# *Igneous rocks*

**Igneous rocks** crystallize from magmatic melts **intruded** at depth into country strata or **extruded** as lava at the surface.

**Extrusive rock**
Igneous rocks that cooled on the surface are termed extrusive. The magma from which they are formed may vary in composition and properties. Viscous magma forms massive steep-side mountains – the familiar cones of many volcanoes. Pockets of trapped gas eventually escape causing violent explosions. Fragments of half-cooled rock are then thrown into the air. Sometimes the lumps are quite large – 20 to 30 cm in length. These are volcanic bombs. As they descend, they twist and turn, and the soft rock becomes spindle-shaped. Smaller particles are called lapilli, meaning "little stones," while the finest dust forms volcanic ash. The molten rock itself flows as a lava and solidifies, giving off gases. Small cavities or vesicles may, as a result, be formed inside this rocky giving a frothy appearance. Pumice stone is a well known example of this phenomenon.

If the magma is more fluid, instead of forming steep volcanoes, it flows into thin sheets over very large areas. The islands of Hawaii are made up of such sheets of basalt, dark, easily-flowing lava.

As a rule all extrusive rocks are predominantly glassy since they cool too rapidly for crystals to form.

**Intrusive rock**
Some magma never reaches the surface but cools within the Earth. The igneous rocks formed are then termed intrusive. If the magma was injected into sedimentary layers along bedding planes, the igneous sheet formed is called a **sill** and is said to be **conformable** with the surrounding rock. Sometimes, the magma forces its way across strata at angles to the bedding planes. These structures are called **dikes** and are said to be **unconformable**.

It may happen that the magma is forced through a comparatively small aperture in the layers and reaches an area where it is actually able to lift up the layers of overhead rock. A bun-shaped intrusion or **laccolith** is then formed. Alternatively the magma may cause strata beneath it to sag, in which case a basin-shaped intrusion or **lopolith** develops.

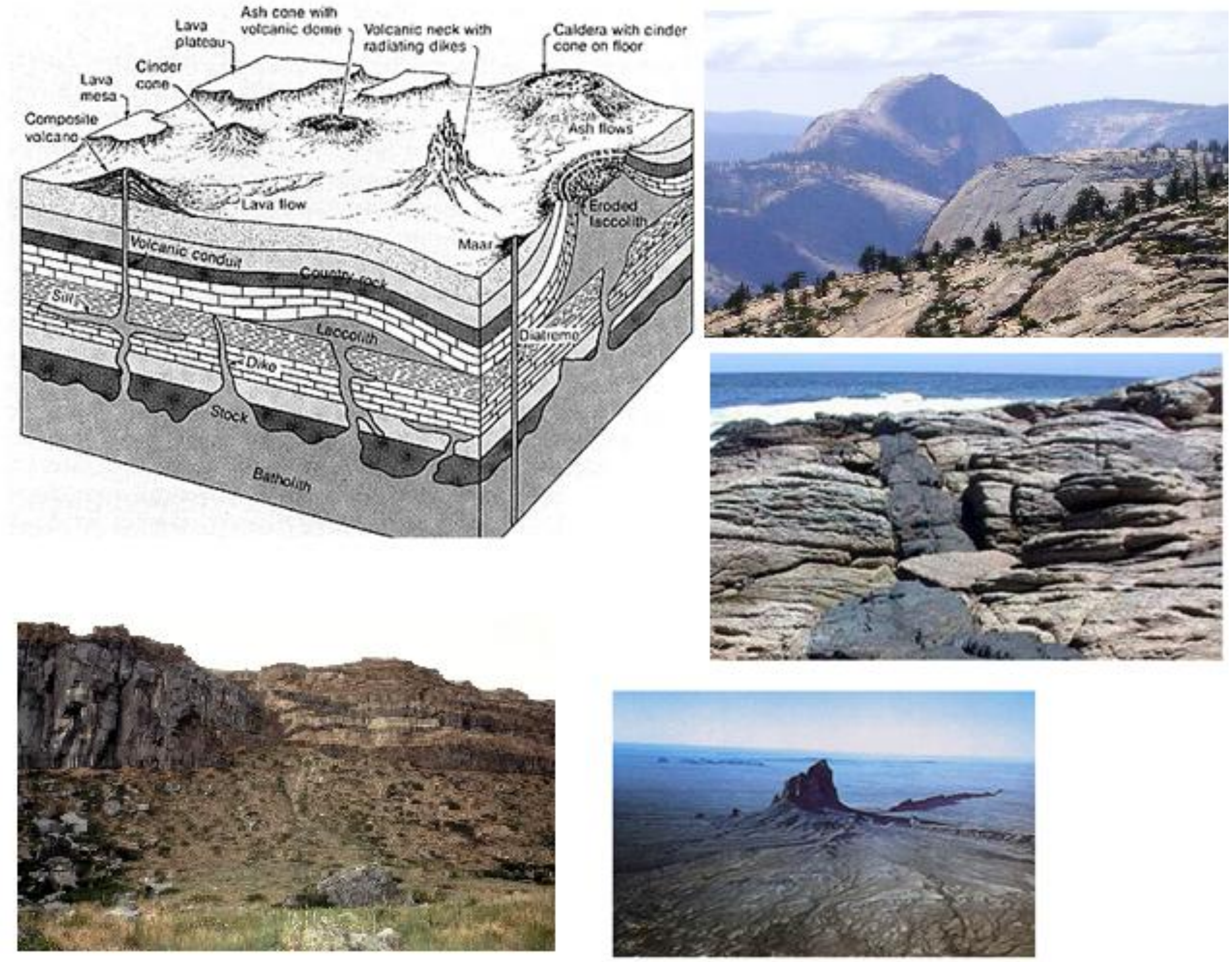
Dikes, sills, and lava flows come from huge chambers of magma that may be several kilometers below the surface. Usually the magma cools at an intermediate rate producing an intermediate structure, either a glassy base containing a few large crystals or a ground mass of very fine crystals. Such rock is described as **hypabyssal**. In some areas, the igneous activity finished many millions of years ago, so that even the magma chambers themselves have solidified. Rocks cooled at such great depths below the surface are called **plutonic** after the Roman god of the underworld, Pluto. The time taken for solidification to be completed may be millions of years. Crystals large enough to be seen with the naked eye are able to form. Examples of such crystalline rocks are granite, usually light-colored (pink or gray), and the dark, heavy gabbros. **Plutonic** igneous rocks are found in large igneous intrusions of crystallized magma.

Plutonic rocks exhibit a fine-grained, ***aphanitic*** texture if the magma cooled close to the surface in volcanic necks or feeder pipes. Grain size increases to coarse-grained, ***phaneritic*** textures for magmas that cooled very slowly at great depth in very large magma chambers.

Erosion may lay bare these old magma reservoirs. When of great size they are called batholiths. Sometimes the roof of the **batholith** extends upward into many domes.

| | | |
|---|---|---|
| ***Major Intrusions*** | *Concordant* | *Lopolith* |
| | *Discordant* | *Batholiths with associated bosses and stocks* |
| ***Minor Intrusions*** | *Concordant* | *Sills, laccoliths, phacoliths* |
| | *Discordant* | *Dykes, ring complexes* |
| ***Major Extrusions*** | *Lava, ignimbrite and ash plateaux* | |
| ***Minor Extrusions*** | *Lava flows, cones, ash beds, volcanic necks and plugs* | |

**Plutonic** structures include ***batholiths, stocks, lopoliths, and lacoliths.***



**Clockwise form topleft Cartoon showing structure of igneous rocks, Batholith, dike, volcanic neck, lacolith and sills**

## Types of igneous rocks

### Dunites

**Dunites** are gray to olive green to 'dun', coarse-grained or phaneritic plutonic igneous rock of ultramafic composition. Comprising greater than ***90% olivine***, with minor pyroxenes and chromite, dunites are olivine-rich end-members of the peridotite group of mantle-derived rocks.

### Peridotite

**Peridotite** is an ultramafic, ultrabasic (less than 45% silica), dense, plutonic igneous rock comprising mostly ***olivine and pyroxene***. Peridotite comprises most of the Earth's upper mantle (*asthenosphere*).

### Gabbro

**Gabbro** is a coarse grained mafic plutonic igneous rock composed of varied percentages of ***pyroxene, plagioclase feldspar, amphiboles, and olivine***. Gabbros can form as massive uniform intrusions or as layered ultramafic intrusions formed by settling of pyroxene and plagioclase feldspar (***pyroxene-plagioclase cumulate***).

### Diorites

**Diorites** are intermediate plutonic igneous rocks composed mainly of ***plagioclase feldspars (usually andesine), hornblende, and/or pyroxenes.*** Depending upon mineral composition, diorites are colored salt-and-pepper, gray, bluish gray, to dark gray, and may have a greenish cast.

### Granodiorites

Granodiorites are intermediate between granite and diorite. They contain more ***plagioclase (Na/Ca) than potassium feldspar. They usually include abundant biotite and hornblende***, giving them a darker appearance than true granites. Other mineral components of Granodiorites include ***quartz, apatite, and sphene***.

### Granite

**Granite** is typically a medium to coarse-grained or porphyritic, felsic, plutonic intrusive igneous rock that is usually pink to dark gray, sometimes black, depending on its chemistry and mineralogy.

Granites primarily consist of ***orthoclase, plagioclase, quartz, hornblende, and either or both micas (muscovite and biotite) with accessory minerals such as magnetite, garnets, zircon and apatite.*** Granites are the commonest basement rocks of the continental crust, many dating from the Precambrian.

Aplite (or haplite) refers to any fine-grained, hypabyssal, igneous rock of simple composition, such as granite composed only of ***alkali feldspars, quartz, and muscovite***.

**Pegmatites** are plutonic rocks with particularly large crystal grains (larger than 20 mm, and usually larger than 50 mm).

Most pegmatites are composed ***quartz, feldspars and micas***, (granitic composition). More rarely, intermediate and mafic pegmatites contain amphiboles, ***Ca-plagioclase feldspar, pyroxenes*** and other minerals.

They may also contain a host other minerals like ***tourmaline, minerals of tin, garnet*** etc.

## Volcanic rocks

Volcanic rocks form from extrusion of lava and eruption of pyroclastics from volcanoes.

The commonest volcanic lavas correspond to ***basaltic (~80%), andesitic (~10%), and rhyolitic (~10%)*** compositions.

### Basalt

**Basalt** is a hard gray or black, mafic igneous volcanic rock that typically contains a preponderance of plagioclase ***and pyroxene. Olivine*** can also be a significant constituent. ***Accessory minerals include iron oxides and iron-titanium oxides***, providing basalt with a paleomagnetic signature.

Basalts are usually fine-grained due to the rapid cooling of lava, though they can contain larger crystals in a fine matrix (porphyritic). They may be vesicular, or be a frothy scoria.

### Andesite

**Andesite** is an aphanitic or, more often, porphyritic extrusive igneous rock with an intermediate composition similar to that of plutonic diorite, containing 52-63 % silica ($SiO_2$) by weight.

### Dacite

**Dacite** is an aphanitic to porphyritic, light to dark gray to black rock of composition in between of andesite and rhyolite (63-68 % $SiO_2$). Like andesite, dacite comprises mostly ***plagioclase with biotite, hornblende, and pyroxenes (augite and/or enstatite). Quartz*** is present within the groundmass or as rounded phenocrysts.

### Rhyolite

**Rhyolite** is Rhyolite is an aphanitic or porphyritic, felsic, extrusive igneous rock with a composition similar to that of granite. Rhyolites are typically composed of ***quartz, alkali feldspar, and plagioclase feldspar; with biotite and pyroxene as accessory minerals***.

