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Volcanoes of Alaska

How many are there?

About 80 percent of all active *volcanoes* in the United States and 8 percent of all active volcanoes on earth are found in Alaska. More than 100 volcanoes and *volcanic fields*—clusters of small volcanoes and cinder cones—are now active or have been active within the last million-and-a-half years. Hardly a year goes by without a major eruption from a volcano in the Aleutian Islands or on the Alaska Peninsula (the Aleutian Arc). Only volcanologists pay much attention to the volcanoes in the largely unpopulated western Arc. The volcanoes the public hears and reads about are usually those that are closer to Anchorage and the population centers of Alaska.

Where are they?

Most of these volcanoes are located along the 2,500 kilometer (1,550 mile) Aleutian Arc that extends westward from central Alaska along the Alaska Peninsula, then out along the Aleutian Islands toward eastern Russia. The arc forms the northern portion of the Pacific "*ring of fire*." Other volcanoes that have been active during the last few thousand years are found in southeastern Alaska and in the Wrangell Mountains. Smaller volcanoes, some active within the last 10,000 years, are found in interior Alaska and in western Alaska as far north as the Seward Peninsula.

Why are they there?

The surface of the earth is made of a collage of "*plates*," each tens of kilometers (a kilometer is about six-tenths mile) thick. These plates move with respect to each other much like ice-floes on a river or the skim on overheated cream soup (see box *Plate movement*).

Most volcanic activity in Alaska is the result of *subduction* which is the convergence of two of these plates. In the Aleutian Arc, the northward-moving Pacific Plate dives beneath the southern margin of Alaska at a rate of 6 to 7.5 centimeters (2.5 to 3 inches) per year. As the Pacific Plate slowly grinds beneath the Alaska portion of the North American Plate, stress and strain are stored and then released in great earthquakes. In fact, about a quarter of all earthquake energy released on earth is released in Alaska, and three of the ten largest earthquakes ever measured happened in Alaska. During this century Alaska has had nearly 70 earthquakes of *magnitude* 7 or greater.

The large earthquakes mentioned above and thousands of smaller ones are located at the boundary of the Pacific and North American plates. These earthquakes form a narrow curtain of activity which deepens northward from the Aleutian trench and is about 100 kilometers (60 miles) deep underneath the Aleutian Arc volcanoes.

As the plate descends into the *mantle* (dense rock that underlies the earth's crust), it undergoes a series of chemical and physical changes caused by increasing pressure and temperature. First comes the release of water that is stored between the individual grains of subducted sediments and in tiny cracks in the oceanic crust.

At greater depths water-bearing minerals (such as *hornblende*) change into non-water-bearing minerals (such as *pyroxene*). Water given off by this process, along with dissolved impurities, rises into the overlying mantle. Addition of water to the mantle lowers its melting point and is one of the processes that leads to the production of *magma* (see illustration). Magma also forms as the mantle that is stirred by the descending plate rises to a position beneath the volcanoes. The reduced pressure favors magma production because magma is less dense than mantle. Under special circumstances the subducted plate itself becomes hot enough to melt.

