Environmental Science, 15e

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12

Geology and Nonrenewable Mineral Resources

Core Case Study: The Crucial Importance of Rare Earth Metals

- There are 17 rare earth metals –
  - Used in the manufacturing of high tech products that are providing current economic growth
    - Products include: liquid crystal display flat screens for computers and TVs, fluorescent and LED light bulbs, and many other essential technologies – even satellites
- How do these rare earth metals affect your life?

12.1 What Are Earth's Geological Processes/What Are Mineral Resources?

- Mineral resources are produced by geological processes active at the surface and within the earth
- The earth's rock cycle takes millions of years to produce mineral resources, making minerals a nonrenewable resource

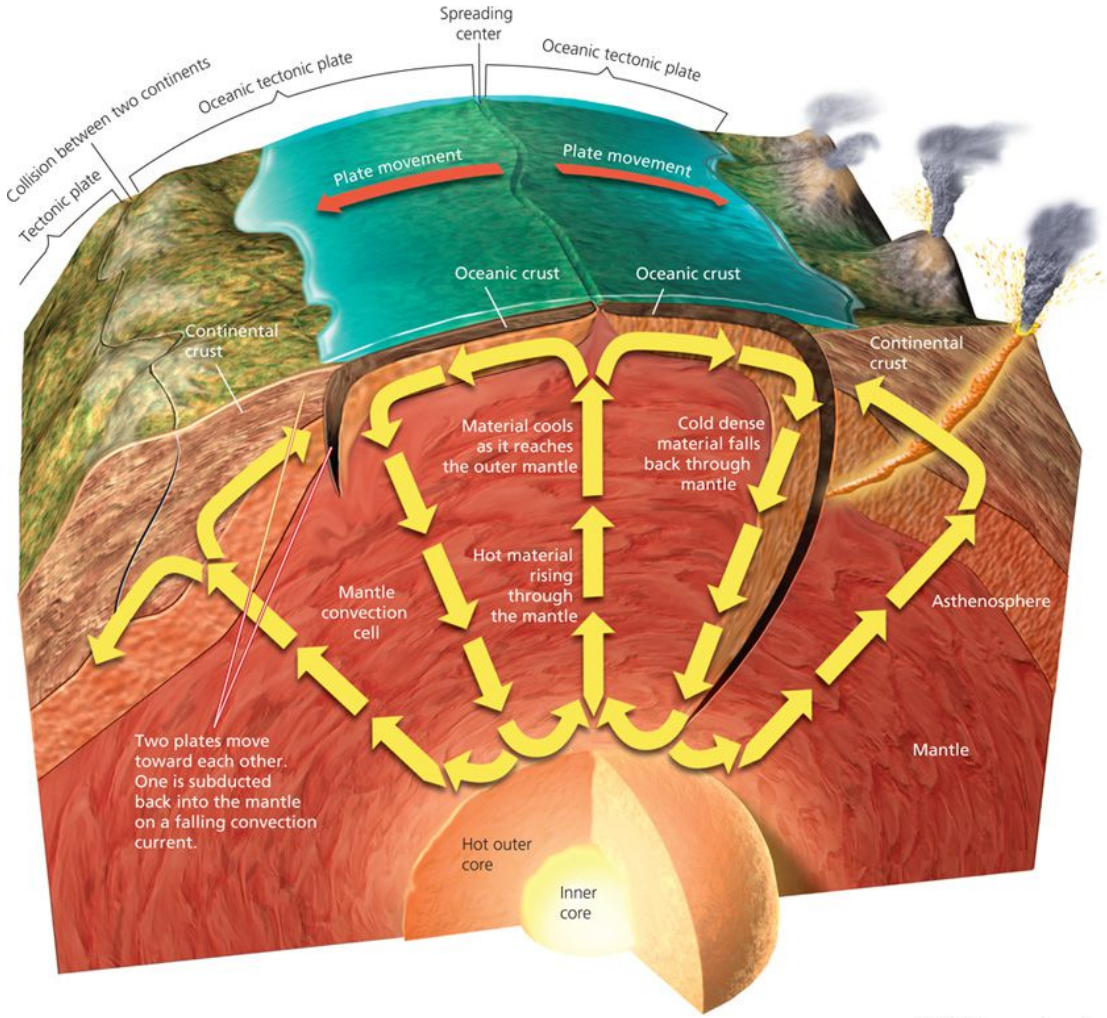
Earth: A Dynamic Planet

- When the earth cooled, three zones were created: the core, the mantle and the crust
  - Core: two types, an inner core (a hot, solid sphere) and an outer core (molten liquid rock)
  - Mantle: thick semi-solid liquid with the ability to flow over geologic time
  - Crust: thin, outermost layer

Convection Cells

- The uppermost mantle is solid, below which is a partially melted zone that flows (asthenosphere)
- High heat in the core and inner mantle generate convection cells (circulation cells) that move heat and rocks around
- Molten rock reaches the earth's surface as volcanic magma
- Rare minerals are found in the lithosphere

The Earth's Layers



What Are Minerals?

