletons from microscopic organisms such as radiolaria and diatoms.

Chemical sedimentary rock forms when mineral constituents in solution become supersaturated and inorganically precipitate. Common chemical sedimentary rocks include oolitic[1] limestone and rocks composed of evaporite[2] minerals such as halite (rock salt), sylvite, barite and gypsum.

Compositional classification schemes:
Sedimentary rocks can be subdivided into compositional groups based on their mineralogy:

- **Siliciclastic sedimentary rocks**, as described above, are dominantly composed of silicate minerals. The sediment that makes up these rocks was transported as bed load, suspended load, or by sediment gravity flows. Siliciclastic sedimentary rocks are subdivided into conglomerates and breccias, sandstone, and mudrocks.
- **Carbonate sedimentary rocks** are composed of calcite (rhombohedral $CaCO_3$), aragonite (orthorhombic $CaCO_3$), dolomite ($CaMg(CO_3)_2$), and other carbonate minerals based on the CO_3^{2-} ion. Common examples include limestone and dolostone.
- **Evaporite sedimentary rocks** are composed of minerals formed from the evaporation of water. The most common evaporite minerals are carbonates (calcite and others based on CO_3^{2-}), chlorides (halite and others built on Cl^-), and sulfates (gypsum and others built on SO_4^{2-}). Evaporite rocks commonly include abundant halite (rock salt), gypsum, and anhydrite.
- **Organic-rich sedimentary rocks** have significant amounts of organic material, generally in excess of 3% total organic carbon. Common examples include coal, oil shale as well as source rocks for oil and natural gas .
- **Siliceous sedimentary rocks** are almost entirely composed of silica (SiO2), typically as chert, opal, chalcedony or other microcrystalline forms.
- **Iron-rich sedimentary rocks** are composed of >15% iron; the most common forms are banded iron formations and ironstones
- **Phosphatic sedimentary rocks** are composed of phosphate minerals and contain more than 6.5% phosphorus; examples include deposits of phosphate nodules, bone beds, and phosphatic mudrocks.

1-Oolitic-Oolite (egg stone) is a sedimentary rock formed from ooids (spherical grains <2mm).
2-Evaporite-water soluble miner sediment.

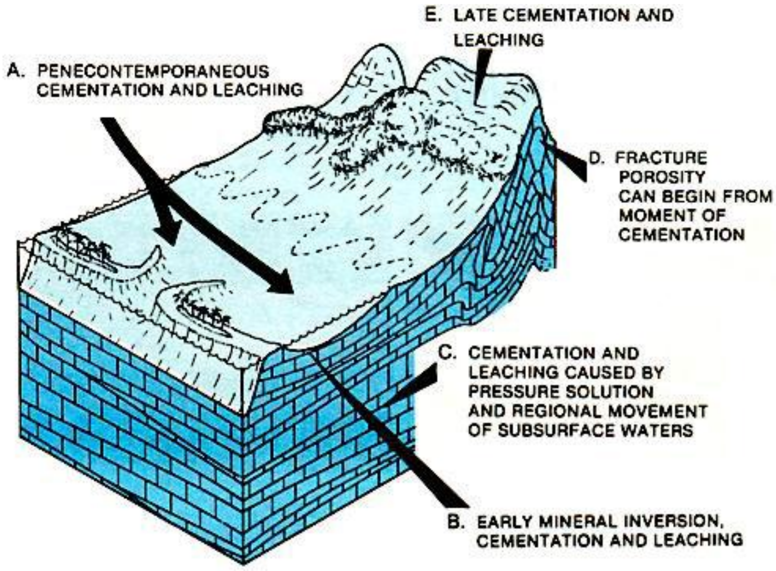
Deposition and diagenesis:

Sediment transport and deposition

Sedimentary rocks are formed when sediment is deposited out of air, ice, wind, gravity, or water flows carrying the particles in suspension. This sediment is often formed when weathering and erosion break down a rock into loose material in a source area. The material is then transported from the source area to the deposition area. The type of sediment transported depends on the geology of the hinterland (the source area of the sediment). However, some sedimentary rocks, like evaporites, are composed of material that formed at the place of deposition. The nature of a sedimentary rock therefore not only depends on sediment supply, but also on the sedimentary depositional environment in which it formed.

