SECONDARY LANDFORMS

1. Role of weathering in the accumulation of oxygen in the atmosphere

2. Primary versus secondary landforms
   a. Primary landform—basic underlying form derived through internal forces of tectonism and volcanism. Powered by geothermal energy from below the surface
   b. Secondary landform—the form that results from the modification of primary landforms through weathering, mass movement, and erosion. Powered by insolation, which drives physical, chemical, and biotic processes above the surface

3. Weathering—breakdown of rocks into regolith (unconsolidated sediments) in situ
   a. Regolith may then be eroded (transported) by denudational agents
   b. Three types of weathering processes
      i. Mechanical
      ii. Chemical
      iii. Biological

4. Mechanical weathering
   a. Freeze-thaw action
      i. Water expands volume by 9% when it freezes
      ii. Ice and frost wedges rocks apart
   b. Exfoliation
      i. Exposed rocks are out of thermodynamic equilibrium with surface environment
      ii. Expansion and spalling of thin sheets of rock in response to removal of overburden

5. Chemical weathering
   a. Hydrolysis—weathering initiated by addition of water to mineral crystals
      i. Mica and feldspar (minerals) in granite (rock) are hydrolized to form clay minerals
   b. Carbonation—chemical reaction of carbon dioxide and water with minerals
      i. Water forms weak acid in soil in the presence of carbon dioxide
      ii. $CO_2 + H_2O = H_2CO_3 + H^+ + HCO_3^-$
      iii. Carbonic acid ($H_2CO_3$) dissolves carbonate minerals (calcite, dolomite) efficiently
      iv. ‘Karst’ landforms develop in areas underlain with limestone
      v. Sinkholes, springs, caves in portions of Georgia and Florida
   c. Oxidation—weathering initiated by incorporation of oxygen into mineral crystals to form oxides
      i. Rust is an iron oxide. $(4Fe + 3O_2 \rightarrow 2(FeO_3))$.

6. Tafoni
   a. Mechanical and some chemical weathering

7. Biological weathering
   a. Earthworms
   b. Mosses and lichens
      i. Some plants produce organic substances, known as chelates, that have the ability to decompose minerals and rocks. Mosses and lichens are two such organisms.
   c. Root weathering
   d. Treefall

8. Constraints on weathering
   a. All three of the following can interact to constrain weathering
      i. Amount of erosional removal of weathered material
         (1) If weathered material is not removed through erosion, less exposure of the rocks, and this causes a reduction in overall weathering rates because they remain buried
      ii. Climate: precip and temperature
         (1) Mechanical weathering is most pronounced in cool, humid climates, because of
(2) Chemical weathering rates (like most chemical reactions) are driven by temperature and water supply. Therefore, chemical weathering is most pronounced in hot, humid regions.

iii. Type of rock and its hardness and friability (propensity to break apart)

b. Weathering examples
   i. Grand Canyon
   ii. Niagara Falls
   iii. Plateaus, mesa, buttes, pinnacles
   iv. Hoodoos

9. Mass movements
   a. Downslope movement of earth materials under the force of gravity.
   b. Factors that determine whether or not movement occurs
      i. Angle of inclination relative to angle of repose
         (1) Angle of repose: maximum angle at which material remains at rest
     ii. Presence of water
         (1) Water often acts as a lubricant at base of the mass movement
     iii. Frictional forces
         (1) Resist downslope moment
     iv. Gravity
         (1) Gravity acts to restore oversteepened slopes to a stable angle.
   c. Criteria for classifying mass movements
      i. Presence or absence of water
      ii. Downhill speed
      iii. Material
      iv. Angle
   d. Types of mass movements
      i. Falls: debris falls at or near vertical angles
         (1) Rock fall,
      ii. Slides: non-vertical movement along hillslope, planar movement surface but without the rotational component that exemplifies slumps
         (1) Rock glide, landslide, debris avalanche
      iii. Flow: debris flows as liquid, more water in this type of mass movement
         (1) Mudflow, earthflow, debris flow
      iv. Slump: rotational geometry of movement
         (1) Rock slump, soil slump
     v. Soil creep: very slow movement of soil
     vi. Solifluction: creep aided by freeze-thaw cycles
   e. Integration of human and natural process in the formation of a mudflow in southern California

10. Erosion - removal of regolith/sediments away from the site of weathering and mass movements.
   a. Erosional (denudational) agents
      i. Fluvial (river) systems
         (1) Fluvial systems comprise rills, streams, and rivers. Influence secondary features of landscape even in desert regions.
         (2) Great Plains Physiographic Province
            (a) Overlain by horizontal sediments from eroding Rocky Mountains and retreating Cretaceous sea
            (b) Badlands National Park: Sediments deeply eroded by fluvial systems
      ii. Eolian (wind)
         (1) Deflation versus abrasion
            (a) Deflation lags
(b) Ventifacts
(c) Yardangs
(d) Haboobs

iii. Glaciers
(1) Interior Lowlands Province
   (a) Low elevations (< 1000 ft) and relief
   (b) Glaciated 18,000 years ago
   (c) Glacial till and loess, terminal moraines
   (d) Numerous lakes and ponds formed from glaciation, including Great Lakes

(2) Canadian Shield
   (a) Scoured by glaciers
   (b) Very old basement rocks exposed at the surface