- Naturally occurring, chemical elements or inorganic compounds (solids) with regularly arranged atoms or ions
  - Mineral resource: one or more minerals that can be extracted, processed, and used in manufacturing
  - Some contain only one element (gold, lanthanum, salt), others contain more than one element as in an inorganic compound (quartz and rare earth oxides)

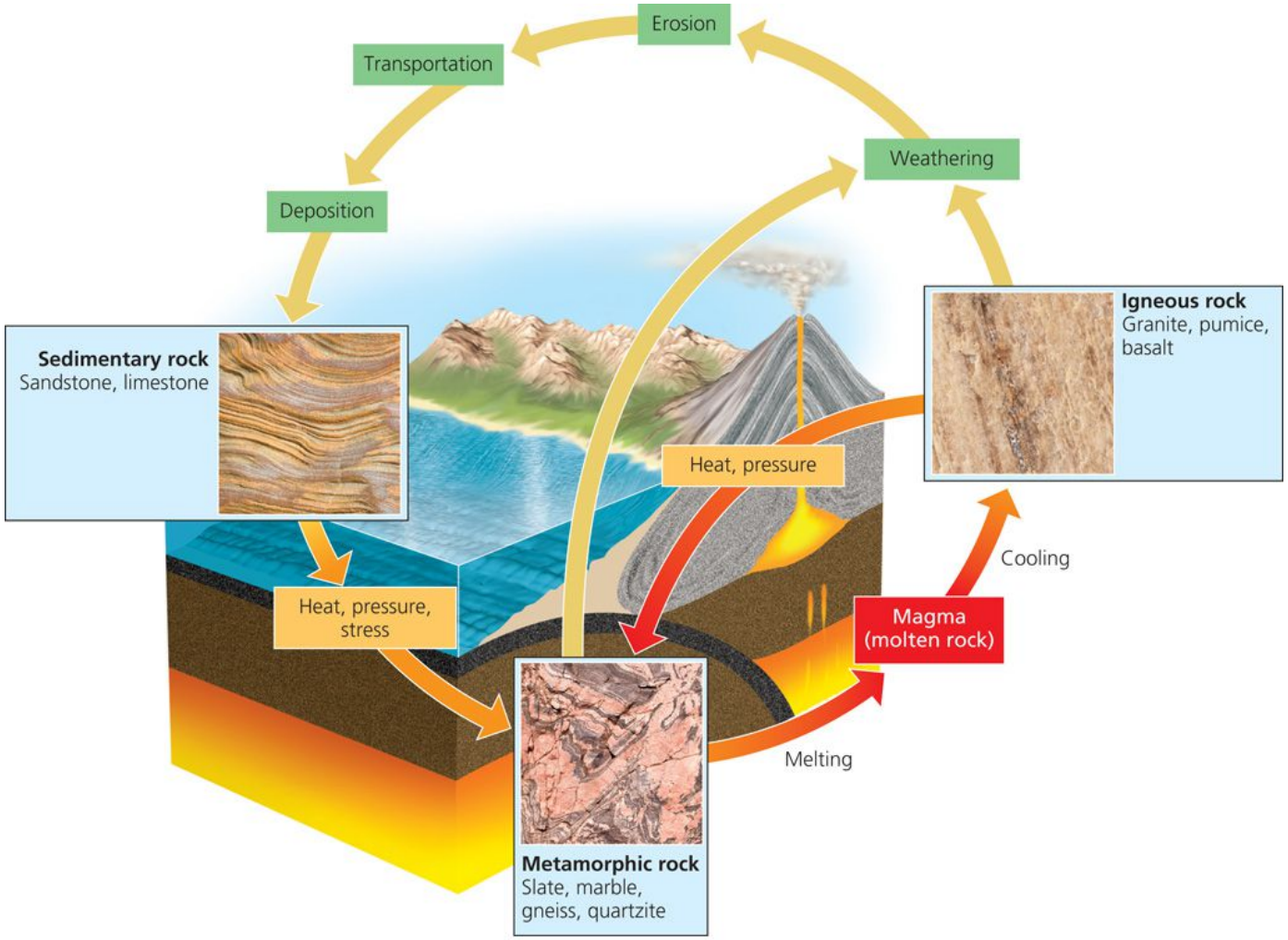
What Are Rocks?

- Rocks: solid collections of one or more minerals in the earth's crust
  - Sedimentary rocks (sandstones, shale)
    - Sediments compacted and cemented into rock
  - Igneous rocks (granite, lava rock)
    - Cooled magma and lava
  - Metamorphic rocks (slate, marble)
    - Exposed and altered by high pressures and temperatures

Recycling of the Earth's Rocks

- Rock cycle: the interaction of physical and chemical processes that work to change rocks from one kind to another
  - Recycling processes: erosion, melting, metamorphism
- The rock cycle is the slowest earth cycle, taking millions of years to recycle – so these resources are nonrenewable

Natural Capital: The Rock Cycle



Nonrenewable Mineral Resources

- Ore: rock that contains a valuable mineral that can be mined and processed cost-effectively
- About 60 metallic elements in the periodic table are mined and used in manufacturing
- Nonmetallic minerals and other inorganic compounds are also used in construction and manufacturing (sand, gravel, limestone, phosphate salts)