Diagenesis:

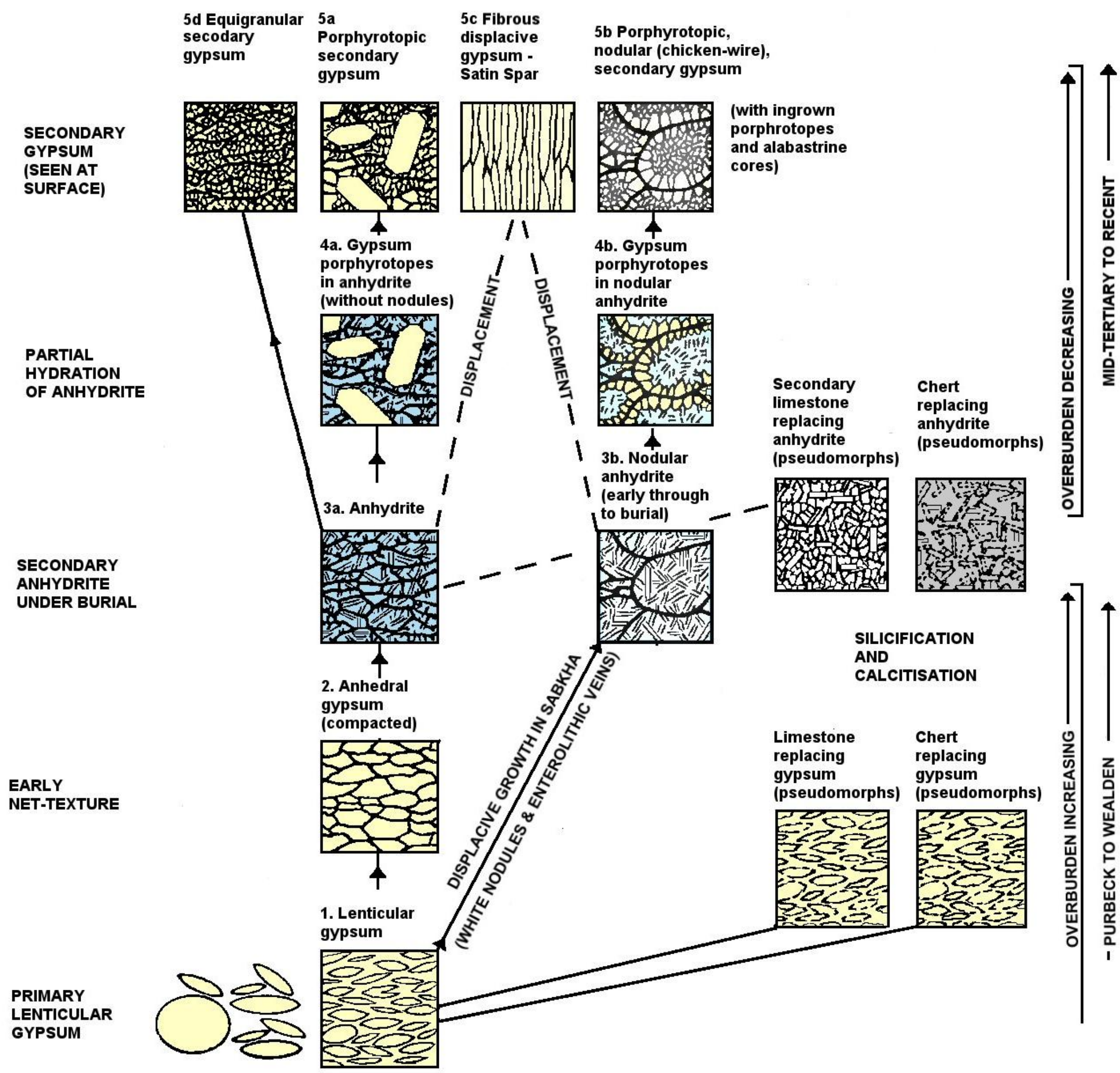
The term diagenesis is used to describe all the chemical, physical, and biological changes, including cementation, undergone by sediment after its initial deposition, exclusive of surface weathering. Some of these processes cause the sediment to consolidate: a compact, solid substance forms out of loose material. Young sedimentary rocks, especially those of Quaternary age (the most recent period of the geologic time scale) are often still unconsolidated. As sediment deposition builds up, the overburden (or lithostatic) pressure rises and a process known as lithification takes place.



