The Danger of Collapsing Lava Domes: Lessons for Mount Hood, Oregon

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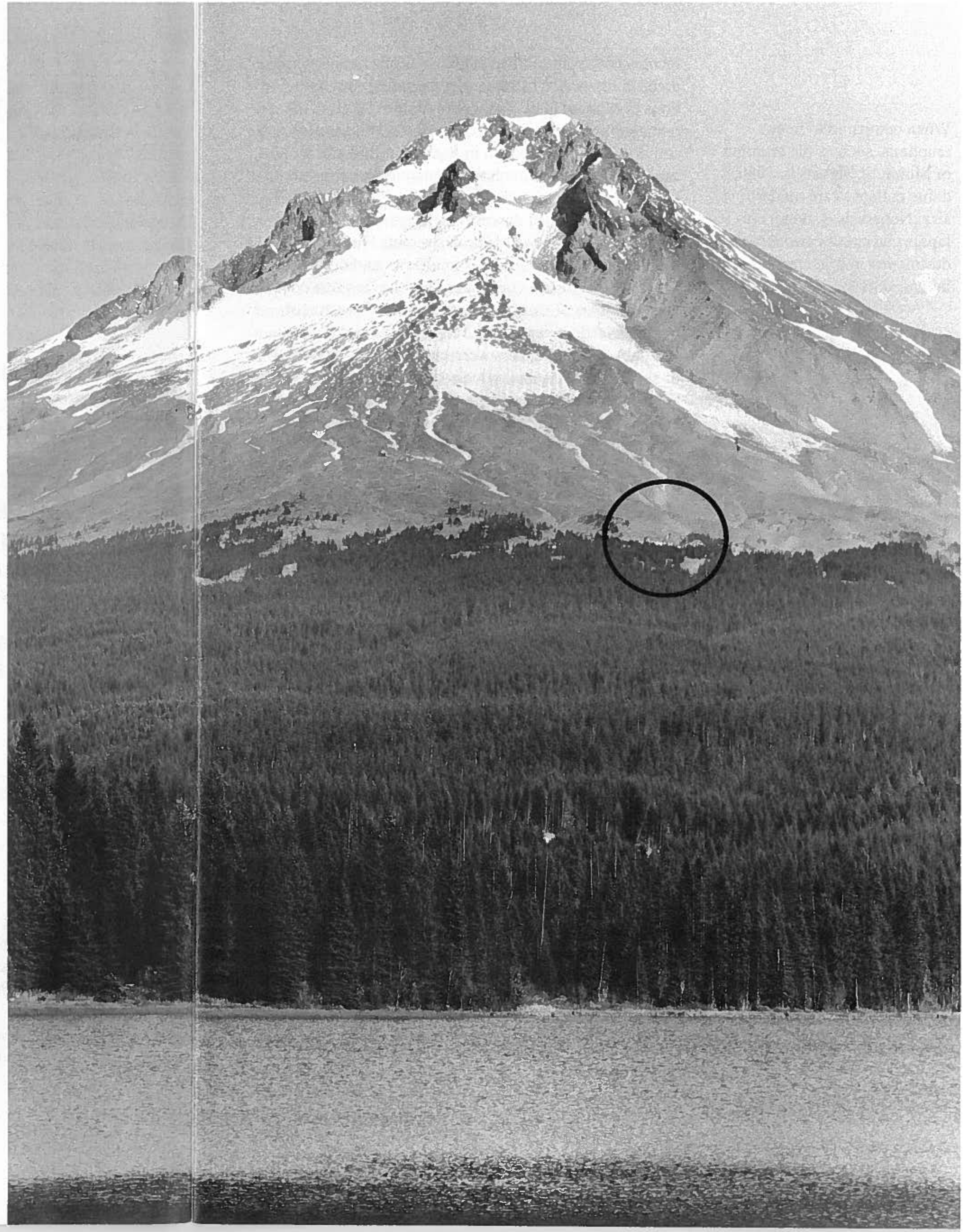
Introduction

Nestled in the crater of Oregon's majestic Mount Hood volcano is Crater Rock, a prominent feature known to thousands of skiers, climbers, and tourists who journey each year to the famous Timberline Lodge located high on the volcano's south flank. Crater Rock stands about 100 m above the sloping crater floor and warm fumaroles along its base emit sulfur gases and a faint steam plume that is sometimes visible from the lodge. What most visitors do not know, however, is that Crater Rock is a volcanic lava dome only 200 years old.

