Geology Laboratory: Sediments and Sedimentary Rocks

Objectives
- Distinguish between sedimentary rocks with clastic, bioclastic, and crystalline textures.
- Identify a sedimentary rock and the major minerals contained within it.
- Estimate grain size, degree of rounding of grains, and degree of grain sorting in a clastic sedimentary rock.
- Recognize sedimentary structures in a sample, such as: stratification; cross-bedding; ripple marks; graded bedding; mud cracks.
- Determine possible environments of deposition for sedimentary rocks, using as clues the rock’s composition, sorting and shape of clasts, structures and color.

Introduction
Though they account for less than 10% of the crust sedimentary rocks cover two-thirds of the Earth’s surface, forming a thin but extensive blanket over igneous and metamorphic rocks. Sediments are the weathered remains of pre-existing rocks (igneous, metamorphic, and even sedimentary) and accumulate in valleys, basins, and just about any flat surface (run your finger across a bookshelf). Since sediments continue to accumulate through time, they provide information about the local environment at the time they were deposited – a layer of sediment represents a snapshot of time, recording evidence of climate, evolution, tectonics, floods, landslides, earthquakes, meteorite impacts, volcanic eruptions, or just about any other type of geological event a person could name.
Rocks at the Earth’s surface gradually are decomposed and disintegrated by various physical and chemical processes, producing solid particles and ions in solution. This weathered material is then transported by wind, water, or glaciers from its source to some sink (any place where sediment can accumulate), where solid material sinks to the bottom forming layers or strata.

This loosely packed unconsolidated material is called sediment. Over time these sediments can be buried, compressed and hardened to form sedimentary rocks. If the sediments are chemical, i.e. ions in solution, they can be precipitated out by biological processes or by evaporation and concentration, forming chemical or biochemical sedimentary rocks.

By carefully observing the mineral composition and texture as well as larger scale sedimentary structures we can discern clues about the history of the rocks, such as:

- The original source of the sediment;
- The nature of the weathering processes by which the rock was broken down;
- The agent of transport (such as wind, water, or ice);
- The duration of the transport (both temporal and length); and
- The physical, chemical, and biological environment into which the sediment was deposited.

**Weathering**

Weathering is the process by which rocks are broken down and decomposed – when a big rock becomes many smaller rocks. Mechanical (or physical) weathering is the breaking of rocks into smaller and smaller pieces with no other alteration.

Clastic sediments are classified by their grain size, ranging from boulders to cobbles to pebbles to sand to silt to clay particles. The Wentworth Scale (*Table 1*) classifies sediments by grain size (measured by the medial diameter).

<table>
<thead>
<tr>
<th>Class</th>
<th>Name</th>
<th>Minimum diameter</th>
<th>Φ size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel</td>
<td>Boulder</td>
<td>256 mm</td>
<td>-8</td>
</tr>
<tr>
<td></td>
<td>Cobble</td>
<td>64 mm</td>
<td>-6</td>
</tr>
<tr>
<td></td>
<td>Pebble</td>
<td>4 mm</td>
<td>-2</td>
</tr>
<tr>
<td>Sand</td>
<td>Coarse sand</td>
<td>1 mm</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Medium sand</td>
<td>0.25 mm</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Fine sand</td>
<td>0.062 mm</td>
<td>4</td>
</tr>
<tr>
<td>Mud</td>
<td>Silt</td>
<td>&lt; 0.004 mm</td>
<td>&gt;8</td>
</tr>
<tr>
<td></td>
<td>Clay</td>
<td>&lt; 0.004 mm</td>
<td>&gt;8</td>
</tr>
</tbody>
</table>

Chemical weathering is the decomposition of rock by the gradual dissolution of component minerals, or alteration of minerals to secondary minerals, usually by reaction with water. Chemical weathering releases ions such as calcium, sodium, potassium and magnesium into the environment in solution. Chemical reactions also produce new minerals such as clays and insoluble iron oxides.
Resistance to chemical weathering in silicate minerals increases with the percentage of silicon-oxygen bonds (Figure 1). Mafic minerals are most susceptible, beginning with olivine (an island silicate), followed by pyroxene (single chain), amphibole (double chain), and biotite (sheet silicate). The feldspars, being network silicates, are more resistant than the mafic minerals. Quartz has all Si-O bonds making it the most stable common mineral, so quartz dominates clastic sediments and comprises the bulk of sand and silt sized sediments and a significant fraction of clay-sized sediments.