# Sedimentary Rocks

Steven Dutch, Natural and Applied Sciences, University of Wisconsin - Green Bay
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## What Rocks Tell Us

| | **How Classified** | **What it Tells Us** |
|---|---|---|
| **Igneous** | Mineral Composition | Tectonic Setting |
| | Texture | Cooling History |
| **Sedimentary** | Grain Size | Energy Level of Environment |
| | Chemical Composition | Surface Environment |
| **Metamorphic** | Chemical Composition | Original Rock Type |
| | Mineral Composition | Temperature, Pressure Conditions |
| | Texture | Degree of Change |

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## Sedimentary Rocks

Deposited on or Near Surface of Earth by Mechanical or Chemical Processes

### Clastic Rocks

- Made of Fragmentary Material
- Deposited by
  - Water (Most Common)
  - Wind
  - Glacial Action
  - Gravity

### Biohemical Sedimentary Rocks

- Evaporation
- Precipitation
- Biogenic Sediments

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## Environmental Clues in Sedimentary Rocks

- Grain Size - Power of Transport Medium
- Grading - Often Due to Floods
- Rounding
- Sorting
- Transport, Reworking
- Cross-bedding-wind, Wave or Current Action
- Fossils

    - Salt Water - Corals, Echinoderms
    - Fresh Water - Insects, Amphibians
    - Terrestrial - Leaves, Land Animals
- Color And Chemistry
    - Red Beds - Often Terrestrial
    - Black Shale - Oxygen Poor, Often Deep Water

# Bedding or Stratification

- Almost Always Present in Sedimentary Rocks
- Originally Horizontal
- Tilting by Earth Forces Later
- Variations in Conditions of Deposition
- Size of Beds (Thickness)
    - Usually 1-100 Cm
    - Can Range From Microscopic to 50m

# Clastic Rocks

## Classified on

- Grain Size
- Grain Composition
- Texture

## Sediment Sizes and Clastic Rock Types

- Shale - Clay less than 0.001 Mm
- Siltstone - Silt .001-0.1 Mm
- Sandstone - Sand .01-1 Mm
- Conglomerate - Gravel 1mm +

Sedimentary rocks made of silt- and clay-sized particles are collectively called *mudrocks*, and are the most abundant sedimentary rocks.

## Some Special Clastic Rock Types

- Arkose - Feldspar - Rich
- Breccia - Angular Fragments
- Graywacke - Angular, Immature Sandstone

# Maturity

- Stability of Minerals
- Rock Fragments
- Rounding or Angularity
- Sorting

Removal of Unstable Ingredients - Mechanical Working

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# Diagenesis

## Compaction

## Cementing

- Quartz
- Calcite
- Iron Oxide
- Clay
- Glauconite
- Feldspar

## Alteration

- Limestone - Dolomite
- Plagioclase - Albite

## Recrystallization

- Limestone

---

# Chemical Sediments

## Evaporites -Water Soluble

- Halite
- Gypsum
- Calcite

## Precipitate

Example: Ca(sol'n) + $SO_4$ (Sol'n) = $CaSO_4$

- Gypsum
- Limestone
- Iron Formations

## Alteration After Deposition

- Dolomite

## Biogenic Sediments

- Limestone - Shells, Reefs, Etc.

## Organic Remains

- Coal
- Petroleum

# Fossil Fuels

## Coal

Coal is a slam-dunk. It's carbonized wood. We know that because the actual wood fragments are easily visible in low-grade varieties of coal, fossilized wood is often found in adjacent rocks, the overall environment is typical of coastal swamp or delta settings, and ancient soils are sometimes found beneath the coal beds. Organic matter goes through a variety of changes as it becomes coal:

Peat

Compacted and partially decomposed organic matter. About 50% carbon.

Lignite

Brown or gray brittle coal with lots of impurities, and often with easily visible plant fragments. About 80% carbon.

Bituminous

Black with banding. Some bands are dull, others shiny. These bands reflect different types of processed plant matter, which are still visible under the microscope. About 90% carbon.

Anthracite

Black or dark gray, metallic luster and conchoidal fracture. A true metamorphic rock, since it's heated beyond the temperatures found in normal sedimentary burial. About 95% carbon

Graphite

Dark gray and metallic, 100% carbon but unburnable in normal flames.

Diamond

Contrary to popular misconception, diamond is NOT the final stage in coal metamorphism! Coal is never buried deeply enough to reach the pressures needed to form diamond. Diamond form in the earth's mantle from carbon that was always in the earth's interior.

Anthracite is the purest and best form of coal. Unfortunately, the temperature difference between bituminous coal and graphite is small, so anthracite is uncommon. Also, unlike flat-lying bituminous, anthracite often occurs in folded rocks, making it hard to mine. Finally, since it burns so hot, it requires special furnaces. So despite its desirable properties, anthracite use has declined substantially.

## Petroleum

The problem with petroleum is that it's a fluid and moves, so it may migrate far from its source. A typical petroleum molecule looks like this:

Octane molecule

The above molecule has eight carbon atoms in a chain and is called *octane*. Molecules with 1-4 carbons are called methane, ethane, propane and butane, respectively. From then on, they are named for the number of carbons in the chain: pentane, hexane, heptane, octane, etc.

Octane makes a good motor fuel, so fuel that burns as well as pure octane is termed 100 octane. Back when Detroit was turning out mammoth Klingon cruisers, some fuels were over 100 octane (outperformed pure octane). Nowadays fuels are 85-90 octane. So if petroleum is the remains of living things, what sorts of organisms make these molecules?

Answer: NONE. If it were that easy, we wouldn't have to look for oil, we'd just toss our garbage into a vat of the right microbes and skim off the petroleum. But lots of organisms make molecules that look like this:

Fatty acid molecule

This is called a fatty acid (octanoic acid to be exact). Most petroleum occurs in marine sedimentary rocks, so we want organisms rich in fatty acids that live in the sea, in huge quantities. And we have them. They're called plankton. Marine plankton, not dinosaurs, are the precursors of petroleum.

Being fluid, petroleum moves, and since it's lighter than water, it floats upward. Left unconfined, it will reach the surface and evaporate or be oxidized. So it has to be confined somehow. Contrary to the popular term "oil pool," oil does not collect in pockets in the rock. It floats upward on water until it either reaches the surface or is trapped *from above*. The most important economic application of an understanding of rocks in three dimensions is the search for *petroleum traps*.

| | |
|---|---|
| Petroleum Traps | In the diagram, light blue represents water-soaked porous rock, dark gray represents petroleum and light gray represents natural gas. Like water in an aquifer, the petroleum and natural gas fill pore spaces in the rocks. All other colors represent impervious rocks.<br>Structural Traps (top)<br>Traps that result from deformation of the rocks by outside forces.<br>Startigraphic traps (bottom)<br>Traps formed by variations within the sedimentary rocks themselves. |

Since oil weighs a lot less than rock, the oil in a well weighs far less than the same volume of rock next to the well. Thus in many cases oil is still under pressure when it reaches the surface. In old-time movies, it was common to see the climax come when oil drillers on the verge of quitting hit oil, got a "gusher" and celebrated in the resulting rain of oil.

Fact: the absolute last thing anyone in the oil business ever wants is a gusher. They are incredibly dangerous to get under control. In fact, when PBS did a series on oil, they could not locate a sound recording of a gusher anywhere and had to interview a few surviving old-timers who could remember what one sounded like. It's been that long since one happened.

However, that pressure is extremely valuable because not only does it get the oil to the surface, but it helps move oil through the rocks to the well. Get greedy and drill too many wells, and you bleed off the pressure, and in the long run you get *less* oil, not more.

## Gas Hydrates

Natural gas hydrates are a curious kind of chemical compound where two dissimilar molecules are mechanically intermingled but not truly chemically bonded. Instead one molecule forms a framework that traps the other molecule. Natural gas hydrates can be considered modified ice structures enclosing methane and other hydrocarbons, but they can melt at temperatures well above normal ice.

At 30 atmospheres pressure, methane hydrate begins to be stable at temperatures above 0 C and at 100 atmospheres it is stable at 15 C. This behavior has two important practical implications. First, it's a nuisance to the gas company. They have to dehydrate natural gas thoroughly to prevent methane hydrates from forming in high pressure gas lines. Second, methane hydrates will be stable on the sea floor at depths below a few hundred meters and will be solid within sea floor sediments. Masses of methane hydrate "yellow ice" have been photographed on the sea floor. Chunks occasionally break loose and float to the surface, where they are unstable and effervesce as they decompose.

The stability of methane hydrates on the sea floor has a whole raft of implications. First, they may constitute a huge energy resource. Second, natural disturbances (and man-made ones, if we exploit gas hydrates and aren't careful) might suddenly destabilize sea floor methane hydrates, triggering submarine landslides and huge releases of methane. Finally, methane is a ferociously effective greenhouse gas, and large methane releases may explain sudden episodes of climatic warming in the geologic past. The methane would oxidize fairly quickly in the atmosphere, but could cause enough warming that other mechanisms (for example, release of carbon dioxide from carbonate rocks and decaying biomass) could keep the temperatures elevated.

| | |
|---|---|
| | In the diagram at left, each vertex is occupied by an oxygen atom and the midpoint of each edge is a hydrogen atom. This atom is attached to one oxygen as part of a water molecule and hydrogen bonded to the other. In the diagram at left one cage is shown with oxygen atoms in blue and hydrogen in red. A methane molecule is shown inside one of the cage skeletons. |

# Facies Changes

Sedimentary rocks change laterally. These changes reflect the different environments where the rocks formed.

### Environment During Deposition

Sedimentary facies

### Rock Types After Burial

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# Landforms Associated with Sedimentary Rocks

| | |
|---|---|
| | Mesa |

| | |
|---|---|
| Sedimentary landforms | Flat-topped hill capped with hard hock<br>Cuesta<br>Gently-tilted layer of hard rock: Door Peninsula. The gentle upper slope, on top of the layer is called the *dip slope*<br>Hogback<br>A sharp ridge of hard rock, edge of a steeply-dipping layer |

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# Metamorphic Rocks

Metamorphism means change – changes that a rock undergoes when it is moved from the place of its origin to a new environment characterized by marked changes in the physical (pressure and temperature, PT) and physico-chemical (partial pressure of $O_2$) conditions.

The change in ambience results in structural and mineralogical reconstitution of the rock in order to achieve equilibrium with the imposed new conditions.

When sedimentary rocks are buried deeper, they get heated. This heating is a combined effect of

1. The overburden of crustal rocks which are normally rich in heat producing radioactive elements.
2. Burial and heating as a result of subduction where one plate overrides another.
3. In folded mountain belts where effective thickness of crust is increased and enormous pressure is produced.

In all three cases metamorphism affects a very large portion of the crust (several thousand square km) and therefore, is known as *REGIONAL METAMORPHISM*.

On a more local scale, we have *THERMAL OR CONTACT METAMORPHISM* which is a result of heating of rocks by the crystallizing magma in the vicinity of intrusions.

The original rock may show new mineralogy or texture, or a mere imprint of the metamorphism over relict mineral or fabric. All these changes provide information on the P and T conditions that prevailed at the time these rocks formed.

The main *FACTORS (AGENTS)* responsible for effecting change in mineralogy and the fabric of the original rock are *TEMPERATURE and PRESSURE.*

The other category of metamorphism is called *CATACLASTIC METAMORPHISM*. This results merely in granulation and crushing of original rocks, but no change in mineralogy.

Fault Breccia, mylonite and pseudotachylite are produced due to intense granulation and crushing of rocks in the vicinity of major faults.

The products of contact metamorphism are fine-grained flinty rocks called *HORNFELS*. Contact metamorphic effects are conspicuous in areas where shales and limestones are intruded by large granite – granodiorite intrusives.

Products of regional metamorphism are more varied. They are SLATES, PHYLLITES, SCHISTS, GNEISSES AND GRANULITES. The slates are the finest grained and gneisses and granulites are coarse grained. They also indicate an increasing grade (T) of metamorphism.