Lava domes are mounds that form when thick, pasty lava is erupted slowly and piles up over a volcanic vent. Crater Rock sits atop the vent and conduit through which molten rock traveled from deep below Mount Hood to the surface. During the past 2,000 years, growth and destruction of earlier lava domes at the site of Crater Rock produced hundreds of pyroclastic flows—avalanches of hot volcanic rock, gas, and air moving at hurricane speed—that swept down the volcano's steep southwest flank as far as 11 km. The strikingly smooth, sloping surface on which the lodge and ski area are built, as well as the nearby community of Government Camp and an important highway across the Cascades, was created by these pyroclastic flows.

During this century, scientists have documented pyroclastic flows generated by growing lava domes at several volcanoes around the world. These studies have helped geologists



Mount Hood in northern Oregon. Mount Hood rises 2,325 m above Trillium Lake, 12 km south of the volcano's summit. About 1,500 and 200 years ago, debris from numerous lava dome collapses at the the site of the Crater Rock dome (sharp peak just below the summit) created the broad smooth slope of the volcano's southwest flank. The famous Timberline Lodge (circle) attracts outdoor enthusiasts to the volcano year around. Photograph by D.E. Wieprecht.

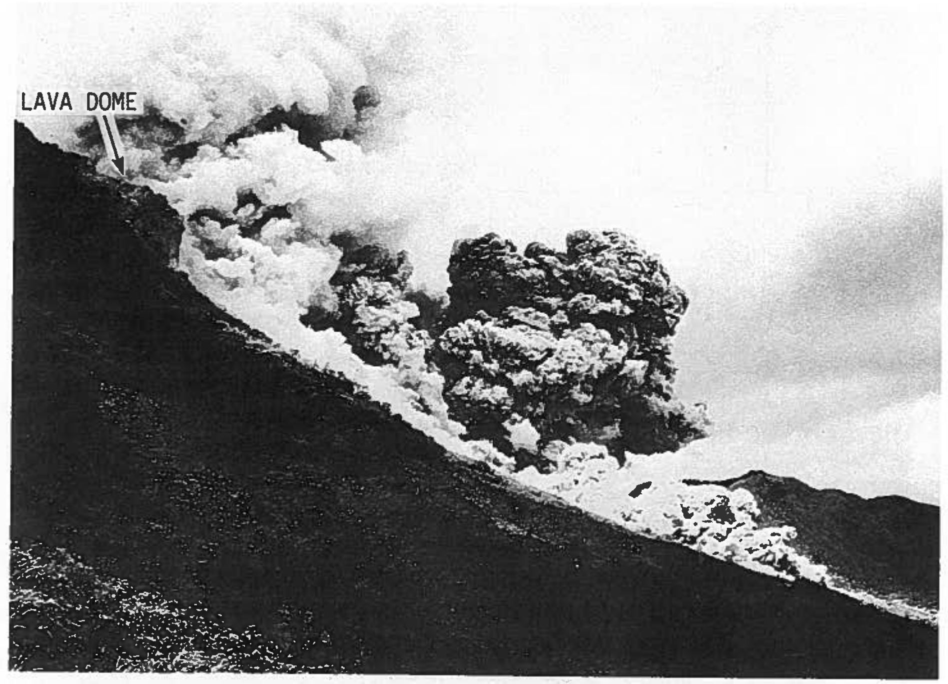
When compared to major eruptions, such as the eruption of Mount St. Helens in 1980, dome collapses are modest in size. Nonetheless, dome collapses can cause considerable destruction and interruption of human activity.

