2.3: Soils

2.3.1. Sand

Sand is any material composed of loose, stony grains between 1/16 mm and 2 mm in diameter. Larger particles are categorized as gravel; smaller particles are categorized as silt or clay. Sands are usually created by the breakdown of rocks, and are transported by wind and water, before depositing to form soils, beaches, dunes, and underwater fans or deltas. Deposits of sand are often cemented together over time to form sandstones.

The most common sand-forming process is weathering, especially of granite. Granite consists of distinct crystals of quartz, feldspar, and other minerals. When exposed to water, some of these minerals (e.g., feldspar) decay chemically faster than others (especially quartz), allowing the granite to crumble into fragments. Sand formed by weathering is termed epiclastic.
Where fragmentation is rapid, granite crumbles before its feldspar has fully decayed and the resulting sand contains more feldspar. If fragmentation is slow, the resulting sand contains less feldspar. Fragmentation of rock is enhanced by exposure to fast-running water, so steep mountains are often source areas for feldspar-rich sands and gentler terrains are often source areas for feldspar-poor sands. Epiclastic sands and the sandstones formed from them thus record information about the environments that produce them. A sedimentologist can deduce the existence of whole mountain ranges long ago eroded, and of mountain-building episodes that occurred millions of years ago from sandstones rich in relatively unstable minerals like feldspar.

The behavior of sand carried by flowing water can inscribe even more detailed information about the environment in sand deposits. When water is flowing rapidly over a horizontal surface, any sudden vertical drop in that surface splits the current into two layers, (1) an upper layer that continues to flow downstream and (2) a slower backflow that curls under in the lee of the drop-off. Suspended sand tends to settle out in the backflow zone, building a slope called a "slip face" that tilts downhill from the drop-off. The backflow zone adds continually to the slip face, growing it downstream, and as the slip face grows downstream its top edge continues to create a backflow zone. The result is the deposition of a lengthening bed of sand. Typically, periodic avalanches of large grains down the slip face (or other processes) coat it with thin layers of distinctive material. These closely-spaced laminations are called "cross bedding" because they angle across the main bed. Cross-bedding in sandstone records the direction of the current that deposited the bed, enabling geologists to map currents that flowed millions of years ago (paleocurrents).

Evidence of grain size, bed thickness, and cross-bedding angle, allows geologists to determine how deep and fast a paleocurrent was, and thus how steep the land was over which it flowed.
Ripples and dunes—probably the most familiar forms created by wind- or waterborne sand—involve similar processes. However, ripples and dunes are more typical of flow systems to which little or no sand is being added. The downstream slip faces of ripples and dunes are built from grains plucked from their upstream sides, so these structures can migrate without growing. When water or wind entering the system (e.g., water descending rapidly from a mountainous region) imports large quantities of sand, the result is net deposition rather than the mere migration of sand forms.

Grain shape, too, records history. All epiclastic grains of sand start out angular and become more rounded as they are polished by abrasion during transport by wind or water. Quartz grains, however, resist wear. One trip down a river is not enough to thoroughly round an angular grain of quartz; even a long sojourn on a beach, where grains are repeatedly tumbled by waves, does not suffice. The well-rounded state of many quartz sands can be accounted for only by crustal recycling. Quartz grains can survive many cycles of erosion, burial and cementation into sandstone, uplift, and re-erosion. Recycling time is on the order of 200 million years, so a quartz grain first weathered from granite 2.4 billion years ago may have gone through 10 or 12 cycles of burial and re-erosion to reach its present day state. An individual quartz grain's degree of roundness is thus an index of its antiquity. Feldspar grains can also survive recycling, but not as well, so sand that has been recycled a few times consists mostly of quartz.

Sand can be formed not only by weathering but by explosive volcanism, the breaking up of shells by waves, the cementing into pellets of finer-grained materials (pelletization), and the precipitation of dissolved chemicals (e.g., calcium carbonate) from solution.

Pure quartz sands are mined to make glass and the extremely pure silicon employed in microchips and other electronic components.

