Overview of Sedimentary Rocks

I. Basic Definitions

A. Denudation of the Earth's surface

1. Dynamic interaction between uplift of Earth's crust and erosion of materials

B. Weathering - disintegration and decomposition of rock at or near the surface of the earth, fragmenting rock into particles
   1. Physical Weathering - physical breakdown
   2. Chemical Weathering - chemical weathering and dissolution

C. Sediment - fragments of rocks and/or minerals that are produced from the weathering of pre-existing rock
   1. Examples: clay, silt, sand, gravel, boulders

D. Erosion - incorporation and transportation of sediment by a mobile agent
   1. Agents of Transportation
      a. wind (e.g. sand dunes, atmosperic dust)
      b. water (rivers, coastal areas)
      c. ice (glaciers)
      d. gravity

E. Mass wasting - transfer of rock material downslope under the influence of gravity

II. Weathering - surface processes operating on rock from the earth's crust

A. Driving mechanism of rock weathering
   1. Igneous and metamorphic rocks
      a. Form at High temperature, High pressure
   2. Rock exposure at Earth's surface
      a. uplift and denudation
   3. Surface: low temperature / low pressure environment
      a. Water-rich environment
   4. High temp / high pressure rocks are unstable in water-rich, low temp/low press. environment of Earth's surface
      a. Weathering drives system to new equilibrium state

B. Physical or Mechanical Weathering

   1. defined: physical diminution or fragmentation of the rock
      a. sediment = fragmented rock particles
      b. sediment composition is controlled by the mineralogy of the parent rock that was subject to weathering

         (1) e.g. weathering of granite produces sediment rich in feldspar and quartz

   2. Frost Wedging - process of alternate freezing and thawing of water/moisture contained in cracks and fractures of rock.

      a. liquid water to ice: ~9% volume expansion
      b. "wedging" apart pieces of rock to form sediment

(1) e.g. TALUS SLOPES - found at base of cliffs or mountain fronts

3. Unloading or release of overburden pressure - particularly common in weathering of granite bodies, e.g. Yosemite National Park.
   a. rock expansion as it is exposed and "unroofed" at the Earth's surface via denudation

   b. Sheeting - rock breaking into concentric, onion-like slabs

4. Thermal Expansion - rock heating / differential expansion
   a. Hot desert regions (e.g. Death Valley)
   b. Forest Fire

5. Organic/Biologic Activity - activities of plants, animals, and humans can act as a weathering agent.
   a. root wedging
   b. burrowing organsims

C. Chemical Weathering

1. Defined - complex chemical processes at the surface of the earth that alter the internal atomic structure of minerals by removing and/or adding elements.

   a. Chemical agents of weathering:

      (1) Water - H_2O - universal solvent
         (a) dipolar molecule

      (2) Carbon dioxide - CO_2 - Carbon dioxide dissolved in water (H_20), produces carbonic acid (H_2CO_3),

         (a) hydrogen in the acid readily displaces any metal ions in minerals and results in producing clay minerals (hydrous aluminum silicates).

   b. Clay Minerals - the stable end product of chemically weathering silicate minerals ("igneous minerals")

      (1) "Clay" - two uses of the term
         (a) a grain size term (very fine mud particles)
         (b) a mineral family
            i) hydrous layered minerals
            ii) stable minerals at Earths' surface

2. Stable vs. Unstable Minerals

   a. the higher the temperature of mineral formation, the less stable the mineral is chemically at the Earth's surface
   b. vice - versa, lower-termp. minerals are more stable

      (1) e.g. quartz is very stable at Earth's surface
         (a) commonly forms sand at the beach

D. Rates of Weathering (How fast, over time, rocks weather)

1. Factors influencing rates

   a. Particle size -
      (1) small particles = faster reaction (greater surface area)
      (2) large particles = slower reaction

   b. Mineral Composition - different minerals have different resistance to weathering
      (1) based on atomic structure, quality of chemical bonds, and temperatures as which mineral crystallize

   c. Climatic factors influence weathering

      (1) Freeze-thaw climate
         (a) Canada - Yes / Brazil - No
      (2) Chemical weathering climate
         (a) hot, humid, abundant rainfall = yes!
         (b) cold / arid = no!

