Volcano Monitoring: Deformation, Seismicity & Gas*

Background pages to accompany: **IRIS' Animations: Volcano Monitoring**

The animations in this set were done in collaboration with the US Geological survey & Mount St. Helens Institute. Most of the information and graphics for this document comes from **www.usgs.gov**

How do you know a volcano could erupt?

Precursory seismicity, deformation of the crater floor and the lava dome, and, to a lesser extent, gas emissions provided telltale evidence of forthcoming eruptions, which is why we selected these three monitoring methods for our first animations.

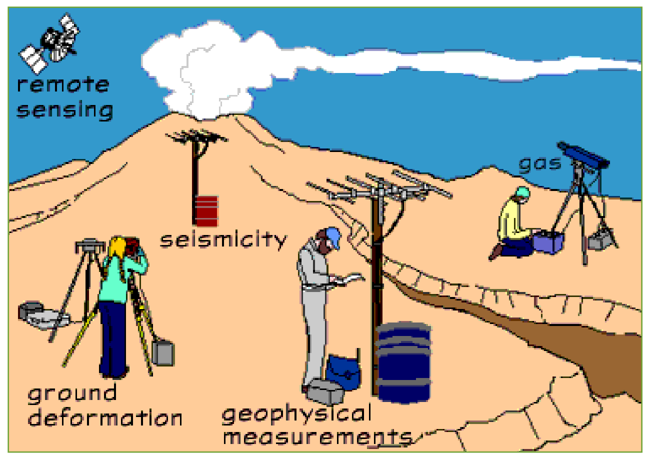
When a volcano begins to show new or unusual signs of activity, monitoring data help us answer critical questions necessary for assessing and then communicating timely information about volcanic hazards. Seismicity and ground deformation, in concert with past geologic history, helped forecast the 1980 eruption of Mount St. Helens and helped save 10's of thousands of lives prior to the 1991 eruption of Mount Pinatubo, Philippines, among others.

Prior to the 2005 activity at Mount St. Helens monitoring equipment recorded a large increase in earthquake activity. Scientists quickly examined other monitoring data including ground deformation, gas, and satellite imagery to assess if a magma or fluid was moving towards the surface. Based on the history of the volcano and the analysis of the monitoring data they were able to determine what types of materials could be moving towards the surface.

HOT Links to Related Resources:

Animations: **Seismic Signatures**
(See "Rock break earthquake")

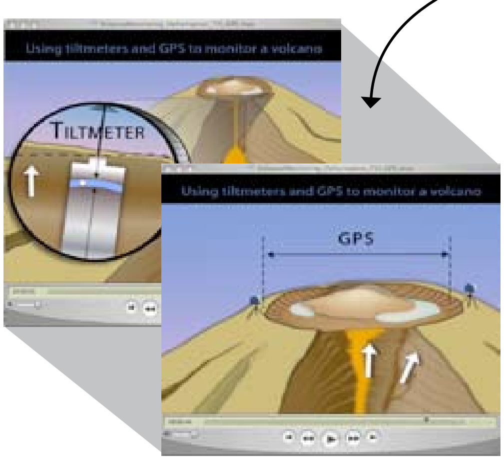
GPS—Measuring Plate Motion

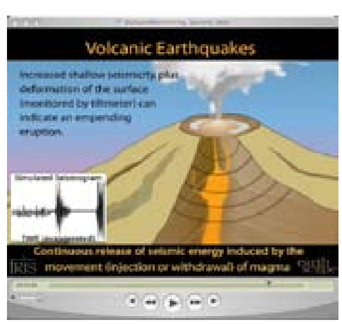


Some techniques used for monitoring volcanoes.

Volcano-monitoring techniques animated include:

- Ground deformation monitored by GPS and tiltmeters
- Earthquake monitoring & types of earthquakes
- Gas monitoring: aerial reconnaissance & land based.