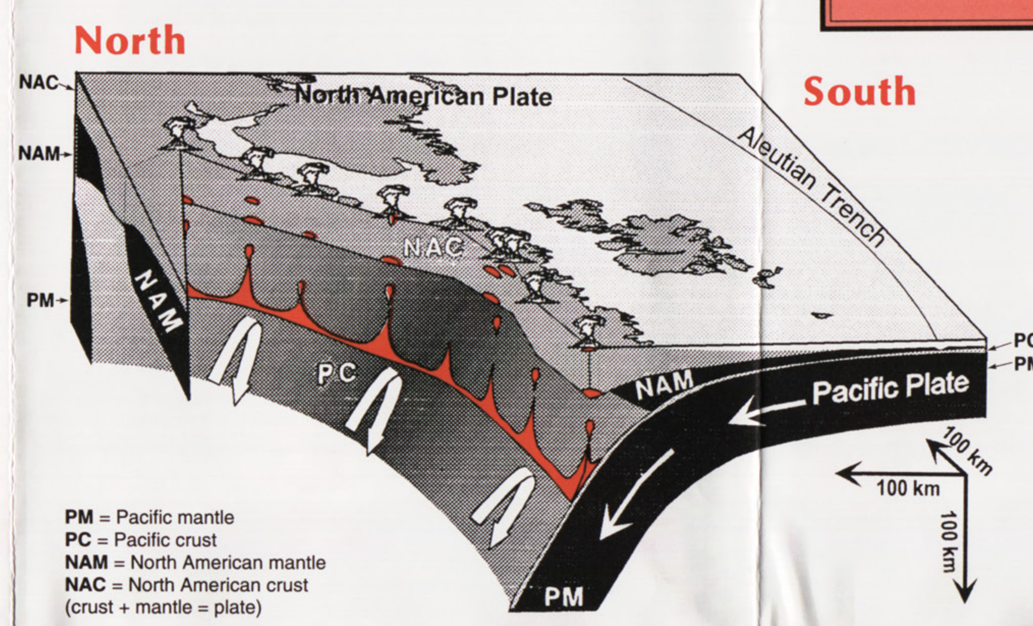
Magma, which results from these processes, is lighter than the surrounding mantle and, therefore, rises toward the surface. *Continental crust* is less dense than mantle and less dense than the mantle-derived magma. So, when the magma reaches the base of the crust it pools and continues to change because of other processes. It heats, then melts, then mixes with the surrounding crust. As the magma cools it crystallizes and the crystals that form differ in composition from the magma. When the crystals are removed from the magma, its composition changes and becomes richer in those chemical components that are not concentrated in crystals. (This process is called fractional crystallization, or fractionation).

The most fundamental change in the magma is the increase in *silica* that this process produces. Subsequent magmas change from the initial *basalts* (less than 53 percent silica) to *andesites* (up to 63 percent silica) then *dacites* (up to 62 percent *silica*). As the silica content increases, the magmas become less dense. At some point they become less dense than the crust and continue their rise toward the surface. Depending on the magmas' rate of rise, they can continue to crystallize, fractionate and assimilate surrounding crust. In extreme cases they can form *rhyolite*, with up to 76 percent silica. Finally the magmas reach the surface. If they are relatively poor in dissolved gases, they erupt nonexplosively and form *lava* flows or domes. If they are rich in dissolved gases, they explode violently (like a thoroughly shaken soda which is uncapped quickly) and form columns of *volcanic ash*, which can reach more than 15 kilometers (45,000 feet) into the atmosphere.

Magmas tend to use the same pathway over and over and erupt from a single volcanic vent. Therefore, over a time span of a million years or more they form large, widely spaced volcanoes rather than a continuous line of smaller cones.

The process outlined above is a thumbnail sketch of the process that forms the volcanoes of the Aleutian Arc. The Wrangell volcanoes formed in a very similar way and are associated with a small sliver of the Pacific Plate that is thrust northeastward beneath central Alaska. Several of the Wrangell volcanoes are among the most voluminous andesite volcanoes in the world—several times the volume of Mt. Rainier in the state of Washington. Elsewhere in the world where andesite volcanoes are so large they are usually many dozens of kilometers from their nearest neighbors, but in the western Wrangell Mountains several of these centers are close as 15 kilometers to each other and of the same geologic age. The relative closeness in place and age reflects a rate of eruption substantially higher than at other subduction zones. This pattern of eruptions puzzles scientists because *seismicity* of the Wrangell Benioff-Wadati Zone is extremely weak.

Two major types of volcanoes in Alaska are not directly tied to the Aleutian subduction zone. The first type is a series of small craters (and one larger one, Mt. Edgecumbe near Sitka) scattered throughout southeastern Alaska. These small volcanoes may be related to the intense shearing along many strike-slip *faults* that are caused by the northward movement of the Pacific Plate. Deep crustal fractures such as these faults may allow magma to rise and volcanoes to form in areas where magma could not normally reach the surface.



Cutaway block diagram of the easternmost Aleutian Arc. Processes leading to the production of magma and its rise toward the surface are described in the text under the heading "Why are they there?" In the diagram the Pacific Ocean is light gray, the upper crust of the Pacific and North American plates is medium gray, and the mantle of the plates is black. The hot plastic mantle below, which the plates ride on, is not shown. Magma is red.

