Foundations of Earth Science

Eighth Edition

Volcanoes and Other Igneous Activity

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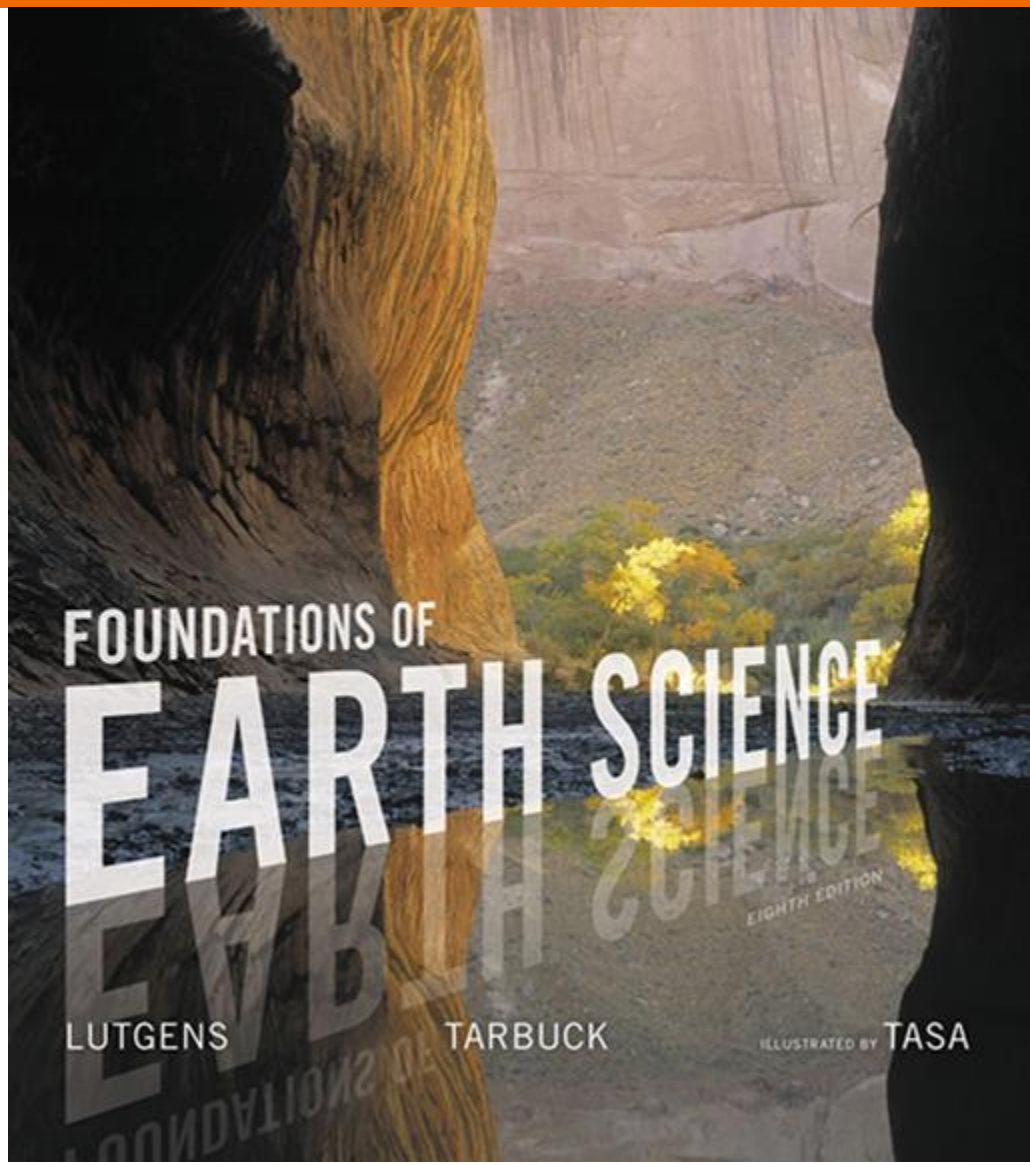


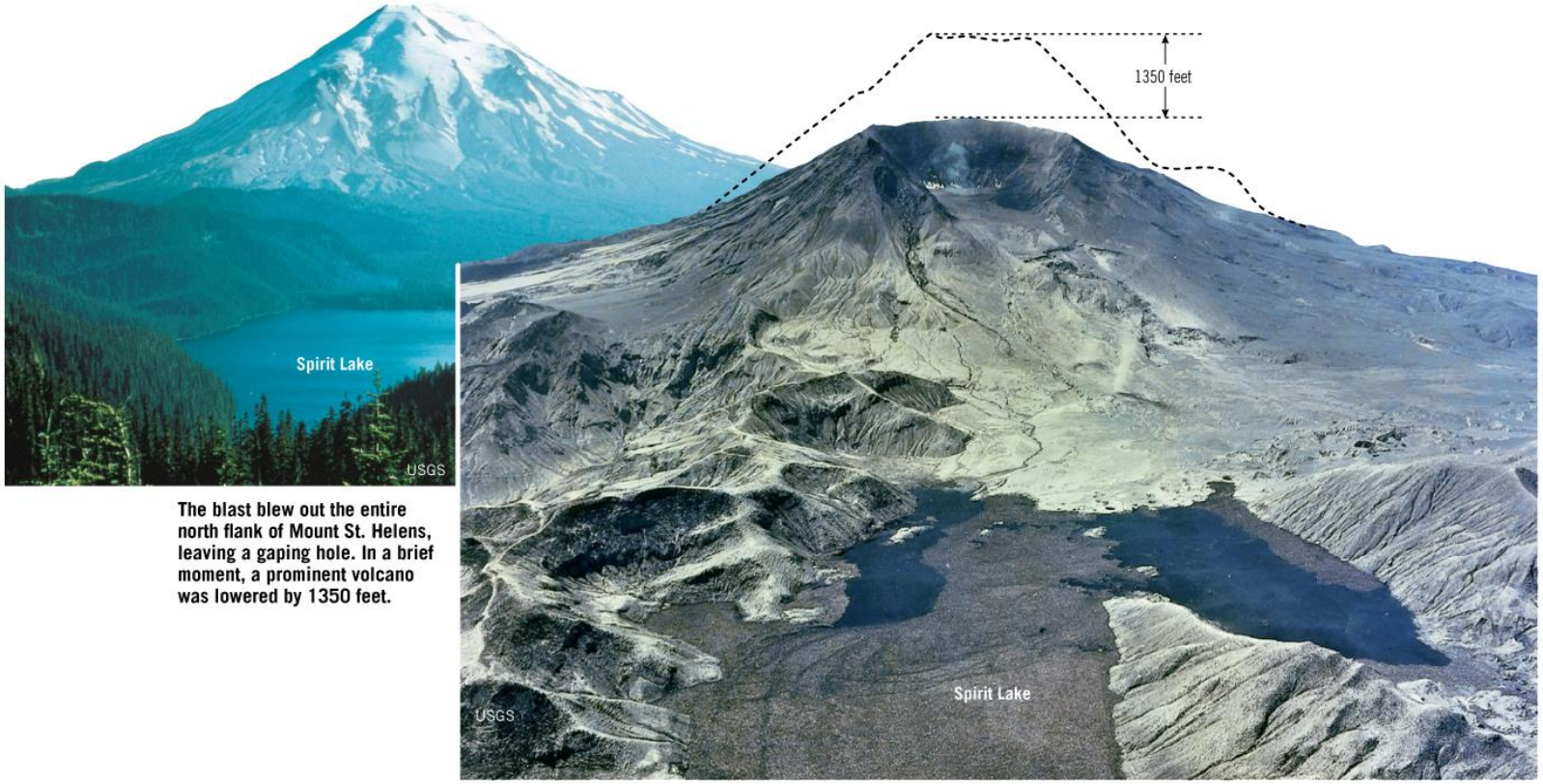
Focus Question 7.1

- Compare and contrast the 1980 eruption of Mount St. Helens with the most recent eruption of Kilauea, which began in 1983.

Mount St. Helens Versus Kilauea

- Mount St. Helens
  - Largest historic eruption in North America
  - Lowered peak by more than 400 m
  - Destroyed all trees in a 400 km^2 area
  - Mudflows 29 km down Toutle River
  - Ejected 1 km^3 ash more than 18 km into stratosphere

Mount St. Helens Versus Kilauea



The blast blew out the entire north flank of Mount St. Helens, leaving a gaping hole. In a brief moment, a prominent volcano was lowered by 1350 feet.

Mount St. Helens Versus Kilauea

Mount St. Helens Versus Kilauea

- Kilauea
  - Quiet eruption of fluid basaltic lava
  - Occasional lava sprays
  - Eruption began in 1983 and has been ongoing for more than 20 years

Focus Question 7.2

- Explain why some volcanic eruptions are explosive and others are quiescent.

Magma: Source Material for Volcanic Eruptions

- **Magma**
  - Molten rock containing crystals and dissolved gas
- **Lava**
  - Erupted magma
- Basaltic magma
  - Generated by partial melting in upper mantle
  - At oceanic crust, erupts as highly fluid lava
  - At continental crust, collects at crust–mantle boundary
    - Partial melting of overlying continental crust generates dense, silica-rich magma

Quiescent Versus Explosive Eruptions

- **Viscosity**
  - Resistance to flow
- How to *decrease* magma viscosity
  - Increase temperature
  - Decrease silica content
    - Rhyolitic magma (>70% Si) forms short, thick flows
    - Basaltic magma (~50% Si) is fluid
- Gas content also dictates nature of eruption
  - Directly related to composition
  - Most common gas is water vapor

The Nature of Volcanic Eruptions

Properties of Magma Bodies with Differing Compositions

Composition	Silica Content (SiO_2)	Gas Content (% by weight)	Eruptive Temperature	Viscosity	Tendency to Form Pyroclastics	Volcanic Landform
Basaltic (mafic) High in Fe, Mg, Ca, low in K, Na	**Least** (~50%)	**Least** (0.5–2%)	**Highest** 1000–1250°C	**Least**	**Least**	Shield volcanoes, basalt plateaus, cinder cones
Andesitic Intermediate amounts of Fe, Mg, Ca, K, Na	**Intermediate** (~60%)	**Intermediate** (3–4%)	**Intermediate** 800–1050°C	**Intermediate**	**Intermediate**	Composite cones
Rhyolitic (felsic) High in K, Na, low in Fe, Mg, Ca	**Most** (~70%)	**Most** (5–8%)	**Lowest** 650–900°C	**Greatest**	**Greatest**	Pyroclastic flow deposits, lava domes

Quiescent Hawaiian-Type Eruptions

- Triggered by addition of magma to near-surface magma chamber
- Inflation and fracture of volcano summit
- Fluid basaltic lava
- Ongoing eruption of Kilauea since 1983

Quiescent Hawaiian-Type Eruptions

Gases readily escape hot fluid basaltic flows, producing lava fountains. Although often spectacular, these features do not cause great loss of life or property.