### 2.3.2. Clay

Clay is a fine-grained (small particle size) sedimentary rock. Clay is so fine-grained it is rarely possible to see the individual mineral particles with the naked eye. The definition of clays describes rocks with particle sizes of less than 4 μm in diameter. Most sedimentary rocks are described using both mineral content and particle size. While this is also true for clays, the particle size description is most reliable and most often used.
The majority of common types of minerals found in clays are kaolinite (a soapy-feeling and lightweight mineral), talc, pyrophyllite, all types of micas, minerals from the chlorite group, feldspars, and a lesser amount of tectosilicates (including quartz).

The mineral content of clays is less variable than other types of sedimentary rock. This is a direct result of the way clays are formed. Water carries the bulk of sediments to their resting place where they are cemented together. The transport of sediments is directly related to the force or velocity of water carrying them. The stronger the velocity of water, the larger and heavier the particle it can move. Conversely, the weaker the flow, the smaller the particle that is carried by the water. As a result, water acts as a winnowing filter for certain types of minerals. The heavier minerals are not carried as far by water currents as are the lighter ones. When water finally comes to rest, it deposits its load of minerals. The last to be released are the lighter and smaller particles, the clay minerals.

Where rivers meet oceans, the clay minerals are so light they are usually carried far out to sea where they fall gently to the bottom forming a fine-grained sediment. These deposits cover organic materials and trap them at the edges of deltas and continental slopes. Over millions of years, the organic materials convert to petroleum and remain trapped by the clays. This relationship makes the study of clays extremely important for petroleum geologists. In addition to this important economic consideration, clays provide important economic resources for a wide variety of other industries.

Depending on the academic source, there are three or four main groups of clays: kaolinite, montmorillonite, smectite, illite, and chlorite. Chlorites are not always considered a clay, sometimes being classified as a separate group within the phyllosilicates. There are approximately 30 different types of "pure" clays in these categories, but most "natural" clays are mixtures of these different types, along with other weathered minerals.

Varve (or varved clay) is clay with visible annual layers, formed by seasonal differences in erosion and organic content. This type of deposit is common in former glacial lakes. When glacial lakes are formed there is very little movement of the water that makes the lake, and these eroded soils settle on the lake bed. This allows such an even distribution on the different layers of clay.
Quick clay is a unique type of marine clay indigenous to the glaciated terrains of Norway, Canada, Northern Ireland, and Sweden. It is highly sensitive clay, prone to liquefaction, which has been involved in several deadly landslides.

Clays exhibit plasticity when mixed with water in certain proportions. When dry, clay becomes firm and when fired in a kiln, permanent physical and chemical changes occur. These reactions, among other changes, cause the clay to be converted into a ceramic material. Because of these properties, clay is used for making pottery items, both utilitarian and decorative. Different types of clay, when used with different minerals and firing conditions, are used to produce earthenware, stoneware, and porcelain. Prehistoric humans discovered the useful properties of clay, and one of the earliest artifacts ever uncovered is a drinking vessel made of sun-dried clay. Depending on the content of the soil, clay can appear in various colors, from a dull gray to a deep orange-red.

Clay tablets were used as the first known writing medium, inscribed with cuneiform script through the use of a blunt reed called a stylus.

Clays sintered in fire were the first form of ceramic. Bricks, cooking pots, art objects, dishware, and even musical instruments such as the ocarina can all be shaped from clay before being fired. Clay is also used in many industrial processes, such as paper making, cement production, and chemical filtering. Clay is also often used in the manufacture of pipes for smoking tobacco. Until the late 20th century bentonite clay was widely used as a mold binder in the manufacture of sand castings.

Clay, being relatively impermeable to water, is also used where natural seals are needed, such as in the cores of dams, or as a barrier in landfills against toxic seepage (lining the landfill, preferably in combination with geotextiles).

Recent studies have investigated clay’s absorption capacities in various applications, such as the removal of heavy metals from waste water and air purification.

