Mudstone

Mudrocks are fine grained sedimentary rocks consisting of mostly silt and clay size fragments. They are sometimes called ***argillites***. Because of their small grain size, they are difficult to study, even with the petrographic microscope. But, they are important rocks because they are the most abundant sedimentary rocks, making up over 65% all sedimentary rocks, are likely the source rocks for petroleum and natural gas, and are sometimes valuable ore deposits. In addition, the mudrocks are the ***protoliths (***precursor rock) for aluminous metamorphic rocks, often called ***pelitic*** metamorphic rocks.

Classification

Classification of mudrocks is mainly based on observations one can make in the field or at the level of a hand specimen. The classification depends on the grain size of the minerals making up the rock and whether or not the rock is ***fissile*** or non-fissile. A fissile rock tends to break along sheet-like planes that are nearly parallel to the bedding planes. Fissility is caused by the tendency of clay minerals to be deposited with their sheet structures [(001) crystallographic planes] parallel to the depositional surface.

Grain Size	Description	Fissile Rock	Nonfissile Rock
>2/3 silt	Abundant silt sized grains visible with a hand lens	Silt-shale	Siltstone
>1/3, <2/3 silt	Feels gritty when chewed	Mud-shale	Mudstone
>2/3 clay	Feels smooth when chewed	Clay-shale	Claystone

Texture

Elements of texture that can be observed in mudrocks include the shapes of the grains, the fissility or lack of fissility, and laminations.

- **Grain shape**. Clay minerals are generally angular and sheet like, reflecting their crystal structure, which is also why most mudrocks are fissile. Silt size quartz grains are usually angular or platy shaped. Little rounding occurs because these minerals are so small that they can be kept in suspension in very low energy currents, with little chance of impact with other grains that would normally cause abrasion and rounding.

- **Fissility**. Whether or not a mudrock is fissile or non-fissile depends on several factors.

    1. The abundance of clay minerals. The more clay minerals contained in the rock, the more likely the rock is to be fissile.

    2. The degree of preferred orientation of the clay minerals. Small clay minerals tend to adhere to one another if they collide during transport. The tendency is increased by increased salinity of the water and the presence of organic matter in the water. Adhesion of small mineral grains is referred to as ***flocculation***. If the clay minerals flocculate, then they are less likely to have a preferred orientation,

and thus less likely to form rocks with fissility.

3. Bioturbation of organisms within or on the surface of the sediment can disturb the preferred orientation of clay minerals, and thus lead to a non-fissile rock.

4. If the clay minerals recrystallize during diagenesis they will tend to do so with a preferred orientation with their (001) crystal planes oriented perpendicular to the maximum principal stress direction. (This process also results in slatey cleavage and foliation in metamorphic rocks). If diagenesis occurs shortly after deposition, then it is likely that the maximum principal stress direction will also be oriented perpendicular to the bedding planes.

- **Laminations**. Laminations are parallel layers less than 1 cm thick. Such laminations can be seen as differences in grain size of the clasts in different laminae - due to changes in current velocity of the depositing medium, or could be due to changes in the organic content and oxidation conditions at the site of deposition of the different layers.

Color
Most mudstones fall into two classes in terms of their color.

- **Gray-Black**. Gray to black color of mudrocks usually indicates the presence of more than 1% organic matter in the form of carbon or some carbon compound. If organic matter occurs in the sediment and there is an abundance of oxygen, the carbon would rapidly be oxidized to CO_2. Thus the presence of reduced carbon indicates a reducing condition at the time of deposition or burial. Such reducing conditions usually occur in stagnant water where little circulation takes place. This can occur in restricted seas, in swamps, and in some lakes and lagoons. Reducing conditions are not usually present in the deep oceans, because of the thermohaline circulation of ocean waters that brings water that originated at the surface in the polar regions to the bottoms of the ocean basins. Rapid burial of sediment can also lead to reducing conditions and preservation of carbon and carbon compounds in the rock.

- **Red-Brown-Yellow-Green**. Red, brown, yellow, and green colorations are a reflection of the oxidation state of Fe in the sediments. Under oxidizing conditions most of the Fe will be Fe^{+3} and give the sediment a red coloration as in Hematite (Fe_2O_3). If the Fe^{+3} occurs as Iron hydroxide [FeO(OH)] (geothite) it gives the sediment a brown coloration. Limonite gives the sediment a yellow color. The absence of oxidized Fe allows the green color given to minerals containing Fe^{+2} to show through. Thus, red, brown, and yellow colored mudrocks reflect deposition in an oxidizing environment. Note, however, that it requires very little hematite in a rock to give the rock a red stain or coloration.