The second type of nonsubduction volcanoes form the basalt fields of western Alaska. These fields are typically made of many coalescing basaltic cinder cones and lava flows, each of which formed over a few weeks or months. It has been suggested that at least some of these fields formed where tension in the crust produced deep fractures and thinning of the crust. The origin of these fields is not well understood, but they are analogous to cinder cone fields northwest of the Japanese volcanoes in southeast Asia, eastern China, and Korea.

Plate Movement

Crustal plates can move with respect to each other in only three ways.

- They can move apart from each other. This movement usually happens in the ocean basins. As two plates move apart, new material from the underlying *mantle* wells up and melts because of the pressure reduction. This melted material oozes onto the ocean floor and produces the long chains of submarine volcanoes which are called mid-ocean ridges.
- The plates can rub past each other producing long, linear earthquake-producing faults. This action is the origin of California's San Andreas *Fault*, which is the boundary between the relatively northward-moving Pacific Plate and the North American Plate.
- One plate can slide beneath another. This process is called *subduction*, and produces the deep submarine trenches around the margins of the Pacific Ocean and the volcanoes of the Pacific "*ring of fire*."

Volcanic Hazards and Volcanic Benefits

Volcanoes erupt a few tenths to a few tens of cubic kilometers (a few hundredths to a few cubic miles) of lava at temperatures of 750 to 1,150 degrees centigrade (1,400 to 2,100 degrees Fahrenheit). These eruptions pose hazards both near the volcano and far downwind. Lavas with relatively low *silica* contents are fluid and often form lava flows, which are rivers of molten rock that flow quickly down slopes. Lavas with higher silica contents are stickier (have higher viscosity) and erupt either explosively or form as domes that perched on top of the volcanic vent. As these domes grow they become oversteepened and fail in avalanches of hot rock and dust which sweep swiftly down the flanks of the volcanoes and form *pyroclastic flows*.

Many of Alaska's volcanoes are ice-covered, which causes additional hazards. Eruption of hot lava onto snow and glacier surfaces can cause rapid melting of the ice. This water then mixes with the fragmented lava to form *lahars*, which are slurries of hot mud and water. Lahars can flow down river drainages far from the volcano. Explosive eruptions can loft *volcanic ash* 15 kilometers (50,000 feet) or more into the air. These eruptions pose a special hazard to aircraft (see section *Ash and aircraft a special Alaska hazard*). Volcanic plumes that are energetic enough to carry volcanic ash, water, and chemical aerosols (principally sulfur-based) into the *stratosphere* can alter local and even global climate for the few years that they are in circulation around the earth. Volcanoes can also erupt corrosive and poisonous gases, which can harm local plant and animal life.

Volcanoes also have their beneficial side. Magma moving toward the surface brings heat with it and can produce geothermal resources hot enough to generate low-cost, environmentally clean electricity. That same heat makes deep groundwater percolate through the volcano and surrounding areas and generates certain types of ore deposits.

Volcanoes in repose form beautiful mountains and are the central attractions of many national parks. Volcanoes in eruption are enthralling in their power and grandeur and demonstrate unequivocally that the earth below the atmosphere and biosphere is not static. Scientifically they are thrilling because they carry information about geological processes happening deep beneath the surface. They are the one facet of the geologic evolution of the planet Earth that can be studied on a human timescale.

Ash and Aircraft—A Special Alaska Hazard

Alaska airspace is extremely busy with long-range, wide-body aircraft as well as bush planes and smaller aircraft. Anchorage International Airport handles more air freight (in dollar value) than any other airport in the United States, and Fairbanks is twelfth on the list and is handling more and more freight each year. There are 40,000-to-50,000 aircraft each year, and 10,000 people each day that fly over or very near Alaska volcanoes as they travel the north Pacific (NOPAC) air routes. The reason for all the activity is Alaska's unique geographic location. All direct air routes between anywhere in the United States (even Los Angeles and Dallas) and Asian cities such as Tokyo and Hong Kong pass through the NOPAC routes. Also, many of the aircraft carrying freight between Europe and Asia come through Anchorage for refueling. A considerable percent of all air freight on earth passes near Alaska's volcanoes.

