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)

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

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 $\sqrt[2]{2}$ and $\sqrt[4]{2}$. The ϕ (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.

U.S. Standard Sieve Mesh #		Millimeters	Microns	ϕ	Wentworth Size Class	
		4096		-12		
		1024		-10	Boulder (-8 to -12 ϕ)	
Use		256		-8		
wire		64		-6	Cobble (-6 to -8 ϕ)	GRAVEL
squares		16		-4	Pebble (-2 to -6 ϕ)	
5		4		-2		
6		3.36		-1.75		
7		2.83		-1.5	Granule	
8		2.38		-1.25		
10		2.00		-1.0		
12		1.68		-0.75		
14		1.41		-0.5	Very coarse sand	
16		1.19		-0.25		
18		1.00		0.0		
20		0.84		0.25		
25		0.71		0.5	Coarse sand	
30		0.59		0.75		
35	½	0.50	500	1.0		
40		0.42	420	1.25		
45		0.35	350	1.5	Medium sand	
50		0.30	300	1.75		
60	¼	0.25	250	2.0		
70		0.210	210	2.25		
80		0.177	177	2.50	Fine sand	
100		0.149	149	2.75		
120	1/8	0.125	125	3.0		SAND
140		0.105	105	3.25		
170		0.088	88	3.5	Very fine sand	
200		0.074	74	3.75		
230	1/16	0.0625	62.5	4.0		
270		0.053	53	4.25		
325		0.044	44	4.5	Coarse silt	
		0.037	37	4.75		
	1/32	0.031	31	5.0		
Analyzed	1/64	0.0156	15.6	6.0	Medium silt	MUD
	1/128	0.0078	7.8	7.0	Fine silt	
by	1/256	0.0039	3.9	8.0	Very fine silt	
		0.0020	2.0	9.0		
Pipette		0.00098	0.98	10.0	clay	
		0.00049	0.49	11.0		
or		0.00024	0.24	12.0		
		0.00012	0.12	13.0		
Hydrometer		0.00006	0.06	14.0		

Figure by MIT OCW.

VI. Sorting: refers to range of sizes in a rock. Well sorted vs. moderately sorted vs poorly sorted


Poorly sorted


Very well sorted

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


Very angular


Sub-rounded


Well rounded

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

after Powers, M . C., 1953, Journal of Sedimentary Petrology, v. 23, p. 118.

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

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: 5.6×10^{15} g/yr
Chemical: 4.0×10^{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
Unloading – causes fracturing. Example: Half Dome, Yosemite, CA.
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 CO_2. Cations and anions in solution are transported by fluid away leaving a space in the rock (e.g., caves in limestone).

$$CaCO_3 + H_2O + CO_2 \leftrightarrow Ca^{2+} + 2HCO_3^-$$

<u>Formation of carbonic acid</u>

Carbon dioxide (CO_2) from the air is dissolved in rainwater to create a weak acid, **carbonic acid** (H_2CO_3). 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:

$$H_2O + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^- \leftrightarrow 2H^+ + CO_3^{2-}$$

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.

$$4KAlSi_3O_8 + 4H^+ + H_2O \rightarrow 4K^+ + 2Al_2Si_2O_5(OH)_4 + 8SiO_2$$

orthoclase + hydrogen ions + water → $K^+_{(aq)}$ + Kaolinite (clay) + silica

$$CaAl_2Si_2O_8 + 2H^+ + H_2O \rightarrow Ca^{++} + Al_2Si_2O_5(OH)_4$$

anorthite + hydrogen ions + water → $Ca^{++}_{(aq)}$ + Kaolinite (clay)

Simplified global weathering equation (the Urey equation)

$$CaSiO_3 + 3H_2O + 2CO_2 \leftrightarrow Ca^{2+} + 2HCO_3^- + H_4SiO_4$$

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}

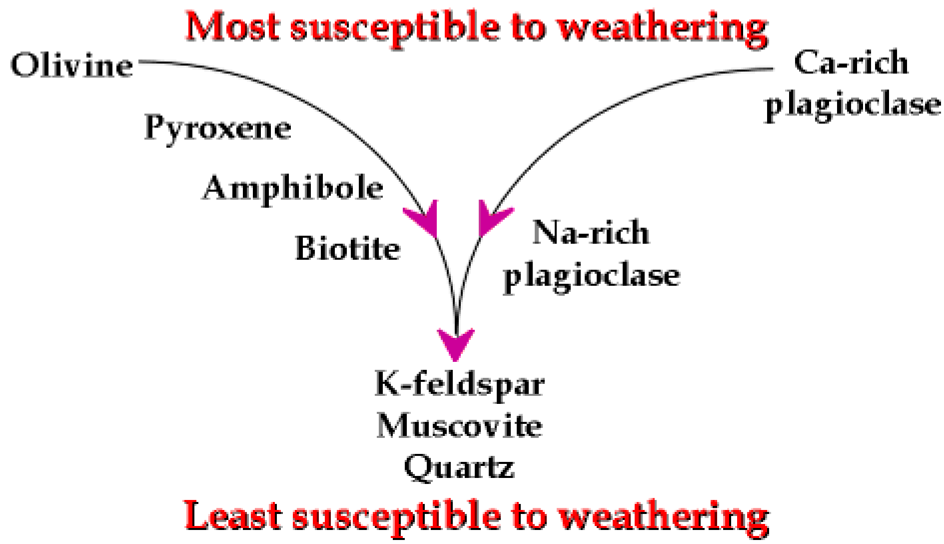
$$4Fe^{+2} + 30_2 \rightarrow 2Fe_2O_3$$

$$4FeSiO_3 + O_2 \leftrightarrow 2Fe_2O_3 + 4SiO_2$$

(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.



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 ($NaCl \rightarrow Na^+ + Cl^-$)

Incongruent solution :

Ions in solution + *new mineral phase*

Mineral	Residual Products	Material in Solution
Quartz	quartz grains	silica
Feldspar	clay minerals	silica, K^+, Na^+, Ca^{2+}
Amphibole (hornblende)	clay minerals, limonite, hematite	silica, Mg^{2+}, Ca^{2+}
Olivine	limonite, hematite	silica, Mg^{2+}

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