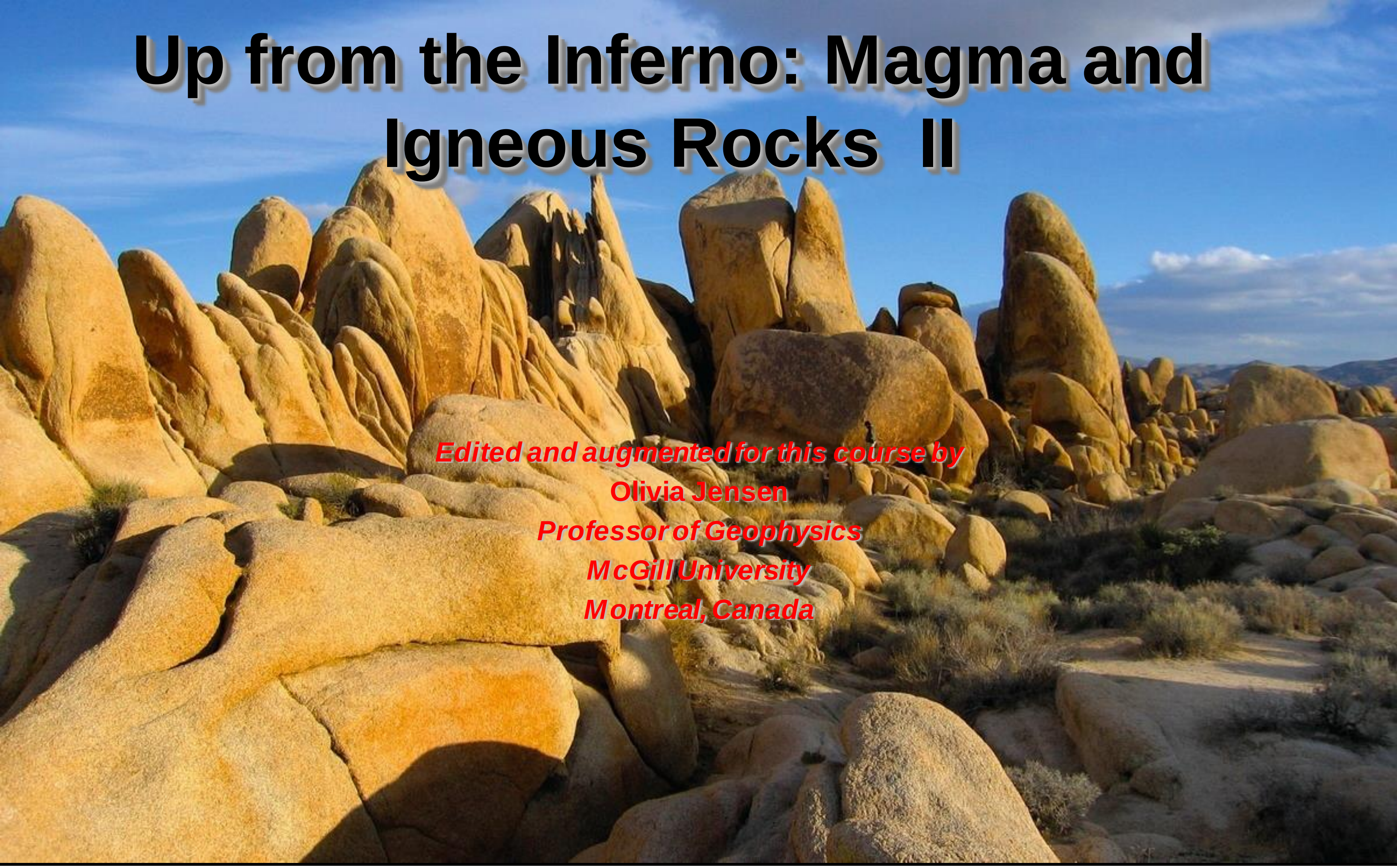


Up from the Inferno: Magma and Igneous Rocks II

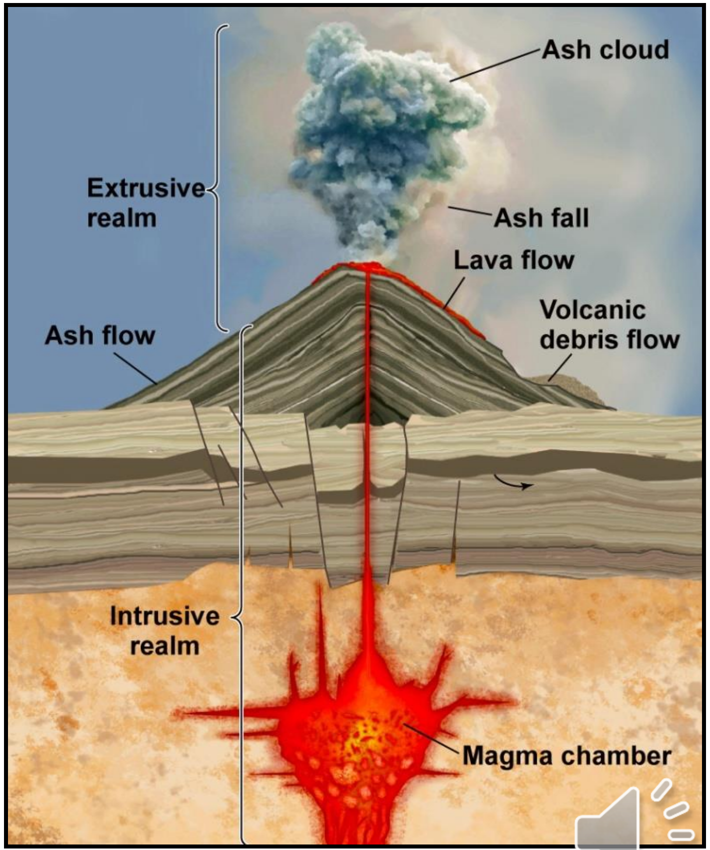
Edited and augmented for this course by
Olivia Jensen
Professor of Geophysics
McGill University
Montreal, Canada

Updated by:
***Rick Oches**, Professor of Geology & Environmental Sciences*
Bentley University
Waltham, Massachusetts

Based on slides prepared by:
***Ronald L. Parker**, Senior Geologist*
Fronterra Geosciences
Denver, Colorado

Igneous Environments

- Two major categories—based on cooling locale.
  - Extrusive settings—cool at or near the surface.
    - Cool rapidly.
    - Chill too fast to grow big crystals.
  - Intrusive settings—cool at depth.
    - Lose heat slowly.
    - Crystals grow slowly and large.

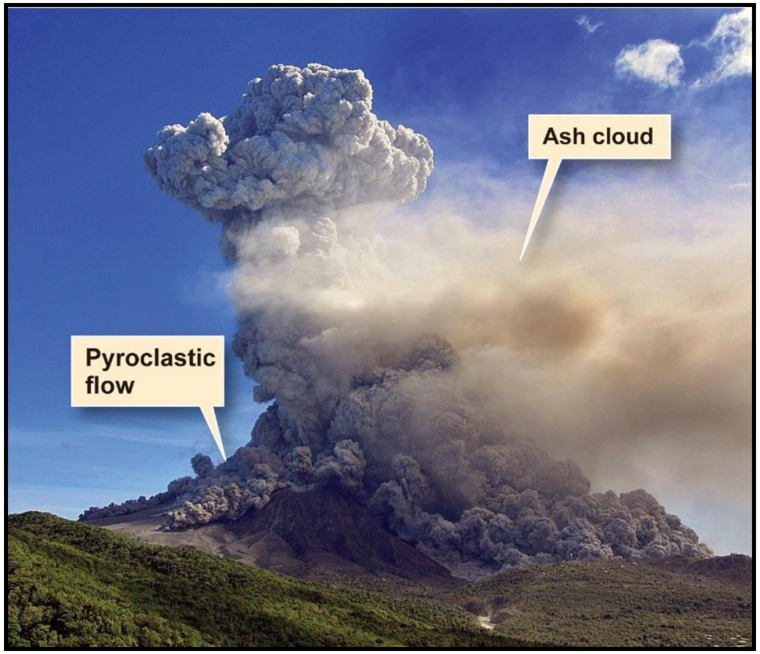


Extrusive Settings

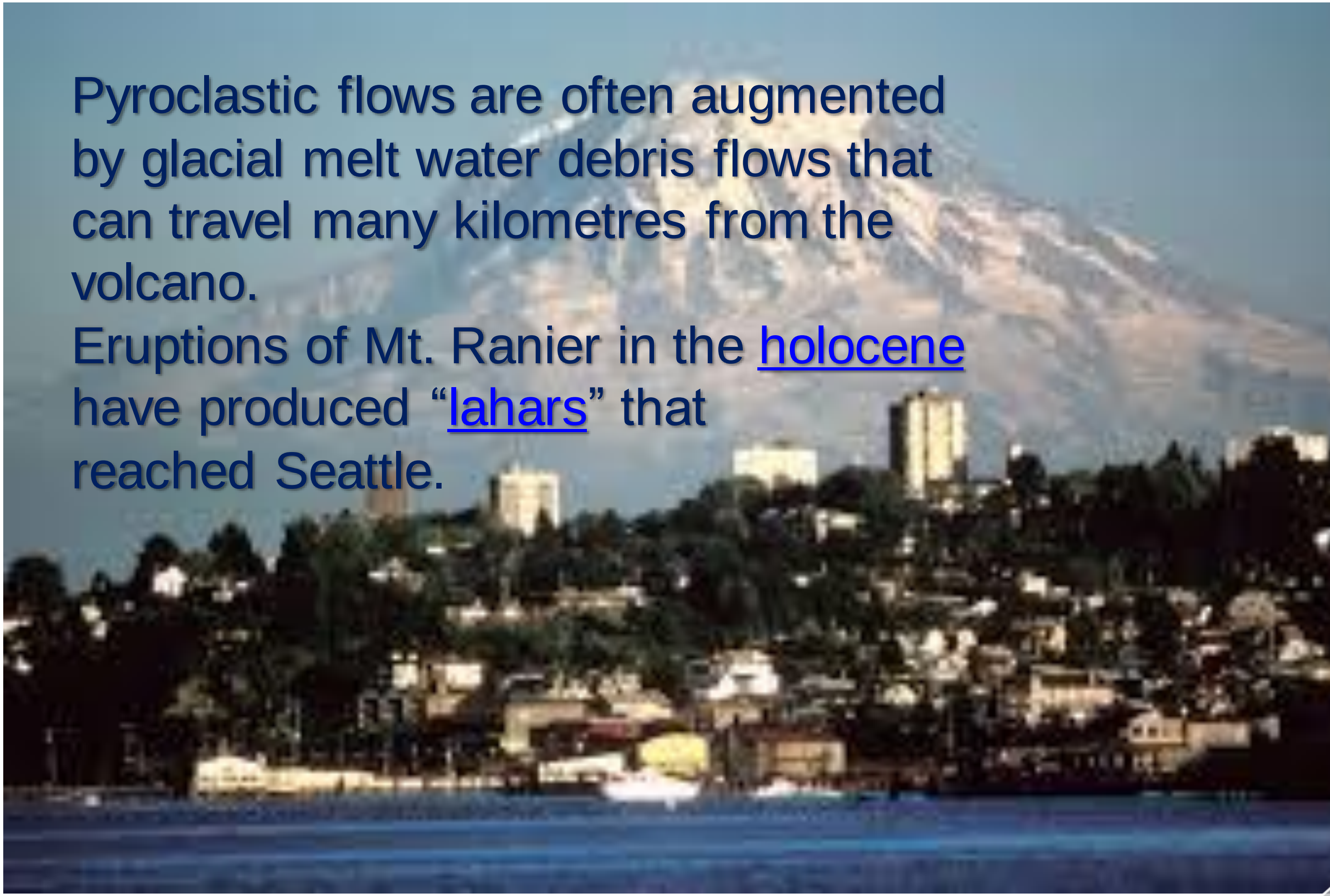
- Lava flows cool as blankets that often stack vertically.
- Lava flows exit volcanic vents and spread outward.
- Low-viscosity lava (basalt) can flow long distances.
- Lava cools as it flows, eventually solidifying.

Extrusive Settings

- **Explosive ash eruptions: Mt. St-Helens** (eruption at 10:00)
  - **High-viscosity felsic magma erupts explosively.**
  - **Yield huge volumes of ash that can cover large regions**
  - **Pyroclastic flow—volcanic ash and debris avalanche**
    - **Races down the volcanic slope as a density current**
    - **Often deadly (example: Vesuvius CE 79)**



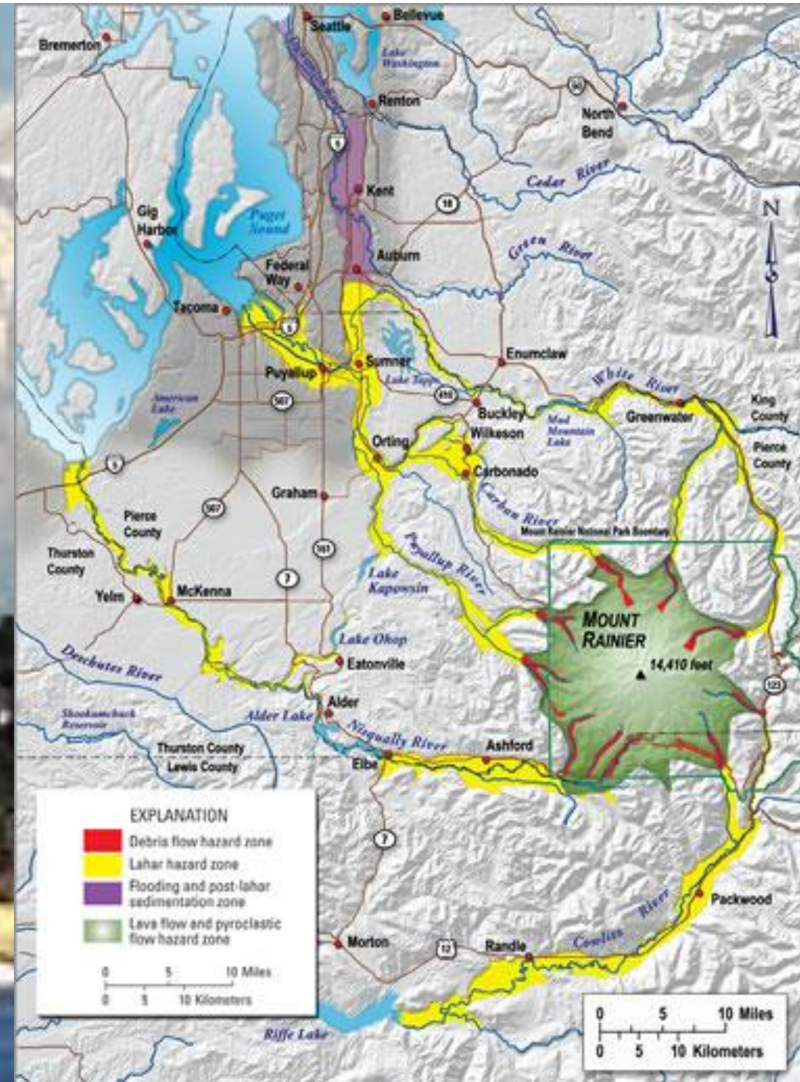
Eruptions of Mt. Ranier



Pyroclastic flows are often augmented by glacial melt water debris flows that can travel many kilometres from the volcano.

Eruptions of Mt. Ranier in the holocene have produced "lahars" that reached Seattle.

Eruptions of Mt. Ranier



Eruption of Mt. Mazama

- 7800 years ago, Mt. Mazama erupted explosively releasing 46-58km^3 of rock/dust materials that spread continent wide.
- This eruption was at least 40x as great, in terms of eruptive materials, as that of Mt. St. Helens.
- This eruption left a collpase "caldera" that is about 9km in diameter that now holds "Crater Lake".
- About 75000 years ago, an even larger super-volcanic eruption formed Lake Toba in Indonesia. The Mt. Toba caldera, infilled by lake, is over 100km long. This event almost caused extinction of human species.

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Eruption of Mt. Toba

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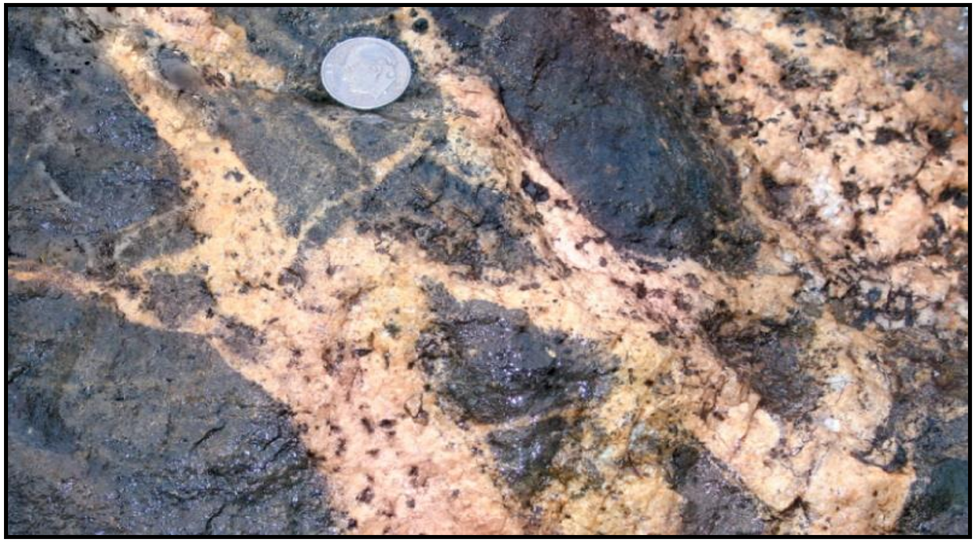
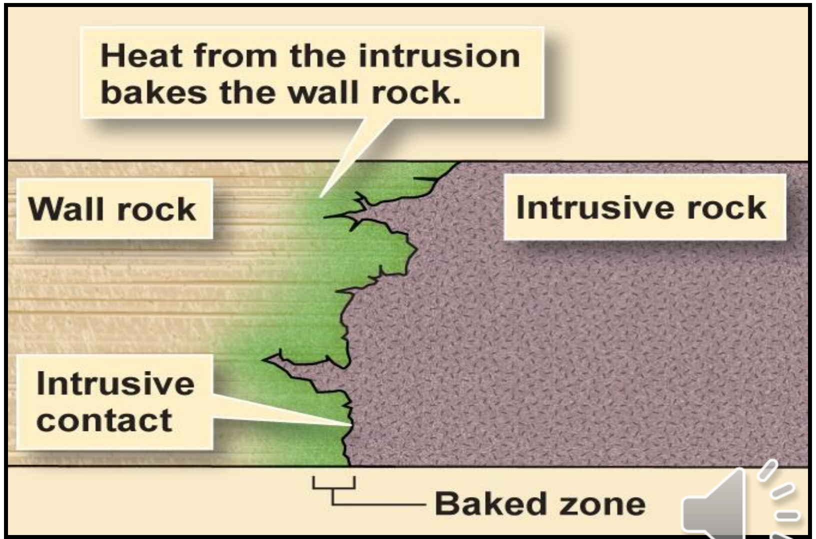
Intrusive Settings

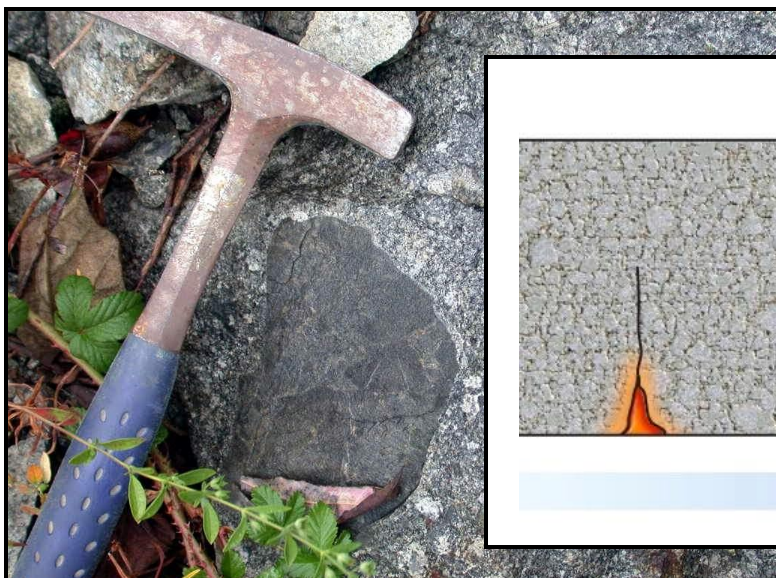
- Magma invades preexisting wall rock by
  - percolating upward between grains.
  - forcing open cracks.
- The wall rock—magma-intrusive contact reveals high heat – contact metamorphism changes mineral forms
  - Baked zone—rim of heat-altered wall rock
  - Chill margin—rim of quenched magma at contact

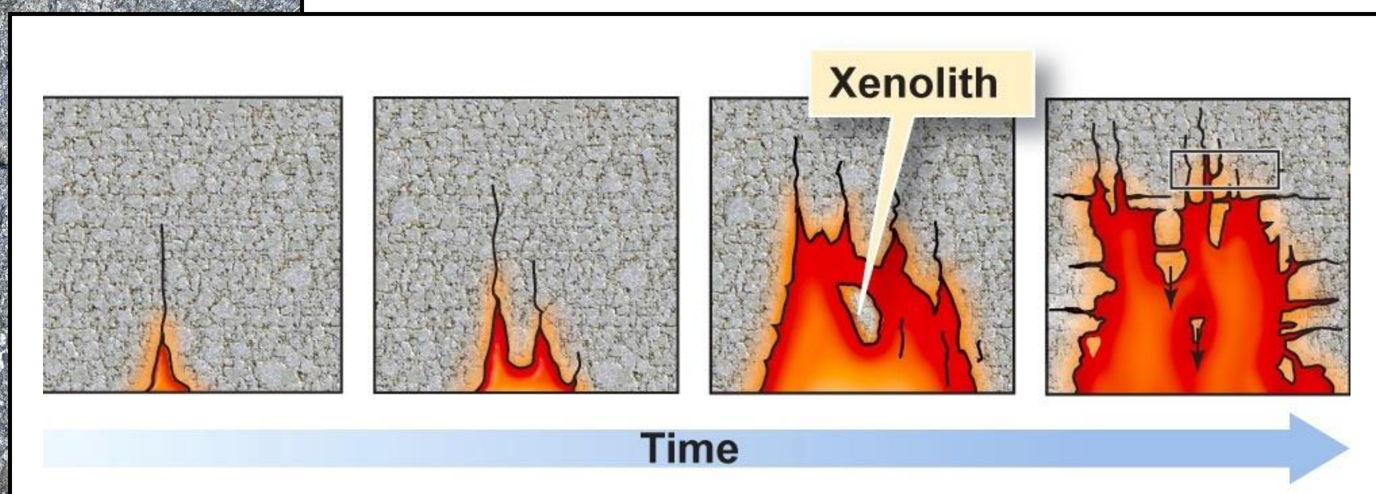




Intrusive Settings

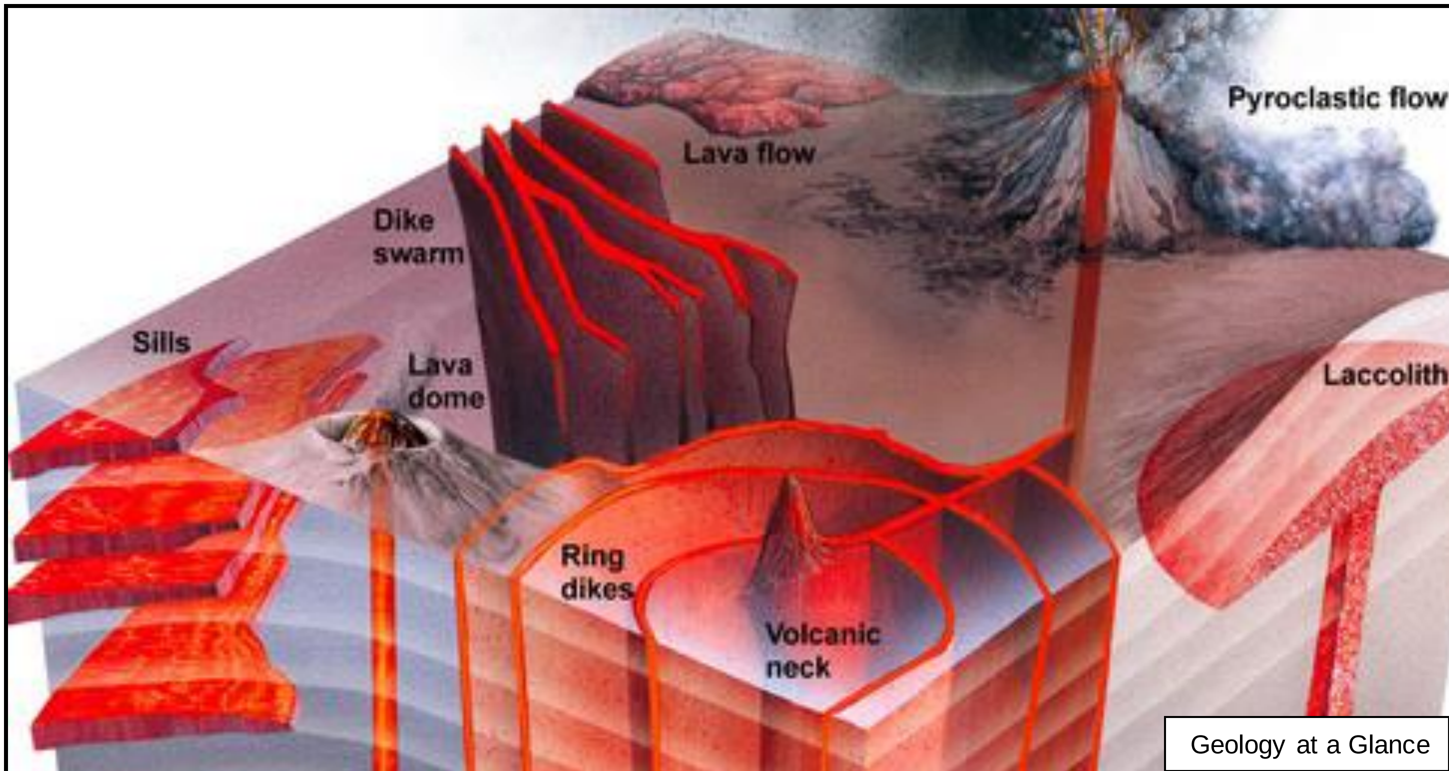
- Magma invades colder wall rock, initiating
  - thermal (heat) contact metamorphism and melting.
  - inflation of fractures, wedging wall rock apart.
  - detachment of large wall rock blocks (stoping), and
  - incorporation of wall rock fragments (xenoliths).
- Magma that doesn’t reach the surface freezes slowly.