Aside from quartz, the family of minerals that is most stable in the wet, oxidizing conditions at the Earth’s surface is called clays. There are many different types of clay, but they have in common that: (1) they are all sheet silicates, like micas; (2) they all are made from microscopic, plate-like crystals; and (3) they adsorb and hold water very well, so clay crystals tend to clump together (a property called “floculation”).

**Erosion/Transportation**

Sediments produced on a slope, or at high elevation, will gradually be transported to lower elevations. Rate of erosion, as well as energy, is a function of topographic relief. In areas of high relief streams have a great deal of power due to greater velocities. Fast moving streams can move large particles over great distances, while slow moving streams in areas of low relief can only move small particles. Solutes are carried away from the source no matter the velocity, as long as there is water available to transport them.

Water is the most important transporting agent since it is everywhere on Earth. The greater the velocity of the stream the larger the clast it is capable of transporting. The maximum clast size in transport in a stream is known as the stream’s *competence*. The maximum sediment load a stream can transport (measured in kilograms per second) is the stream’s *capacity*. In any stream different clast sizes will be carried downstream at different velocities – the greater the clast size, the lower the velocity.

Sediment transport in a stream is divided into *bedload* (clasts move along the streambed, rarely losing contact with the stream bed), saltating load (clasts bounce along the stream bottom, traveling from a few centimeters to several meters per bounce) and the suspended load (particles rarely if ever touch the stream bed). It is the suspended load that gives larger streams their muddy appearance (Figure 2). These different modes of transport lead
to winnowing, or separation of different grain sizes from one another, with finer materials transported further and further downstream.

**Figure 2:**
Meander loop on the Amazon River. The opacity of the water is caused by the high concentration of suspended clay and silt particles.

Wind is capable of transporting the smallest particles only (up to medium or coarse sand in a strong wind). Sand grains tend to saltate (bounce) in wind and thus can’t efficiently be moved far from their source area. Finer materials (silt- and clay-sized) can be suspended in air as long as the wind blows, and are commonly moved from continent to ocean basins, or even to other continents.

Glaciers move downhill like huge viscous rivers and can transport any material that falls on top of, or get frozen within, the ice. Also, rocks frozen to the bottom of a glacier are dragged along the bedrock at the bottom of the ice, grinding it to a fine powder called glacial flour (**Figure 3**).

**Figure 3:**
Glacial till is a very poorly sorted sediment deposit. Clast sizes range from clay-sized rock flour to boulders the size of cars. Rock hammer (center right) for scale.

**Particle shape**
If you break a rock with a hammer, you will produce residue with sharp edges and corners. Clasts produced by mechanical weathering are typically angular. During transportation rock fragments are constantly abraded by impacts with other particles (thus continuing the mechanical weathering process), gradually decreasing their size and rounding sharp edges (**Figure 4**).
As sediment spends more time in transport the particles gradually become smaller, smoother and rounder. Terms such as well-rounded, sub-rounded, and angular correspond to the amount of abrasion (thus transport distance) the grain has undergone. Angular sediment grains are typically found near their source. Well-rounded grains have gone through many high-energy collisions, indicating long transport distances and/or energetic environments such as beaches or fast moving streams.

**Particle sorting**
Sorting refers to the similarity or difference in size of all of the sediment grains in an individual rock. If all of the grains are the same size, the rock is *well-sorted*. If the grains vary by several size classes the rock is *medium-sorted*. If the grains differ greatly in size the rock is *poorly-sorted*. A poorly sorted rock may consist of a range of grain sizes, or it may have large grains, such as pebbles and cobbles, embedded in a finer matrix, or *groundmass* (Figure 5).
Deposition
The term “sediment” means “to settle out.” Clastic sediments accumulate in quiet environments such as desert basins, lakes and the ocean. During transport sediments can be stored temporarily in many environments such as river channels and floodplains, cliff bottoms, valleys and canyons, tidal flats, beaches, swamps, and any other locale at which there is insufficient energy available to move materials to the next base level.

Chemical sediments accumulate in bodies of water when dissolved ions become precipitate as mineral crystals. Inorganic chemical precipitation occurs when evaporation concentrates solutes. Common examples are halite (rock salt), gypsum (rock gypsum) and calcite (limestone).