How Explosive Eruptions Are Triggered

- Pressure decreases as magma rises
  - Dissolved gas forms expanding bubbles
- Viscous magma expels fragmented lava and gas
  - Buoyant plumes of material (**eruption columns**)
- Rapid ejection of magma
  - Reduces pressure in magma chamber
  - Causes further expansion and eruption

How Explosive Eruptions Are Triggered

Focus Question 7.3

- List and describe the three categories of materials extruded during volcanic eruptions.

Lava Flows

- 90% of lava is basaltic
  - Most is erupted on seafloor (submarine volcanism)
  - Flows in thin, broad sheets or ribbons
  - Flow rate ~10 to 300 m/hr
    - Up to 30 km/hr downhill
- ~9% is andesitic/intermediate
- <1% is rhyolitic
  - Thick flows move imperceptibly slow
  - Don’t flow beyond a few km from vents

Lava Flows

- Two types of basaltic lava flows:
  - **Aa**
    - Rough, jagged blocks with sharp edges
    - Cooler, more viscous basaltic flows
  - **Pahoehoe**
    - Smooth, ropy surfaces
    - Hotter, less viscous basaltic flows

Lava Flows

A. Active aa flow overriding an older pahoehoe flow.

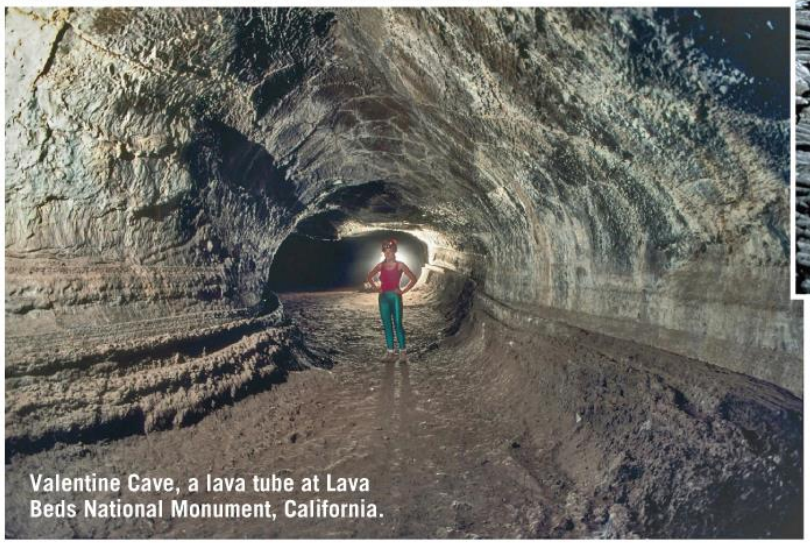
B. Pahoehoe flow displaying the characteristic ropy appearance.

Lava Flows

- **Lava tubes**
  - Insulated pathways of a lava flow
- Pillow lavas
  - Numerous tube-like structures stacked atop each other
  - Form on the ocean floor

Lava Flows

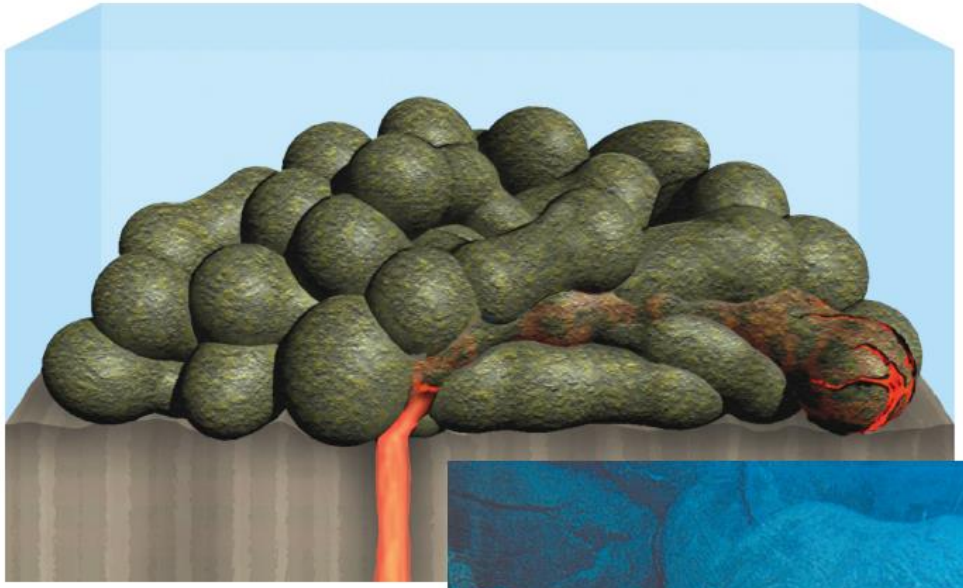
A. Lava tubes are cave-like tunnels that once served as conduits carrying lava from an active vent to the flow's leading edge.



Valentine Cave, a lava tube at Lava Beds National Monument, California.

B. Skylights develop where the roofs of lava tubes collapse and reveal the hot lava flowing through the tube.

Lava Flows



Pillow lavas form on the ocean floor and have elongated shapes, resembling toothpaste coming out of a tube.

Gases

- Gases in magma are **volatiles**
  - Dissolved into magma because of confining pressure
  - ~1–8% of total magma volume
  - Most abundant gases (in decreasing order): water vapor, carbon dioxide, sulfur dioxide, lesser amounts of hydrogen sulfide, carbon monoxide, and helium
  - Contribute to atmosphere
    - Significant quantities can alter global climate

Pyroclastic Materials

- **Pyroclastic materials or tephra**
  - Particles erupted from a volcano (ash and dust)
  - Hot ash fuses to form welded tuff
  - Lapilli and cinders are the size of small beads to walnuts
  - Blocks are larger than 64 mm
  - Bombs are streamlined blocks ejected while still molten
- **Scoria** is vesicular ejecta
- **Pumice** is felsic equivalent

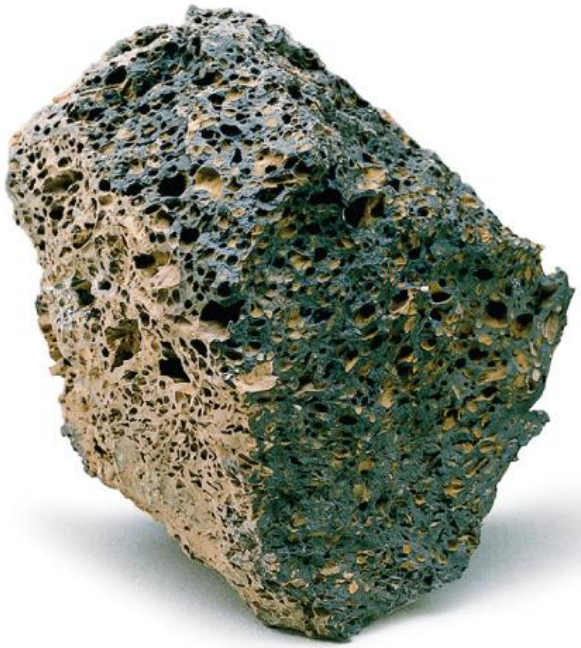
Materials Extruded During an Eruption

Pyroclastic Materials (Tephra)

Particle name	Particle size	Image
Volcanic ash*	Less than 2 mm (0.08 inch)	
Lapilli (Cinders)	Between 2 mm and 64 mm (0.08–2.5 inches)	
Volcanic bombs	More than 64 mm (2.5 inches)	
Volcanic blocks		

*The term volcanic dust is used for fine volcanic ash less than 0.063 mm (0.0025 inch).

Materials Extruded During an Eruption



A. Scoria is a vesicular rock commonly having a basaltic composition. Pea-to-basketball size scoria fragments make up a large portion of most cinder cones (also called *scoria cones*).

B. Pumice is a low density vesicular rock that forms during explosive eruptions of viscous magma having an andesitic to rhyolitic composition.

Focus Question 7.4

- Draw and label a diagram that illustrates the basic features of a typical volcanic cone.

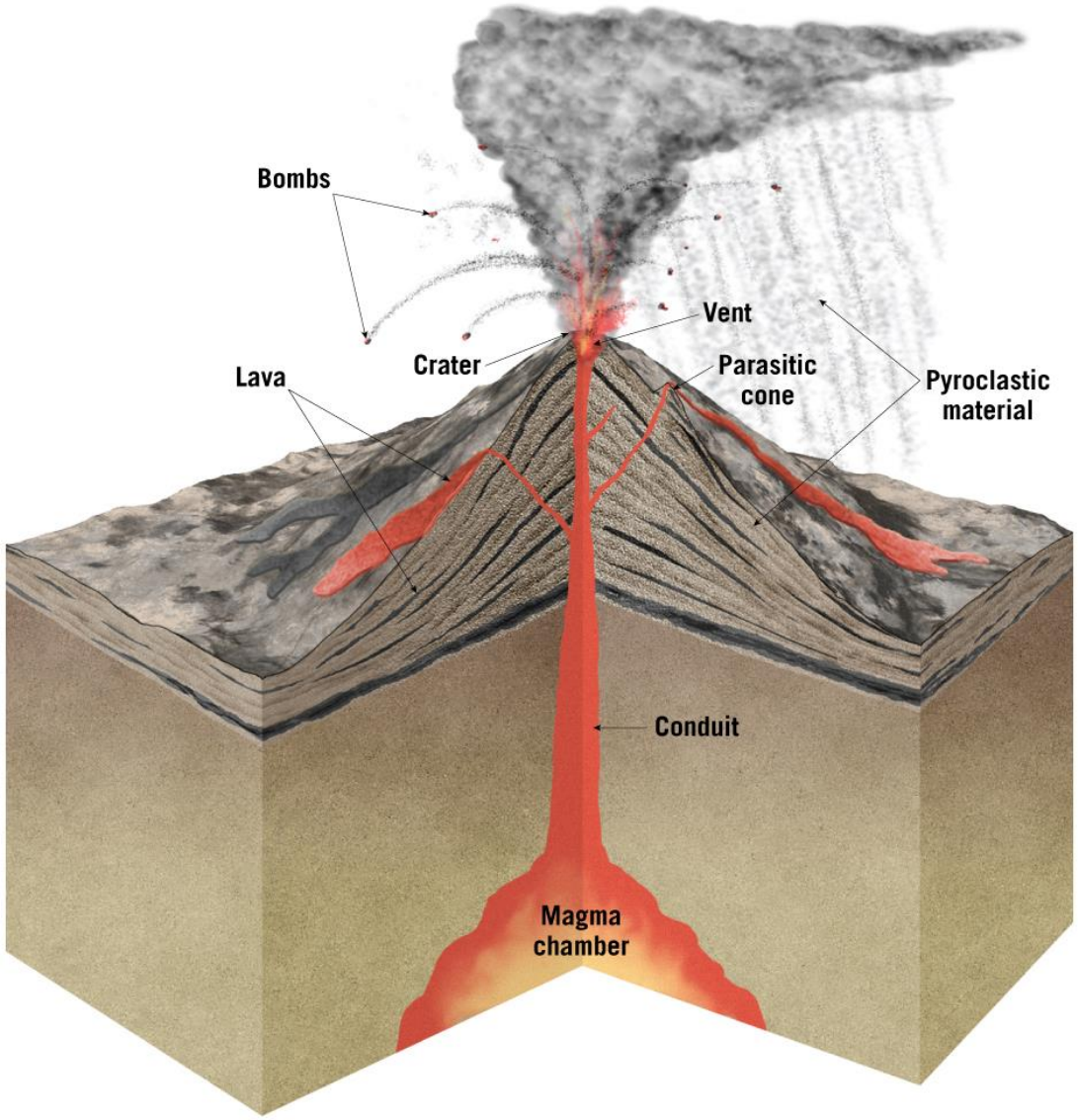
Anatomy of a Volcano

- Volcanic landforms are the result of many generations of volcanic activity
  - Eruptions start at a **fissure**
  - Flow is localized into a circular **conduit**
  - Conduit terminates at a **vent**
  - Successive eruptions form a **volcanic cone**

Anatomy of a Volcano

- **Crater**
  - Funnel-shaped depression at the summit
  - Form by erosion during, or collapse following, eruptions
  - **Calderas** are craters >1 km
- Flank eruptions generate **parasitic cones**
- Secondary vents that emit gas only are called **fumaroles**

Anatomy of a Volcano



Focus Questions 7.5

- Summarize the characteristics of shield volcanoes.
- Provide one example of this type of volcano.

