CHAPTER 5: SEDIMENTARY ROCKS

This chapter is a summary of sedimentary rocks and their terminology. Most of the sedimentary rock units in the Fells are secondary to the igneous rocks in the previous chapter and have mostly been lightly metamorphosed. As a result, this will not be a comprehensive treatment of the subject. It will make you familiar with some introductory characteristics of sedimentary rocks but does not further explain how they form much beyond what is in Chapter 2.

(Note: Terms in red and italics appear as entries in the companion glossary.)

In Chapter 2 we learned that weathering processes break down rocks to form particles, or *clasts*, and dissolved constituents. When particles eroded from existing rocks are transported and deposited, this produces a sedimentary deposit. This can lead to the formation of *clastic sedimentary rocks* when the sediment undergoes *lithification* (compaction, dewatering, and cementation). Sediment can also accumulate by other processes. The remains of dead organisms, such as shells, skeletons, or plant debris, can accumulate as sediment. It is also possible for chemical precipitation of such things as salt to create layers of sediment. These processes together produce *non-clastic sedimentary rock*, i.e., sediment not formed from clasts derived from the erosion of previous rocks.

5.1 - IS IT SEDIMENTARY?

There are several characteristics shared by sedimentary rocks that are the result of their origin as sediment. First, clastic sedimentary rocks are made of particles that are always lying on top of each other. They may be touching, but they do not enclose each other or interlock. Thus, they form a *non-interlocking texture* (Fig. 5.1). In clastic sedimentary rocks, the particles that are derived from other rocks are usually, but not always, rounded to some degree. They get this way when they are transported and collide with other particles or rock surfaces (Fig. 5.2). Additionally, some clasts may erode by dissolving or degrading due to chemical decay, which tends to make them rounder, either during or before transport.

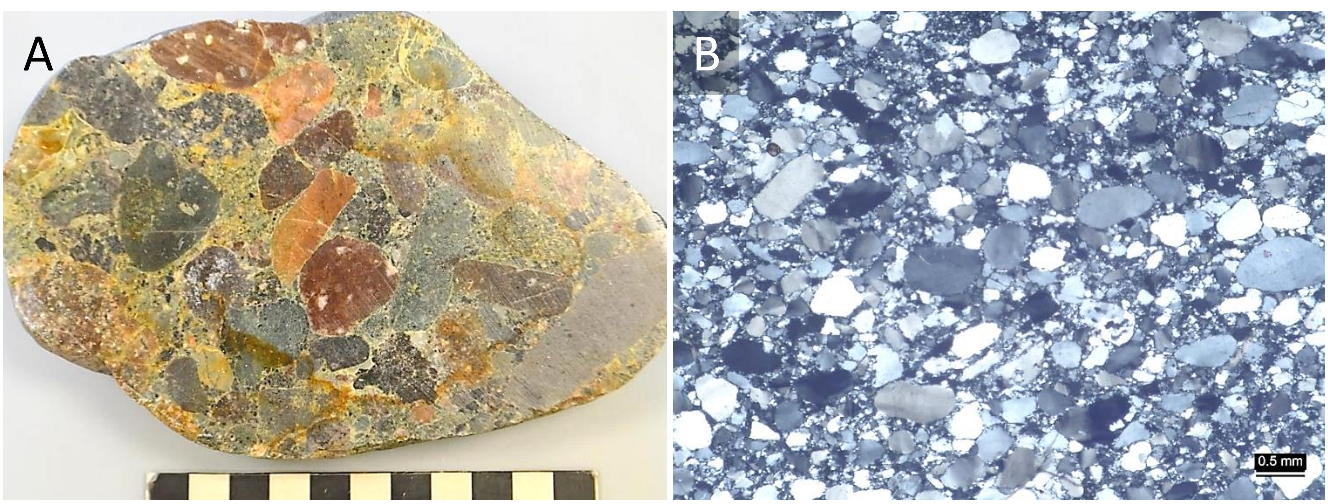


Figure 5.1 *– Non-interlocking grains (touching but not enclosing each other) in clastic sedimentary rocks. Note how the particles on both images are also rounded to some extent. Compare these images with the interlocking crystals seen in igneous rocks (Fig. 4.1). A) Conglomerate boulder from a Boston Harbor beach. The rock was cut on a rock saw. Scale in cm. B) Thin section view with crossed polarizers of non-interlocking quartz sand grains in a sandstone in the Fells.*

Figure 5.2 *– Rounded particles (pebbles and cobbles) on a beach in Acadia National Park in Maine, where wave activity has caused particle collisions and rounding. Most of the clasts are from local igneous rock formations. Just below the center of the image is an igneous rock with inclusions (arrow). There are a few other cobbles with inclusions as well.*

In almost all cases, sedimentary rocks are laid down in nearly horizontal layers that are stacked one on top of each other. As a result, most sedimentary rock formations display *bedding* (Fig. 5.3A). Sedimentary rocks can also have *fossils*, which are features left by organisms. Fossils may form because the hard parts of organisms are either preserved or chemically replaced (Fig. 5.3B), or the organism left an impression in the sediment that became buried. This can include the impression of an organism's body or tracks, trails and footprints (Fig. 5.3C). Fossils can be visible with your naked eye, or they can be microfossils only visible in a microscope. Not all sedimentary rocks have the features discussed above, and there are rare exceptions in which a sedimentary rock has none of these features. However, when we see non-interlocking and rounded grains, bedding, and fossils, it means that the rock is sedimentary.