LIMESTONES UNDERGO CEMENTATION, LEACHING AND OTHER DIAGENESIS (MINERAL ALTERATION OR INVERSION, NEOMORPHISM, GRAIN GROWTH CAUSED BY RECRYSTALLIZATION) DURING DEPOSITION, BURIAL AND SUBSEQUENT UPLIFT

Sedimentary rocks are often saturated with seawater or groundwater, in which minerals can dissolve or from which minerals can precipitate. Precipitating minerals reduce the pore space in a rock, a process called cementation. Due to the decrease in pore space, the original connate fluids are expelled. The precipitated minerals form cement and make the rock more compact and competent. In this way, loose clasts in a sedimentary rock can become "glued" together.

When sedimentation continues, an older rock layer becomes buried deeper as a result. The lithostatic pressure in the rock increases due to the weight of the overlying sediment. This causes compaction, a process in which grains mechanically reorganize. Compaction is, for example, an important diagenetic process in clay, which can initially consist of 60% water. During compaction, this interstitial water is pressed out of pore spaces. Compaction can also be the result of dissolution of grains by pressure solution. The dissolved material precipitates again in open pore spaces, which means there is a net flow of material into the pores. However, in some cases a certain mineral dissolves and not precipitate again. This process is called leaching which increases pore space in the rock.



Some biochemical processes, like the activity of bacteria, can affect minerals in a rock and are therefore seen as part of diagenesis. Fungi and plants (by their roots) and various other organisms that live beneath the surface can also influence diagenesis.

Burial of rocks due to on going sedimentation leads to increased pressure and temperature, which stimulates certain chemical reactions. An example is the reactions by which organic material becomes lignite or coal. When temperature and pressure increase still further, the realm of diagenesis makes way for metamorphism, the process that forms metamorphic rock.

SEDIMENTARY ENVIRONMENTS OF DEPOSITION

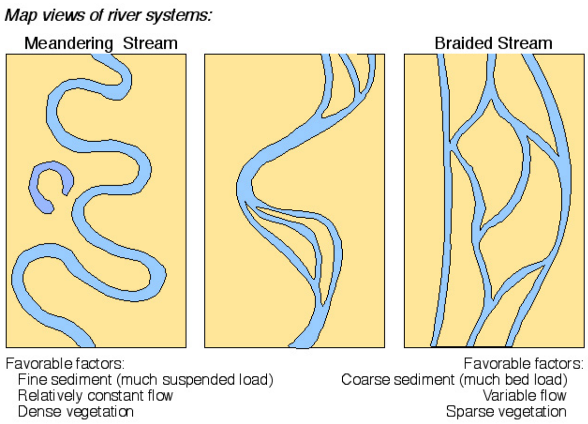
Following is the properties of sedimentary rocks deposited within various sedimentary environments.

1. Continental Environments- predominantly siliciclastic sediments (conglomerate, sandstone, siltstone, etc.) characterized by scarce fossils and no marine fossils.

   Fluvial (rivers)

   a. Alluvial Fans - deposits that form at the base of mountains where rapidly flowing streams suddenly emerge from a narrow valley, spread over, slow down, and dump the larger particles in their sediment load.

   b. Braided Rivers - characterized by many channels separated by bars or small islands. Braiding results from rapid, large fluctuations in the volume of river water, and an abundance of coarse sediment.

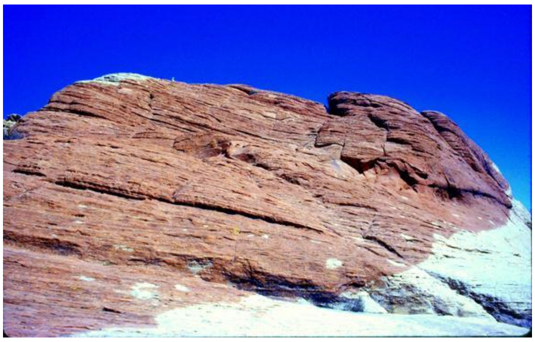


c. Meandering Rivers - confined to one, highly sinuous channel, and contain finer sediment load than braided rivers. Meandering rivers also form bars, but they are formed on the inside bend of meander loops

