Chapter 5: Weathering and Soils

Fig. 5.14
OBJECTIVES

• Recognize that weathering breaks down minerals and rocks and occurs as a result of both mechanical and chemical processes.

• Explain the processes that cause mechanical weathering, which is responsible for rock disintegration.

• Explain the reactions that cause chemical weathering, which is responsible for rock decomposition.
OBJECTIVES

• Describe how soils form and what factors control the development of soil profiles.

• Discuss the role plate tectonic processes play in weathering, soil development, and global temperature variation.
Weathering and Soils: An Overview

• **Weathering**: the physical disintegration of rocks and the chemical decomposition of their component minerals
  • Occurs far too slowly for us to observe
  • Few process have had a more profound effect on Earth’s evolution.

• **Soil**: the portion of Earth’s surface sediment that can sustain life
  • Formed by the weathering of bedrock
  • One of our most valuable resources
  • Distribution has profoundly influenced human history.
Weathering

- **Weathering**: the in-place breakdown of surface materials into loose sediment consisting of broken rock and mineral fragments

- First step in formation of sedimentary rock

- Types
  - Mechanical weathering
  - Chemical weathering
Mechanical Weathering

- **Mechanical weathering** disintegrates rocks without causing any change in the chemical composition of the rocks.

Mechanical weathering reduces rocks to smaller and smaller fragments.

Fig. 5.1
Mechanical Weathering

- **Joints**: regularly spaced cracks in rock outcrops
  - Form from stress (such as temperature or pressure change)
  - **Columnar or exfoliation**
  - Facilitate more physical and chemical weathering processes

**Formation of Columnar Joints:**
The columnar joints at Giant’s Causeway in Northern Ireland were formed by cooling of basalt.
Mechanical Weathering

• **Frost Wedging**
  • Water percolates into cavities, cracks, joints in the rock
  • Air temperature falls; water freezes and expands

• **Crystal Wedging**
  • Impure water lodges in rock cavities
  • Water evaporates
  • Salt crystals form and grow outward
  • When crystals make contact with the opposite wall, they push the crack farther apart
Mechanical Weathering

Crystal Wedging and Cleopatra’s Needle: (a) Crystals form, push against each other, wedging cracks farther apart. (b) Cleopatra’s Needle, a monument made of granite, in Alexandria, Egypt, where it had stood for 3500 years. (c) After 75 years in New York’s Central Park, the inscriptions have suffered severe damage.

Fig. 5.5
Mechanical Weathering

• Thermal Expansion and Contraction
  • Each mineral in a rock has a different susceptibility to thermal expansion and contraction.
    • Some expand more with the same increase in temperature.
    • Changes occur near surface level.
  • Repeated heating and cooling may form a crack parallel to the surface of the rock.
    • The surface layer may split apart from the main body of rock and crumble.
    • Additional rock surface is exposed, process continues.
Mechanical Weathering

• **Organic Processes**
  - Plant roots invading cracks in rocks
    - Roots expand, enlarge cracks, disintegrate rock.
  - Burrowing activity by animals
    - Opens cracks, moves rock fragments, overturns soil.
    - Soils rich in microorganisms decompose twice as rapidly as sterile clay.

• **Human Activities**
  - Quarry excavation, road construction, land development, digging, blasting, etc. expose and fracture rocks that would otherwise be protected from weathering.
Mechanical Weathering

Organic Processes: By enlarging cracks and fractures in rocks, the growth of these trees contributes to mechanical weathering.
Chemical Weathering

• Chemical weathering decomposes surface rocks and minerals through chemical reactions.
  • Water and acid rain act as solvents.
  • Minerals dissolve at different rates.
  • Some minerals dissolve completely.
  • Other minerals react with water or oxygen to form new minerals.

• Three important types of chemical weathering.
  • Dissolution
  • Hydrolysis
  • Oxidation
Chemical Weathering

• **Dissolution**
  - Minerals with relatively weak bonds dissolve.
  - Nonsilicate materials (esp. chlorides, carbonates, and sulfates) have weaker ionic bonds.
  - Water and rainwater (acidic) are solvents.
  - Totally dissolves, removes ions in solution.

Fig. 5.8 Dissolution of halite (salt)
Chemical Weathering

- **Hydrolysis**
  - Hydrogen ions in water extract ions from a mineral’s crystal structure
  - Reaction forms new mineral

(a) Structure of feldspar: silicate tetrahedra are resistant, but ions between tetrahedra can be removed in solution. (b) Feldspar in soil undergoes hydrolysis when attacked by acidic water and weathers to form kaolinite clay.