Encounters between aircraft and volcanic ash are serious because the ash causes severe damage to the engines as well as other parts of the airplane. Two processes damage jet engines, particularly long-range, wide-body airplanes such as DC-10s and Boeing 747s that are used for international transport. The first damaging process is mechanical abrasion of moving parts such as compressor and turbine blades. The abrasion reduces the efficiency of the engine but does not typically cause engine failure. The second mechanism is deposition of ash in the hot parts of the engine. Jet engines, particularly those on large airplanes used on international routes, operate near the melting temperature of volcanic ash. Ingestion of ash can foul the fuel nozzles, combuster, and turbine causing surging, flame out, immediate loss of engine thrust, and engine failure.

In the past 12 years more than 60 jet airplanes have been damaged by volcanic ash. Seven of those resulted in engine failure, although all seven eventually restarted enough engines to land without loss of life.

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Glossary

Andesite. Volcanic rock, magma, or lava with between 53 and 63 weight percent *silica*. In between *basalt* and *dacite* in silica content.
Basalt. Volcanic rock, magma, or lava with less than 53 weight percent *silica*. Basalt is fluid (has low viscosity) and usually forms lava flows.
B.P. Years before the present.
Caldera. Large, semicircular depression in the summit of a volcano, many times larger than a single vent produced by a very large eruption. In Alaska, volcanoes calderas are typically 5–10 kilometers (3–6 miles) across.
Continental Crust. Uppermost surface of the earth composed of relatively light (low density) rocks which form the continental land masses.
Crust. Uppermost surface of the earth composed of relatively light (low density) rocks. Continental crust forms land masses and large islands and is composed of rock types like sandstone, schist, granite, and andesite. Oceanic crust forms the floors of the ocean basins and is made of basalt.
Dacite. Volcanic rock, magma, or lava with between 63 and about 70 weight percent *silica*. In between andesite and rhyolite in silica content.
Fault. A crack in the surface of the earth where rocks on either side move with respect to each other.
Holocene. The period of time extending from the present to about 10,000 years ago.
Hornblende. A mineral made mostly of silica, iron, magnesium, aluminum, and calcium which contains a few weight percent water.
Lahar. Slurry of fragments of lava, ash, and water; flows quickly down the slopes of a volcano. Can be cold or warm and often has the consistency of cement. Same as *volcanic mudflow*.
Lava. Molten rock (magma) that erupts from a volcano.
Magma. Molten rock within the earth. On eruption magma becomes lava.
Magnitude. Measure of the intensity of an earthquake. Each unit increase is roughly a thirty-fold increase in energy.
Mantle. Dense rock made of minerals that are principally combinations of silica, iron, and magnesium and underlies the crust and overlies the earth's metallic core. The top few tens of kilometers are rigid and form the bases of the crust plates which move with respect to each other. At depths of 100–350 kilometers (60–210 miles), the mantle is plastic and weak, and forms the layer on which plates move.
Plate tectonics. The concept that the earth's surface is composed of an interlocking network of one to two dozen large plates, each tens of kilometers thick. The plates move with respect to each other as they float on the viscous mantle. Plates move apart from each other at spreading ridges (most of which are in the oceans) come together at subduction zones, and move past each other horizontally along large *faults*.
Pleistocene. The period of time extending from the beginning of the Holocene (about 10,000 years ago) to about 1.64 million years ago.
Pyroclastic flows. Mixture of hot gases and finely to coarsely fragmented lava that moves quickly down the flanks of a volcano.
Pyroxene. A mineral made mostly of silica, iron, magnesium, and calcium which does not contain water
Rhyolite. Volcanic rock, magma, or lava with more than about 72 weight percent *silica*. Rhyolite is very viscous (sticky) and eruptions of this material are often very explosive.
"Ring of fire." The nearly continuous chain of volcanoes that circle the Pacific Ocean. All these volcanoes are formed by subduction of oceanic plates beneath continental margins.
Seismicity. Shaking of the earth caused by movement along faults or by movement of gases and magma within volcanoes.
Seismometer. Instrument that detects earthquakes by measuring the shaking of the earth.
Shearing. Movement resulting from stresses that cause rock bodies to slide past each other. In the brittle upper crust this usually results in earthquakes along *faults*.
Shield volcano. A broad volcano with low surface slope composed mostly of lava flows erupted from a single vent or a few closely spaced vents. Forms over a period of hundreds of thousands of years.
Silica. Chemical compound composed of two oxygen atoms for every silicon atom. Oxygen and silicon are the most common elements in the earth's crust.
Stratocone. Steep-sided volcano composed of many layers of lava flows, ash, and pyroclastic flows produced by eruptions from a single vent or a few closely spaced vents. Forms over a period of hundreds of thousands of years; also known as stratovolcano or composite volcano.
Stratosphere. The outer layer of the atmosphere that is above about 10–20 kilometers (6–12 miles).
Subduction. The process in which one crustal plate slides beneath another.
Tephra. Collective term for all solid material explosively ejected from a volcano.
Volcanic ash. Finely fragmented particles of rocks and mineral derived from magma in an explosive eruption.
Volcanic field. A closely spaced collection of small cinder cones and lava flows each of which are produced by individual eruptions of days-to-months duration.
Volcano. An roughly circular opening in the earth's surface through which magma erupts. Also the landform produced by erupted material that accumulates around the vent.