III. Sedimentary Rocks

A. Sedimentary Rocks- rocks that are derived and formed at the earth's surface.

1. "sedimentary" - latin root means "settling" - e.g. sediment settling in water

2. A process of weathering in which the atmospheric processes at the earth's surface slowly disintegrate and decompose the igneous rocks. Sediment is generated (e.g. sand or gravel) via weathering and subsequently transported by running water, gravity, waves, glaciers, wind and sediment is deposited. After sediment is lithified or cemented into solid rock (analogous to concrete).

3. Sed. rocks account for only 5% of the earth's crust/lithosphere, however they cover 75% of the earth's surface exposures. The sedimentary environment is a surface environment (at surface pressures and temperatures)

4. Rock Interpretation = reconstruction of ancient sed. environments (e.g. river, shallow ocean, deep ocean, lagoon, lake, swamp).
   (1) fossils

5. Sedimentary rocks are where we find many natural resources such as coal and oil, also many ore minerals are found in sedimentary rock "hosts".

B. Basic Terminology

1. Weathering - disintegration and decomposition of rock at or near the surface of the earth, fragmenting rock into particles

2. Sediment - fragments of rocks and/or minerals that are produced from the weathering of pre-existing rock

3. Erosion - incorporation and transportation of sediment by a mobile agent, usually water, wind, or ice.

4. Lithification - refers to the process of converting loose sediment or mud into solid rock.

a. compaction - as sediments accumulate and become buried with time, the weight of overburden compact the sediment

(1) clay minerals are cohesive (sticky) and serve as a binding agent for sediment
(2) compaction also involves dehydration and hardening of sediment into rock

b. cementation - solutions carry ions into pours between sediments, with time ions may be precipitated as cements under appropriate chemical condition.

(1) Common cements include calcite, silica, and iron oxide.

C. Sedimentary Rock Types/Classification

Detrital vs. Chemical Sedimentary Rocks.

1. Detrital Sedimentary Rocks: "Detrital" = Fragmented Origin.

a. Composition: sediments composed of quartz, clay, feldspars, and associated array of just about any other mineral in lesser proportions (e.g. amphibole, or any of silicate/igneous minerals, as well as recycled sedimentary rocks).

(1) E.g. Granite is weathered - produces quartz, and feldspars, plus mica: quartz is most resistant mineral and as a result is most common remnant product.

(2) the composition of the original rock (ig., sed., met.) that is weathered will have a direct influence on the composition of the sediment/sed. rock that results.

b. Texture of Sediment - size, shape and arrangement of sediment grains in the rock

(1) Sediment Size Classification (i.e. Average Diameters of Particles)

Sediment Size	Resulting Rock
Clay = < 1/512 mm = < 0.002 mm	Shale or Mudstone
Silt = 1/512 - 1/16 mm = 0.002 - 0.0625 mm	Siltstone
Sand = 1/16 - 2 mm = 0.0625 -2.0 mm	Sandstone
Gravel = >2.0 mm	Conglomerate / Breccia
Pebbles= 2.0 - 64 mm	
Cobbles = 64 - 256 mm	
Boulders = >256 mm	

(2) Grain Shape

(a) Angular vs. Rounded Grains
i) Rounded Grains = more transport / tumbling
(b) Spherical vs. Non-spherical Grains

(3) Grain Sorting

(a) Degree to which grains are same size

i) poorly sorted sediment - different sizes
ii) highly sorted sediment - same size

c. Detrital Rock Types (shale, sandstone, conglomerate)

(1) Shale - detrital sed. rock consisting of lithified clay and silt sized particles, very small particles < 1/16 mm (must use microscope to see particles),

(2) Sandstone - detrital sed. rock made up of sand sized grains.