*From USGS' **How We Monitor Volcanoes**: **http://volcanoes.usgs.gov/activity/methods/index.php**

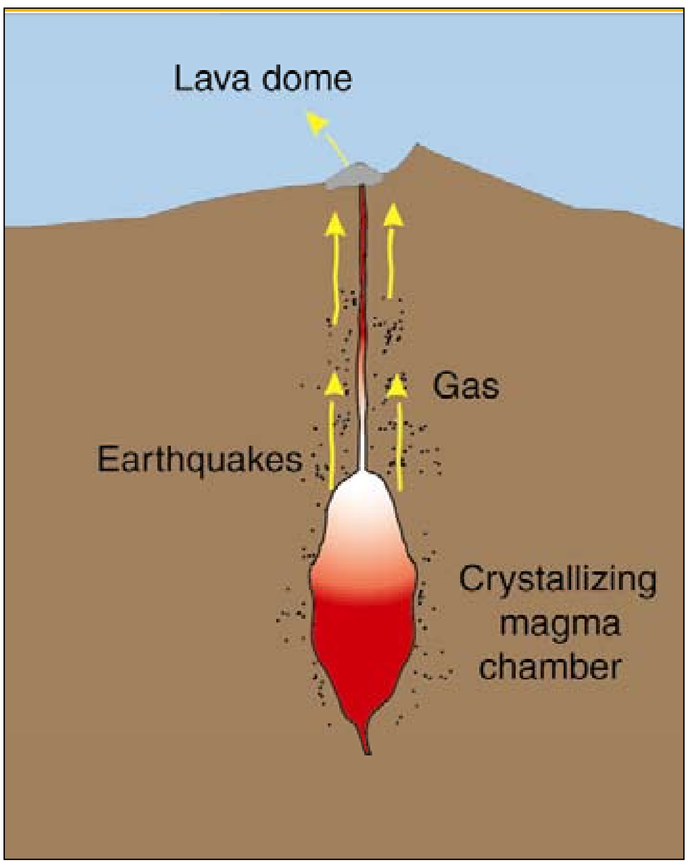
Deformation—GPS & Tiltmeters

Changes to the surface of a volcano (volcano deformation) can provide clues about what is happening deep below the surface. Most volcano deformation can only be detected and measured with precise surveying techniques. The Volcano Hazards Program has installed networks of sensitive deformation instruments around volcanoes to monitor changes over time. These instruments, along with satellite-based technologies help us to better understand the volcanoes we watch and allow us to provide eruption warnings.

GPS

The current constellation of satellites provides the GPS user with 5 to 8 satellites in view from anywhere on Earth, if one has an unobstructed view of the sky in all directions. With this much information, a GPS receiver can very quickly determine its position to within a matter of meters. On volcanoes, however, an accuracy of a few centimeters or less is extremely important for detecting the build up of stress and pressure caused by magma rising toward the ground surface. To obtain this kind of accuracy in our measurements, we need to take other factors into account, including the variation in the speed of the signal transmitted from the satellite as it travels through the atmosphere and the uncertainty in the position of the satellite.

A common way of eliminating these potential errors is to set up GPS receivers over several volcano benchmarks at the same time so that we can simultaneously collect data from the same satellites. Since most of the error associated with the delay of the signal through the atmosphere and the location of the satellites becomes the same for all sites, we can determine their positions relative to one another to less than a centimeter. For the greatest accuracy, we collect GPS data for 8 to 24 hours and then calculate the position of the benchmark utilizing more precise satellite locations and modeling the atmospheric delay.



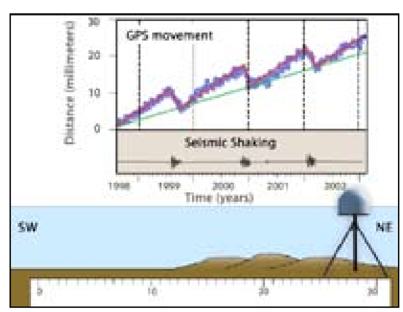
Left: (Image from U.S.G.S.)

