Sedimentary Rock and the Production of Sediment

**Sedimentology** = scientific study of sediments and sedimentary rocks. Includes production of sediment, transport, deposition, & lithification. Provides the basis for geological interpretations of earth-surface signals.

**Stratigraphy** = scientific study of sedimentary strata

Sedimentary rocks have an average thickness of about 1800 m on the continents. This thickness is quite variable, with some areas like the Canadian Shield having no cover of sedimentary rocks, and other areas, like the Louisiana and Texas Gulf coasts, having more than 20,000 m of sedimentary rock cover.

About 66% of all continental areas have a cover of sedimentary rocks.

Older sedimentary rocks are exposed over a smaller area than younger sedimentary rocks. Over 40% of the exposed sedimentary rocks are younger than Cretaceous in age.

I. Three Rock Types: Sedimentary, Metamorphic, Igneous

II. Types of Sedimentary Rocks:

**A. Clastics (fragmental)**

- Detrital Particles
- Derived from pre-existing rocks
- Derived external to the depositional basin
**B. Chemical: Allochemical Particles** biochemical origin
Ooids, fossil fragments, pellets, pelagic tests (siliceous and calcareous)

![Image of allochemical particles]

**C. Chemical: Orthochemical Components**
Chemical Precipitates
Secondary cement
Primary chemical sediments: halite, etc

**D. Organic Particulate Material (detrital organic matter)**
terrestrial and particulate marine pelagic

![Image of organic particulate material]

Coal

Structureless gypsum.
III. Class sizes: GRAIN SIZE SCALES FOR SEDIMENTS

The grade scale most commonly used for sediments is the Wentworth scale (actually first proposed by Udden), which is a logarithmic scale in that each grade limit is twice as large as the next smaller grade limit. For more detailed work, sieves have been constructed at intervals $\sqrt{2}$ and $\sqrt[3]{2}$. The $\phi$ (phi) scale, devised by Krumbein, is a much more convenient way of presenting data than if the values are expressed in millimeters, and is used almost entirely in recent work.

<table>
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Figure by MIT OCW.

Courtesy of MIT OCW. Used with permission.
VI. Sorting: refers to range of sizes in a rock. Well sorted vs. moderately sorted vs poorly sorted

VII. Rounding: angular vs. subangular vs subrounded vs rounded

VIII. Sediment vs, Sedimentary rock:

- gravel vs. conglomerate
- sand vs. sandstone
- silt vs siltstone
- clay vs claystone (or shale)
- fine grained (silt and mud) rock is commonly referred to as mudstone

Courtesy of SEPM (Society for Sedimentary Geology). Used with permission.

IX. Sandstone Composition

Field composition terms for sandstone:
Quartzite (>50% quartz grains);
Arkose or Feldspathic sandstone (<50% quartz & more feldspar than lithic grains);
Lithic sandstone (<50% quartz & more lithic grains than feldspar).

provenance (determining source areas)

Earth surface can be thought of as a giant chemical reactor.
About 20% of earth's crust is composed of quartz, > 60% is feldspar.
However, Quartz is dominant mineral in siliciclastic rocks.

Bottom line. The geochemistry of sedimentary rocks is less complicated than that of igneous and metamorphic rocks.

WEATHERING AND SEDIMENTARY ROCKS

Weathering - Processes acting at the earth's surface to decompose and breakdown rocks.

Types of Weathering

Mechanical or Physical - the breakdown of rock material into smaller and smaller pieces with no change in the chemical composition of the weathered material.

Chemical - the breakdown of rocks by chemical agents (e.g., water).

Physical weathering breaks rocks down into smaller pieces thus increasing the surface area over which chemical weathering can occur.

Relative Contributions:
Mechanical: $5.6 \times 10^{15}$ g/yr
Chemical: $4.0 \times 10^{15}$ g/yr

Roughly equal, but not equally distributed over earth surface.

Production of Sediment via Weathering

Controls
Precipitation
Temperature
Relief

Dependant on
Latitude
Geography
Oceanography
Physical Weathering is most significant in:
- Cold
- dry
- high relief areas

Protolith composition influences sediment production rate

Thermal Expansion and Contraction – leads to fracturing
Frost Action - Water in cracks freezes and expands, wedging apart rocks.
Abrasion – Impacts and grinding by moving particles.
Organic - Cracking of rocks by plant roots and burrowing animals.