(3) Conglomerate - lithified gravels (boulders, to pea sized sediment), often poorly sorted with finer sediment between gravel.

2. Chemical / Biochemical Sedimentary Rocks -

a. Processes
(1) Chemical sediments may be directly precipitated under high concentrations of ions in water (e.g. halite/rock salt), or
(2) ions may be "fixed" by organisms living in the water in shells, accumulation of shells may then provide material for chemical sedimentary rock.

b. Texture of Chemical Sedimentary Rocks
(1) Crystalline Texture
(a) sugary appearance, crystals visible to eye
(b) interlocking mineral crystals
(2) Microcrystalline Texture
(a) crystalls too small to see, need microscrope

c. Limestone - composed of a mosaic of the mineral calcite ($CaCO3$) and forms by either chemical precipitation or biochemical processes. Biochemical processes account for 90% of the limestones.

d. Dolomite - similar to limestone, but has Mg incorporated into $CaCO3$, $CaMgCO3$.

e. Chert - $SiO2$, microscrystalline silica deposited from solution in open ocean.

f. Evaporites - chemical sed. rock that result from precipitation of minerals via evaporation of water.

(1) E.g. halite/rock salt ($NaCl$) and Gypsum ($CaSO4$). Commonly associated with shallow seas and brine lakes (e.g. Salt Lake).

g. Ironstone - composed of iron-bearing minerals (hematite, limonite)

h. Coal - carbon-based rock derived from plant material
(1) Bituminous coal - "soft coal", black
(2) Anthracite coal - "hard coal", brownish
(3) Lignite - "brown" immature coal
(4) Peat - brown / compressed plant debris

3. Other Terms

a. Clastic vs. nonclastic -

(1) clastic = fragmental. E.g. sandstone is a clastic detrital rock, fossiliferous limestone is a clastic chemical rock,

(2) non-clastic = massive, crystalline appearance; if limestone has no fossils evident, then would be considered non-clastic.

4. Sedimentary Rock Classification System

a. Detrital Rocks - distinguished mainly by grainsize and grain composition (mineralogy of grains)

(1) subdivided on basis of texture and composition

b. Chemical Rocks - distinguished mainly by composition of minerals (halite, gypsum, chert)

(1) subdivided on basis of chemical composition / mineralogy

c. Biochemical Rocks - fossil-based, made up of shells or skeletal fragments

(1) subdivided on basis of grain size / crystallinity

Overview of Sedimentary Structures and Sedimentary Environments

IV. Basic Concepts

A. Spectrum of Sedimentary Processes
1. Weathering / Erosion (Sediment Creation)
2. Transportation of Sediment
a. Energy Driven
(1) Mechanical Energy (Gravity)
b. Increase energy, increase mass that can be transported
(1) e.g. boulder transport requires greater system energy that silt
c. Transportation: Results from critical Energy Thresholds
3. Deposition of Sediment
a. Transport Energy Decreases below Critical Threshold = "Deposition"
b. Deposition = "settling"
4. Sedimentary Layering ("Stratification")
a. Sediments are layered (stratified) through time, due to influence of gravity
5. Sediment Burial
a. Burial results from continued deposition
(1) Subsidence and Compaction Through Time
b. "Sedimentary Basins" = subsiding sediment traps near the Earth's Surface
6. Lithification of Unconsolidated Sediments
a. Transformation into Sedimentary Rock

B. Sedimentary Environments

1. Surface environments that promote accumulation of sediment
a. Marine - ocean-related
(1) Nearshore
(a) e.g. Beach

(2) Offshore
(a) e.g. deep ocean
b. Nonmarine - terrestrial
(1) e.g. Rivers, Lakes, Glaciers

2. Sedimentary environments influence style of process, which in turn influences the style of sedimentary deposit

3. Sedimentary Facies
a. Physical, chemical, and biological characteristics of sedimentary rocks
b. Sedimentary facies are the "footprint" left by the sedimentary environment
(1) Reconstruction of ancient sedimentary environments
(2) "paleogeography" - reconstructing ancient surface systems of the the Earth.