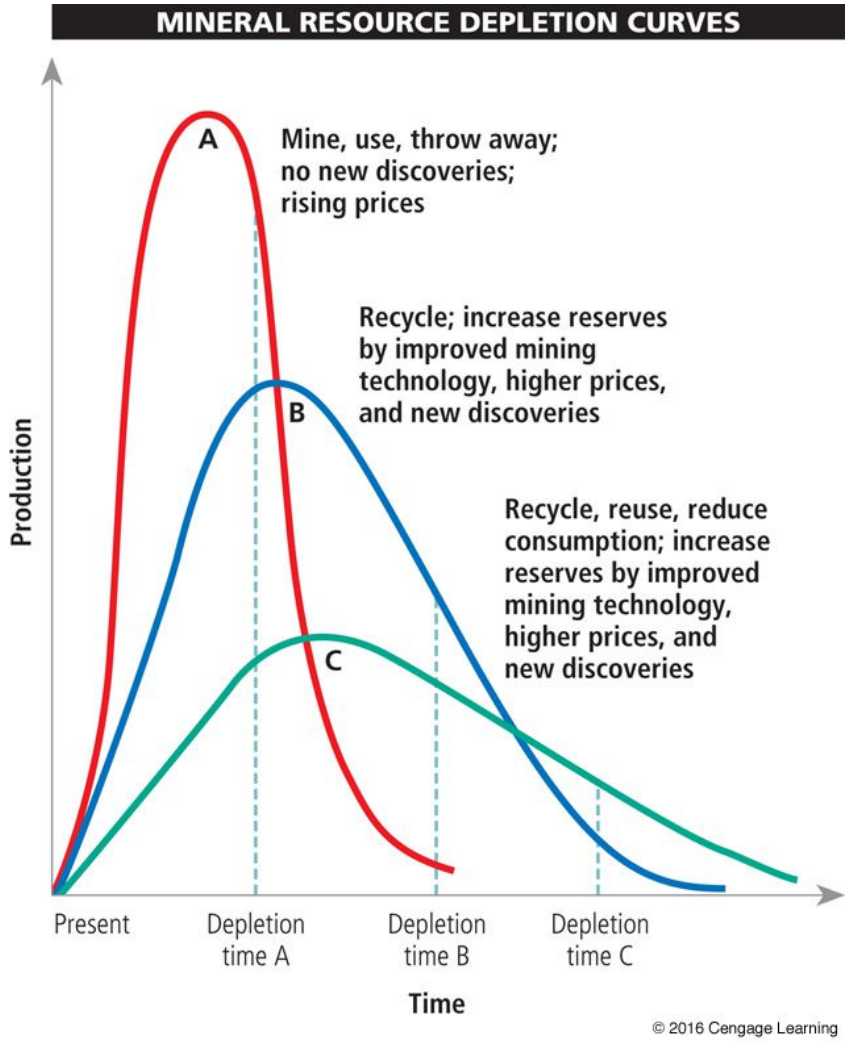
12.2 How Long Might Supplies of Nonrenewable Mineral Resources Last?

- Mining nonrenewable mineral resources is limited by the cost of finding, extracting, and processing them (economic depletion)
- Environmental and economic factors limit the ways in which the supply of mineral resources can be extended

Economic Depletion of Nonrenewable Mineral Resources

- Reserves: resource deposits that can be profitably extracted
  - Expand when new geographic sites are found, when prices increase, or when extraction of previously expensive reserves becomes profitable
  - Actual or potential supply and consumption rate control future supplies
  - Depletion time: time to use up 80% of available resources at a given rate of use

Natural Capital Depletion: Depletion Time Estimates



Market Prices Affect Supply – Can We Mine Lower-Grade Ores?

- If supply is scarce, the market price rises
  - Factors that limit mining lower-grade ores
    - Larger volume of rock to process, higher cost, dwindling supplies of freshwater needed in processing, environmental impacts of larger quantities for waste disposal
    - New technologies can make mining lower-grade ores profitable
  - Biomining: use of bacteria to remove ore from rocks – but this may take decades to develop

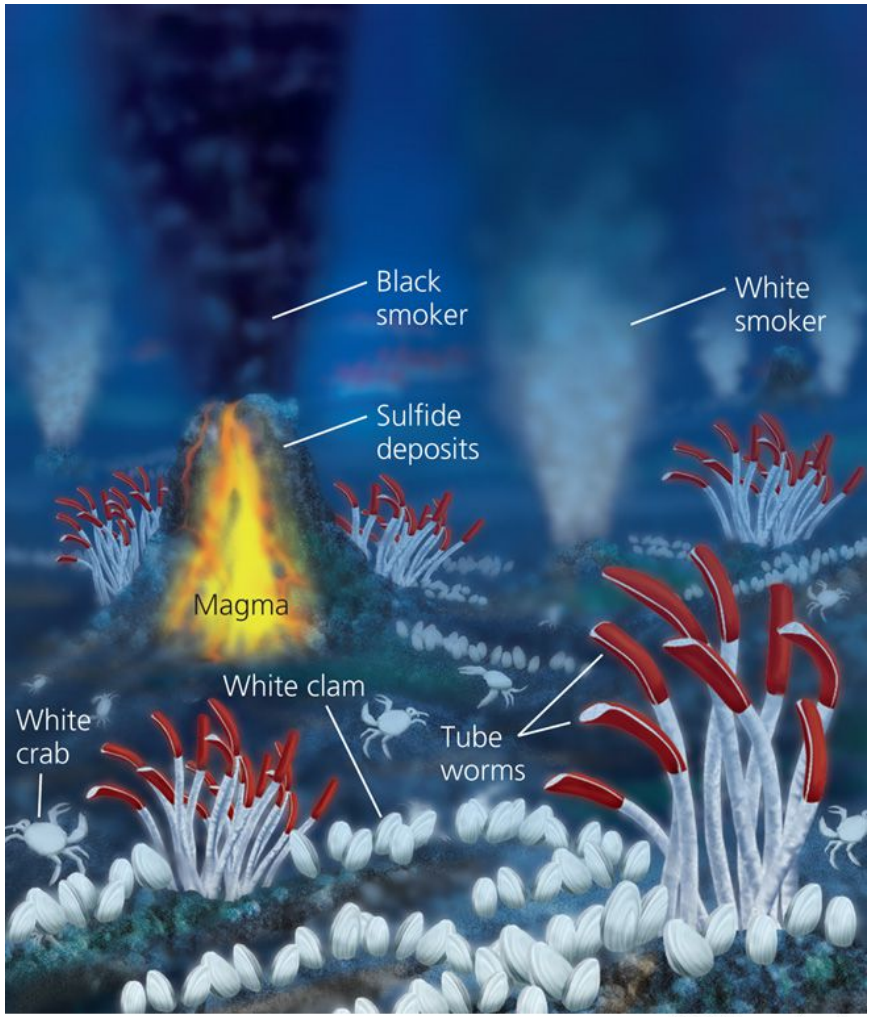
Can We Get More Minerals From the Ocean?