![Chemical Weathering Diagram](image)
Chemical Weathering

- **Oxidation**: a compound loses electrons during a chemical reaction.
- **Reduction**: a compound gains electrons during a chemical reaction.
- **Oxidation-reduction** or **redox** reactions result in one compound losing electrons while another compound gains electrons.
  - Minerals with abundant iron are particularly susceptible to redox reactions.
- Rate of oxidation increases in the presence of water.
Chemical Weathering

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

- Oxidation of Pyrite
  \[ 2\text{FeS}_2(s) + 7\text{O}_2(g) + \text{H}_2\text{O}(l) \rightarrow \text{Fe}^{2+}(aq) + 4\text{SO}_4^{2-} + 4\text{H}^+(aq) \]

Fig. 5B
Chemical Weathering

• **Hydration**
  • Clay minerals absorb water into their crystal structure, resulting in expansion.
  • Rocks that contain abundant clay minerals are weakened by this expansion.

• **Other Influencing Factors**
  • Mechanical weathering
  • Time
  • Climate
Soils

- **Regolith**: loose layer of rock and mineral fragments produced by weathering

- **Soil**: a portion of this loose material

- Main Types of Soils
  - **Residual**: from underlying bedrock
  - **Transported**: moved by running water, ice, wind

Fig. 5.14
Soils

- Soils consist of:
  - Disintegrated and decomposed rock
  - Decayed remains of animal and plant life
  - Microorganisms
  - Pore spaces containing trapped air, water, and dissolved nutrients

Fig. 5.15
Soil Processes: Plants absorb inorganic chemicals from the soil and produce organic matter by way of photosynthesis. Animals use this organic material, either by grazing on and digesting the plants directly or by eating other animals. The decomposition of dead plants and animals returns these chemicals to the soil.

Fig. 5.16
Soils

- Factors Influencing Soil Development
  - Underlying bedrock
  - Sediment deposition
  - Time (weathering)
  - Climate
  - Topography
  - Organic activity
Variation of Soil Development with Climate: The richest soil develops in tropical regions where the abundant precipitation facilitates weathering of bedrock, development of vegetation, and flourishing microorganisms. Soil development is poor in desert regions due to a lack of sufficient rainfall and in polar regions because the cold climate restricts the development of vegetation.
Soils

- **Soil Profiles**: the layered structures of soils
  - Determine agricultural use of soils

- Characteristic Sequences of Layers
  - **O Horizon**: uppermost layer rich in organic matter
  - **A Horizon**: plant roots, microorganisms, burrowing animals
  - **A and O Horizons (together)**: topsoil, zone of leaching
  - **B Horizon**: zone of accumulation below the A horizon
  - **E Horizon**: separates the A and B horizons in older soils
  - **C Horizon**: mostly fragmented and weathered bedrock
Soil Profiles: (a) A typical soil profile features a characteristic sequence of layers. (b) Processes result in the development of a zone of leaching and a zone of accumulation. (c) Sometimes a transition (E horizon) forms between the A and B horizons.
Soils

Soil Types

(a) Pedalfer

Temperate climate
Humus and leached soil (quartz and clay minerals also present)
Some iron and aluminum oxides precipitate; all soluble materials leached away
Granite bedrock

(b) Laterite

Wet climate
Thin or absent humus
Thick deposits of insoluble iron and aluminum oxides; quartz
Thin leached zone
Mafic igneous bedrock

(c) Pedocal

Dry climate
Humus and leached soil
Calcium carbonate pellets and nodules precipitated
Sandstone, shale, and limestone bedrock

Fig. 5.20
Weathering, Soils, and Plate Tectonics

- Plate tectonic processes
  - Promote weathering in the formation of joints
  - Lead to the formation of volcanoes, which affect soil development
  - Dictate topography, which affects both weathering and soil development
  - Affect the rates of continental weathering, transport of soluble ions, and extraction of carbon dioxide from the atmosphere, all of which may in turn affect global temperatures.
SUMMARY

• Weathering breaks down rocks and minerals at Earth’s surface.

• Weathering results from both mechanical and chemical processes.

• Soil is a product of weathering that supports plant growth.

• Plate tectonic processes promote weathering and soil formation.