Weathering and Soils

Summary

- Weathering extends to whatever depth air, water, and microscopic forms of life penetrate the Earth's crust. Water solutions, which enter the bedrock along joints and other openings, attack the rock chemically and physically, causing breakdown and decay.
- Physical and chemical weathering, although involving very different processes, generally work together.
- Growth of crystals, especially ice and salt, along fractures and other openings in bedrock is a major process of physical weathering. Others include intense fires that cause spalling and fracturing, the wedging action of plant roots, and the churning of rock debris by burrowing animals. Each of these processes can have large cumulative effects over time.
- Chemical weathering involves the transformation of minerals that are stable deep in the Earth into forms that are stable at the Earth's surface. The principal processes are hydrolysis, leaching, oxidation, hydration, and dissolution..

- Subdivision of large blocks into smaller particles increases total surface area and thereby accelerates chemical weathering.
- The effectiveness of weathering depends on rock type and structure, surface slope, local climate, and the time over which weathering processes operate.
- Because heat and moisture speed chemical reactions, chemical weathering is far more active in moist, warm climates than in dry, cold climates.
- Soils consist of regolith capable of supporting plants. Soils develop distinctive horizons, the characteristics of which are a function of climate, vegetation cover, soil organisms, parent material, topography, and time.
- The classification system used in the United States places soils in 11 soil orders based on their physical characteristics.
- Paleosols are ancient buried soils that can provide clues about former landscapes, plant cover, and climate and are useful for subdividing, correlating, and dating the strata in which they are found.

- Soil erosion and degradation are global problems that have been increasing as world population rises. Effective control measures include crop rotation, plowing along contours rather than downslope, terracing, and tree planting but halting widespread loss of soils is a formidable challenge.
- Weathering is an integral part of the rock cycle. The silicate minerals least resistant to weathering are the ferromagnesian minerals with the least amount of polymerization of silicate tetrahedra

A Choice

- Material choices for a monument
  - Granite
  - Basalt
  - Peridotite
  - Limestone
  - Marble
  - Sandstone
  - Quartzite
  - Slate

•Mechanical Weathering
  •Breakdown
•Chemical Weathering
  •Chemical Alterations

• rock to regolith

•Soil Formation

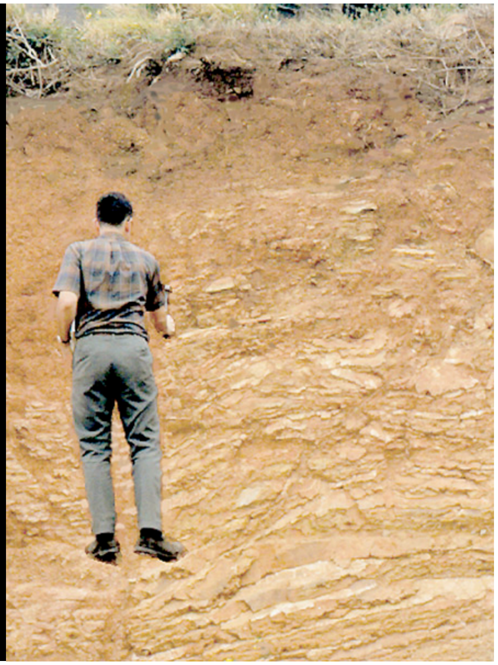


Figure 6.1

Physical Weathering

- Stresses are Generated By:
  - Unloading
    - Rock Joints
    - Exfoliation
  - Frost Wedging
    - Large positive volume change from water to ice
  - Crystal growth
    - Salt crystals
  - Biological Activity
    - Roots wedge rocks apart
  - Temperature Changes
    - Fires