C. Sedimentary Structures

1. Depositional forms in sediment that are preserved in the rock record
a. e.g. ripple marks, or worm burrows

2. Sedimentary Processes Produce Sedimentary Structures / Sedimentary Structures are used to Reconstruct Sedimentary Process

D. Stratigraphy

1. Study of the spatial and temporal relationships in sedimentary layers or strata

a. 3-D spatial geometry
(1) Vertical vs. Horizontal Stratigraphic Relationships

b. Geologic time perspective: when? how long ago?

(1) Ordering of geologic events through time

V. Basics of Sediment Transportation

A. Energy vs. Mass of Sediment

1. The greater the mass (e.g. grain diameter) of sediment, the greater the energy needed to transport

a. e.g. question: could wind transport a boulder the size of this room?

2. Examples of Sedimentary Processes and Energy Source

a. Flowing Water / Rivers ---- gravity + climate
b. Flowing Glacial Ice ------ gravity + climate
c. Landslide / Rock Fall ------ gravity
d. Wind Blown Sediment ---------climate / air flow

3. Agents of Transportation: gravity, wind, water, ice

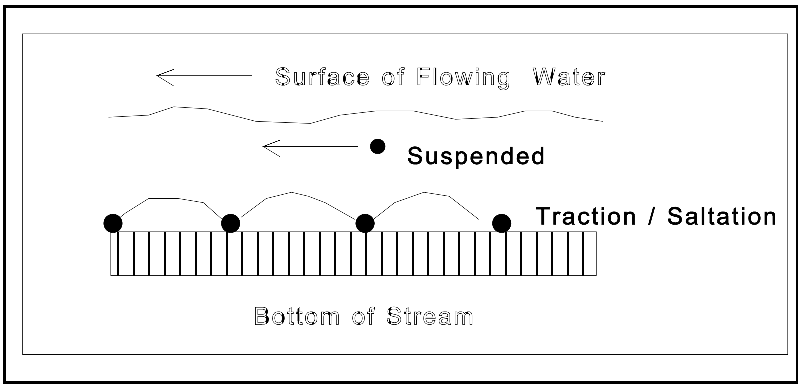
a. Energy relates directly to velocity of motion
(1) stream velocity, wind velocity, etc.

B. Methods of Transporting Sediment

1. Suspension - sediment is suspended in the body of the transporting medium
    a. e.g. blowing dust in the atmosphere
    b. e.g. brown clay and silt in the river after a rain storm

2. Bedload / Traction - sediment is rolled and tumbled at the base of the transporting medium
    a. e.g. a cobble rolling along the bottom of a stream

    b. <u>Saltation</u>: bouncing of particles via upcurrents, and trajectory fall under force of gravity.