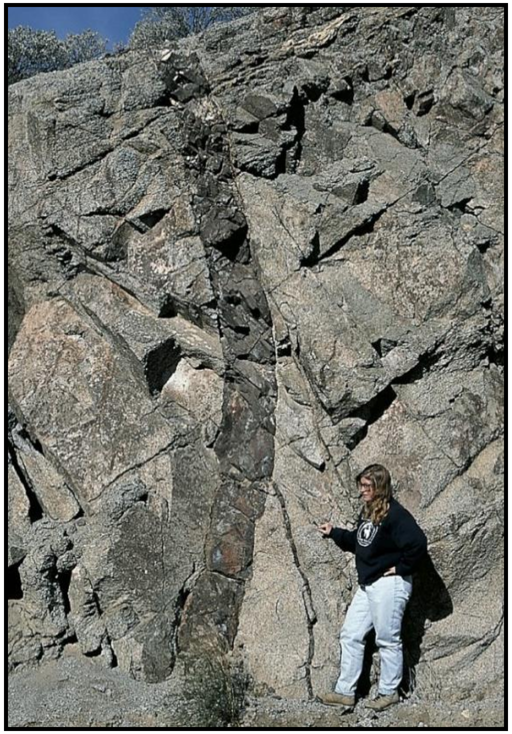
Intrusive Settings

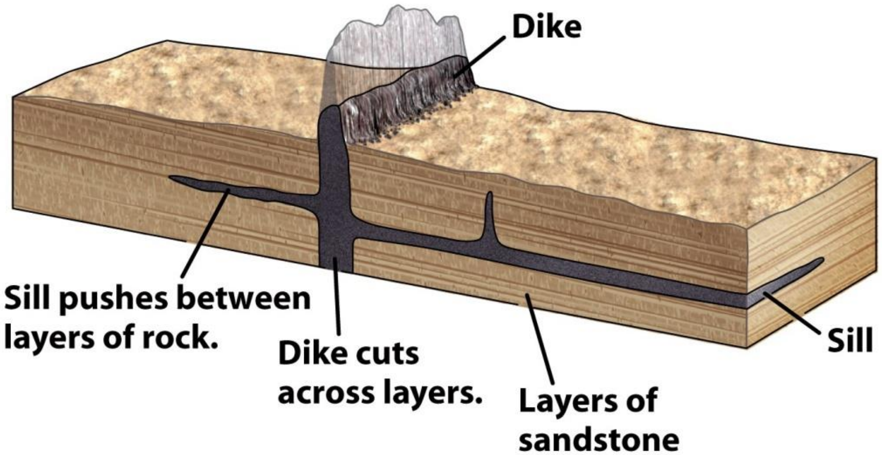
- Geologists categorize intrusions by shape.
  - Tabular (sheet)—planar with uniform thickness
  - Blister-shaped—a sill that domes upward
  - Balloon-shaped—blobs of melted rock

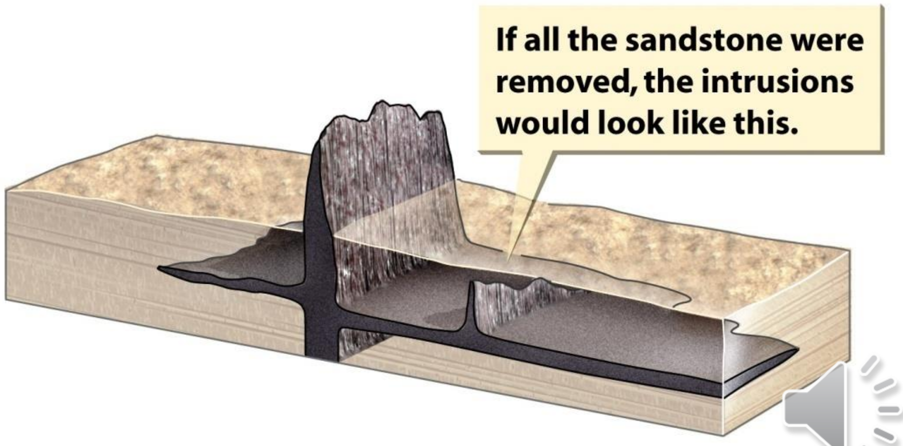


Intrusive Settings

- Tabular intrusions
  - tend to have uniform thicknesses.
  - often can be traced laterally.
  - have two major subdivisions.
    - Sill—injected parallels to rock layering
    - Dike—cuts across rock layering

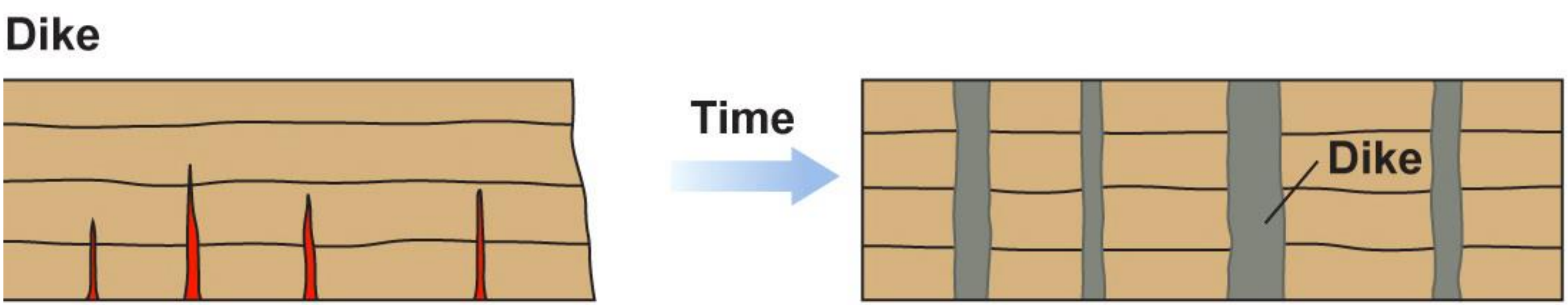






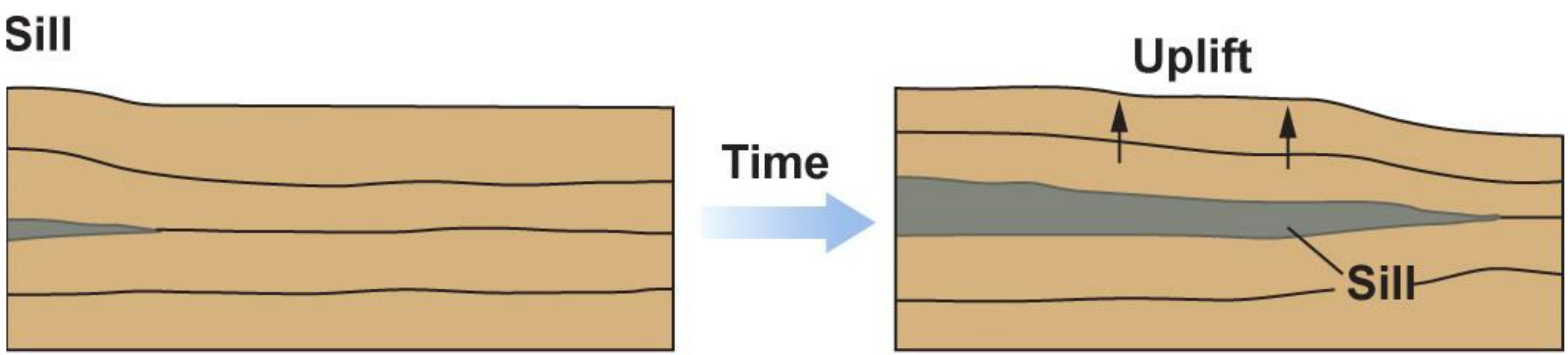
Intrusive Settings

- Tabular intrusions
  - Dikes and sills modify invaded country rock.
    - They cause the rock to expand and inflate.
    - They thermally alter the country rock.
  - Dikes
    - cut across preexisting layering (bedding or foliation).
    - spread rocks sideways.
    - dominate in extensional settings.



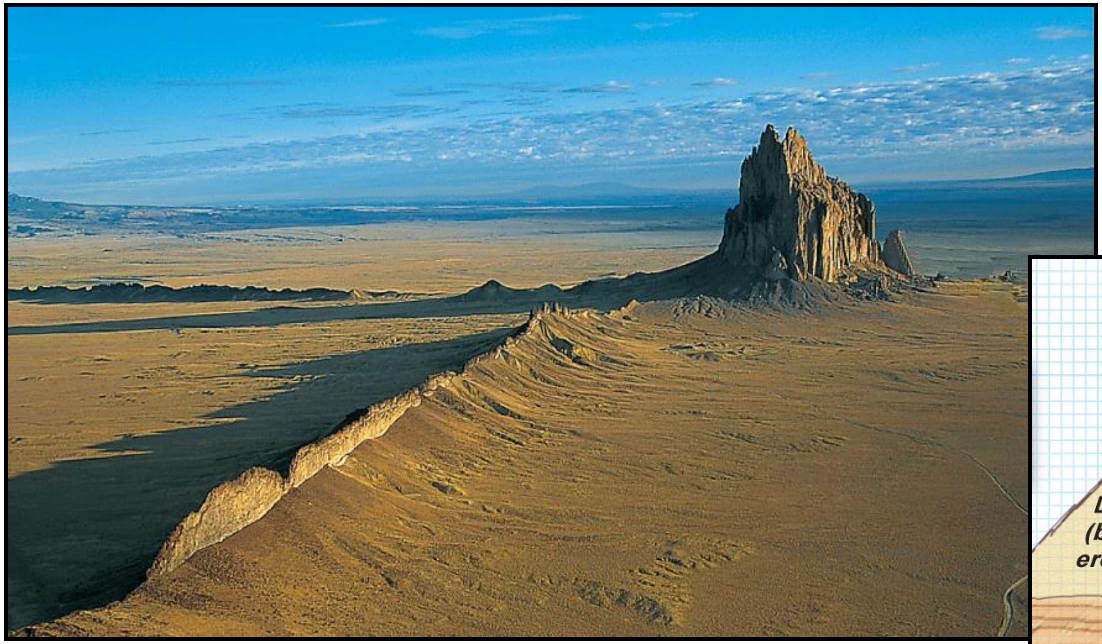
Tabular Intrusions

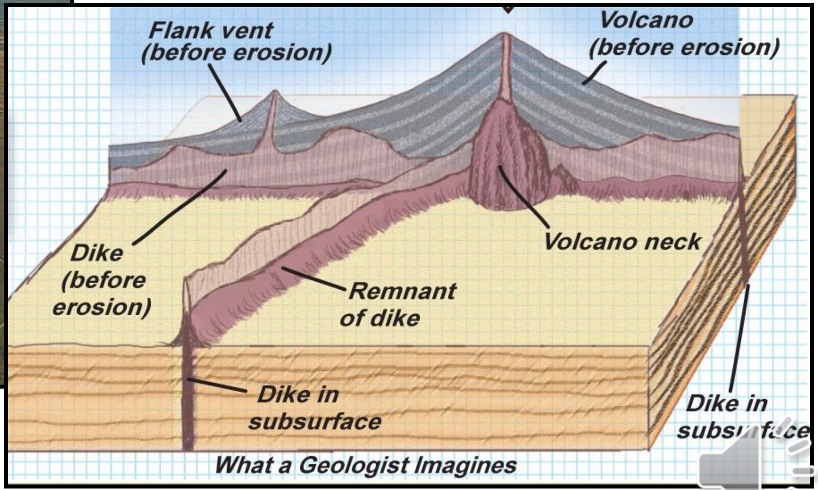
- Sills
  - are injected parallel to preexisting layering.
  - are usually intruded close to the surface.
- Both dikes and sills exhibit wide variability in
  - size.
  - thickness (or width).
  - lateral continuity.



Intrusive Settings

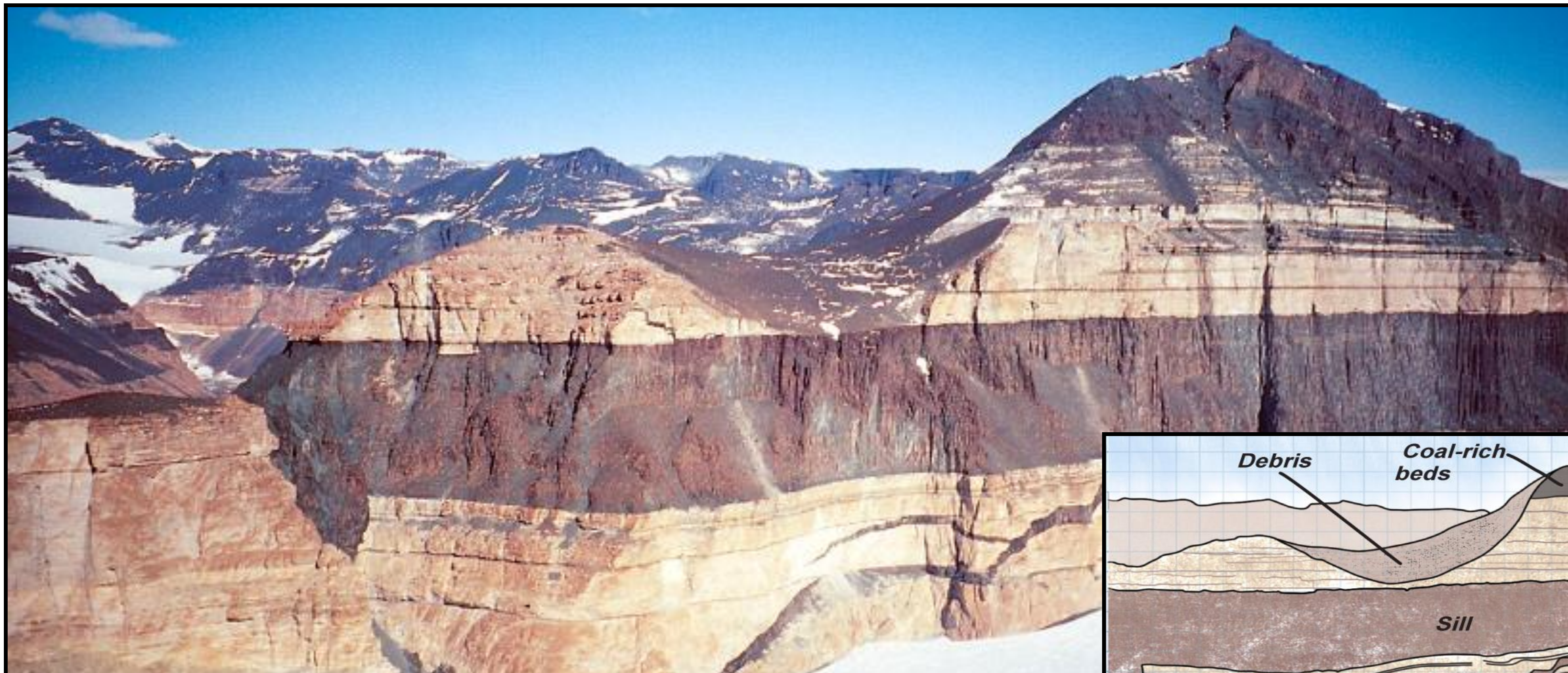
- Tabular intrusions
  - Dikes—cut across rock layering.
    - Dikes sometimes occur in swarms.
    - Three dikes radiate away from Shiprock, New Mexico, an eroded volcanic neck.

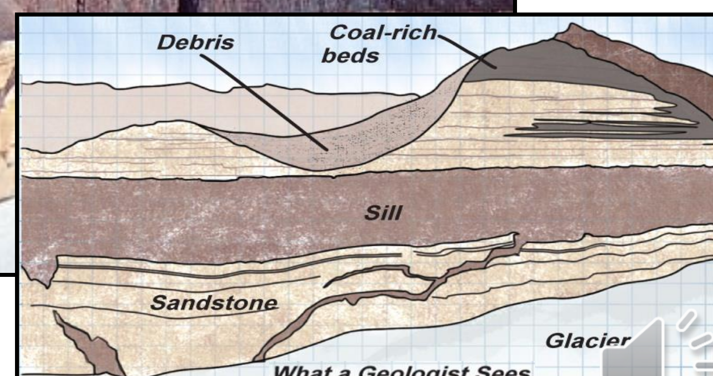




Intrusive Settings

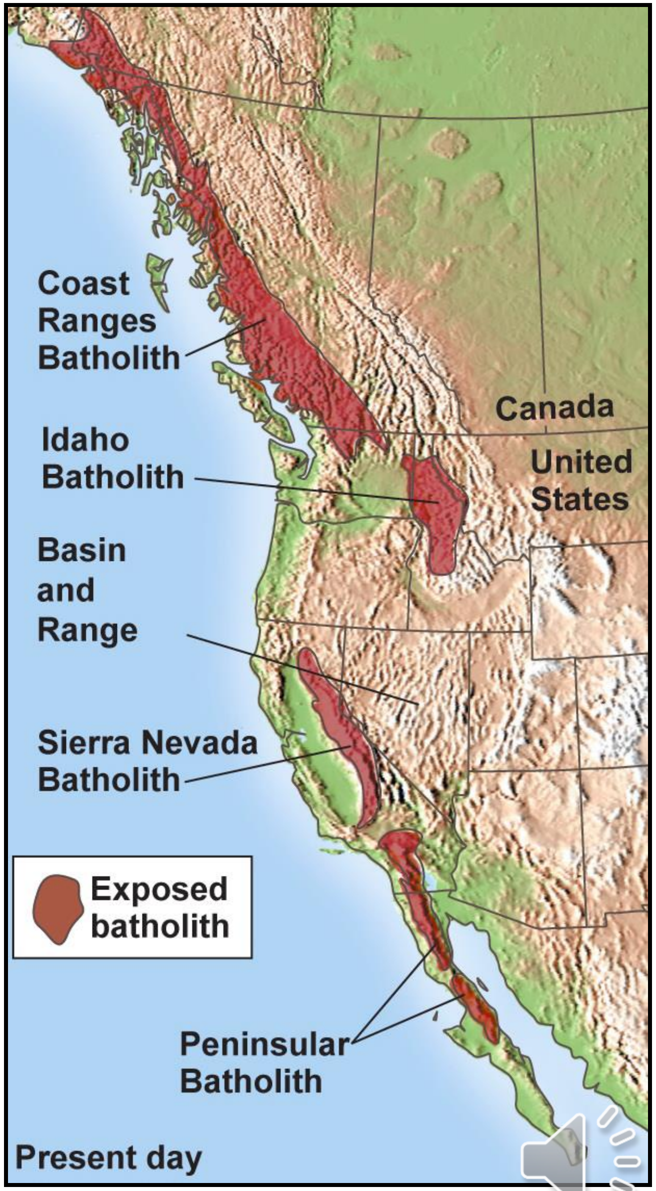
- Tabular intrusions
  - Sills—injected parallel to layering.
    - Basalt (dark) intruded light sandstones in Antarctica.
    - Intrusion lifted the entire landscape above.





Plutonic Activity

- Plutons (subsurface cooled magma chambers) may amass into a batholith.
  - Immense volumes of intrusives
  - Form above subduction zones
  - May add magma for tens of Ma
  - Batholiths mark former subduction.
- The [North shore mountains]of Vancouver are the result of erosion of an immense granitic pluton (OJ). They are magmatic intrusions, not volcanoes.



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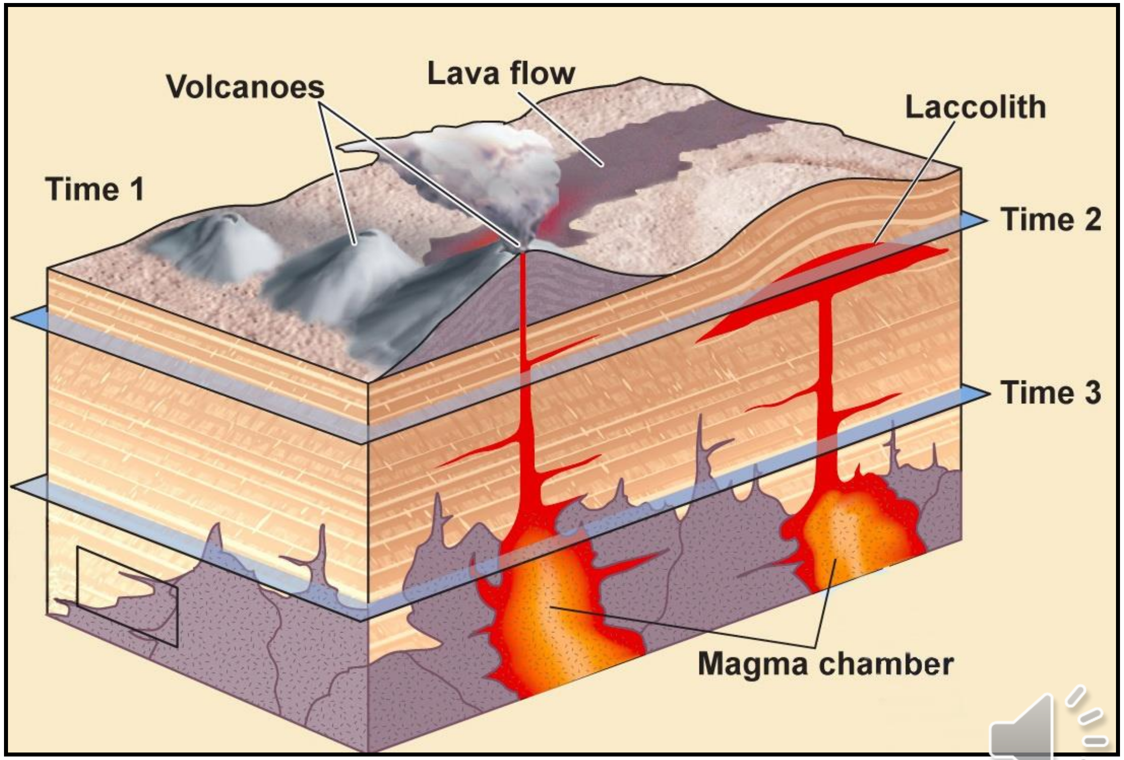
Intrusive and Extrusive

- Intrusive and extrusive rocks commonly co-occur.
- Magma chambers feed overlying volcanoes.
- Magma chambers may cool to become plutons.
- Many igneous geometries are possible.

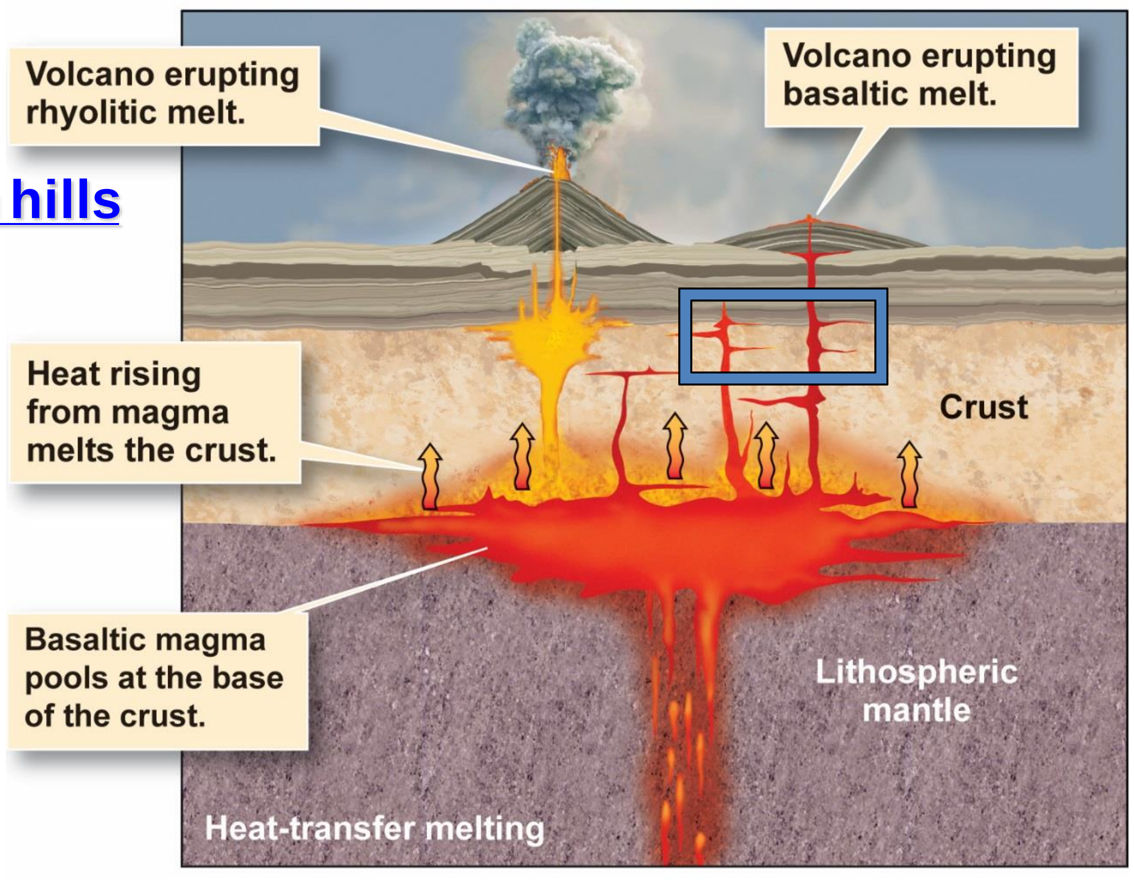
How did [Mt. Royal]() form?