- Most minerals occur in such low concentrations in the ocean that it is not profitable to mine them
  - Sediments along coasts and continental shelves have large amounts of minerals that can be extracted (sand, copper, iron, diamonds)
- Possible to extract minerals near volcanic regions on the ocean floor – hydrothermal vents/black smokers

Deep Sea Mining

- Rising prices for rare earth mineral now make deep sea mining profitable
  - China is using remote-controlled underwater equipment to explore black smokers
- In 2011, the UN International Seabed Authority was established to monitor mining in international waters
  - Deep sea mining processes may disturb sediments and harm filter feeders

Natural Capital: Hydrothermal Deposits



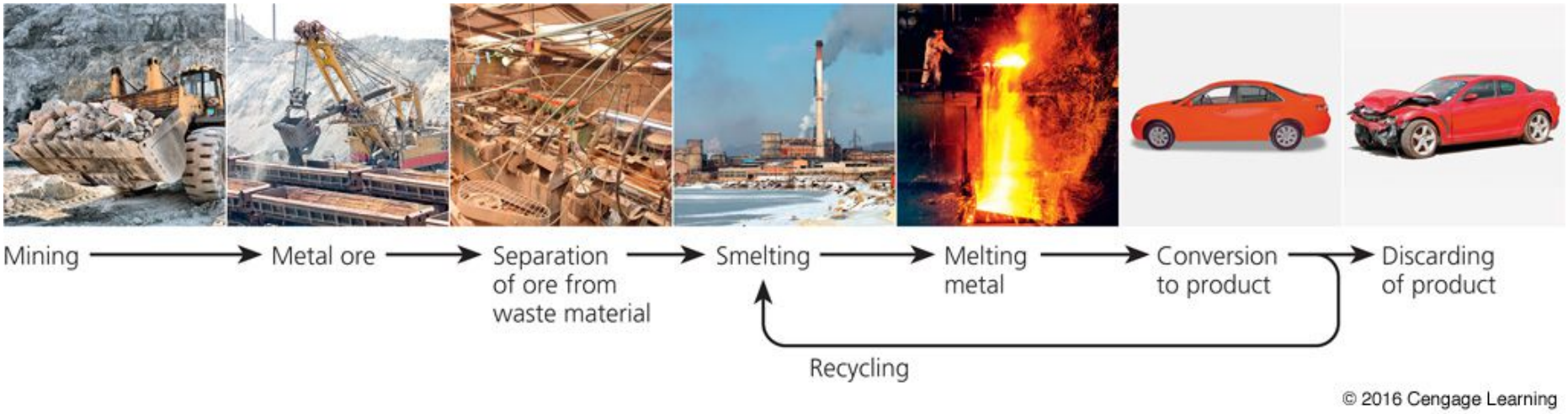
12.3 What Are Environmental Effects of Using Nonrenewable Mineral Resources?

- Environments, ecosystems and ecosystem services are dramatically affected by extraction of minerals
  - Causing soil erosion, and producing large amounts of solid waste, and pollution of air, water, and soil

Extracting Minerals Can Have Harmful Environmental Effects

- Life cycle of a mineral: extraction, processing, manufacturing a product, and disposal and recycling of wastes
  - Consumes large amounts of freshwater and energy and produces pollution and waste
- Accessible high-grade ores are mined first
  - Extracting low-grade ores costs more money and has more harmful environmental effects

The Life Cycle of Metals



Shallow Mining Techniques

- Surface mining: shallow deposits and overburden (vegetation and rock) are cleared – topography and type of resource determines methods used
  - Open-pit mining: digging very deep holes
- Strip mining: extraction of resources in horizontal beds near the earth's surface
  - Large earth movers strip overburden/power shovels remove the mineral deposits (coal)

