EENS 2040	Natural Disasters
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Volcanic Hazards & Prediction of Volcanic Eruptions	

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Volcanic Hazards

This lecture will begin with a video entitled "Understanding Volcanic Hazards". This video was prepared by the International Association of Volcanology and Chemistry of the Earth's Interior in several languages, and was designed show people living in the vicinity of volcanoes the possible effects of an eruption. Although the terminology may vary slightly from what we have learned in this course, the effects are the same and the footage of volcanic eruptions in progress is spectacular. The video is dedicated to the 23,000 people who died as a result of mudflows (lahars) from the 1985 eruption of Nevado del Ruiz volcano in Colombia, and is intended to help prevent similar disasters in the future. The video covers:

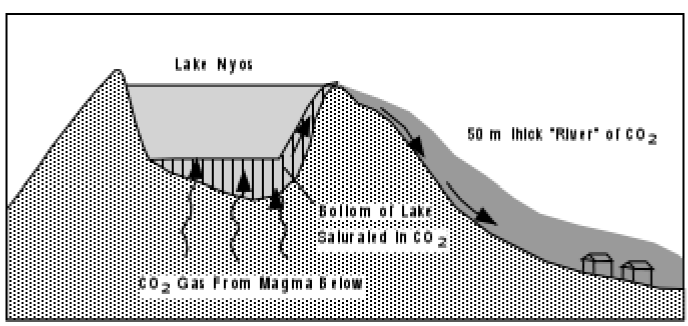
- Ash Falls (tephra falls)
- Hot Ash Flows (pyroclastic flows)
- Mudflows (lahars)
- Volcanic Landslides (debris flows and debris avalanches)
- Lava Flows
- Volcanic Gases

Primary Effects of Volcanism

- Lava Flows
  - Lava flows are common in Hawaiian and Strombolian type of eruptions, the least explosive.
  - Although lava flows have been known to travel as fast as 64 km/hr, most are slower and give people time to move out of the way.
  - Thus, in general, lava flows are most damaging to property, as they can destroy anything in their path.
  - Control of lava flows has been attempted with limited success by bombing flow fronts to attempt to divert the flow, and by spraying with water to cool the flow. The latter is credited with saving the fishing harbor during a 1973 eruption of Heimaey in Iceland.

- Violent Eruptions and Pyroclastic Activity
    - Pyroclastic activity is one of the most dangerous aspects of volcanism.
    - Hot pyroclastic flows cause death by suffocation and burning. They can travel so rapidly that few humans can escape.
    - Lateral blasts knock down anything in their path, can drive flying debris through trees.
    - Ash falls can cause the collapse of roofs and can affect areas far from the eruption. Althoughash falls blanket an area like snow, they are far more destructive because tephra deposits have a density more than twice that of snow and tephra deposits do not melt like snow.
    - Ash falls destroy vegetation, including crops, and can kill livestock that eat the ash covered vegetation.
    - Ash falls can cause loss of agricultural activity for years after an eruption, a secondary or tertiary effect.