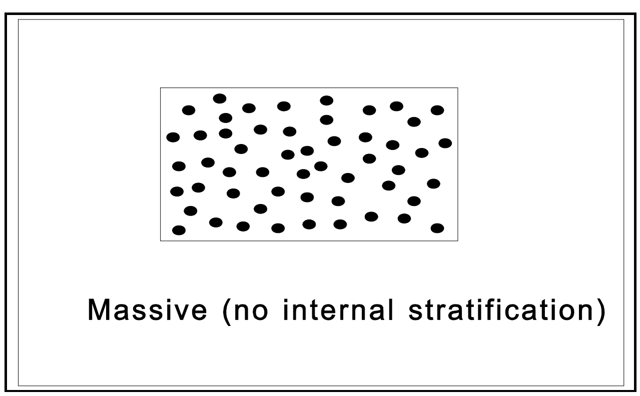


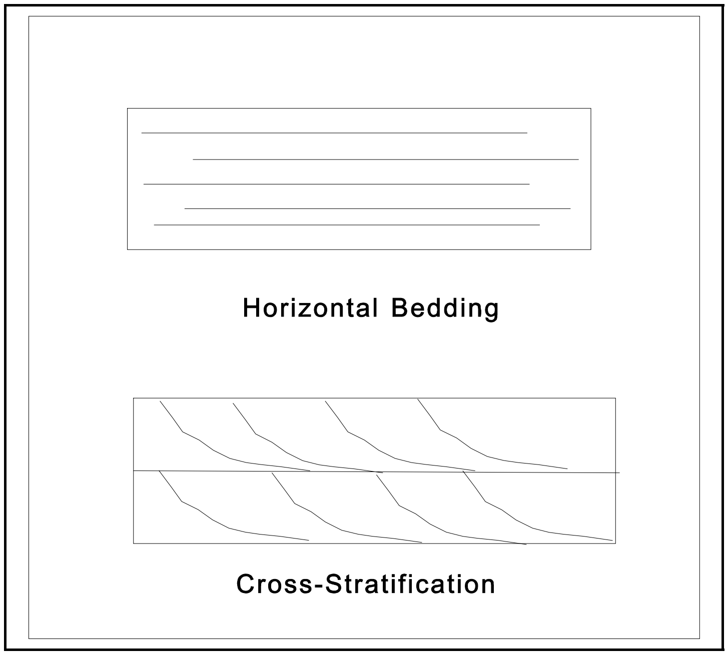
3. Dissolved Load - dissolved ions transported in a fluid medium
    a. e.g. dissolved salt in a river

VI. STRATIFICATION

A. <u>Stratification</u> = Horizontal layering of sediment under gravity
    1. <u>Strata</u> = multiple layers of sediment (plural),
    2. <u>Beds</u>: Strata greater than 1 cm in thickness,
    3. <u>Laminae</u>: Strata thinner than 1 cm in thickness

B. Internal Stratification
    1. Massive - no evidence of internal layering within a sedimentary rock bed

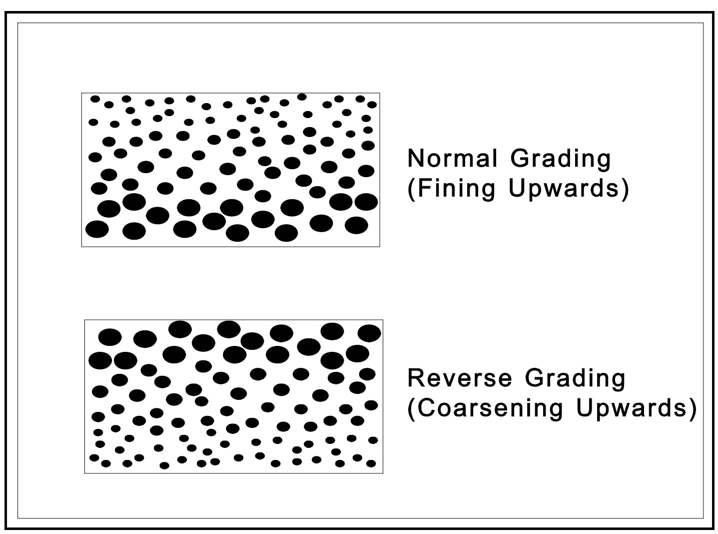




2. Horizontal vs. Cross-Stratified

3. Graded Bedding: a layer of sediment in which particle sizes change systematically in a vertical and/or lateral direction

