Volcanic Landforms and Processes
**Background**

**Volcano:** a rupture in the crust of a planetary-mass object (Earth) that allows lava, volcanic ash (tephra), and gasses to escape from a magma chamber below the surface.

**Classification Based on Activity:**

**Active:** have been observed in eruption during historic time

**Dormant:** have no historic record but show evidence of geologically recent activity

**Extinct:** geologically dead

_Cotopaxi, Ecuador_

_El Capitan, Arizona_
Igneous Landforms: result from both constructive and erosional processes

- Eruptions at the surface produce volcanic landforms primarily controlled by the type of magma (basaltic, andesitic, rhyolitic)
- Subsurface injection and differential erosion produce secondary landforms (dikes, sills, batholiths etc.)
- Viscosity influences the style of eruption, flow characteristics of lava and resulting landforms (temperature, composition, gas content)
Viscosity: resistance to flow

- Tectonic setting
- Source of lava
- Composition

Andesite: sediments, water, oceanic crust and continental crust

Intermediate composition

Basalt: asthenosphere and oceanic crust

Lower percentages of silicon and oxygen
Andesitic-rhyolitic volcanoes

Subduction zone
Deep-ocean trench

Folded sediments
Basaltic oceanic crust with sediments on top

Rising of partially melted asthenosphere

Transform fault
Little or no volcanism

Explosive eruptions
Numerous volcanoes
Andesitic-rhyolitic magma

Subduction zone

Spreading center
Voluminous basaltic magma
Volcanic mountain ranges
Peaceful eruptions

Fault
Composition, Viscosity and Eruptive Style

Composition:
- Basalt
- Andesite
- Rhyolite

Viscosity:
- Fluid
- Pasty

Eruptive Style:
- Quiet
- Violent

Temperature:
- Hot
- Cool
Eruption Products

**Lava:** molten rock extruded from the magma chamber through fissures or central vents of the volcanic cone.

**Tephra:** all fragmental material produced by a volcanic eruption regardless of composition, size or emplacement mechanism. Often characterized based on size. Ash, cinders, bombs, blocks

**Gases:** release of pressure and the rate of degassing of magma influences severity of eruption (tied to **viscosity**).
Eruption Products

Lava Flows

- Topographic features vary considerably with the composition of magma.
- Basalt: fluid, forms thin laterally extensive flows
- Siliceous, viscous magmas (rhyolite/dacite) form thick pasty flows with steep margins.
- Lobate forms, lava levees, crescent-shaped pressure ridges, irregular surfaces and lack of surface streams

rhyolitic dome, Long Valley area
Eruption Products

Pahoehoe lava
- Basaltic lava
- Low viscosity
- Cools moderately slowly
- Ropelike appearance

Aa lava (pronounced aa-aa)
- Basaltic lava
- Higher viscosity
- Solidifies while flowing
- Angular pieces
Eruption Products

Pillow Basalts
- Lava extruded underwater
- Cools and contracts
- Spherical masses
- Ocean floor
Eruption Products

Lava Levee

- Surface cooling, movement of crustal slabs to the flanks due to flow structure, eventual overtopping
Eruption Products

Lava Tubes

1. Lava flows from volcanic eruptions tend to become “channeled” into a few main streams.
2. The overflows of lava from these streams often cool and solidify, creating stacked layers of lava around the flow.
3. After many hours or days, the lava melts downward into the ground, giving the tube a taller, more narrow cross-section.
4. A solid crust can form overhead and enclose the tube. The tube then insulates the flowing lava within, allowing it to flow great distances.
5. After the eruption subsides and the flows harden, these lava tubes become a cave, sometimes with remnants of the ebbing lava flow preserved.