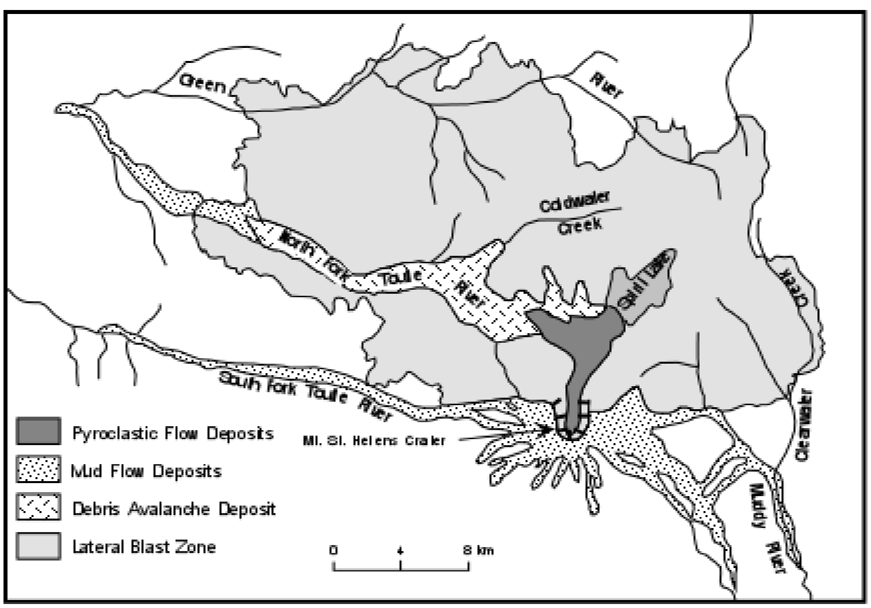
- Poisonous Gas Emissions
    - Volcanoes emit gases that are often poisonous to living organisms. Among these poisonous gases are: Hydrogen Chloride (HCl), Hydrogen Sulfide (H_2S), Hydrogen Fluoride (HF), and Carbon Dioxide (CO_2).
    - The Chlorine, Sulfur. and Fluorine gases can kill organisms by direct ingestion, or by absorption onto plants followed by ingestion by organisms.
    - In 1984, CO_2 gas escaping from the bottom of Lake Monoun, a crater lake in the African country of Cameroon, killed 37 people.
    - In 1986 an even larger CO_2 gas emission from Lake Nyos in Cameroon killed more than 1700 people and 3000 cattle.



After Abbott, 1996

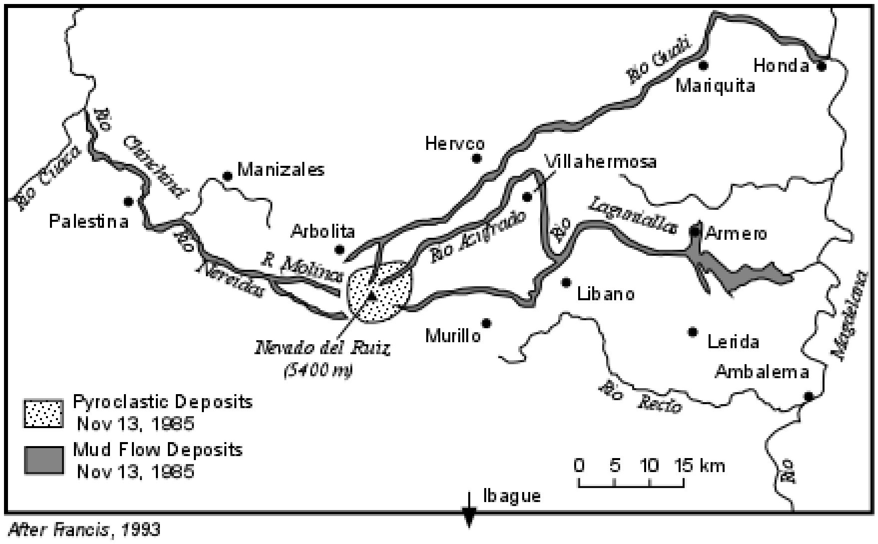
Secondary and Tertiary Effects of Volcanism

- Mudflows (Lahars)
  - Volcanoes can emit voluminous quantities of loose, unconsolidated tephra which become deposited on the landscape. Such loose deposits are subject to rapid removal if they are exposed to a source of water.
  - The source of water can be derived by melting of snow or ice during the eruption, emptying of crater lakes during an eruption, or rainfall that takes place any time with no eruption.
  - Thus, mudflows can both accompany an eruption and occur many years after an eruption.
  - Mudflows are a mixture of water and sediment, they move rapidly down slope along existing stream valleys, although they may easily top banks and flood out into surrounding areas.
  - They have properties that vary between thick water and wet concrete, and can remove anything in their paths like bridges, highways, houses, etc.
  - During the Mt. St. Helens eruption of May 18, 1980, mudflows were generated as a result of snow melt on the volcano itself, and deposition of tephra in streams surrounding the mountain.