Columnar Jointing

Exfoliation

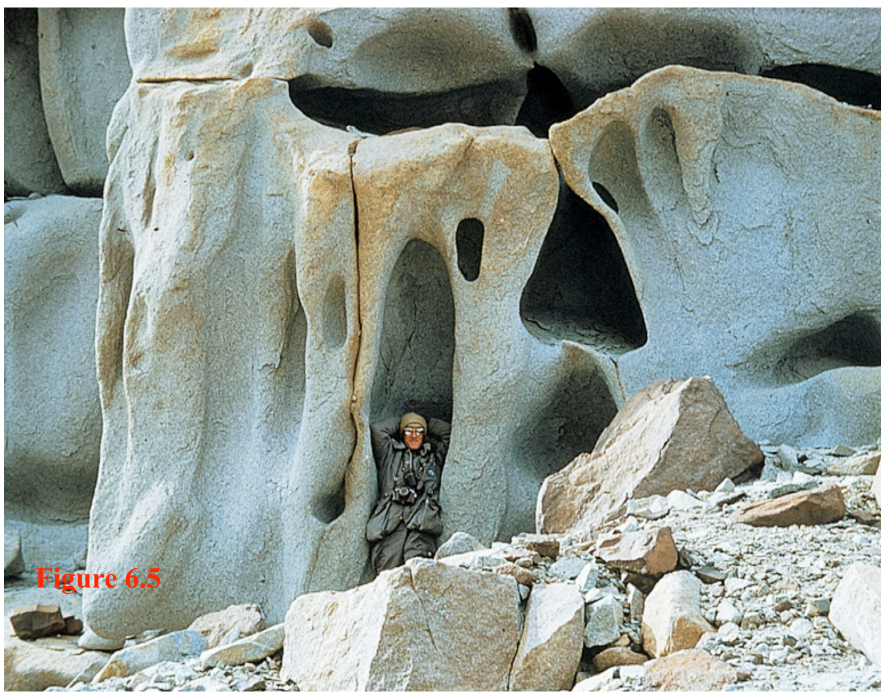


Figure 6.5

Figure 6.6

Chemical Weathering Pathways

- Rocks “re-adjust” to the temperature and pressure conditions near Earth’s surface
- Four chemical pathways:
  - Dissolution
    - mineral soluble in water
  - Hydrolysis.
  - Leaching.
  - Oxidation.

Acid and Base

- $H_2O \longrightarrow H^+ \ + \ (OH)^-$
- pH is roughly a measure of concentration of H^+

  pH = - log(concentration)

  pH > 7 basic

  pH = 7 neutral

  pH < 7 acid

Chemical Weathering

- **Water solutions are usually weak acids**
  - example: Carbonic acid

$$CO_2 + H_2O \longrightarrow \underbrace{H^{+1} + HCO_3^{-1}}_{\text{carbonic acid}}$$

- **Rocks react with acidic or basic solutions**
  - Soluble vs Insoluble products

Chemical Weathering

- **Hydrolysis**
  - H^{+1} or OH^{-1} ions of water <u>REPLACE</u> ions of a mineral
  - Clay minerals formed as the reaction product:

$$\underset{\text{potassium feldspar}}{4\,KAlSi_3O_8} + \underset{\text{H ion}}{4H^{+1}} + \underset{\text{water}}{2H_2O} \rightarrow 4\,K^{+1} + \underset{\text{kaolinite}}{Al_4Si_4O_{10}(OH)_8} + 8SiO_2$$

Leaching – removal of soluble material

- **Hydration**
  - Absorption of water into a crystal structure

$$\underset{\text{hematite}}{2Fe_2O_3} + \underset{\text{water}}{3H_2O} \rightarrow \underset{\text{goethite}}{2Fe_2O_3 \cdot 3H_2O}$$

- **Oxidation (Fe^{+2} to Fe^{+3})**

$$\underset{\text{wustite}}{4FeO} + \underset{\text{oxygen}}{O_2} \longrightarrow \underset{\text{hematite}}{2Fe_2O_3}$$

Minerals	Solid weathering products		Soluble ions in solution	Neutral species in solution
Feldspar →	Clay minerals	+	Na^{1+} and Ca^{2+}	Silica
Fe^{2+} mineral →	Clay minerals and goethite	+	Mg^{2+}	Silica
Magnetite →	Goethite			
Feldspar →	Clay minerals	+	Na^{1+} and K^{1+}	Silica
Mica →	Clay minerals	+	K^{1+}	
Fe^{2+} mineral →	Clay minerals and goethite	+	Mg^{2+}	Silica
Quartz →	Quartz			