More Techniques: Surface and Subsurface Mining

- Contour strip mining: process that terrace sides of mountains, often for mining coal
  - Overburden from each new terrace is dumped on the one below
- Mountaintop mining: removing of mountaintop with explosives
  - Used in the Appalachians – very destructive
- Subsurface mining: deep shafts are dug into the earth to remove the minerals

Natural Capital Degradation: Contour Strip Mining

Jim West/Age Fotostock

Mining Produces Solid Wastes

- Surface and subsurface mining produces ¾ of all solid wastes – a major cause of air and water pollution
  - Pollutes 40% of the western mountain watersheds in the U.S.
  - Responsible for 50% of the toxic chemicals released into the atmosphere
  - Severe environmental impacts occur where regulations and enforcement are not followed

Processing Ores Have Harmful Environmental Effects

- Mining produces tailings: waste rock leftover after the ore has been extracted
  - Tailings are left in piles, when blown by wind or washed out by rainfall they contaminate topsoil, surface water, and groundwater
- Smelting: when heat and chemicals are used to extract the ores – sulfur dioxide
  - Huge quantities of air pollution can result from this process

12.4 How Can We Use Mineral Resources More Sustainably?

- Some mineral resources are scarce
- Humans need to find substitutes for these, and recycle and reuse minerals already mined – to reduce environmental damage

Possible Solution: Finding Substitutes for Scarce Mineral Resources

- The current technological revolution in materials science is finding many substitutes for minerals/metals
  - Silicon is replacing metals, fiber optic cables are replacing copper and aluminum wires, and plastics are being used in many new ways
- Finding substitutes for some rare minerals (platinum) may not be possible

Using Mineral Resources More Sustainably

- Reuse or recycle metal products
- Redesign manufacturing processes to use less mineral resources
- Reduce mining subsidies
- Increase subsidies for reuse, recycling, and finding substitutes
- Some products are being redesigned so they do not need rare minerals (hybrid cars)

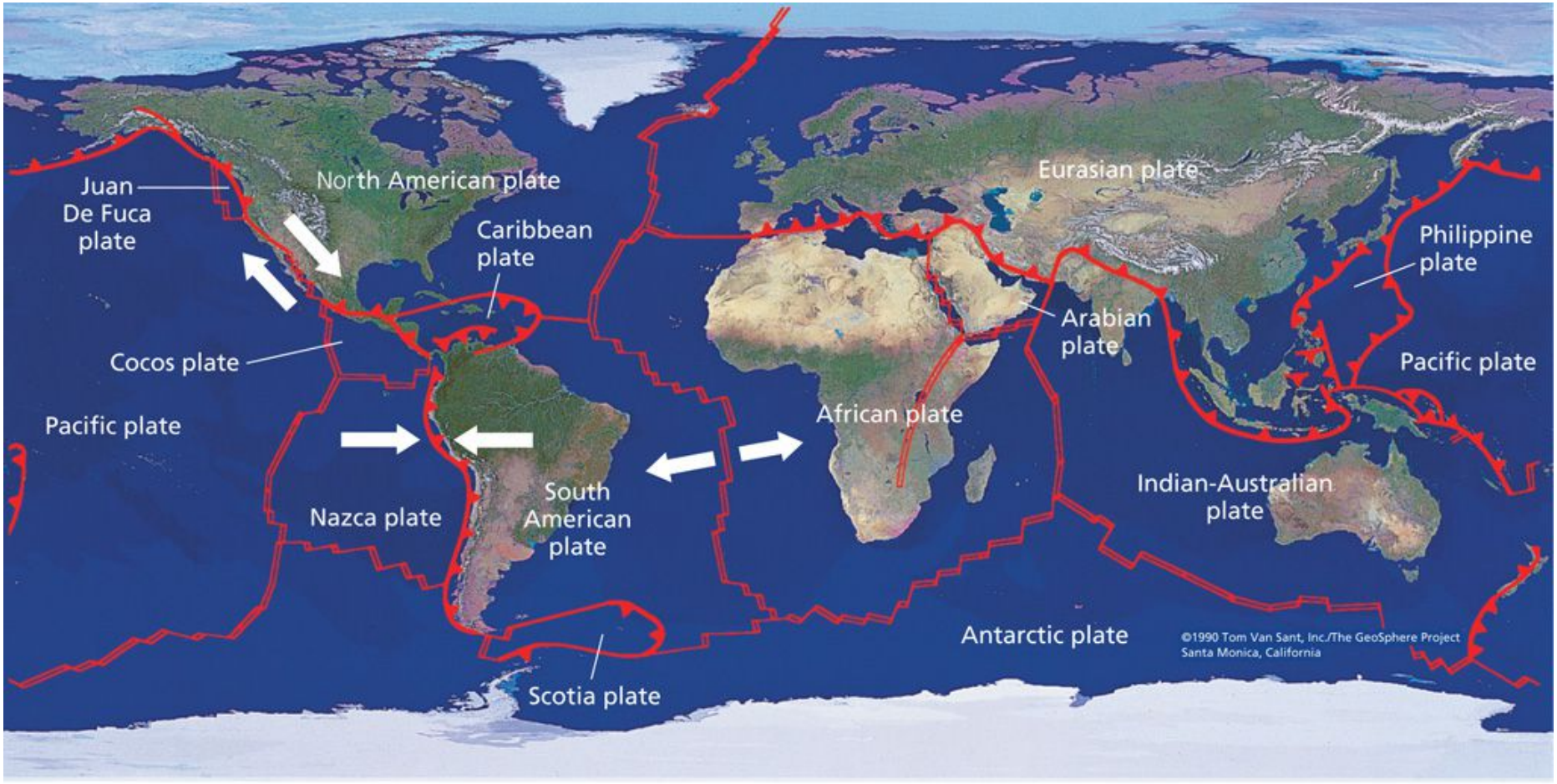
12.5 What Are the Earth's Major Geological Hazards?