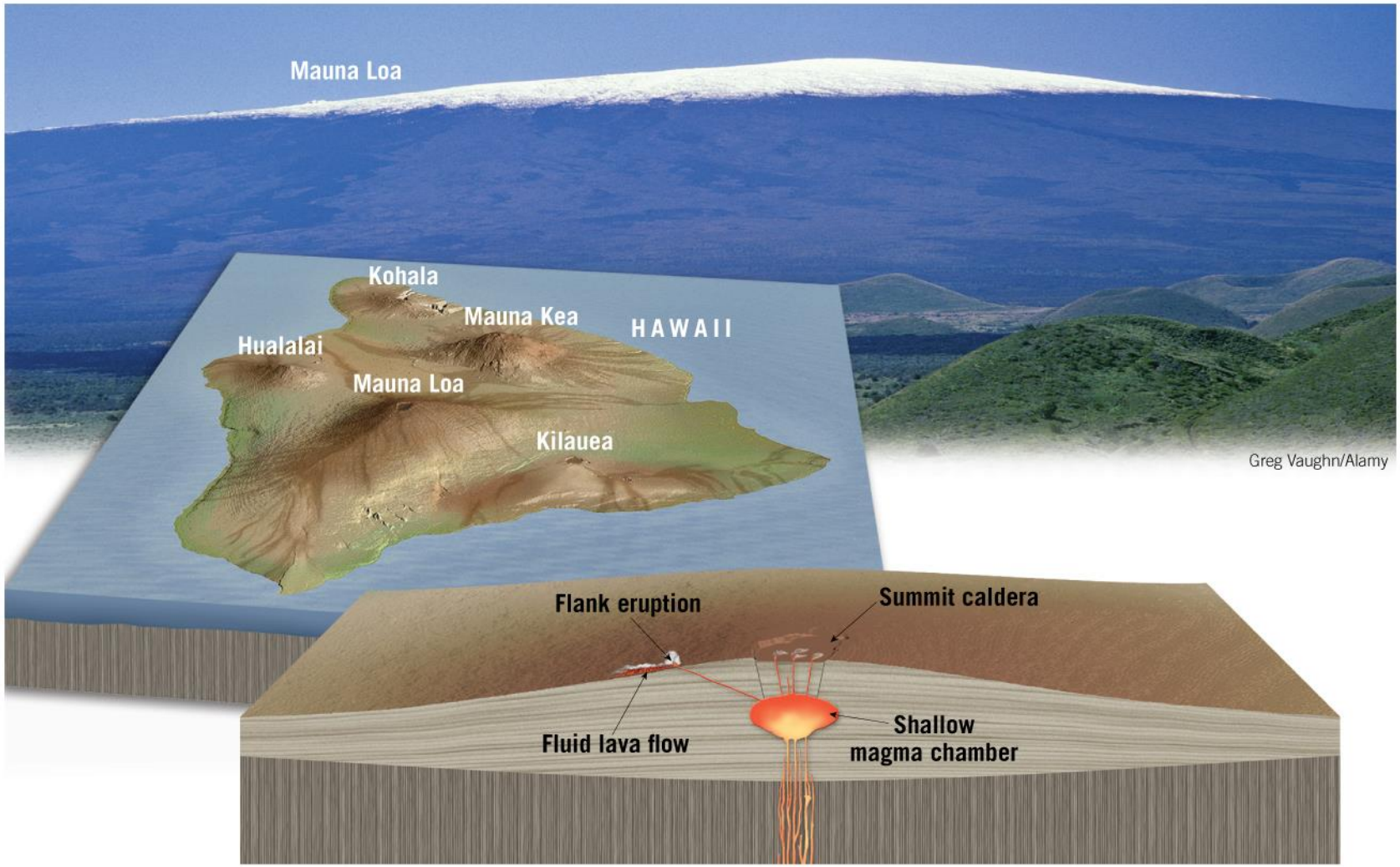
Shield Volcanoes

- Broad domed structures built by accumulation of basaltic lava
- Most begin as **seamounts** (submarine volcano)
  - e.g., Canary Islands, Hawaiian Islands, Galapagos, Easter Island, Newberry Volcano in Oregon

Mauna Loa: Earth's Largest Shield Volcano

- 9 km high
- Low angle slopes
- Well-developed caldera from collapse of magma chamber following eruption

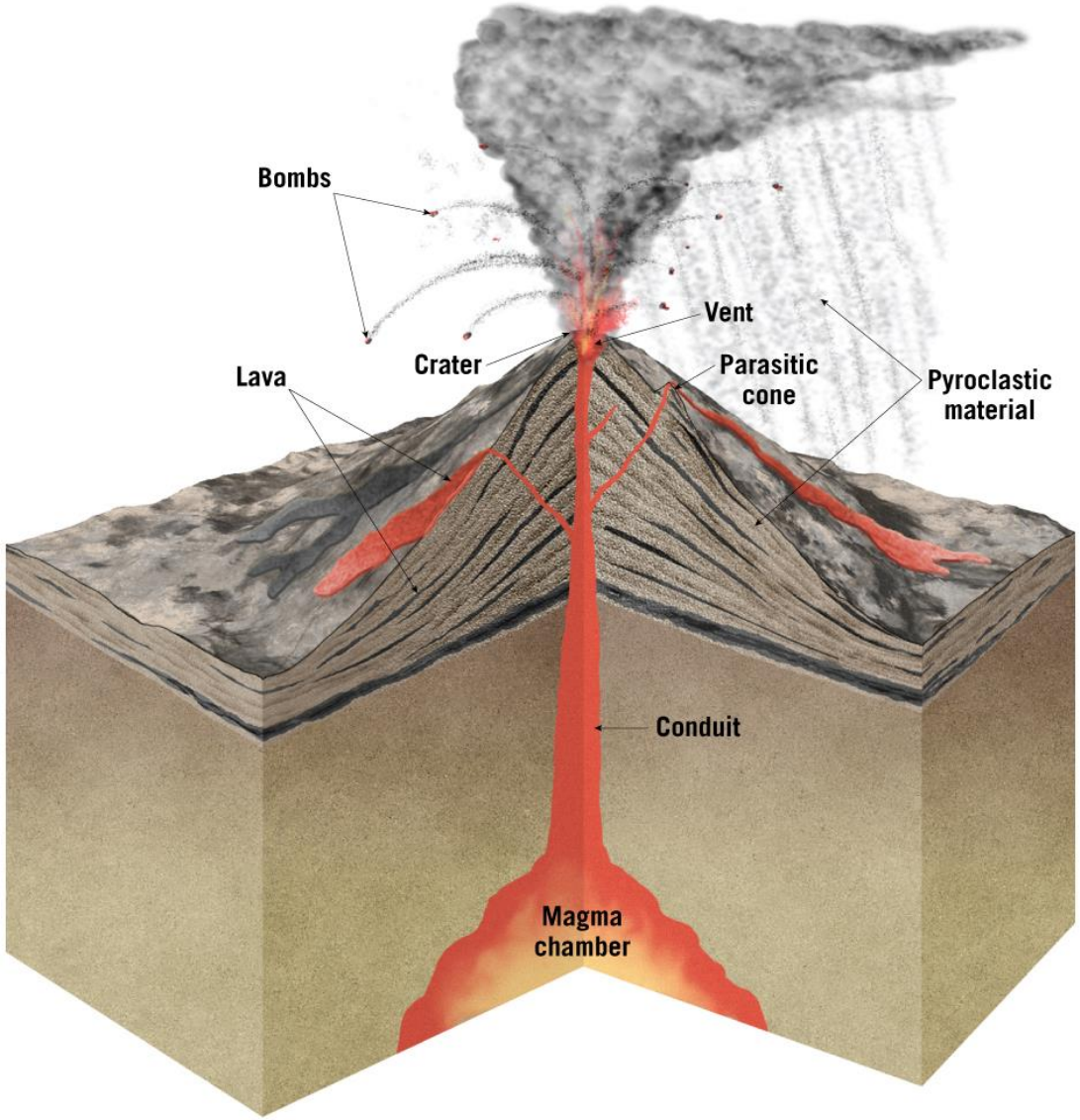
Mauna Loa: Earth's Largest Shield Volcano



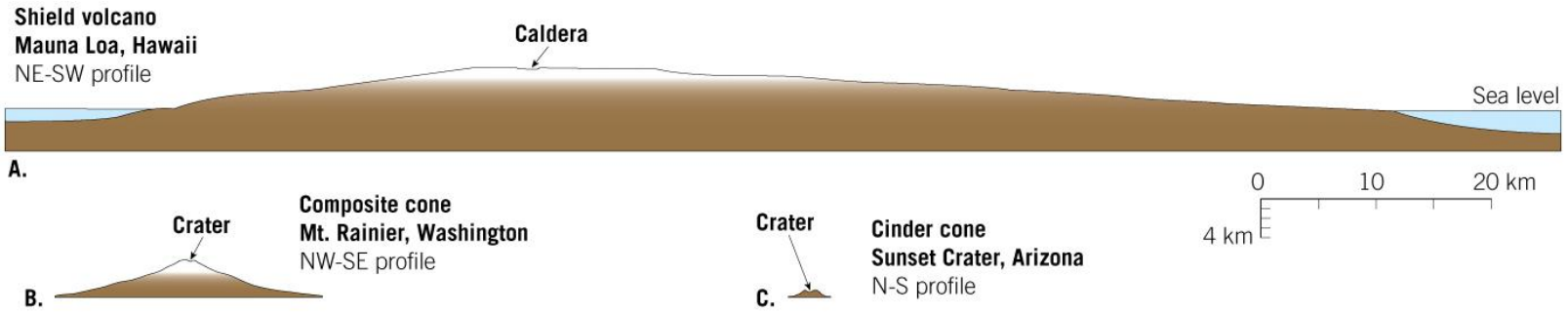
Kilauea: Hawaii's Most Active Volcano

- Kilauea is most active and studied volcano
  - 50 eruptions since 1823
  - Most recent began in 1983
- Magma chamber inflates and earthquake swarms indicate an impending eruption

Kilauea: Hawaii's Most Active Volcano



Shield Volcanoes



Focus Question 7.6

- Describe the formation, size, and composition of cinder cones.

