

Sedimentary rocks come **in three varieties**:

**Clastic** = Greek for ‘broken’ particles called “Clasts”

**Chemical** = precipitates from water

**Biogenic** = composed of the shells, tissues, and skeletons of organisms

Typically, all these rock types **deposited from a fluid medium** (water or air) and show stratification = layering caused by repeated cycles of deposition of sediments

**Clastic Rocks**

Composed of mineral grains, rock fragments, and chemical precipitates (often as cements); can also include pyroclastic rocks and ‘water-laid’ tuffs

Classified by **grain rounding, grain size, sorting, and composition**

**Grain rounding:**

- 1) = degree of sharpness of the grain edges;
- 2) typically increases with length and time of transport
- 3) coarse grained sediments differentiated into “breccia” = angular clasts, and “conglomerate” = rounded clasts

**Size:**

Boulders:	>25.6 cm	
Cobbles	6.4 to 25.6 cm	These Three = conglomerate or breccia
Pebble	2 mm to 6.4 cm	
Sand	0.0625 mm to 2 mm	= Sandstone, Arenites or, if lots of clay = greywacke
Silt	0.0625-0.0039 mm	Siltstone
Clay	<0.0039 mm	Claystone or shale (separated by degree of layering (fissile fracture))

In practice, the silt/clay difference can be determined by feeling the rock—if at all rough or gritty (particularly between the teeth) it is silt, if no, clay

**Sorting:**

Well sorted to poorly sorted = degree of similarity in grain size

Indicates distance of transport and transport mechanisms

Typically, well sorted sediments have been transported farther and longer than poorly sorted sediments since transportation breaks down unstable grains

For example, rarely get sandstones full of clay since the energy to transport sand tends to wash the clay out unless sediments are not transported far.

**Composition:**

Five main components:

- 1. **quartz** Sandstones rich in quartz called “Quartz sandstone”, Quartz arenite” or “Quartzite” (*Arenite* = no clay, *Wacke* = clay bearing)
- 2. **feldspar** Sandstones rich in feldspar called “Arkose” or “arkosic sandstone”

3. **rock fragments** (Called “*Lithics*”; sandstones rich in lithics called “lithic sandstone” or greywacke)
4. **heavy minerals—magnetite**
5. **cements** (usually carbonates or silica)

*Unstable grains* = rock fragments and feldspars (as well as mafic minerals); susceptible to chemical weathering and physical fragmentation during transport

*As transport energy increases, and distance of transport increases*, have loss of fines, better sorting, better rounding, and loss of unstable minerals

“**Mature**” versus “**immature**” clastic rocks

### Chemical Sediments

Inorganic and biologically-mediated precipitates

Plants and bacteria can reduce the pH of water causing carbonates to precipitate

- a. For example:  $\text{H}_2\text{O} + \text{CO}_2 = \text{H}_2\text{CO}_3$  (Carbonic acid)
- b. Calcite ( $\text{CaCO}_3$ ) +  $\text{HCO}_3^-$  (Carbonic acid =  $\text{Ca} + 2\text{HCO}_3^-$ ) (Bicarbonate)

Evaporation, reduced temperature, or reduced pressure can cause super-saturated solutions to dump their mineral load—often get salts this way

### Biogenic sediments

Remains of organisms: two main types:

1. **skeletal sediments** (composed of skeletons (usually silica or carbonates) to form *carbonate ooze*, *bioclastic sediment* (coarse-grained carbonate skeletons), and *siliceous ooze*; when lithified (cemented) become *limestone* and *chert*)
2. **organic rocks** = coal and oil shale (more than ~50% organic matter)

### Turning sediments to rocks

Three processes:

1. **Compaction**—reducing pore space and squeezing the clays and rock fragments around more stable mineral grains; rock fragments break down to form clays; caused by loading beneath other sediments

*The “greywacke’ paradox:* How can a sandstone be full of clay?—

*Answer:* it started off as a lithic sandstone, but the lithics broke down to clays during compaction.

2. **Cementation**—precipitation of calcium carbonate, silica or sometimes oxides—fills in pore space, starting where grains touch and continuing to fill larger spaces

3. **Recrystallization**—as burial pressures increase, unstable minerals may alter to form more stable minerals or larger sized crystals—carbonates and siliceous oozes often recrystallize;
  - a. **Chert** forms by dissolution and re-precipitation of silica as burial temperatures and pressures increase—get a phase transformation first, Opal-a to Opal c-t followed by growth in crystals (to cryptocrystalline quartz (chert))
  - b. In carbonates: biogenic calcareous ooze goes to chalk, goes to limestone with increase in cementation and recrystallization
  - c. **Dolomite** forms by replacement of original calcite when Mg+ replaces part of the Ca ions.

