Volcanoes and Intrusive Landforms

- **Volcano** – a vent in Earth’s surface through which magma, volcanic gasses and volcanic ash erupt; the landform that is produced by the ejected material.

- **Intrusive Landform** - an emplacement of crystallized magma beneath Earth’s surface which is later exposed at the surface by erosion of overlying rock and uplift of the intrusive body.

Why study volcanoes?

- Eruption of lava is Earth’s primary method of adding new rock to the oceanic and continental crusts.
- Volcanoes release gasses to the atmosphere necessary to sustain life on Earth.
- Volcanoes release gasses to the atmosphere which condense to form water of the hydrosphere.
- Submarine volcanoes release chemical nutrients to the oceans necessary to sustain marine life.
- Weathering of volcanic rocks provides Earth’s most nutrient-rich agricultural soils.
- Volcanoes are threats to the safety of millions of people.

Importance of Intrusive Landforms

- Provide an observable ‘window’ to igneous processes (such as partial melting and magma crystallization) which occur beneath Earth’s surface.
- Provide important clues to igneous processes which occur beneath volcanoes.
- Provide important clues to the composition of Earth’s mantle and lower crust, where most magmas form by partial melting.
- Are a source of many important ore minerals and building stones.

Why does one volcano erupt in a different ‘style’ than another?

The most important factor in determining the shape and size of a volcano, as well as its eruptive ‘style’ is:

- **Magma Viscosity** – ‘resistance’ of a magma to flow; how ‘easily’ a magma will flow.
  - High viscosity magma – resistant to flow, flows very slowly.
  - Low viscosity magma – flows freely, flows very quickly.

Why do volcanoes have different shapes?

- Volcano – a vent in Earth’s surface through which magma, volcanic gasses and volcanic ash erupt; the landform that is produced by the ejected material.
- Intrusive Landform - an emplacement of crystallized magma beneath Earth’s surface which is later exposed at the surface by erosion of overlying rock and uplift of the intrusive body.
Water – low viscosity

Honey – high viscosity

Shear stress

Fluid

Stationary bottom

Shear strain rate – the rate at which a fluid deforms as a shear stress is applied

viscosity = shear stress/shear strain rate

Most magmas behave as Bingham fluids because solid crystals and gas bubbles provide resistance to flow when stress is applied.

What factors affect magma viscosity?

- **Magma Composition**
  - High Si content = higher viscosity
  - Long Si-O-Si-O-Si-O- chains impede free flow

- **Magma Temperature** – high temperature = lower viscosity
  - At high temperatures, Si and O atoms vibrate very rapidly, making it less likely that enough chemical bonds will form to create long Si-O chains

- **Dissolved Gas** – higher concentration of dissolved gasses (H₂O, CO₂) = lower viscosity
  - Dissolved gas molecules to break up Si-O chains
    - HO-Si-O-Si-OH   HO-Si-O-Si-OH

In a magma, the melt must flow around and through the crystals, making it more difficult for the magma to move.

The higher the Si content, the more and larger crystals are likely to be present.
The effect of temperature on magma viscosity is the same as that on maple syrup: 
**heat decreases viscosity.**

Dissolved gasses, such as $H_2O$ and $CO_2$ tend to ‘break-up’ Si-O chains, resulting in lower viscosity.

What are the effects of magma viscosity on ‘style’ of a volcanic eruption?

- High viscosity magmas (intermediate/felsic) typically result in explosive eruptions
  - High viscosity prevents most dissolved gasses from **exsolving** during magma ascent.
  - Most gas exsolution occurs just prior to eruption, forming a ‘froth’ of magma just below the magma chamber surface
  - When upward pressure of frothed magma exceeds downward pressure of overlying rock, magma is suddenly released in an explosive eruption, producing volcanic gasses, volcanic ash and frothed magma
  - Example: Mount St. Helens

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**Explosive Eruption**

Mt. St. Helens, May 18 1980
• Low viscosity magmas (mafic) usually result in quiescent eruptions
  – Low viscosity allows gases to exsolve and escape to surrounding rock throughout magma ascent
  – As magma reaches surface, most gases have been lost, so frothing of magma is minimal; produces an eruption of mainly lava flows
  – Example: Mauna Loa, Kilauea (Hawaii)

Table 9.1, p. 253

<table>
<thead>
<tr>
<th>Composition</th>
<th>silica Content</th>
<th>viscosity</th>
<th>gas Content</th>
<th>tendency to form</th>
<th>volcanic landform</th>
</tr>
</thead>
<tbody>
<tr>
<td>basalt</td>
<td>Low (&lt;50%)</td>
<td>Low</td>
<td>Low (1%)</td>
<td>Low</td>
<td>block lava flow</td>
</tr>
<tr>
<td>andesite</td>
<td>intermediate</td>
<td>intermediate</td>
<td>intermediate</td>
<td>intermediate</td>
<td>composite cone</td>
</tr>
<tr>
<td>rhyolite</td>
<td>Medium (70%)</td>
<td>constant</td>
<td>medium (5%)</td>
<td>constant</td>
<td>pyroclastic flow</td>
</tr>
</tbody>
</table>