Cinder Cones

- **Cinder cones** (**scoria cones**)
  - Symmetrical
  - Steep-sided
  - Loose accumulations of ejected scoria
    - Commonly pea- to walnut-sized fragments
  - Basaltic composition, reddish-brown color
  - Some produce lava flows
  - Craters are relatively large and deep

Cinder Cones

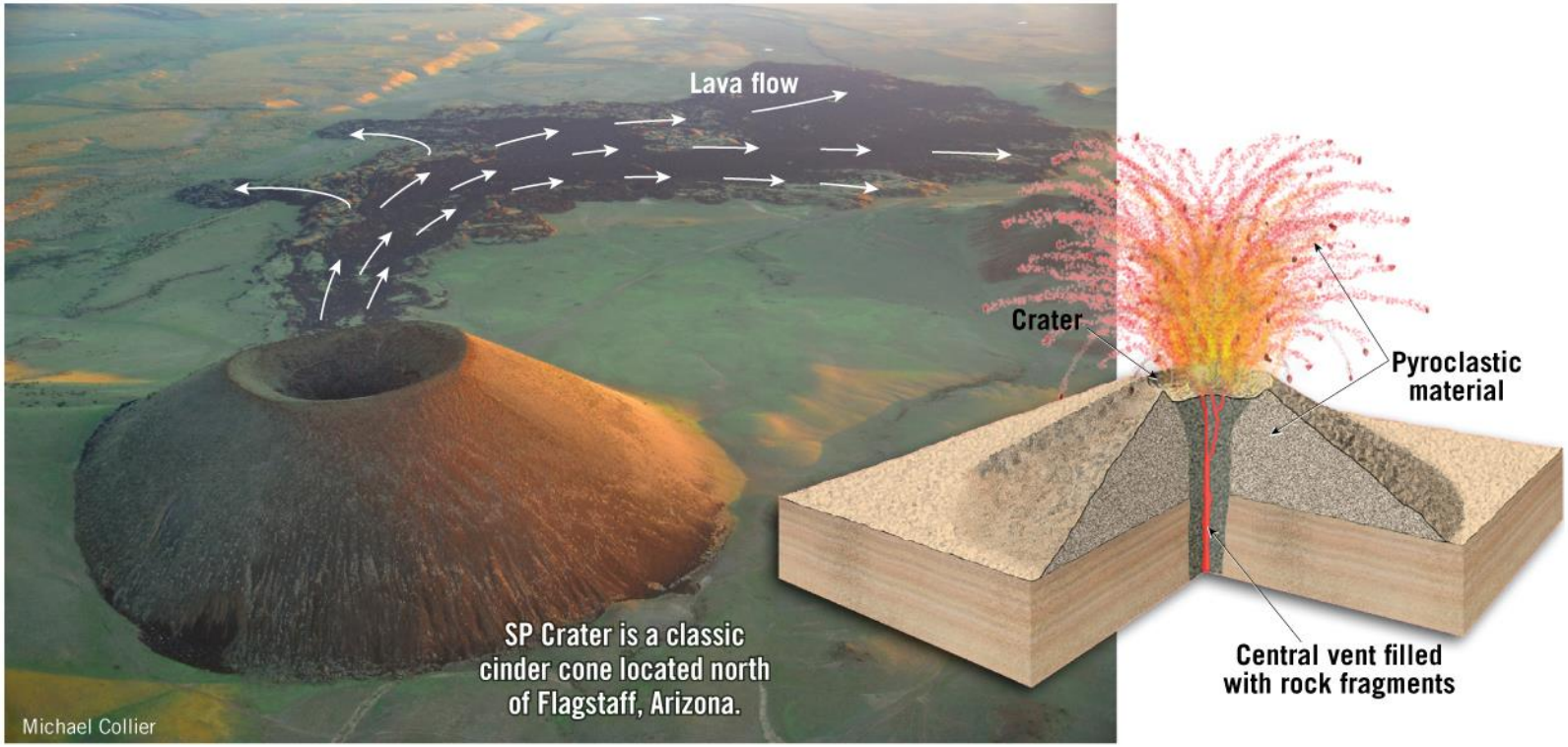
- Cinder cones form quickly
  - Many in less than one month
  - Generally in a single eruptive event
  - Small size (30–300 m)

Cinder Cones

Parícutin, a cinder cone located in Mexico, erupted for nine years.

An aa flow emanating from the base of the cone buried much of the village of San Juan Parangaricutiro, leaving only remnants of the village's church.

Cinder Cones



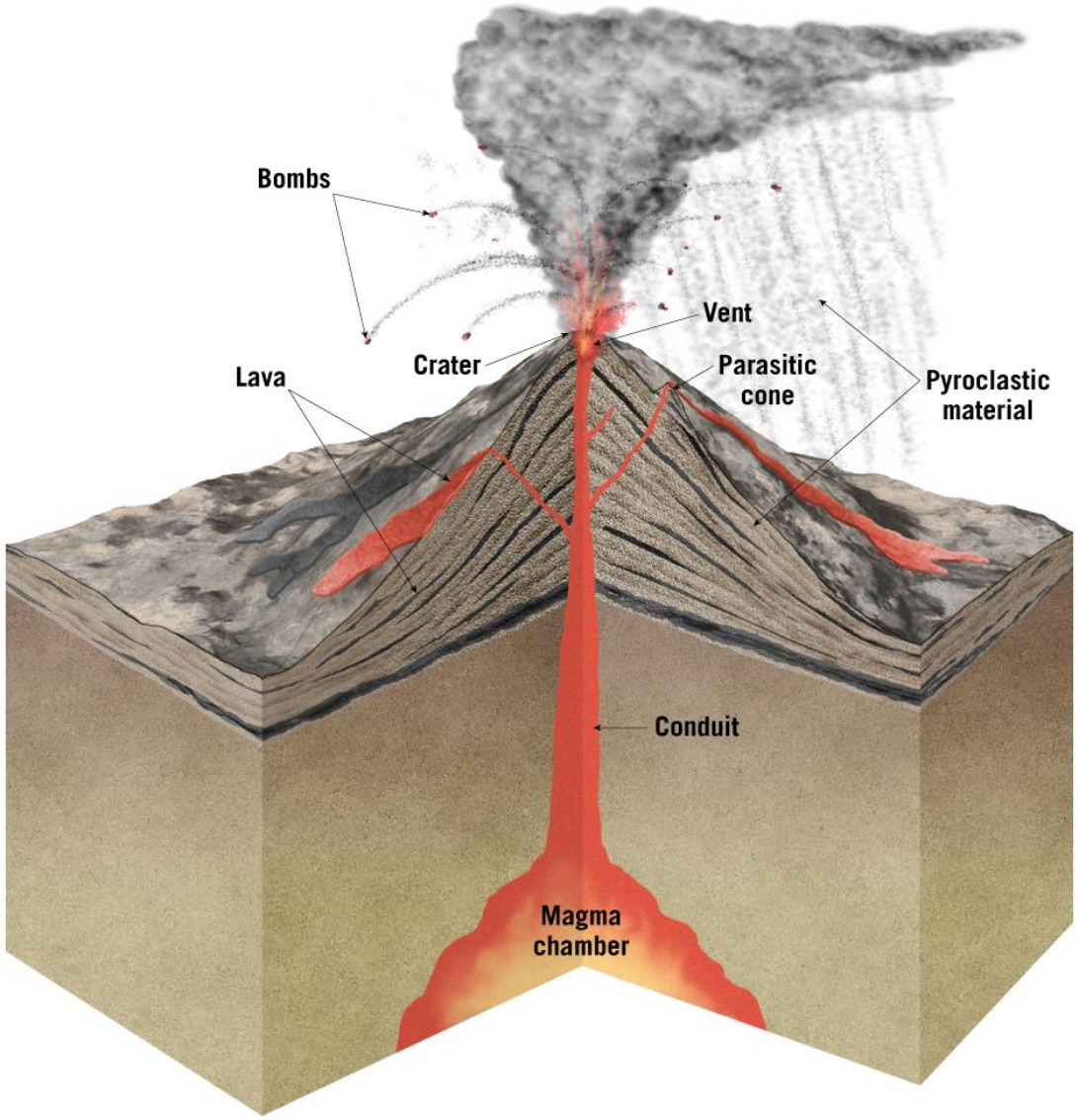
Focus Questions 7.7

- List the characteristics of composite volcanoes.
- Describe how these volcanoes form.

Composite Volcanoes

- **Composite cones** or **stratovolcanoes**
  - Located around the *Ring of Fire*
  - Large, symmetrical cones
  - Built by layers of cinder and ash alternating with lava flows
  - Primarily silica-rich andesitic magma
  - Associated with explosive eruptions and abundant pyroclastic material
  - Steep summit and gradually sloping flanks

Composite Volcanoes



Focus Question 7.8

- Describe the major geologic hazards associated with volcanoes.