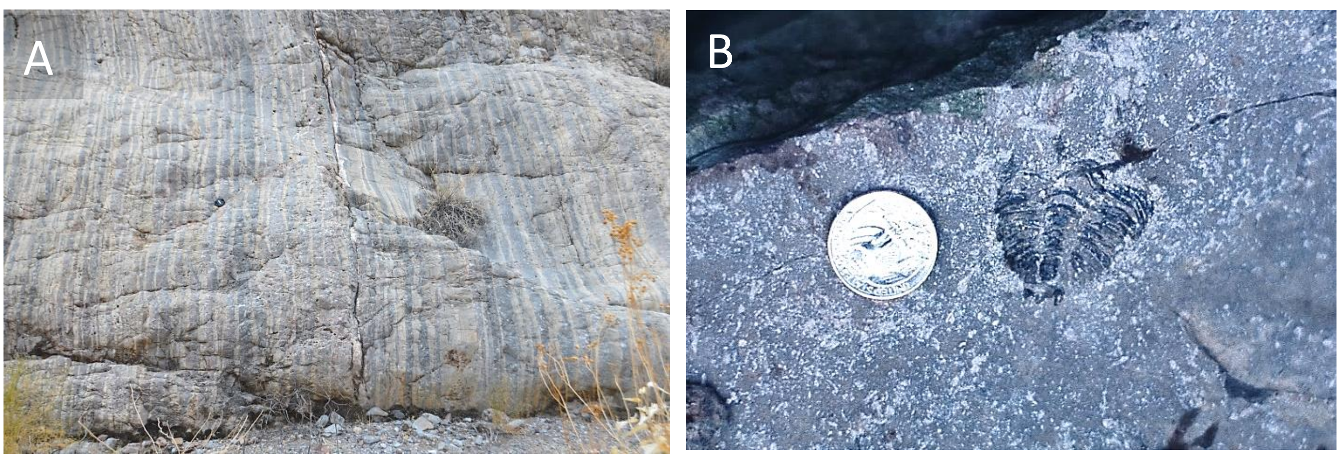


Figure 5.3 *– A) Cyclic (regularly repeated) bedding in limestone of the Bonanza King Formation in Fall Canyon, Death Valley, California. Camera lens cap left of center for scale. B) Pygidium (tail) and rear thorax of trilobite ("trilo-butt") preserved in limestone at Clark Reservation, Syracuse, New York. Quarter for scale. C) Jurassic dinosaur tracks from the Connecticut River valley of Massachusetts. Dime for scale.*

5.2 CLASTIC SEDIMENTARY ROCKS

The classification of clastic sedimentary rocks is based on *grain size*, which is the size of the particles that make up the rock. Particles are classified by their diameter as *gravel* (including granules, pebbles, cobbles and boulders), *sand*, *silt*, and *clay* (Fig. 5.4). Figure 5.5 shows the numerical size boundaries for the different size classes and the names of clastic sedimentary rocks made up of grains of that size. A term that is not listed on Figure 5.5 but that is encountered in rock descriptions in the Boston area is argillite. *Argillite* is very hardened shale or mudstone. It is usually brittle and breaks across bedding plains, but doesn't have characteristics suggesting it was significantly metamorphosed, notably there is a lack of slatey cleavage, which we will learn about in Chapter 6. The term argillite has become more loosely used as a substitute term for mudstone and shale, even when they are not very hard, and it has been applied to rocks that have poorly developed slatey cleavage, where slate would be a better term. Siltstone, shale, and claystone make up about 65% of all sedimentary rocks, not just clastic sedimentary rocks.

Figure 5.4 *– Grain size classification of sedimentary particles, clasts or grains. Examples of rounded (above) and angular (below) gravel types are shown. Note that clay particles attach to each other, or are said to be cohesive, and form hard layers or fragments when dry. In Figure 5.5 below are the exact definitions of the size classes of sedimentary particles and the names of clastic sedimentary rocks made from these particle sizes.*

Grain size	Sediment type	Clastic Sedimentary Rock Type
> 2 mm	rounded gravel	conglomerate
	angular gravel	breccia
2.0 – 0.0625 mm	sand	sandstone
0.0625 – 0.002 mm	silt	siltstone
< 0.0625 mm	mixed silt and clay	shale
< 0.002 mm	clay	claystone

Figure 5.5 *–Grain sizes of sedimentary particles and the names of clastic sedimentary rocks made from these particle or clast sizes.*

In addition to grain size, it is also possible to determine shapes of particles and their sorting when the particles are large enough to see, especially in conglomerates (Fig. 5.6). The shape of particles is measured by their *roundness,* ranging from angular to well rounded. *Sorting* refers to how uniform the grain sizes are in a rock. If all the particles are nearly the same grain size, as might be the case with sandstone made from beach sand or deposited by the wind, the sediment is well sorted. Conversely, a mixture of particle sizes from clay to boulders would be poorly sorted.