Mount Royal?

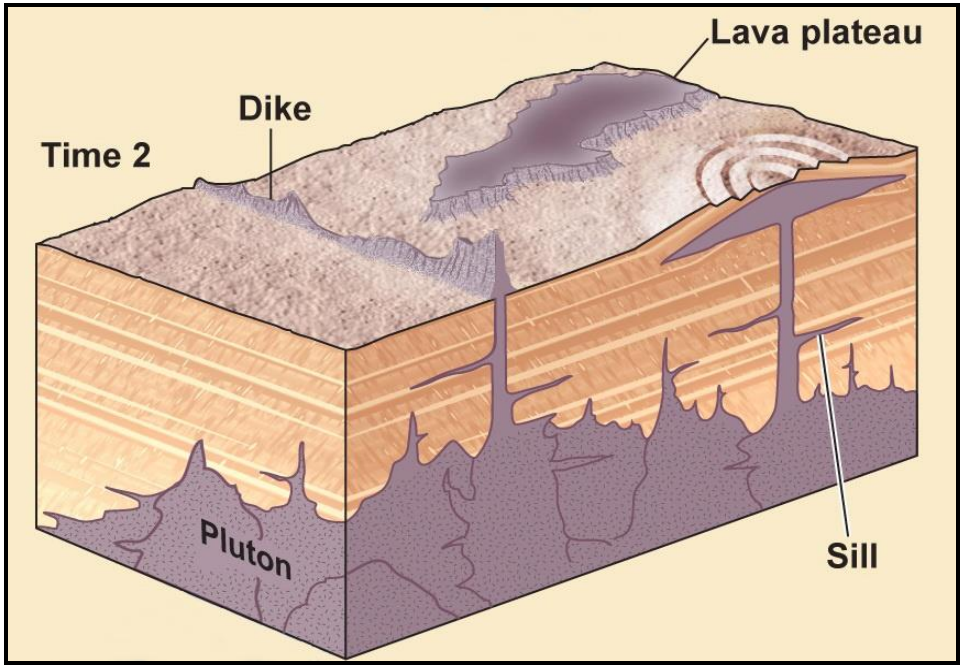
- The gabbroic core of Mt. Royal formed as an intrusion at a depth of about 1.3km ~125Ma. Magma rose into the sedimentary section which has since been "unroofed".

Monteregion hills



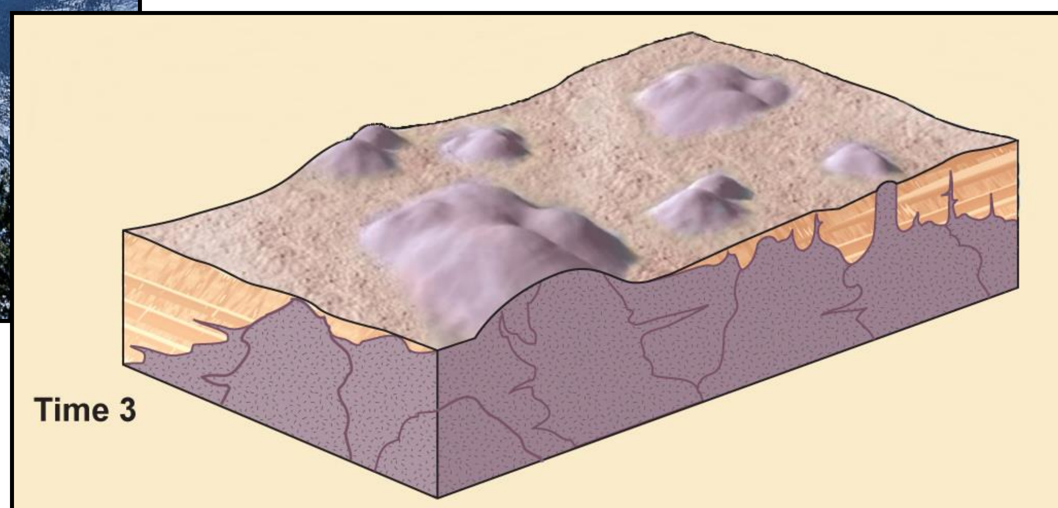
Intrusive and Extrusive

- With erosion, progressively deeper features are exposed.
  - Vertical dikes
  - Horizontal sills
  - Mushroom-shaped laccoliths



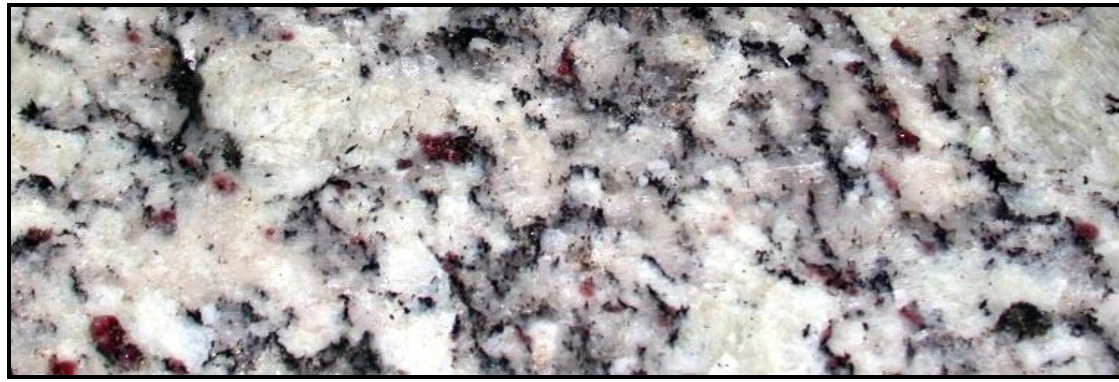
Influence on Landscape

- Continued uplift and erosion exposes a pluton.
  - Intrusive rocks are usually more resistant to erosion.
  - Thus, intrusive rocks often stand high on the landscape.
- “Unroofing” (erosion of covering geological units) takes long periods of geologic time: “exhumation”.



Describing Igneous Rock

- Igneous rock is used extensively as building stone.
  - Office buildings
  - Kitchens
- Why?
  - Durable (hard)
  - Beautiful

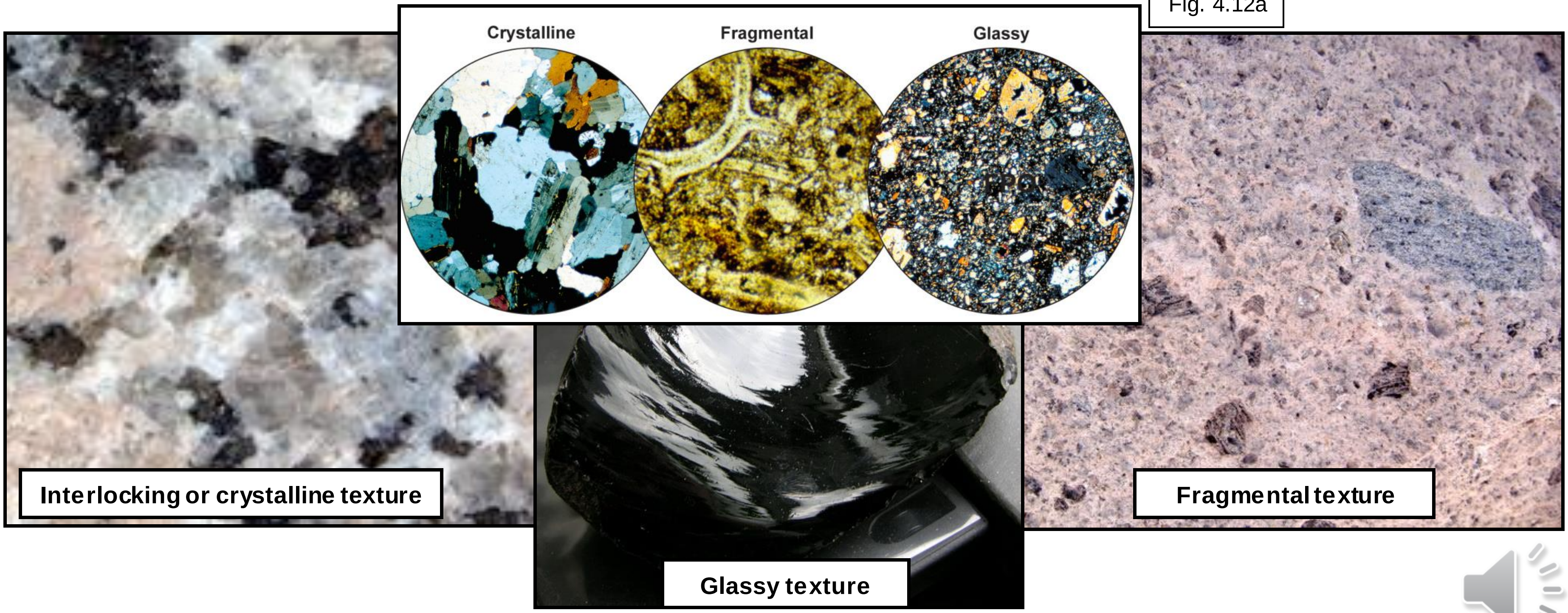


- Often called "granite"; it is not always true granite.
- Useful descriptions of igneous rock
  - Color (light or dark)
  - Texture

Describing Igneous Rocks

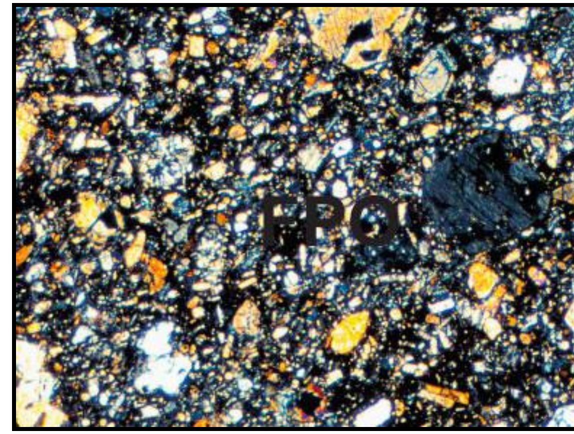
- The size, shape, and arrangement of the minerals
  - Crystalline—interlocking crystals fit like jigsaw puzzle
  - Fragmental—pieces of preexisting rocks, often shattered
  - Glassy—made of solid glass or glass shards
- Texture directly reflects magma history.

Fig. 4.12a

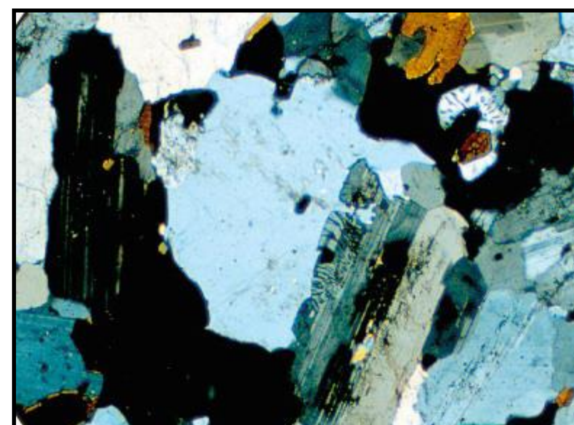


Crystalline Igneous Textures

- Interlocking mineral grains from solidifying melt
- Texture reveals cooling history.
  - Fine-grained
    - Rapid cooling
    - Crystals do not have time to grow.
    - Extrusive

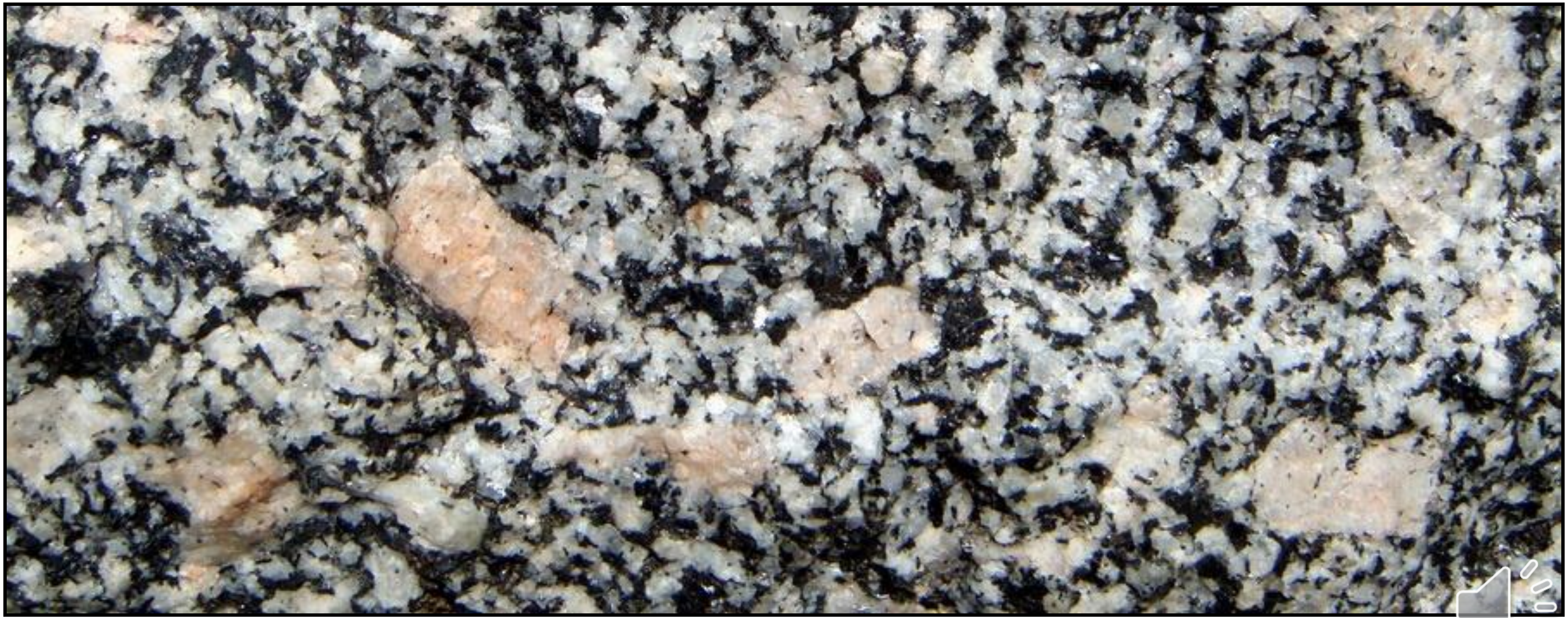


  - Coarse-grained
    - Slow cooling
    - Crystals have a long time to grow.
    - Intrusive



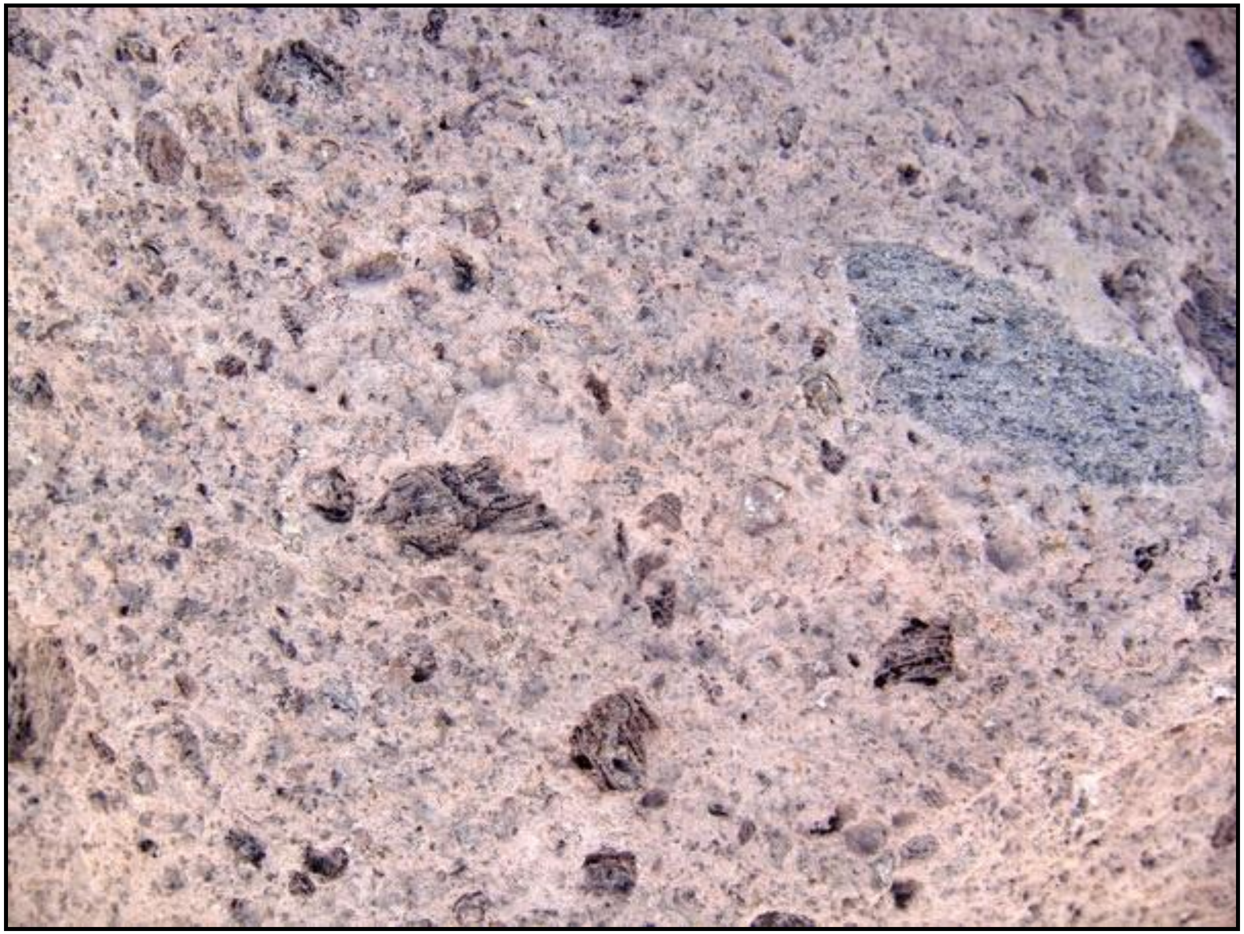
Crystalline Textures

- Texture reveals cooling history.
  - Porphyritic texture—a mixture of coarse and fine crystals
    - Indicates a two-stage cooling history.
      - Initial slow cooling creates large phenocrysts.
      - Subsequent eruption cools remaining magma more rapidly.



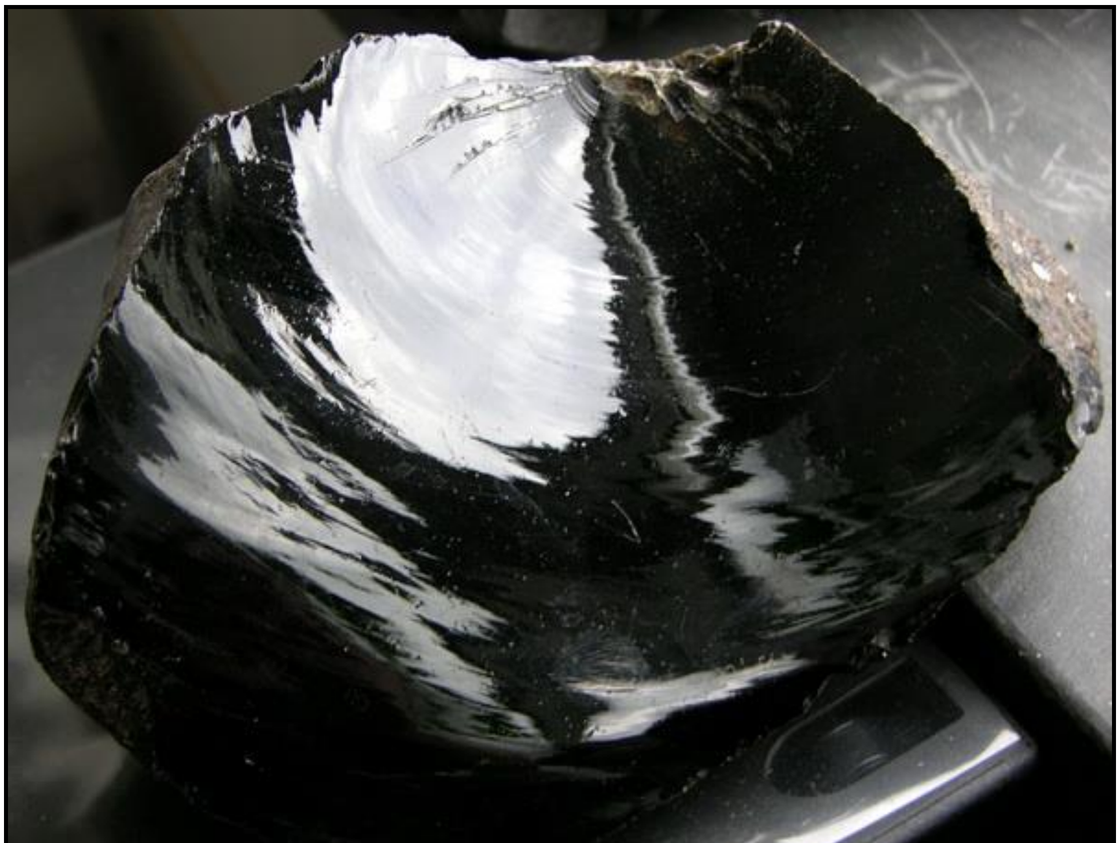
Fragmental Textures

- Preexisting rocks that were shattered by eruption
- After fragmentation, the pieces fall and are cemented.



Glassy Textures

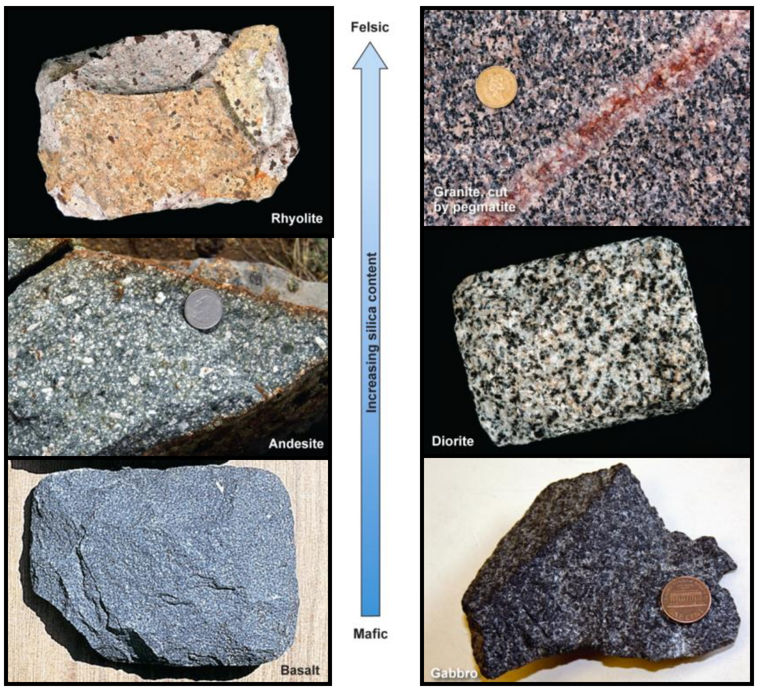
- Solid mass of glass or crystals surrounded by glass
- Fracture conchoidally
- Result from extremely rapid cooling of lava



Crystalline Classification

- **Classification is based on composition and texture.**

Fine　Coarse

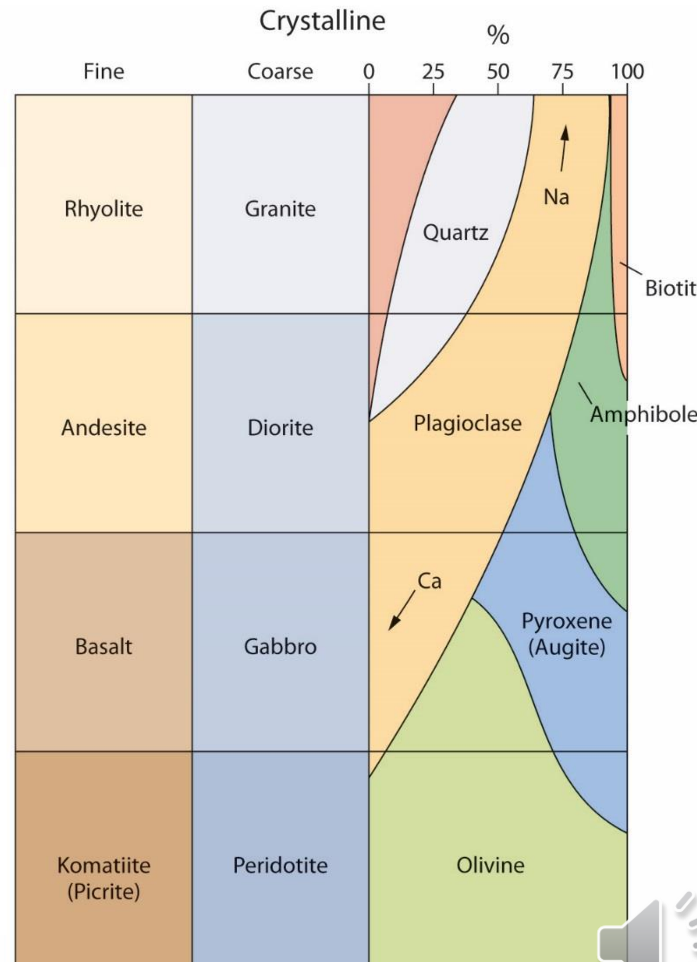


Felsic

Intermediate

Mafic

Ultramafic



Glassy Classification

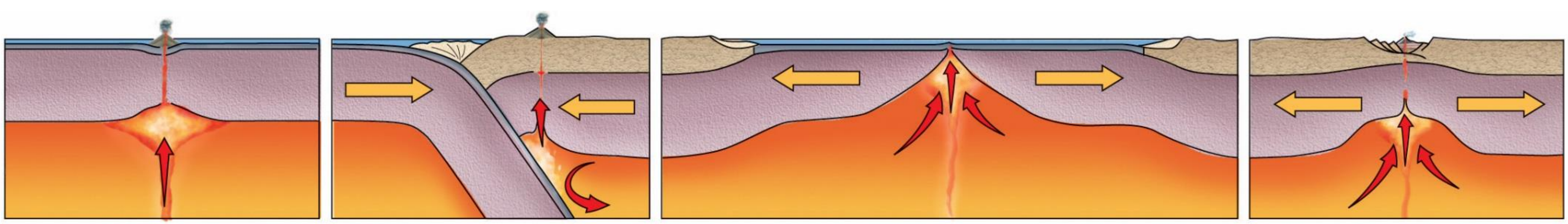
- More common in felsic igneous rocks
  - Obsidian—felsic volcanic glass
  - Pumice—frothy felsic rock full of vesicles; it floats.
  - Scoria—glassy, vesicular mafic rock

Pyroclastic Classification

- Pyroclastic—fragments of violent eruptions
  - Tuff—volcanic ash that has fallen on land
  - Volcanic breccia—made of larger volcanic fragments cemented together

Where Does Igneous Activity Occur?