Volcanic Hazards

- 70 volcanic eruptions expected each year
- One large-volume eruption each decade
- 500 million people live near active volcanoes
- Volcanic hazards include:
  - Pyroclastic flows
  - Lahars
  - Lava flows
  - Ash and volcanic gasses

Volcanic Hazards

Pyroclastic Flow: A Deadly Force of Nature

- **Pyroclastic flow (nuee ardente)**
  - Hot volcanic gas infused in incandescent ash and lava fragments
  - Gravity driven, can move up to 100 km/hr
  - Low-density cloud of hot gases and fine ash on top of layer of vesicular pyroclastic material
- Caused by collapse of eruption columns

Volcanic Hazards

B. St. Pierre before the 1902 eruption.

A. St. Pierre following the eruption of Mount Pelée.

Lahars: Mudflows on Active and Inactive Cones

- **Lahars**
  - Fluid mudflows
  - Water-saturated volcanic debris move down steep volcanic slopes
  - Can occur on dormant/extinct volcanoes

Lahars: Mudflows on Active and Inactive Cones

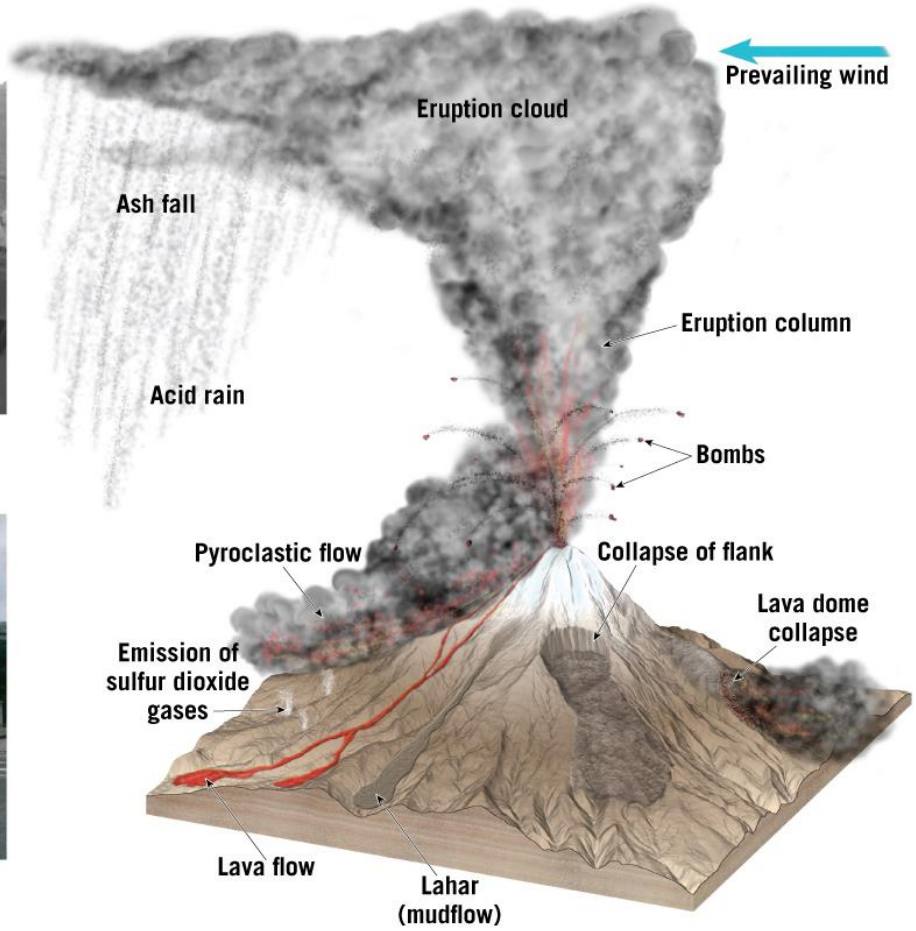
Other Volcanic Hazards

- Tsunamis
  - Caused by collapse of volcano flanks into the ocean
- Ash
  - Can damage buildings, living things, aircraft engines
- Sulfur dioxide
  - Affects air quality and creates acid rain
- Atmospheric cooling
  - Ash and aerosols reflect solar energy

Volcanic Hazards

Ash and other pyroclastic materials can collapse roofs, or completely cover buildings.

Lava flows can destroy homes, roads, and other structures in their paths.



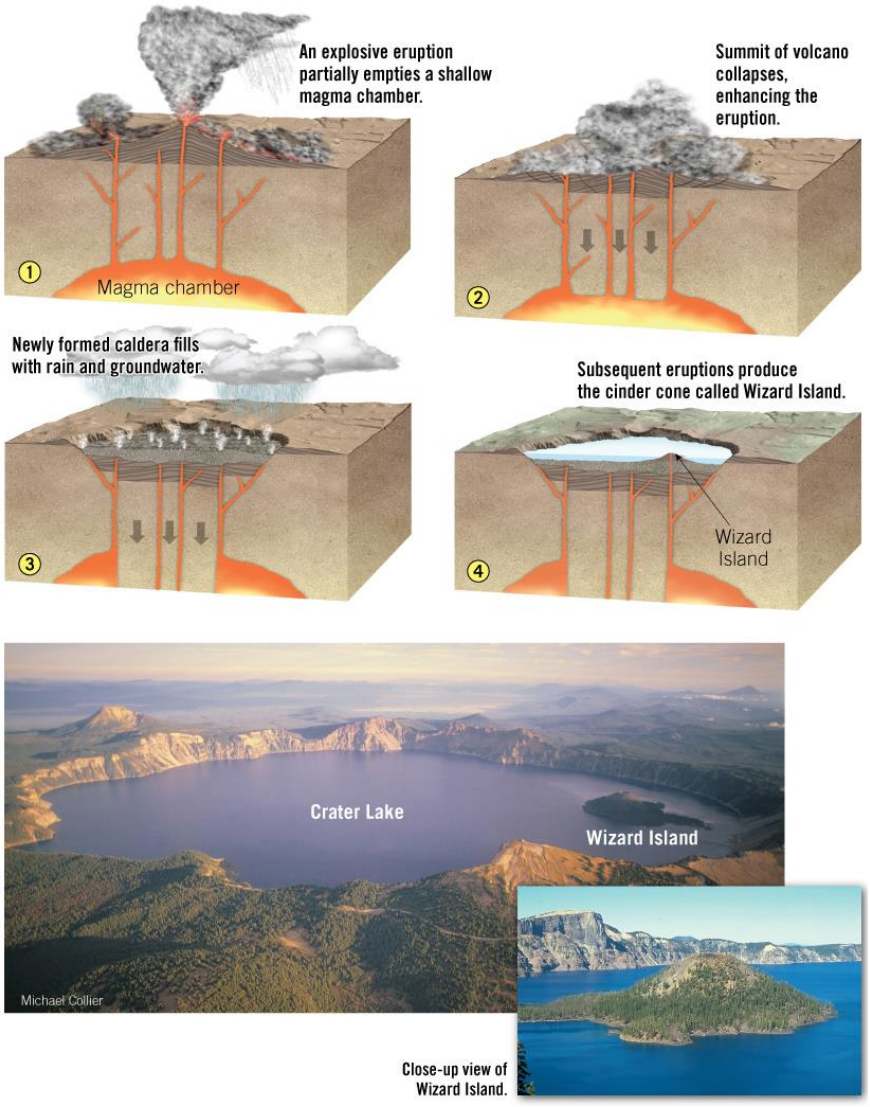
Focus Questions 7.9

- List volcanic landforms other than shield, cinder, and composite volcanoes.
- Describe their formation.

Other Volcanic Landforms

- **Caldera**
  - Steep-sided crater less than 1 km in diameter
  - Formed by summit collapse following draining of the magma chamber