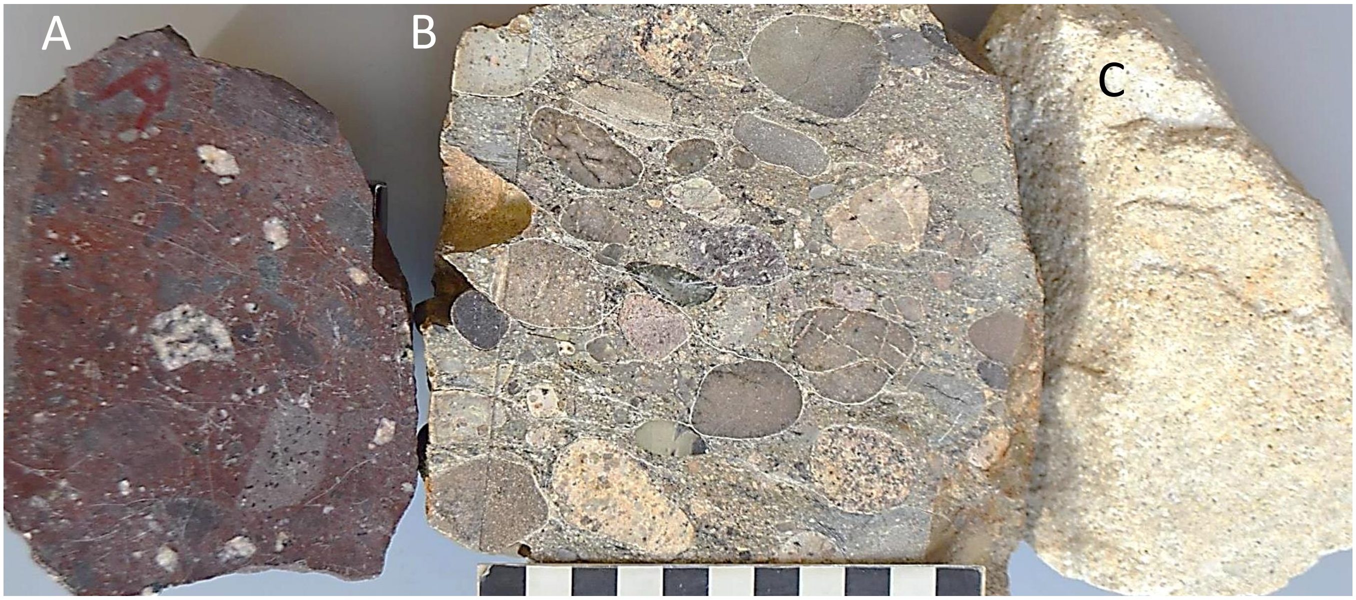


Figure 5.6*– Clastic sedimentary rocks with different particle shapes and sorting. A) Very poorly sorted conglomerate with angular particles in a muddy matrix from the Roxbury Conglomerate at Nantasket, Massachusetts. B) Conglomerate with moderate sorting (pebbles with a sandy matrix) and rounded pebbles from the Roxbury Formation in Hammond Pond Park in Newton, Massachusetts. C) Well-sorted sandstone from the Palmerton Sandstone in Palmerton, Pennsylvania.*

The classification of conglomerates involves not only the size of particles in the rock but the shape and sorting of the finer particles, or the *matrix*, that occur between the gravel grains (Fig. 5.7). A conglomerate made of highly *angular* (non-rounded) gravel particles is called *breccia*. A conglomerate that is poorly sorted with mud in its matrix and in which the gravel particles are often not touching each other is known as a *diamictite*. Sandstones and conglomerates can also be subdivided into different types by the composition of the grains that make up the rock (Fig. 5.8). Grain compositions can be dominated by rock fragments that each have multiple mineral grains or other materials, in which case the sandstone or conglomerate is known as a *lithic sandstone or lithic conglomerate*. When feldspar dominates, they are known as *arkosic sandstone or arkosic conglomerate*, and *quartz* is used as an adjective when a sandstone or conglomerate is dominated by quartz, as in quartz sandstone or quartz pebble conglomerate.