Figure 6.9 B

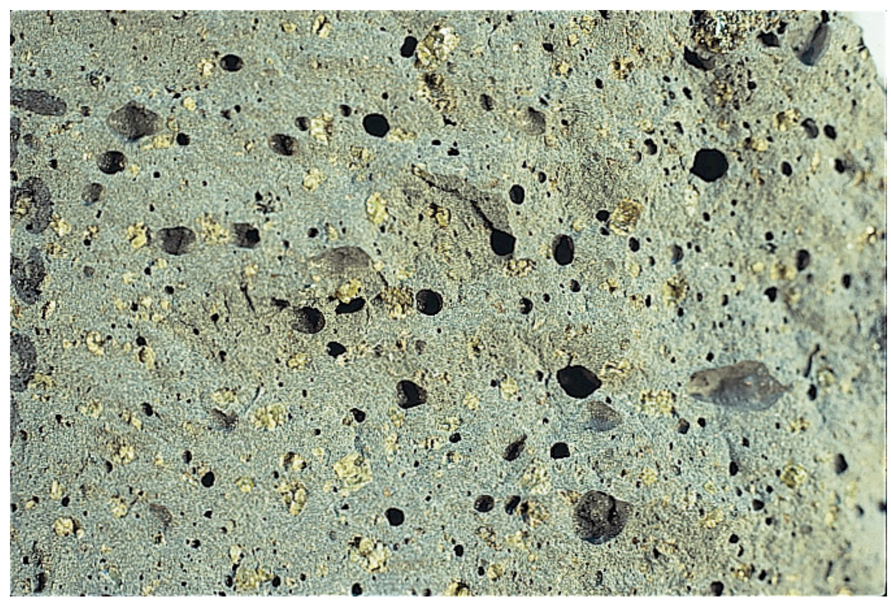


Figure 6.9 A

- **Carbonates (Limestone)**

$$CO_2 + H_2O \rightarrow \underbrace{H^{+1} + HCO_3^{-1}}_{\text{bicarbonate ion}}$$

carbonic acid

$$\underset{\text{limestone}}{CaCO_3} + H_2CO_3 \rightarrow \underbrace{Ca^{+2} + 2(HCO_3)^{-1}}_{\text{OUT OF SYSTEM}}$$

- **Leaves silica and clay**

Granite – chemical weathering

- Granite decomposes by the combined effects of dissolution, hydrolysis, and oxidation.
  - Feldspar, mica, and ferromagnesian minerals weather to clay minerals and soluble Na^{1+}, K^{1+}, and Mg^{2+} ions.
  - The quartz grains, being relatively inactive chemically, remain essentially unaltered.

Basalt – Chemical Weathering

- Plagioclase feldspar and ferromagnesian minerals form clay minerals and soluble ions (Na^{1+}, Ca^{2+}, and Mg^{2+}).
- The iron from ferromagnesian minerals, together with iron from magnetite, forms goethite.

Limestone – Chemical Weathering

- Limestone readily dissolves, leaving behind only the nearly insoluble impurities (chiefly clay and quartz) that are always present in small amounts in the rock.
  - Minerals such as gold, platinum, and diamond persist during weathering.