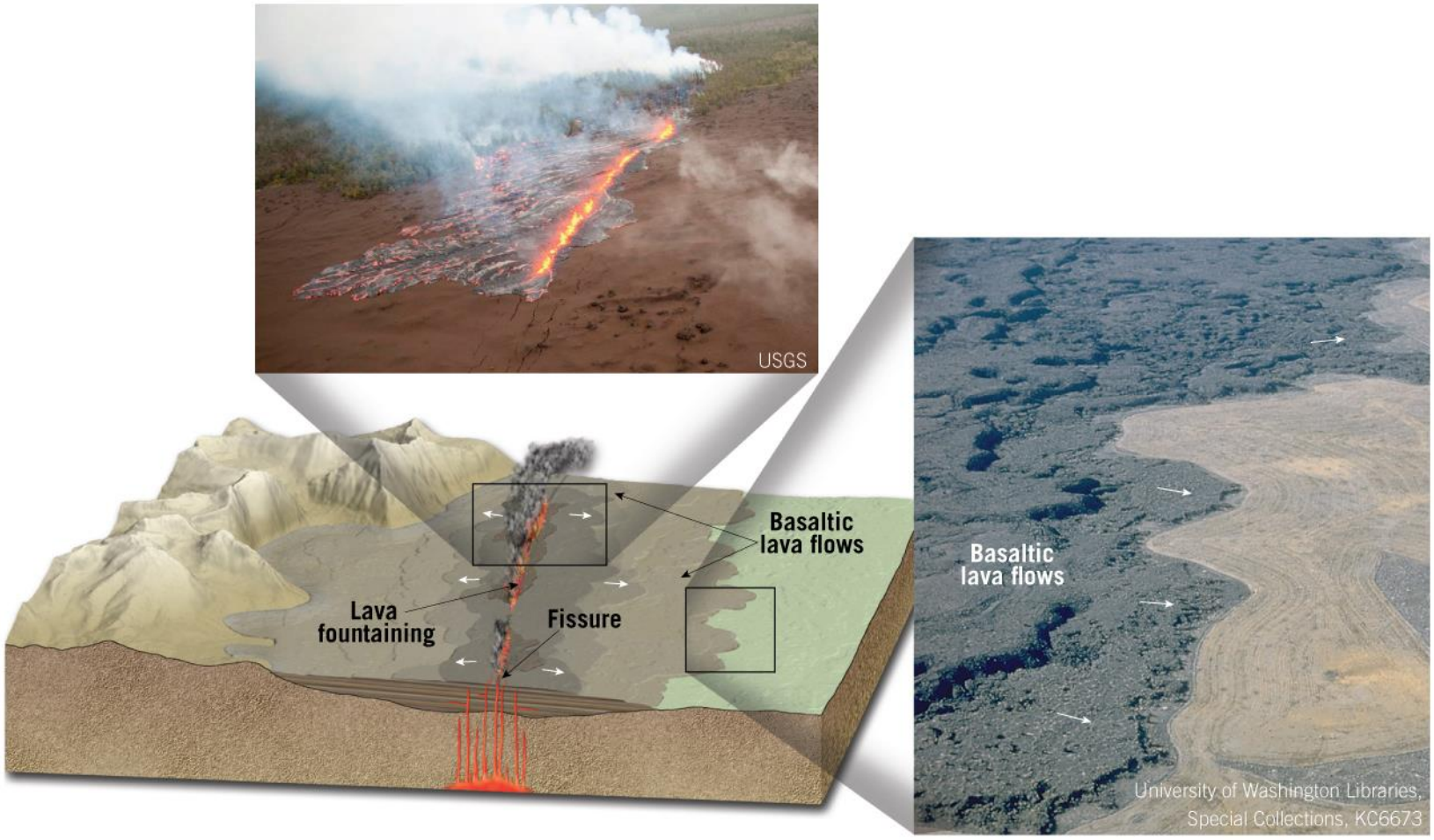
Other Volcanic Landforms



Other Volcanic Landforms

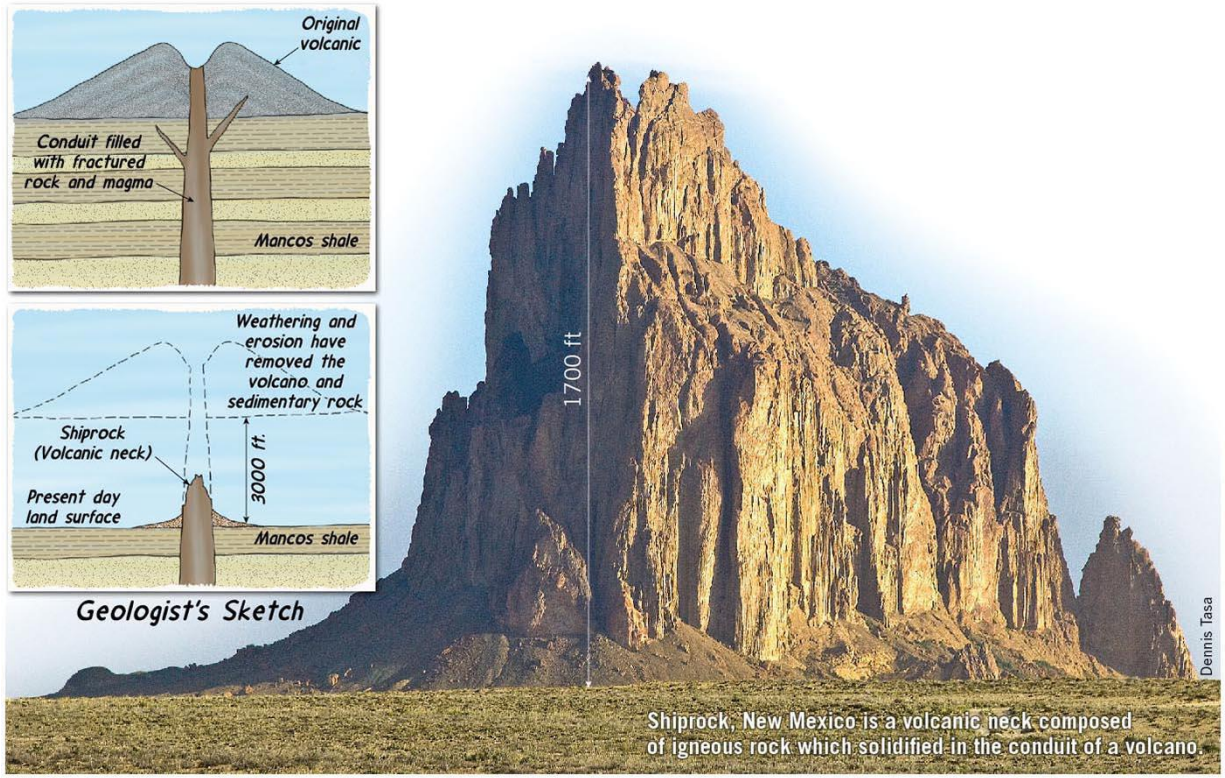
- **Fissure eruptions**
  - Emit basaltic lavas from fissures (fractures)
- **Basalt plateaus**
  - Flat, broad accumulations of basalt emitted from fissures
- **Flood basalts**
  - Molten lava having flowed long distances within a basalt plateau

Other Volcanic Landforms



Other Volcanic Landforms

- **Volcanic necks (plugs)**
  - Eroded volcanic cones expose the solidified magma inside the conduit



Focus Question 7.10

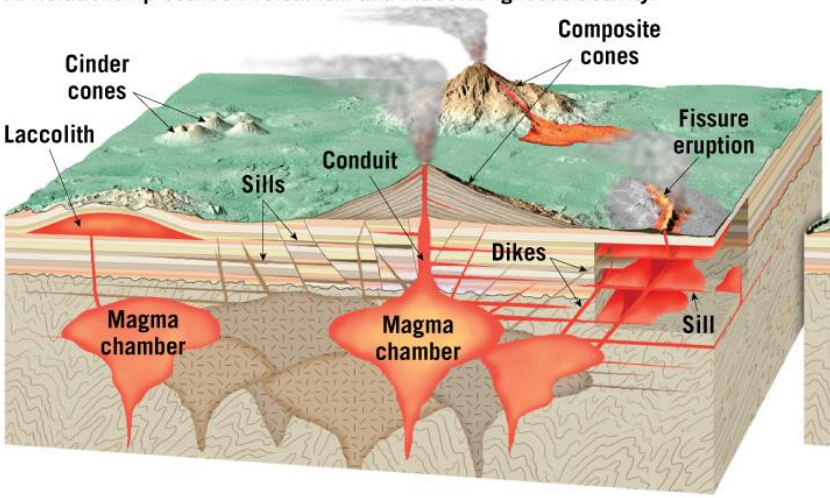
- Compare and contrast these intrusive igneous structures:
  - Dikes.
  - Sills.
  - Batholiths.
  - Stocks.
  - Laccoliths.

Intrusive Igneous Activity

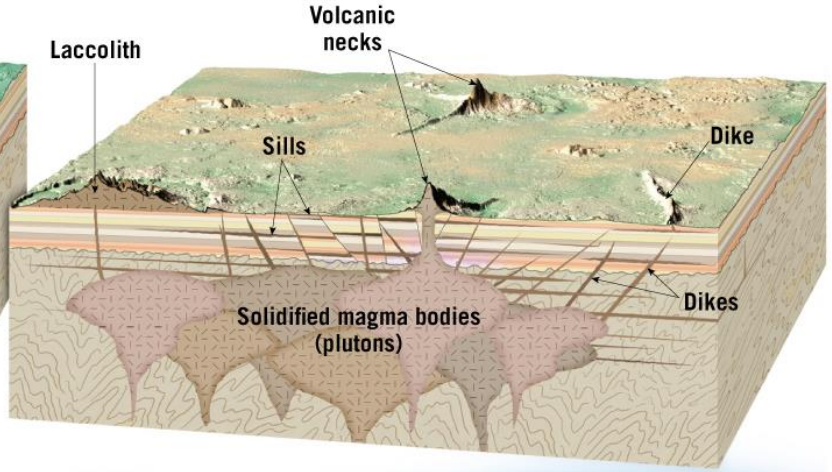
- Magma that crystallizes in Earth's crust **displacing host** or **country rock** forms **intrusions** or **plutons**
  - Exposed by uplift and erosion
- Classified according to shape
  - **Tabular** or **massive**
  - May cut across existing structures
    - **Discordant**
  - Or inject parallel to features
    - **Concordant**

Intrusive Igneous Activity

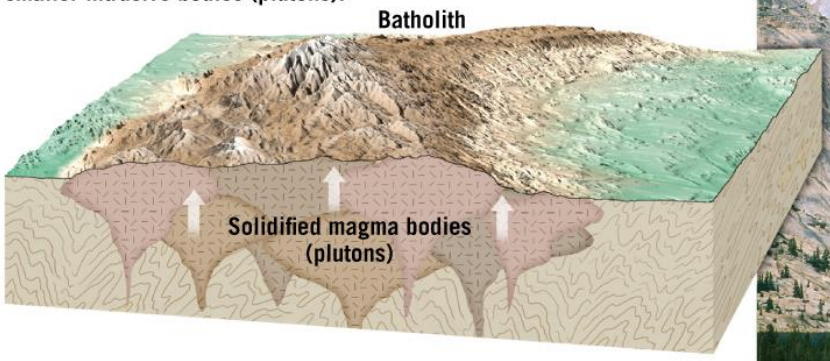
A. Relationship between volcanism and intrusive igneous activity.

