Geology and Nonrenewable Minerals

Chapter 14
Core Case Study: Environmental Effects of Gold Mining

- **Gold producers**
  - South Africa
  - Australia
  - United States
  - Canada

- **Cyanide heap leaching**
  - Extremely toxic to birds and mammals
  - 2000: Collapse of a dam retaining a cyanide leach pond
  - Impact on organisms and the environment
Gold Mine with Cyanide Leach Piles and Ponds in South Dakota, U.S.
14-1 What Are the Earth’s Major Geological Processes and Hazards?

- **Concept 14-1A** Gigantic plates in the earth’s crust move very slowly atop the planet’s mantle, and wind and water move the matter from place to place across the earth’s surface.

- **Concept 14-1B** Natural geological hazards such as earthquakes, tsunamis, volcanoes, and landslides can cause considerable damage.
The Earth Is a Dynamic Planet

- What is geology?

- Three major concentric zones of the earth
  - Core
  - Mantle
    - Including the asthenosphere
  - Crust
    - Continental crust
    - Oceanic crust: 71% of crust
Major Features of the Earth’s Crust and Upper Mantle

- Abyssal hills
- Abyssal floor
- Oceanic ridge
- Abyssal floor
- Trench
- Volcanoes
- Folded mountain belt
- Craton
- Abyssal plain

- Oceanic crust (lithosphere)
- Continental crust (lithosphere)
- Continental shelf
- Continental slope
- Continental rise

- Mantle (lithosphere)
- Mantle (asthenosphere)

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Abyssal hills
Abyssal Oceanic ridge
Abyssal floor
Trench
Volcanoes
Folded mountain belt
Craton
Abyssal plain
Oceanic crust (lithosphere)
Continental crust (lithosphere)
Mantle (lithosphere)
Mantle (asthenosphere)
Continental shelf
Continental slope
Continental rise
The Earth Beneath Your Feet Is Moving (1)

- Convection cells, or currents
- Tectonic Plates
- Lithosphere
The Earth Beneath Your Feet Is Moving (2)

- Three types of boundaries between plates
  - Divergent plates
    - Magma
    - Oceanic ridge
  - Convergent plates
    - Subduction
    - Subduction zone
    - Trench
  - Transform fault; e.g., San Andreas fault
The Earth’s Crust Is Made Up of a Mosaic of Huge Rigid Plates: Tectonic Plates
Two plates move towards each other. One is subducted back into the mantle on a falling convection current.

Material cools as it reaches the outer mantle. Cold dense material falls back through the mantle.

Hot material rises through the mantle.

Mantle convection cell.

Collision between two continents.

Oceanic tectonic plate.

Initial plate movement.

Subduction zone.

Ocean trench.

Continental crust.

Oceanic crust.

Spreading center.

Oceanic tectonic plate.

Plate movement.

Ocean.

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The Earth’s Major Tectonic Plates
The San Andreas Fault as It Crosses Part of the Carrizo Plain in California, U.S.
Some Parts of the Earth’s Surface Build Up and Some Wear Down

- **Internal geologic processes**
  - Generally build up the earth’s surface

- **External geologic processes**
  - **Weathering**
    - Physical, Chemical, and Biological
  - **Erosion**
    - Wind
    - Flowing water
    - Human activities
    - Glaciers
Weathering: Biological, Chemical, and Physical Processes

- **Parent material (rock)**

  - **Biological weathering** (tree roots and lichens)
  - **Chemical weathering** (water, acids, and gases)
  - **Physical weathering** (wind, rain, thermal expansion and contraction, water freezing)

- **Particles of parent material**
Parent material (rock)

- Biological weathering (tree roots and lichens)
- Chemical weathering (water, acids, and gases)
- Physical weathering (wind, rain, thermal expansion and contraction, water freezing)

Particles of parent material
Parent material (rock)

Biological weathering (tree roots and lichens)

Chemical weathering (water, acids, and gases)

Physical weathering (wind, rain, thermal expansion and contraction, water freezing)