Chemical Weathering
Factors influencing rate of chemical weathering are:
-Particle size - Smaller the particle size the greater the surface area and hence the more rapid the weathering
-Composition
-Climate - temperature, water
-Type and amount of vegetation

The three common chemical reactions associated with chemical weathering are dissolution, hydrolysis, and oxidation.
**Dissolution**
Dissolution of soluble minerals, commonly in the presence of CO₂. Cations and anions in solution are transported by fluid away leaving a space in the rock (e.g., caves in limestone).

\[ \text{CaCO}_3 + \text{H}_2\text{O} + \text{CO}_2 \leftrightarrow \text{Ca}^{2+} + 2\text{HCO}_3^- \]

**Formation of carbonic acid**
Carbon dioxide (CO₂) from the air is dissolved in rainwater to create a weak acid, **carbonic acid** (H₂CO₃). All rain is mildly acidic (average pH ~5.6).

Interlinked reactions for combining water and carbon dioxide and the two-stage ionization (dissociation) of carbonic acid:

\[ \text{H}_2\text{O} + \text{CO}_2 \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{HCO}_3^- \leftrightarrow 2\text{H}^+ + \text{CO}_3^{2-} \]

**Hydrolysis**
Feldspar, the most common mineral in rocks on the earth's surface, reacts with free hydrogen ions in water to form a secondary mineral such as kaolinite (a type of clay) and additional ions that are in solution.

\[ 4\text{KAISi}_3\text{O}_6 + 4\text{H}^+ + \text{H}_2\text{O} \rightarrow 4\text{K}^+ + 2\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4 + 8\text{SiO}_2 \]
orthoclase + hydrogen ions + water \( \rightarrow \) K⁺ (aq) + kaolinite (clay) + silica

\[ \text{CaAl}_2\text{Si}_2\text{O}_6 + 2\text{H}^+ + \text{H}_2\text{O} \rightarrow \text{Ca}^{++} + \text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4 \]
anorthite + hydrogen ions + water \( \rightarrow \) Ca²⁺ (aq) + kaolinite (clay)

**Simplified global weathering equation (the Urey equation)**

\[ \rightarrow \text{CaSiO}_3 + 3\text{H}_2\text{O} + 2\text{CO}_2 \leftrightarrow \text{Ca}^{2+} + 2\text{HCO}_3^- + \text{H}_4\text{SiO}_4 \]
Calcium silicate system (including Ca-plagioclase)

**Oxidation**
Loss of an electron from an element (commonly Fe or Mn), typically forming oxides or hydroxides.

Loss of electron by a metal {ferrous to ferric state}

\[ 4\text{Fe}^{+2} + 3\text{O}_2 \rightarrow 2\text{Fe}_2\text{O}_3 \]

\[ 4\text{FeSiO}_3 + \text{O}_2 \leftrightarrow 2\text{Fe}_2\text{O}_3 + 4\text{SiO}_2 \]
(pyroxene) (hematite) (silica)
Goldich Weathering Stability Series
Predicts relative abundance of particulate residues produced in a (typical) weathering environment from rock-forming, protolith minerals. Approximately inverse of Bowen’s Reaction Series.

**Most susceptible to weathering**
- Olivine
- Pyroxene
- Amphibole
- Biotite

**Least susceptible to weathering**
- Ca-rich plagioclase
- Na-rich plagioclase
- K-feldspar
- Muscovite
- Quartz

Resistant Particulate Residues
Stable (with respect to surface conditions) primary mineral grains; quartz, feldspar, rock fragments

Ions in Solution
Ions introduced into the surface and ground water by chemical degradation of primary mineral grains

**Congruent solution:**
Produces only ions in solution (NaCl → Na⁺ + Cl⁻)

**Incongruent solution:**
Ions in solution + new mineral phase

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Residual Products</th>
<th>Material in Solution</th>
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<tbody>
<tr>
<td>Quartz</td>
<td>quartz grains</td>
<td>silica</td>
</tr>
<tr>
<td>Feldspar</td>
<td>clay minerals</td>
<td>silica, K⁺, Na⁺, Ca²⁺</td>
</tr>
<tr>
<td>Amphibole (hornblende)</td>
<td>clay minerals, limonite, hematite</td>
<td>silica, Mg²⁺, Ca²⁺</td>
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<tr>
<td>Olivine</td>
<td>limonite, hematite</td>
<td>silica, Mg²⁺</td>
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Insitu Minerals (minerals formed in place)

Clay Minerals: hydrous aluminum silicates

Oxides
- Hematite - iron oxide
- Goethite/Limonite – hydrated iron oxide
- Gibbsite - aluminum hydroxide

Amorphous Silica