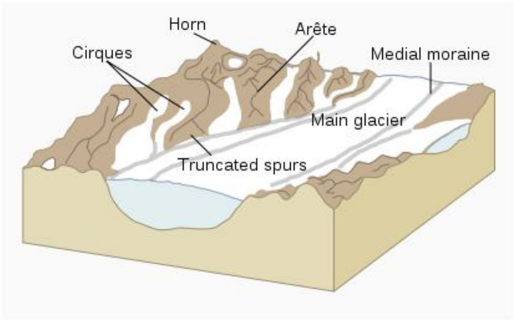
Lacustrine (lakes) - difficult to characterize. They may contain numerous sedimentary structures, including cross-bedding, ripples, graded beds, footprints, mudcracks, and raindrop impressions. Fossils may be common. Plant fossils and freshwater bivalves and gastropods are particularly abundant.

Paludal (swamps and marshes) - organic-rich shale and sandstone or coal deposits with thin stringers of siltstone and shale. Plant fossils are common in all stages of preservation.

Eolian (deserts and near beaches) - recognized by dune deposits, although the dominant sedimentary layering that is preserved is horizontal.

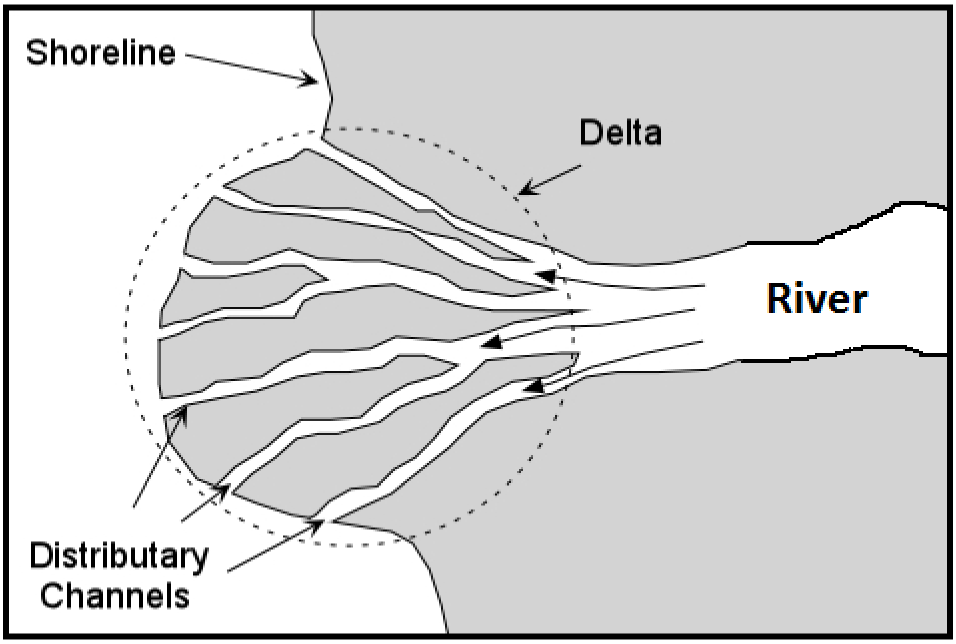


Glacial - range in size from small bodies deposited by valley glaciers (alpine glaciers) to large sheets dumped from continental glaciers. Characterized by a variety of facies, but the most unique is diamictites, or pebbly mudstones.