[Diagram of lava tube formation and types: surface tube, semi-trench, true trench, interior tube, rift tube]
Eruption Products

Pressure Ridges (tumulus/tumuli)

- outer edge of the lava flow hardens and restricts the advancing lava underneath

Devils Hills, Oregon
Eruption Products

**Tephra**: generic classification for all eruption generated fragmented material
- **pyroclasts**: airborne fragments
- Size Classification
  - Ash: particles < 2mm in diameter, rock, glass, minerals
  - Lipilli: or **cinders**, 2mm – 64 mm in diameter, vesicular texture
  - Bombs: > 64 mm in diameter, molten projectile
  - Blocks: > 64 mm in diameter, solid projectile
Eruption Products

Volcanic Gases
- Volatiles
  - $\text{H}_2\text{S}$ – Hydrogen sulfide
  - $\text{H}_2\text{O}$ – Water vapor
  - $\text{SO}_2$ – Sulfides
  - $\text{CO}_2$ – Carbon dioxide
  - $\text{N}_2$ – Nitrogen
  - $\text{HCl}$ – Hydrochloric Acid

Contributes to eruption characteristics
- High gas content magma has the potential for violent eruptions when coupled with high viscosity
- Viscous, silica rich magmas trap gas
  - Expansion is prevented, pressure builds, eruption results in rapid degassing
Eruption Products

**Pyroclastic Flow**: high-speed avalanche of hot ash, rock fragments and gas generated during an eruption from rapid degassing of magma.
**Lahar:** mudflow (mass wasting event) generated when erupting magma comes in contact with snow/ice. Fan deposits can show a classic fining upward sequence.
Volcanic Landforms

Note: forms tied to magma composition and viscosity
### Volcanic Landforms

<table>
<thead>
<tr>
<th>rock/magma type</th>
<th>silicon content and viscosity</th>
<th>common eruption style</th>
<th>common volcano form</th>
</tr>
</thead>
<tbody>
<tr>
<td>rhyolite</td>
<td>very high</td>
<td>explosive</td>
<td>Caldera</td>
</tr>
<tr>
<td>andesite</td>
<td>high</td>
<td>explosive or effusive</td>
<td>stratovolcano</td>
</tr>
<tr>
<td>basalt</td>
<td>moderate</td>
<td>effusive</td>
<td>shield volcano, cinder cone</td>
</tr>
</tbody>
</table>

Special case: **Phreatic** eruptions occur when magma hits water. And the water flashes to steam explosively.
Shield Volcanoes

- associated with mafic (Fe, Mg rich), low silica content lava (basalt)
- Lava thin, not viscous
- Holds little gas
- Usually quiet eruptions
- Lava travels long distances, spreads out in thin layers
- Shield volcanoes are rounded domes, with gentle slopes

Shield Volcano: low, often large, dome-like accumulation of basalt lava flows emerging from long, radial fissures on flanks
Volcanic Landforms

Shield Volcanoes

• The Hawaiian Islands are classic examples hotspot shield volcanoes.
• Mauna Loa is over 9 miles high
• Active volcanoes at the southern end
• **Sea Mounts** submarine volcanoes
• **Guyots** flat topped wave eroded sea mounts at the northern end
Volcanic Landforms

Shield Volcanoes

Basaltic lava also erupts:
- Along midocean ridges
  - Seafloor spreading
  - Many volcanic islands along mid-Atlantic Ridge
- Beneath continental plates
  - Hotspot generates large volume of basaltic lava
  - Forms flood basalts

Basaltic lava on Heimaey Island, Iceland, on mid-Atlantic Ridge

Continental flood basalts, Columbia Plateau, U.S.
Volcanic Landforms

- Basaltic lava flows from fissures
- Layered structure
- Covers continental crust

Columbia River Basalts
14-16 million years old
Volcanic Landforms

- Basaltic lava flows from fissures
- Layered structure, lava/sediments
- Columnar Jointing
- Basalt Plateaus or Flood Basalts
  - Large scale landforms
Volcanic Landforms

Basaltic **Cinder** (Scoria Cones) and **Spatter** Cones

- **Projectiles**
  - Ballistic
  - Wind-borne
  - Tuff (ash) cones, rings, maars
  - Multiple along a fissure
- **Tuff (ash) cones, rings, maars**
  - **Phreatomagmatic** eruptions

![Image of a volcanic eruption and landforms]
Volcanic Landforms

Tuff Cones, Tuff Rings, Maars

Maar Eruption

Ash cloud
Base surge
Steam-driven explosion
Ground-water
Rising hot magma

Vertical scale is exaggerated
1 - 2 km

Late stage lava fountains & scoria cones
Maar crater
Ash & tuff ring
Water depleted
Rising hot magma

Pyroclastic deposits
Lake
Water table
Host rock or sediments
Collapsed walls of crater
Vent fill
Volcanic neck