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Typical Eruptions

This summary of the significant volcanic activity in Alaska between 1989 and 1994 shows that eruptions are frequent and gives a "snapshot" of Aleutian Arc activity.

1989

Okmok Volcano (53°26' N., 168°07' W.). *Ash* emission from intracaldera cone on February 14 and 26. Plume reached 1,400 meters (4,500 feet) altitude.

Pavlof Volcano (55°25'20" N., 161°53'30" W.). Ash emission events to 600 meters (373 miles) above the summit on February 28 and March 2; possibly continued into August.

Akutan Peak (54°08' N., 165°59' W.). Minor ash eruptions from intracaldera cone intermittently between late February and late April, and in late May through July. Light ashfall in Akutan village.

Redoubt Volcano (60°24'15" N., 152°44'30" W.). Major explosive eruption on December 14 followed increase in seismicity; explosions on December 15 accompanied by *tephra-fall*, *pyroclastic flows,* and *lahars* in Drift River valley. Continuous eruption of tephra December 16–18. Tephra plumes to higher than 12 kilometers (40,000 feet). Air traffic disrupted. Nearly fatal jet airplane encounter with ash plume over Talkeetna Mountains on December 15. Dome growth begins about December 22.

1990

Redoubt Volcano (60°29'15" N., 152°44'30" W.) Explosive eruptions accompanied by dome collapse, pyroclastic flows, tephra falls, lahars on January 2, 8, 11, 16; February 15, 21, 24, 18; March 4, 9, 14, 23, 29; April 6, 15, 21, 26. Tephra plumes higher than 12 kilometers (40,000 feet). Major disruptions in air traffic. Ash fell on Anchorage and the Kenai Peninsula. Dome growth continued into June. Minor steam and ash emissions continue into late 1990.

Kiska Volcano (52°6'35" N., 177°36'25" W.). Ash and steam plume observed on June 1. Pilot reported cloud reached 3.5 kilometers (11,000 feet) altitude.

Akutan Peak (54°08' N., 165°59" W.). Ash and steam plumes erupted from the intracaldera cinder cone to heights of several hundred to 1,800 meters (6,000 feet) above the vent on September 6, 21, 22, 30 and October 1.

1991

Redoubt Volcano (60°29'15" N., 152°44'30" W.). Minor ash emissions from lava dome; fallout confined to summit crater. Declining seismicity.

Akutan Peak (54°8' N., 165°59' W.). Ash and steam plumes reported up to several kilometers over the volcano on September 15, 27, 29 and October 11, 13, 14, 18, 19, 30.

Westdahl Peak (54°31' N., 164°39' W.). Fissure eruption reported November 29, ash and steam plume to 7 kilometers (23,000 feet). Light ashfall and rumbling heard in False Pass on December 9, 12, 16, 26. Brief disruption to air traffic. Overflight documented lahar activity in conjunction with early phase of eruption; blocky lava flows steamed down canyons on volcano's east flank.

1992

Mount Spurr's Crater Peak (61°16'10" N., 152°14'15" W.). Following 10 months of increased seismicity and a formal warning of unrest from the Alaska Volcano Observatory, brief explosive eruptions on June 27, August 18, September 16–17 send tephra plumes above 14 kilometers (45,500 feet). Air traffic disrupted. Ashfall of 1–3 millimeters (one-tenth inch) on Anchorage closes International Airport for 20 hours on August 18–19. Intense swarm of earthquakes accompanies intrusion on November 9–10.