Figure 6.11

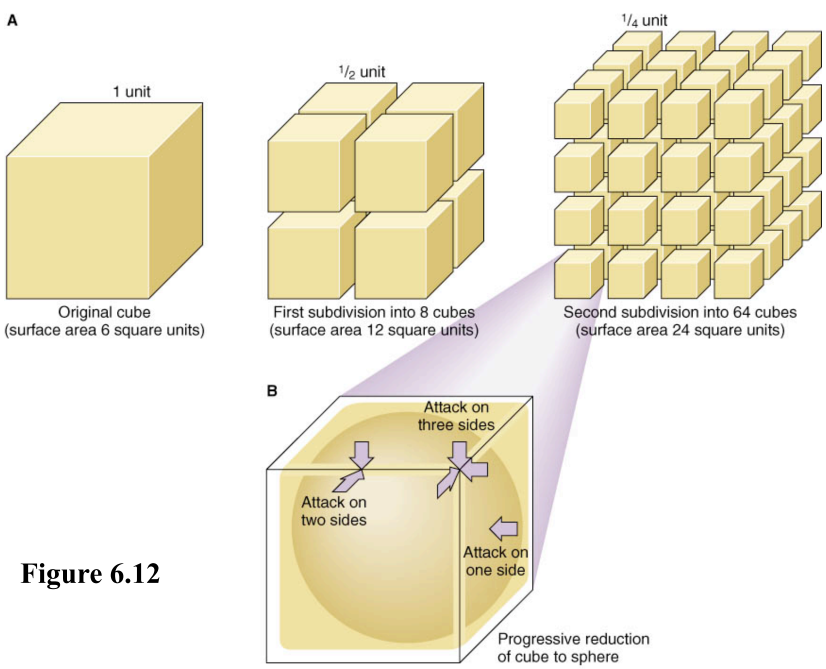


Figure 6.12

Factors Influencing Weathering

- Mineralogy.
  - Silicate mineral resistance to weathering controls:
    - **Chemical composition of the mineral.**
    - **Degree of polymerization of silicate tetrahedra**
    - **The acidity of the waters with which the mineral reacts.**

Factors Influencing Weathering

- Most stable chemical compositions:
  - Ferric oxides and hydroxides.
  - Aluminum oxides and hydroxides.
  - Quartz.
  - Clay minerals.
  - Muscovite.
  - Potassium feldspar.
  - Biotite.
  - Sodium feldspar (albite-rich plagioclase).
  - Amphibole.

Factors Influencing Weathering

- Least stable chemical compositions:
  - Pyroxene.
  - Calcium feldspar (anorthite-rich plagioclase).
  - Olivine.
  - Calcite.

- Rock type and structure
  - Grain size, jointing, ….

Factors Influencing Weathering

- Slope angle.
  - Steep slope, solid products of weathering move quickly away, continually exposing fresh bedrock to renewed attack.
  - Gentle slopes, weathering products are not easily washed away and in places may accumulate to depths of 50 m or more.

Factors Influencing Weathering

- Climate.
  - Moisture and heat promote chemical reactions.
    - Weathering is more intense and generally extends to greater depths in a warm, moist climate
      - In moist tropical lands, like Central America and Southeast Asia, obvious effects of chemical weathering can be seen at depths of 100 m or more.

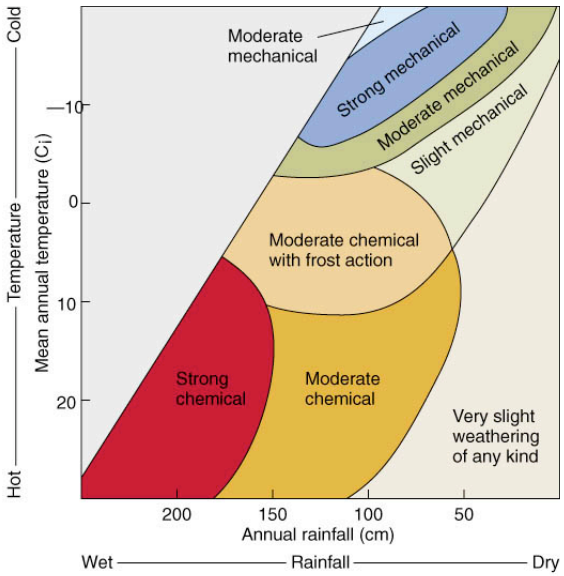


Figure 6.14

Factors Influencing Weathering

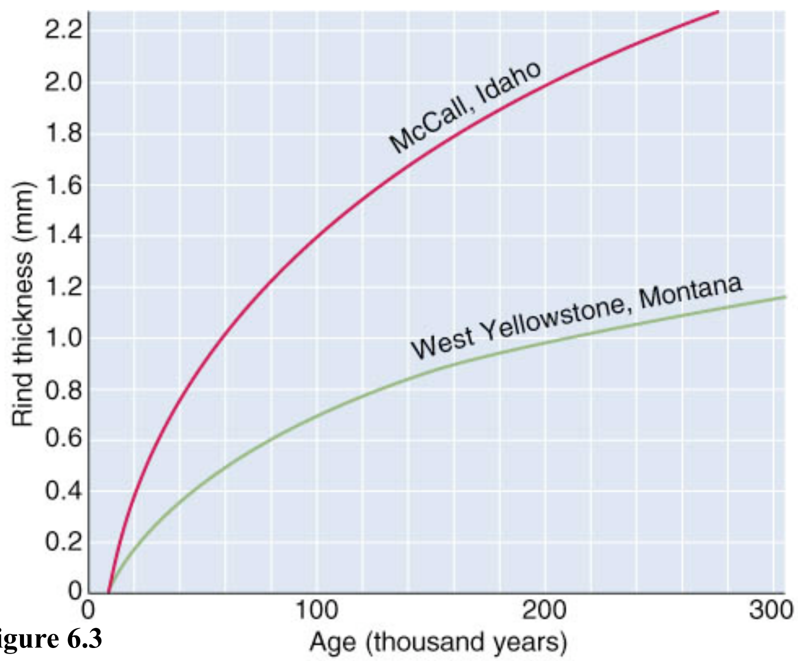
- Limestone and marble are highly susceptible to chemical weathering in a moist climate and commonly form low, gentle landscapes.
- In a dry climate, however, the same rocks form bold cliffs because, with scant rainfall and only patchy vegetation, little carbonic acid is present to dissolve carbonate minerals.