2.3.3. Rock

To the geologist, the term rock means a naturally occurring aggregate of minerals that may include some organic solids (e.g., fossils) and/or glass. Rocks are generally subdivided into three large classes: igneous, sedimentary, and...
metamorphic. These classes relate to common origin, or genesis. Igneous rocks form from cooling liquid rock or related volcanic eruptive processes. Sedimentary rocks form from compaction and cementation of sediments. Metamorphic rocks develop due to solid-state, chemical and physical changes in pre-existing rock because of elevated temperature, pressure, or chemically active fluids.

With igneous rocks, the aggregate of minerals comprising these rocks forms upon cooling and crystallization of liquid rock. As crystals form in the liquid rock, they become interconnected to one another like jigsaw puzzle pieces. After total crystallization of the liquid, a hard, dense igneous rock is the result. Also, some volcanic lavas, when extruded on the surface and cooled instantaneously, will form a natural glass.

![Sample of igneous gabbro, Rock Creek Canyon, California](source Wikimedia)

Glass is a mass of disordered atoms, which are frozen in place due to sudden cooling, and is not a crystalline material like a mineral. Glass composes part of many extrusive igneous rocks (e.g., lava flows) and pyroclastic igneous rocks. Alternatively, some igneous rocks are formed from volcanic processes, such as violent volcanic eruption. Violent eruptions eject molten, partially molten, and non-molten igneous rock, which then falls in the vicinity of the eruption. The fallen material may solidify into a hard mass, called pyroclastic igneous rock. The texture of igneous rocks (defined as the size of crystals in the rock) is strongly related to cooling rate of the original liquid. Rapid cooling of liquid rock promotes formation of small crystals, usually too small to see with the unaided eye. Rocks with this cooling history are called fine-textured igneous rocks. Slow cooling (which usually occurs deep underground) promotes formation of large crystals. Rocks with this cooling history are referred to as coarse-textured igneous rocks.

The mineral composition of igneous rocks falls roughly into four groups: silicic, intermediate, mafic, and ultramafic. These groups are distinguished by the amount of silica (SiO$_4$), iron (Fe), and magnesium (Mg) in the constituent minerals. Mineral composition of liquid rock is related to place of origin within the body of the earth. Generally speaking, liquids from greater depths within the earth contain more Fe and Mg and less SiO$_4$ than those from shallow depths.

In sedimentary rocks, the type of sediment that is compacted and cemented together determines the rock's main characteristics. Sedimentary rocks composed of sediment that has been broken into pieces (i.e., clastic sediment), such as gravel, sand, silt, and clay, are clastic sedimentary rocks (e.g., conglomerate, sandstone, siltstone, and shale, respectively). Sedimentary rocks composed of sediment that is chemically derived (i.e., chemical sediment), such as dissolved elements like calcium (Ca), sodium (Na), iron (Fe), and silicon (Si), are chemical sedimentary rocks. Examples
of chemical sedimentary rocks are limestone (composed of calcium carbonate), rock salt (composed of sodium chloride), rock gypsum (composed of calcium sulfate), ironstones (composed of iron oxides), and chert (composed of hydrated silica). Biochemical sedimentary rocks are a special kind of chemical sedimentary rock wherein the constituent particles were formed by organisms (typically as organic hard parts, such as shells), which then became sedimentary particles. Examples of this special kind of sedimentary rock include chalk, fossiliferous limestone, and coquina. Sedimentary rocks are formed from sediment in two stages: compaction and cementation. Compaction occurs when sediments pile up to sufficient thickness that overlying mass squeezes out water and closes much open space. Cementation occurs when water flowing through the compacted sediment deposits mineral crystals upon particles thus binding them together. The main cement minerals are calcite (CaCO₃), hematite (Fe₂O₃), and quartz (SiO₂).