Particles of parent material

Fig. 14-6, p. 348
Volcanoes Release Molten Rock from the Earth’s Interior

- **Volcano**
  - Fissure
  - Magma
  - Lava

- 1980: Eruption of Mount St. Helens

- 1991: Eruption of Mount Pinatubo

- Benefits of volcanic activity
Creation of a Volcano

Extinct volcanoes

Eruption cloud

Ash Acid rain

Ash flow

Lava flow

Mud flow

Landslide

Central vent

Magma conduit

Magma reservoir

Solid lithosphere

Partially molten asthenosphere

Upwelling magma

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Extinct volcanoes

Eruption cloud

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Ash flow

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Central vent

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Magma reservoir

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Upwelling magma

Acid rain
Earthquakes Are Geological Rock-and-Roll Events (1)

- **Earthquake**
  - Seismic waves
  - Focus
  - Epicenter
  - Magnitude
  - Amplitude
Earthquakes Are Geological Rock-and-Roll Events (2)

- Richter scale
  - Insignificant: <4.0
  - Minor: 4.0–4.9
  - Damaging: 5.0–5.9
  - Destructive: 6.0–6.9
  - Major: 7.0–7.9
  - Great: >8.0
Earthquakes Are Geological Rock-and-Roll Events (3)

- Foreshocks and aftershocks
- Primary effects of earthquakes
Major Features and Effects of an Earthquake

- Liquefaction of recent sediments causes buildings to sink
- Two adjoining plates move laterally along the fault line
- Landslides may occur on hilly ground
- Earth movements cause flooding in low-lying areas
- Shock waves
- Epicenter
- Focus
Liquefaction of recent sediments causes buildings to sink.

Two adjoining plates move laterally along the fault line.

Earth movements cause flooding in low-lying areas.

Landslides may occur on hilly ground.

Shock waves.

Epicenter.

Focus.

Fig. 14-8, p. 350
Areas of Greatest Earthquake Risk in the United States

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Areas of Greatest Earthquake Risk in the World
Earthquakes on the Ocean Floor Can Cause Huge Waves Called Tsunamis

- Tsunami, tidal wave

- Detection of tsunamis

- December 2004: Indian Ocean tsunami
  - Magnitude of 9.15
  - Role of coral reefs and mangrove forests in reducing death toll
Formation of a Tsunami and Map of Affected Area of Dec 2004 Tsunami

- Earthquake in seafloor swiftly pushes water upwards, and starts a series of waves.
- Waves move rapidly in deep ocean reaching speeds of up to 890 kilometers per hour.
- As the waves near land they slow to about 45 kilometers per hour but are squeezed upwards and increased in height.
- Waves head inland causing damage in their path.

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Undersea thrust fault

Upward wave

Earthquake

Bangladesh
India
Burma
Thailand
Sri Lanka
Malaysia
Indonesia
Sumatra
December 26, 2004, tsunami

Fig. 14-11, p. 352
Shore near Gleebruk in Indonesia before and after the Tsunami on June 23, 2004
Gravity and Earthquakes Can Cause Landslides

- **Mass wasting**
  - Slow movement
  - Fast movement
    - Rockslides
    - Avalanches
    - Mudslides

- Effect of human activities on such geological events
Active Figure: Geological forces
Active Figure: Plate margins
Concept 14-2  The three major types of rocks found in the earth’s crust—sedimentary, igneous, and metamorphic—are recycled very slowly by the process of erosion, melting, and metamorphism.
There Are Three Major Types of Rocks (1)

- Earth’s crust
  - Composed of minerals and rocks
- Three broad classes of rocks, based on formation

1. Sedimentary
   - Sandstone
   - Shale
   - Dolomite
   - Limestone
   - Lignite
   - Bituminous coal
There Are Three Major Types of Rocks (2)

2. Igneous
   • Granite
   • Lava rock

3. Metamorphic
   • Anthracite
   • Slate
   • Marble
The Earth’s Rocks Are Recycled Very Slowly

- Rock cycle

- Slowest of the earth’s cyclic processes
Natural Capital: The Rock Cycle Is the Slowest of the Earth’s Cyclic Processes
Erosion
Transportation
Weathering
Deposition

Igneous rock
Granite, pumice, basalt

Sedimentary rock
Sandstone, limestone

Heat, pressure
Magma (molten rock)
Cooling
Melting

Metamorphic rock
Slate, marble, gneiss, quartzite
14-3 What Are Mineral Resources, and what are their Environmental Effects?

- **Concept 14-3A** Some naturally occurring materials in the earth’s crust can be extracted and made into useful products in processes that provide economic benefits and jobs.