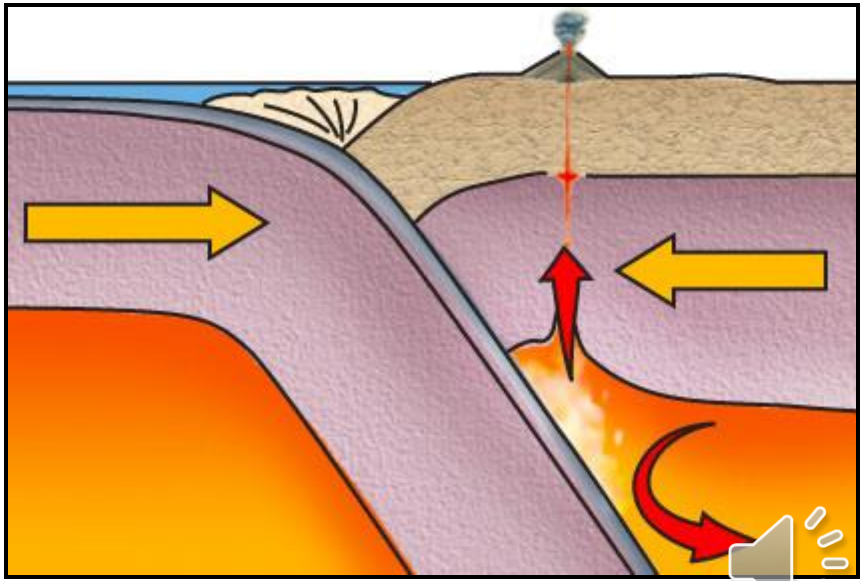
- Igneous activity occurs in four plate-tectonic settings.
  - Isolated hot spots
  - Volcanic arcs bordering deep ocean trenches
  - Mid-ocean ridges
  - Continental rifts
- Established or newly formed tectonic plate boundaries
- Except: hot spots, which are independent of plates



Mantle plume and a hot-spot volcano | Subduction yields a volcanic arc. | Melting occurs beneath a mid-ocean ridge. | Melting occurs beneath a continental rift.

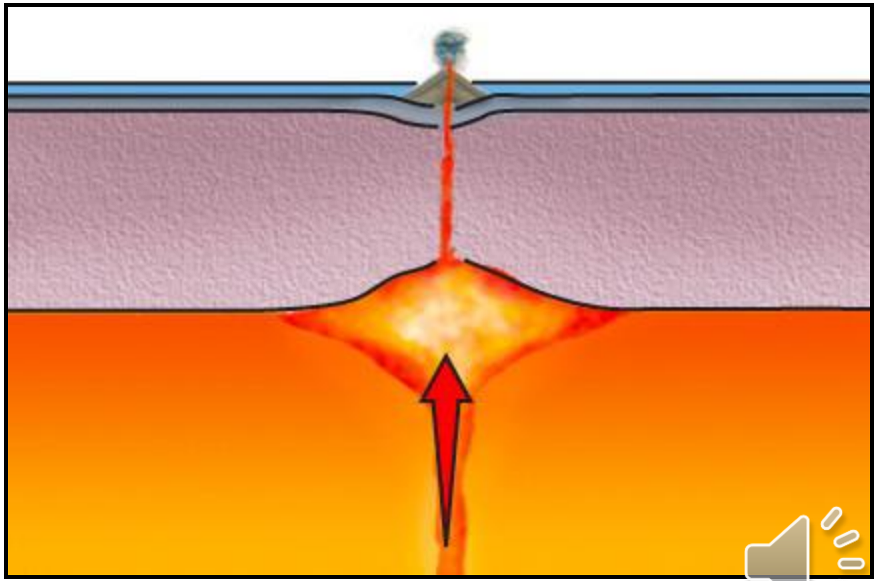
Volcanic Arcs

- Most subaerial volcanoes on Earth reside in arcs.
- Mark convergent tectonic plate boundaries
  - Deep oceanic trenches and accretionary prisms
  - Subducting oceanic lithosphere adds volatiles (water).
  - Rocks of the asthenosphere partially melt.
  - Magma rises and creates volcanoes on overriding plate.
  - Magma may differentiate.
- Examples:
  - Aleutian Islands
  - Japan
  - Java and Sumatra



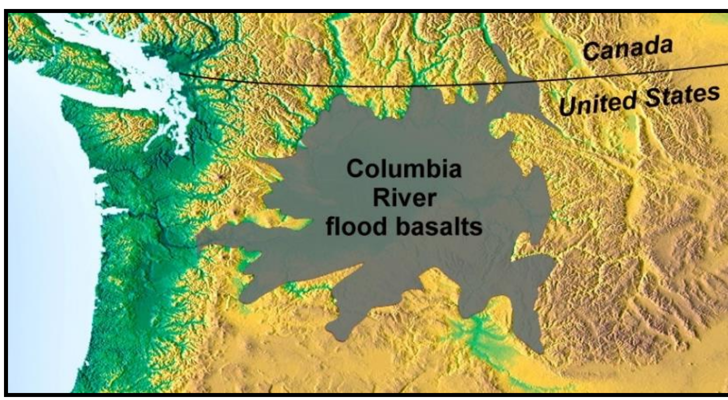
Hot Spots

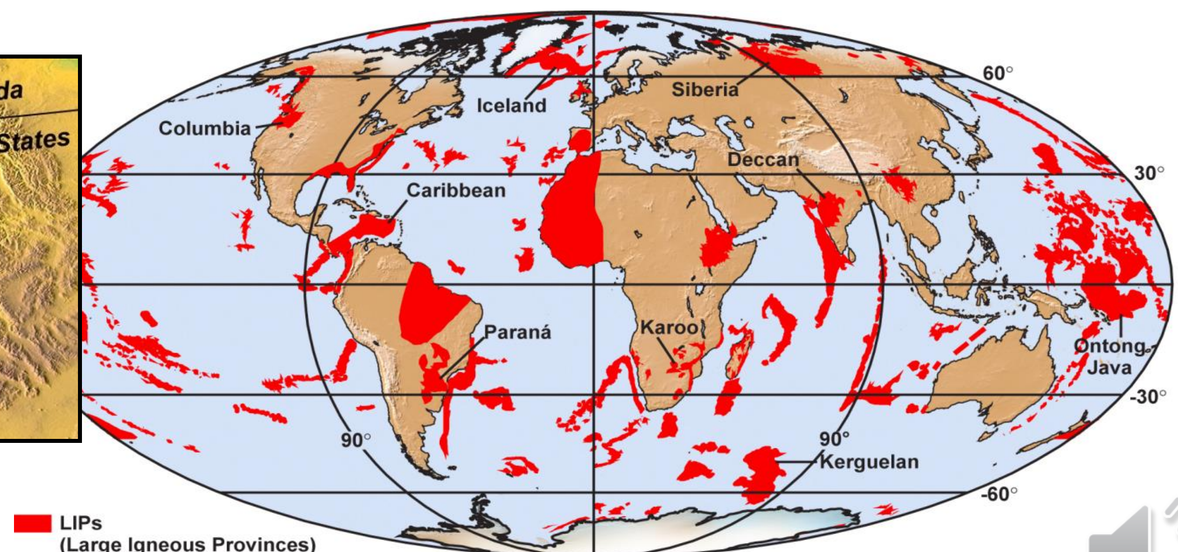
- About 50–100 mantle-plume hot-spot volcanoes exist.
- Independent tectonic plate boundaries
- May erupt through oceanic or continental crust.
  - Oceanic—mostly mafic magma (basalt)
  - Continental—mafic and felsic (basalt and rhyolite)
- Burn a volcano chain through overiding tectonic plate
  - Creates a hot-spot track (example Hawai'ian chain, New England hot-spot chain and Mt. Royal)



Large Igneous Provinces (LIP)

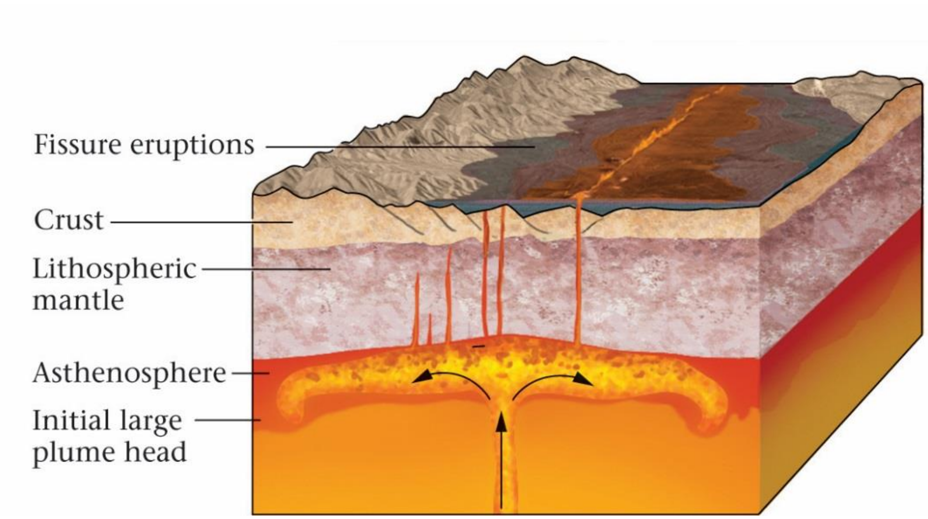
- LIPs—unusually large outpourings of magma
  - Mostly mafic, include some felsic examples
  - Mantle plume first reaches the base of the lithosphere.
  - Erupts huge volumes of mafic magma as flood basalts.
    - Low viscosity
    - Can flow tens to hundreds of kms
    - Accumulate in thick piles





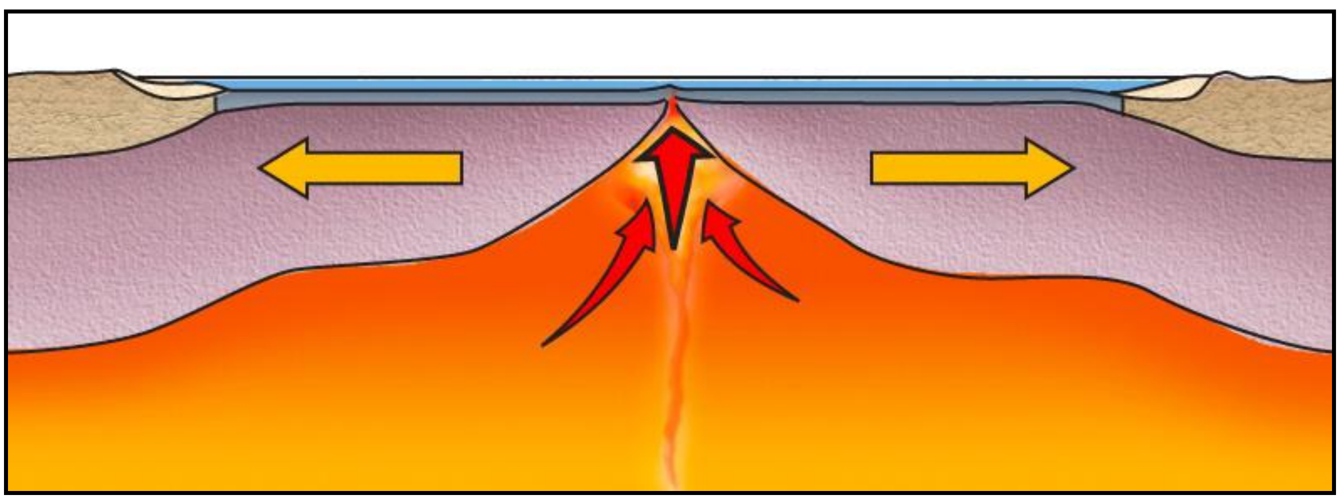
Continental Rifts

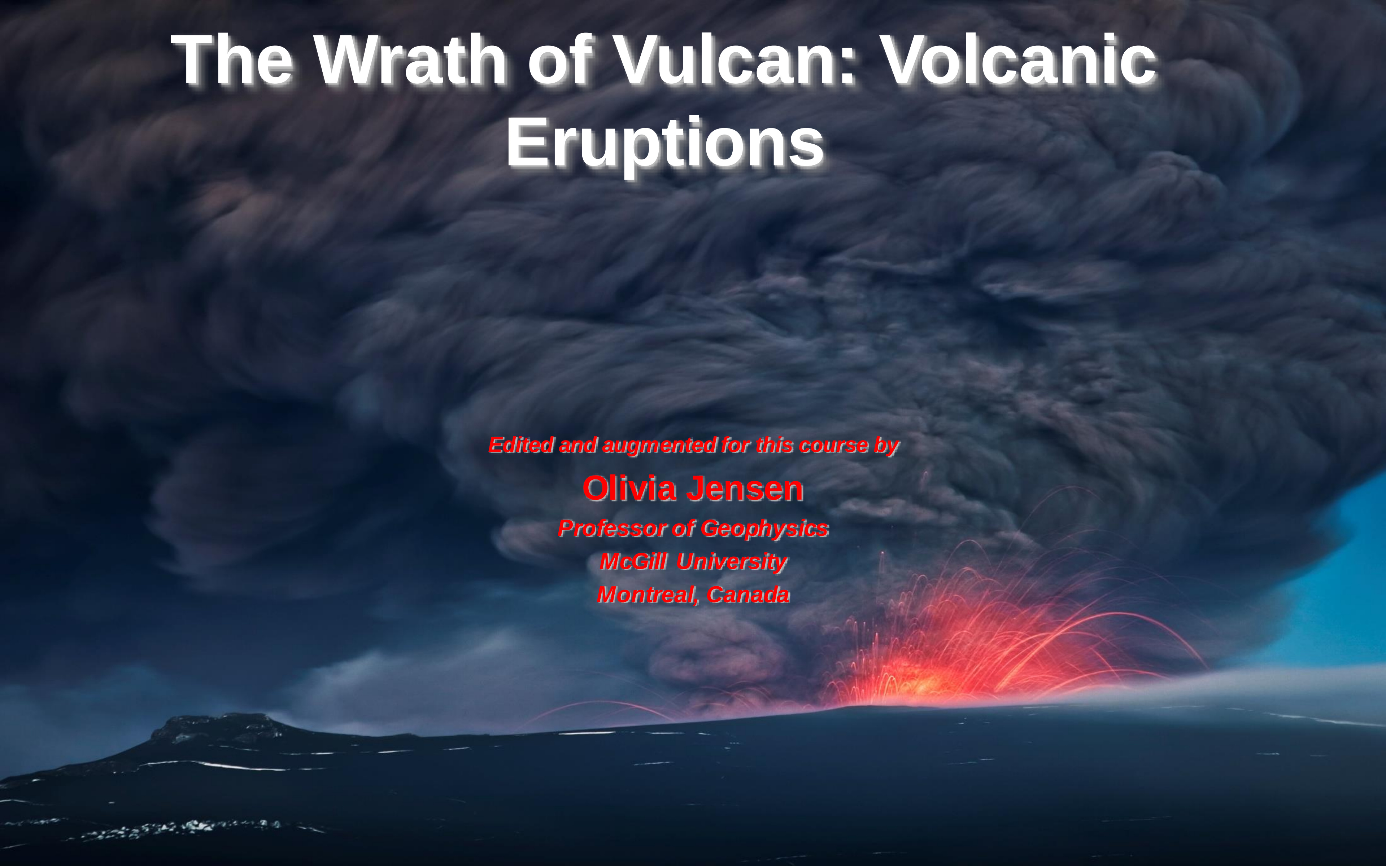
- Places where continental lithosphere is being stretched
- Rifting thins the lithosphere.
  - Causes decompressional melting of mafic rock.
  - Heat transfer melts crust, creating felsic magmas.
- Example: East African Rift Valley



Mid-Ocean Ridges

- Most igneous activity takes place at mid-ocean ridges.
  - Rifting spreads plates leading to decompression melting.
  - Basaltic magma wells up and fills magma chambers.
  - Solidifies as gabbro at depth.
  - Moves upward to form dikes or extrude as pillow basalt.





The Wrath of Vulcan: Volcanic Eruptions

Edited and augmented for this course by

Olivia Jensen

Professor of Geophysics

McGill University

Montreal, Canada

Updated by:

***Rick Oches**, Professor of Geology & Environmental Sciences*

Bentley University

Waltham, Massachusetts

Based on slides prepared by:

***Ronald L. Parker**, Senior Geologist*

Fronterra Geosciences

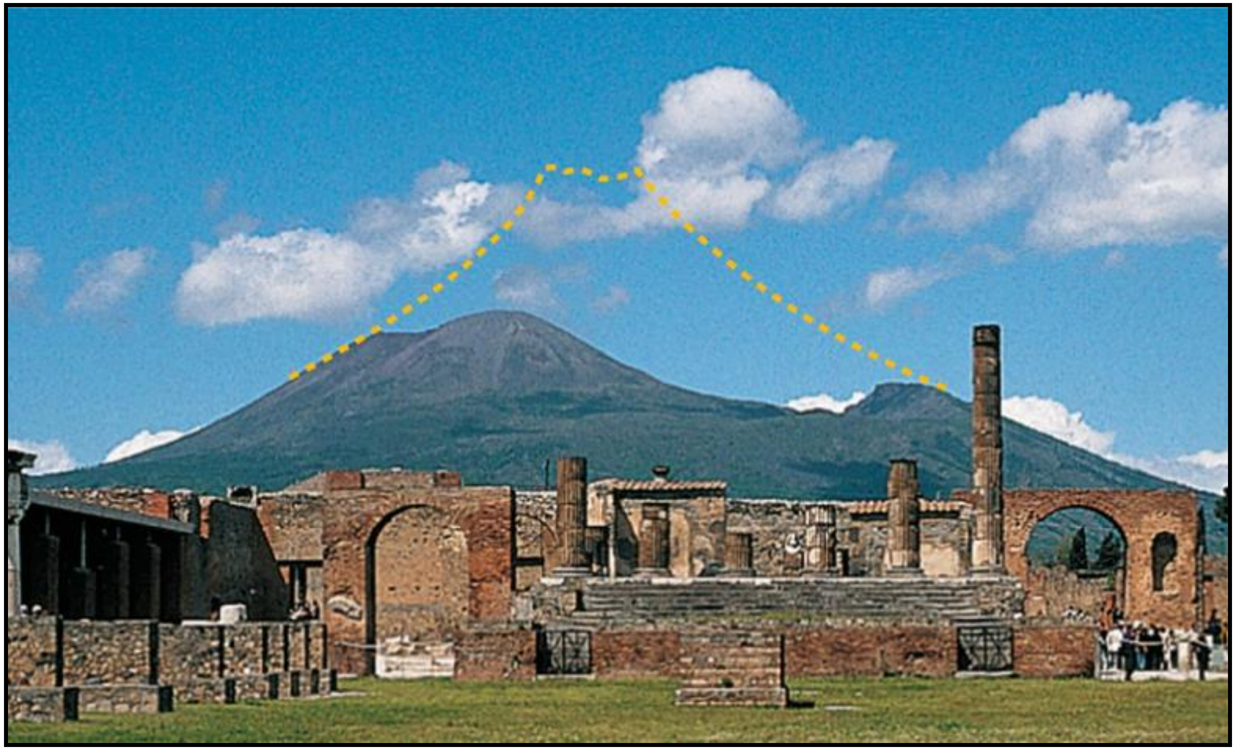
Denver, Colorado

Volcanic Eruptions

- What is a volcano?
  - An erupting vent through which molten rock surfaces.
  - A mountain built from magmatic eruptions.
- The first rock masses on Earth resulted from volcanoes
- Now, volcanoes are a clear result of tectonic activity.
- Volcanoes pose a number of hazards to humans.
- Vulnerable cities
  - Mexico City
  - Seattle, U.S
  - Naples, Italy

Volcanic Eruptions

- In 79 C.E. Mount Vesuvius erupted violently.
- Pyroclastic debris destroyed Pompeii, killing 20,000.
- A record of Roman life was preserved under ash.



Volcanic Eruptions

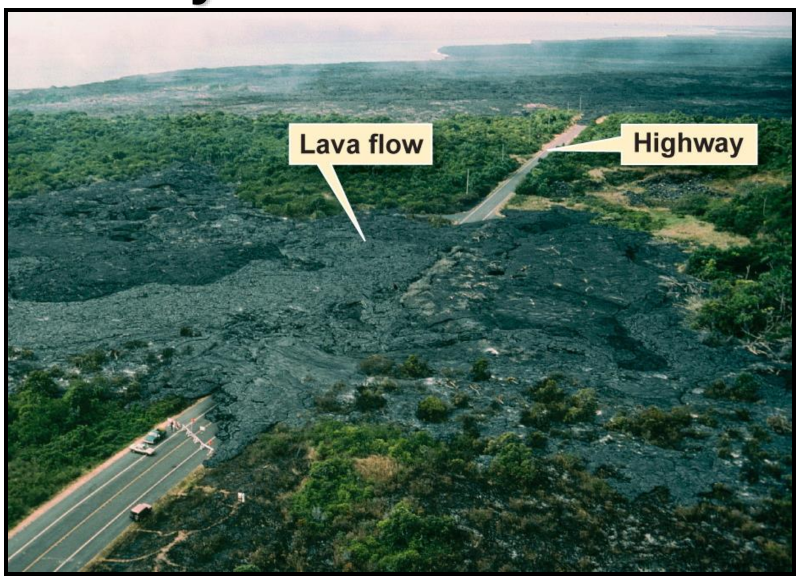
- Eruptions are often unpredictable, dangerous.
  - Build large mountains
  - Blow mountains to bits
- Eruptions can
  - provide highly productive soils to feed a civilization.
  - extinguish a civilization in a matter of minutes.
- Eruptions affect climate and civilizations.

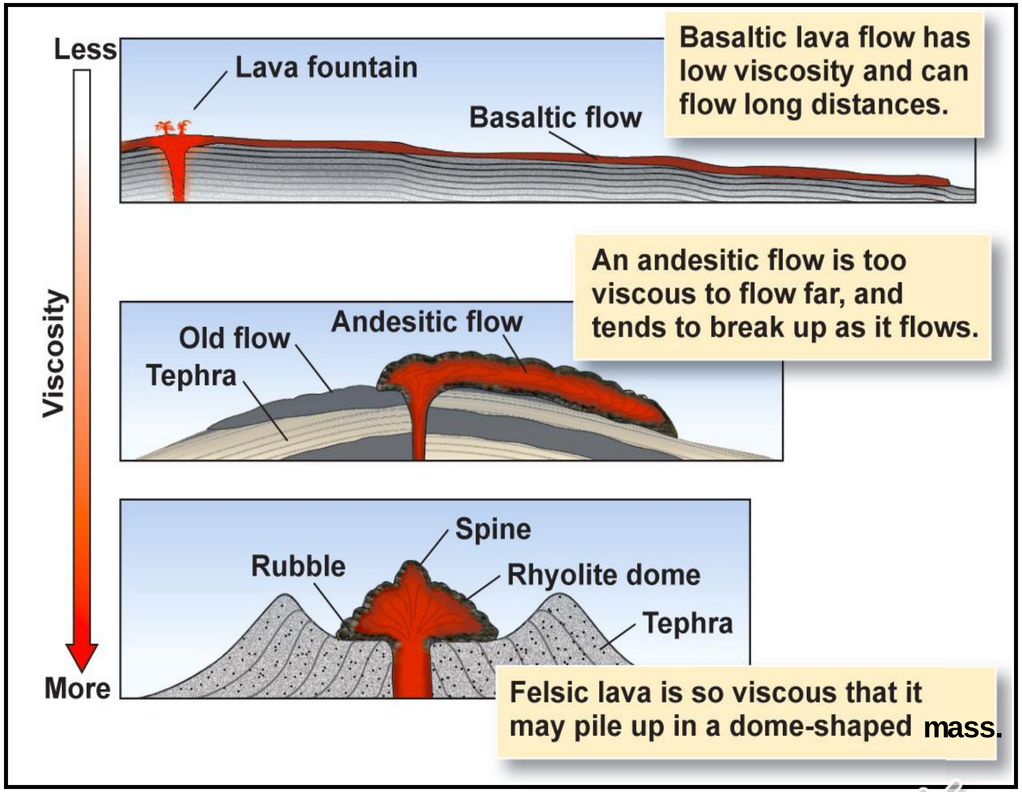
Volcanic Materials

- The products of volcanic eruption come in three forms:
  - Lava flows—molten rock that moves over the ground
  - Pyroclastic debris—fragments blown out of a volcano
  - Volcanic gases—expelled vapor and aerosols

Lava Flows

- Lava can be thin and runny or thick and sticky.
- Flow style depends on viscosity, which depends on
  - composition, especially silica (SiO_2) content; high silica, high viscosity.
  - temperature.
  - gas content.
  - crystal content





Basaltic Lava Flows

- Mafic lava—very hot, low silica, and low viscosity
- Basalt flows are often thin and fluid.
  - They can flow rapidly (up to 30 km per hour).
  - They can flow for long distances (up to several hundred km).
    - Most flows measure less than 10 km.
    - Long-distance flow is facilitated by lava tubes.