Biochemical precipitation occurs in bodies of water that can support life. Many animals and plants extract calcium (Ca\(^{2+}\), produced from the weathering of silicate minerals) and carbonate (CO\(_3\)^{2-}\), a product of the dissolution of atmospheric CO\(_2\) into rain water) to form structures such as shells or internal skeletons. Other organisms extract hydrous SiO\(_2\) (also a product of silicate weathering) to make shells or skeletons (Figure 6). When these organisms die, their hard body parts sink to the bottom to form carbonate or silicate ooze (or mud).

Coal is another type of biochemical sedimentary rock that forms when plants die in swamps or deltaic environments. The plants decay in reducing conditions (little or no oxygen present), first forming a fibrous material called peat, and then later a black rock called lignite. Both of these carbon-rich materials have been used for millennia as fuels.

An important aspect of the study of sedimentary rocks is gaining an understanding of the conditions under which a particular rock formed. Knowledge of these conditions allows us to reconstruct aspects of the geologic history of an area. From this knowledge we can infer how environmental conditions have changed, we can predict where we might find ore materials or fossil fuels, and we can even make tentative predictions about how conditions may change in the future.

James Hutton, the father of modern geology, proposed the principle of Uniformitarianism (“the present is the key to the past”), which states that the conditions under which, for instance, an ancient sandstone deposit formed can be inferred by looking at the
environments in which sands accumulate today. Table 3 lists a variety of modern sedimentary environments and the types of rocks we associate with each.

**Sedimentary structures**
Structures are features in rocks that formed during or after deposition of the sediments, but typically before its conversion into rock. Most structures are visible to the naked eye in the field, and they provide important evidence about the transporting agent and depositional environment.

**Figure 7:**
Horizontal stratification in siltstone found along the eastern side of Owens Valley north of Owens Lake. These beds were deposited along the lake margins more than 10,000 years ago when Owens Lake was much deeper.

*Stratification*, or *bedding*, is the most common structure, as most sediments are deposited in horizontal layers (*Figure 7*). Finer layers called *laminations* form in finer sediments due to minor changes in grain size or mineralogy (*Figure 8*). Since soft, wet sediments provide good substrate for rooted plants or burrowing animals these fine laminations are rarely preserved. Presence of fine laminations in a sedimentary rock (such as a shale or sandstone) is usually evidence that the sediment was deposited in an environment hostile to multi-cellular organisms (a reducing environment, for instance).

**Figure 8:**
Fine laminations found in the Kimmeridge Clay along England’s Jurassic Coast; total thickness here is ~50 cm. The dark-colored layers are primarily organic clay, while the lighter layers are coccolith fragments. The individual layers in the shale are no more than a few millimeters thick, and represent annually deposited layers that remain undisturbed by rooted plants or burrowing animals since the time of deposition.
Figure 9:

Assymetrical cross beds in deposited sand. In both examples the sand was transported from left to right on the photo.

Above are fine (a few centimeters) cross beds found in a stream bed near the Grand Canyon.

At left is the Navajo Sandstone as it appears in Zion Canyon. These deposits consist of wind-blown sand transported in a dune field. The horizontal layers separating the cross beds range in height from a few feet to dozens of feet.

_Cross-bedding_ is indication of deposition (typically of sand or silt) in a moving current, such as a streambed or in the wind (sand dunes). It is expressed as a series of parallel lines within the bed that are at a constant angle to the bedding (see Figure 9). _Ripples_ (Figure 10) are the surface expression of cross-beds, and can be asymmetrical if the current flows in one direction (as in a stream) or symmetrical if the current oscillates (as in shallow-water waves).

Figure 10:

Ripples at two different scales in Death Valley National Park. In the foreground are windblown ripples 5-10 cm in wavelength. Though deposited by wind and not water, these ripples are similar to those in the right-hand photo in Figure 9. The dune crests visible represent larger ripples with scale lengths 10s of meters across. These are analogous to the cross beds depicted in the left hand photo in Figure 9.
Graded bedding develops when a sediment-rich current gradually slows, depositing coarser sediments at first, then gradually finer and finer sediments, producing a “fining upward” sequence (Figure 11). Graded beds will form whenever a current: (1) transports a range of grain sizes; and (2) slows gradually. A flood deposit on a river will commonly be graded for example, while a landslide (which typically comes to a stop abruptly) will not.

![Decreasing grain size upward through the bed indicating deposition from a waning current.](image)

Figure 11:
Graded bedding is represented by a deposit in which sediment grain size decreases toward the top of the bed. This occurs when a strong current gradually weakens.