- **Concept 14-3B** Extracting and using mineral resources can disturb the land, erode soils, produce large amounts of solid waste, and pollute the air, water, and soil.
We Use a Variety of Nonrenewable Mineral Resources

- **Mineral resource**
  - Fossil fuels
  - Metallic minerals
  - Nonmetallic minerals

- **Ore**
  - High-grade ore
  - Low-grade ore

- Importance and examples of nonrenewable metal and nonmetal mineral resources
Mineral Use Has Advantages and Disadvantages

- Advantages of the processes of mining and converting minerals into useful products

- Disadvantages
The Life Cycle of a Metal Resource

1. Surface mining
2. Metal ore
3. Separation of ore from gangue
4. Smelting
5. Melting metal
6. Conversion to product
7. Discarding of product
8. Recycling
Surface mining → Metal ore → Separation of ore from gangue → Smelting → Melting metal → Conversion to product → Discarding of product

Recycling

Fig. 14-14, p. 355
Surface mining → Metal ore → Separation of ore from gangue → Smelting → Melting metal → Conversion to product → Discarding of product

Recycling
Extracting, Processing, Using Nonrenewable Mineral and Energy Resources

NATURAL CAPITAL DEGRADATION

Extracting, Processing, and Using Nonrenewable Mineral and Energy Resources

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### Extracting, Processing, and Using Nonrenewable Mineral and Energy Resources

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There Are Several Ways to Remove Mineral Deposits (1)

- **Surface mining**
  - Shallow deposits removed

- **Subsurface mining**
  - Deep deposits removed

- Type of surface mining used depends on
  - Resource
  - Local topography
There Are Several Ways to Remove Mineral Deposits (2)

- Types of surface mining
  - Open-pit mining
  - Strip mining
  - Contour mining
  - Mountaintop removal
Natural Capital Degradation: Open-Pit Mine in Western Australia
Natural Capital Degradation: Contour Strip Mining Used in Hilly or Mountainous Region
Undisturbed land

Overburden

Highwall

Coal seam

Overburden

Pit

Bench

Coal seam

Spoil banks

Fig. 14-17, p. 357
Natural Capital Degradation: Mountaintop Coal Mining in West Virginia, U.S.
Mining Has Harmful Environmental Effects (1)

- Scarring and disruption of the land surface
  - E.g., spoils banks

- Loss of rivers and streams

- Subsidence
Mining Has Harmful Environmental Effects (2)

- Major pollution of water and air
- Effect on aquatic life
- Large amounts of solid waste
Banks of Waste or Spoils Created by Coal Area Strip Mining in Colorado, U.S.
Illegal Gold Mine
Ecological Restoration of a Mining Site in New Jersey, U.S.
Removing Metals from Ores Has Harmful Environmental Effects (1)

- Ore extracted by mining
  - Ore mineral
  - Gangue
  - Smelting

- Water pollution
Removing Meals from Ores Has Harmful Environmental Effects (2)

- Liquid and solid hazardous wastes produced

- Use of cyanide salt of extract gold from its ore
  - Summitville gold mine: Colorado, U.S.
Natural Capital Degradation: Summitville Gold Mining Site in Colorado, U.S.
Concept 14-4A  All nonrenewable mineral resources exist in finite amounts, and as we get closer to depleting any mineral resource, the environmental impacts of extracting it generally become more harmful.

Concept 14-4B  An increase in the price of a scarce mineral resource can lead to increased supplies and more efficient use of the mineral, but there are limits to this effect.
Mineral Resources Are Distributed Unevenly (1)

- Most of the nonrenewable mineral resources supplied by
  - United States
  - Canada
  - Russia
  - South Africa
  - Australia
Mineral Resources Are Distributed Unevenly (2)

- **Strategic metal resources**
  - Manganese (Mn)
  - Cobalt (Co)
  - Chromium (Cr)
  - Platinum (Pt)
Science Focus: The Nanotechnology Revolution

- **Nanotechnology, tiny tech**

- **Nanoparticles**
  - Are they safe?