recognize the products of similar volcanic activity hundreds to thousands of years old, including past eruptions at Mount Hood. Two recent dome eruptions are remarkable in their similarity to Mount Hood's past activity — Unzen volcano in Japan and Redoubt Volcano in Alaska. Both volcanoes extruded a series of lava domes that grew above steep slopes. The domes frequently collapsed downslope, triggering explosions and pyroclastic flows. Many destructive lahars (an Indonesian term for volcanic mudflows and debris flows) occurred as a consequence of the frequent collapses. Lahars at Unzen were triggered by erosion of pyroclastic-flow deposits during intense rainfall. At Redoubt Volcano, lahars were caused by rapid melting of snow and ice by the pyroclastic flows.

In this article, we describe the ways in which pyroclastic flows are generated from a lava dome and compare the effects of the Unzen and Redoubt dome eruptions to illustrate the type of activity that is almost certain to occur in the future at Mount Hood. Of course, the Unzen and Redoubt eruptions also illustrate potential volcanic activity at other volcanoes in the Cascade Range that have erupted domes, notably Mount St. Helens and Glacier Peak in Washington and Mount Shasta in northern California.

Pyroclastic Flows Triggered by Dome Collapses or Explosions

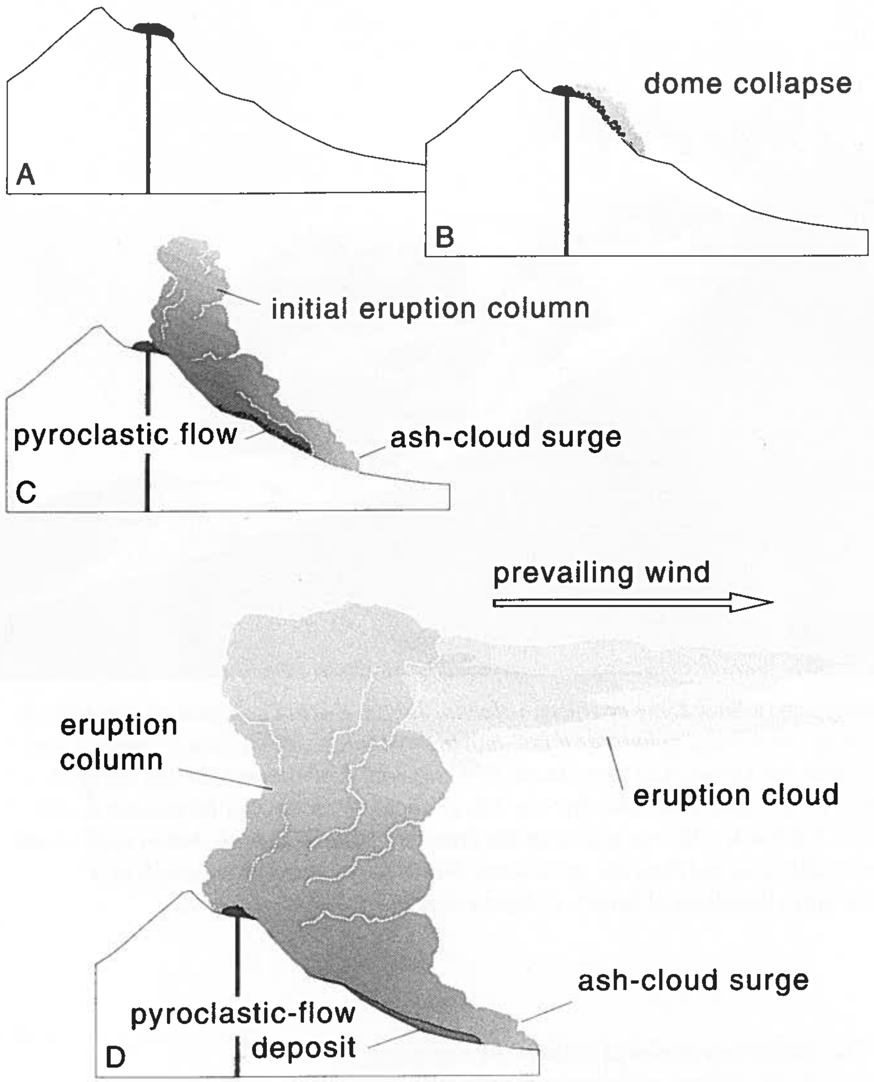
A growing lava dome provides geologists with an exceptional opportunity to study pyroclastic flows. One of the most lethal of volcanic phenomena, a pyroclastic flow is extremely dangerous to observe close up. When a lava dome grows high and steep sided or when it spreads onto a steep slope, the dome becomes unstable. Huge blocks or whole sections of the dome can suddenly break away to form an avalanche of mostly solidified, but still-hot lava fragments. With initial temperatures as high as 950° C, the fragments rapidly disintegrate and the entire moving mass becomes a pyroclastic flow of shattered lava fragments and searing-hot gases. As a pyroclastic flow races across the ground at hurricane speed, a more dilute and highly turbulent cloud of hot gas and mostly ash-sized lava fragments, called an ash-cloud surge by scientists, forms above the flow. Ash-cloud surges are more mobile than the denser, coarser pyroclastic flows and can travel from hundreds of meters to a few kilometers farther.