Basaltic Lava Flows

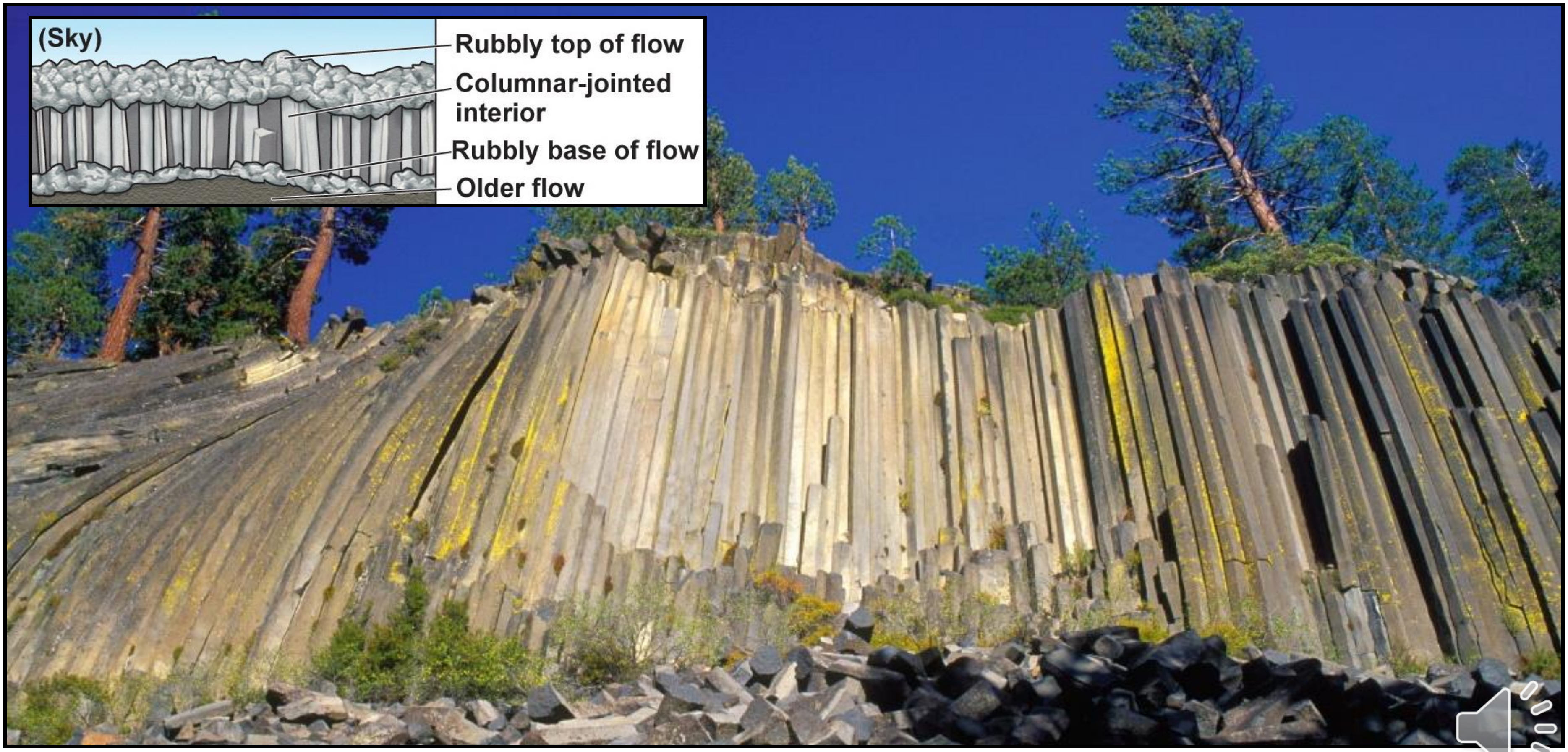
- Pahoehoe (pa-hoy-hoy)—a Hawaiian word describing basalt with a glassy, ropy texture
  - Pahoehoe forms when extremely hot basalt forms a skin.
  - With flow, the skin is rolled into ropy ridges and furrows.

Basaltic Lava Flows

- A’a’ (ah-ah) is a Hawaiian word describing basalt that solidifies with a jagged, sharp, angular texture.
  - A’a’ forms when hot flowing basalt cools and thickens.
  - With flow, lava crumbles into shards and fragments.
  - A’a’ is what you say walking on this material barefoot.

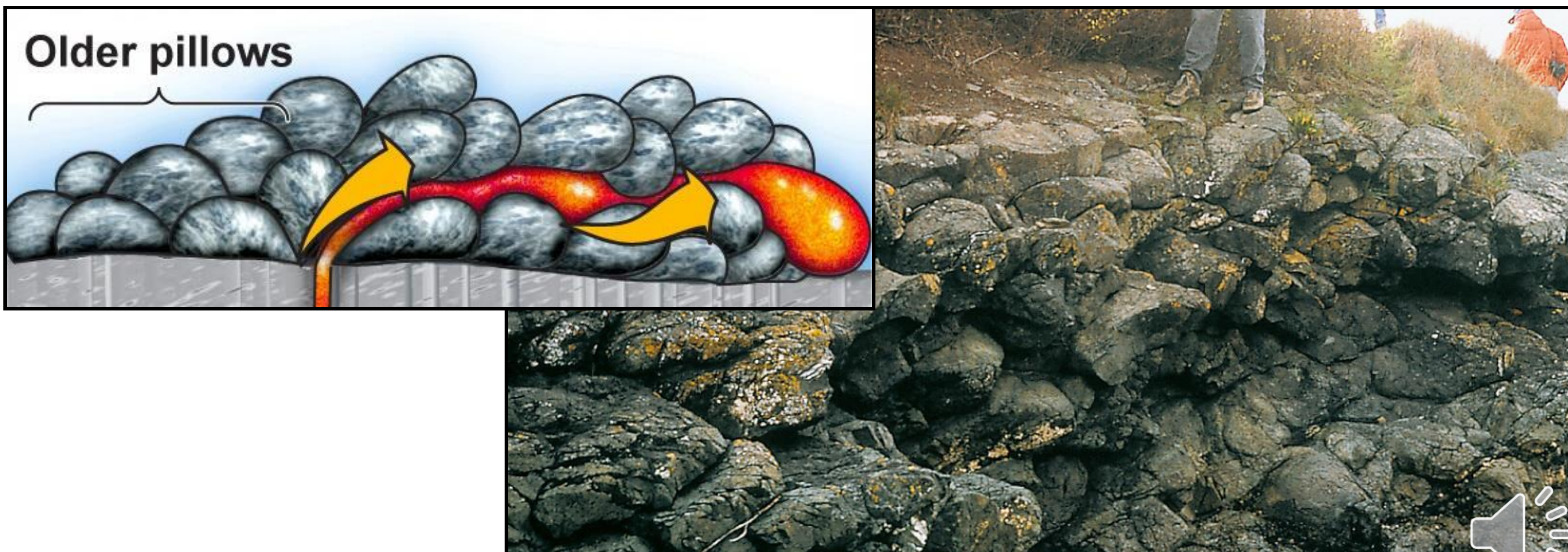
Basaltic Lava Flows

- Solidified flows may contract with vertical fractures, creating polygonal columns. [Giant's Causway]() (OJ)
- This feature, called *columnar jointing*, indicates lava.



Basaltic Lava Flows

- **Pillow basalt—round blobs of basalt cooled in water**
  - **Underwater, basalt cools instantly forming a pillow.**
    - **The pillow surface is cracked, quenched glass.**
    - **Lava pressure ruptures a pillow to form the next blob.**
    - **The process repeats to form a mound of pillow basalts.**
  - **Common on the mid-ocean ridge**

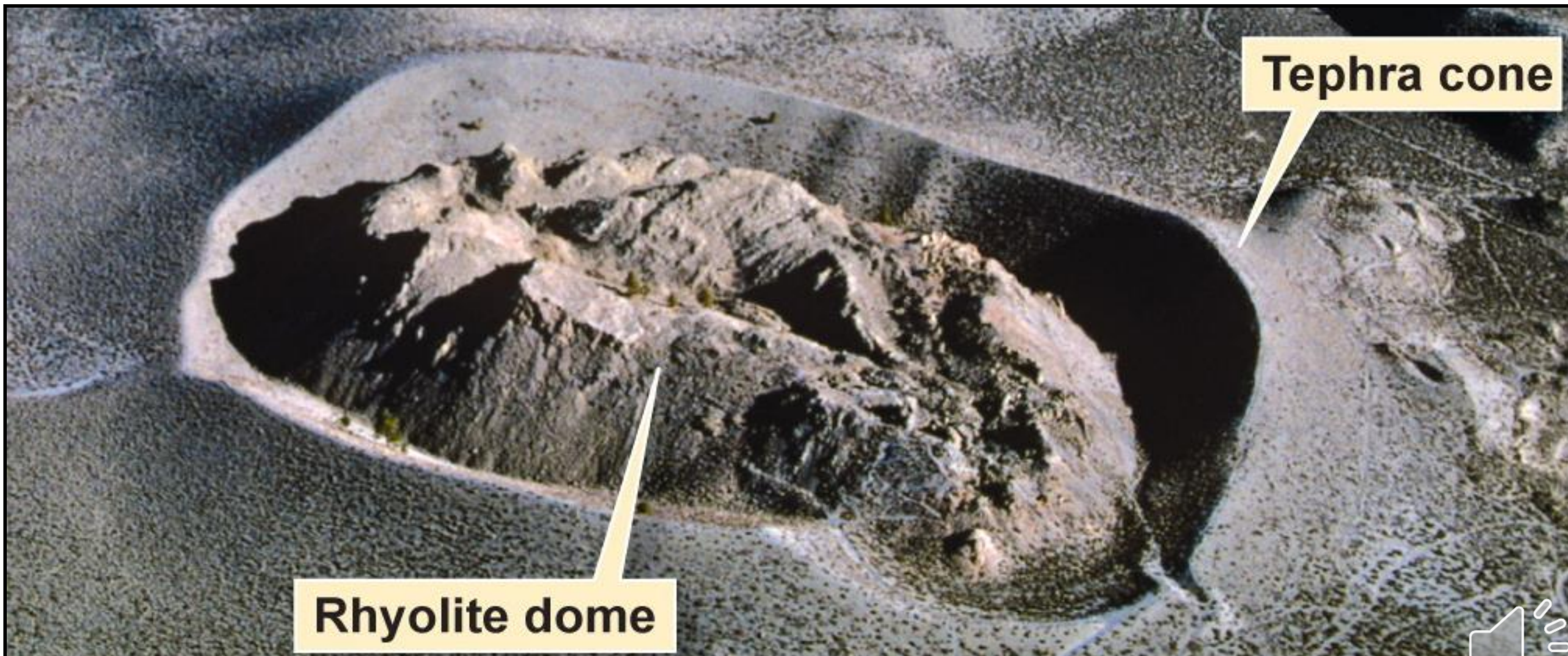


Andesitic Lava Flows

- Higher SiO_2 content makes andesitic lavas viscous.
  - Unlike basalt, they do not flow rapidly.
  - Instead, they mound around the vent and flow slowly.
- The crust fractures into rubble, called blocky lava.
- Andesitic lava flows remain close to the vent.

Rhyolitic Lava Flows

- Rhyolite has the highest SiO_2 and the most viscous lava.
- Rhyolitic lava rarely flows.
- Rather, lava plugs the vent as a lava dome.
- Sometimes lava domes are blown to smithereens.



Rhyolitic Lava Flows

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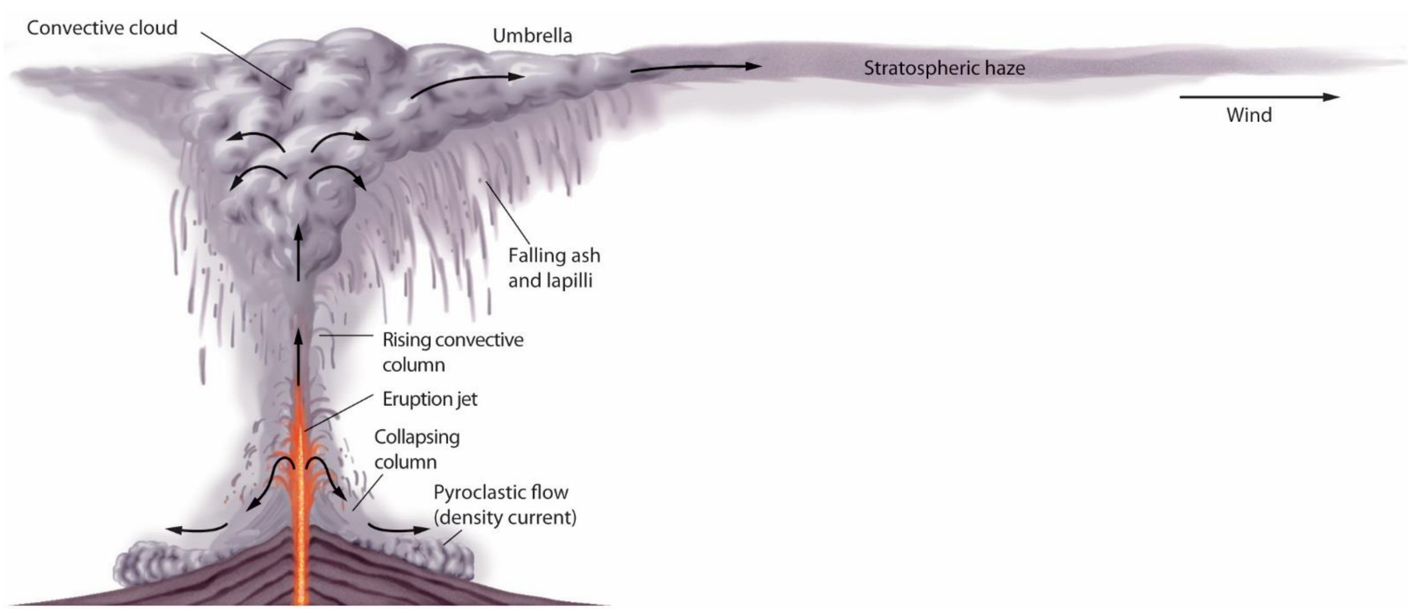
- Rhyolitic lava rarely flows.
- Rather, lava plugs the vent as a lava dome.
- Sometimes lava domes are blown to smithereens.

Mt. St. Helens

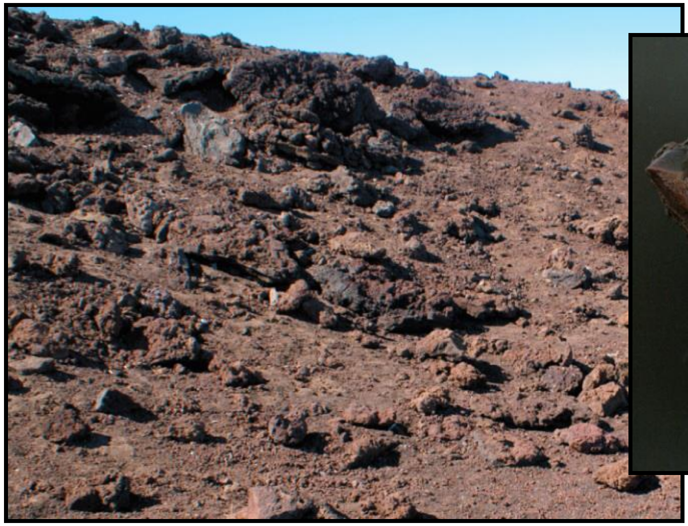
Volcaniclastic Deposits

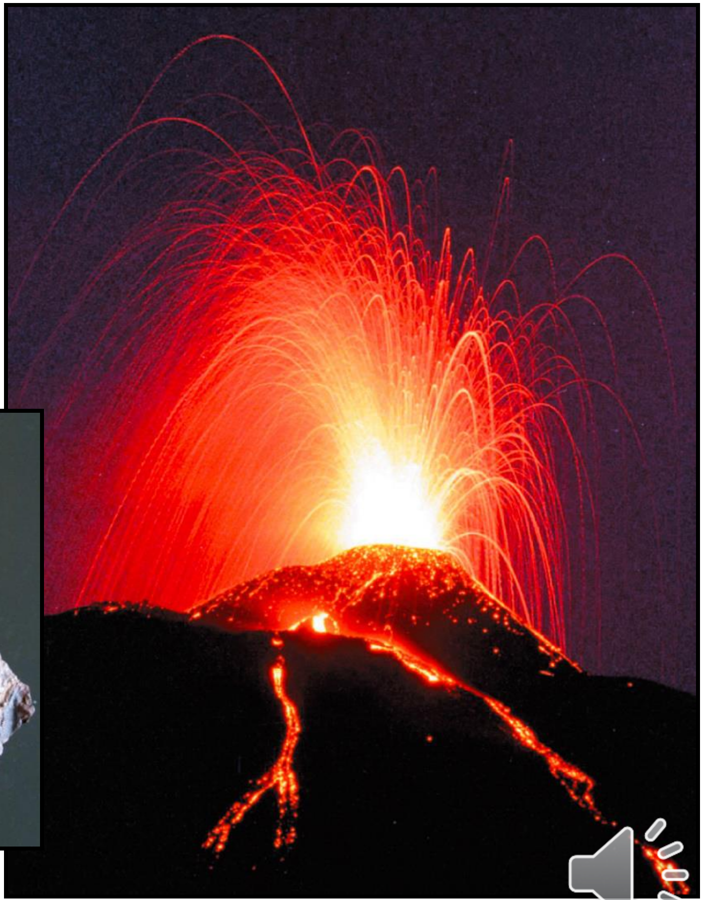
- Volcanoes often erupt large quantities of fragments.
- Volcaniclastic deposits include
  - pyroclastic debris—lava fragments that freeze in air.
  - preexisting rock—blasted apart by eruption.
  - landslide debris—blocks that have rolled downslope.
  - lahars—transported as water-rich slurries.



Pyroclastic Debris

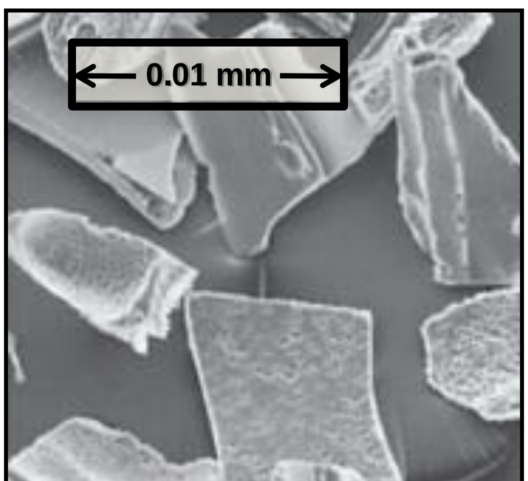
- Basaltic eruptions
  - Released gases eject clots and drops of molten magma.
  - Sometimes basaltic eruptions form dramatic fountains.
    - Lapilli—pea-sized fragments
    - Pele's tears—frozen droplets
    - Pele's hair—thin glass strands
    - Blocks—large fragments
      - Bombs—streamlined





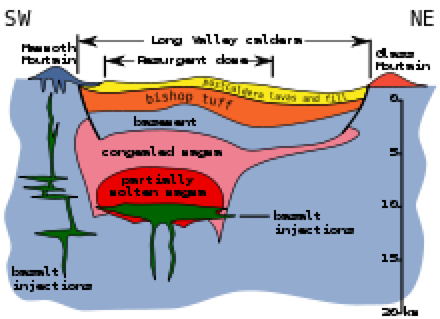
Pyroclastic Debris

- Andesitic or rhyolitic eruptions
  - More viscous magmas; more volcanic gases
  - Make these volcanoes more prone to explode
  - Explosive eruptions generate huge volumes of debris.
    - Pumice—frothy volcanic glass
    - Ash—fragments less than 2 mm in diameter
    - Pumice lapilli—angular pumice fragments
    - Accretion lapilli—clumps formed by falling through moist air



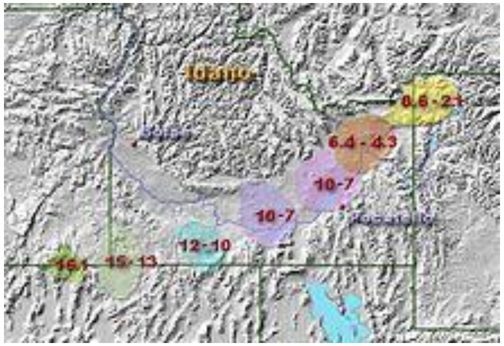
Again Mt. Toba (75ka)

- **We know of several "supervolcano" eruptions in recent geological time. Mt. Toba might have been the largest of them. What Would Happen if a Mt. Toba Eruption Happens Again ? (video)**



Long Valley, CA

Lake Toba, Indonesia



Yellowstone hotspot

- **Closer to home: What if the Yellowstone supervolcano erupts? (a future possibility -- video)**

You might look to the Yellowstone Volcano Observatory

Campi Flegrei

- The Phlegraean fields: the site of the city of Naples, Italy sits within a caldera of a super volcano.