   a. Normal Grading: fining of grain sizes in an upward direction



   b. Inversely Graded: Coarsening of grain sizes in an upward direction

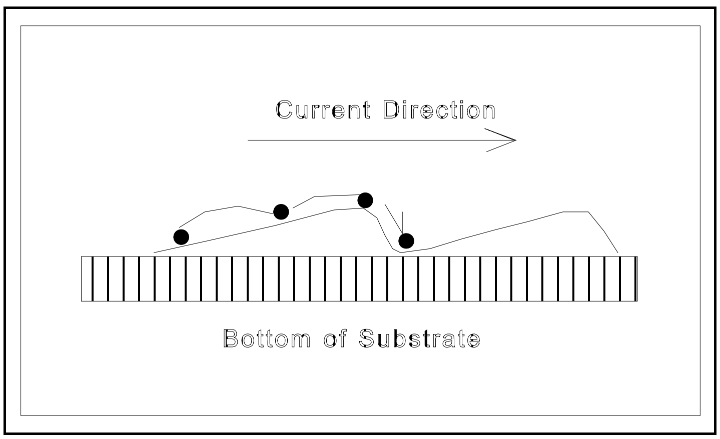
VII. Sedimentary Structures

A. Sedimentary Structures primarily result of physical transportation processes, or biologic processes, or post-depositional processes or chemical processes.

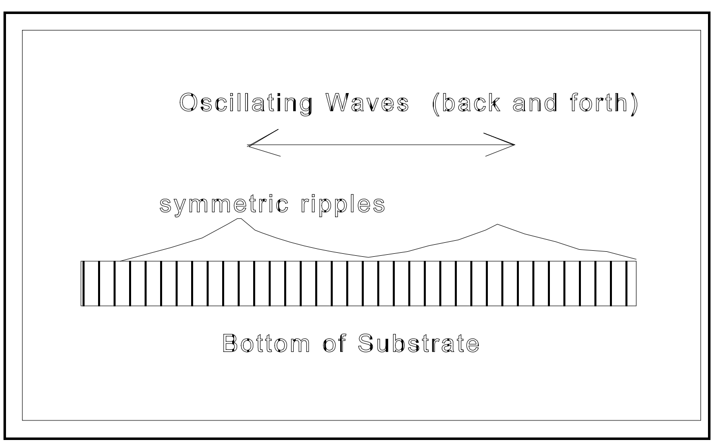
1. Paleocurrents - flowing fluids at the time of deposition mold sediment into characteristic shapes
   a. shapes can provide evidence of the direction of current flow at the time of deposition (maybe millions of years ago!!!).

B. Basic Examples of Sedimentary Structures

1. Asymmetric Current Ripples - flowing water and currents move sediment in small-scale forms know as "ripples" of sediment



2. Symmetric or Oscillation Ripples: symmetrical in cross-sectional form, developed under shallow water conditions within oscillating wave base (lakes or ocean beaches)



3. Sole Marks: sedimentary structures found on the bottom or "soles" of beds, essentially comprised of positive relief casts derived from underlying sediment surface.

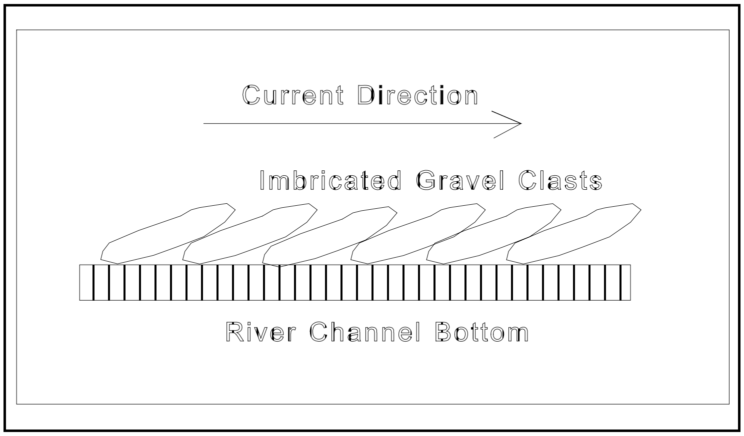
   a. Flute Casts: current-formed erosion structure, bulbous cast formed by scouring of sediment interface, bulbous end generally points up-current.

b. Load Casts: irregular knobs found on sandstones overlying shale beds.
c. Tool Marks: groove casts; infilling of mold formed by dragging object across sediment interface

4. Trace Fossils: i.e. Ichnology:

a. Tracks, trails, burrows
b. Bioturbation: general mixing of sediment by dirt eaters.