## Sedimentary Structures

### Sediments occur in 'strata' or layers

Layers have internal structure:

1. **Massive bedding**—no internal structure
2. **Graded bedding**--coarser material at bottom of bed (normally graded) or at top (inversely graded)
3. **Cross-stratification**—formed by migrating ripples, dunes, or sediment waves—curved surfaces that are concave in the direction of sediment transport and ripple movement
  - a. Cross-stratification can be a variety of scales from small ripple sets to 3-5 m high dune foresets
4. **Climbing ripples**—indicator of rapid sedimentation since sediment supply overcomes erosion
5. **Sole marks**—scratches or 'prod-marks' on the base of rapidly deposited beds caused by pieces of rock or wood being dragged along by a rapidly flowing current
6. **Mud cracks**—polygonal cracks often filled with mud or sand indicating wetting-drying cycles
7. **Tracks and trails**—**underprints** caused by compaction of sediment beneath a foot, or can have horizontal or vertical burrows—often filled with different type of sediment—appear *circular or oval* in cross-section

## **Facies**

Strata characteristic of particular environments

**Walther's law:** Facies that represent adjacent environments will tend to occur adjacent to each other; e.g. stream channel sandstones and floodplain deposits; beach sands, marsh mud and back-beach dune deposits

### **Large scale depositional pattern:**

1. **Fining-upward sequences**—sedimentary layers become progressively finer-grained up section
2. **Coarsening upward sequences**—become coarser upwards
  - a. These sequence types indicate increasing or decreasing distance from the sediment source
3. **Onlap**—strata that pinch-out up onto a surface
4. **Offlap**—strata pinching out down on a surface
5. **Channels**—erosion surfaces that are half-moon shaped with erosional bases
6. **Reefs**—organic build-ups that interfinger with fine-grained sediments; these can be wave-resistant structures or can form below the depth of storms (deep-water reefs)

## **Characteristics of Sedimentary Facies**

### **Alluvial fans**

1. coarsening-upward with few small-scale sedimentary structures
2. boulders often not well rounded (short transport distance)
3. poorly sorted with abundant rock debris (also short transport)
4. little soil and few fossils
5. red sediment owing to oxidation of iron by the air (typical for non-marine sediments)
6. lap up against mountain bedrock

### **Stream deposits**

1. sandstones with conglomerate in channels
2. cross bedding common
3. sands often pink with Fe-oxides, can be well sorted
4. interbedded with siltstone and claystone representing overbank deposits or pond-fillings
5. soils may be present, particularly in fine-grained overbank or marsh deposits
6. fossils in overbank deposits or at the bases of channels
7. may have coal
8. both fining-upward and coarsening-upward sequences due to stream channel migration

### **Sand dunes**

1. well sorted sandstones
2. large scale cross bedding (1 m or more high)
3. discontinuous soils in blowouts,
4. tracks and trails in low areas between dunes

### **Shoreline deposits**

1. *fine-grained* clay and mud rich in *organic matter* and *root marks* (back beach marsh)
2. marsh sediments also have *abundant fossils* of brackish-water oysters and snails (low diversity), *wood* common, sometimes *mud cracks*
3. channels filled with sand or silt,--red or pink if in freshwater, yellow or green in salt water
4. beach is *well sorted* sand, *few fossils*, *planar lamination*
5. Foreshore (Plunge zone in breakers): gravelly to coarse sand, cross-bedding and few burrows, yellow sand
7. offshore sands—sandstone and siltstone, burrowed, high fossil diversity, cross-bedded or massive beds depending upon water depth,

### **Reef systems**

1. nearshore settings may be sandy (like the beaches above) or may consist of “lime mud”
2. lagoonal lime mud with few types of fossils, laminated beds, mud cracks, stromatolites, often gray or black with Fe-pyrite., sometimes chert
3. reef composed of massive limestone with diverse fossils, no stratification commonly with lots of pore space, even caverns where carbonates have been dissolved away
4. fore reef—blocks of reef limestone in lime mud, massive layers, contorted bedding associated with slides or slumps
5. Offshore—fine grained lime mud with abundant fossils, massive bedding (often highly burrowed), sometimes chert

### **Deep Marine—Submarine Canyon fills**

1. well stratified with beds of regular thickness and laterally extensive
2. Channels filled with cobbles and pebbles, often poorly sorted with abundant fine grained sediment
3. abundant sole marks
4. fining-upward and coarsening upward cycles
5. few fossils (other than microfossils), but trace fossils common on bedding surfaces
6. beds frequently show graded-bedding (“Bouma Sequences”) from  
**Turbidity currents**

### **Deep Sea**

1. fine grained carbonate/siliceous limestone or red clay

2. massive bedding with abundant burrows
3. few large fossils, but microfossils may be abundant
4. chert nodules common
5. gradual upward gradation from biogenic sediments to red clay

### **Tectonic Settings**

Putting it all together

### **Mid Ocean Ridges**

Typical sequence:

1. pillow basalts (perhaps mixed with some calcareous sediment)
2. umbers (metal-rich sediments blown out of black smokers and hydrothermal vents)
3. deep sea carbonates
4. siliceous sediment or chert
5. red clay with mn-nodules

Reflects the gradual subsidence of the originally hot, buoyant ocean crust into deeper water where carbonates are dissolved

### **Ocean-Continent**