• **Lava Flow** – a ‘stream’ of molten rock

• **Volcanic Gas** – gas ‘dissolved’ in magma, similar to gas dissolved in carbonated beverages

• **Pyroclastic Materials** – explosively ejected rock, lava, and volcanic ash
aa lava flow

What happens when you fall into a lava flow?

High Viscosity Rhyolitic Lava

Very High Viscosity Obsidian Flow

Columnar Jointing
**Columnar Jointing**

**Volcanic Gasses**

Most abundant: H$_2$O, CO$_2$, SO$_2$, N$_2$, Cl$_2$, H$_2$, Ar

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**Importance of Volcanic Gas**

- Provide energy to trigger explosive eruptions
  - Under ‘dormant’ conditions, volcanic gasses escape the magma chamber to the atmosphere through cracks in Earth’s surface (fumaroles)
  - If gasses become trapped and cannot escape, internal gas pressure may increase to exceed pressure of overlying rock. Sudden release of gasses triggers an explosive eruption

**Fumarole with sulfur - Kilauea Volcano**

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**Pyroclastic Material**

- **Pyroclastic Material** – any material explosively ejected from a volcano
  - *Volcanic ash* – microscopic volcanic glass
  - *Pumice* – vesicular, glassy rock formed by ‘freezing’ of frothy lava
  - *Lapilli* – visible to naked eye, less than 2 mm in diameter
  - *Cinder* – 2 to 64 mm in diameter
  - *Block* > 64 mm diameter, erupted as hardened lava
  - *Bomb* > 64 mm diameter, erupted as molten lava

**Volcanic Ash**
Types of Eruptions

- Hawaiian – lava fountaining and low viscosity lava flows
- Strombolian – mostly blocks and bombs
- Vulcanian – mostly gas, ash, cinder, pumice
- Plinian – large quantities of volcanic ash and pyroclastic flows
**Types of Volcanoes**

- Volcano morphology (shape) is dependent upon:
  - Style of eruption (quiescent or explosive)
  - Eruptive products (lava flows or pyroclastic materials)
**Basaltic Plateau (Flood Basalt Plateau)**

- Eruption of very low viscosity basaltic lavas from fissures to form large plateaus.

**Columbia River Basalt Plateau**

- Age = 17 my
- Area = 200,000 km²
- Ave Thickness > 1 km

**Fissure**

**Flood Basalts**

**Shield Volcano**

- Eruption of low viscosity basaltic lavas
- High with broad, gently sloping flanks
- Most form on ocean floor
- Examples: Hawaii (Muana Loa, Kilauea), Iceland, Galapagos Islands

**Shield Volcano**
Mauna Loa Volcano, Hawaii

Mauna Loa is Earth’s largest volcano.

Cinder Cone

- Eruption of mostly loose, cinder-sized pyroclastic material from gas-rich basaltic magma
- Sometimes erupt lava flows
- Small: typically < 300 m elevation
- Example: Paricutin, Mexico

Cinder Cone

Paricutin volcano, Mexico (1948)

The church at Paricutin, Mexico

Cinder cone in central Utah being mined for ‘lava rock’.
Composite Volcano (Stratovolcano)

- Alternating layers of lava flow and pyroclastic material. Lava flows protect underlying pyroclastic deposits from erosion.
- Characterized by explosive eruptions
  - Typically erupt greater volume of pyroclastic material than lava flow
- High with steep flanks
- Example: Mt. St. Helens, WA; Mt. Rainier, WA; Mt. Hood, OR; Popocatepetl, Mexico; Pinatubo, Philippines

Features Common to Stratovolcanoes

- **Crater** – steep walled depression at or near summit from which lava and pyroclastic materials are ejected

- **Dome (Spine)** – Accumulation of viscous lava directly over a volcano’s vent. Acts to ‘plug’ the underlying vent.
Mt. St. Helens crater produced by the May, 1980, eruptions

Mt. St. Helens crater wall, north side

Mt. St. Helens dome (1980-1986), viewed from the south crater rim

Stratovolcanoes – Common Eruptive Materials and Processes

- **Ash Fall** – Thick accumulation of volcanic ash particles. Commonly stick to one another to form tuff.
- **Ash Flow (Pyroclastic Flow)** – Hot accumulation of rock, gas and ash (Temp. = approx. 1000 °C) moving at velocities up to 125 mph. Hot ash particles stick together, forming a welded tuff (ignimbrite)

Stratovolcanoes – Common Eruptive Materials and Processes

- **Lahar** – volcanic mudflow caused by mixing of water and volcanic ash. May occur during small or large eruptions, or during a dormant period.