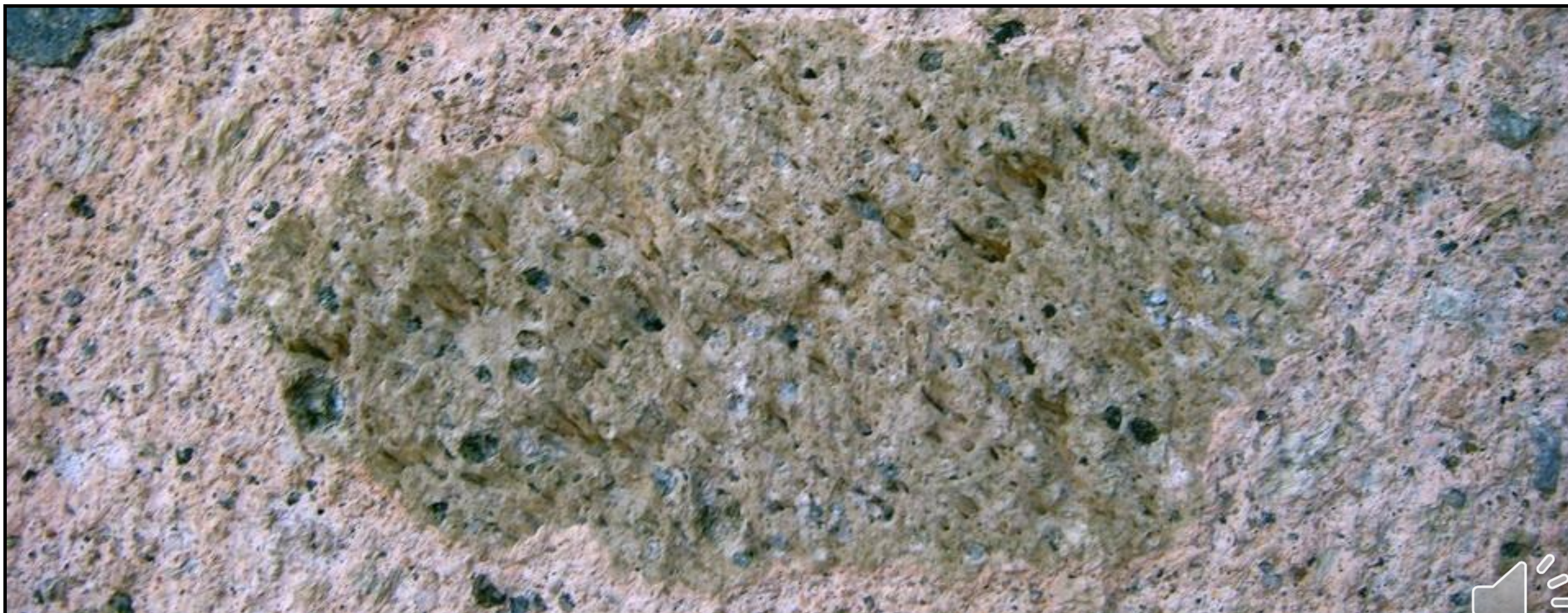
- Major eruptions:
  - 39000 years ago
  - 15000 years ago
  - Documentary
- Vesuvius/Pompeii
  - CE 79

Pyroclastic Debris

- Pyroclastic flow (from the French *nuée ardente*, meaning glowing ash cloud):
  - Avalanches of hot ash (200º to 450ºC) that race downslope
  - Move up to 300 km per hour; incinerate all in their path
  - Deadly; they kill everything quickly.
  - Several historic examples:
    - Mount Vesuvius
    - Mount Pelée
    - Mount Augustine

Pyroclastic Deposits

- Andesitic or rhyolitic eruptions
  - Tephra—deposits of pyroclastic debris of any size.
  - Tuff—lithified ash, may or may not contain lapilli
    - Air-fall tuff—accumulations of ash that fall like snow
    - Ignimbrite—tuff deposited while hot that welds together



Other Volcaniclastic Deposits

- **Volcanic debris flow—wetted debris that moves downhill**
  - **Occur where volcanoes are covered with ice and snow or drenched in abundant rain**
  - **Volcanic debris flows move downslope like wet concrete.**
  - **Lahar—water-rich debris flow of ash and blocks**
    - **Can move very fast (~50 km/hour) and very far (~tens of km).**

Volcanic Gas

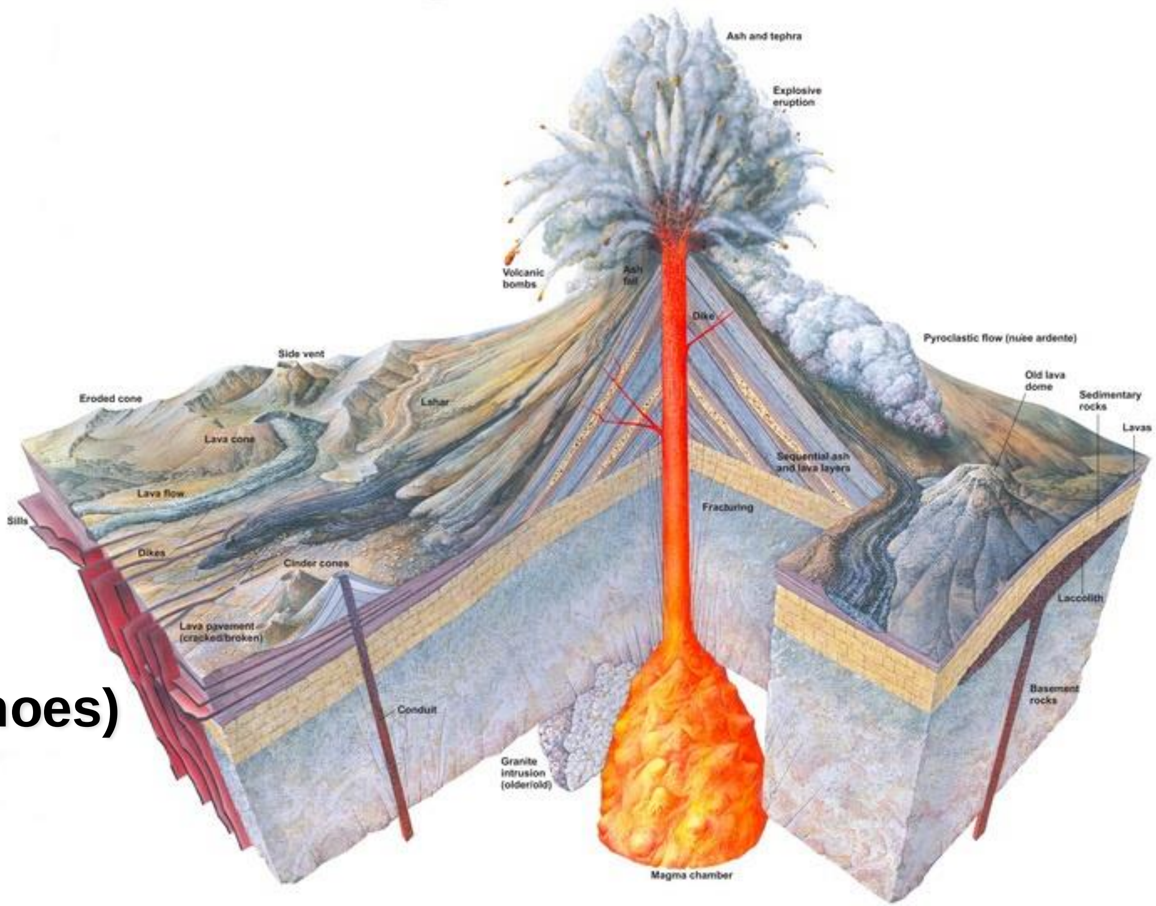
- Up to 9% of magma may be gas.
  - Water (H_2O) – the most abundant gas
  - Carbon dioxide (CO_2) – second in abundance
  - Sulfur dioxide (SO_2) and hydrogen sulfide (H_2S)
    - rotten-egg smell

Volcanic Gas

- Gases are expelled as magma rises (P drops).
- SO_2 reacts with water to form aerosol sulfuric acid.
- Style of gas escape controls eruption violence.
  - Low viscosity (basalt)—easy escape; mellow eruption
  - High viscosity (rhyolite)—difficult escape; violent release
- Gas bubbles in rock are called vesicles.

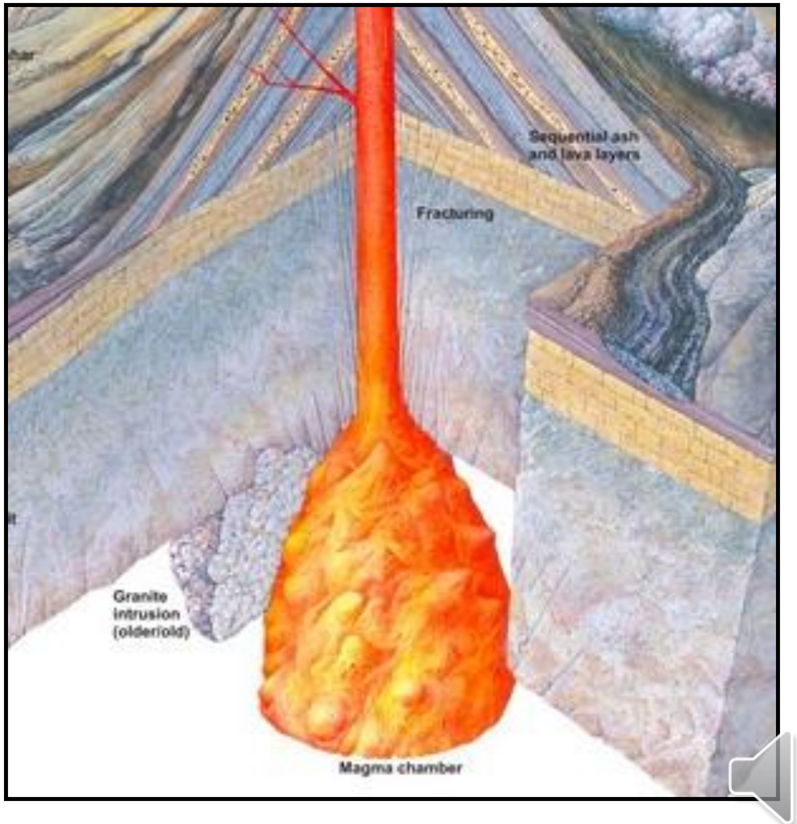
Volcanic Architecture

- Volcanoes have characteristic features.
  - Magma chamber
  - Fissures and vents
  - Craters
  - Calderas
  - Distinctive profiles
    - Shield volcanoes
    - Scoria cones (cinder cones)
    - Stratovolcanoes (composite volcanoes)



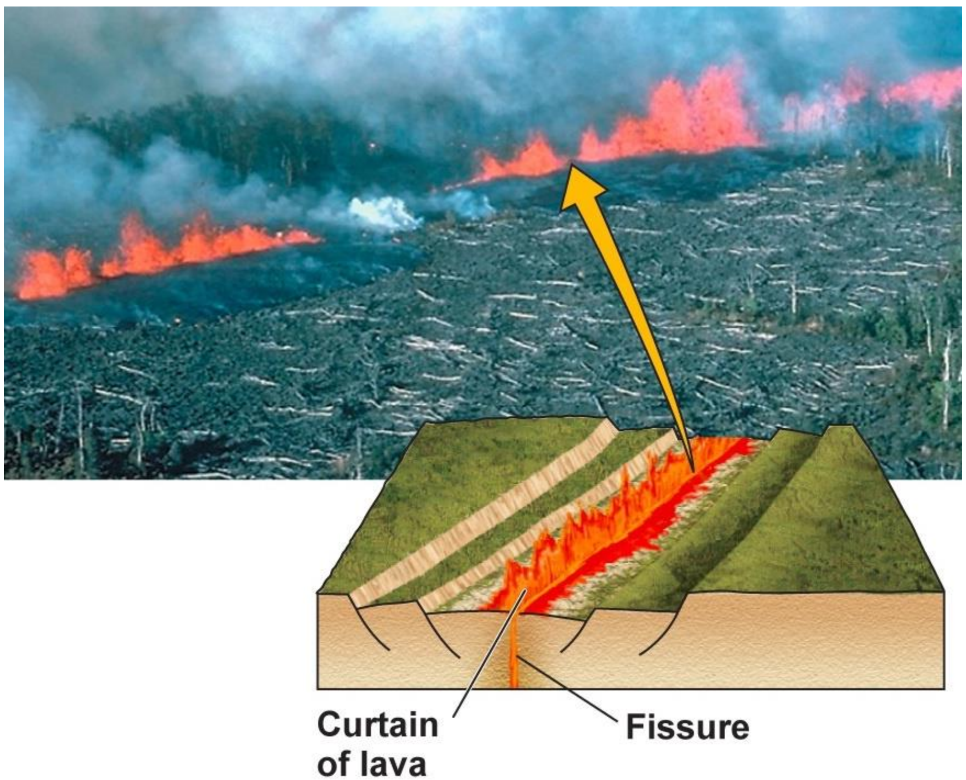
Volcanic Architecture

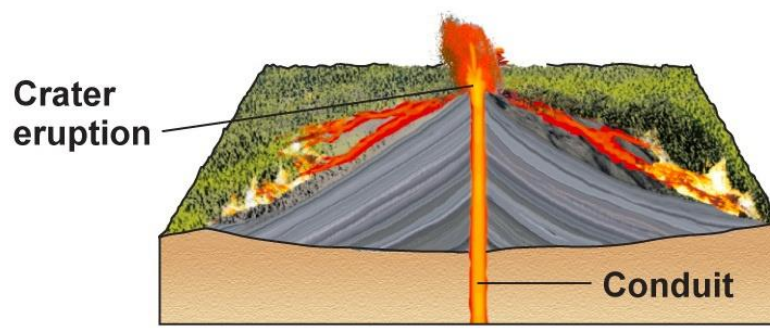
- **Magma chambers are located in the upper crust.**
  - **Usually an open cavity or area of highly fractured rock**
  - **May contain a large quantity of magma**
- **Some magma cools here to form intrusive igneous rock.**
- **Some magma may rise to the surface to form a volcano.**



Volcanic Architecture

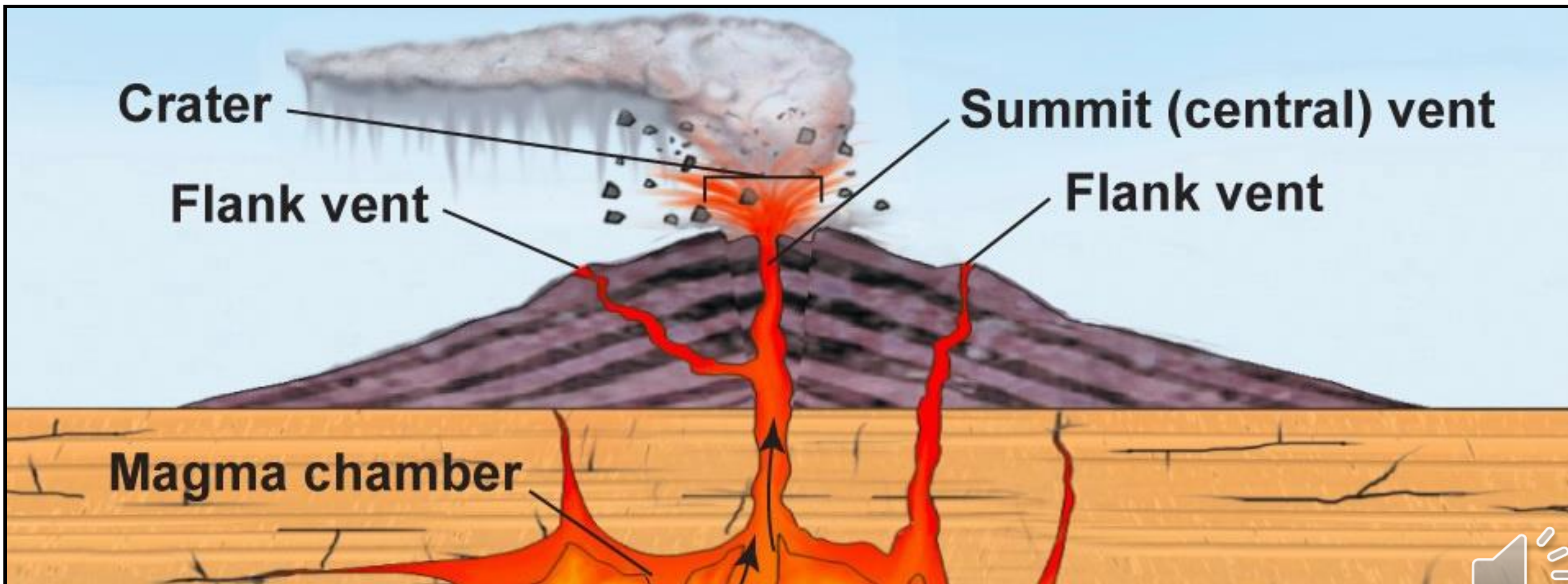
- Some magma rises via a conduit to the surface.
- Magma may erupt along a linear tear called a *fissure*.
  - Fissure eruptions may display a "curtain of fire."
  - Fissures evolve into discrete vents and craters.





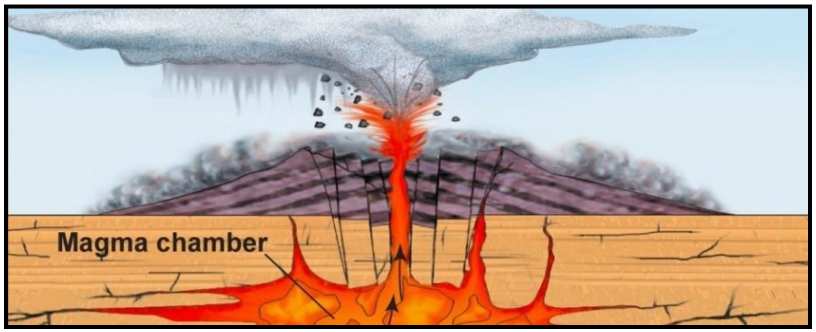
Volcanic Architecture

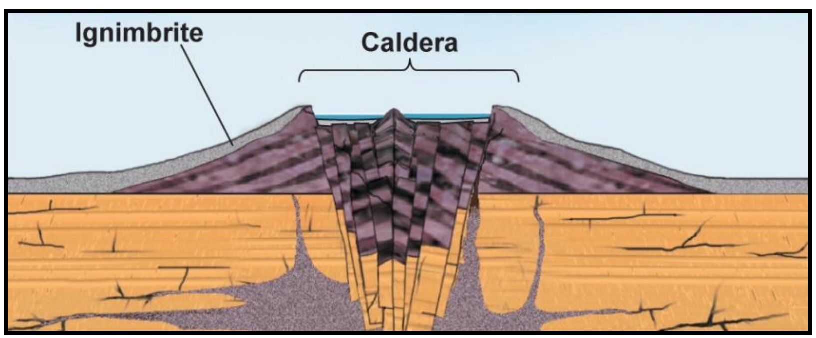
- Crater—a bowl-shaped depression atop a volcano.
- Craters are up to 500 m across and 200 m deep.
- Form as erupted lava piles up around the vent
  - Summit eruptions—located within the summit crater
  - Flank eruption—located along the side of a volcano



Volcanic Architecture

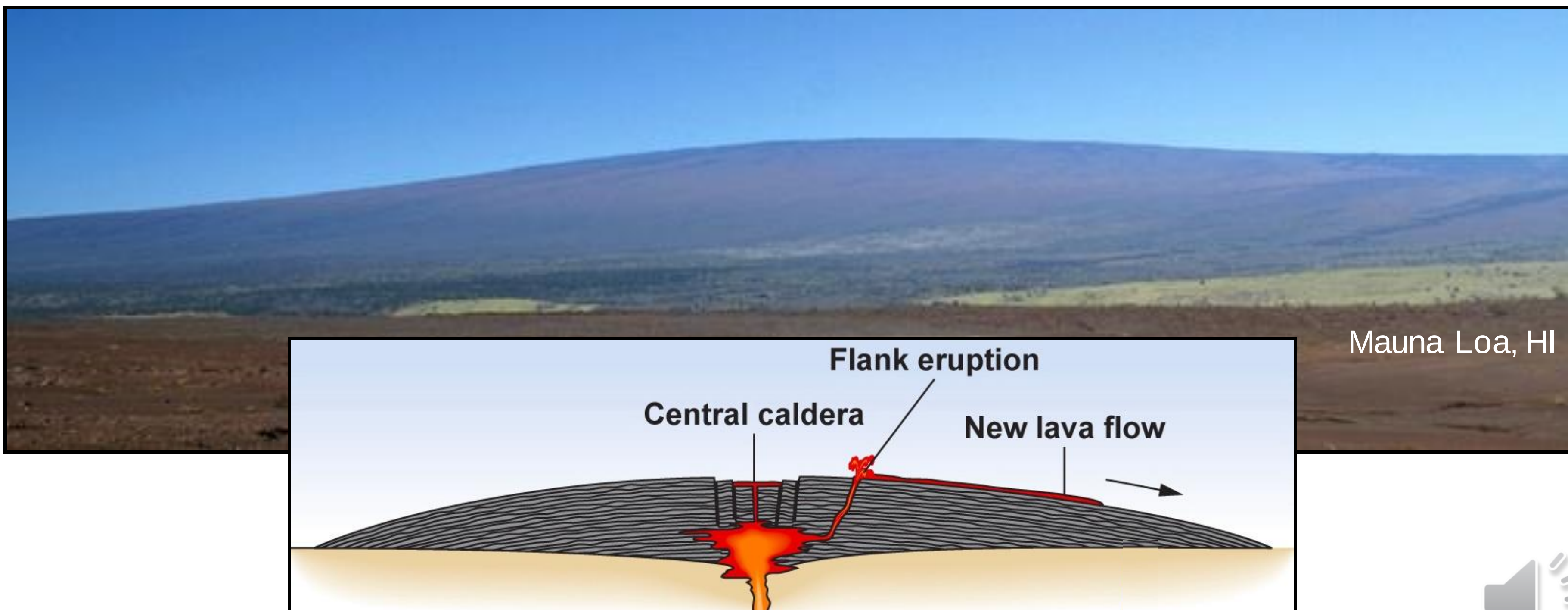
- A caldera is a gigantic volcanic depression.
  - Much larger than a crater (one to tens of km across)
  - Usually exhibit steep sidewalls and flat floors
- A magma chamber empties and the volcano collapses in.





Volcanic Architecture

- Shield volcanoes
  - Broad, slightly dome-shaped (like an inverted shield)
  - Constructed by lateral flow of low-viscosity basaltic lava.
  - Have a low slope and cover large geographic areas
  - Mauna Loa on Hawaii is a perfect example.



Volcanic Architecture

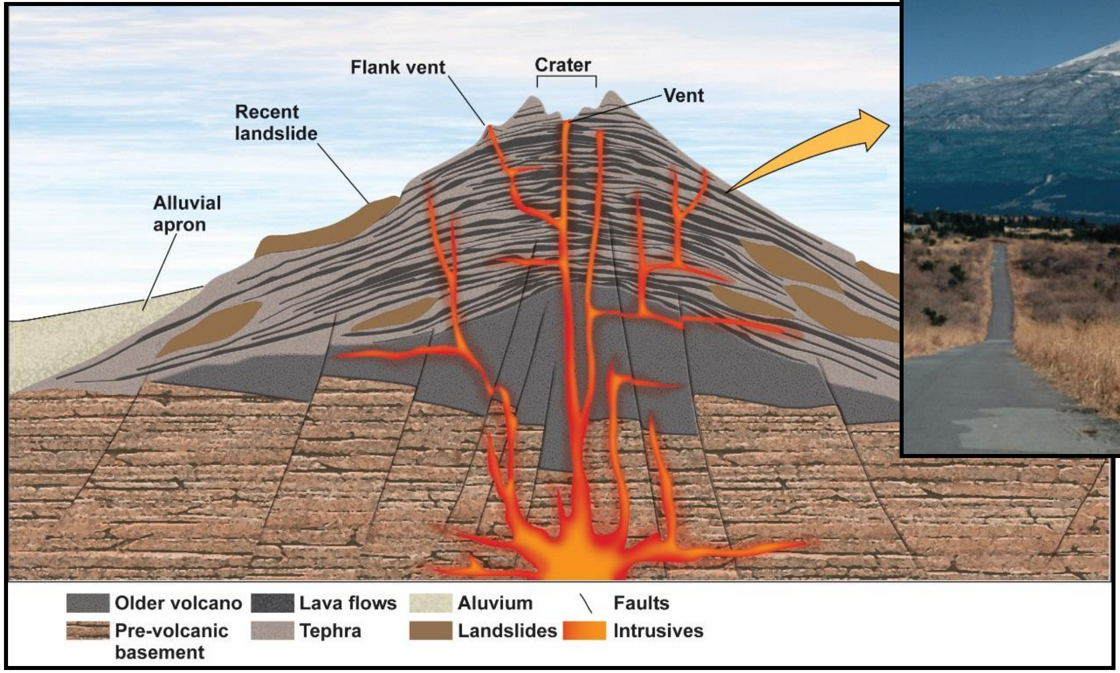
- Scoria cones (also called cinder cones)
  - Conical piles of tephra; the smallest type of volcano
  - Built of ejected lapilli and blocks piled up at a vent
  - Often symmetrical, with a deep summit crater
  - Typically from a single eruption event

Volcanic Architecture

- Scoria cones (also called cinder cones)
  - The cinders are often used in garden decoration

Volcano Types

- Stratovolcanoes (also called composite volcanoes)
  - Large, cone-shaped volcanoes with steeper slopes
  - Made of alternating layers of lava, tephra, and debris
  - Examples include Mount Fuji, Mount Rainier, Mount Vesuvius



Eruptive Style

- Will it flow or will it blow? Two dominant styles:
  - Effusive eruptions—produce lava flows
  - Explosive eruptions—blow up

Eruptive Style

- Effusive eruptions—produce a vast outpouring of lava
  - Lava flows stream away from vents.
  - Lava lakes can form near, or inside, the vent.
  - Can produce huge lava fountains.
- Common with mafic magma (basalt)
  - Very hot
  - Low viscosity

Eruptive Style

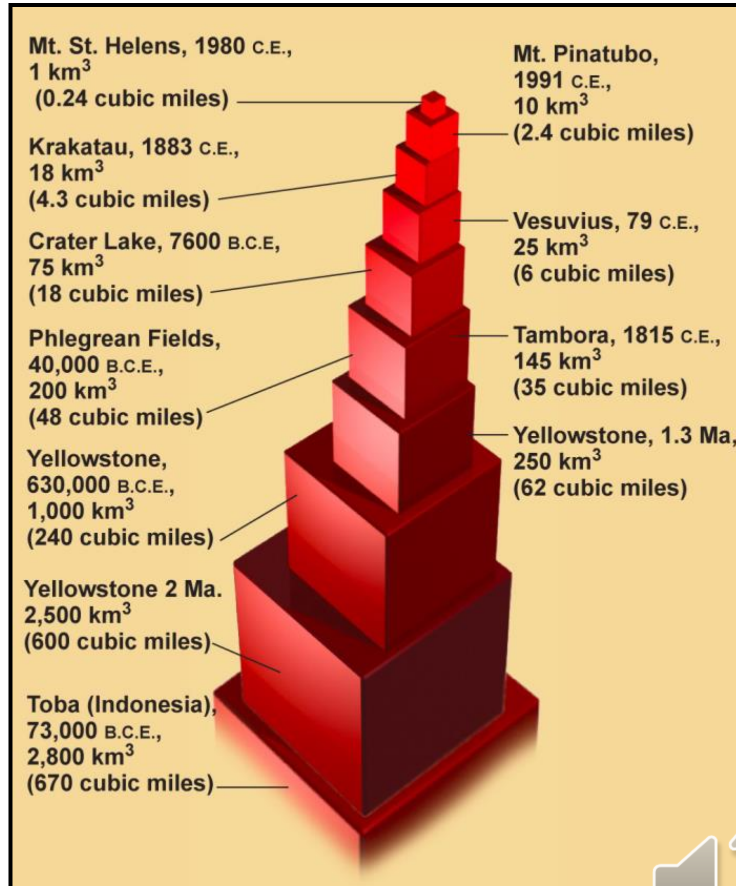
- Explosive eruptions—release pressure catastrophically
  - High gas pressure is from more viscous SiO_2-rich magma
  - Create pyroclastic flows and cover the land with tephra
  - Can eject many cubic kilometers of debris skyward
- Mostly andesitic and rhyolitic compositions

Eruptive Style

- Eruptive style is related to volcano type:
  - Effusive eruptions form shield volcanoes (Hawai'i).
  - Small pyroclastic eruptions form scoria cones.
  - Alternating effusive and pyroclastic eruptions result in stratovolcanoes (Mount Etna, Sicily).
  - Large explosive eruptions create calderas (Yellowstone).