- Investigate potential ecological, economic, health, and societal risks

- Develop guidelines for their use until more is known about them
Supplies of Nonrenewable Mineral Resources Can Be Economically Depleted

- Future supply depends on
  - Actual or potential supply of the mineral
  - Rate at which it is used

- When it becomes *economically depleted*
  - Recycle or reuse existing supplies
  - Waste less
  - Use less
  - Find a substitute
  - Do without
Natural Capital Depletion: Depletion Curves for a Nonrenewable Resource

- **Mine, use, throw away; no new discoveries; rising prices**
  - Curve A

- **Recycle; increase reserves by improved mining technology, higher prices, and new discoveries**
  - Curve B

- **Recycle, reuse, reduce consumption; increase reserves by improved mining technology, higher prices, and new discoveries**
  - Curve C

Axes:
- **Production**
- **Time**

- Present
- Depletion time A
- Depletion time B
- Depletion time C

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Mine, use, throw away; no new discoveries; rising prices

Recycle; increase reserves by improved mining technology, higher prices, and new discoveries

Recycle, reuse, reduce consumption; increase reserves by improved mining technology, higher prices, and new discoveries

A

B

C
Mine, use, throw away; no new discoveries; rising prices

Recycle; increase reserves by improved mining technology, higher prices, and new discoveries

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Present  Depletion time A  Depletion time B  Depletion time C

Time

Stepped Art
Fig. 14-23, p. 361
Market Prices Affect Supplies of Nonrenewable Minerals

- Subsidies and tax breaks to mining companies keep mineral prices artificially low.

- Does this promote economic growth and national security?

- Scarce investment capital hinders the development of new supplies of mineral resources.
Case Study: The U.S. General Mining Law of 1872

- Encouraged mineral exploration and mining of hard-rock minerals on U.S. public lands

- Developed to encourage settling the West (1800s)

- Until 1995, land could be bought for 1872 prices

- Companies must pay for clean-up now
Is Mining Lower-Grade Ores the Answer?

- Factors that limit the mining of lower-grade ores
  - Increased cost of mining and processing larger volumes of ore
  - Availability of freshwater
  - Environmental impact

- Improve mining technology
  - Use microorganisms, *in situ*
  - Slow process
  - What about genetic engineering of the microbes?
Can We Extend Supplies by Getting More Minerals from the Ocean? (1)

- Mineral resources dissolved in the ocean-low concentrations

- Deposits of minerals in sediments along the shallow continental shelf and near shorelines
Can We Extend Supplies by Getting More Minerals from the Ocean? (2)

- Hydrothermal ore deposits

- Metals from the ocean floor: manganese nodules
  - Effect of mining on aquatic life
  - Environmental impact
Concept 14-5  We can try to find substitutes for scarce resources, reduce resource waste, and recycle and reuse minerals.
We Can Find Substitutes for Some Scarce Mineral Resources (1)

- Materials revolution
- Nanotechnology
- Silicon
- High-strength plastics
  - Drawbacks?
We Can Find Substitutes for Some Scarce Mineral Resources (2)

- Substitution is not a cure-all
  - Pt: industrial catalyst
  - Cr: essential ingredient of stainless steel
We Can Recycle and Reuse Valuable Metals

- Recycling
  - Lower environmental impact than mining and processing metals from ores

- Reuse
There Are Many Ways to Use Mineral Resources More Sustainability

- How can we decrease our use and waste of mineral resources?

- Pollution and waste prevention programs
  - Pollution Prevention Pays (3P)
  - Cleaner production
Solutions: Sustainable Use of Nonrenewable Minerals

- Do not waste mineral resources.
- Recycle and reuse 60–80% of mineral resources.
- Include the harmful environmental costs of mining and processing minerals in the prices of items (full-cost pricing).
- Reduce mining subsidies.
- Increase subsidies for recycling, reuse, and finding substitutes.
- Redesign manufacturing processes to use less mineral resources and to produce less pollution and waste (cleaner production).
- Use mineral resource wastes of one manufacturing process as raw materials for other processes.
- Slow population growth.
Case Study: Industrial Ecosystems: Copying Nature

- Mimic nature: recycle and reuse most minerals and chemicals

- Resource exchange webs

- Ecoindustrial parks

- Industrial forms of biomimicry
  - Benefits
Solutions: An Industrial Ecosystem in Denmark Mimics Natural Food Web
Greenhouses

Oil refinery

Sulfuric acid producer

Sludge

Pharmaceutical plant

Local farmers

Surplus natural gas

Electric power plant

Surplus natural gas

Fish farming

Surplus sulfur

Cement manufacturer

Wallboard factory

Surplus calcium sulfate

Area homes

Waste heat

Waste heat

Waste heat

Waste heat

Waste heat

Fly ash

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