5.3 CEMENTS IN SEDIMENTARY ROCKS

All the clastic sedimentary rocks described above are transformed from sediment (loose material) to sedimentary rock (hardened sediment) as a result of compaction, which decreases the sizes of pore spaces and squeezes water out of the sediment, usually due to the weight of sediment that has accumulated above. Most sedimentary rocks have an additional process leading to what we call *lithification*, or the hardening of the rock. Groundwater that circulates through the pore spaces between sediment particles carries dissolved constituents, which over time can chemically

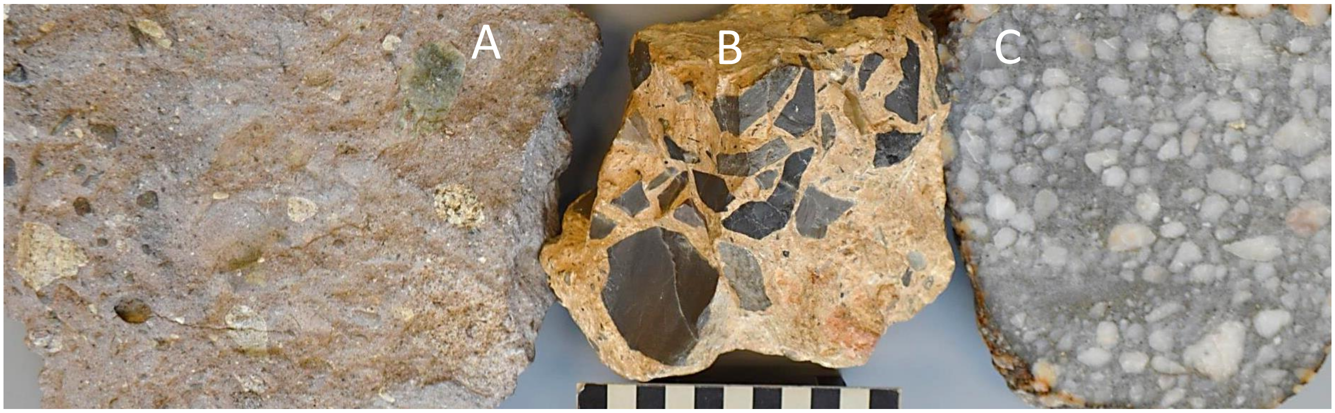


Figure 5.7 *– Types of conglomerates according to sorting and particle shape. A) Diamictite - a poorly sorted conglomerate with a muddy and sandy matrix. Particles are partly rounded in this diamictite from the Squantum Member of the Roxbury Formation at Squantum, Massachusetts. B) Sedimentary breccia, a conglomerate with highly angular particles that are all the same type (limestone) and have not experienced any rounding. The matrix is a very fine calcium carbonate (calcite) cement. This rock is from the floor of a cave where blocks fell from the ceiling and shattered, only to later be cemented by calcite on the floor of the cave. Compare this with inclusions in an igneous rock (Fig. 4.14B). C) A relatively well sorted conglomerate with rounded quartz pebbles in a matrix of quartz sand from the Oneida Conglomerate recovered from stream sediment along Steele Creek near Ilion, New York. This rock is cemented by pyrite, giving the rock a gray color.*

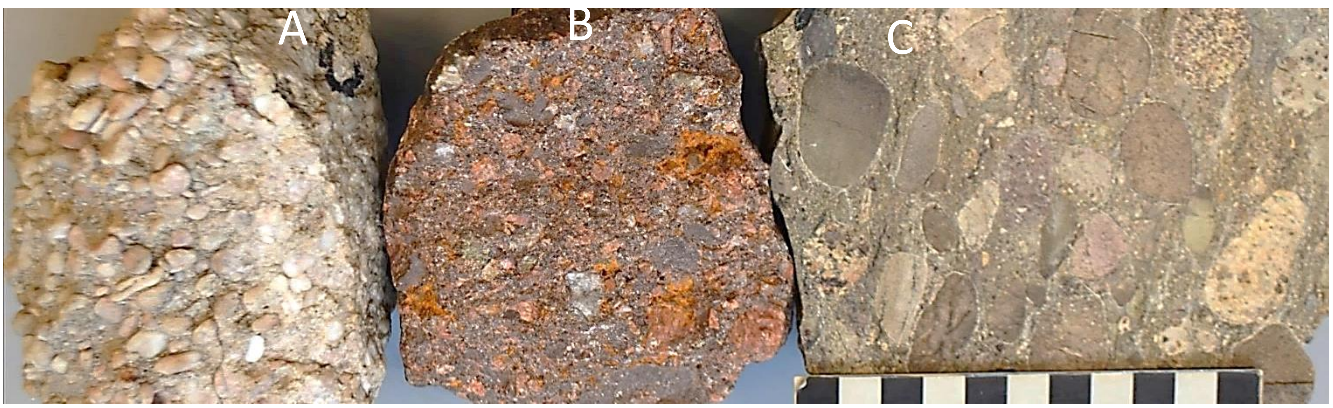


Figure 5.8 *– Different compositional types of sandstone and conglomerate. A) Quartz conglomerate, which is dominated by rounded quartz pebbles, from the Palmerton Sandstone at Palmerton, Pennsylvania. B) Arkosic conglomerate, with more than 25% particles that are feldspar, in this case potassium or alkali feldspar, from the Connecticut Valley of Massachusetts. There can also be arkosic conglomerates and sandstones dominated by plagioclase, but this rock was used as an example because it is easier to identify the orangish-red alkali feldspar (see Fig. 3.10). C) Lithic conglomerate, with more than 25% particles that are rock fragments. This sample is from the Roxbury Formation in Hammond Pond Park, Newton, Massachusetts.*

precipitate between the grains, creating a mineral *cement* that glues the particles together. This can happen in the plumbing in your house if your water has dissolved iron or calcium carbonate, which will precipitate in the pipes. The most common cements in rocks are quartz, calcite (calcium carbonate), and iron oxide (Fig. 5.9). Compacted clay particles can also behave like cement. Quartz is by far the hardest of the cements. Rocks that are cemented by calcite will react or fizz with hydrochloric acid. Iron oxide is probably the most conspicuous cement since it gives the rock an orange to reddish-brown color. This is what happens in the formation of red sandstone, siltstone, and shale. Red sandstone is the rock from which brownstone apartments are made.