With metamorphic rocks, the nature of the pre-existing rock (protolith) determines in large part the characteristics of the ultimate metamorphic rock. Regardless of protolith, however, almost all metamorphic rocks are harder and more dense than their protoliths. A protolith with flat or elongate mineral crystals (e.g., micas or amphiboles) will yield a metamorphic rock with preferentially aligned minerals (due to directed pressure). Such metamorphic rocks are called foliated metamorphic rocks (e.g., slate and schist). Non-foliated metamorphic rocks (e.g., marble and quartzite) come from protoliths that have mainly equidimensional mineral crystals (e.g., calcite and quartz, respectively). For example, a protolith shale will yield a foliated metamorphic rock, and a protolith limestone will yield marble, a non-foliated metamorphic rock. Metamorphic rocks possess distinctive grades or levels of metamorphic change from minimal to a maximum near total melting. Low-grade metamorphic rocks generally have fine-textured crystals and low-temperature indicator minerals like the mica chlorite. High-grade metamorphic rocks generally have coarse-textured crystals and very distinctive foliation, plus high-temperature indicator minerals like the silicate mineral staurolite.

Rock is a brittle natural solid found mainly in the outer reaches of Earth's crust and upper mantle. Material that would be brittle rock at such shallow depths becomes to one degree or another rather plastic within the body of the earth. The term "rock" is not generally applied to such non-brittle internal Earth materials. Therefore, rock is a concept related to the outer shell of the earth. The term rock may also be properly applied to brittle natural solids found on the surfaces of other planets and satellites in our solar system. Meteorites are rock. Naturally occurring ice (e.g., brittle water ice in a glacier, H₂O) is also a rock, although we do not normally think of ice this way. Rock has been an important natural resource for people from early in human evolution. Rocks' properties are the key to their specific usefulness, now as in the past. Hard, dense rocks that could be chipped into implements and weapons were among the first useful possessions of people. Fine-textured and glassy rocks were particularly handy for these applications. Later on, rock as building stone and pavement material became very important, and this continues today in our modern world. All of Earth's natural mineral wealth, fossil energy resources, and most groundwater are contained within rocks of the earth's crust.

Rock is a natural occurrence mass of cohesive organic or inorganic material, which forms a part earth crest of which most rocks are composed of one or more minerals. Rocks can be classified in different ways. The most used classification is based on their origin, in which the following classes can be distinguished.

Igneous rock; a rock that has solidified from molten rock material (magma), which was generated within the Earth. Well known are granite and basalt

Sedimentary rock; a rock formed by the consolidation of sediment settle out in water, ice of air and accumulated on the Earth's surface, either on dry land or under water. Examples are sandstone, lime stone and clay stone Metamorphic
rock; any class of rocks that are the result of partial or complete recrystallization in the solid state of pre-existing rocks under conditions of temperature and pressure that are significantly different from those obtaining at the surface of the Earth.

When determining the dredge-ability of rock, distinction has to be made between the properties of intact rock and that of a rock mass. Depending on the fracture density of the rock the cutter will cut intact rock or break out rock blocks.

In the first case the strength (tensile- and compressive strength), deformation properties (E-value) and the petrography (mineralogical proposition) of the intact rock determines the production completely. The second case the fracture frequency and the weathering of the rock is more important than the strength of the intact rock. It is known that the absence of water in rock is important for the rock strength. When saturated with water the rock strength can be 30 to 90% of the strength of dry rock. Therefore rock samples have to be sealed immediately after drilling in such a way that evaporation of or intake of water is avoided. It has to be mentioned that this does not mean that cutting forces in saturated rock are always lower than in dry rock. The petrography is important for the weir of rock cutting tools.

Figure 2-12: Sandstone formations, Vermillion Cliffs, Arizona (source www.reddit.com).

Figure 2-13: Columns of Basalt of the Scottish Island of Staffa (National Geographic).
Figure 2-14 A: Aid to identification of rock for engineering purposes (After BS 5930:1981).

Figure 2-15 B: Aid to identification of rock for engineering purposes (After BS 5930:1981).
Figure 2-16: Utica Shale, Fort Plain, New York (Wikipedia).

Figure 2-17: The rock formation cycle (galleryhip.com).