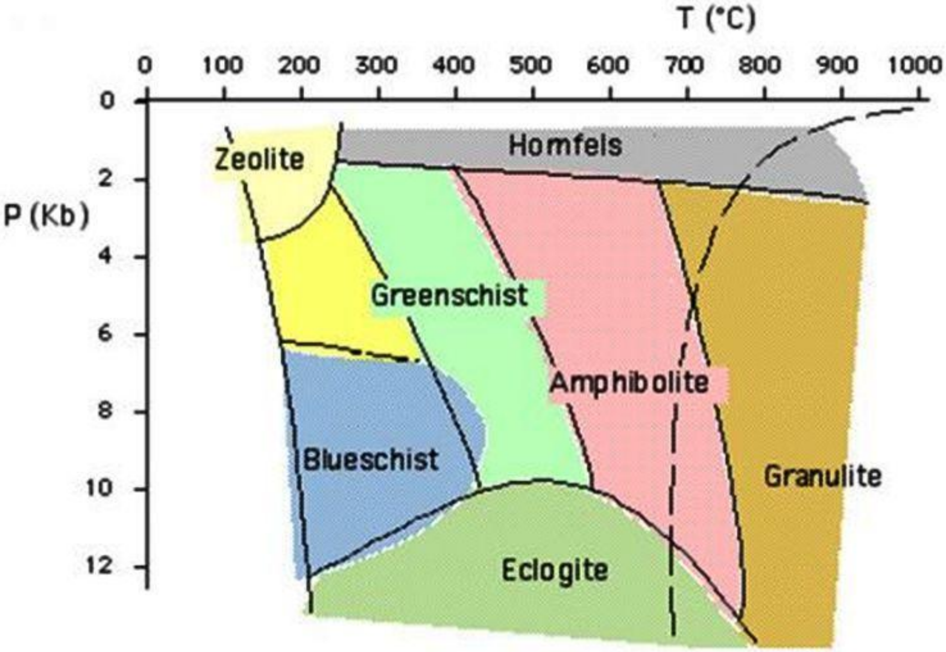


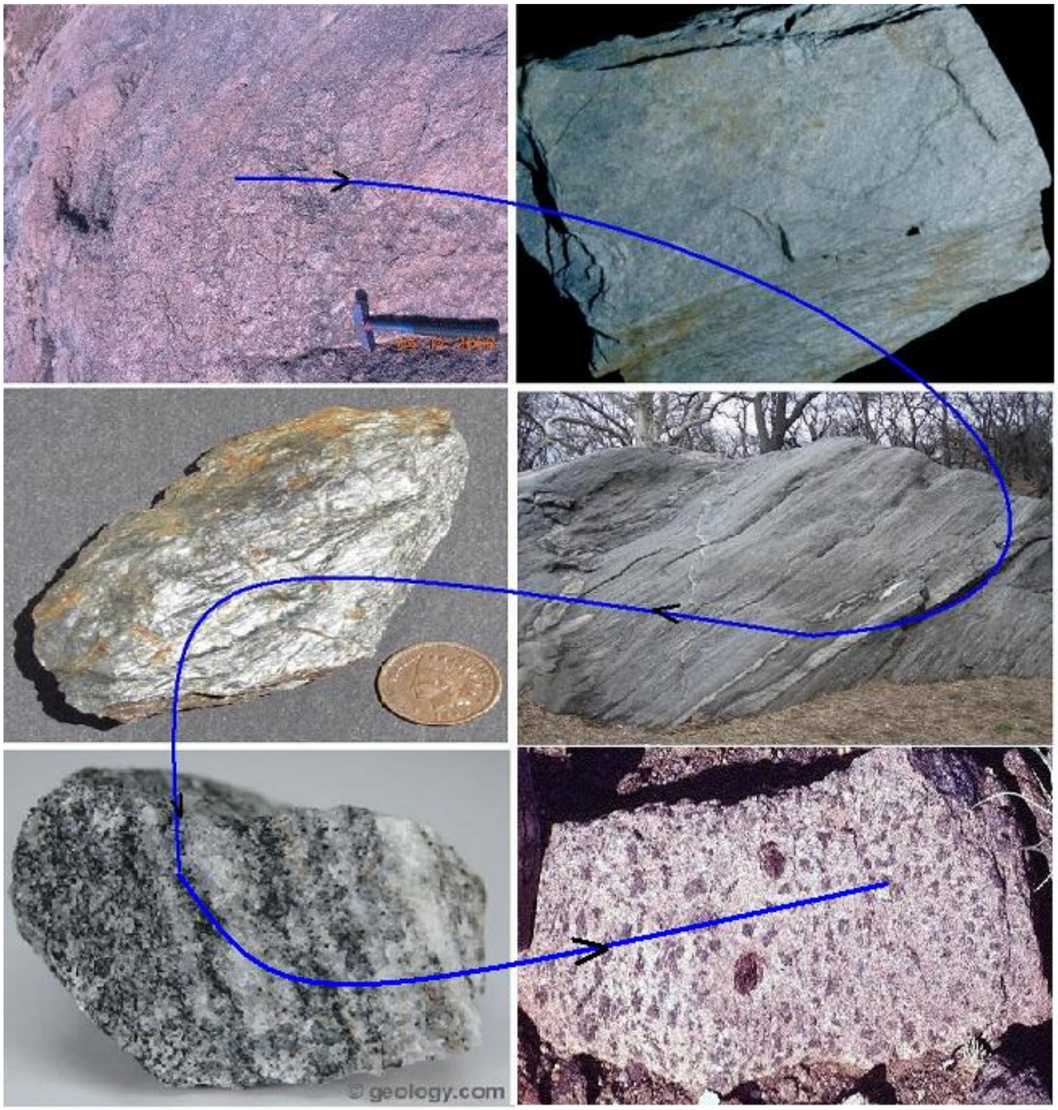
*Figure showing different facies of metamorphism and their PT conditions*

*Texture or fabric of metamorphic rocks*

The most common textural feature (fabric) of a metamorphic rock is FOLIATION characterized by parallel arrangement of minerals or other elements of the rock.

This is variously known as slaty cleavage in very fine grained clayey rocks, schistocity in micaceous rocks and gneissocity in quartzo-felspathic rocks.

Schists show a general increase in grain size with increasing temperature of metamorphism.



**Along the arrow: Cataclastic Breccia, Slate, Phyllite, Schist gneiss and granulite**

Metamorphic rocks are commonly named on the basis of their mineralogy and texture. For example biotite schist, hornblende schist etc. besides the mineral in their name they commonly contain some quartz and felspars.

*Mineralogy of metamorphic rocks*

Minerals common in schists and hornfelses are micas, hornblende, pyroxenes, epidote and feldspars.

Almandine and staurolite are more common in schists rather than in hornfelses.

Minerals not found in hornfelses are are glaucophane, jadeite,

Similarly wollastonite, forsterite, andalusite etc are rare or less common in regional metamorphism.

*Conditions of metamorphism*

Normal pressure and temperature encountered during regional metamorphism falls in the range of 0.3 to 1.5 Giga Pascal and 200 to 750-800$^{o}$C respectively (1Gp = 10 Kilo bar; 1 bar = 0.987 atmosphere). This corresponds to average crustal depths of 6 to 20km.

A **conglomerate** is a sedimentary rock consisting of individual clasts larger than sand (>2 mm) within a finer-grained matrix that have become cemented together. Conglomerates are consisting of rounded fragments and are thus differentiated from breccias, which consist of angular clasts. Both conglomerates and breccias are characterized by clasts.

## Contents

# 1. Classification

In addition to the factors described in this section, conglomerates are classified in terms of both their rounding and sorting.

### 1.1 Texture

Paraconglomerates consist of a matrix-supported rock that contains at least 15% sand-sized or smaller grains (<2 mm), the rest being larger grains of varying sizes.

Orthoconglomerates consist of a clast-supported rock with less than 15% matrix of sand and finer particles.

Metamorphic alteration transforms conglomerate into metaconglomerate.

A conglomerate at the base of the Cambrian in the Black Hills, South Dakota.

Tertiary conglomerate at Resting Springs Pass, Mojave Desert, California.

### 1.2 Clast composition

Conglomerates are classified for the lithologies of the clasts.

- Monomict - clasts with only a single lithology
- Oligomict - clasts of only a few different lithologies
- Polymict - clasts of many different lithologies
- Intraformational - clasts derived from the same formation in which they are found
- Extraformational - clasts derived older rocks than the formation in which they are found

### 1.3 Clast size

Conglomerates are also classified by the dominant clast size.

- Granule conglomerate 2–4 mm
- Pebble conglomerate 4–64 mm
- Cobble conglomerate 64–256 mm
- Boulder conglomerate >256 mm

## 2. Sedimentary environments

Conglomerates are deposited in a variety of sedimentary environments.

### 2.1 Deepwater marine

In turbidites, the basal part of a bed is typically coarse-grained and sometimes conglomeratic. In this setting, conglomerates are normally very well sorted, well-rounded and often with a strong A-axis type imbrication of the clasts.[5]

### 2.2 Shallow marine

Conglomerates are normally present at the base of sequences laid down during marine trangressions above an unconformity, and are known as *basal conglomerates*. They represent the position of the shoreline at a particular time and will be diachronous.[6]

### 2.3 Fluvial

Conglomerates deposited in fluvial environments are typically well-rounded and well-sorted. Clasts of this size are carried as bedload and only at times of high flow-rate. The maximum clast size decreases as the clasts are transported further due to attrition, so conglomerates are more characteristic of immature river systems. In the sediments deposited by mature rivers, conglomerates are generally confined to the basal part of a channel fill where they are known as *pebble lags*.[7] Conglomerates deposited in a fluvial environment often have an AB-plane type imbrication.

### 2.4 Alluvial

Alluvial deposits are formed in areas of high relief and are typically coarse-grained. At mountain fronts individual alluvial fans merge together to form braidplains and these two environments are associated with the thickest deposits of conglomerates. The bulk of conglomerates deposited in this setting are clast-supported with a strong AB-plane imbrication. Some matrix-supported conglomerates are present, a result of debris-flow deposition on some alluvial fans.[5]

### 2.5 Glacial

Glaciers carry a lot of coarse-grained material and many glacial deposits are conglomeratic. Tillites, the sediments deposited directly by a glacier, are typically poorly-sorted, matrix-supported conglomerates. The matrix is generally fine-grained, consisting of finely milled rock fragments. Waterlain deposits associated with glaciers are often conglomeratic, forming structures such as eskers.[7]

## 3. Examples

A spectacular example of conglomerate can be seen at Montserrat, near Barcelona. Here erosion has created vertical channels giving the characteristic jagged shapes for which the mountain is named (Montserrat literally means "jagged mountain"). The rock is strong enough to be used as a building material - see Montserrat abbey front at full resolution for detail of the rock structure.

Another spectacular example of conglomerate, the Crestone Conglomerate may be viewed in and near the town of Crestone, at the foot of the Sangre de Cristo Range in Colorado's San Luis Valley. The Crestone Conglomerate is a metamorphic rock stratum and consists of tiny to quite large rocks that appear to have been tumbled in an ancient river. Some of the rocks have hues of red and green.

Conglomerate may also be seen in the domed hills of Kata Tjuta, in Australia's Northern Territory.

In the nineteenth century a thick layer of Pottsville conglomerate was recognized to underlie anthracite coal measures in Pennsylvania.[8]

## 4. Fanglomerate

Fanglomerate

When a series of conglomerates accumulates into an alluvial fan, in rapidly eroding (e.g. desert) environments, the resulting rock unit is often called a **fanglomerate**. These form the basis of a number of large oil fields, e.g. the Tiffany and Brae fields in the North Sea. These fanglomerates were actually deposited into a deep marine environment but against a rapidly moving fault line, which supplied an intermittent stream of debris into the conglomerate pile. The sediment fans are several kilometers deep at the fault line and the sedimentation moved focus repeatedly, as different sectors of the fault moved.

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# What is Conglomerate?

Conglomerate is a clastic sedimentary rock that contains large (greater than two millimeters in diameter) rounded clasts. The space between the clasts is generally filled with smaller particles and/or a chemical cement that binds the rock together.

**Conglomerate:** The specimen shown is about two inches (five centimeters) across. It is made up of chert and limestone clasts bound in a matrix of sand and clay.

# What is the Composition of Conglomerate?

Conglomerate can have a variety of compositions. As a clastic sedimentary rock it can contain clasts of any rock material or weathering product that is washed downstream or down current. The rounded clasts of conglomerate can be mineral particles such as quartz or they can be sedimentary, metamorphic or igneous rock fragments. The matrix that binds the large clasts together can be a mixture of sand, mud and chemical cement.