Ash Eruption Column, Galunggung Volcano, Indonesia, 1982
Ash fall at Clark Air Base, Philippines, after 1991 eruption of Mt. Pinatubo

Ash Fall Deposits

Pyroclastic Flow at Mayon Volcano, Philippines (September, 1984)

Pyroclastic flows at Mayon Volcano, Philippines (September, 1984)

Pyroclastic flow at Unzen Volcano, Japan, (1993) moving into a residential district (previously evacuated).

Pyroclastic Flow Deposits, NM

Bandelier National Monument, New Mexico
Cave Dwelling in the Bandeleir Tuff

Lahar formed by excessive rainfall at Santiaguito Volcano, Guatemala, 1989

Lahar filled N. Fork Toutle River Valley east of Mt. St. Helens, WA – 1980 eruption

Twisted girders of a highway bridge, North Fork Toutle River, Mt. St. Helens, WA

The ‘Buried A-Frame’ along the N. Fork Toutle River Valley

Mud and boulders left by a series of recent lahars along the White River, Mt. Hood, OR during excessive rainfall and glacial outbursts
Lahars generated by a small eruption at Nevado del Ruiz Volcano, Colombia, S.A. (1985) killed over 25,000 in the nearby town of Armero.

Nevado del Ruiz Volcano, Colombia, SA

Location of part of the town of Armero, now buried beneath lahar deposits along Rio Lagunillas.

Hazard-Zone Map, Nevado del Ruiz, Colombia

Pulitzer Prize winning photo – Carol Guzy, Miami Herald
Other Volcanic Landforms

- **Volcanic Pipe (Volcanic Neck)** – conduit connecting magma chamber to overlying volcano
- **Caldera** – crater which forms when a volcano collapses into partially empty magma chamber
- **Lava Tube** – underground conduit through which lava flows

In what movie was Devils Tower made famous?

Volcanic Pipe – Devil’s Tower, WY

Caldera – Crater Lake NP, OR. Formed during massive eruption of Mt. Mazama volcano, approximately 6600 ybp
Satellite imagery (GPS) detected uplift of the Yellowstone caldera between 1996 - 2000. Each color ring represents uplift of a little more than one inch.

Mt St Helens
1980 - 2007
Mt. St. Helens and Spirit Lake, pre-1980

Mt. St. Helens Lodge, 1950

Mt. St. Helens Lodge, 1950

Mount St. Helens Lodge, 1950

Harry Truman, 1896 - 1980

Owner of Spirit Lake Lodge and 16 cats
Killed in 1980 eruption

May, 1980 Eruption of Mt. St. Helens

May, 1980 Eruption of Mt. St. Helens

March, 1980 - steam explosions

Bulge developing on volcano’s north slope
Major eruption, May 18 @ 8:32 AM

Effects of Lateral Blast on Forest
Effects of Lateral Blast

Lateral Blast Zone - October, 1980

Spirit Lake Following the 1980 Eruptions

Ridge West of Spirit Lake

Hummocks formed by debris avalanche
Growth of volcanic dome

Erosion of ash and mud
Dr. David Johnston (1949 – 5/18/1980)

2004-Present Mt. St. Helens Activity

September, 2004

Uplift of glacier on north side of dome
October 1, 2004 – Steam and Ash Eruption

September 22 Seismogram

October 1 Eruption Seismogram

October 3, 2004 – Uplift of Crater Floor

October 4, 2004 – Steam from Vent

October 6, 2004 Eruption (Vulcanian)
October 6, 2004 - Landslide and Small Lahar

October 14, 2004 - Eruption of New Lava

November 5, 2004 - New Lava and Uplift

November 6, 2004

March 8, 2005 eruption

Infrared Measurement of Dome Temp.
March 8, 2005 eruption

New Dome – March 2005 (eruption rate approximately 2 cubic meters/second)

Old and New Domes – March, 2005

October, 2005

February, 2007 – current dome dimensions approximately 3400 ft long and 1725 ft wide.
Historic Eruptions

Mt. Vesuvias, Italy (79, 1631)

- 79 eruption: 2000 deaths by ash fall and ash flow
- 1631 eruption: 4000 deaths by ash fall and ash flow

2008 MTSU Geology Field Course Students

New Dome - August, 2008
Pliny the Elder (23-79 AD)

‘Fortune Favors the Brave!’
Virgil, *The Aeneid*

Mt. Etna, Sicily (1169, 1669)

1169 eruption – 15,000 deaths by ash fall and ash flow
1669 eruption – 20,000 deaths by ash fall and ash flow

Etna Eruption, 2002

Laki volcano, Iceland (1783)

10,500 deaths by ash flows, fluorine gas and resulting famine

The Laki eruption emitted 80 million tons of sulfuric acid aerosol (80 times that of MSH). The aerosol droplets blocked sunlight, cooling the lower atmosphere. In eastern North America, the ave. temp was 4.8 degrees below the 225 year ave. following the eruption. In the entire North America, ave. temps decreased by 1 degree.