Factors Influencing Weathering

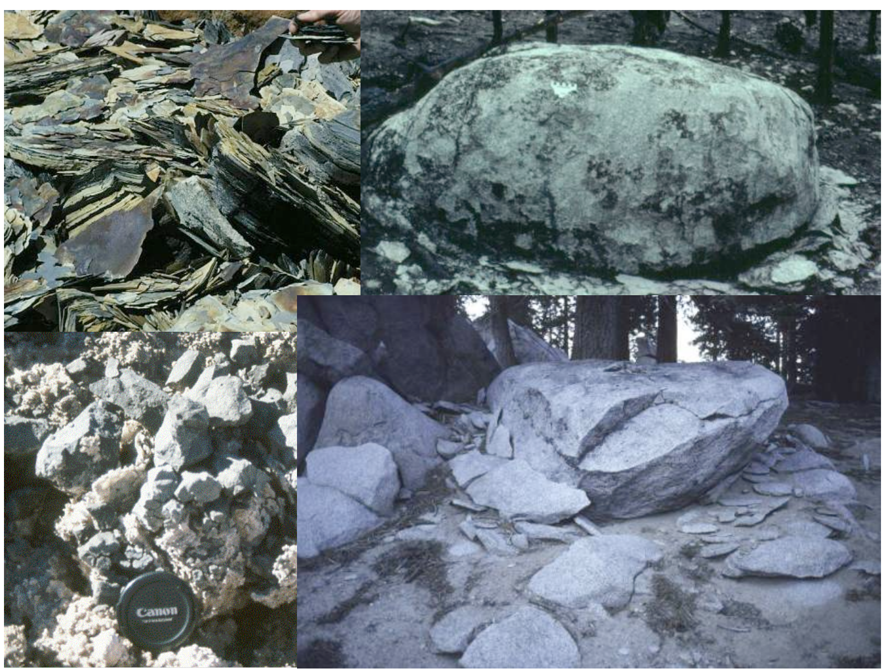
- Burrowing animals.
  - Large and small burrowing animals bring partly decayed rock particles to the land surface.
    - Although burrowing animals do not break down rock directly, the amount of disaggregated rock they move over many millions of years must be enormous.

Factors Influencing Weathering

- Time.
  - Hundred to thousands of years are required for a hard igneous or plutonic rock to decompose.
  - Weathering processes are speeded up by increasing temperature and available water, and by decreasing particle size.
  - The rate of weathering tends to decrease with time as the weathering profile, or a weathering rind, thickens.


McCall, Idaho
West Yellowstone, Montana
Rind thickness (mm)
Age (thousand years)
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0
100
200
300
Figure 6.3


THOMAS


Canon

Soils:Origin And Classification

Soils are one of the most important natural resources. Soils support the plants that are the basic source of our nourishment and provide food for domesticated animals. Soils store organic matter, thereby influencing how much carbon is cycled in the atmosphere as carbon dioxide, and they also trap pollutants.