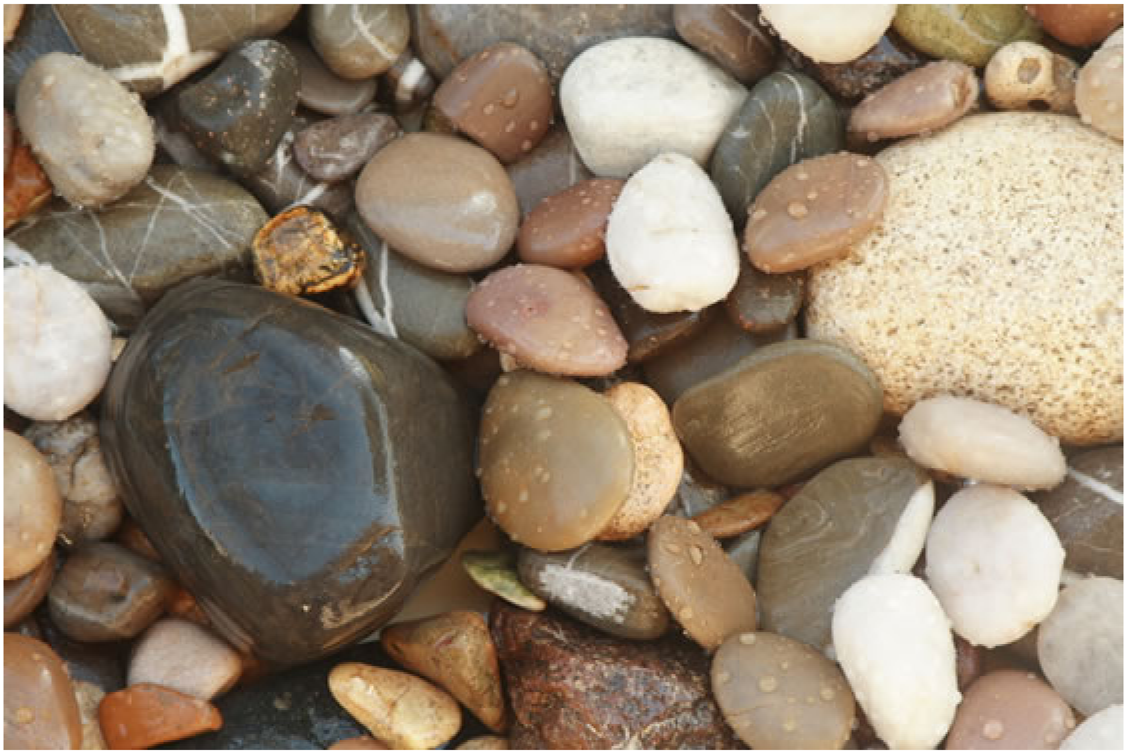
**Conglomerate Close-Up:** A detailed view of conglomerate showing the pebble-size clasts with sand and smaller size particles filling the spaces between them. The largest pebbles in this view are about ten millimeters across. Image by the United States Geological Survey.

# How Does Conglomerate Form?

Conglomerate forms where a sediment of rounded clasts at least two millimeters in diameter accumulates. It takes a strong water current to transport particles this large. So the environment of deposition might be along a swiftly flowing stream or a beach with strong waves. There must also be a source of large-size sediment particles somewhere up current. The rounded shape of the clasts reveal that they were tumbled by running water or moving waves.

**Conglomerate-Forming Environment:** A beach where strong waves have deposited rounded, cobble-size rocks. If buried and lithified these materials might be transformed into a conglomerate. Image copyright by iStockPhoto and Jason van der Valk.

Conglomerates often begin by being deposited as a sediment consisting mainly of small clasts as shown in the photo below. The finer size sand and clay which fill the spaces between the larger clasts is often deposited later on top of the large clasts and then sifts down between them to fill the interstitial spaces. .



**Conglomerate-Size Sediment Clasts:** Pebble-size clasts of many compositions deposited together on a beach. Quartz, sandstone and limestone clasts are all easily recognizable. Largest clast is about two inches (five centimeters) across. Image copyright by iStockPhoto and Ivan Ivanov.

# What is Conglomerate Used For?

Conglomerate has very few commercial uses. Its inability to break cleanly makes it a poor candidate for dimension stone and its variable composition makes it a rock of unreliable physical strength and durability. Conglomerate can be crushed to make a fine aggregate that can be used where a low-performance material is suitable. Many conglomerates are colorful and attractive rocks that are rarely used as an ornamental stone for interior use.

# Sandstone

**Sandstone** (sometimes known as arenite) is actually a sedimentary rock formed by the consolidation and compaction of sand-sized grains ( 0.0625 – 2 mm, in diameter consisting of quartz, feldspar and rock fragments), held together by natural cement, such as silica, or calcium carbonate, iron oxides or a fine-grained matrix of silt and clay particles. Sometimes the spaces between grains may be empty. Sandstones are commonly gray, buff, red, brown tan or yellow, although green and some other colors are also found. Green sandstones often contain, in addition to sand and glauconite, fossil shells and iron oxides; those that break apart easily are known as greensands and are sometimes used to replenish depleted potash in soils. Sandstone is typically the youngest of the quartz-based rocks, with each rock having a different level of porosity, hardness and compressive strength. Owing to their natural beauty, sandstones are used for interior as well as exterior decoration including flooring, paving, cladding walls and floors.

Natural sandstone is an extremely hard and tough material. The hardness of sandstone varies according to the character of the cementing material; quartz sandstones cemented with quartz are the hardest. Varieties of sandstone include arkose, which contains feldspar and resembles granite, and graywacke, a gray or sometimes greenish or black rock composed of quartz and fledspar with numerous fragments of other rocks, such as shale, slate, quartzite, granite, and basalt. Sandstone may be crushed to the form of loose sand grains, which can then be put to the same industrial uses as sand. See brownstone.

**Uses:** Sandstones are widely used in construction and industry. Because of their abundance, diversity, and mineralogy, sandstones are also important to geologists as indicators of erosional and depositional processes. Some sandstones are resistant to weathering, yet are easy to work. This makes sandstone a common building and paving material. Because of the hardness of the individual grains, uniformity of grain size and friability of their structure, some types of sandstone are excellent materials for making grindstones, sharpening blades and other implements. Non-friable sandstone can be used to make grindstones for grinding grain, e.g., gritstone.

Rock formations that are primarily composed of sandstone usually allow percolation of water and other fluids and are porous enough to store large quantities, making them valuable aquifers and petroleum reservoirs. Fine-grained aquifers, such as sandstones, are more apt to filter out pollutants from the surface than are rocks with cracks and crevices, such as limestone or other rocks fractured by seismic activity.

## Origins

Sand from Coral Pink Sand Dunes State Park, Utah. These are grains of quartz with a hematite coating providing the orange color. Scale bar is 1.0 mm.

Millet-Seed sandstone macro (size: ~4 cm or ~1.6 in).

Sandstones are *clastic* in origin (as opposed to either *organic*, like chalk and coal, or *chemical*, like gypsum and jasper).[2] They are formed from cemented grains that may either be fragments of a pre-existing rock or be mono-minerallic crystals. The cements binding these grains together are typically calcite, clays and silica. Grain sizes in sands are defined (in geology) within the range of 0.0625 mm to 2 mm (0.002-0.079 inches). Clays and sediments with smaller grain sizes not visible with the naked eye, including siltstones and shales, are typically called *argillaceous* sediments; rocks with larger grain sizes, including breccias and conglomerates are termed *rudaceous* sediments.

Red sandstone interior of Lower Antelope Canyon, Arizona, worn smooth by erosion from flash flooding over millions of years.

The formation of sandstone involves two principal stages. First, a layer or layers of sand accumulates as the result of sedimentation, either from water (as in a river, lake, or sea) or from air (as in a desert). Typically, sedimentation occurs by the sand settling out from suspension; i.e., ceasing to be rolled or bounced along the bottom of a body of water (e.g., seas or rivers) or ground surface (e.g., in a desert or erg). Finally, once it has accumulated, the sand becomes sandstone when it is compacted by pressure of overlying deposits and cemented by the precipitation of minerals within the pore spaces between sand grains.

The most common cementing materials are silica and calcium carbonate, which are often derived either from dissolution or from alteration of the sand after it was buried. Colors will usually be tan or yellow (from a blend of the clear quartz with the dark amber feldspar content of the sand). A predominant additional colorant in the southwestern United States is iron oxide, which imparts reddish tints ranging from pink to dark red (terracotta), with additional manganese imparting a purplish hue. Red sandstones are also seen in the Southwest and West of England and Wales, as well as central Europe and Mongolia. The regularity of the latter favors use as a source for masonry, either as a primary building material or as a facing stone, over other construction.

The environment where it is deposited is crucial in determining the characteristics of the resulting sandstone, which, in finer detail, include its *grain size*, *sorting* and *composition* and, in more general detail, include the rock geometry and sedimentary structures. Principal environments of deposition may be split between terrestrial and marine, as illustrated by the following broad groupings:

- Terrestrial environments

Sandstone near Stadtroda, Germany.

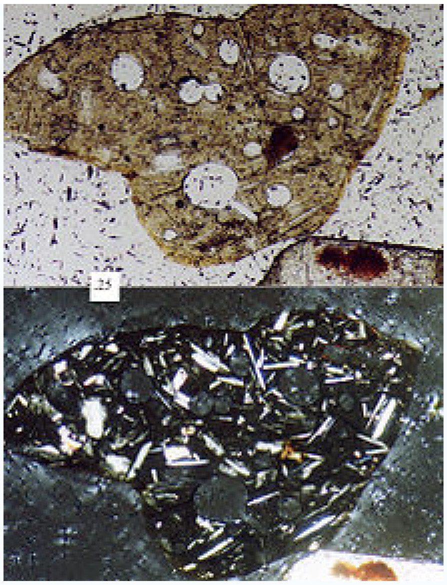
1. Rivers (levees, point bars, channel sands)
2. Alluvial fans
3. Glacial outwash
4. Lakes
5. Deserts (sand dunes and ergs)

- Marine environments

1. Deltas
2. Beach and shoreface sands
3. Tidal flats
4. Offshore bars and sand waves
5. Storm deposits (tempestites)
6. Turbidites (submarine channels and fans)

# Types

Sandstone composed mainly of quartz grains



Photomicrograph of a volcanic sand grain; upper picture is plane-polarized light, bottom picture is cross-polarized light, scale box at left-center is 0.25 millimeter. This type of grain would be a main component of a lithic sandstone.

Sandstones fall into several major groups based on their mineralogy and texture. Below is a partial list of common sandstone types.

- quartz arenites are made up almost entirely of quartz grains, usually well sorted and rounded. These pure quartz sands result from extensive weathering that occurred before and during transport and removed everything but quartz, the most stable mineral. They are common in beach environments.
- arkoses are more than 25 percent feldspar.[2] The grains tend to be poorly rounded and less well sorted than those of pure quartz sandstones. These feldspar-rich sandstones come from rapidly eroding granitic and metamorphic terrains where chemical weathering is subordinate to physical weathering.
- lithic sandstones contain many lithic fragments derived from fine-grained rocks, mostly shales, volcanic rocks, and fine-grained metamorphic rocks.
- graywacke is a heterogeneous mixture of lithic fragments and angular grains of quartz and feldspar, and/or grains surrounded by a fine-grained clay matrix. Much of this matrix is formed by relatively soft fragments, such as shale and some volcanic rocks, that are chemically altered and physically compacted after deep burial of the sandstone formation.
- Eolianite is a term used for a rock which is composed of sand grains that show signs of significant transportation by wind. These have usually been deposited in desert environments. They are commonly extremely well sorted and rich in quartz.
- Oolite is more a limestone than a sandstone, but is made of sand-sized carbonate ooids, and is common in saline beaches with gentle wave action.

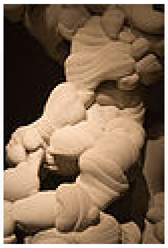
Sandstone composition is (generally) based on the make up of the framework, or sand-sized grains in the sandstone. This is typically done by point-counting a thin section of the sandstone using a method like the Gazzi-Dickinson Method. The composition of a sandstone can have important information regarding the genesis of the sediment when used with QFL diagrams.

According to the USGS, U.S. sandstone production in 2005 was 192,000 metric tons worth $24.3 million, the largest component of which was the 121,000 metric tons worth $9.75 million of flagstone or dimension stone.[3]

## Gallery

Sandstone with iron oxide bands

A sandstone quarry at Jodhpur, India



A natural sandstone formation composed of cemented quartz sand

Sandstone patterns on a chamber wall in Petra

Arbroath Abbey, showing distinctive sandstone coloring

Arches National Park Sandstone landscape

Sail Rock in Russia.

Sandstone formation, Eilat Massif, Israel

A modern residence with sandstone external veneer

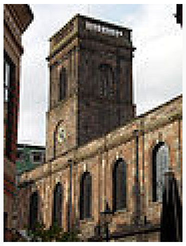
Fossil shells in sandstone

Sandstone-based building architecture, Hawa Mahal in Jaipur, India

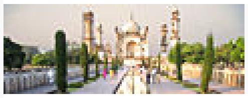
A sandstone building (with granite columns) in Sydney, Australia

Richmond Bridge, Sandstone, Australia

Berea sandstone Auglaize County courthouse in Wapakoneta, Ohio

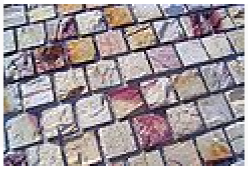


St Ann's Church, Manchester: Originally built in 1712 with Collyhurst sandstone, much of which has required repair or replacement.



Bibi Ka Maqbara: Known as the Poor Man's Taj Mahal, this tomb is made of sandstone except for the marble dome.

Outcrop of the Silurian Tuscarora Formation, Centre County, Pennsylvania, a ridge-forming sandstone in the Appalachian Mountains.