Prior to a volcanic eruption, intrusion of magma will cause pressurization by:

- Increasing volume
- Heating of ground water
- Release of gas

This results in:

- Earthquakes
- Ground deformation
- Gas emission



Right: GPS shows change in position over time. See GPS animations on IRIS' Animations Page: **GPS—Measuring Plate Motion**

TILTMETERS

Telemetry from electronic tiltmeters in the crater at Mount St. Helens contributed to accurate predictions of all six effusive eruptions from June 1981 to August 1982. Tilting of the crater floor began several weeks before each eruption, accelerated sharply for several days, and then abruptly changed direction a few minutes to days before extrusion began. Each episode of uplift was caused by the intrusion of magma into the lava dome from a shallow source, causing the dome to inflate and eventually rupture. Release of magma pressure and increased surface loading by magma added to the dome combined to cause subsidence just prior to extrusion[1].

Measuring tiny changes in the slope angle or "tilt" of the ground at a volcano is one of the oldest methods for monitoring deformation caused by moving magma. When magma forces the ground up, the slope of adjacent areas will usually tilt away from the center of uplift by only a fraction of a degree. Conversely, if the ground subsides as a consequence of magma moving below, the slope of adjacent areas will tilt toward the center of subsidence. We use electronic tiltmeters for continuously recording such ground tilts on volcanoes, and they have become the most widely used instrument for measuring volcano ground deformation in real time.

Like a carpenter's level, an electronic tiltmeter uses a small container filled with a conducting fluid and a "bubble" to measure a change in slope. Electrodes placed in the fluid and into the bubble determine the bubble's position--as the bubble moves, voltage output from the electrode changes in a way that correlates to the amount of tilt that caused the bubble to move.

Tiltmeters measure the amount of tilt in microradians, which is the angle turned by raising one end of a beam one kilometer long the width of a dime (equivalent to 0.00006 degree!). Originally designed as part of the guidance and control system for military missiles, a variety of electronic tiltmeters are now available for volcano monitoring, each with different resolutions and ranges. For example, we use tiltmeters with ranges of between 100 and 10,000 microradians depending on the volcano and expected degree of tilt.

[1] Dzurisin D, Westphal JA, Johnson DJ., 1983, Eruption Prediction Aided by Electronic Tiltmeter Data at Mount St. Helens: Science, Vol. 221

Seismicity

Earthquake activity beneath a volcano almost always increases before an eruption because magma and volcanic gas must first force their way up through shallow underground fractures and passageways. When magma and volcanic gases or fluids move, they will either cause rocks to break or cracks to vibrate. When rocks break high-frequency earthquakes are triggered. However, when cracks vibrate either low-frequency earthquakes or a continuous shaking called volcanic tremor is triggered. (See figure in box next page.)

Most volcanic-related earthquakes are less than a magnitude 2 or 3 and occur less than 10 km beneath a volcano. The earthquakes tend to occur in swarms consisting of dozens to hundreds of events. During such periods of heightened earthquake activity, scientists work around the clock to detect subtle and significant variations in the type and intensity of seismic activity and to determine when an eruption is occurring, especially when a volcano cannot be directly observed.

A seismometer is an instrument that measures ground vibrations caused by a variety of processes, primarily earthquakes. To keep track of a volcano's changing earthquake activity, we typically must install between 4 and 8 seismometers within about 20 km of a volcano's vent, with several located on the volcano itself. Seismic networks are made up of several instruments. Having enough of the right instruments located in strategic places is especially important for detecting earthquakes smaller than magnitude 1 or 2; sometimes, these tiny earthquakes represent the only indication that a volcano is becoming restless. If a seismometer is located more than 50 km away, these tiny earthquakes could go undetected.