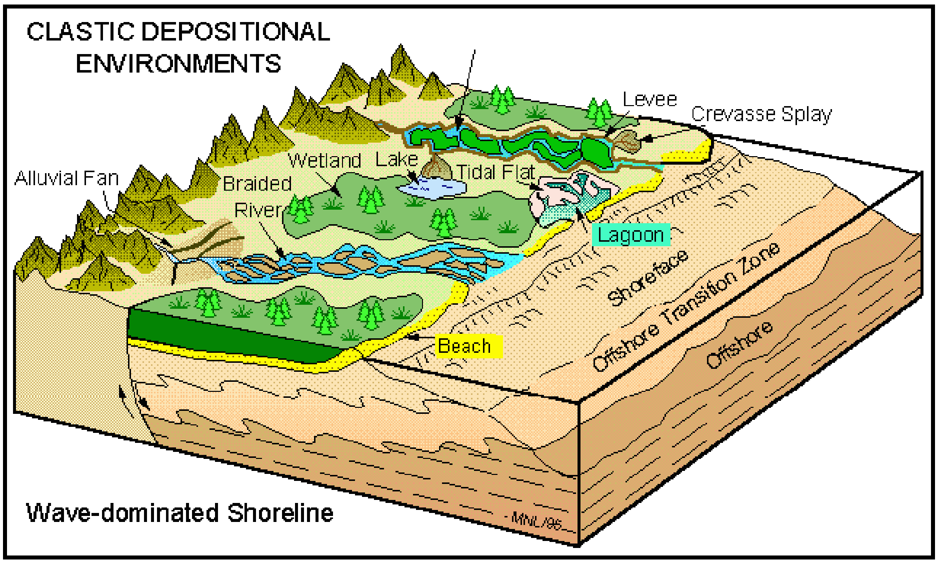
2. Transitional to Shallow Marine Environments

1. Deltas - form where rivers enter a standing body of water, slow down, and deposit more sediment than can be removed by waves and currents. Although deltas also from in lakes, the largest deltas occur in the oceans. Deltas are composed of several sub-environments, from the fluvial delta-top to the submarine base of the delta.



2. Beaches and Barrier Islands - long, narrow accumulations of sand parallel to the shoreline. Barrier islands are separated from land by a shallow lagoon or marsh. Beach faces are composed primarily of fine- to medium-grained, well-sorted sand that displays sub horizontal parallel laminations and low-angle, seaward-, landward- and alongshore-dipping cross beds. The variously dipping cross beds are a result of the back-and-forth action of tides and long shore currents. Burrows are common in sediments of the transition zone between the beach and open shelf.

3. Clastic shelf - bounded by coastal environments on the landward side and by the continental slope on the seaward side. Sediments consist mainly of sand and mud, and near shore sands commonly grade seaward through a transition zone of mixed sand and mud to deeper-water muds. Cross bedding is common in the sands and bio-turbation is common in the muds.



4. Carbonate shelves and platforms - located primarily at low latitudes in clear, shallow, tropical seas where little continental, clastic sediment is introduced.

3. Deep Marine

1. Pelagic - fine-grained sediments deposited far from land influence by slowly settling particles suspended in the water column.
   a. Carbonate ooze - carbonate shells of tiny planktonic organisms (foraminifera, coccolithoforids)
   b. Silica ooze - silica shells of tiny planktonic organisms (radiolarian, diatoms)
   c. Red clay - clay-sized particles of continental origin (mostly transported by wind). Very high Fe and Mn contents produce the coloration, and frequently Mn pavements, crusts and nodules are found in this environment.

2. Turbidites - fining-upward deposits that were transported seaward in deep-sea channels and canyons by high-density, sediment laden currents. In map view, turbidites form fans that spread outward on the sea floor from the mouths of the canyons.

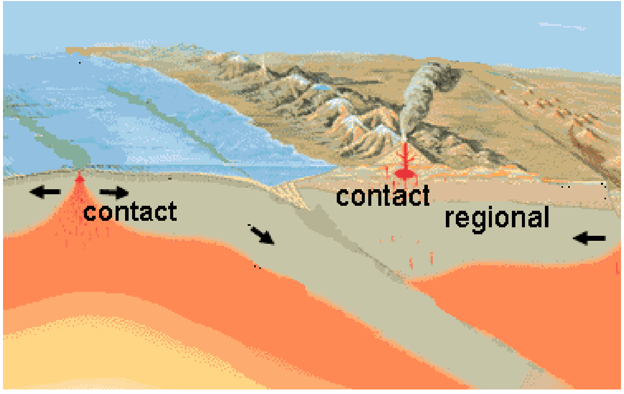
Metamorphic rocks arise from the transformation of existing rock types, in a process called metamorphism, which means "change in form". The original rock (protolith) is subjected to heat and pressure, (temperatures greater than 150 to 200 °C and pressures of 1500 bars or 1480.38 atm) causing profound physical and/or chemical change. The protolith may be sedimentary rock, igneous rock or another older metamorphic rock.