Sandstone pavers with iron oxide patterns mined from the Kimberley cover the large area of Federation Square in Melbourne.

Humayun's Tomb made with red sandstone, in 1571, Delhi, India

*Bete Giyorgis*, among many monolithic churches carved from red sandstone during the 12th and 13th centuries in Lalibela, Ethiopia.

Prepared sample of sandstone

# Shale

Shale is a fine-grained, clastic sedimentary rock composed of mud that is a mix of flakes of clay minerals and tiny fragments (silt-sized particles) of other minerals, especially quartz and calcite. The ratio of clay to other minerals is variable. Shale is characterized by breaks along thin laminae or parallel layering or bedding less than one centimeter in thickness, called fissility. Mudstones, on the other hand, are similar in composition but do not show the fissility.

Shale rock is a type of sedimentary rock formed from clay that is compacted together by pressure. They are used to make bricks and other material that is fired in a kiln.

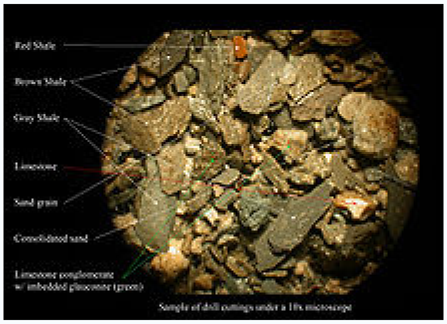
## Contents

## Historical mining terminology

Before the mid 19th century, the terms slate, shale and schist were not sharply distinguished. In the context of underground coal mining, shale was frequently referred to as slate well into the 20th century.

## Texture

Shale typically exhibits varying degrees of fissility breaking into thin layers, often splintery and usually parallel to the otherwise indistinguishable bedding plane because of parallel orientation of clay mineral flakes. Non-fissile rocks of similar composition but made of particles smaller than 0.06 mm are described as mudstones (1/3 to 2/3 silt particles) or claystone (less than 1/3 silt). Rocks with similar particle sizes but with less clay (greater than 2/3 silt) and therefore grittier are siltstones. Shale is the most common sedimentary rock.



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Sample of drill cuttings of shale while drilling an oil well in Louisiana. Sand grain = 2 mm. in dia.

## Composition and color

Shales are typically composed of variable amounts of clay minerals and quartz grains and the typical color is gray. Addition of variable amounts of minor constituents alters the color of the rock. Black shale results from the presence of greater than one percent carbonaceous material and indicates a reducing environment. Red, brown and green colors are indicative of ferric oxide (hematite - reds), iron hydroxide (goethite - browns and limonite - yellow), or micaceous minerals (chlorite, biotite and illite - greens).

Clays are the major constituent of shales and other mudrocks. The clay minerals represented are largely kaolinite, montmorillonite and illite. Clay minerals of Late Tertiary mudstones are expandable smectites whereas in older rocks especially in mid to early Paleozoic shales illites predominate. The transformation of smectite to illite produces silica, sodium, calcium, magnesium, iron and water. These released elements form authigenic quartz, chert, calcite, dolomite, ankerite, hematite and albite, all trace to minor (except quartz) minerals found in shales and other mudrocks.

Shales and mudrocks contain roughly 95 % of the organic matter in all sedimentary rocks. However, this amounts to less than one percent by mass in an average shale. Black shales which form in anoxic conditions contain reduced free carbon along with ferrous iron ($Fe^{2+}$) and sulfur ($S^{2-}$). Pyrite and amorphous iron sulfide along with carbon produce the black coloration.

## Formation

Limey shale overlaid by limestone, Cumberland Plateau, Tennessee

The process in the rock cycle which forms shale is compaction. The fine particles that compose shale can remain suspended in water long after the larger and denser particles of sand have deposited. Shales are typically deposited in very slow moving water and are often found in lakes and lagoonal deposits, in river deltas, on floodplains and offshore from beach sands. They can also be deposited on the continental shelf, in relatively deep, quiet water.

'Black shales' are dark, as a result of being especially rich in unoxidized carbon. Common in some Paleozoic and Mesozoic strata, black shales were deposited in anoxic, reducing environments, such as in stagnant water columns. Some black shales contain abundant heavy metals such as molybdenum, uranium, vanadium, and zinc. The enriched values are of controversial origin, having been alternatively attributed to input from hydrothermal fluids during or after sedimentation or to slow accumulation from sea water over long periods of sedimentation.

Fossils, animal tracks/burrows and even raindrop impact craters are sometimes preserved on shale bedding surfaces. Shales may also contain concretions consisting of pyrite, apatite, or various carbonate minerals.

Shales that are subject to heat and pressure of metamorphism alter into a hard, fissile, metamorphic rock known as slate. With continued increase in metamorphic grade the sequence is phyllite, then schist and finally to gneiss.

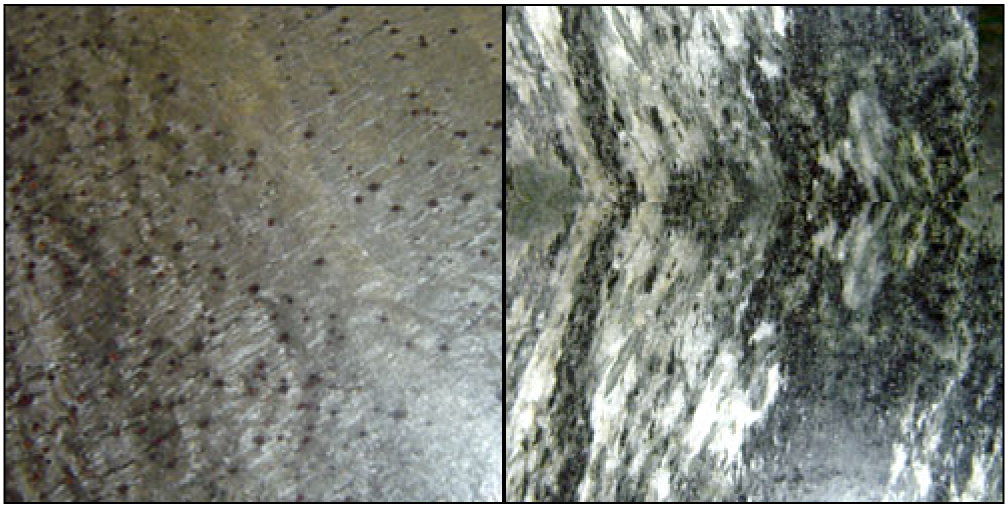
Weathering shale at a road cut in southeastern Kentucky

## See also

- Bituminous shale
- Oil shale
- Burgess shale
- Barnett Shale
- Bearpaw Shale
- Shale gas
- Shale gas in the United States
- Wianamatta shale
- Wheeler Shale

**Slate Stone Natural**

Fine grain  Slate from a quarry is hard weaving, impermeable, resistant to atmosphere pollution, frost, normal heat and rapid temperature charges.  Slate is charactrised as 'fairly hard. The hard-wearing waterproof and rot proof properties of Slate make it ideally suited for a whole host of external and internal features and application are virtually endless, being limited only by the designer's imagination. Floor used Slate are known wit a life in excess of several years, and they are still popular today. Fireplace surrounds and hearths, worktops, breakfast bare and internal fountains, wall facing, chimneys, barbecues, garden walls and steps, are just some of the ways in which our stone and slates have been and are being used.



**Limestone** is a sedimentary rock composed largely of the mineral calcite (calcium carbonate: $CaCO_3$) which came from the beds of evaporated seas and lakes and from sea animal shells. Like most other sedimentary rocks, limestones are composed of grains, however, around 80-90% of limestone grains are skeletal fragments of marine organisms such as coral or foraminifera. Other carbonate grains comprising limestones are ooids, peloids, intraclasts, and extraclasts. Some limestones do not consist of grains at all and are formed completely by the chemical precipitation of calcite or aragonite. i.e. travertine.

The solubility of limestone in water and weak acid solutions leads to karst landscapes. Regions overlying limestone bedrock tend to have fewer visible groundwater sources (ponds and streams), as surface water easily drains downward through joints in the limestone. While draining, water and organic acid from the soil slowly (over thousands or millions of years) enlarges these cracks; dissolving the calcium-carbonate and carrying it away in solution. Most cave systems are through limestone bedrock.

Some limestones may have been derived from non-biogenic calcite formation. Although some limestones can be nearly pure calcite, there is often a large amount or sand or silt that is included in the shelly debris.

# Contents

# 1. Description

Limestone often contains variable amounts of silica in the form of chert (aka chalcedony, flint, jasper, etc) or siliceous skeletal fragment (sponge spicules, diatoms, radiolarians), as well as varying amounts of clay, silt and sand sized terrestrial detritus carried in by rivers. The primary source of the calcite in limestone is most commonly marine organisms. These organisms secrete shells made of aragonite or calcite and leave these shells behind after the organism dies. Some of these organisms can construct mounds of rock known as reefs, building upon past generations. Below about 3,000 meters, water pressure and temperature causes the dissolution of calcite to increase non-linearly so that limestone typically does not form in deeper waters (see lysocline). Secondary calcite may also be deposited by supersaturated meteoric waters (groundwater that precipitates the material in caves). This produces speleothems such as stalagmites and stalactites.

Another form taken by calcite is that of oolites (oolitic limestone) which can be recognized by its granular appearance.

Limestone makes up about 10% of the total volume of all sedimentary rocks.[1][2] Limestones may also form in both lacustrine and evaporite depositional environments.[3][4]

Calcite can be either dissolved by groundwater or precipitated by groundwater, depending on several factors including the water temperature, pH, and dissolved ion concentrations. Calcite exhibits an unusual characteristic called retrograde solubility in which it becomes less soluble in water as the temperature increases.

When conditions are right for precipitation, calcite forms mineral coatings that cement the existing rock grains together or it can fill fractures.

Karst topography and caves develop in carbonate rocks due to their solubility in dilute acidic groundwater. Cooling groundwater or mixing of different groundwaters will also create conditions suitable for cave formation.

Coastal limestones are often eroded by organisms which bore into the rock by various means. This process is known as bioerosion. It is most common in the tropics, and it is known throughout the fossil record (see Taylor and Wilson, 2003).

Because of impurities, such as clay, sand, organic remains, iron oxide and other materials, many limestones exhibit different colors, especially on weathered surfaces. Limestone may be crystalline, clastic, granular, or massive, depending on the method of formation. Crystals of calcite, quartz, dolomite or barite may line small cavities in the rock. Folk and Dunham classifications are used to describe limestones more precisely.

Travertine is a banded, compact variety of limestone formed along streams, particularly where there are waterfalls and around hot or cold springs. Calcium carbonate is deposited where evaporation of the water leaves a solution that is supersaturated with chemical constituents of calcite. Tufa, a porous or cellular variety of travertine, is found near waterfalls. Coquina is a poorly consolidated limestone composed of pieces of coral or shells.

During regional metamorphism that occurs during the mountain building process (orogeny) limestone recrystallizes into marble.

Limestone is a parent material of Mollisol soil group.

Limestones form usually close to the source of shelly debris although some significant transport can occur. Great sources for limestone are reefs. Reefs have been in existence for most of the history of life on Earth, but they have changed in the species that build them.

All the carbonate shelled organisms needed the same requirements out of their ocean environments: sunlight, a food source, and enough turbulence to remove sand and clay. Reefs tend to be offshore from sandy beaches but not in too deep of water to not have sunlight. In fact reefs often build upon the skeletal debris of former reef inhabitants to continually grow upward to the sea surface where turbulence keeps the reef "clean" from sand and clay debris.

The rock coquina is a variety of limestone - composed entirely of fragments of sea shells.

But most limestones have a significant amount of carbonate mud. This mud matrix can even constitute 100% of the limestone rock. Origins of this mud are debated and may just be a fine grained mud left from the erosion and abrasion of calcite shells. There maybe a non-biogenic origin too. At times modern carbonate muds can accumulate in the oceans in thick layers that are destined for limestone formation. A limestone variety is caused by swift currents that rolled carbonate mud into small beads that (once solidified) look like tiny eggs. This limestone variety is called an oolite and is sometimes very ornamental.