Kenneth A. Bevis © 2013
Volcanic Landforms

Stratovolcanoes

The nature of an eruption depends on the type of magma involved. Felsic (Feldspar, Silica Rich) lavas associated with stratovolcanoes

- Rhyolite, Andesite
- Thick, resistant to flow
- Builds steep slopes around volcanic vents
- Tall, steep cone, with crater

Stratovolcano: volcano constructed of multiple layers of lava and tephra
Stratovolcanoes

- Most active stratovolcanoes on circum-Pacific mountain belt
- Associated with subduction zones
- Felsic lavas produce explosive eruptions, degassing restricted due to high viscosity
- Central part of volcano may explode, or draining of magma chamber and collapse of roof block may create caldera: central depression
Volcanic Landforms

Mount Somma, Italy, summit caldera contains the upper cone of Mount Vesuvius

Somma: volcanic caldera partially filled by a new central cone
Volcanic Landforms

A **complex volcano**, also called a **compound volcano**, is mixed landform consisting of related volcanic centers and their associated lava flows and pyroclastic rock.

They may form due to changes in eruptive habit or in the location of the principal vent area on a particular volcano.

![Compound Volcano and Strato-Volcano Diagram](image)
Volcanic Landforms

Lava Domes

The plug is nearly the height of the Washington Monument and the width of four football fields.
Lassen Peak, CA is a plug dome volcanic landform
Built from felsic lava
One of the largest on Earth
Carved by glaciers during the Ice Age
Igneous Intrusive Landforms

- **Denudation** exposes the features
- **Discordant Plutons**: cut across the bedding or foliation of the host rock (dykes, necks)
- **Concordant Plutons**: injections of magma parallel to the bedding or foliation of host rocks (sills, laccoliths)
Igneous Intrusive Landforms

- **Discordant Plutons**: separated based on size
- **Volcanic Necks**: solidification of magma in the main conduit, exposed through differential erosion
- **Dikes**: tabular plutons, cut across bedding, usually associated with solidification in fissures
Igneous Intrusive Landforms

- **Discordant Plutons:**
- **Stocks:** irregularly shaped, larger than other intrusions < 100 km$^2$
- **Batholiths:** irregularly shaped, larger than other intrusions > 100 km$^2$
Igneous Intrusive Landforms

- **Concordant Plutons**:
- **Laccolith**: mushroom-shaped plutons
  - injected parallel to the structure of the host rock
  - domes up the overlying rocks
  - < 10:1 diameter vs thickness (laccolith grades to sill)
Igneous Intrusive Landforms

- **Concordant Plutons:**
- **Sills:** tabular plutons intruded parallel to the structure of enclosing rocks
  - Injected along bedding planes of sedimentary rocks
  - Mesas, buttes, cuestas, hogbacks
  - Order cm – 10s m thick, km in length
Examples of Geomorphic Features and Sequences
Examples of Geomorphic Features and Sequences

(A) volcano-sedimentary processes

constructive
- lava flow, rafting, littoral cones

destructive
- post-emplacement lava tube
- phreatic eruptions

- dyke lava lake, intrusion fountaining
- slope failure, cone collapse
- intermittent or initial ph eruption
- vent migration, crater breaching

proximal ballistics/fallout from eruption column, grain-flow, rootless lava flow
ash-fallout
rarely PDC, multiple venting

(B) typical deposits

lava rock and scoriaceous lapilli (+fallout tephra)
ash to block, spatter
welded or agglutinated spatter
debris infill
ash to block, spatter

(C) geomorphologic features

lava flow field
- debris apron
- flank
- crater
- flank
- debris apron
- tephra blanket

- crater rim rounding
- truncated flanks due to lava outflow
- crater infill (lava and/or debris)
- dyke intrusion
- erosion resistant inner ‘core’
- fall-dominated beds
- spatter-fed lava flow
- preserved fallout deposits

- outpour point
- aa lava flow
- rafted mound
- initial phreatomagmaticism
- minor groundwater
- feeder dykes
Additional Background Material

Igneous Rocks

Light Colored  Dark Colored

Earth's Surface

Rhyolite  Basalt

Depth

Diorite  Diabase

Granite  Gabbro

Fine  Crystal Grain Size  Coarse