Metamorphic rocks make up a large part of the Earth's crust and are classified by texture and by chemical and mineral assemblage (metamorphic facies). They may be formed simply by being deep beneath the Earth's surface, subjected to high temperatures and the great pressure of the rock layers above it. They can form from tectonic processes such as continental collisions, which cause horizontal pressure, friction and distortion. They are also formed when rock is heated up by the intrusion of hot molten rock called magma from the Earth's interior. Some examples of metamorphic rocks are gneiss, slate, marble, schist, and quartzite. These also include minerals, known as index minerals; include sillimanite, kyanite, staurolite, andalusite, and some garnet. Other minerals, such as olivines, pyroxenes, amphiboles, micas, feldspars, and quartz, may be found in metamorphic rocks, but are not necessarily the result of the process of metamorphism. These minerals formed during the crystallization of igneous rocks. They are stable at high temperatures and pressures and may remain chemically unchanged during the metamorphic process.

The change in the particle size of the rock during the process of metamorphism is called recrystallization. For instance, the small calcite crystals in the sedimentary rock limestone and chalk change into larger crystals in the metamorphic rock marble, or in metamorphosed sandstone, recrystallization of the original quartz sand grains results in very compact quartzite, also known as metaquartzite, in which the often larger quartz crystals are interlocked. Both high temperatures and pressures contribute to recrystallization. High temperatures allow the atoms and ions in solid crystals to migrate, thus reorganizing the crystals, while high pressures cause solution of the crystals within the rock at their point of contact.

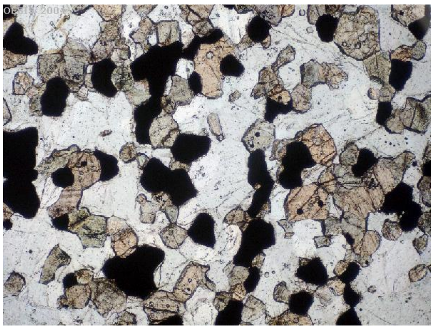
Types of metamorphism

Contact metamorphism is the name given to the changes that take place when magma is injected into the surrounding solid rock (country rock). The changes that occur are greatest wherever the magma comes into contact with the rock because the temperatures are highest at this boundary and decrease with distance from it. Around the igneous rock that forms from the cooling magma is a metamorphosed zone called a contact metamorphism aureole. Aureoles may show all degrees of metamorphism from the contact area to unmetamorphosed (unchanged) country rock some distance away. The formation of important ore minerals may occur by the process of metasomatism at or near the contact zone.



When a rock is contact altered by an igneous intrusion it very frequently becomes more indurated, and more coarsely crystalline. Many altered rocks of this type were formerly called hornstones, and the term hornfels is often used by geologists to signify those fine grained, compact, non-foliated products of contact metamorphism. A shale may become a dark argillaceous hornfels, full of tiny plates of brownish biotite; a marl or impure limestone may change to a grey, yellow or greenish lime-silicate-hornfels or siliceous marble, tough and splintery, with abundant augite, garnet, wollastonite and other minerals in which calcite is an important component. A diabase or andesite may become a diabase hornfels or andesite hornfels with development of new hornblende and biotite and a partial recrystallization of the original feldspar. Chert or flint may become a finely crystalline quartz rock; sandstones lose their clastic structure and are converted into a mosaic of small close-fitting grains of quartz in a metamorphic rock called quartzite.

Hornfels



Hornfel under microscope*

Biotite

Chert

Andesite

*Rocks close to a large igneous intrusion are heated to high temperatures but not deformed. Their minerals change, but they tend not to develop a new banding or cleavage. This makes a hard, fine-grained rock called a hornfels.

If the rock was originally banded or foliated (as, for example, a laminated sandstone or a foliated calc-schist) this character may not be obliterated, and a banded hornfels is the product; fossils even may have their shapes preserved, though entirely recrystallized, and in many contact-altered lavas the vesicles are still visible, though their contents have usually entered into new combinations to form minerals that were not originally present. The minute structures, however, disappear, often completely, if the thermal alteration is very profound; thus small grains of quartz in shale are lost or blend with the surrounding particles of clay, and the fine ground-mass of lavas is entirely reconstructed.