Westdahl Peak (54°31' N., 164°39' W.). Fissure eruption that began on November 29, 1991, ended in mid-January. Lava flow covered 5 square kilometers (2 square miles) on the northeast flank of Westdahl Peak.

Akutan Peak (54°08' N., 165°59' W.). Minor steam and ash emission from intracaldera cinder cone on March 8 continuing through late May; plumes reach a maximum altitude of 4.6 kilometers (15,000 feet). Small ash plume to 1.8 kilometers (6,000 feet) on December 18.

Bogoslof Volcano (53°56' N., 168°02' W.). New lava dome, about 90 meter high and 350 meter across, emplaced at north end of Bogoslof Island between July 6 and 24. Accompanying ash and steam plumes rose to a maximum of 8 kilometers (26,000 feet).

Seguam Volcano (52°19' N., 172°30' W.). Small ash eruptions from near Pyre Peak send plumes to more than 1.2 kilometers (4,000 feet) above sea level on December 27 and 30.

1993

Mount Veniaminof (15°12' N., 159°24' W.). Intermittent minor ash and steam plumes from intracaldera. Cinder cone began forming July 30 and continued throughout the year. Light dusting of fine ash on Port Heiden on August 4. Incandescent material observed over the summit caldera at night on several occasions. New pit melted into summit ice cap adjacent to cone.

Seguam Volcano (52°19' N., 172°30' W.). Ash burst from vents near Pyre Peak to several kilometers (a few miles) altitude on May 28, and possibly on June 2. Activity resumed in late July through late August and included production of a lava flow.

Mount Spurr's Crater Peak (61°16'10" N., 152°14'15" W.). Declining seismicity; level of concern color code downgraded to green on March 5.

1994

Kanaga Volcano (51°55'30" N., 177°09'40" W.). Increased steaming from summit crater and upper flank fumaroles first noted on February 17, 1993. Beginning in early January 1994 minor ash plumes usually less than 1 kilometer (3,000 feet) over the summit continue intermittently throughout the year. Occasional sulfur smell in Adak. Avalanching of incandescent fragmental debris down the north flank into the sea reported in April. Significant ash plumes to about 7.5 kilometers (24,000 feet) altitude on February 21, to about 4.5 kilometers (15,000 feet) August 18–21. Dusting of ash on Adak on August 20 and disruption of air traffic into Adak on August 22. AVHRR satellite imagery detects hot spot near Kanaga summit intermittently throughout the year depending on weather conditions. Occasional steam plume sighted over the volcano throughout the year when weather conditions allow.

Mount Veniaminof (15°12' N., 159°24' W.). Nearby residents and pilots reported intermittent steam and ash bursts.

Mount Cleveland (52°49'30" N., 169°56'40" W.). Brief burst of ash to about 10.5 kilometers (34,000 feet) on May 25. Ashfall confined to northeast flank of the volcano.

Shishaldin Volcano (54°45'20" N., 163°58'15" W.). Pilot reported of a possible eruption on October 4; steam plume to 3 kilometers (10,000 feet) altitude with minor amounts of ash.

Some Notable or Recent Eruptions

Mount Spurr

On June 27, 1992, following 39 years of inactivity, Crater Peak vent on the south flank of Mount Spurr volcano burst into eruption at 7:04 a.m. Alaska daylight time (ADT). This and subsequent eruptions on August 18 and September 16 and 17 lasted about four hours and lofted ash about 15 kilometers (50,000 feet) into the atmosphere. June, August, and September eruptions released 44, 52, and 56 million cubic meters (56, 66, and 71 million cubic yards) of andesitic *tephra*.

The August eruption caused the most far-reaching effects when it deposited 3 millimeters (a tenth-of-an-inch) of ash on Anchorage, 125 kilometers (77 miles) east of the volcano. *Pyroclastic flows* surged down the flanks of Crater Peak during the August and September eruptions. In all eruptions, *lahars* and debris flows descended Crater Peak's south flank and some reached the Chakachatna River.

Real-time seismic monitoring tracked the 10-month buildup of precursory earthquakes and allowed timely warning of the increasing unrest to state and federal government officials, the military, air carriers, and local citizens. This monitoring was augmented with other types of observations and provided the basis for accurate eruption advisories that minimized economic losses. In particular, because of an efficient ash-cloud warning system in Alaska and new awareness of the problem of ash clouds within the aviation community, no jet airplanes were damaged.