- Geological processes move rocks around the planet and within the earth
- These processes are reflected in volcanic eruptions, earthquakes, tsunamis, erosion, and landslides

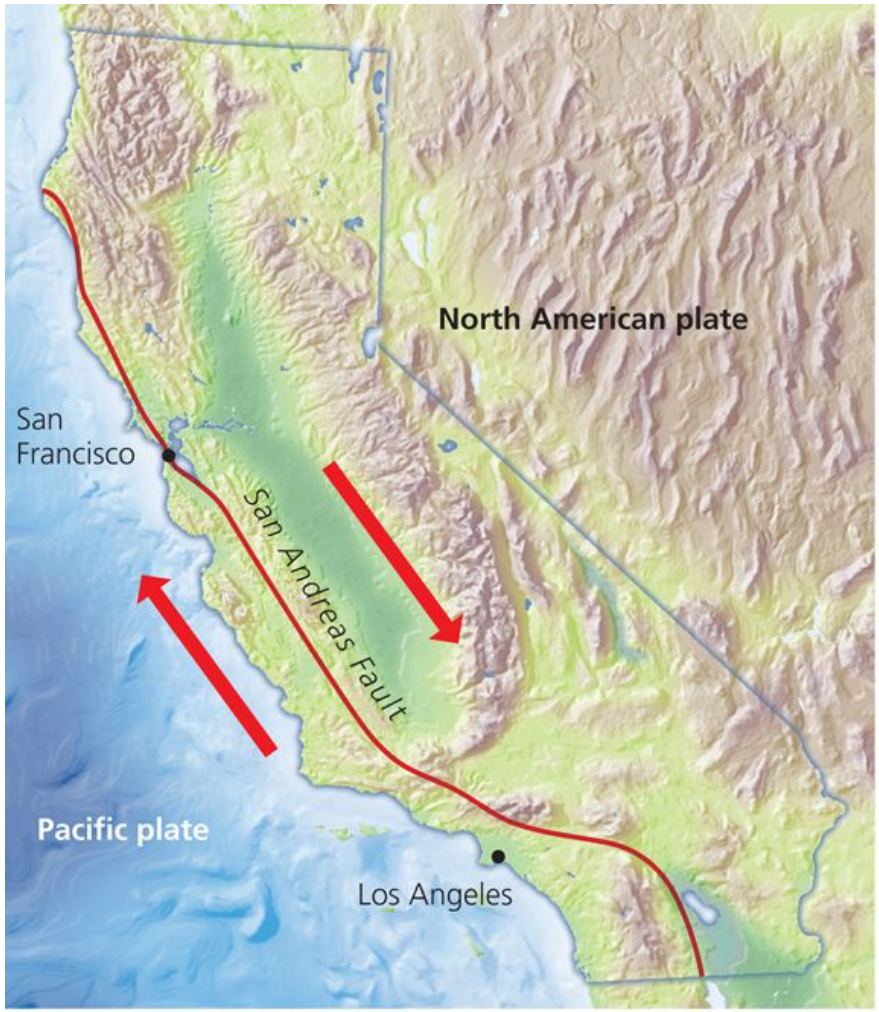
Tectonic Plates

- The earth's surface is divided into many tectonic plates that are rigid and move very slowly on top of the asthenosphere
- Over geologic time, these plates have moved, split apart, and rejoined
- These geologic forces are extremely strong, especially near their boundaries
  - They create mountains/deep valleys and cause earthquakes and volcanic eruptions