Collapse of a lava dome at Unzen volcano, Japan. Partial collapse of this actively growing lava dome generates a fast-moving avalanche of hot lava fragments and volcanic gas known as a pyroclastic flow (moving downslope from left to right). Small pyroclastic flows like this one travel about 70 km/hr, but large ones easily reach 200 km/hr. The steep face of the dome is about 70 m high. Note cloud of ash convecting upward from the pyroclastic flow. Copyrighted photograph by T. Yamamoto, Geological Survey of Japan, reprinted with permission.

The sudden gravitational collapse of a growing dome may also trigger a violent explosion by relieving pressure on the dome's interior. When a mass of rock is removed from the outer solidified shell of the dome, gas dissolved in the hot, pasty rock inside the dome can expand with tremendous force, hurling lava fragments as far as 10 km and contributing additional hot debris to the pyroclastic flow.

Pyroclastic flows can also be generated solely by the explosive release of volcanic gases that have accumulated inside a dome or by the flashing to steam of super-hot groundwater within or beneath a dome. Such explosions can occur months or even years after a dome stops growing. For example, as magma within a dome cools and crystallizes, dissolved gas is expelled from the still-molten rock. Sufficient gas pressure may

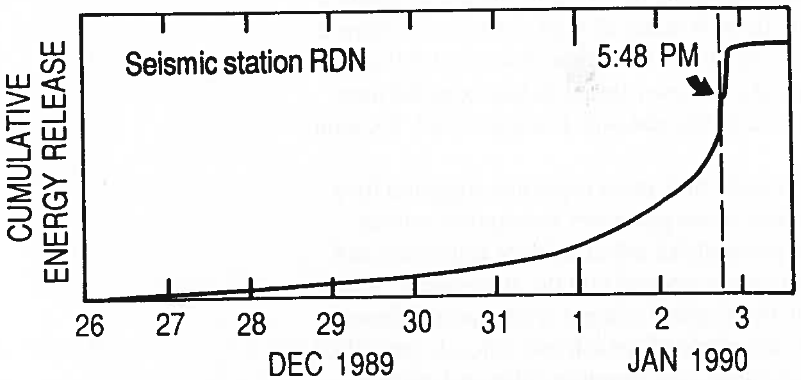


Sketches of a dome collapse showing the development of a pyroclastic flow, ash-cloud surge, eruption column, and eruption cloud. A, Pasty lava oozes onto the volcano's surface to form a lava dome perched precariously above a steep slope. B, Part of the dome collapses, forming a hot avalanche of lava blocks. C, The avalanche becomes a fast-moving mixture of shattered lava fragments, volcanic gas, and air called a pyroclastic flow. A dilute cloud with smaller ash-sized fragments and greater mobility, called an ash-cloud surge, forms above and in front of the pyroclastic flow. An eruption column composed of hot gas and ash begins to rise above the area covered by the main body of the pyroclastic flow. D, The ash-cloud surge travels beyond the pyroclastic flow, where it can rush up nearby hillslopes and overtop ridges. The eruption column continues to grow upward, sometimes reaching the stratosphere. Prevailing winds transport the ash away from the volcano; when detached from the volcano, the volcanic ash and gas are known as an eruption cloud.