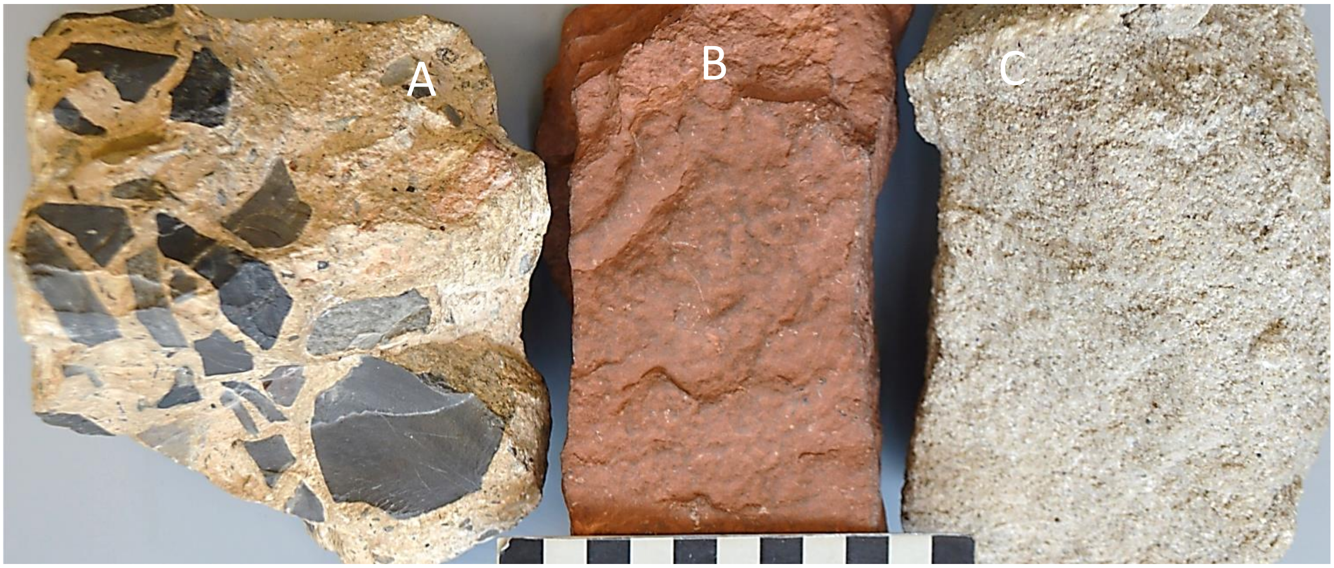


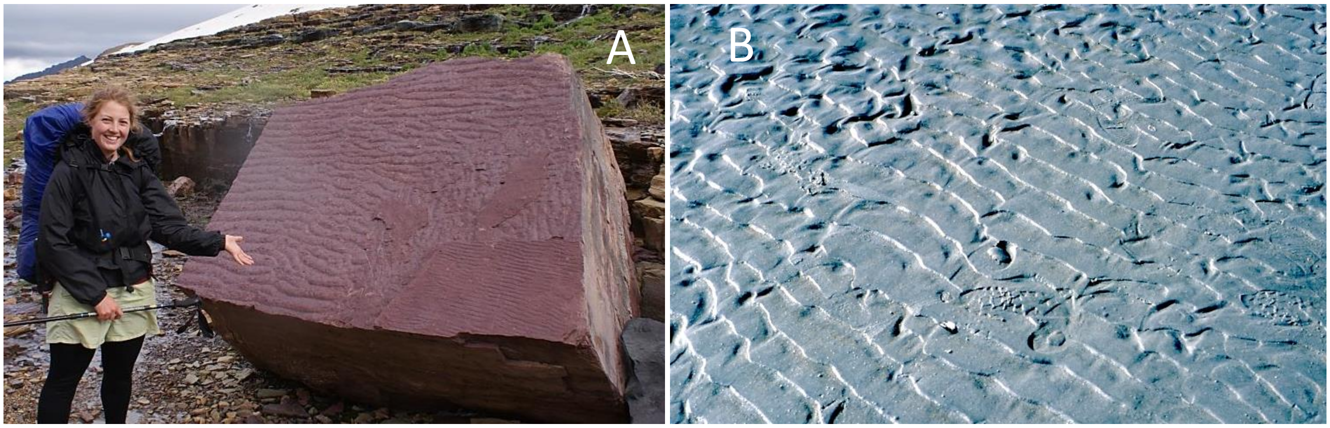
Figure 5.9 *– Common cements in clastic sedimentary rocks. A) Calcite cement in breccia where the matrix is very fine calcium carbonate. This rock is from the floor of a cave where blocks fell from the ceiling and shattered to later be cemented together by calcite on the floor of the cave. B) Iron oxide (hematite) cement in a fine-grained red sandstone/siltstone from Arizona. For more on hematite refer to Figs. 2, 3, and 16 in Chapter 3. C) Quartz cement in well sorted sandstone from the Palmerton Sandstone in Pennsylvania.*