Mineralogy
Clay minerals are the most abundant minerals in mudstones, making up over 60% of all mudstones. Other minerals like quartz, feldspar, carbonate minerals, organic compounds (not really minerals), sulfides, and hematite also occur.

- **Clay Minerals**. Three groups of clay minerals occur in sedimentary rocks, and are most easily distinguished using x-ray diffraction techniques as discussed in your mineralogy class.

  - Kaolinites [$Al_2Si_2O_5(OH)_4$] are formed in warm moist climates where Ca, Na, and K ions are leached and removed in solution during the weathering process. Thus, the presence of kaolinite clays indicates a source in a humid tropical climate.

  - Smectites are expanding clays. That is they can expand by taking in water between layers. Montmorillinite-$(\frac{1}{2}Ca,Na)_{0.7}(Al,Fe,Mg)_4Si,Al)_8O_{20}(OH)_4{\cdot}nH_2O$ is a good example. These clays form from weathering of Fe -Mg rich igneous and metamorphic rocks in temperate climates, and are the most abundant clays in modern sediment.

  - Illites - $K_{1-1.5}Al_4Si_{7-6.5}Al_{1-1.5}O_{20}(OH)_4$ - These clays are formed by weathering of feldspars in temperate climates and by alteration of smectite clays during diagenesis. They have a structure similar to muscovite.

  - Mixed layer clays are clays that show interlayering between smectites like layers and illite like layers in the same crystal. These are also common clays in the modern sediment.

  If one looks at mudrocks of various ages, it is observed that Tertiary and younger mudrocks consist mostly of smectites and mixed layer clays, In older mudrocks illite is the dominant clay mineral, and in early Paleozoic and older rocks less than 10% of the clay minerals are smectite clays. This is likely due to diagenetic processes that convert the smectites to illites over time. Such a conversion would involve the release of elements like Si, Ca, Na, Mg, and Fe from the clays. Most of these released elements likely remain in the mudrock and crystallize to form quartz, chlorite, albite, calcite, dolomite, siderite, and ankerite, which are all minerals that occur in mudrocks. Many of these minerals may in fact be products of diagenesis.

- **Quartz**. Most of the quartz that occurs in mudrocks is single crystals. Most of the silt-sized fraction is quartz, but very little of the clay sized fraction is quartz. Single crystal of quartz may originate as detrital grains produced by abrasion of larger grains, may be diagenetically produced during the smectite to illite transformation, or may be recrystallized remains of silica secreting organisms like diatoms and radiolaria.

- Feldspar. Feldspars also occur in the silt-sized fraction of most mudstones, but in very small amounts. The lack of feldspars in mudrocks in comparison to river sediment is due to the unstable nature of feldspar - it continues to weather even after deposition, and due to diagenetic changes that take place in the sediment.

- **Carbonate Minerals**. Carbonate minerals occur in mudrocks with about the same abundance as feldspars. Most is probably calcite and is produced either by diagenesis or as detrital grains produced by foraminefera or other microorganisms.

- **Organic Matter**. As discussed above, deposition in waters with restricted circulation or rapid burial can result in reducing conditions and the preservation of carbon and carbon compounds in mudrocks. In some cases, like oil shales, the carbon compounds undergo further transformations that convert them to hydrocarbons like petroleum. Otherwise, the carbon or carbon compounds generally tend to give the rock a dark gray to black color.

- **Others**. Other minerals, like sulfide minerals, including pyrite, are found in black shales, again produced under reducing conditions, and hematite, likely indicating oxidizing conditions during deposition or diagenesis.

- **Bentonites**. One particular type of mudrock consist of mostly of white colored smectite clays and colloidal silica. These are produced by the alteration of siliceous fine-grained volcanic ash. These often contain small amounts of quartz and sanidine, which likely represented phenocrysts in the ash producing magma. Bentonite layers usually represent pyroclastic fall deposits, and as such they make excellent marker beds, both because they are widespread, and because the sanidine in the ash can be dated by K-Ar methods.

Environments of Deposition

Mudrocks represent texturally and mineralogically mature sediments deposited in low energy environments. The fine grain size of these sediments means that that the sediment can be suspended for long times in relatively quiet, low energy currents. This results in deposition on the abyssal plains of the oceans, at the distal ends of deltas, in quiet lakes and swamps, and as wind blown dust. Large deposits of wind blown dust are called ***loess***, and consist of mostly silt-sized fragments. While the small fragments can be transported into lakes and oceans easily by streams, it is likely that large quantities of these fragments could also reach the oceans by wind transport.