Weathering & Soils

Soil Profile

- **Soil: Portion of regolith that supports rooted plants**
  - **Some amount of ORGANIC ma**

"A" Horizon: Zone of Leaching Grey to Black

"B" Horizon: Zone of Accumulation Brown to Red

"C" Horizon: Slightly Weathered Bedrock

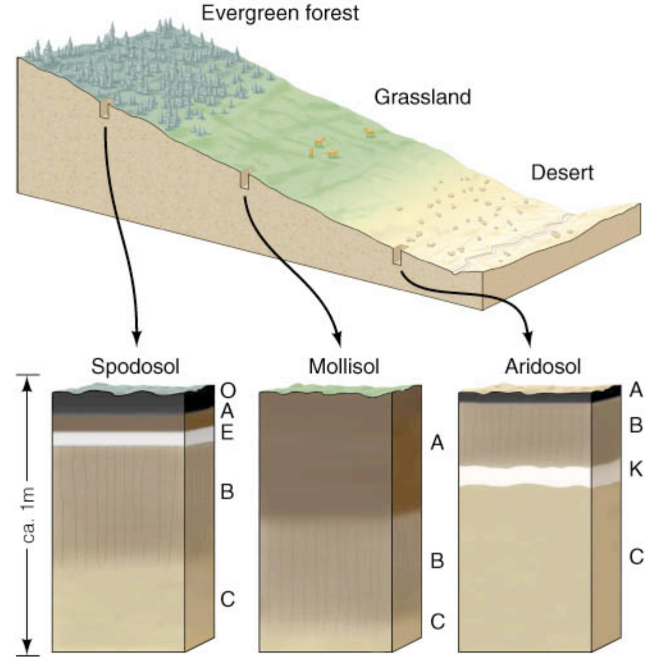


Figure 6.14

Soil Profiles

- Soil profiles:
  - As a soil develops from the surface downward, an identifiable succession of approximately horizontal weathered zones, called soil horizons, forms.
  - The soil horizons constitute a soil profile.
  - The uppermost horizon may be a surface accumulation of organic matter (**O horizon**).
  - An **A horizon** may either underlie an O horizon or lie directly beneath the surface.
  - The A horizon is dark because of the presence of humus (decomposed residue of plant and animal tissues, which is mixed with mineral matter).

Figure 6. 17

Soil Types

- Different soils result from the influence of six formative factors:
  - Climate.
  - Vegetation cover.
  - Soil organisms.
  - Composition of the parent material.
  - Topography.
  - Time.

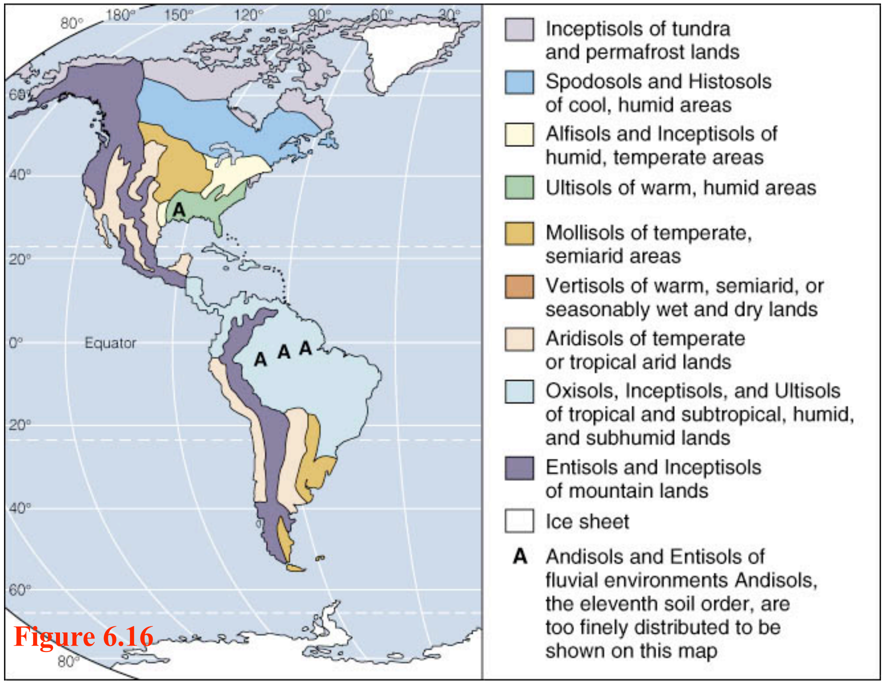


Figure 6.16

Polar soils

- Polar soils generally are dry and lack well-developed horizons.
  - They are classified as **entisols**.
  - In wetter high-latitude environments, mat-like tundra vegetation overlies perennially frozen ground: they form water-logged soils that are rich in organic matter, called **histosols.**
  - On well-drained sites soils develop recognizable A and B horizons called **inceptisols**.