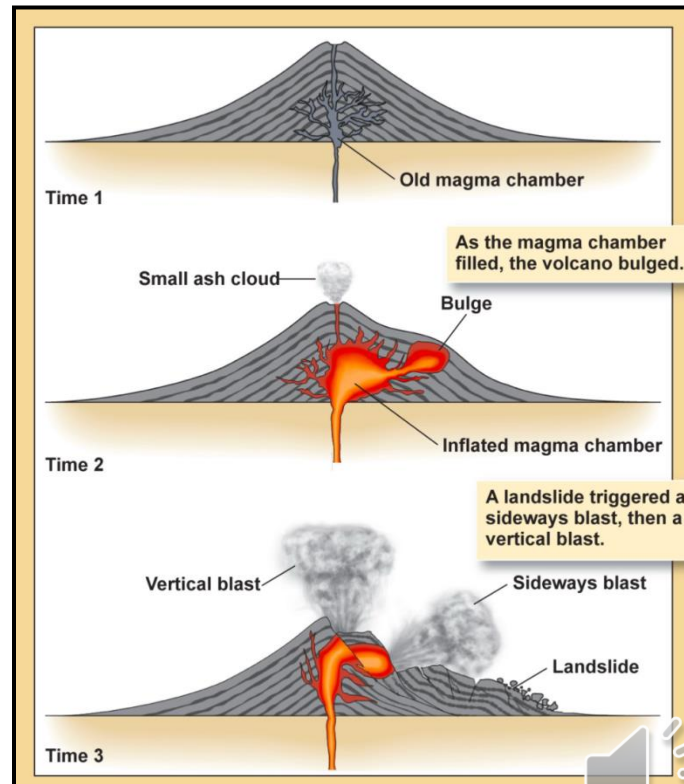
Eruptions to Remember

- There are many impressive examples of volcanic eruptions recorded in the recent geologic past, historical records, and recent observations.
  - Phlegraean fields (Naples)
    - Erupted 200 km³ (39ka)
  - Taupō Volcano (New Zealand)
    - Erupted 430 km³ (27ka)
  - Yellowstone National Park is part of a caldera 72 km across.
    - Erupted 2600 km³ (2 Ma).
  - Mt. Toba
    - Erupted 2800 km³ (75ka)
      almost extincted human life



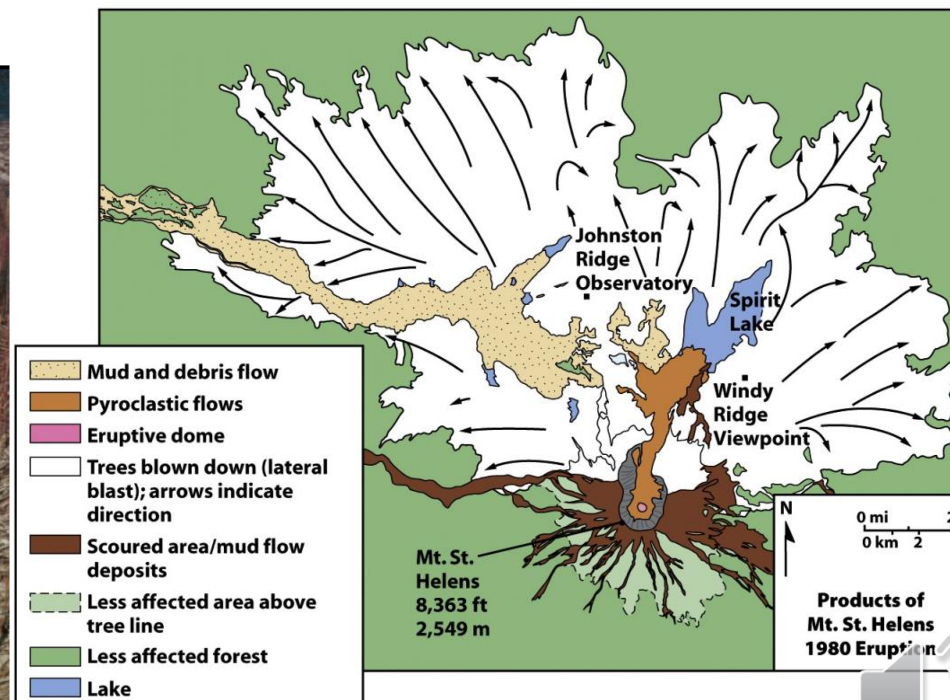
Recent eruptions to Remember

- **Mount St. Helens—erupted May 18, 1980, at 8:32 a.m.**
  - **An earthquake-triggered landslide released pressure.**
  - **An initial vertical blast led to a much stronger lateral blast.**
    - **The lateral blast tore off the entire north side of the mountain.**
    - **About 440 m was blasted away.**



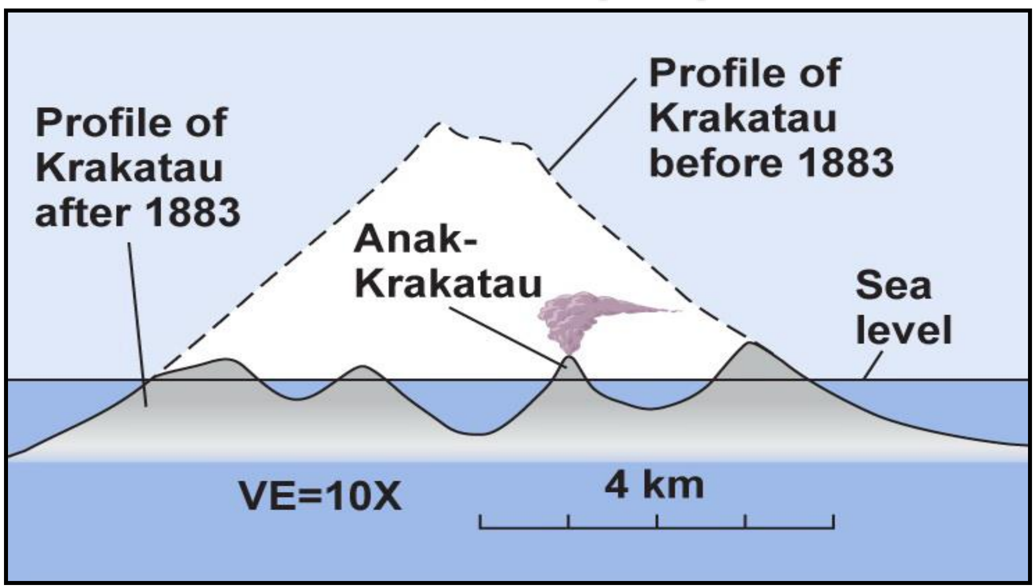
Recent eruptions to Remember

- **Mount St. Helens—erupted May 18, 1980, 8:32 a.m.**
  - **The blast devastated 600 km^2 and killed 61 people.**
  - **Lahars plugged the Toutle River; closed the Columbia.**
  - **Ash fell in North Dakota; highways and rail lines stopped.**
  - **Destroyed timber was valued at several hundred million dollars.**



19th Century eruptions to Remember

- Krakatau—a volcano between Java and Sumatra
  - The 9-km island, 800 m above the sea, erupted May 20, 1883.
  - Continued erupting through June and July.
  - On August 27, 1883, at 10 a.m., the island was obliterated.
    - The magma chamber was breached by the ocean.
    - The island was blown to smithereens.
    - Tsunami waves killed 36,000 people.

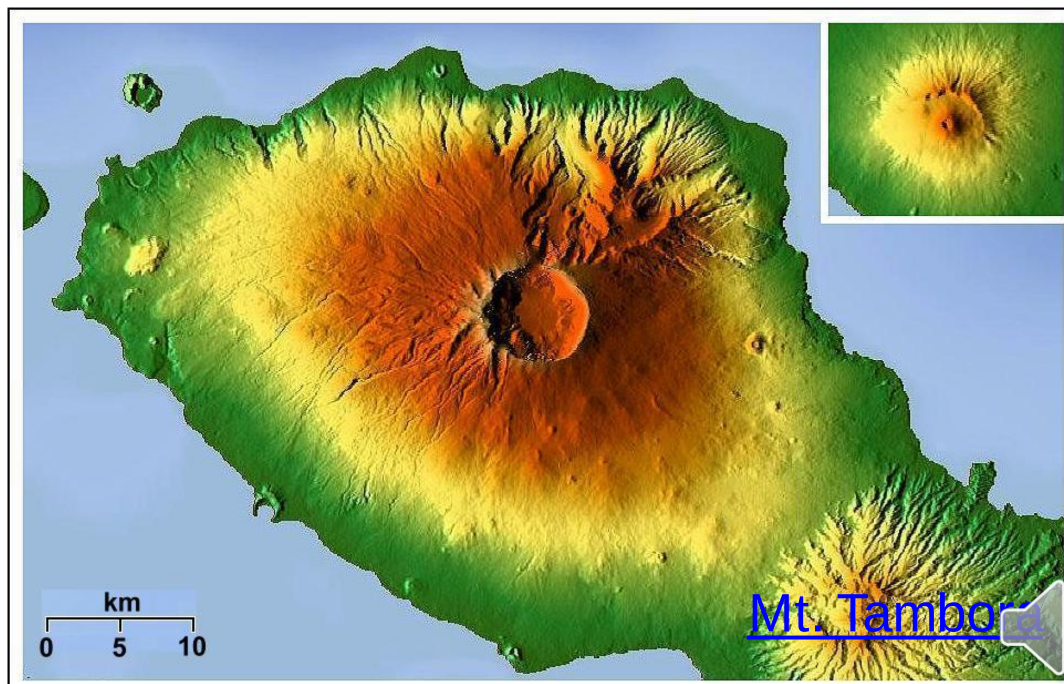


Box 5.1d

19th Century eruptions to Remember

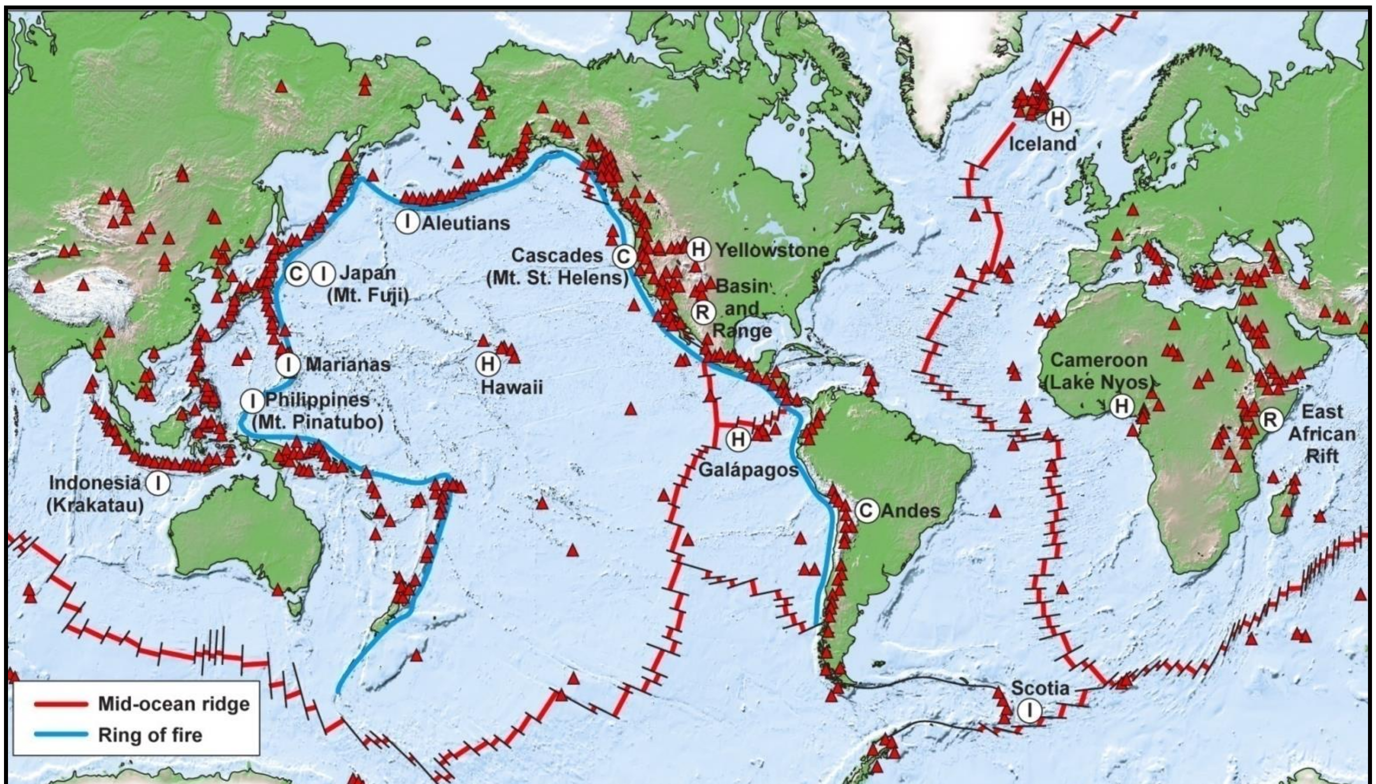
- **Tambora — a volcano on Sumbawa, Indonesia**
  - **Explosive eruption on April 10, 1815.**
  - **71000 direct fatalities**
  - **Following: the “Year without a summer”**
  - **The year-long climate depression caused global crop failures resulting in the worst famine of the 19th century.**
  - **Size comparison:**

  Tambora:Vesuvius



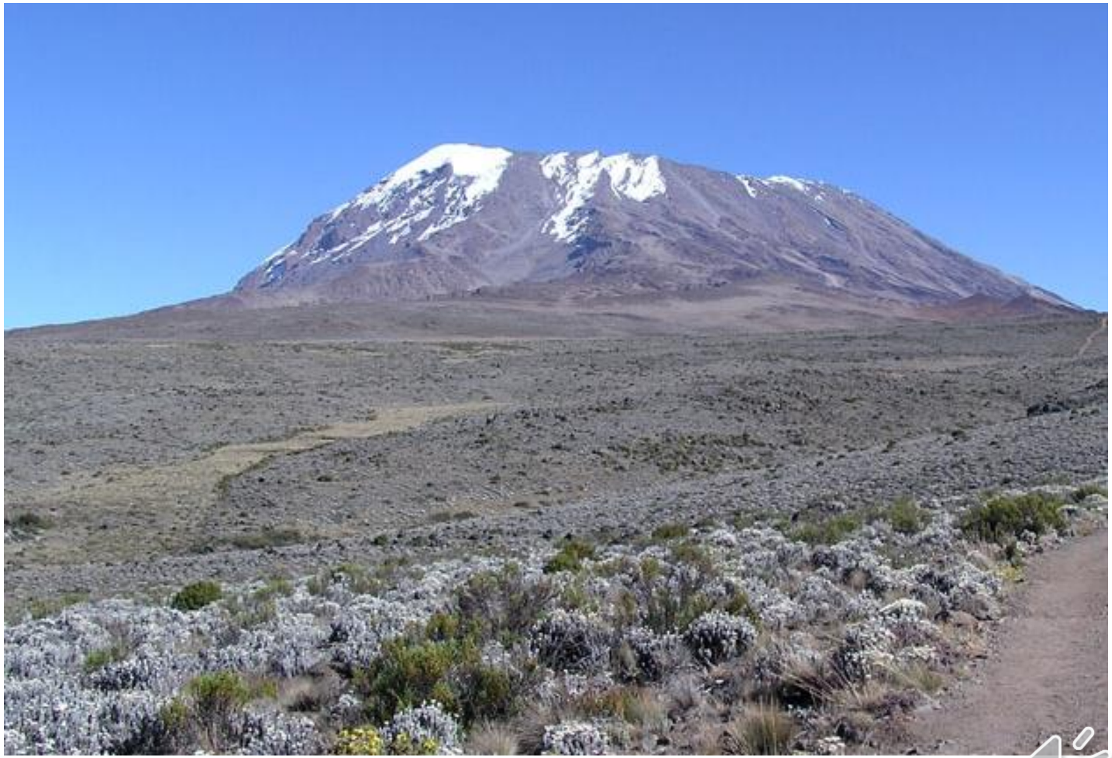
Geologic Settings of Volcanism

- Convergent boundaries – most subaerial volcanoes
  - Arc volcanoes develop on the overriding plate
  - Continental arcs and oceanic island arcs are common.
- The Ring of Fire dominates Pacific margins.



Geologic Settings of Volcanism

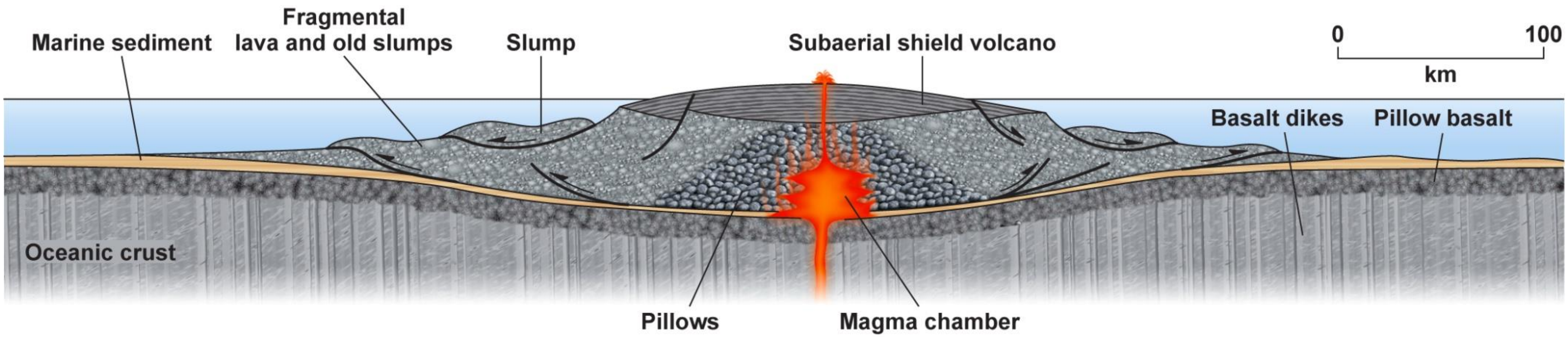
- Continental rifts—many volcano types reflecting:
  - Partial melting of the mantle (mafic magmas)
  - Partial melting of the crust (felsic magmas)
  - Effusive and explosive eruptions
- Examples:
  - Mount Kilimanjaro, Tanzania
    - Stratovolcano



http://en.wikipedia.org/wiki/File:Kibo_summit_of_Mt_Kilimanjaro_001.JPG

Geologic Settings of Volcanism

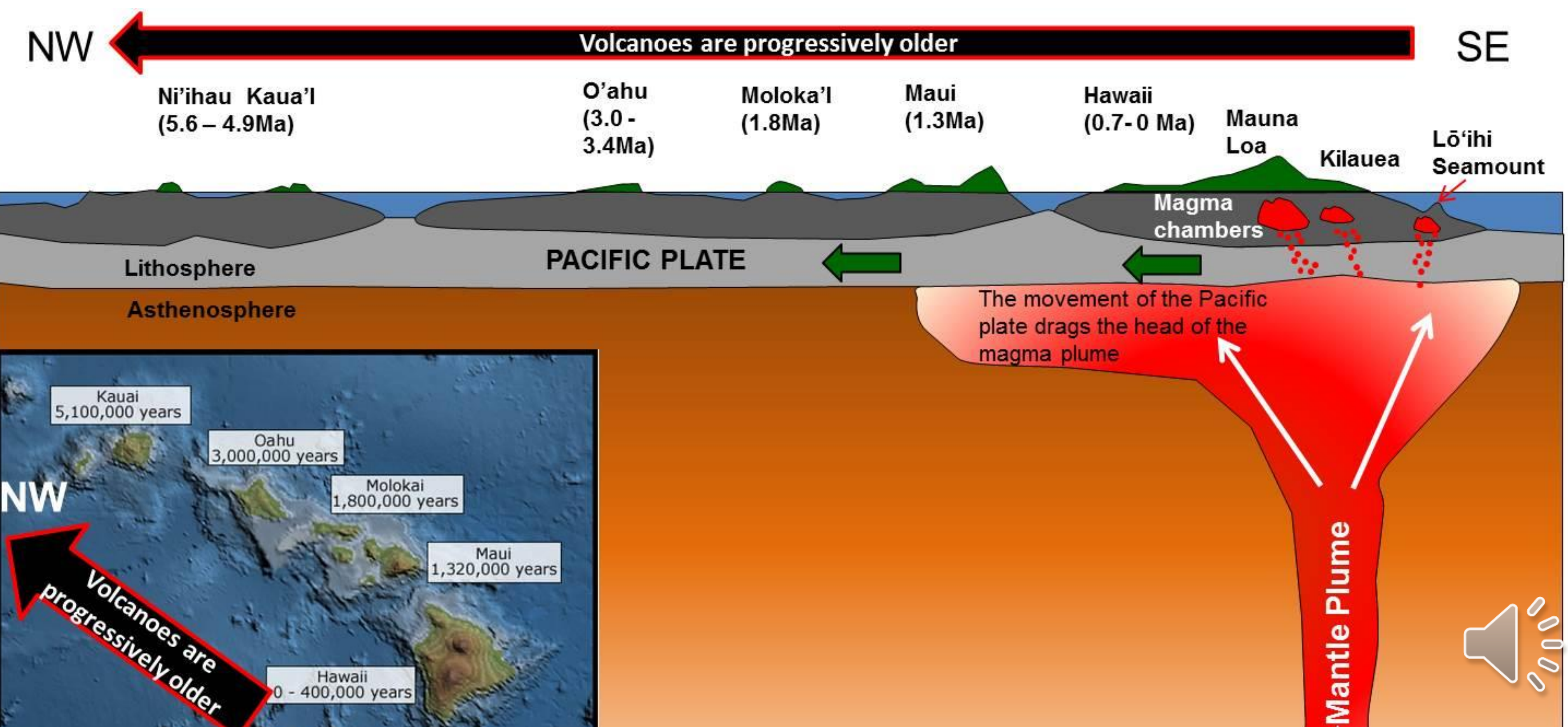
- Oceanic hot spot—a plume under an oceanic plate such that forming Hawai’i
  - Thousands of thin basalt flows build up through time.
  - Building above sea level, basalt can flow long distances.
  - Lava builds upward and outward and the island grows.
  - Submarine slumps remove large masses of the volcano.



Geologic Settings of Volcanism

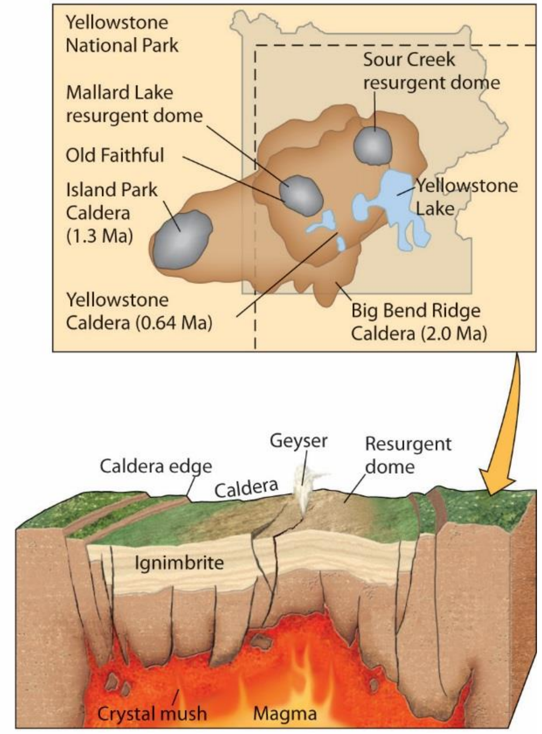
- **Oceanic hot spot—a plume under an oceanic plate penetrates the plate and successively forms Hawai'ian Islands**

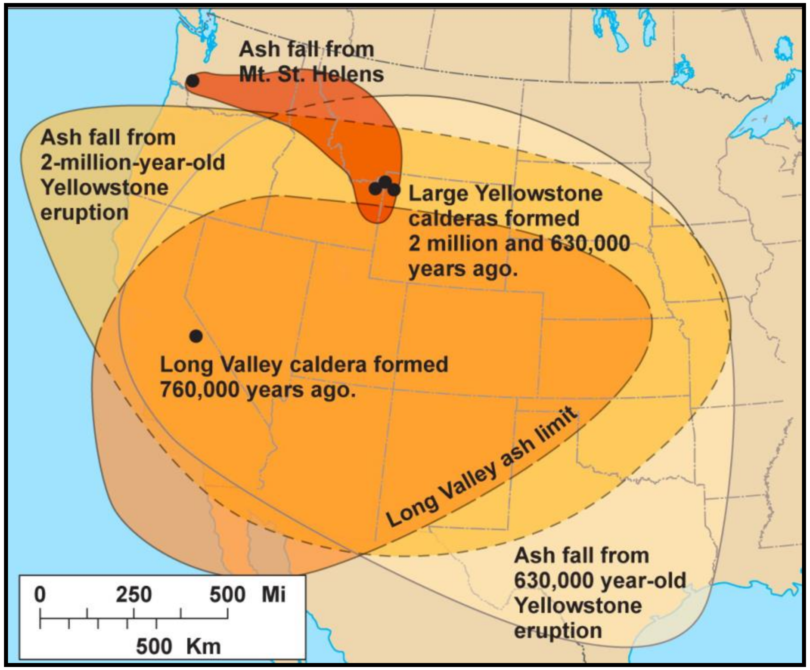
500 km



Continental Hot Spot Volcanoes

- Continental hot spot—thin crust, shallow magma.
  - Yellowstone—eruption ~630 Ka created a 72-km caldera.
    - A thousand times more powerful than Mt. St. Helens
    - Blanketed 2500 sq. km. in pyroclastic debris
    - Magma beneath the caldera continues to fuel geysers