Tambora volcano, Indonesia (1815)

92,000 deaths by ash flows and resulting famine
Resulted in the ‘year without a summer’ (1816).
400 million tons sulfuric acid aerosol released, resulting in summer frosts in New England.
2004 – Discovery of civilization buried by 1815 Tambora eruption

Krakatau volcano, Indonesia (1883)

40,000 deaths by tidal wave
First large eruption studied by scientists

Krakatau

Mt. Pelee, Martinique (1902)

28,000 deaths by ash flows
Mt Pelee destruction, 1902

El Chichon volcano, Mexico (1982)

3500 deaths by ash fall and pyroclastic flows

Below: Thick pyroclastic flow deposited by 1982 eruptions

Above: Stream flowing from a 1982 pyroclastic flow. Orange color is due to high concentrations of dissolved minerals, making the waters useless for human and animal consumption, as well as irrigation

Major Volcanoes of Mexico

Nyos volcano, Cameroon (1986)

1700 deaths by carbon dioxide release from Lake Nyos

Nyos volcano, Cameroon (1986)
‘Human-induced’ Lake Nyos degassing is being carried out to prevent another disaster.

Mt. Pinatubo, Philippines (1991)
435 deaths by ash flows, lahars and resulting diseases

Mt. Pinatubo pyroclastic flow

Mt. Pinatubo SO₂ atmospheric distribution. Formation of sulfuric acid aerosols blocked sunlight, lowering Northern Hemisphere temperatures by approx. 0.5°C.

Soufriere Hills volcano, Montserrat (1998)
19 killed by ash flows
10,000 residents evacuated
Path of pyroclastic flows on the southwest flank of Soufriere Hills volcano. Town at the base of the volcano is Plymouth.

Destruction in the town of Plymouth caused by pyroclastic flows and subsequent lahars.

Santorini (Thera) volcano, Aegean Sea, Greece (3600 BP)

Tidal waves wiped out Crete, resulting in end of Minoan period and beginning of bronze age period

Hotels and villas along the Santorini caldera wall.
Katmai volcano, Alaska (1912)
Largest volcanic eruption in last 100 years

In the Valley of Ten Thousand Smokes, Katmai ash deposits are up to 200m thick.

Nevado del Ruiz, Colombia S.A.
1985 – approx. 25,000 killed by lahars

Galeras, Colombia S.A.
1993 – 6 scientists killed + 3 tourists
Eruption ~75,000 years ago was largest in last 2 million years (approx. 2,800 times greater than the 1980 eruption of MSH)

Mt. Fuji, Japan. 1707 – heavy ash and tephra fall resulted in an undocumented number of deaths due to starvation.

Bezymianni volcano, Kamchatka, Russia

1955-56 and subsequent eruptions very similar to that at Mt. St. Helens.
Ol Doiny Lengai, Tanzania

Erupts lowest viscosity (natrocarbonatite) lava of any volcano on Earth

Largest Eruptions since approx 5000 BC
Intrusive Landforms

• **Importance**: provide important information about internal earth igneous processes, such as melting and crystallization, which cannot be directly observed.

• Classification of intrusive landforms is based upon:
  – Size
  – Shape
  – Relationship to surrounding 'country' rock

Discordant Intrusive Bodies

• Margins cut across layering in surrounding country rock
  – **Pluton** - general term describing a discordant body
  – **Batholith** > 100 km² exposed at surface.
  – **Stock** < 100 km² exposed at surface
  – **Dike** – sheet-like intrusive body

Stone Mtn. GA Stock

Sierra Nevada Batholith
Granitic Dike Cutting Metamorphic Rock

Loma de Cabrera Batholith, Dominican Republic

Cordillera Central terrain, Dominican Republic

Melting if source-rock in the LDC Batholith

Cordillera Central transportation network

Panning for gold in the Cordillera Central
Future gold miners

Concordant Intrusive Bodies

- Margins are parallel to layering in surrounding country rock
  - Sill - sheet-like body formed when magma is injected along sedimentary bedding surfaces
  - Laccolith – lens-shaped body that arches overlying strata.

Sill (Antarctica)

Laccolith – Bear Butte, SD