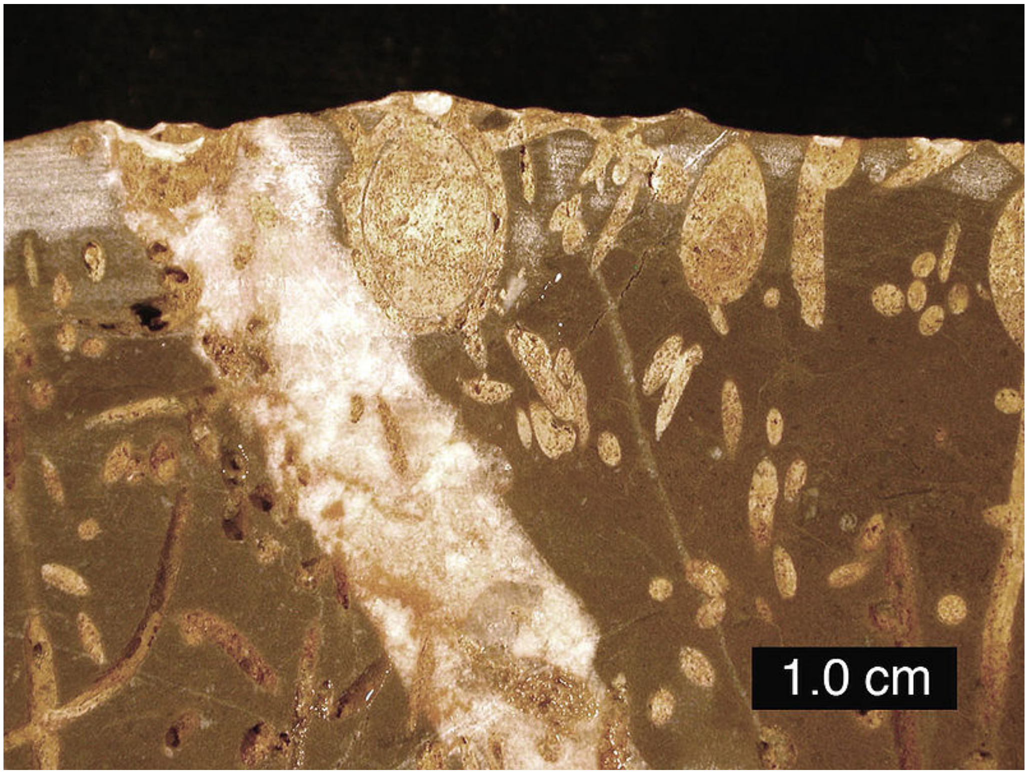
Metamorphosed, fairly pure limestone forms the metamorphic rock, marble.  During the metamorphic process, the crystals of fine grained calcite in the limestone become merged and melded into other large crystals forming the interlocking course grained texture of the marble.  All limestones under go some kind of alteration after initial solidification.  These alterations can include dolomitization, recrystalization, styolitization, compaction, cementation and exsolution to name a few.  All of these things are considered part of the diagenetic process.  Diagenesis is anything that happens to a sedimentary rock after original deposition.  At some point diagenesis and metamorphism meet and the stone is no longer a limestone, but a marble.

## 2. Types

Limestone cropping at São Pedro de Moel beach, Marinha Grande, Portugal

| **Composition** |
|---|
| Calcium carbonate: inorganic crystalline calcite and/or organic calcareous material. |

Portland Admiralty Roach from a quarry face on the Isle of Portland, Dorset, England.



Cross-section of a Carboniferous limestone bored by Jurassic organisms (bivalves and *Trypanites),* Mendip Hills, England;

Coquina from Florida.

## 3. Limestone landscape

*Karst topography*

*The Cudgel of Hercules*, a tall limestone rock and Pieskowa Skała Castle in the background.

Limestone is partially soluble, especially in acid, and therefore forms many erosional landforms. These include limestone pavements, pot holes, cenotes, caves and gorges. Such erosion landscapes are known as karsts. Limestone is less resistant than most igneous rocks, but more resistant than most other sedimentary rocks. Limestone is therefore usually associated with hills and downland and occurs in regions with other sedimentary rocks, typically clays.

Bands of limestone emerge from the Earth's surface in often spectacular rocky outcrops and islands. Examples include the Burren in Co. Clare, Ireland; the Verdon Gorge in France; Malham Cove in North Yorkshire and the Isle of Wight[5], England; on Fårö near the Swedish island of Gotland, the Niagara Escarpment in Canada/United States, Notch Peak in Utah, the Ha Long Bay National Park in Vietnam and the hills around the Lijiang River and Guilin city in China.

The Florida Keys, islands off the south coast of Florida, are composed mainly of oolitic limestone (the Lower Keys) and the carbonate skeletons of coral reefs (the Upper Keys), which thrived in the area during interglacial periods when sea level was higher than at present.

Unique habitats are found on alvars, extremely level expanses of limestone with thin soil mantles. The largest such expanse in Europe is the Stora Alvaret on the island of Öland, Sweden. Another area with large quantities of limestone is the island of Gotland, Sweden. Huge quarries in northwestern Europe, such as those of Mount Saint Peter (Belgium/Netherlands), extend for more than a hundred kilometers.

The world's largest limestone quarry is at Michigan Limestone and Chemical Company in Rogers City, Michigan.[6]

# Uses of limestone

- The manufacture of quicklime (calcium oxide) and slaked lime (calcium hydroxide);
- Cement and mortar;
- Pulverized limestone is used as a soil conditioner to neutralize acidic soil conditions;
- Crushed for use as aggregate—the solid base for many roads;
- Geological formations of limestone are among the best petroleum reservoirs;
- As a reagent in flue gas desulfurization (sulfur dioxide air pollution control);
- Glass making, in some circumstances;
- Added to paper, plastics, paint, tiles, and other materials as both white pigment and a cheap filler.
- Toothpaste
- Suppression of methane explosions in underground coal mines
- Added to bread and cereals as a source of calcium
- Calcium supplement for poultry (when ground up)
- Remineralizing and increasing the alkalinity of purified water to prevent pipe corrosion and to return essential nutrients
- Used in blast furnaces to extract iron from its ore
- Medicines
- Cosmetics
- Art (sculptures)

- This rock is used in concrete and is an excellent building stone for humid regions.

## Other uses of limestone

Limestone is very common in architecture, especially in North America and Europe. Many landmarks across the world, including the Great Pyramid and its associated Complex in Giza, Egypt, are made of limestone. So many buildings in Kingston, Canada were constructed from it that it is nicknamed the 'Limestone City'. On the island of Malta, a variety of limestone called Globigerina limestone was for a long time the only building material available, and is still very frequently used on all types of buildings and sculptures. Limestone is readily available and relatively easy to cut into blocks or more elaborate carving. It is also long-lasting and stands up well to exposure. However, it is a very heavy material, making it impractical for tall buildings, and relatively expensive as a building material.

The Great Pyramid of Giza. One of the Seven Wonders of the Ancient World, the structure is made entirely from limestone.

Courthouse built of limestone in Manhattan, Kansas

A limestone plate with a negative map of Moosburg in Bavaria is prepared for a lithography print

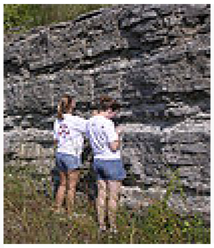
Limestone was most popular in the late 19th and early 20th centuries. Train stations, banks and other structures from that era are normally made of limestone. Limestone is used as a facade on some skyscrapers, but only in thin plates for covering rather than solid blocks. In the United States, Indiana, most notably the Bloomington area, has long been a source of high quality quarried limestone, called Indiana limestone. Many famous buildings in London are built from Portland limestone.

Limestone was also a very popular building block in the Middle Ages in the areas where it occurred since it is hard, is durable, and commonly occurs in easily accessible surface exposures. Many medieval churches and castles in Europe are made of limestone. Beer stone was a popular kind of limestone for medieval buildings in southern England.

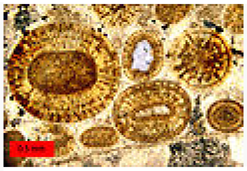
Limestone and (to a lesser extent) marble are reactive to acid solutions, making acid rain a significant problem to the preservation of artifacts made from this stone. Many limestone statues and building surfaces have suffered severe damage due to acid rain. Acid-based cleaning chemicals can also etch limestone, which should only be cleaned with a neutral or mild alkaline-based cleaner.

## Gallery

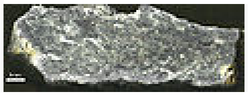
Limestone in Waitomo District, New Zealand.



A stratigraphic section of Ordovician limestone exposed in central Tennessee, U.S. The less-resistant and thinner beds



Thin-section view of a Middle Jurassic limestone in southern Utah. The round grains are ooids; the largest is 1.2 mm in diameter. This limestone is an oosparite.



Etched section of a sample of fossiliferous limestone from the Kope Formation near Cincinnati, Ohio.

are composed of shale. Vertical lines are drill holes for explosives used during road construction.

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**Karst topography** is a landscape shaped by the dissolution of a layer or layers of soluble bedrock, usually carbonate rock such as limestone or dolomite.

Due to subterranean drainage, there may be very limited surface water, even to the absence of all rivers and lakes. Many karst regions display distinctive surface features, with sinkholes or dolines being the most common. However, distinctive karst surface features may be completely absent where the soluble rock is mantled, such as by glacial debris, or confined by a superimposed non-soluble rock strata. Some karst regions include thousands of caves, even though evidence of caves that are big enough for human exploration is not a required characteristic of karst.

# Background

Karst topography is characterized by subterranean limestone caverns, carved by groundwater. The geographer Jovan Cvijić (1865–1927) of western Serbia, studied widely in the Dinaric Kras region. His publication of *Das Karstphänomen* (1893) established that rock dissolution was the key process and that it created most types of dolines - the diagnostic karst landforms. The Dinaric Kras thus became the type area for dissolutional landforms and aquifers; the regional name *kras*, Germanicised as "karst", is now applied to modern and paleo-dissolutional phenomena worldwide. Cvijić related the complex behaviour of karstic aquifers to development of solutional conduit networks and linked it to a cycle of landform evolution. After Cvijić, two main kinds of karstic areas exist: **holokarst** i.e. karst developed at whole as it is Dinaric region along eastern Adriatic coast comprises deep in the inland of Balkan Peninsula and **merokarst** developed imperfectly with some karstic forms as it is in eastern Serbia. He is recognized as "the father of karst geomorphology".

Different terms for karst topography exist in other languages—for example, *yanrong* in Chinese and *tsingy* in Malagasy. The international community has settled on *karst*, the German name for Kras, a region in Slovenia partially extending into Italy, where it is called "Carso" and where the first scientific research of a karst topography was made. The name has an Indo-European origin (from *karra* meaning "stone"), and in antiquity it was called "Carusardius" in Latin. The Slovene form *grast* is attested since 1177, and the Croatian *kras* since 1230.

A karst landscape in Minerve, Hérault, France.

The karst hills of The Burren on the west coast of Ireland

# Chemistry

Karst lake (Doberdò del Lago, Italy), from underground water springing into a depression. This lake has no surface inlet or outlet.

Karst landforms are generally the result of mildly acidic water acting on soluble bedrock such as limestone or dolostone. The carbonic acid that causes these features is formed as rain passes through the atmosphere picking up $CO_2$, which dissolves in the water. Once the rain reaches the ground, it may pass through soil that may provide further $CO_2$ to form a weak carbonic acid solution: $H_2O + CO_2 \rightarrow H_2CO_3$ (the acid). Recent studies of sulfates, in karst waters, suggests sulfuric acid and hydrosulfuric acid may also play an important role in karst formation.

This mildly acidic water begins to dissolve the surface along with any fractures or bedding planes in the limestone bedrock. Over time, these fractures enlarge as the bedrock continues to dissolve. Openings in the rock increase in size, and an underground drainage system begins to develop, allowing more water to pass through the area, and accelerating the formation of underground karst features.

Somewhat less common than this limestone karst is gypsum karst, where the solubility of the mineral gypsum provides many similar structures to the dissolution and redeposition of calcium carbonate.

# Formations

Limestone pavement in Dent de Crolles, France

The karstification of a landscape may result in a variety of large or small scale features both on the surface and beneath. On exposed surfaces, small features may include flutes, runnels, clints and grikes, collectively called karren or lapiez. Medium-sized surface features may include sinkholes or cenotes (closed basins), vertical shafts, foibe (inverted funnel shaped sinkholes), disappearing streams, and reappearing springs. Large-scale features may include limestone pavements, poljes and blind valleys. Mature karst landscapes, where more bedrock has been removed than remains, may result in karst towers, or haystack/eggbox landscapes. Beneath the surface, complex underground drainage systems (such as karst aquifers) and extensive caves and cavern systems may form.