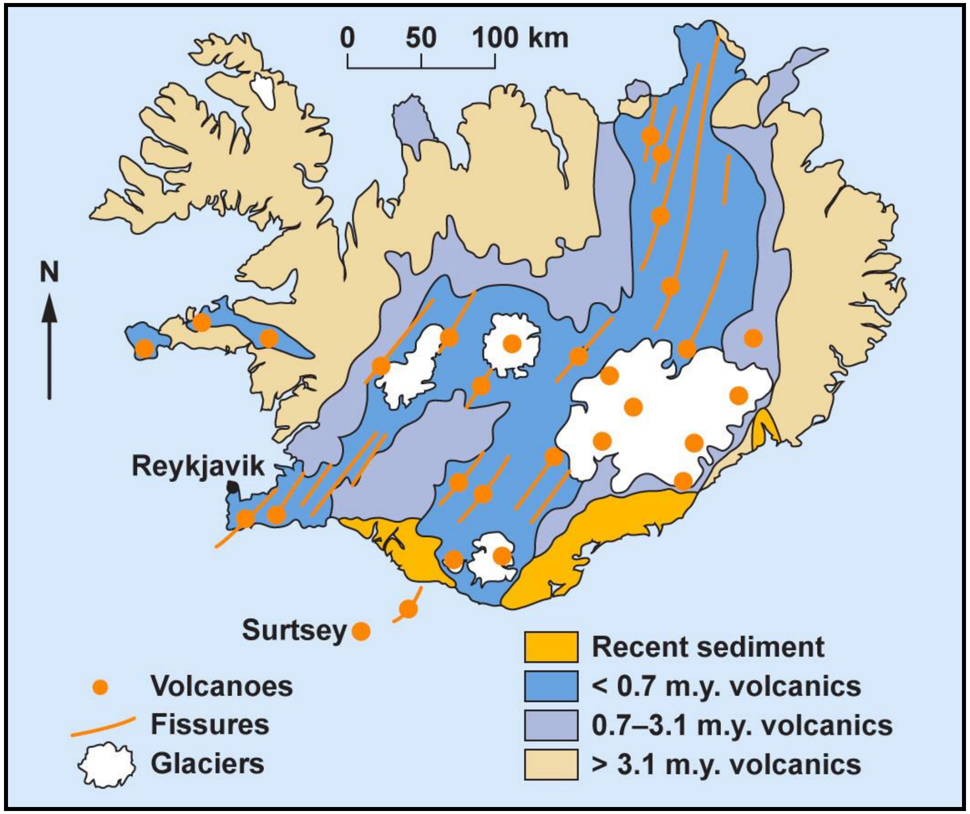
Geologic Settings of Volcanism

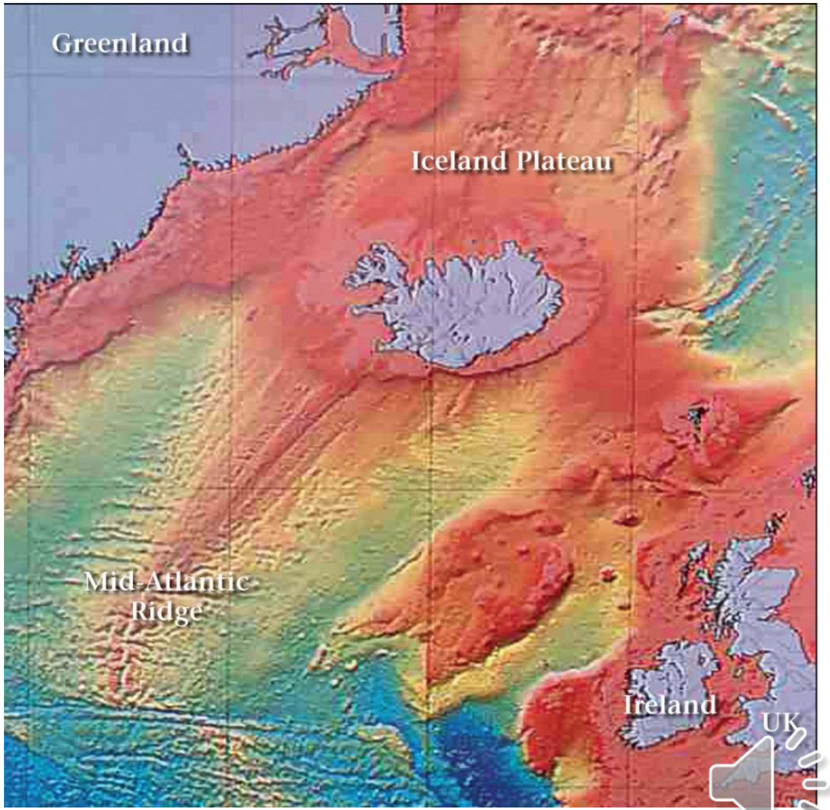
- Flood basalts—voluminous lava eruption above a plume
  - When a mantle plume intersects base of rifting lithosphere:
  - Lava spreads over large areas; great thicknesses stack up.
  - Creates a large igneous province (LIP) (i.e., Columbia River Plateau)

Fig. .15

Geologic Settings of Volcanism

- Iceland is a hot spot that straddles the Mid-Atlantic Ridge.
  - Lava has built the hot spot/ridge above sea level.
  - The island is being torn apart by a divergent boundary.
  - Volcanoes trace the mid-ocean ridge rift valley.





Volcanic Hazards

- Volcanic eruptions cause great harm to humans.
  - Eruptions have profoundly influenced human history.
  - In the past 2,000 years: an estimated 250,000 deaths.
- Many populated areas have active volcanoes.
  - More humans live in volcano hazard areas than ever before.
- Understanding volcanic behavior is the best defense.

Eruptive Hazards

- Lava flows—lava threats are mostly from basalt.
  - Lava may completely destroy immovable objects.
    - In 2002, Goma, Congo, was flooded by basaltic lava.
  - It is rare for lava flows to kill people.
    - Usually, there is warning and lava rarely moves fast.
    - Sometimes, however, people watching lava flows are killed.

Eruptive Hazards

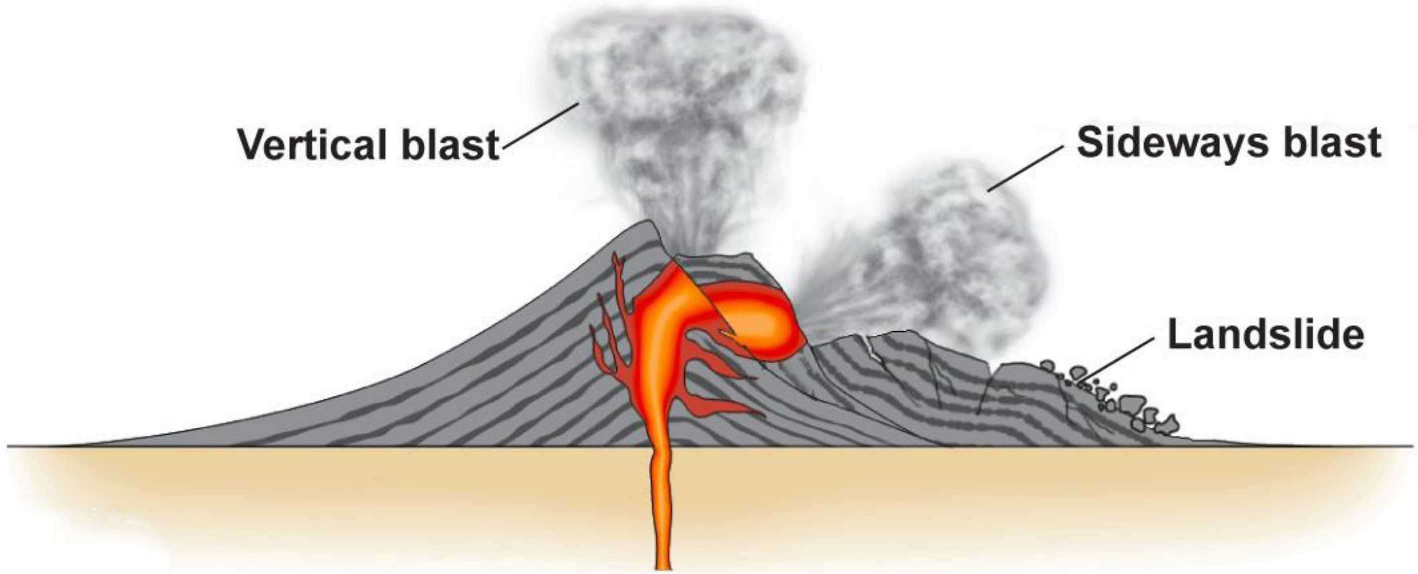
- Threat of falling ash and lapilli
  - Can completely bury landscapes, killing plants and crops.
  - Tephra is heavy; it causes roof collapses.
  - Tephra is gritty; it abrades car and airplane engines.
  - Floodwaters easily move tephra as deadly lahars.

Volcanic Hazards

- Blast—rarely, explosions are ejected sideways.
  - Mount St. Helens—lateral blast tore off north side.
    - Destroyed over 600 km^2 of forest and killed 61 people.
  - Blast hazard is uncommon; most eruptions are vertical.

Volcanic Hazards

- Landslides—eruption-related slope failures.
  - Eruptions can trigger landslides.
    - Large masses of material are deposited rapidly near vent.
    - Earthquakes initiate failure of unstable slopes.
  - Mount St. Helens:
    - The eruption immediately followed a 3-km^3 slope failure.
    - Slide material moved more than 20 km from the peak.



Box. 5.1b

Eruptive Hazards

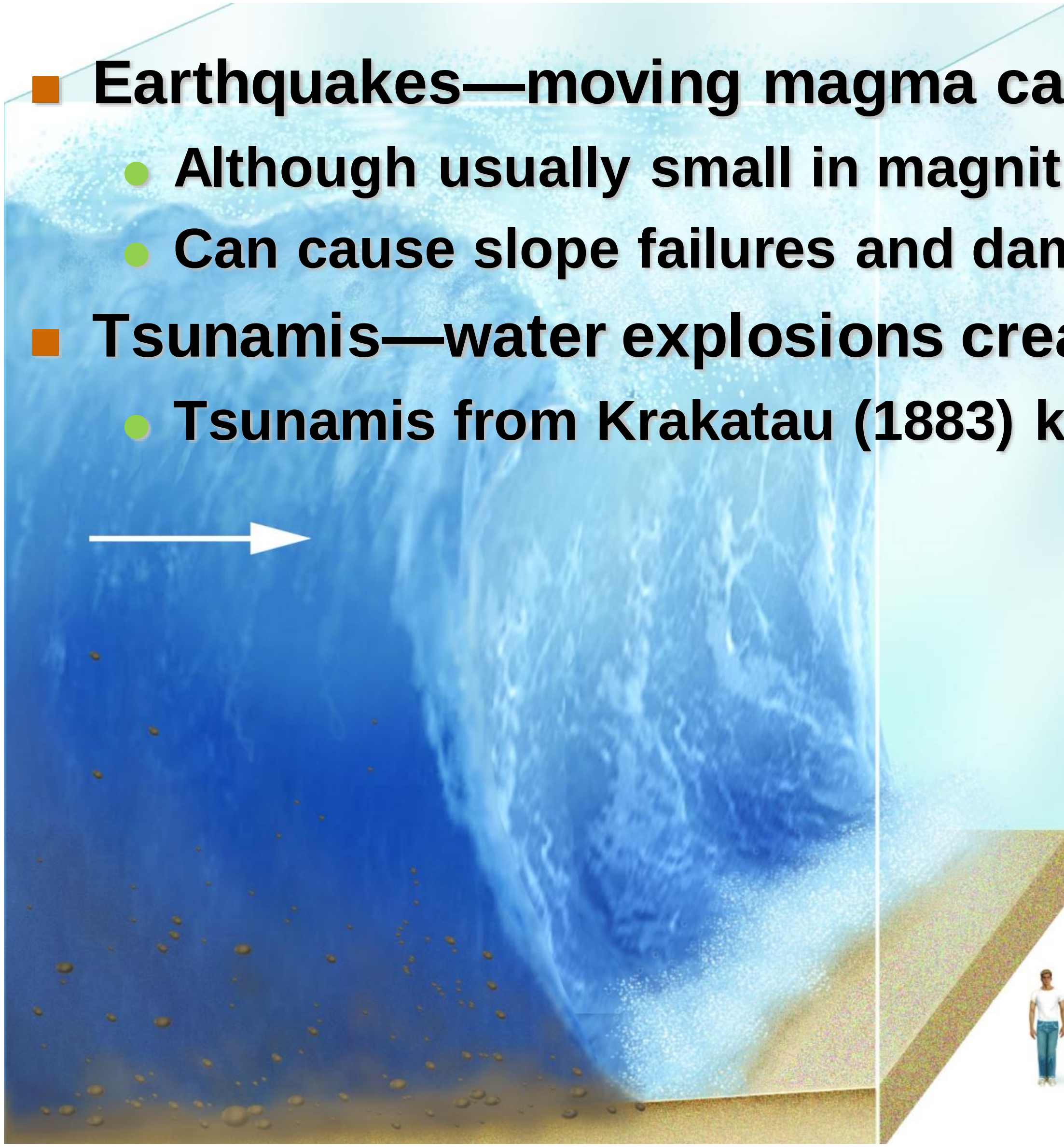
- Threat of pyroclastic flows—superheated ash clouds
  - Move extremely fast (100 to 300 km/hour) on a carpet of air.
  - They are so hot (500 to 1000 ° C) they kill every living thing.
  - Flatten buildings and forests, leaving destruction behind.

Volcanic Hazards

- **Lahars—mudflows result when water moves ash.**
  - **Like concrete, this material is more dense than water.**
  - **It can carry away everything (people, houses, bridges).**
  - **Nevado del Ruiz, Colombia, buried the town of Armero in 5 meters of ash and mud, killing over 25,000 people.**

Volcanic Hazards

- Earthquakes—moving magma causes earthquakes.
  - Although usually small in magnitude, they are frequent.
  - Can cause slope failures and damage to structures.
- Tsunamis—water explosions create giant waves.
  - Tsunamis from Krakatau (1883) killed 36,000 people.

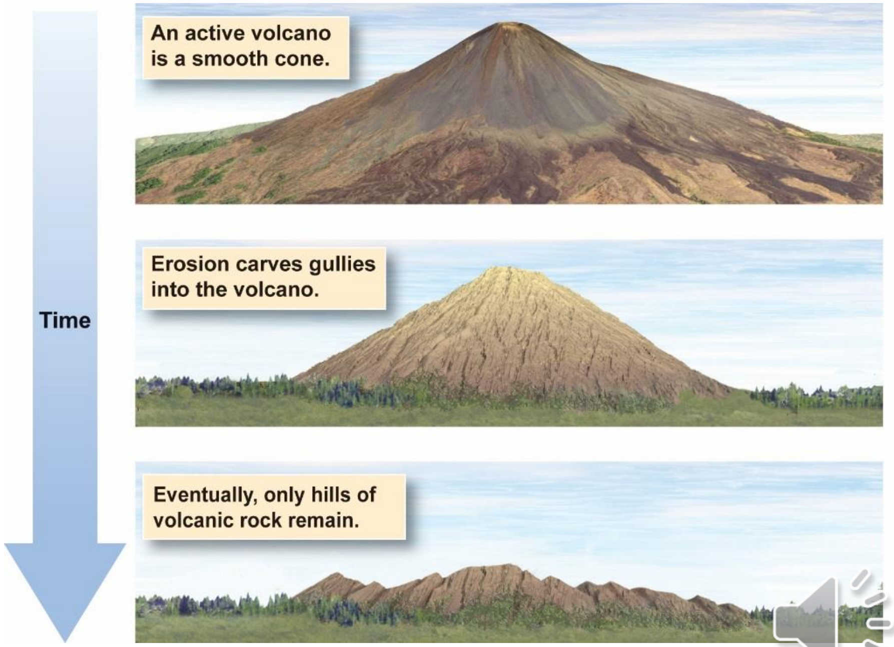


Volcanic Hazards

- Threat of gas and aerosols
  - Aerosols can cause respiratory problems in people.
  - Volcanic gases can be poisonous (H_2S, CO_2).
    - Lake Nyos, Cameroon, 1986—belched CO_2 during overturn.
      - Moved down the valleys as a heavier-than-air underflow.
      - Asphyxiated 1,742 people and head of 6,000 cattle.

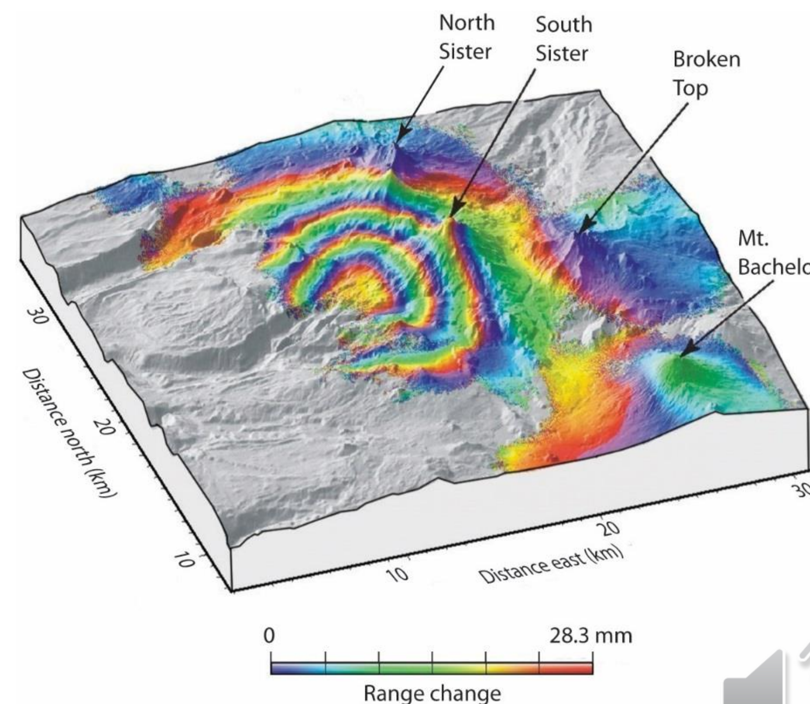
Protection from Eruptions

- Recurrence interval—average time between eruptions
  - Active—erupting, recently erupted or likely to erupt
  - Dormant—hasn't erupted in hundreds to thousands of year
  - Extinct—not capable of erupting
- Tectonics can shut off magma, then erosion takes over.



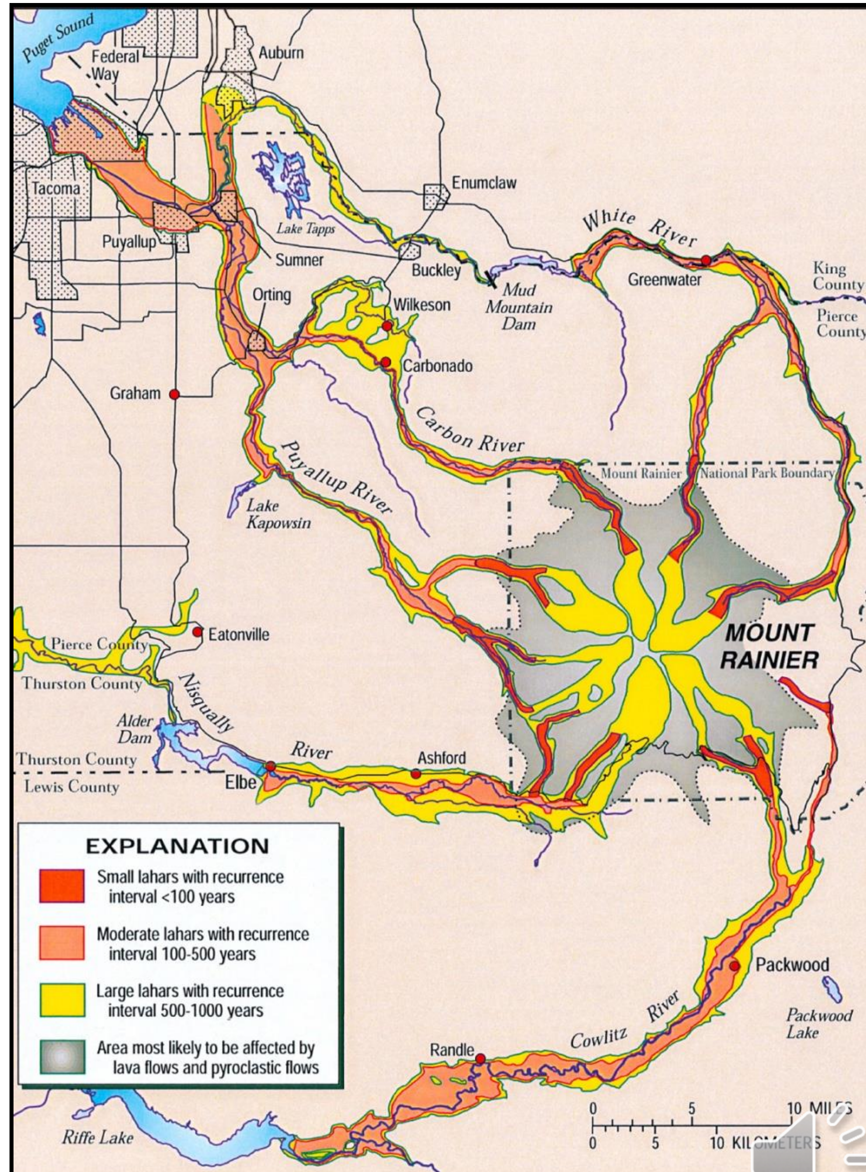
Protection from Eruptions

- Warning signs indicate that an eruption is imminent.
  - Earthquake activity—magma flow increases seismicity.
  - Heat flow—magma causes volcanoes to “heat up.”
  - Changes in shape—magma causes expansion.
  - Emission increases—changes in gas mix and volume.
- These signs cannot predict the exact timing or the style.



Mitigating Volcanic Hazards

- Planning
  - Danger assessment maps
    - Delineate danger areas
      - Pyroclastic flows
      - Lahars
      - Landslides
    - Used for planning, zoning



Mitigating Volcanic Hazards

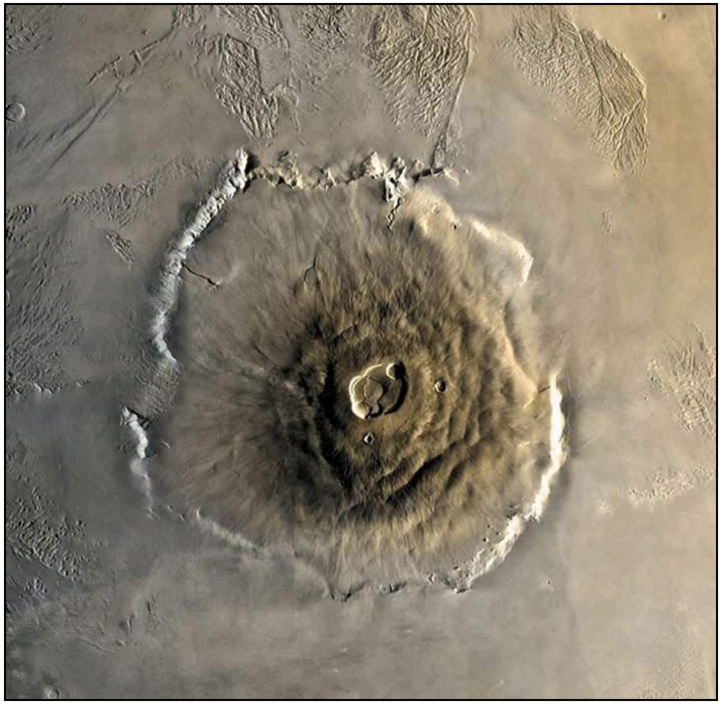
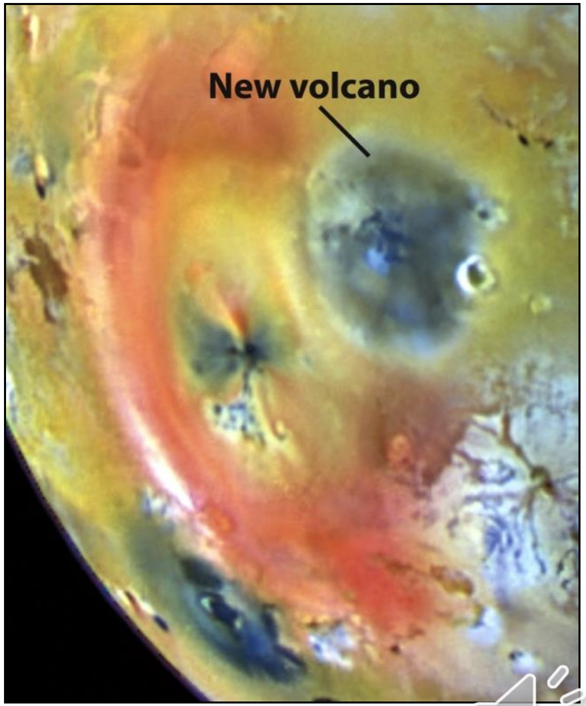
- Evacuation—moving those at high risk saves lives.
  - Mount St. Helens—timely evacuation saved hundreds.
  - Even if eruptions don’t occur, there are large expenses.
- Diverting flows—flowing lava can be diverted.
  - Explosives
  - Heavy equipment.
  - Seawater

Volcanoes and Climate

- **Volcanic eruptions can be large enough to alter climate.**
  - **Ash and aerosols (tiny liquid droplets) injected into stratosphere, rapidly circling the globe.**
  - **Particles remain in stratosphere for months to years.**
  - **This reflects solar radiation, causing atmospheric cooling.**
    - **1815 was the "year without a summer" due to Mt. Tambora.**

Volcanoes on Other Planets?

- Volcanic activity evident on the Moon and planets.
  - Lunar maria (dark “seas”) are regions of flood basalts.
  - Olympus Mons—extinct Martian shield volcano, largest in the Solar System
  - The Jovian moon Io has active volcanoes.

Volcanic magmas formed the first surface rocks

- **When? Our geological record goes back to ~4.3+ Ga.**

- **What happened to these original rocks?**
  - Mostly lost to our observation
  - Erosion produced sedimentary rocks
  - Subsequent rocks have been multiply cycled through tectonic processes
  - What is left? A series of layered sediments has overlain the original record.