Temperate Latitude Soils

- Temperate-latitude soils:
  - **Alfisols**, characteristic of deciduous woodlands, have a clay-rich B horizon beneath.
  - Acidic **spodosols** develop in cool, moist evergreen forests.
  - Grasslands and prairies typically develop **mollisols** having thick, dark-colored, organic-rich A horizons.
  - Soils formed in moist subtropical climates, commonly displaying a strongly weathered B horizon, are called **ultisols.**

Desert Soils

- In dry climates, where lack of moisture reduces leaching, carbonates accumulate in the profile during the development of **aridosols.**
  - Over extensive arid regions of the southwestern United States, carbonates have in this way built up a solid, almost impervious layer of whitish calcium carbonate known as **caliche**.

Figure 6.18

Tropical Soils

- Tropical soils:
  - In tropical climates soils are oxidized in **oxisols.**
  - **Vertisols** contain a high proportion of clay.
  - In tropical regions where the climate is very wet and warm, the product of deep weathering is called **laterite.**
    - One product of lateritic weathering is ferric hydroxide ($Fe(OH)_3$---$FeO.OH + H_2O$).
    - The resulting stone-like material, called lateritic crust or ironstone, can be used as construction material.

Figure 6.19

Rate of Soil Formation

- In southern Alaska retreating glaciers leave unweathered parent material.
  - Despite the cold climate, within a few years an A horizon develops on the newly exposed and revegetated landscape.
  - As the plant cover becomes denser, carbonic and organic acids acidify the soil and leaching becomes more effective.

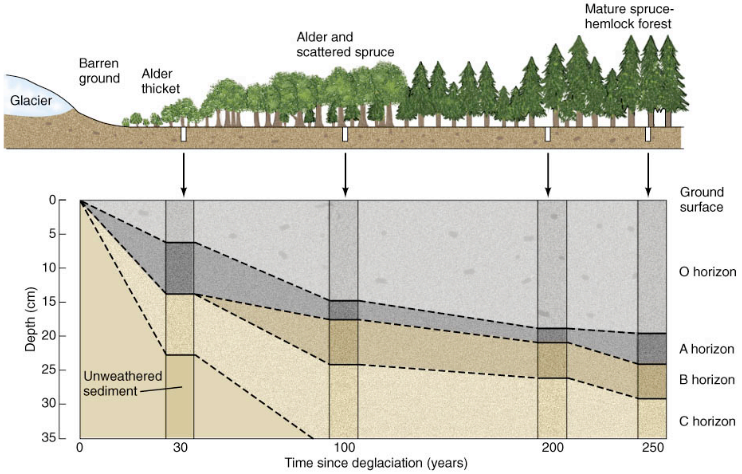


Figure 6.20

Rate of Soil Formation

- After about 50 years, a B horizon appears and the combined thickness of the A and B horizons reaches about 10 cm.
- Over the next 150 years, a mature forest develops on the landscape and the O Horizon continues to thicken (but the A and B horizons do not increase in thickness).

Paleosols

- Buried soils which have become part of the stratigraphic record are called **paleosols**.