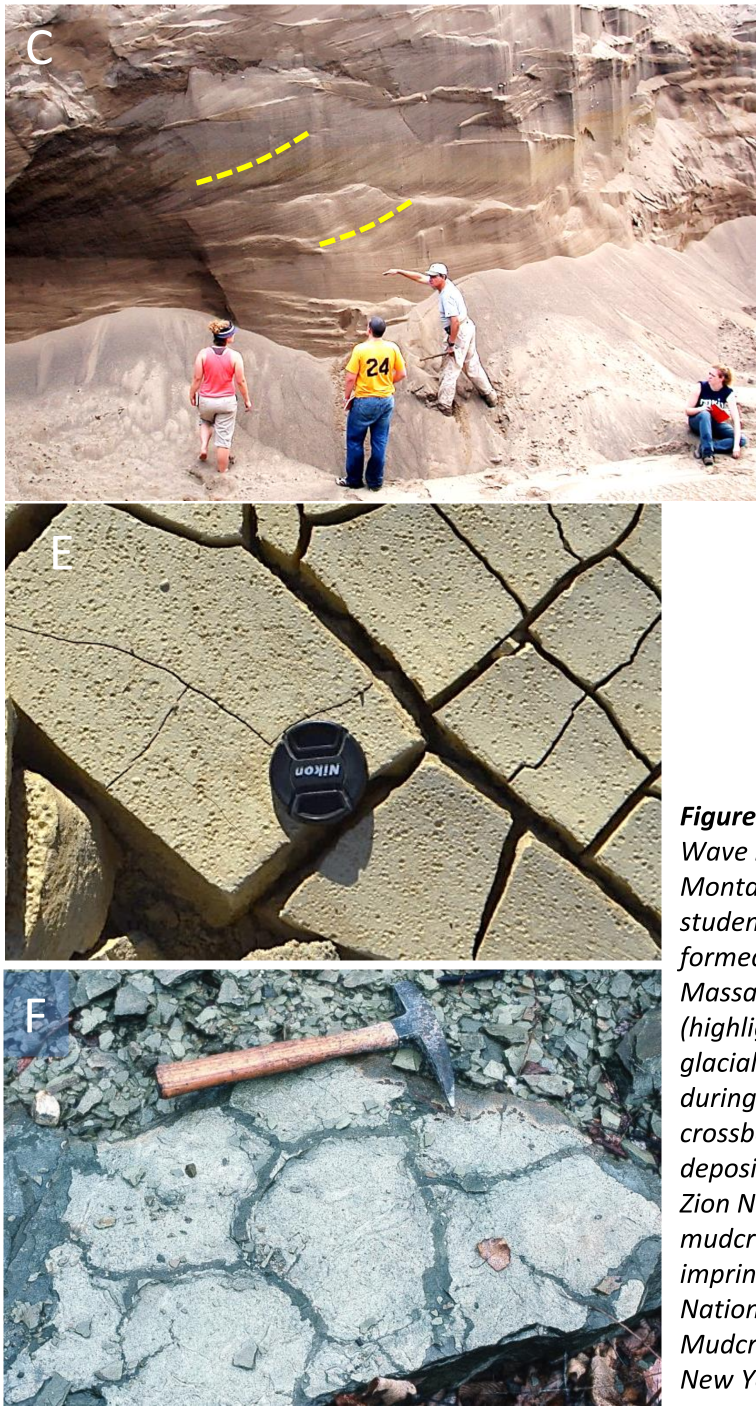
5.4 SEDIMENTARY STRUCTURES IN CLASTIC SEDIMENTARY ROCKS

Layers of sediment deposited to form clastic sedimentary rocks sometimes preserve the shapes of the surface features of beds, or they have grain arrangements within beds that tell us something about the environment in which the sediment was deposited. These features are referred to as *sedimentary structures*. Looking at how sedimentary structures form in modern environments, or in controlled laboratory settings in flumes (artificial channels) and wave tanks, allows us to make interpretations about the rocks in which they occur.