After Tilling, 1984

  - On November 13, 1985 a mudflow generated by a small eruption on Nevado del Ruiz volcano in Columbia flowed down slope and devastated the town of Armero, 50 km east of the volcano and built on prior mudflow deposits. The town had several hours of warning from villages higher up slope, but these warnings were ignored, and 23,000 people died in the mudflow that engulfed the town.



After Francis, 1993

- Debris Avalanches and Debris Flows
  - Volcanic mountains tend to become oversteepened as a result of the addition of new material over time as well due to inflation of the mountain as magma intrudes.
  - Oversteepened slopes may become gravitationally unstable, leading to a sudden slope failure that results in landslides, debris slides or debris avalanches. We will cover these types of hazards in more detail later in the course and in the next lecture.
  - During the May 18, 1980 eruption of Mt. St. Helens, Washington, a debris avalanche was triggered by a magnitude 5.0 earthquake. The avalanche removed the upper 500 m of the mountain, and flowed into the Spirit Lake, raising its level about 40 m. It then moved to the west filling the upper reaches of the North Fork of the Toutle River valley (see map above).
  - Debris avalanches, landslides, and debris flows do not necessarily occur accompanied by a volcanic eruption. There are documented cases of such occurrences where no new magma has been erupted.
- Flooding
  - Drainage systems can become blocked by deposition of pyroclastic flows and lava flows. Such blockage may create a temporary dam that could eventually fill with water and fail resulting in floods downstream from the natural dam.
  - Volcanoes in cold climates can melt snow and glacial ice, rapidly releasing water into the drainage system and possibly causing floods. Jokaulhlaups occur when heating of a glacier results in rapid outburst of water from the melting glacier.

- Tsunami
  - Debris avalanche events, landslides, caldera collapse events, and pyroclastic flows entering a body of water may generate tsunami.
  - During the 1883 eruption of Krakatau volcano, in the straits of Sunda between Java and Sumatra, several tsunami were generated by pyroclastic flows entering the sea and by collapse accompanying caldera formation. The tsunami killed about 36,400 people, some as far away from the volcano as 200 km.
- Volcanic Earthquakes and Tremors
  - Earthquakes usually precede and accompany volcanic eruptions, as magma intrudes and moves within the volcano.
  - Although most volcanic earthquakes are small, some are large enough to cause damage in the area immediately surrounding the volcano, and some are large enough to trigger landslides and debris avalanches, such as in the case of Mount St. Helens.
  - Volcanic Tremor (also called harmonic tremor) is a type of continuous rhythmic shaking of the ground that is generated by magma moving underground.
- Atmospheric Effects
  - Since large quantities of ashand volcanic gases can be injected into the atmosphere, volcanism can have a short-term effect on climate.
  - Volcanic ash can cause reflection of solar radiation, and thus can cause the temperatures to be cooler for several years after a large eruption.

    The 1815 eruption of Tambora volcano in Indonesia, was the largest in recorded history. The year following the Tambora eruption (1816) was called the "year without summer". Snow fell in New England in July.
  - Volcanic gases like SO_2 also reflect solar radiation. Eruptions in 1981 at El Chichón Volcano, Mexico, and 1991 at Pinatubo, Philippines, ejected large quantities of SO_2 into the atmosphere. The effects of the El Chichón eruption were masked by a strong El Niño in the year following the eruption, but Pinatubo caused a lowering of average temperature by about 1^oC for two years following the eruption.
  - Volcanic gases like CO_2 are greenhouse gases which help keep heat in the atmosphere. During the mid-Cretaceous (about 90 to 120 million years ago) the CO_2 content of the atmosphere was about 15 times higher than present. This is thought to have been caused by voluminous eruptions of basaltic magma on the sea floor. Average temperatures were likewise about 10 to 12^oC warmer than present.

- Famine and Disease

    As noted above, tephra falls can cause extensive crop damage and kill livestock. This can lead to famine.
    Displacement of human populations, breakdown of sewerage and water systems, cut off of other normal services can lead to disease for years after an eruption, especially if the infrastructure is not in place to provide for rapid relief and recovery.

Volcanic Fatalaties

Over the last 500 years, volcanoes have directly or indirectly been responsible for over 275,000 deaths. The greatest killers have been pyroclastic flows, tsunami, lahars, and famine (see Table 7.1 in your text).