The Earth's Tectonic Plates



The San Andreas Fault



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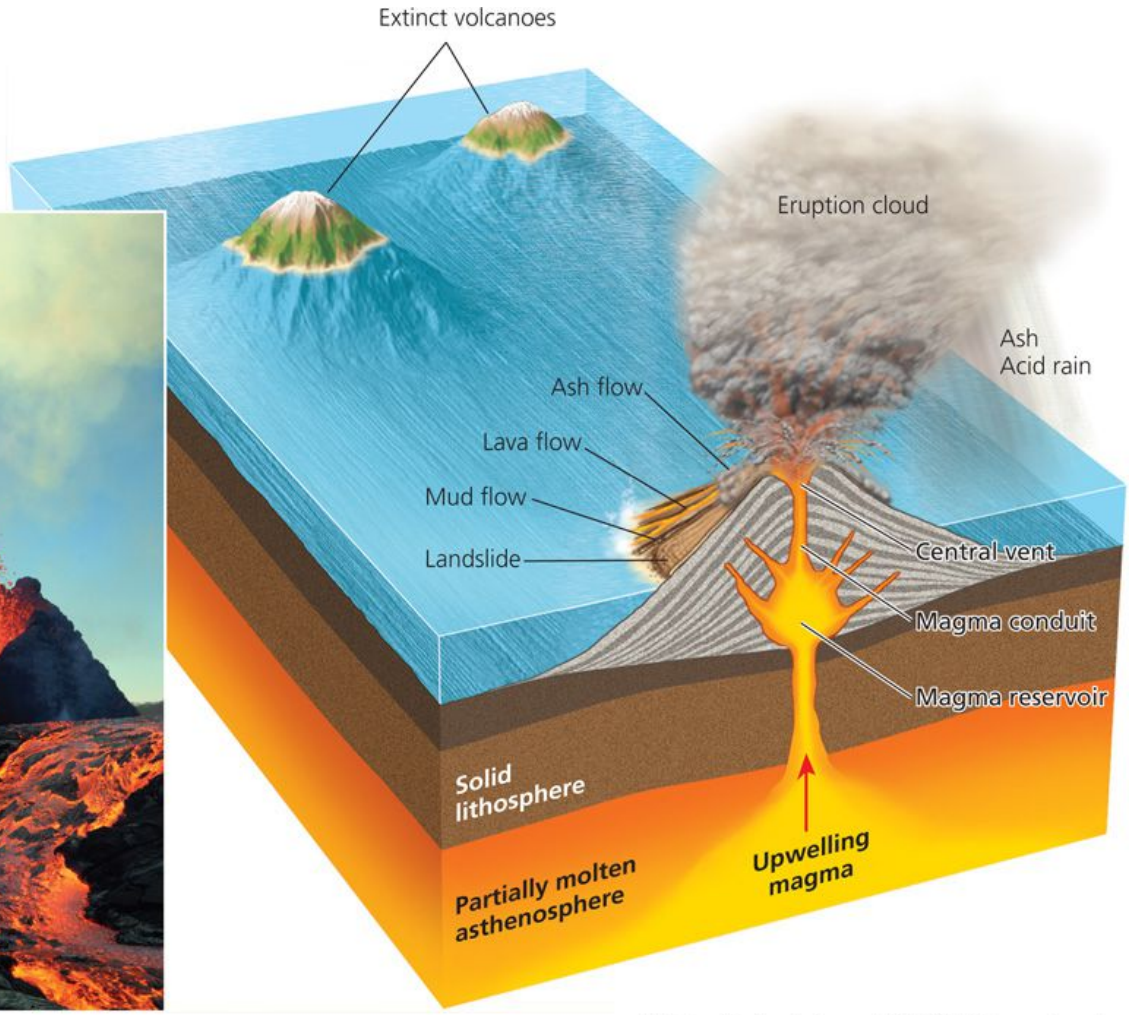
Volcanoes Release Molten Rock From the Earth's Interior

- Volcanoes: where plumes of magma reach the earth's surface through a central vent or long cracks called fissures
  - Often form along tectonic plate boundaries
  - Eruptions put lava rock, glowing hot ash, liquid lava, and gases into the environment
- Benefits are beautiful scenery and fertile soils caused by erosion of volcanic rocks

Volcanoes



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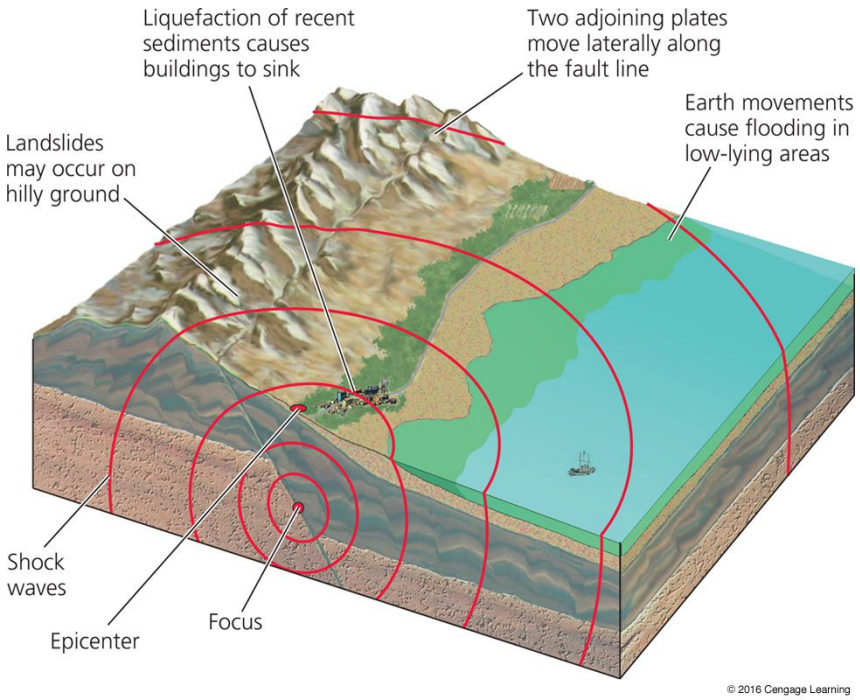
Earthquakes Are Geological Rock-and-Roll Events

- Stresses within the earth's mantle cause earthquakes – these usually take place along fault lines
  - Seismic waves move away from the earthquake's focus
  - Richter scale measures the magnitude
  - Earthquakes cause serious damage to buildings, bridges, freeways, pipelines
    - Largest earthquake – Chile, in 1960, at 9.5 on the Richter scale