Anchorage and the Matanuska-Susitna Valley, which together make up the State of Alaska's center of population and economic activity, suffered \$5–\$8 million in unavoidable losses from the August ashfall. Additional but unevaluated costs were incurred from flight delays in large North American airports to the south and east as ash clouds of the August and September eruptions passed overhead.

Redoubt Volcano

The 1989–1990 eruption of Redoubt Volcano, 177 kilometers (110 miles) southwest of Anchorage, began on December 14, 1989. After less than 24 hours of warning seismicity, a huge ash cloud heralded the volcano's fourth and most damaging eruption of this century. *Volcanic ash* generated by about 23 individual explosive episodes between December 1989 and April 1990 caused severe damage to aircraft, severely disrupted air traffic above southern Alaska, and caused local power outages and school closures. Some disruption to air traffic was caused as far afield as south Texas.

The explosions produced hot, fast-moving clouds of ash, rock debris, and gas that swept across Redoubt's heavily glaciated north flank. In the Drift River valley, these events triggered massive debris flows that threatened an oil tanker terminal near the river's mouth. Partial flooding of the terminal compound on two occasions forced authorities to modify its operating procedures and temporarily halted oil production from 10 platforms in Cook Inlet. The total cost of the eruption was about \$160 million, which made it the second most costly volcanic eruption in the history of the United States.

Katmai

The world's largest 20th century eruption and the largest *rhyolite* eruption in recorded history occurred in the Katmai region on the Alaska Peninsula. The eruption started at 1:00 p.m. on June 6, 1912. During the next 60 hours of continuous explosive activity some 30 cubic kilometers (7 cubic miles) of *ash* and *pyroclastic flows* erupted. About half the material was dispersed as windblown ash which fell as thick as 30 centimeters (12 inches) on the town of Kodiak, 170 kilometers (105 miles) away, fouled water supplies, and damaged buildings. The other half of the material formed an ashflow sheet that filled a glacier-carved valley some 200 meters (650 feet) thick and formed the Valley of Ten Thousand Smokes. The vent from which the magma erupted is now plugged by Novarupta dome, which formed at the end of the eruption.

The magma was apparently withdrawn from beneath Mount Katmai, a *stratocone* 10 kilometers (6 miles) away, because during the eruption the summit of Mount Katmai collapsed, forming a 5-square-kilometer (2-square mile) caldera which now contains a lake. The collapse of Mount Katmai simultaneously with the eruption led early workers to mistakenly believe Mount Katmai was the source vent for the eruption. More than 50 years after the eruption scientists found that virtually all the magma that erupted came from Novarupta.

Volcano Monitoring

As magma moves beneath a volcano prior to an eruption, it often generates earthquakes, causes the surface of the volcano to swell, and causes the amount of gases emitted by the volcano to increase. By monitoring these changes, scientists are often able to anticipate eruptive activity and issue warnings of possible hazards. While not all of these changes are observed before every eruption, combining observations of each of these precursors often allows scientists to accurately forecast eruptions.

Often the first indication of an impending eruption is an increase in earthquake activity. Generally a network of six to eight *seismometers* are positioned around a volcano. Sometimes at remote or less hazardous volcanoes only a single seismometer is used. Readings from each seismometer are continuously radioed to a central recording site where scientists determine the locations, sizes, numbers, and types of earthquakes. Often in the weeks or days prior to an eruption the number and size of earthquakes that occur beneath the volcano will increase. In some cases the earthquakes will move to progressively shallower depths beneath the volcanic vent. At some volcanoes, low-frequency earthquakes and a continuous seismic disturbance called tremor will occur shortly before an eruption.

As magma moves to shallower depths it often causes the surface of the volcano to swell. Scientists monitor this deformation of the ground's surface using a variety of surveying techniques and instruments. Electronic distance meters (EDM) bounce infrared light off of targets on the volcano's surface to accurately determine the distance between the EDM and the target. Repeated measurements allow the displacement of the target to be measured. Scientists may also use the global positioning system (GPS, a network of precise navigational satellites) to monitor changes in the ground surface. In some cases instruments called tiltmeters will be cemented to the volcanoes sides. These instruments operate much like a carpenters level and record the amount which the volcanoes surface bulges or tilts. Data from both tiltmeters and GPS receivers can be radioed from the volcano to a central recording site for analysis in real-time.