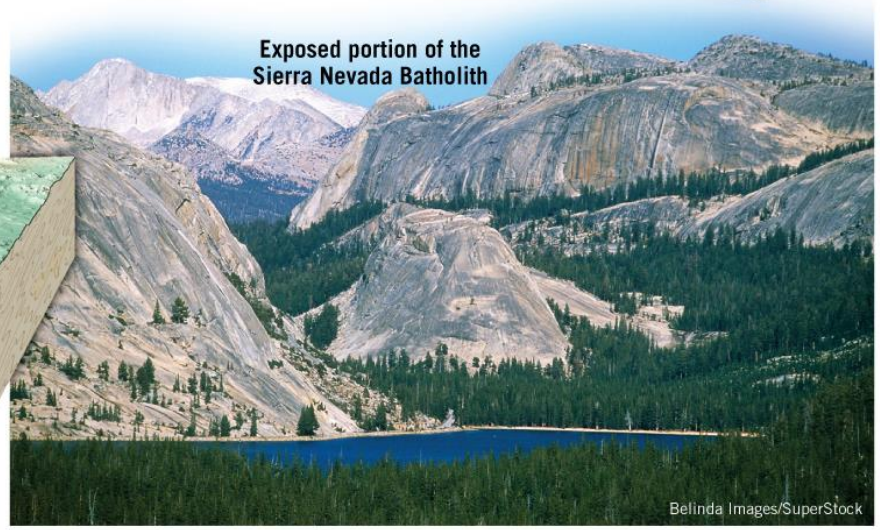


B. Basic intrusive structures, some of which have been exposed by erosion.



C. Extensive uplift and erosion exposed a batholith composed of several smaller intrusive bodies (plutons).

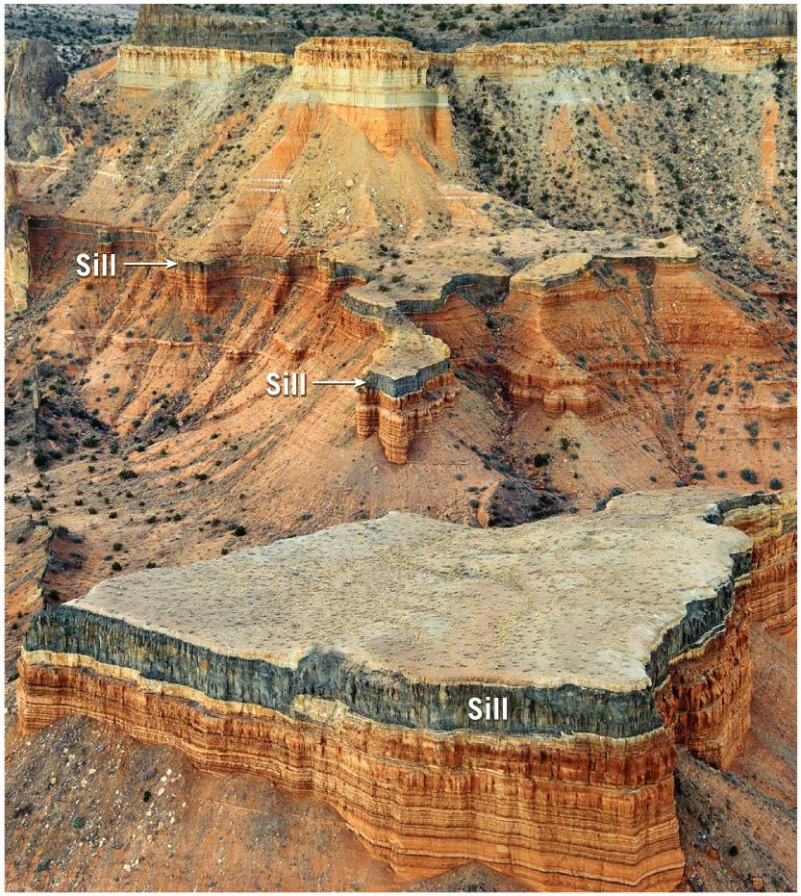


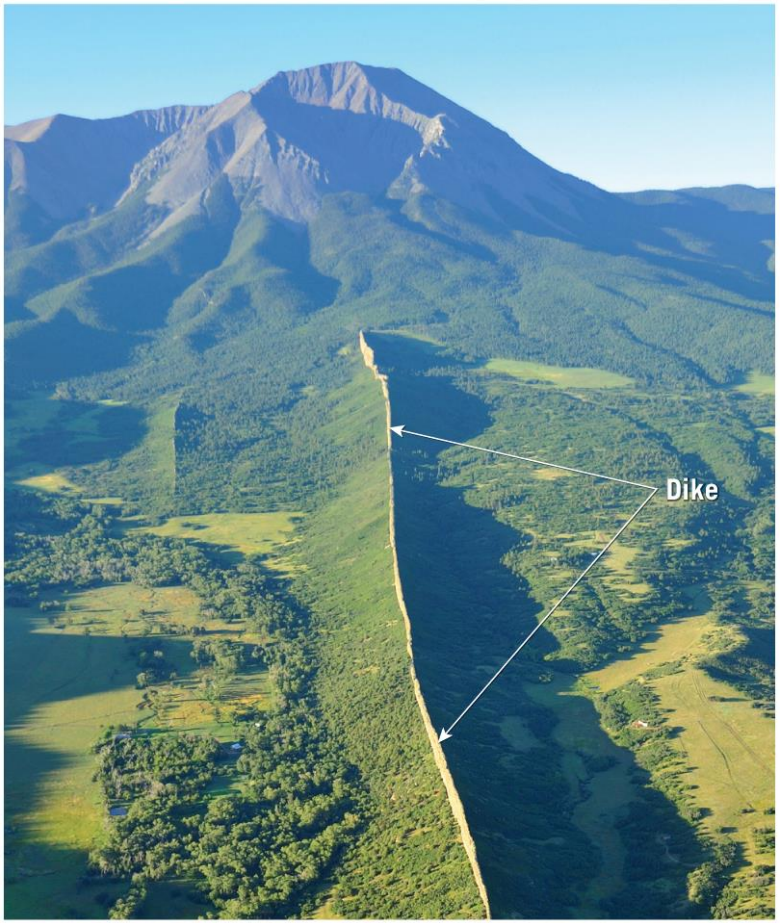


Intrusive Igneous Activity

- **Tabular** intrusive bodies
  - Magma is injected into a fracture or other zone of weakness
- **Dikes** are discordant
- **Sills** are concordant

Intrusive Igneous Activity





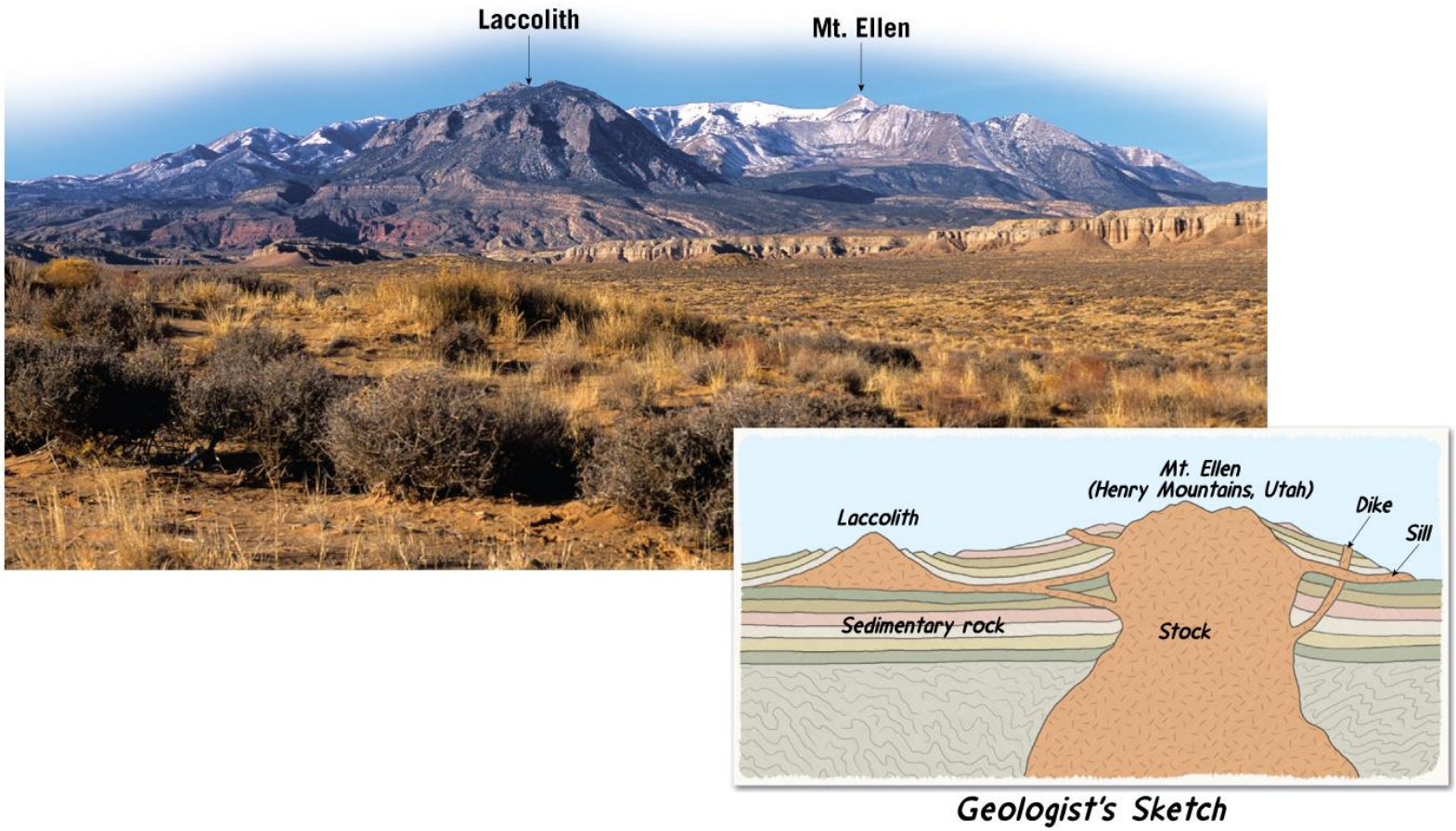
Intrusive Igneous Activity

- **Columnar jointing** occurs as a result of shrinkage fractures that develop when igneous rocks cool

Intrusive Igneous Activity

- Large intrusive bodies include:
  - **Batholiths**
    - Linear masses of felsic rocks hundreds of km long
  - **Stocks**
    - Surface exposure <100 km^2
  - **Laccoliths**
    - Lift the sedimentary strata that they penetrate

Intrusive Igneous Activity



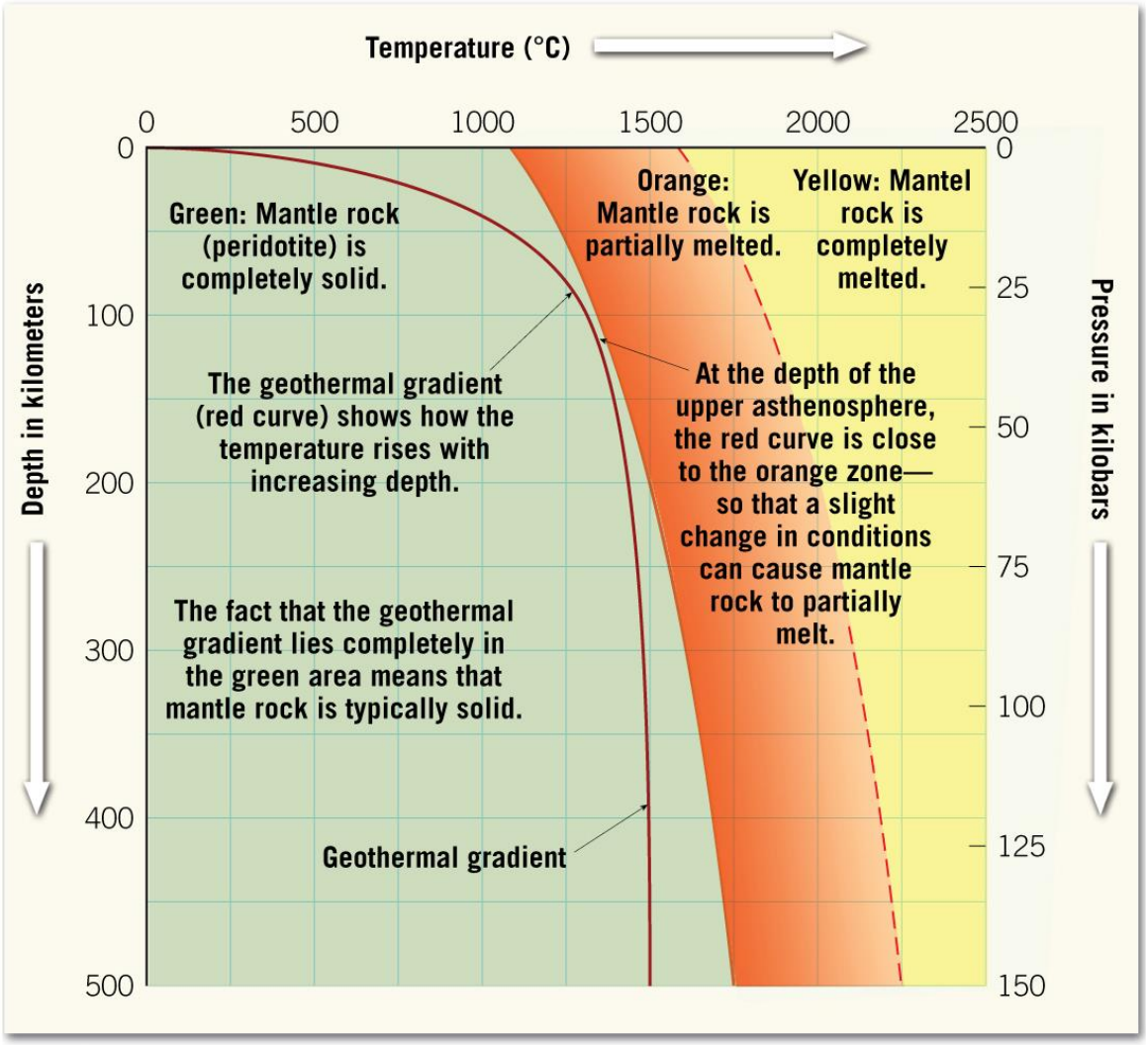
Focus Question 7.11

- Summarize the major processes that generate magma from solid rock.