Beneficial Aspects of Volcanism

Since this course concentrates on the damaging effects of volcanism, we won't spend too much time on the topic of the beneficial aspects of volcanism. We note here, that volcanism throughout Earth history is responsible for outgasing of the Earth to help produce both the atmosphere and hydrosphere. Volcanism helps renew the soil, and soils around active volcanoes are some the richest on Earth. Hydrothermal processes associated with volcanism produce rich ore deposits, and the heat rising around magma bodies can sometimes be tapped to produce geothermal energy.

Mitgation of Volcanic Disasters

The best mitigation against casualties from volcanic eruptions is to provide warning based on eruption forecasts and knowledge of the past behavior of the volcano, and call for evacuations. Little can be done to protect property as the energy involved in volcanic eruptions is too great and few structures will survive if subjected to volcanic processes.

As volcanic ash in the atmosphere has been known to cause problems with airplanes, a system currently exists to keep aircraft out of ash clouds.
This can have severe economic consequences as evidenced by the near shutdown of European airports during the 2010 eruption of a volcano in Iceland.

Because evacuation plans rely on knowledge of when the volcano might erupt and how it will behave when it does erupt, we will next discussion predicting volcanic eruptions and volcanic behavior.

Predicting Volcanic Eruptions and Volcanic Behavior

Before discussing how we can predict volcanic eruptions, its important to get some terminology straight by defining some commonly used terms.

Active Volcano - An active volcano to volcanologists is a volcano that has shown eruptive activity within recorded history.   Thus an active volcano need not be in eruption to be considered active.

- Currently there are about 600 volcanoes on Earth considered to be active volcanoes.

- Each year 50 to 60 of volcanoes actually erupt.

***Extinct Volcano* -** An extinct volcano is a volcano that has not shown any historic activity, is usually deeply eroded, and shows no signs of recent activity. How old must a volcano be to be considered extinct depends to a large degree on past activity.

- For example, Yellowstone Caldera is about 600,000 years old and is deeply eroded. But fumorolic activity, hot springs, and geysers all point to the fact that magma still exists beneath the surface. Thus, Yellowstone Caldera is not considered extinct.

- Other volcanoes that are deeply eroded, smaller, and much younger than Yellowstone, that show no hydrothermal activity may be considered extinct.

***Dormant Volcano* -** A dormant volcano (sleeping volcano) is somewhere between active and extinct. A dormant volcano is one that has not shown eruptive activity within recorded history, but shows geologic evidence of activity within the geologic recent past.

- Because the lifetime of a volcano may be on the order of a million years, dormant volcanoes can become active volcanoes all of sudden. These are perhaps the most dangerous volcanoes because people living in the vicinity of a dormant volcano may not understand the concept of geologic time, and there is no written record of activity. These people are sometimes difficult to convince when a dormant volcano shows signs of renewed activity.

- Yellowstone Caldera would be considered a dormant volcano.

- Mount St. Helens was a considered a dormant volcano, having not erupted for 123 years, before its reawakening in 1980.

- Mount Pinatubo in the Philippines had been dormant for over 400 years before its eruption in 1991.

- Mount Vesuvius, near Naples, Italy was considered an extinct volcano prior to its devastating eruption of 79 A.D.

Long - Term Forecasting and Volcanic Hazards Studies

- Studies of the geologic history of a volcano are generally necessary to make an assessment of the types of hazards posed by the volcano and the frequency at which these types of hazards have occurred in the past. The best way to determine the future behavior of a volcano is by studying its past behavior as revealed in the deposits produced by ancient eruptions. Because volcanoes have such long lifetimes relative to human recorded history, **geologic studies are absolutely essential**.

- Once this information is available, geologists can then make forecasts concerning what areas surrounding a volcano would be subject to the various kinds of activity should they occur in a future eruption, and also make forecasts about the long - term likelihood or probability of a volcanic eruption in the area.