The Witch's Finger stalagmite in Carlsbad Caverns, USA

Erosion along limestone shores, notably in the tropics, produces karst topography that includes a sharp makatea surface above the normal reach of the sea and undercuts that are mostly the result of biological activity or bioerosion at or a little above mean sea level. Some of the most dramatic of these formations can be seen in Thailand's Phangnga Bay and Halong Bay in Vietnam.

Calcium carbonate dissolved into water may precipitate out where the water discharges some of its dissolved carbon dioxide. Rivers which emerge from springs may produce tufa terraces, consisting of layers of calcite deposited over extended periods of time. In caves, a variety of features collectively called speleothems are formed by deposition of calcium carbonate and other dissolved minerals.

# Hydrology

A karst spring in the Jura mountains near Ouhans in eastern France at the source of the river Loue

Farming in karst areas must take into account the lack of surface water. The soils may be fertile enough, and rainfall may be adequate, but rainwater quickly moves through the crevices into the ground, sometimes leaving the surface soil parched between rains.

A karst fenster is where an underground stream emerges onto the surface between layers of rock, cascades some feet, and then disappears back down, often into a sinkhole. Rivers in karst areas may disappear underground a number of times and spring up again in different places, usually under a different name (like Ljubljanica, the river of seven names). An example of this is the Popo Agie River in Fremont County, Wyoming. Simply named "The Sinks" and Sinks Canyon State Park, the river flows into a cave in a formation known as the Madison Limestone, and then rises again a half-mile down the canyon in a placid pool. A Turlach is a unique type of season lake found in Irish karst areas which are formed through the annual welling-up of water from the underground water system.

Water supplies from wells in karst topography may be unsafe, as the water may have run unimpeded from a sinkhole in a cattle pasture, through a cave and to the well, bypassing the normal filtering that occurs in a porous aquifer. Karst formations are cavernous and therefore have high rates of permeability, resulting in reduced opportunity for contaminants to be filtered out.

Groundwater in karst areas is just as easily polluted as surface streams. Sinkholes have often been used as farmstead or community trash dumps. Overloaded or malfunctioning septic tanks in karst landscapes may dump raw sewage directly into underground channels.

The karst topography itself also poses difficulties for human inhabitants. Sinkholes can develop gradually as surface openings enlarge, but quite often progressive erosion is unseen and the roof of an underground cavern suddenly collapses. Such events have swallowed homes, cattle, cars, and farm machinery.

The Driftless Area National Wildlife Refuge in Iowa protects *Discus macclintocki*, a species of ice age snail surviving in air chilled by flowing over buried karst ice formations.

## Pseudokarst

Pseudokarsts are similar in form or appearance to karst features, but are created by different mechanisms. Examples include lava caves and granite tors—for example, Labertouche Cave in Victoria, Australia and paleocollapse features.

## Notable karst areas

Various karst landforms have been found on all continents except Antarctica. Notable karst areas are:

**Madagascar**

- Anjajavy Forest, western Madagascar
- Ankarana Reserve, Madagascar
- Madagascar dry deciduous forests, western Madagascar
- Tsingy de Bemaraha Strict Nature Reserve, Madagascar

### Asia

**Poland**

- Polish Jura Chain (Jura Krakowsko-Częstochowska)
- Holy Cross Mountains (Góry Świętokrzyskie) with the Jaskinia Raj
- Tatra Mountains including the Jaskinia Wielka Śnieżna (Great Snowy Cave)—the longest cave in Poland

**Romania**

- Apuseni Mountains, Romania

**Serbia**

Phong Nha Cave in Phong Nha-Ke Bang, Vietnam

**China**

- Area around Guilin and Yangshuo
- Jiuzhaigou and Huanglong National Park, (UNESCO World Heritage Site)
- South China Karst, World Heritage Site
- Stone Forest
- Zhangjiajie National Forest park, forming part of the Wulingyuan scenic area, World Heritage Site

**Georgia**

- Arabika Massif (including Voronya Cave—the world's deepest cave), Abkhazia, Georgia

**Indonesia**

- Bantimurung, Indonesia
- Gunung Sewu, Indonesia

**Israel**

- Ofra region, Israel
- Dinaric Alps region
- merokarst of eastern Serbia

**Scotland**

- Assynt, southeast Skye and near Kentallen in Scotland, United Kingdom

**Slovakia**

- Slovak Paradise, Slovak Karst and Muránska planina, Slovakia

**Slovenia**

- Region of Inner Carniola, Goriška, Upper Carniola and Lower Carniola
- Kras (German: *Karst*), a plateau in southwestern Slovenia and northeastern Italy

**Spain**

El Torcal (Antequera - Spain)

- Picos de Europa and Basque mountains, northern Spain
- Larra-Belagua, Navarre, northern Spain
- Cadí mountain range, Spain
- Garraf Natural Park area, Spain

**Japan**

- Akiyoshi Plateau, Japan
- Atetsudai and Taishakudai Plateaus, Japan
- Shikoku Karst, Japan
- Hiraodai Plateau, Japan
- Okinoerabujima Island and other islets of Nansei Islands, Japan

**Laos**

- Vang Vieng, Laos

**Lebanon**

Dunnieh mountains, North Lebanon

- Jeita Grotto, Lebanon
- Parts of Mount Lebanon

**Malaysia**

- Gunung Mulu National Park, Malaysia
- Kilim Karst Geoforest Park, Langkawi, Malaysia
- Kinta Valley, Perak, Malaysia
- Perlis State Park, Perlis, Malaysia
- Batu Caves, Selangor, Malaysia

**Philippines**

- El Nido, Palawan, Philippines
- Coron, Palawan, Philippines
- Sagada, Mountain Province, Philippines
- Chocolate Hills, Bohol, Philippines

- Ciudad Encantada in the Cuenca province, Castilla-La Mancha
- El Torcal de Antequera nature preserve, southern Spain

**Switzerland**

- Karst and Caves of Switzerland
- 7,900 square kilometres (3,100 sq mi), or 19% of the surface of Switzerland, is karst.
- Within this area lies the majority of the 7,500 currently known Swiss caves, with an accumulated passage length of more than 1,200 kilometres (750 mi).

**Ukraine**

- Podolia and Bukovina regions in the northeastern edge of the Carpathian Mountains.
- Includes some of the largest gypsum karst caves in the world, including the Optymistychna Cave Cave, which is over 200,000 meters in length, making it the longest cave in Eurasia, the third longest in the world, and the longest gypsum cave in the world.

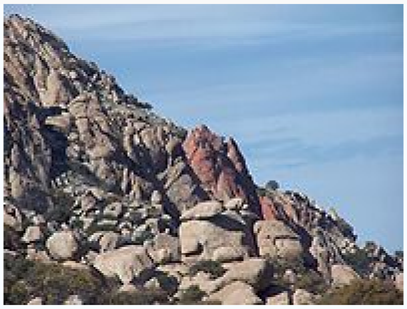
**Wales**

- Southern region of the Brecon Beacons National Park, Wales, United Kingdom

## North America

**Canada**

- Marble Canyon, British Columbia
- Monkman Provincial Park, British Columbia
- Northern Vancouver Island, British Columbia
- Niagara Escarpment, Ontario
- Port au Port Peninsula, Newfoundland
- Nahanni region in the Northwest

| | |
|---|---|
| - Negros and Gigante Islands, Negros Oriental, Philippines<br>- Virac, Catanduanes, Philippines<br>- | Territories<br>- Wood Buffalo National Park in Alberta and the Northwest Territories<br>- Avon Peninsula, Nova Scotia<br><br>- |

**Dolomite**

Dolomite is the name of a sedimentary carbonate rock and a mineral, both composed of calcium magnesium carbonate $CaMg(CO_3)_2$ found in crystals.

Dolomite rock (also dolostone) is composed predominantly of the mineral dolomite. Limestone that is partially replaced by dolomite is referred to as dolomitic limestone, or in old U.S. geologic literature as *magnesian limestone*. Dolomite was first described in 1791 as the rock by the French naturalist and geologist, Déodat Gratet de Dolomieu (1750–1801) for exposures in the Dolomite Alps of northern Italy.

| | |
|---|---|
| **Chemistry** | CaMg(CO3)2 |
| **Uses** | As an ingredient in cement and also as a mineral specimen |
| **Color** | Color is often pink or pinkish and can be colorless, white, yellow, gray or even brown |
| **Hardness** | 4.5-5 |
| **Specific gravity** | 2.85 |

Dolomite rock, also sometimes called dolostone, is usually a former limestone in which the mineral calcite is altered to dolomite.

Dolomite is very significant in the petroleum business because it forms underground by the alteration of calcite limestone. This chemical change is marked by a reduction in volume and by recrystallization, which combine to produce open space (porosity) in the rock strata. Porosity creates avenues for oil to travel and reservoirs for oil to collect. Naturally, this alteration of limestone is called dolomitization, and the reverse alteration is called dedolomitization. Both are still somewhat mysterious problems in sedimentary geology.

## Properties

The mineral dolomite crystallizes in the trigonal-rhombohedral system. It forms white, gray to pink, commonly curved crystals, although it is usually massive. It has physical properties similar to those of the mineral calcite, but does not rapidly dissolve or effervesce (fizz) in dilute hydrochloric acid unless it is scratched or in powdered form. The Mohs hardness is 3.5 to 4 and the specific gravity is 2.85. Refractive index values are $n_\omega = 1.679 - 1.681$ and $n_\varepsilon = 1.500$. Crystal twinning is common. A solid solution series exists between dolomite and iron rich ankerite. Small amounts of iron in the structure give the crystals a yellow to brown tint. Manganese substitutes in the structure also up to about three percent MnO. A high manganese content gives the crystals a rosy pink color noted in the image above. A series with the manganese rich kutnohorite may exist. Lead and zinc also substitute in the structure for magnesium.

## Formation

Dolomite bedrock underneath a Bristlecone Pine, White Mountains, California.

Vast deposits are present in the geological record, but the mineral is relatively rare in modern environments. Laboratory synthesis of stoichiometric dolomite has been carried out only at temperatures of greater than 100 degrees Celsius (conditions typical of burial in sedimentary basins), even though much dolomite in the rock record appears to have formed in low-temperature conditions. The high temperature is likely to speed up the movement of calcium and magnesium ions so that they can find their places in the ordered structure within a reasonable amount of time. This suggests that the lack of dolomite that is being formed today is likely due to kinematic factors.[*clarification needed*]

Modern dolomite does occur as a precipitating mineral in specialized environments on the surface of the earth today. In the 1950s and 60s, dolomite was found to be forming in highly saline lakes in the Coorong region of South Australia. Dolomite crystals also occur in deep-sea sediments, where organic matter content is high. This dolomite is termed "organogenic" dolomite.

Recent research has found modern dolomite formation under anaerobic conditions in supersaturated saline lagoons along the Rio de Janeiro coast of Brazil, namely, Lagoa Vermelha and Brejo do Espinho. One interesting reported case was the formation of dolomite in the kidneys of a Dalmatian dog.[*citation needed*] This was believed to be due to chemical processes triggered by bacteria. Dolomite has been speculated to develop under these conditions with the help of sulfate-reducing bacteria.[*citation needed*]

The actual role of bacteria in the low-temperature formation of dolomite remains to be demonstrated. The specific mechanism of dolomitization, involving sulfate-reducing bacteria, has not yet been demonstrated.[5]

Dolomite appears to form in many different types of environment and can have varying structural, textural and chemical characteristics. Some researchers have stated "there are dolomites and dolomites", meaning that there may not be one single mechanism by which dolomite can form. Much modern dolomite differs significantly from the bulk of the dolomite found in the rock record, leading researchers to speculate that environments where dolomite formed in the geologic past differ significantly from those where it forms today.

Reproducible laboratory syntheses of dolomite (and magnesite) leads first to the initial precipitation of a metastable "precursor" (such as magnesium calcite), to be changed gradually into more and more of the stable phase (such as dolomite or magnesite) during periodical intervals of dissolution and reprecipitation. The general principle governing the course of this irreversible geochemical reaction has been coined Ostwald's step rule.

For a very long time scientists had difficulties synthesizing dolomite. However, in a 1999 study, through a process of dissolution alternating with intervals of precipitation, measurable levels of dolomite were synthesized at low temperatures and pressures.[6]

### Coral atolls

Dolomitization of calcite also occurs at certain depths of coral atolls where water is undersaturated in calcium carbonate but saturated in dolomite. Convection created by tides and sea currents enhance this change. Hydrothermal currents created by volcanoes under the atoll may also play an important role.