5. Imbricate Structure (Pebbles): under high energy flow conditions pebbles may take on inclined imbricate orientation, with inclination pointing upstream.



6. Mudcracks and Raindrop Imprints: evidence of subaerial exposure of semi-consolidated sediment surface.

a. Clay shrinks as it dries, results in polygon fractures

VIII. Sedimentary Environments and Facies Analysis

A. Sedimentary Environments

1. Defined by the complex interaction of physical, chemical and biological conditions under which sediment accumulates.

a. Characteristics of a given sedimentary environment yield a specific product of sediment and/or sedimentary rock.

B. Sedimentary Products

1. "Facies": a body of sediment or sedimentary rock that display characteristic or distinctive textural, structural and compositional properties.

a. Facies by definition: readily detectable and discernable characteristics (chemical, physical or biologic).

**A sedimentary facies is the product of the sedimentary environment and its processes

C. Paleoenvironmental Analysis

1. Goal: to reconstruct surface environments of deposition in the geologic past

2. Key Concept: "Law of Uniformitarianism" - the present is the key to the past.

   a. modern day observations can be used to reconstruct ancient geologic environments

3. Importance: Environmental interpretation important for defining the nature and character of resources found in the sedimentary environment (e.g. oil, coal, natural gas)

IX. Principal Environments of Deposition (refer to diagram in text on p. 131)

1. Continental (Nonmarine): Sedimentary environments found in a terrestrial setting

   a. Fluvial: Associated with processes of aqueous fluid flow on land (i.e. stream and river settings)

      (1) Alluvial Fan: characteristic environment found at the front of steep mountain slopes. Sediment laden streams exiting canyon mouth, depositing sediment in cone-shaped fan at front of mountain.

      (2) Braided vs. Meandering Fluvial

   b. Desert (Aeolian): dry climates, general lack of vegetation + high amounts of weathered sediment = wind-dominated sediment transport (sand dune amalgamation)

   c. Lacustrine: lake-related sedimentation, streams and rivers flowing into standing water (feeding lakes), dumping sediment along lake margins, fine quiet water sedimentation and/or organo-chemical deposition

      (1) Evaporite Basins - high evaporation + dry climate results in salt deposits (e.g. Great Salt Lake, Utah)

   d. Glacial: continental/alpine morainal and/or till depositional processes, high amounts of sediment rapidly deposited; outwash processes cross-over into "glacio-fluvial" realm.

2. Marginal Marine: essentially coastal plain sedimentation where terrestrial fluvial environments transition into the marine/ocean environment

   a. Deltaic: environment characterized by fluvial system depositing sediment into standing body of oceanic (and/or lacustrine) water. Sediment accumulation in form of delta.

   b. Beach/Barrier Bar: wave-dominated beach processes as rivers deliver sediment to coastal area; waves re-work sediment into beach deposits.

Barrier Bar: Offshore accumulation of sediment, wave dominated on lee side of island, slack-water dominated on landward side of island

c. Estuarine/Lagoonal: similar to lacustrine, only in marginal marine setting, water chemistry is saline, quiet water sedimentation with bio-critter processes abundant.

d. Tidal Flat: low-lying coastal areas heavily influenced by tidal rise/fall of water, tides rework sediment, bio-critter processes abundant.

3. Open Marine
   a. shallow ocean setting

      (1) Shelf: encompasses sand-dominated shelf or carbonate-dominated shelf accumulations

      (2) Organic Reef: biochemical build-up of carbonate structure comprised of living marine organisms, dominated by corals and algae + other critters

   b. Oceanic: i.e. deeper ocean setting

      (1) Slope: steep-gradient slope transitional to shallow-water shelf and deep ocean floor
         (a) Submarine canyons/submarine fan systems

      (2) Deep-ocean Floor
         (a) Abyssal plain, quiet water mud accumulation