- During such studies, geologists examine sequences of layered deposits and lava flows. Armed with knowledge about the characteristics of deposits left by various types of eruptions, the past behavior of a volcano can be determined. Bore holes often provide data (such as you discovered in your homework exercise)

- Using radiometric age dating of the deposits the past frequency of events can be determined.

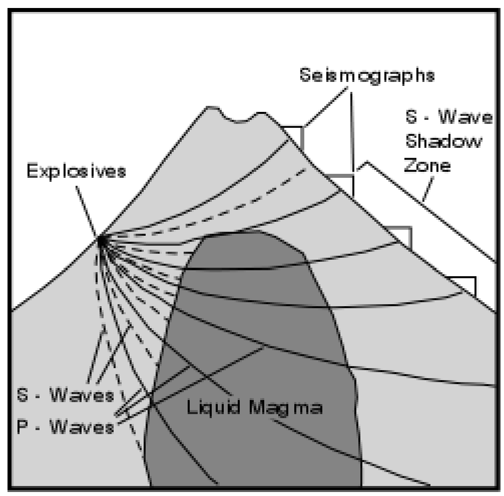
- This information is then combined with knowledge about the present surface aspects of the volcano to make volcanic hazards maps which can aid other scientists, public officials, and the public at large to plan for evacuations, rescue and recovery in the event that short-term prediction suggests another eruption.

- Such hazards maps delineate zones of danger expected from the hazards discussed above: lava flows, pyroclastic flows, tephra falls, mudflows, floods, etc.

Short - Term Prediction based on Volcanic Monitoring

Short - term prediction of volcanic eruptions involves monitoring the volcano to determine when magma is approaching the surface and monitoring for precursor events that often signal a forthcoming eruption.

- **Seismic Exploration and Monitoring -** Since seismic waves are generated by both earthquakes and explosions, and since S-waves cannot pass through liquids, arrays of seismographs can be placed around a volcano and small explosions can be set off to generate seismic waves. If a magma body exists beneath the volcano, then there will be zone were no S-waves arrive (an S-wave shadow zone) that can be detected. Monitoring the movement of the S-wave shadow zone can delineate the position and movement of the magma body.



After Murck et al., 1996

As noted above, as magma moves and deforms rocks it may be responsible for the generation of earthquakes. Thus, there is usually an increase in seismic activity prior to a volcanic eruption. Focal depths of these precursor earthquakes may change with time, and if so, the movement of magma can sometimes be tracked. In addition, volcanic tremor, as noted above, can also be indication that magma is moving below the surface.

- **Changes in Magnetic Field** - Rocks contain minerals such as magnetite that are magnetic. Such magnetic minerals generate a magnetic field. However, above a temperature called the Curie Temperature, these magnetic minerals show no magnetism. Thus, if a magma body enters a volcano, the body itself will show no magnetism, and if it heats the surrounding rocks to temperatures greater than the Curie Temperature (about 500^{o}C for magnetite) the magnetic field over the volcano will be reduced. Thus, by measuring changes in the magnetic field, the movement of magma can sometimes be tracked.

- **Changes in Electrical Resistivity -** Rocks have resistance to the flow of electrical current which is highly dependent on temperature and water content. As magma moves into a volcano this electrical resistivity will decrease. Making measurements of the electrical resistivity by placing electrodes into the ground, may allow tracking of the movement of magma.