accumulate to cause an explosion. The sudden fragmentation of the dome by an explosion can generate a pyroclastic flow. A series of such explosions occurred at the dome on Mount St. Helens between 1989 and 1991, several years after lava was last extruded onto the dome (see *Earthquakes & Volcanoes*, vol. 23, number 2).

A pyroclastic flow or an explosion triggered by a dome-collapse event generates an eruption column composed primarily of ash-sized rock fragments and gases that convect upward into the atmosphere. When material in the eruption column is transported downwind, it forms a "cloud" of ash and volcanic gas called an eruption cloud. Low eruption columns typically form eruption clouds that travel only a few tens to hundreds of kilometers from the volcano. High eruption columns penetrate the stratosphere and can form erup-

Measuring the growth rate of a lava dome (arrow) at Redoubt Volcano, Alaska. Scientists use various methods to track the rate of magma supply to a growing dome. In this photograph, a scientist peers through a theodolite, an instrument that precisely measures horizontal and vertical angles, to estimate changes in the dome's rate of growth. Photograph by R.G. McGimsey.



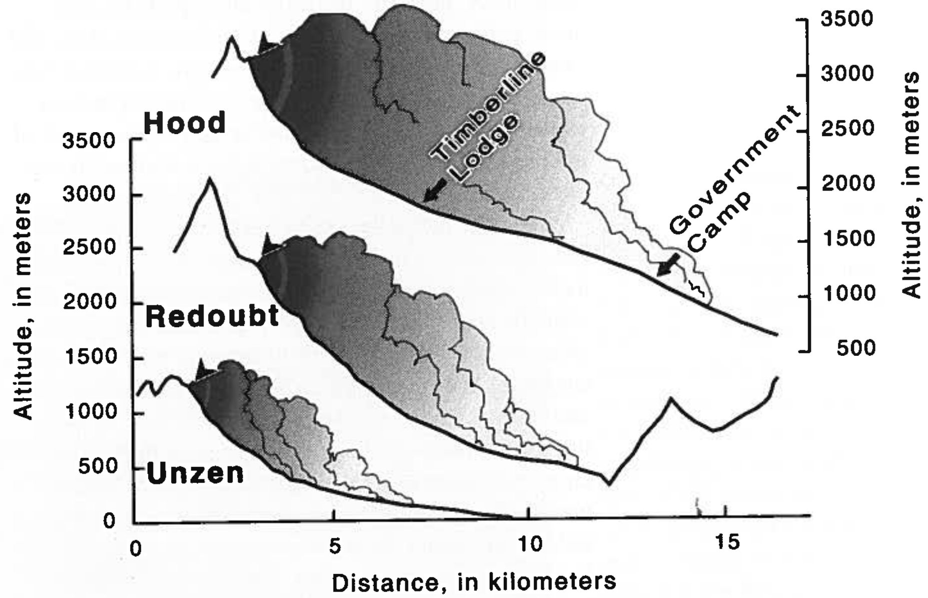
Cumulative seismic-energy release at Redoubt Volcano during a period of dome growth as recorded by a seismograph station about 3 km from the dome. The sharp upturn in the curve reflects a sudden increase in seismic activity beneath the volcano prior to a large explosion and dome collapse on January 2, 1990. This increase in seismicity was the basis for warnings issued by the U. S. Geological Survey's Alaska Volcano Observatory before the explosion that occurred at 5:48 PM. Such precise warnings are not usually possible before volcanic-dome collapses.

tion clouds that spread hundreds or thousands of kilometers downwind. Regardless of their size, eruption clouds interfere with and imperil air travel and lead to ash fall that can disrupt everyday life.