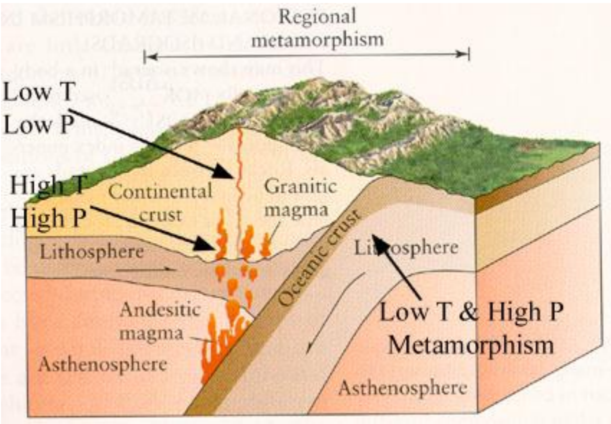

Ripple laminated sandstone

By recrystallization in this manner peculiar rocks of very distinct types are often produced. Thus shales may pass into cordierite rocks, or may show large crystals of andalusite (and chiastolite), staurolite, garnet, kyanite and sillimanite, all derived from the aluminous content of the original shale. A considerable amount of mica (both muscovite and biotite) is often simultaneously formed, and the resulting product has a close resemblance to many kinds of schist. Limestones, if pure, are often turned into coarsely crystalline marbles; but if there was an admixture of clay or sand in the original rock such minerals as garnet, epidote, idocrase, wollastonite, will be present. Sandstones when greatly heated may change into coarse quartzites composed of large clear grains of quartz. These more intense stages of alteration are not so commonly seen in igneous rocks, because their minerals, being formed at high temperatures, are not so easily transformed or recrystallized.

In a few cases rocks are fused and in the dark glassy product minute crystals of spinel, sillimanite and cordierite may separate out. Shales are occasionally thus altered by basalt dikes, and feldspathic sandstones may be completely vitrified. Similar changes may be induced in shales by the burning of coal seams or even by an ordinary furnace.

There is also a tendency for metasomatism between the igneous magma and sedimentary country rock, whereby the chemicals in each are exchanged or introduced into the other. Granites may absorb fragments of shale or pieces of basalt. In that case, hybrid rocks called skarn, which don't have the characteristics of normal igneous or sedimentary rocks. Sometimes invading granite magma permeates the rocks around, filling their joints and planes of bedding, etc., with threads of quartz and feldspar. This is very exceptional but instances of it are known and it may take place on a large scale.

Regional metamorphism, also known as dynamic metamorphism, is the name given to changes in great masses of rock over a wide area. Rocks can be metamorphosed simply by being at great depths below the Earth's surface, subjected to high temperatures and the great pressure caused by the immense weight of the rock layers above. Much of the lower continental crust is metamorphic, except for recent igneous intrusions. Horizontal tectonic movements such as the collision of continents create orogenic belts[1], and cause high temperatures, pressures and deformation in the rocks along these belts. If the metamorphosed rocks are later uplifted and exposed by erosion, they may occur in long belts or other large areas at the surface. The process of metamorphism may have destroyed the original features that could have revealed the rock's previous history. Recrystallization of the rock will destroy the textures and fossils present in sedimentary rocks. Metasomatism will change the original composition.