Figure 6.21

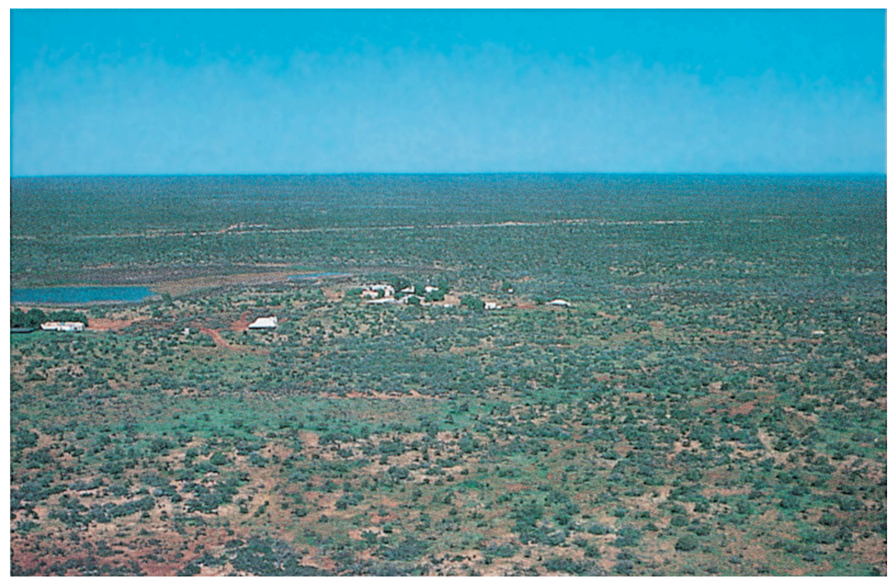


Figure 6.27

Soil Erosion

- It may take a very long time to produce a well-developed soil but destruction of soil may occur rapidly.
- Rates of erosion are determined by:
  - Topography.
  - Climate.
  - Vegetation cover.
  - Human activity.

Soil Erosion Due to Human Activity

- With world population greater than 6 billion, global agricultural production increases dramatically.
- In many third world nations, population growth has forced farmers onto lands that foster rapid soil erosion:
  - Steep slopes.
  - Semiarid regions where plowed land is prone to severe wind erosion.

Soil Erosion Due to Human Activity

- Economic pressures have led farmers to shift from ecologically favorable land-use practices to the planting of profitable row crops that often leave the land vulnerable to increased rates of erosion.
- Deforestation has led to accelerated rates of surface runoff and destabilization of soils due to loss of anchoring roots.

Soil Erosion Due to Human Activity

- Soils in the humid tropics, when stripped of their natural vegetation cover and cultivated, quickly lose their fertility.
- When the O and A horizons are eroded away, the fertility and the water-holding capacity of the soil decrease.

Soil Erosion Due to Human Activity

- Farmers in the United State are now losing about 5 tons of soil for every ton of grain they produce.
- Soil loss in Russia is at least as rapid.
- In India the soil erosion rate is estimated to be more than twice as high.
- Increased farming in the region above a dam in Pakistan has reduced the dam life expectancy from 100 to 75 years.
  - Increased soil erosion has produced more silt that is filling the lake formed by the dam.

Control of Soil Erosion

- Reduce areas of bare soil to a minimum.
- Reduce overgrazing.
- If row crops such as corn, tobacco, and cotton must be planted on a slope, alternating strips of grass or similar plants resist soil erosion;
- Crop rotation.

Erosion on Slopes

- On a gentle, 1 percent slope, an average of 3 tons of soils are lost per hectare each year.
- A 5 percent slope loses 87 tons per hectare.
    - At this rate a 15 cm thickness of topsoil would disappear in about 20 years,
- On a 15 percent slope, 221 tons per hectare per year are lost.
- Terracing can reduce the loss of soil on farmed slopes.

Global Weathering Rates and High Mountains

- Although a multitude of rivers enter the sea, the three largest contributors of dissolved substances are:
  - The Yangtze River, which drains the high Tibetan Plateau of China.
  - The Amazon River, which drains the northern Andes in South America.
  - The Ganges-Brahmaputra river system which drains the Himalayas.

Global Weathering Rates and High Mountains

- These three rivers deliver about 20 percent of the water and dissolved matter entering the oceans.
- The amount of dissolved matter in rivers is greatest in areas of sedimentary rocks (Himalayas, Andes, and Alps).

Global Weathering Rates and High Mountains

- Because high mountains forces moisture-bearing winds to rise, they generally receive large amounts of precipitation, resulting in:
  - High rates of river runoff.
  - High erosion rates.
- Evidence from ocean sediments points to an increase in the amount of dissolved matter reaching the oceans in the past 5 million years.

Global Weathering Rates and High Mountains

- Sediments shed from the rising Himalayas coarsen from silts deposited about 5 million years ago to gravels about 1 million years old.
  - Rivers draining the mountains gained increasing energy.
  - Mountain slopes became steeper.
  - Stream channels become steeper.