Mud cracks form on horizontal surfaces, such as lake beds, when mud (a mixture of clay, silt and, sometimes, fine sand) dries and shrinks (Figure 12). The presence of significant amount of clay minerals, which swell significantly when wet and shrink significantly when dry, exacerbate this process. Cracks begin as straight lines and curve to meet adjacent cracks at right angles. Mud cracks are ephemeral features, but are often preserved in the geologic record when open cracks fill with secondary sediment.

![Mudcracks occur on low-lying flat surfaces when mud (silt and clay particles) slowly dries and shrinks.](image)

Figure 12:
Mudcracks occur on low-lying flat surfaces when mud (silt and clay particles) slowly dries and shrinks.

Diagenesis/Lithification
The processes by which sediments are turned into sedimentary rocks are known as diagenesis (also called lithification). Compaction occurs when the pressure of overlying sediments squeezes out excess water and presses grains together. Cementation is the process of gluing the sediment grains together. This often involves minerals in solution, such as calcite, precipitating within pore spaces in the sediments. It is important to note that, while cementing agents sometimes have compositions similar to the sediment itself, it is not unusual for the cement and the sediment to be unrelated.
Colors
Quartz and calcite, you will recall from your lab on minerals, are intrinsically colorless minerals. Since quartz and calcite make up the bulk of sedimentary deposits, the color of the rock will usually depend upon secondary constituents such as the cement. Cement type and color are dependent upon conditions at the time of deposition and lithification, we can learn much about the conditions under which the rock was formed by looking at its color:

Red and reddish brown colors are attributable to hematite (iron oxide). Iron is produced from the weathering of mafic minerals and easily forms an insoluble precipitate with oxygen. Precipitation of hematite implies deposition in a dry, oxidizing environment. These conditions are most common in continental (terrestrial) environments, such as mountains and deserts.

Yellowish to rusty browns indicate the presence of goethite (hydrsous iron oxide), which forms under oxidizing conditions in the presence of water. This implies deposition in well-drained nonmarine or transitional areas that are barren of vegetation (such as floodplains, beaches or barrier islands).

Light gray to bluish to white colors resemble the true colors of the sediments, indicating that the cementing agent is colorless calcite or chalcedony (or sometimes the white clay known as kaolinite). This indicates deposition in neutral to slightly reducing conditions such as shallow marine or lake environment.

Medium to dark green colors indicate the presence of reduced iron minerals and clay. Glauconite and chlorite are both green micas (similar in composition to biotite). These colors are most often associated with deposition in an environment that is low in oxygen, such as a deep lake or an isolated marine basin.

Dark grays or blacks are attributable to the presence of incompletely decomposed organic matter along with clay minerals (especially smectite). This implies an environment that has little or no oxygen, such as a stagnant marine basin, a tidal or non-marine swamp, or the quieter portions of a river delta. It is not uncommon to find lenses of coal within rocks such as these.

Classification of Sedimentary Rocks
The two types of sediment provide the basis for the two categories of sedimentary rock: (1) detrital or clastic rocks are made of solid particles derived from outside the basin of deposition; and (2) chemical or biochemical rocks are formed within the basin by the precipitation of ions from solution, either through evaporation and concentration or through organic processes. Classification within these two groups is based on texture and mineral composition.

Texture
Clastic or detrital sedimentary rocks are characterized by discrete clasts or grains of rocks, minerals or fossils. The sediment grains are not intergrown with each other but are cemented together with a chemical precipitate of hydrous silica (chalcedony), calcite or
iron oxide. The clasts probably were derived from outside the basin of deposition, but fossils and chemical precipitates have likely come from inside the basin.

If the clastic texture is due to abundant fossils or fossil fragments, it is known as bioclastic. These fragments can range from broken shell fragments up to a centimeter in diameter to fine, almost microscopic shells of planktonic organisms (i.e. chalk and diatomite) to small, concentric spheres of calcite or silica known as ooids.

Clay-sized particles of platy or flat minerals, such as clays or micas, will tend to align themselves with their flat sides parallel to the depositional surface. Rocks formed in this manner from these types of sediments are easily split into sheets parallel to the flat faces of the tiny grains and are called fissile.

Chemical or biochemical rocks that do not have clastic textures often have crystalline textures. This is most apparent in evaporite minerals such as halite or gypsum. Biochemical precipitates occur most commonly as microcrystalline minerals, which can only be seen with a microscope. The texture of a microcrystalline rock will be similar to that of the mineral chalcedony: it will have a somewhat waxy luster and may display conchoidal fracture.