An Earthquake

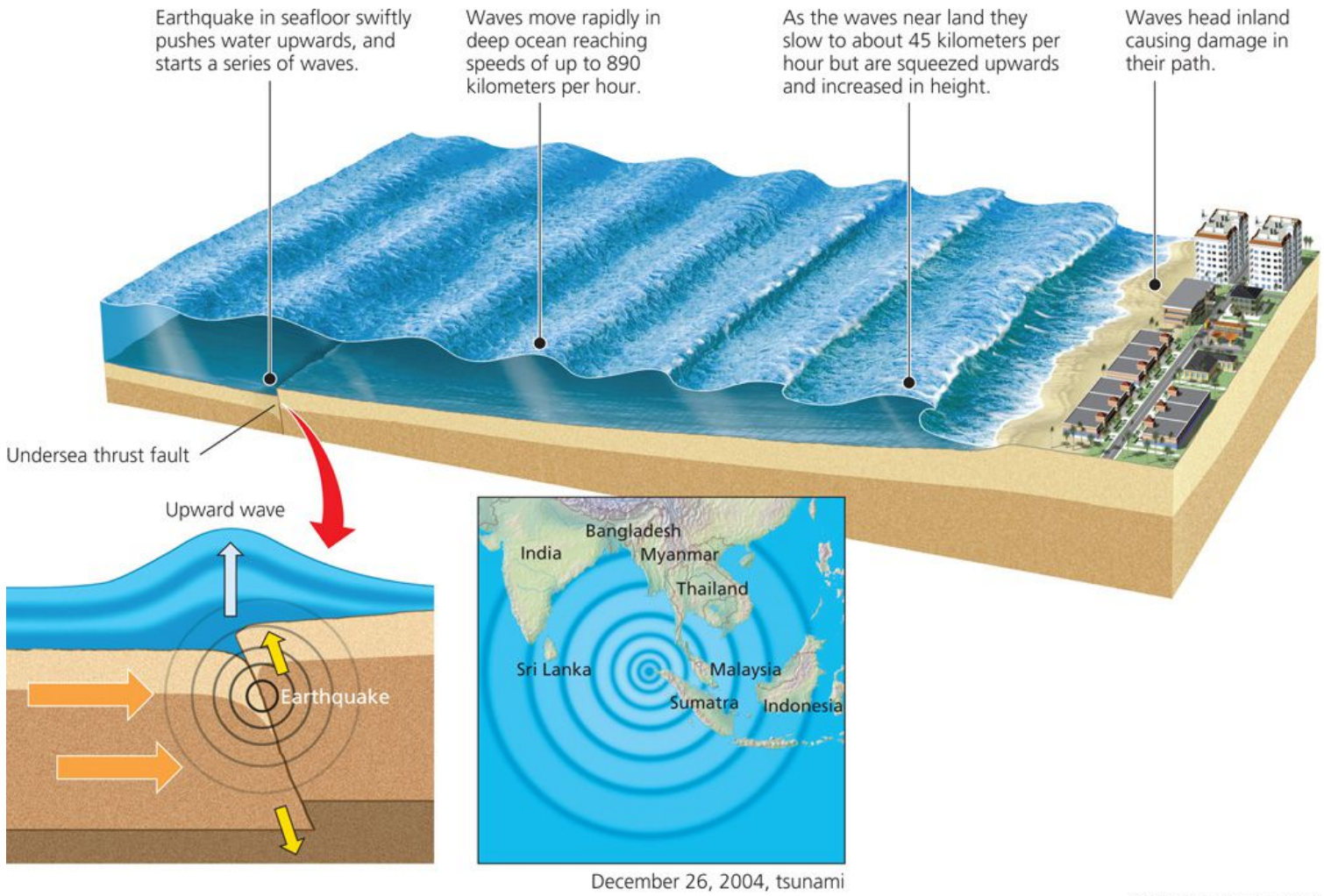



AP Photo/Jorge Cruz

Earthquakes on the Ocean Floor Generate Huge Waves Called Tsunamis

- Earthquakes that take place on the ocean floor lift or depress large segments of the crust displacing the water above
  - This generates tsunami waves that travel far across the oceans and roar inland over coastal human settlements

The Formation of a Tsunami



Additional Case Study: A Scarcity of Rare Metals is Hindering Green Technologies

- Some green technologies are not used due to shortages of rare earth minerals
  - Materials are not reused because it is chemically easier and cheaper to extract them from ore deposits than to remove them from manufactured products
  - Every year 49 million tons of e-waste – from cell phones to refrigerators – accumulates in urban trash (less than 10% is recycled)

Additional Case Study: Organizations Researching Solutions to These Problems

- The Critical Materials Institute looks for substitutes/works on developing ways to make better use of available resources
  - UMICORE in Belgium works to recycle rare earth metals from industrial residues, electronic scrap and spent catalysts
  - Why are products containing rare earth metals not being recycled?
  - How can UMICORE contribute to the principle of sustainability?

Scarcity of Rare Earth Metals and the Three Big Ideas

- Natural occurrences of rare earth elements are associated with igneous rocks – both are formed by the earth's dynamic processes
- Rare earth minerals are not concentrated in large ore deposits, so mining is costly
- Scientists are working to find ways of recycling and using substitutes for rare earth metals