Gas

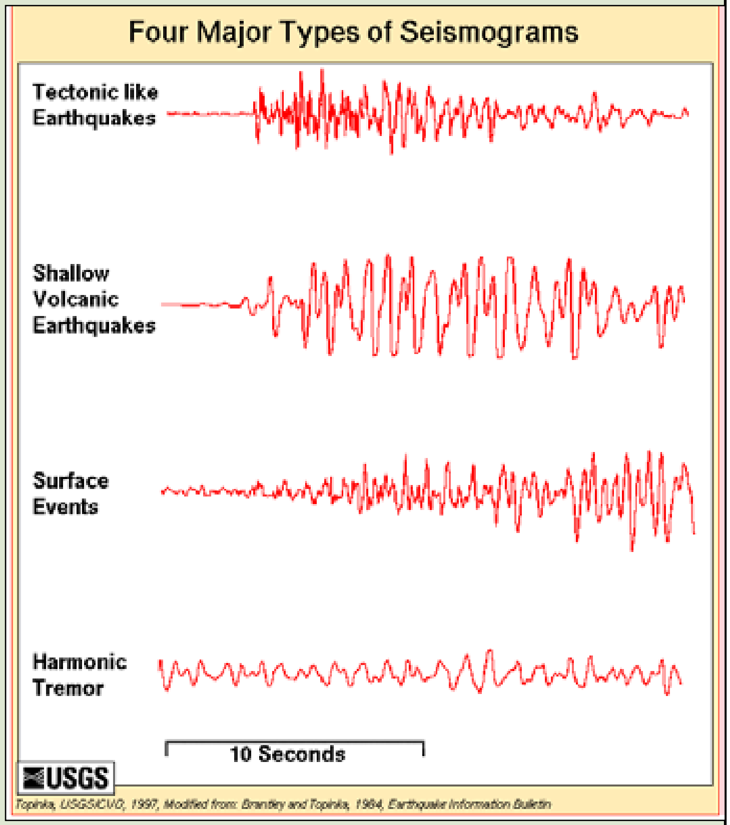
Scientists have long recognized that gases dissolved in magma provide the driving force of volcanic eruptions, but only recently have new techniques permitted routine measurement of different types of volcanic gases released into the atmosphere. Sulfurous volcanic gas and visible steam are usually the first things people notice when they visit an active volcano, for example Mount St. Helens pictured here. A number of other gases also escape sight unseen into the atmosphere through

Typical seismograms seen at Mount St. Helens

Seismograph stations record ground movement from many sources (See the series of animations called **Seismic Signatures** on **IRIS** Animation pages). The four seismograms at right include both tectonic and volcanic earthquakes to show how to broadly discern the difference. Sudden seismicity beneath a volcano is a strong indication that magma is ascending (Figure below). Accelerated seismicity and surface deformation indicates a likelihood that the volcano could erupt.

Seismologist separate volcanic events in the vicinity of Mount St. Helens further into:

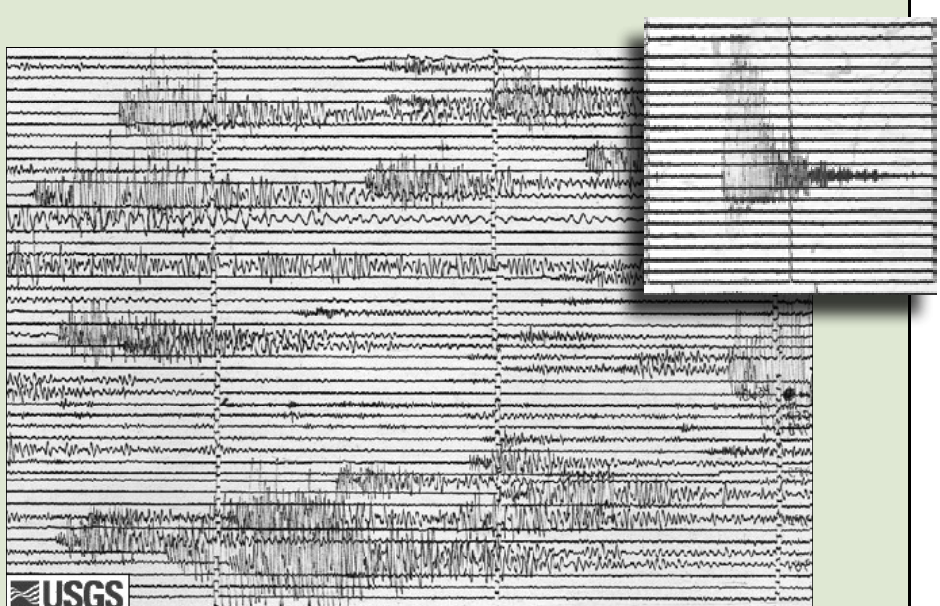
1) Two types of high-frequency earthquakes occur near the volcano and under the volcano at depths of more than 4 kilometers.
2) Medium- and low-frequency earthquakes occur at shallow depths (less than 3 kilometers) within the volcano and increase in number and size before eruptions. Temporal changes in the energy release of the low-frequency earthquakes have been used in predicting all the eruptions since October 1980.
3) During and after eruptions, two types of low-frequency emergent surface events occur, including rockfalls and steam or gas bursts from the lava dome (from **Malone SD, Boyko C, Weaver CS**.)