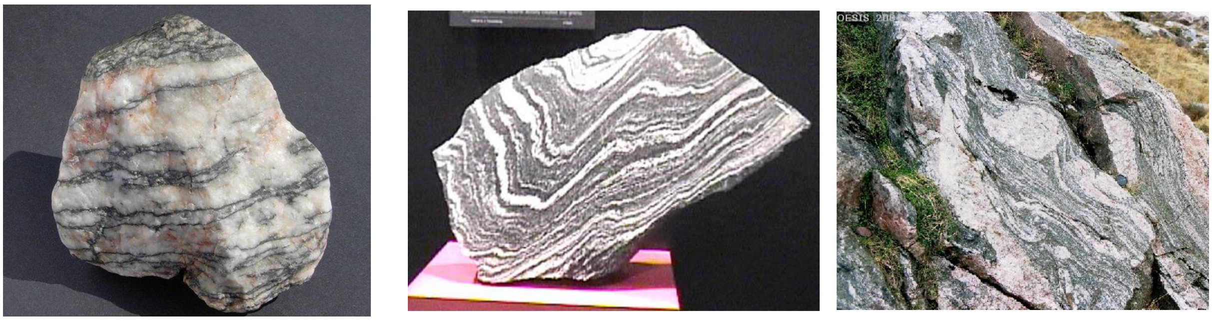
Regional metamorphism tends to make the rock more indurated and at the same time to give it a foliated, shistose or gneissic texture, consisting of a planar arrangement of the minerals, so that platy or prismatic minerals like mica and hornblende have their longest axes arranged parallel to one another. For that reason many of these rocks split readily in one direction along mica-bearing zones (schists). In gneisses, minerals also tend to be segregated into bands; thus there are seams of quartz and of mica in a mica schist, very thin, but consisting essentially of one mineral. Along the mineral layers composed of soft or fissile minerals the rocks will split most readily, and the freshly split specimens will appear to be faced or coated with this mineral; for example, a piece of mica schist looked at face-wise might be supposed to consist entirely of shining scales of mica. On the edge of the specimens, however, the white folia of granular quartz will be visible. In gneisses these alternating folia are sometimes thicker and less regular than in schists, but most importantly less micaceous; they may be lenticular, dying out rapidly. Gneisses also, as a rule, contain more feldspar than schists do, and are tougher and less fissile. Contortion or crumbling of the foliation is by no means uncommon; splitting faces are undulose or puckered.

1- Orogeny refers to forces and events leading to a severe structural deformation of the Earth's lithosphere (crust and uppermost mantle) due to the engagement of tectonic plates.

Schistosity and gneissic banding (the two main types of foliation) are formed by directed pressure at elevated temperature, and to interstitial movement, or internal flow arranging the mineral particles while they are crystallizing in that directed pressure field.

Rocks that were originally sedimentary and rocks that were undoubtedly igneous may be metamorphosed into schists and gneisses. If originally of similar composition they may be very difficult to distinguish from one another if the metamorphism has been great. A quartz-porphyry, for example, and a fine feldspathic sandstone, may both be metamorphosed into a grey or pink mica-schist.

Schists



Gniesses

STRUCTURES OF METAMORPHIC ROCKS

Holmes has suggested a convenient grouping of metamorphic structures into

1. Cataclastic structure: soft rocks like shale or tuffs develop cleavage harder rocks scattered and finally crushed to power with the formation.
2. Maculose structure: in this porphyroblasts of strong minerals are well developed like chloritoid feature.
3. Schistose structure: this structure is formed due to predominance in a metamorphic rock of flacky, lamellar, tabular and high cleavage minerals ex: mica, chlorite etc.
4. Granulose structure: is due to the predominance of equidimensional minerals such as quartz, feldspar etc.
5. Gneissose structure: a secondary rough foliation developed as a result of pressure on the di-solidified rocks, the banded or folia or lenses in gneisses etc.
6. Xenoblastic structure: the crystallographic facies are rarely developed an recrystallised metamorphic mineral.
7. Idioblastic structure: a flow mineral which posses crystallizing faces, are able to assert their proper crystallize form, even against the resistance of a solid medium.

TEXTURES OF METAMORPHIC ROCKS

The distinction between texture and structure remains the same in the igneous rocks, but it is harder to disting high between the two in the case of metamorphic rocks. The texture of metamorphic rocks depend on the shape of the mineral and the modes of growth and mutual arrangement, there structures depends on the inter relation of various textures with in the rock units and frequently dominated by the directive forces due to unequal pressure.

Textures which are due to recrystallization are described as CRYSTALLOBLASTIC.

Relict or palimpsest structures: relies of original rock in a rock that has new metamorphic structure.

Porphyroblastic: large crystals formed by recrystallization in a finer matrix of schist or slate.

Poikiloblastic: having large crystals with many large inclusions or oplitic texture are recognizable.

Granoblastic: when granulitic texture is present.

Augen structure: lens of some minerals in a crushed matrix.

Mylonitic structure: crushed completely alternation takes place, involving the formation of complex minerals form those of simples chemical types.