A common sedimentary structure is *ripples* (Fig. 5.10A-B), which are linear ridges of sand formed perpendicular to the motion of a fluid (water or air). Depending on the type of ripple, they can indicate an environment where there was gentle wave activity or a unidirectional current. *Wave* or *oscillatory ripples* (Fig. 10A) are symmetric in cross section (also called symmetric ripples). They can be used to indicate environments that might occur in a shallow water coastal setting with waves or in shallow water puddles where the wind creates small waves. *Current ripples* (Fig. 10B; also called asymmetric ripples) are asymmetric in cross section, being steep on the down flow side, which allows you to determine what direction the current was flowing when the ripples were formed. Inside current ripples are *crossbeds*, or beds formed on the dipping downstream face of the ripple. *Crossbeds* dip down flow at 10-30°, significantly away from horizontal, and allow us to determine a current direction. Crossbeds form not only on the downstream faces of ripples but can also be much larger, forming on the downstream faces of channel bars in rivers (Fig. 5.10C) and on the downwind sides of sand dunes (Fig. 5.10D).

Sedimentary structures can also develop in muddy deposits. A common example is where mud dries out and cracks, causing the development of polygonal *mudcracks* (Fig. 10E-F). Mudcracks can occur with *raindrop imprints* where raindrops strike wet, but still stiff, mud and form small craters that are preserved when the sediment dries out. Mudcracks and raindrop imprints are commonly formed on flood plains where flooding deposits mud that later dries out.





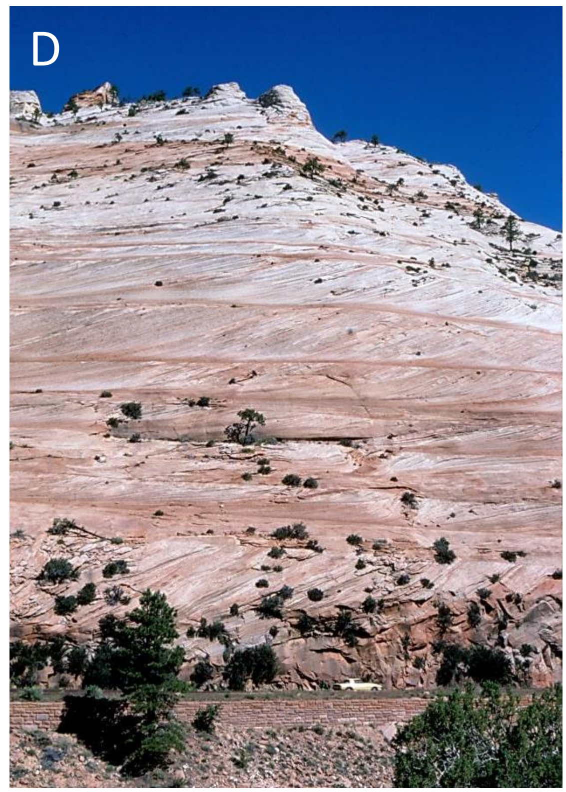


***Figure 5.10** – Common sedimentary structures. A) Wave ripples in red siltstone in Glacier National Park, Montana. Image and scale courtesy of former Tufts student, Megan Chaisson. B) Modern current ripples formed by a tidal current on a sand flat at Plum Island, Massachusetts. Footprints for scale. C) Crossbeds (highlighted by yellow lines) formed in late Pleistocene glacial river deposit at Poland, New York. Image taken during Tufts University geology field trip. D) Giant crossbeds (tilted) within horizontal beds created by deposition of sand dunes in the Navajo Sandstone of Zion National Park, Utah. Car for scale. E) Modern mudcracks formed in dried puddle with raindrop imprints (small craters) in Gower Gulch, Death Valley National Park, California. Camera lens cap for scale. F) Mudcracks in the Shawangunk Formation of southern New York. Rock hammer for scale.*

5.5 NON-CLASTIC SEDIMENTARY ROCKS

Non-clastic sedimentary rocks are the result of biological or chemical accumulation or precipitation and are classified by the dominant type of non-clastic material in the rock. Since there are no exposures of non-clastic sedimentary rock in the Fells, I will only mention a few common types (Fig. 5.11). One non-clastic sedimentary rock is far more common than any of the others and makes up about 20% of *all* sediment rock units on Earth. This is *limestone*, which is defined as a sedimentary rock made of mostly calcite ($CaCO_3$). Most limestone is formed from shells of organisms such as corals, clams, snails or several different microorganisms. Limestone also contains calcite that is secreted by organisms of various types, including algae. Far less abundant is limestone that is formed by chemical precipitation due to the evaporation of sea or lake water in arid or tropical regions or by chemical reactions when water drips into a cave or seeps out of the ground to form springs at the land surface. Some limestones formed in marine and lake environments have been chemically altered to have half of their calcium replaced with magnesium to form *dolomite* ($CaMg(CO_3)_2$). This forms a closely related rock, *dolostone* (also often called dolomite).

There are several other non-clastic sedimentary rock types (Fig. 5.11). Some are rock formations dominated by *salt* (sodium chloride - NaCl) and *gypsum* (hydrated calcium sulfate – $CaSO_4{\cdot}2H_2O$), formed by evaporation of ocean or lake water. We refer to these deposits as *evaporites*. *Silica*, a form of hydrated quartz also forms a non-clastic sedimentary rock called *chert*. Chert is the result of the accumulation of very tiny microfossils (diatoms and radiolarian) made of silica or the chemical recrystallization of silica that was left by these organisms. Silica deposits can also be the result of deposition by hydrothermal fluids associated with hot springs. Silica deposits have several common names, including agate, chalcedony, flint, jasper, and opal, depending on their color, water content, and reflectance properties. Another important non-clastic rock type is *coal*, which is the compressed and chemically altered remains of plant debris that accumulated in a place where it got buried before it could completely decay in the presence of oxygen. Coal units represent ancient peat or swamp deposits.