Can Collapses Be Predicted?

Predicting exactly when a dome will collapse has proved elusive for scientists. Generally speaking, a dome will collapse when its strength is exceeded by the downward pull of gravity or by the force of an explosion from within the dome. The factors that affect the balance between dome strength and gravity include the steepness of slope and roughness of the ground surface on which the dome rests, development of fractures in the dome, rate of lava extrusion, volatile (gas) content, and thickness of the dome.

Volcano-monitoring techniques help scientists assess a dome's instability and likelihood of collapse. For example, during growth of the Unzen and Redoubt domes, observations of the locations and character of earthquakes, the rate of volcanic gas release, and the rate of dome growth were useful in detecting changes in the rate of magma delivery to the dome or in pin-



Topographic profiles and distance traveled by pyroclastic flows and ash-cloud surges. Arrowheads point to lava domes on each profile. The Redoubt and Unzen plots represent recent observations; the Mount Hood plot is inferred from prehistoric deposits. Ratios of height loss to distance traveled by flows and surges initiated by dome collapse can provide a rough guideline for estimating the range of distances that future events will travel.

pointing when a new episode of growth would begin. However, even with this information, the best that scientists could do at both volcanoes was to advise officials that dome collapses were more likely, perhaps even imminent. In general, predictions of specific collapse events cannot yet be made.

Identification of Hazardous Areas

Because the timing of a dome-collapse event cannot be reliably predicted, the best strategy for reducing risk to people from a growing dome is to limit access to areas that could be swept by a pyroclastic flow or its overriding ash-cloud surge. A long-term strategy for reducing risk to people and property is to minimize development within hazardous areas. The scientific basis for identifying these areas hinges on several factors: comparison of elevation loss to runout distance for observed pyroclastic flows and ash-cloud surges from domes, estimated volume of a potential collapse, local topography, geologic record of deposits from past dome collapses, and the state of restlessness of the volcano (for example, variations in seismic activity). The same general strategy applies in minimizing human exposure to lahars that may occur as a consequence of intense rainfall or the melting of snow and ice by hot pyroclastic flows.

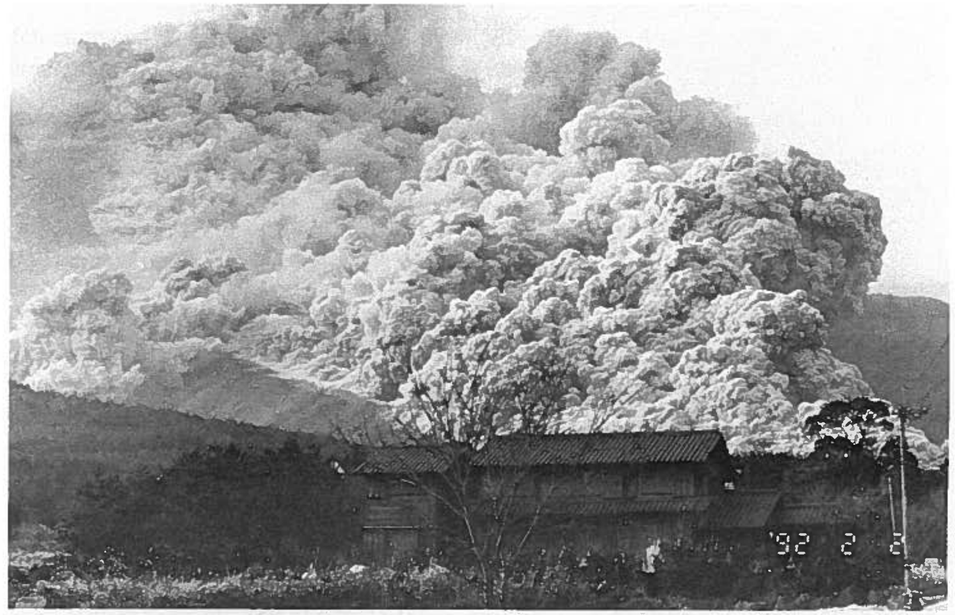
Whether public access to these potentially hazardous areas is restricted, especially for worst-case scenarios, depends on the level of risk that the public and officials are willing to accept. Agreement on an acceptable level of risk is difficult to achieve when such decisions may require people to abandon their land, homes, and businesses for extended periods of time. If an initial dome collapse fails to produce pyroclastic flows large enough to reach the outer boundary of a designated hazard area, public pressure often develops to reduce the size of the exclusion zone, even though the true hazard has not changed. These issues severely tested Japanese scientists and officials in 1991 when, after 198 years of quiet, Unzen volcano erupted a lava dome.