### Uses

Dolomite is used as an ornamental stone, a concrete aggregate, a source of magnesium oxide and in the Pidgeon process for the production of magnesium. It is an important petroleum reservoir rock, and serves as the host rock for large strata-bound Mississippi Valley-Type (MVT) ore deposits of base metals (that is, readily oxidized metals) such as lead, zinc, and copper. Where calcite limestone is uncommon or too costly, dolomite is sometime used in its place as a flux (impurity remover) for the smelting of iron and steel. Large quantities of processed dolomite are used in the production of float glass (flat glass).

In horticulture, dolomite and dolomitic limestone are added to soils and soilless potting mixes to lower their acidity ("sweeten" them) and as a magnesium source. Home and container gardening are common examples of this use.

### See also

- List of minerals
- Evaporite

## Laboratory 5

# Sedimentary Structures Laboratory

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**See newer version of this page at**
**http://facstaff.gpc.edu/~pgore/geology/historical_lab/sedstructureslab.pdf**

In this lab you will learn to recognize and identify sedimentary structures. Primary sedimentary structures are those which form during (or shortly after) deposition of the sediment. Some sedimentary structures are created by the water or wind which moves the sediment. Other sedimentary structures form after deposition - such as footprints, worm trails, or mudcracks. Primary sedimentary structures can provide information about the environmental conditions under which the sediment was deposited; certain structures form in quiet water under low energy conditions, whereas others form in moving water or high energy conditions.

# TYPES OF PRIMARY SEDIMENTARY STRUCTURES

## I. INORGANIC SEDIMENTARY STRUCTURES

A. **Bed forms and surface markings** These are features which form on the surface of a bed of sediment. At the time of formation, the "surface of a bed" is equivalent to the sea floor, or the bottom of a lake or river, for example. In a sequence of sedimentary rock, bed forms and surface markings are found on bedding planes.

   1. **Ripples** are undulations of the sediment surface produced as wind or water moves across sand. Ripples which form in *unidirectional currents* (such as in streams or rivers) tend to be **asymmetrical**. Crests of asymmetrical ripples may be straight, sinuous, or lobe-like, depending on water velocity. Asymmetrical ripples have a steep slope on the downstream side, and a gentle slope on the upstream side. Because of this unique geometry, asymmetrical ripples in the rock record may be used to determine ancient current directions or paleocurrent directions. In *waves or oscillating water*, **symmetrical ripples** are produced. Crests of symmetrical ripples tend to be relatively straight, but may bifurcate (or fork).

*Asymmetrical ripples and cross-bedding*

*Symmetrical wave ripples and wave ripple cross-stratification*

*Symmetrical wave ripples*
*and wave-ripple cross-stratification in*
*Triassic lakebeds from the Culpeper Basin, Virginia*

*Asymmetrical ripples on a beach in Australia*

Interactions between waves and currents may produce a more complex pattern of **interference ripples**.

*Interference ripples on the Georgia coast; south end of Jekyll Island. These ripples are produced by the interaction of waves and currents in the ridge and runnel system at the beach.*

*Interference ripples in Paleozoic rocks in the Appalachian Valley and Ridge Province of northwestern Georgia*

2. **Mudcracks** are a polygonal pattern of cracks produced on the surface of mud as it dries. The mud polygons between the cracks may be broken up later by water movement, and redeposited as intraclasts (particularly in lime muds).

MUDCRACKS

*Recent mudcracks in a quarry near Frederick, Maryland*

*Triassic mudcracks in a quarry in Culpeper, Virginia*

3. Raindrop prints are circular pits on the sediment surface produced by the impact of raindrops on soft mud.

RAINDROP PRINTS

B. **Internal bedding structures**

These are sedimentary structures which are best seen looking at a side view of a sedimentary rock or sequence of sedimentary rocks.

1. **Stratification** (or layering) is the most obvious feature of sedimentary rocks. The layers (or strata) are visible because of differences in the color or texture of adjacent beds. Strata thicker than 1 cm are commonly referred to as **beds**. Thinner layers are called **laminations** or **laminae** . The upper and lower surfaces of these layers are called **bedding planes**.

*Laminations*

*Laminations on a beach,*
*St. Simons Island, Georgia*

*Stratification (also called bedding) in Paleozoic rocks*
*in the Red Mountain roadcut, Birmingham, Alabama*

   **Varves** are a special type of lamination which forms in glacial lakes. Varves represent deposition over one year, and their formation is related to seasonal influences. Varves are generally graded, with the coarser material at the bottom (silt or sand) representing the spring and summer meltwater runoff, and the finer material at the top representing slow settling of clays and organic matter from suspension during the winter months when the lake is covered with ice. Counting of varves in the geologic record has been used to measure the ages of some sedimentary deposits.

2. **Graded bedding** results when a sediment-laden current (such as a turbidity current) begins to slow down. The grain size within a graded bed ranges from coarser at the bottom to finer at the top. Hence, graded beds may be used as "up indicators".

*Graded bedding*

3. **Cross-stratification** is a general term for the internal bedding structure produced in sand by moving

wind or water. If the individual inclined layers are thicker than 1 cm, the cross-stratification may be referred to as **cross-bedding**. Thinner inclined layering is called **cross-lamination**. Cross-stratification forms beneath ripples and dunes. The layering is inclined at an angle to the horizontal, dipping downward in the downcurrent direction. Hence, cross-beds may be used as paleocurrent indicators, or indicators of ancient current flow directions. Cross-beds usually curve at the bottom edge, becoming tangent to the lower bed surface. The upper edge of individual inclined cross-beds is usually at a steep angle to the overlying bedding plane. Hence, cross-beds may also be used as "up indicators".

*Asymmetrical ripples and cross-bedding*

*Cross-stratification in a beach cut, Jekyll Island, Georgia*

*Cross-stratification in an outcrop of*
*upper Paleozoic rocks in Birmingham, Alabama*

Large scale cross-bedding in Triassic dune sands,
Bay of Fundy, Nova Scotia, Canada

C. **Sole marks**

**Sole marks** are bedding plane structures preserved on the bottom surfaces of beds. They generally result from the filling in of impressions made into the surface of soft mud by the scouring action of the current, or by the impacts of objects carried by the current. If sand is deposited later over the mud, filling in these structures, they will be preserved in relief on the bottom of the sandstone bed. (These structures are not usually seen on the surfaces of shale beds because they tend to weather away.)

1. **Tool marks** are produced as "tools" (objects such as sticks, shells, bones, or pebbles) carried by a current bounce, skip, roll, or drag along the sediment surface. They are commonly preserved on the lower surfaces of sandstone beds as thin ridges. Tool marks are generally aligned parallel to the direction of current movement.

TOOL MARKS

2. **Flute marks** are produced by erosion or scouring of muddy sediment, forming "scoop-shaped" depressions. They are commonly preserved as bulbous or mammilary natural casts on the bottoms of sandstone beds. Because of their geometry, flute marks (also called flute casts) can be used to determine paleocurrent directions.

FLUTE MARKS

## II. ORGANIC OR BIOGENIC SEDIMENTARY STRUCTURES

Organic or biogenic sedimentary structures are those which are formed by living organisms interacting with the sediment. The organisms may be animals which walk on or burrow into the sediment, or they may be plants with roots which penetrate the sediment, or they may be bacterial colonies which trap and bind the sediment to produce layered structures.

A. **Trace fossils or ichnofossils**

Trace fossils or ichnofossils include tracks, trails, burrows, borings, and other marks made in the sediment by organisms. They are **bioturbation structures** formed as the activities of organisms disrupt the sediment. As organisms tunnel through sediment, they destroy primary sedimentary structures (such as laminations) and produce burrow marks. Bioturbation continuing over a long period of time will thoroughly mix and homogenize the sediment. Through this process, a laminated sediment can be altered to a massive, homogeneous sediment with no readily discernable layering or other sedimentary structures.

1. **Tracks** or footprints are impressions on the surface of a bed of sediment produced by the feet of animals. Examples include dinosaur footprints or bird tracks. In some cases, tracks are found as sole marks on the bottoms of beds, where sediment has infilled the tracks, and preserved them as casts.

   A *line of tracks* showing the path along which an animal walked (as opposed to an isolated footprint) is called a **trackway**.

*Dinosaur tracks,*

*Dinosaur State Park,*
*Rocky Hill, Connecticut*

*Modern racoon trackway, North Carolina*

2. **Trails** are groove-like impressions on the surface of a bed of sediment produced by an organism which crawls or drags part of its body. Trails may be straight or curved.

*Trails*
*Climactichnites,*
*505 million years old, Late Cambrian,*
*New York*

3. **Burrows** are excavations made by animals into soft sediment. Burrows may be used by organisms for dwellings, or may be produced as a subterranean organism moves through the soil or sediment in search of food. Burrows are commonly filled in by sediment of a different color or texture than the surrounding sediment, and in some cases, the burrows may have an internally laminated backfilling. Burrow fillings may become cemented and hard, weathering out of the rock in rope-like patterns.

*Burrows in Triassic rocks,*
*Deep River Basin, North Carolina*

*Several types of burrows, including*
*branching, U-shaped, and vertical*

***Skolithos** worm burrows in quartzite. Cambrian Weverton Quartzite, Harpers Formation, or Antietam Formation.*
*Cross-stratification and laminations about 1 cm thick are present in some of the samples. Stream cobbles found in Henson Creek, Prince Georges County, Maryland.*
*Scale in centimeters and inches. Image courtesy of A. O'Neil.*

4. **Borings** are holes made by animals into hard material, such as wood, shells, rock, or hard sediment. Borings are ususlly circular in cross-section. Some snails are predators and produce borings or "drill holes" into other molluscs, such as clams, to eat them. Another mollusc, known as the "shipworm", drills holes into wood. Sponges also produce borings, commonly riddling shells with numerous small holes.
5. **Root marks** are the traces left by the roots of plants in ancient soil zones (called paleosols). Rootmarks typically branch downward in a pattern resembling an upside-down tree. Root marks are sometimes gray or greenish, penetrating reddish-brown paleosols. This contrast in color can make them easy to see and identify.

*Rootmarks in the Triassic Deep River Basin, North Carolina*

B. **Biostratification structures**

Biostratification structures are sedimentary layering produced through the activities of organisms. Stromatolites are the only type of biostratification structure we will study.

1. **Stromatolites** are mound-like structures formed by colonies of sediment-trapping cyanobacteria (commonly called blue-green algae). These organisms inhabit some carbonate tidal flats, and produce dome-like laminations in lime mud (fine-grained limestone or micrite). Stromatolites are "organo-sedimentary structures", and not fossils because they contain no recognizable anatomical features. Stromatolites form today in only a few places in the world, primarily in hypersaline environments (such as Shark Bay, Australia), and a few freshwater carbonate- precipitating lakes. In the geologic record, most stromatolites are found in Precambrian and lower Paleozoic limestones. The cyanobacteria which formed these stromatolites were photosynthetic, and they are therefore responsible for changing the character of the Earth's atmosphere from one dominated by carbon dioxide to one with significant quantities of free oxygen.

*Stromatolites,*
*Ordovician, western Maryland*

*Stromatolites*

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## DETERMINING "UP DIRECTION"

When you examine a sequence of beds which has been tectonically deformed and possibly overturned, it is necessary to determine the "*up direction*". This is done by studying the sedimentary structures for clues. Sedimentary structures such as graded beds, cross beds, mudcracks, flute marks, symmetrical (but not asymmetrical) ripples, stromatolites, burrows, tracks, and other structures can be used to establish the original orientation of the beds. (Fossils can also be used to establish up direction, if they are present in the rock in life position.) Carefully examine the sedimentary structures in any dipping sedimentary sequence, because the rocks can be *overturned* by tectonic forces, and what initially appears to be younger because it is on top, may in fact turn out to be at the bottom of the section!

*Illustration of overturned beds*.

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## Summary

The following list is a summary of the sedimentary structures mentioned in this lab:

**I. Inorganic sedimentary structures**

- A. Bedforms and surface markings
    - 1. Ripples
        - Asymmetrical ripples
        - Symmetrical ripples
        - Interference ripples
    - 2. Mudcracks
    - 3. Raindrop prints
- B. Internal bedding structures
    - 1. Stratification (strata)
        - Beds
        - Laminations or laminae
        - Varves
    - 2. Graded bedding

        3. Cross-stratification
            - Cross-bedding (cross-beds)
            - Cross-lamination

    C. Sole marks
        1. Tool marks
        2. Flute marks

## II. Organic or biogenic sedimentary structures

A. Trace fossils or ichnofossils
    1. Tracks
    2. Trackways
    3. Trails
    4. Burrows
    5. Bioturbation
    6. Borings
    7. Rootmarks

B. Biostratification structures
    - Stromatolites

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