Seismograms recognized at Mount St. Helens:

(1) deep earthquakes and those located away from the volcano, which produce high-frequency signatures and sharp arrivals similar to tectonic earthquakes,
(2) shallow earthquakes, located under the dome at depths of less than 3 kilometers, which produce medium-to-low-frequency seismic arrivals,
(3) surface events, such as gas and tephra events, rockfalls associated with dome growth, and snow and rock avalanches from the crater walls, which produce complicated signatures with no clear beginning or end, and
(4) harmonic tremor, which is a long-lasting, very rhythmic signal whose origin is not well understood but which is often associated with active volcanoes.

In 1980, the University of Washington had just completed the establishment of a system of seismometers to help monitor the Cascade volcanoes. The first indications of a major problem came on March 20, when a 4.2 magnitude earthquake was recorded beneath Mount St. Helens. Harmonic tremor, continued daily (Figure 6). Three days later another 4.0 M was recorded, and that evening the earthquakes began occurring in swarms centered directly beneath the volcano, at a rate of about 15 per hour. By March 25, M4 events were shaking the volcano at a rate of about 3 per hour. On the same day, several overflights revealed new fractures on the glacier surfaces and a number of avalanches and rockfalls. (From **How Volcanoes Work.**)



Seismogram upper right shows M4 earthquake March 20, 1980.
Helicorder shows 48 hours of harmonic tremor March 21 to 23 (USGS).

hot fumaroles, active vents, and porous ground surfaces. The gases escape as magma rises toward the surface, when it erupts, and even as it cools and crystallizes below ground.

A primary objective in gas monitoring is to determine changes in the release of certain gases from a volcano, chiefly carbon dioxide and sulfur dioxide. Such changes can be used with other monitoring information to provide eruption warnings and to improve our understanding of how volcanoes work. In recent years, we have directed increased attention toward volcanic gas emissions because of the newly appreciated hazards they sometimes pose and their effects on the Earth's atmosphere and climate.

Gases released by most volcanoes are difficult to sample and measure on a regular basis, especially when a volcano becomes restless. Direct sampling of gas requires that scientists visit a hot fumarole or an active vent, usually high on a volcano's flank or within its summit crater. At some volcanoes, gases discharge directly into crater lakes. The remote location of these sampling sites, intense and often hazardous fumes, frequent bad weather, and the potential for sudden eruptions can make regular gas sampling sometimes impossible and dangerous.

Measuring gases remotely is possible but requires ideal weather and the availability of suitable aircraft or a network of roads around a volcano. Consistent and favorable wind conditions are needed to carry gases from vents and fissures to where they can be measured. In some cases, automated on-site gas monitoring is feasible. Under corrosive conditions, only a few sensors are available, however, for continuously recording the concentrations of specific gases.

Scientists face yet another challenge--acid gases, like SO2, easily dissolve in water. Thus, volcanoes with abundant surface or subsurface water can prevent scientists from measuring the emission of acid gases as magma rises toward the surface and even after explosive eruptions. Because CO2 is is less likely to be masked by the presence of water, measuring it when a volcano first becomes restless and between eruptions may be important for determining whether significant magma degassing is occurring.

Gas fumes rising from Mount St. Helens. The visible portion is mostly steam.