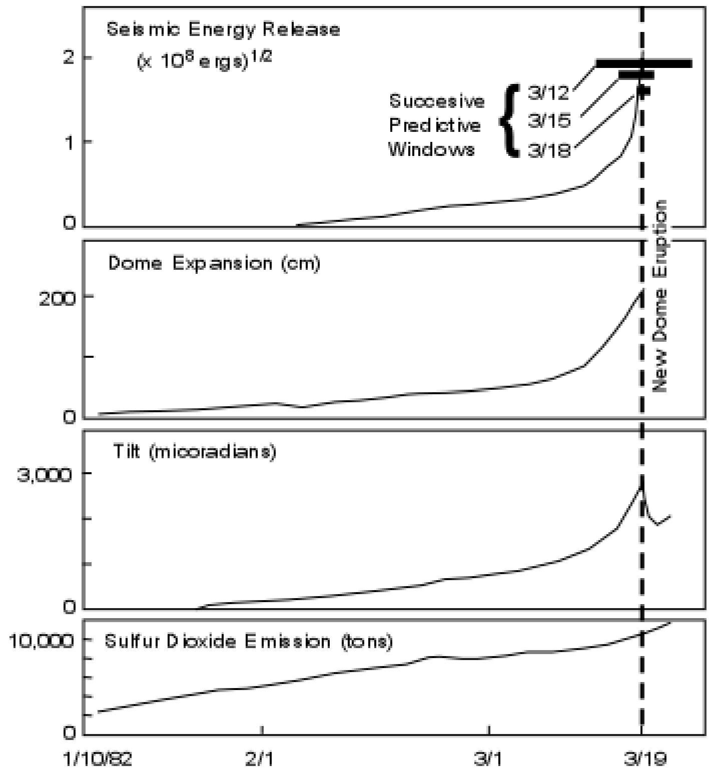
- **Ground Deformation -** As magma moves into a volcano, the structure may inflate. This will cause deformation of the ground which can be monitored. Instruments like tilt meters measure changes in the angle of the Earth's surface which are measured in microradians 0.00018^{o}. Other instruments track changes in distance between several points on the ground to monitor deformation.

- **Changes in Groundwater System** - As magma enters a volcano it may cause changes in the groundwater system, causing the water table to rise or fall and causing the temperature of the water to increase. By monitoring the depth to the water table in wells and the temperature of well water, spring water, or fumaroles, changes can be detected that may signify a change in the behavior of the volcanic system.

- **Changes in Heat Flow -** Heat is everywhere flowing out of the surface of the Earth. As magma approaches the surface or as the temperature of groundwater increases, the amount of surface heat flow will increase. Although these changes may be small they be measured using infrared remote sensing.
- **Changes in Gas Compositions -** The composition of gases emitted from volcanic vents and fumaroles often changes just prior to an eruption. In general, increases in the proportions of hydrogen chloride (HCl) and sulfur dioxide (SO_2) are seen to increase relative to the proportion of water vapor.

In general, no single event can be used to predict a volcanic eruption, and thus many events are usually monitored so that taken in total, an eruption can often be predicted. Still, each volcano behaves somewhat differently, and until patterns are recognized for an individual volcano, predictions vary in their reliability. Furthermore, sometimes a volcano can erupt with no precursor events at all.

After the catastrophic eruption of Mount St. Helens on May 18, 1980, a volcanic dome began to grow in the crater. Growth of this dome occurred sporadically, and sometimes small eruptions occurred from the dome. After several years of dedicated monitoring, scientists are now able to predict with increasing accuracy eruptions from this dome. An example is shown in the graphs to the right. In the weeks prior to an eruption on March 19, 1982, the amount of seismic energy released increased, the amount dome expansion increased, tilt increased, and SO_2 emissions increased prior to the event.



Beginning on March 12, a prediction was made that an eruption would be likely within the next 10 days. On March 15, the prediction was narrowed to likely within 4 days, and on March 18 scientists predicted that an eruption would occur within the next two days. On March 19 the eruption did occur.

Note that eruption predictions such as in this example are only possible if constant monitoring of a volcano takes place. Monitoring is an expensive endeavor, and not all active or potentially active volcanoes are monitored. Still, if people living around volcanoes are aware of some of the precursor phenomena that occur, they may be able to communicate their findings of anomalous events to scientists who can begin monitoring on a regular basis and help prevent a pending disaster.

Education and communication is essential in reducing risk from volcanic hazards!

Examples of questions on this material that could be asked on an exam

1. What are the main volcanic hazards? Which of these have the greatest potential to cause damage at large distances from the volcano?
2. What effects can volcanism have on global climate? Give some examples.
3. Although volcanoes usually have a negative effect on human populations, what postive aspects to do they provide.
4. Define an active volcano, a dormant volcano, and an extinct volcano?
5. What is the best indicator of the future behavior of a volcano and how is thus done?

6. What types of monitoring is necessary for short term prediction of volcanic eruptions? What things seem to be most important to monitor?

References
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