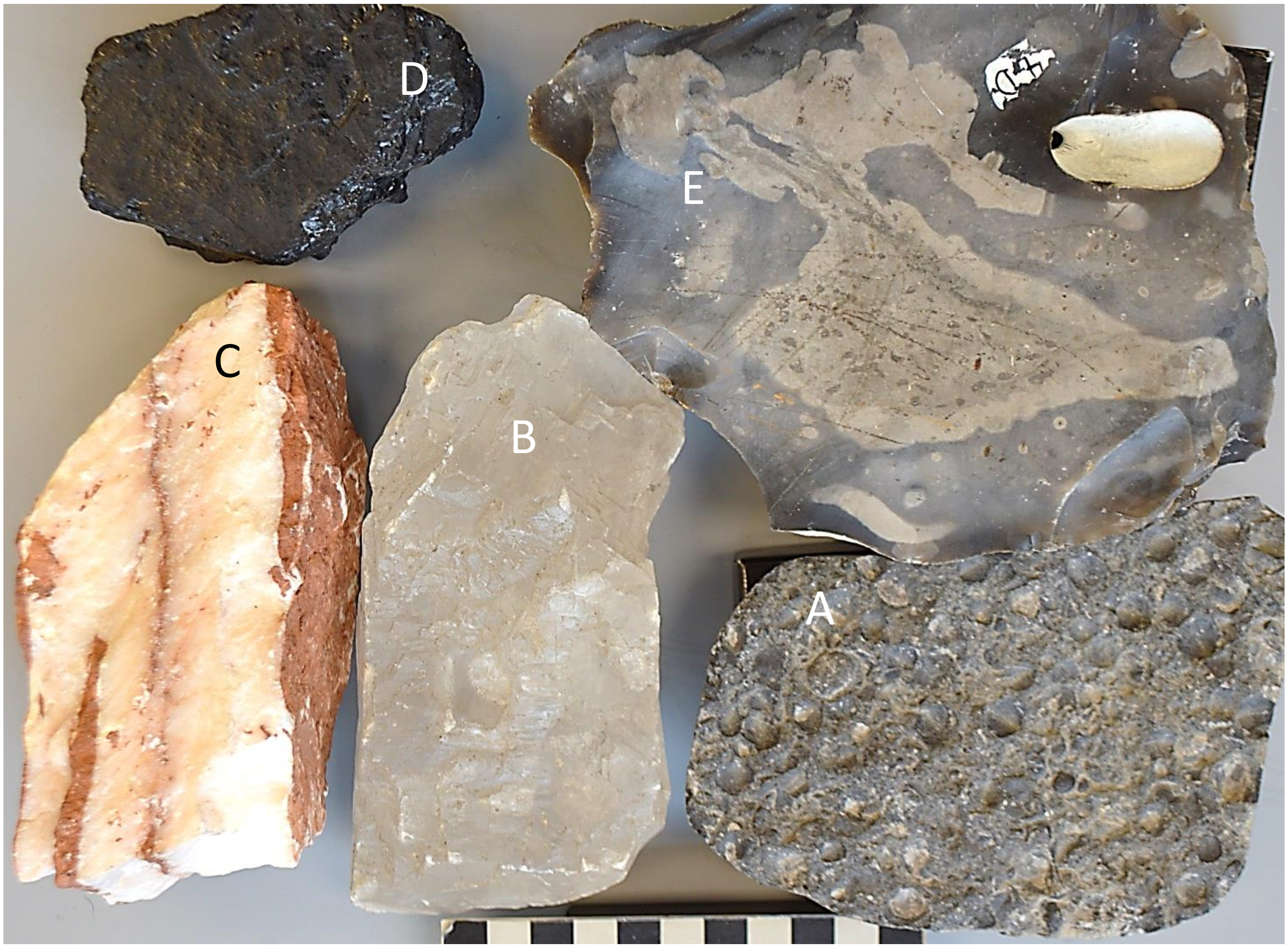


Figure 5.11 *– Some common non-clastic sedimentary rocks. A) Limestone with fossils. The fossils (small shells) are brachiopods in the Trenton Limestone of central New York. B) Rock salt (mostly the mineral halite – NaCl; unknown source) and C) rock made of mostly gypsum ($CaSO_4 \cdot 2H_2O$; unknown source) are both precipitated from evaporating lake or ocean water. D) Coal from eastern Pennsylvania formed from highly compressed and devolatilized decaying plant matter. E) Sedimentary silica or chert, which occurs in many varieties. Shown here is flint from nodules in chalk (limestone) beds at the White Cliffs of Dover on the southern coast of England.*