Partial Melting

- Earth's crust and mantle are composed primarily of solid rock
- Rock is composed of a variety of minerals with different melting points
  - Rocks melt over a range of temperatures
  - Incomplete melting of rocks is **partial melting**

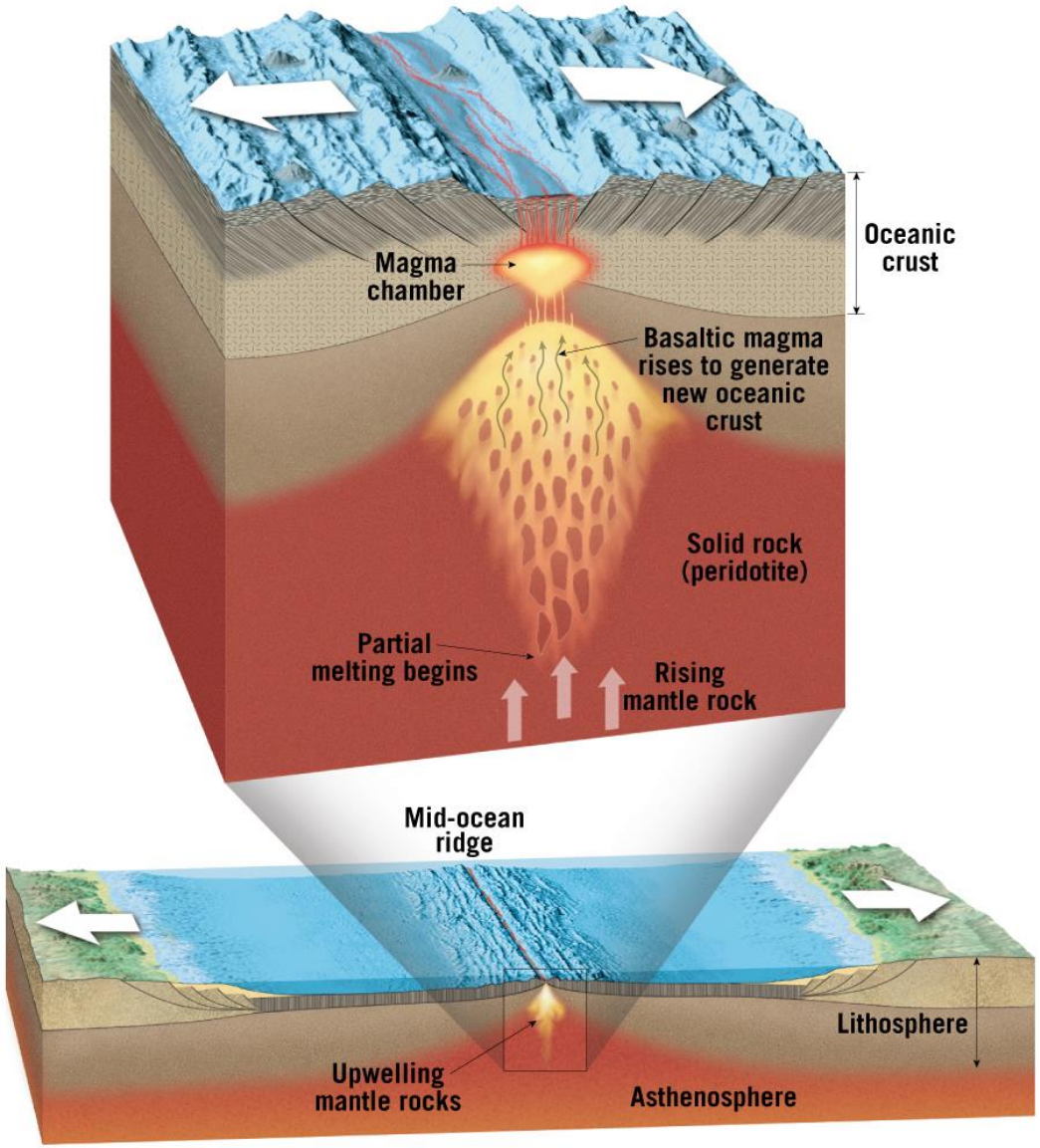
Partial Melting



Generating Magma from Solid Rock

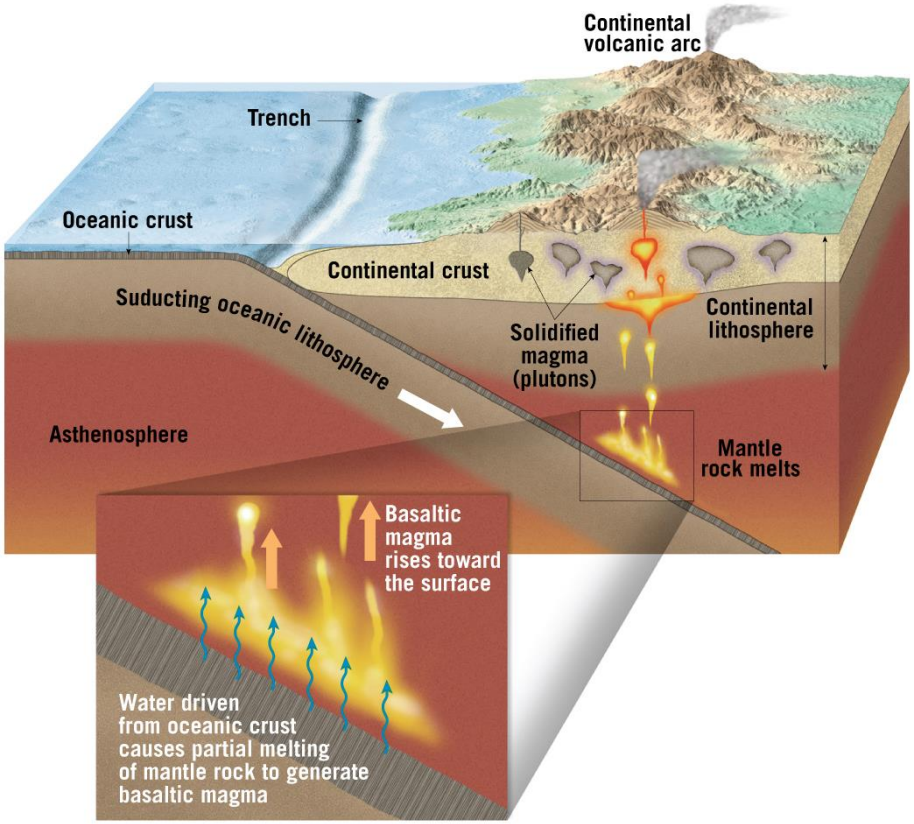
- **Geothermal gradient** averages ~25°C/km
- Mantle is solid under normal conditions
- Pressure increases melting temperature
  - **Decompression melting** is triggered when confining pressure decreases
  - Occurs at oceanic ridges

Generating Magma from Solid Rock



Generating Magma from Solid Rock

- Adding water lowers melting temperature
  - Occurs at convergent boundaries



Generating Magma from Solid Rock

- Mantle derived magma pools beneath crustal rocks
- Heat from basaltic magma generates silica-rich magma via melting of continental crust
- Also occurs during continental collisions

Focus Question 7.12

- Explain how the geographic distribution of volcanic activity is related to plate tectonics.

Plate Tectonics and Volcanism

- Most volcanoes are found near:
  - **Ring of Fire** around the Pacific Ocean
  - Mid-ocean ridges
- Few are randomly distributed

Plate Tectonics and Volcanism

Plate Tectonics and Volcanism

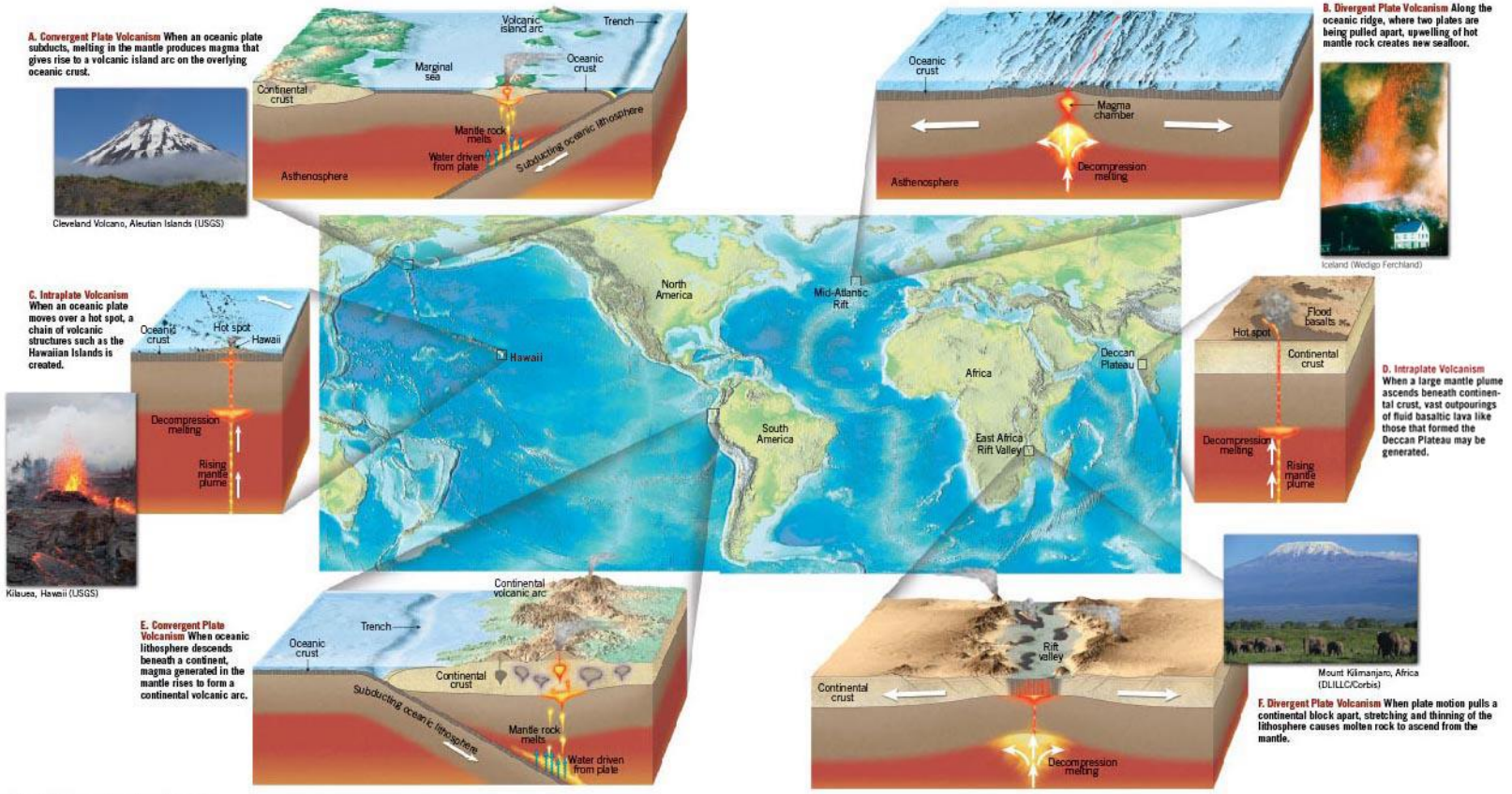


Plate Tectonics and Volcanic Activity

- **Intraplate volcanism**
  - A **mantle plume** of hot material ascends to the surface