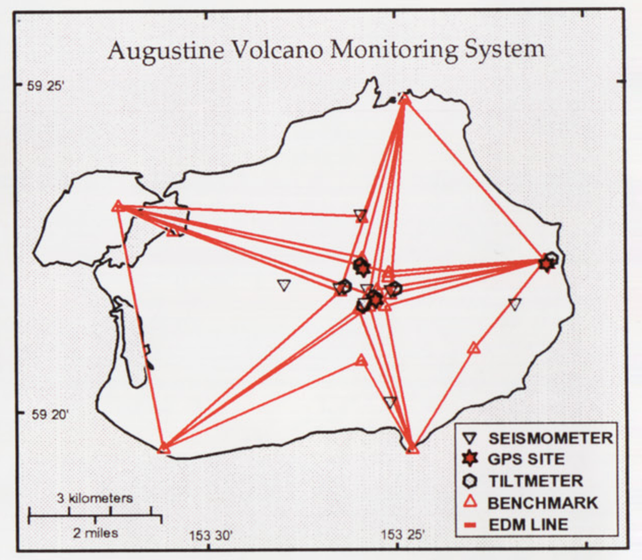
The combined use of all these techniques is shown on the accompanying figure of Augustine Volcano, which is perhaps the best instrumented *stratocone* in North America.

As magma nears the ground surface it releases several species of gas. These include water (steam), carbon dioxide, and sulfur dioxide. Sulfur dioxide is the easiest of these to monitor. Measurements of sulfur dioxide are made using an instrument called a correlation spectrometer (COSPEC) which can measure the absorption of sunlight by sulfur dioxide. The COSPEC can be used from the ground or mounted in an airplane that circles the volcano.

An important component in identifying hazards at a given volcano are geologic studies of the deposits from past eruptions. Frequently a given volcano will develop a characteristic eruptive style and size that will remain approximately the same for thousands of years. Identifying the types and sizes of past eruptions allows estimates of the areas and types of hazards that may be expected in the event of a future eruption at a given volcano.

Decades of monitoring many restless volcanoes around the world have shown that each volcano is different. Some reawakening volcanoes such as Mount Spurr show increased earthquake activity for many months before they erupt, while others like Redoubt Volcano may have less than a day of increased seismic activity. Some volcanoes will deform visibly, as Mount St. Helens did and some will not. Other volcanoes like Augustine vent large quantities of gas before they erupt.

To successfully predict eruptions scientists consider information from all the monitoring techniques. This information is generally analyzed on a high-speed system of networked computers. Once patterns emerge that suggest an eruption may be imminent a warning will be issued. Advance warnings were made for a number of eruptive events during the 1989–90 eruptions of Redoubt Volcano, as well as two of the three eruptions of Mount Spurr in 1992.



The Alaska Volcano Observatory

The Alaska Volcano Observatory (AVO) is a joint program of the United States Geological Survey (USGS), the Geophysical Institute of the University of Alaska Fairbanks (UAFGI), and the State of Alaska Division of Geological & Geophysical Surveys (DGGS). AVO monitors and studies Alaska's hazardous volcanoes, predicts and records eruptive activity, and works closely with other agencies to implement public safety measures. AVO is presently focusing on the volcanoes in the Cook Inlet region. These volcanoes lie in the region of Alaska's greatest population and near centers of important commercial international air transportation and oil and gas production. AVO was formally established in 1988 in response to the 1986 eruption of Augustine Volcano and in time to warn of the 1989 eruption of Redoubt Volcano. Most recently AVO successfully monitored and notified the public of the 1992 eruptions of Mount Spurr volcano located only 125 kilometers (77 miles) west of Anchorage.

THE SEAL OF THE STATE OF ALASKA

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Publication of this report is required by Alaska Statute 41 "to determine the potential of Alaska land for production of metals, minerals, fuels, and geothermal resources; the location and supplies of groundwater and construction materials; the potential geologic hazards to buildings, roads, bridges, and other installations and structures; and shall conduct such other surveys and investigations as will advance knowledge of the geology of Alaska."

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