Eruption of Unzen Volcano, 1991–1993

When pasty lava first breached the forested summit crater of Unzen in May 1991 after several months of small explosions, nearby residents may have breathed a sigh of relief. The slow extrusion of gas-poor lava quietly built a small dome that made the volcano seem less threatening and less likely to erupt explosively. But, within three days, as the margin of the growing lava dome crept toward the crater's precipitous edge and then became perched above the volcano's east flank, the first of many small pyroclastic flows swept as far as 2 km down the volcano.

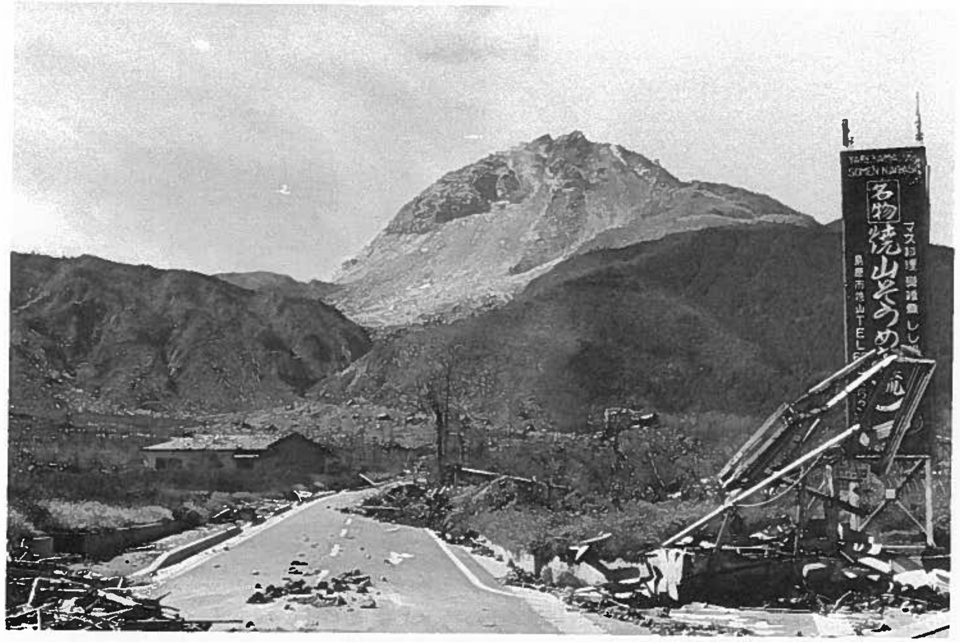
Suddenly on June 3, a much larger dome collapse and explosion produced a pyroclastic flow and ash-cloud surge that raced 4.5 km from the crater, burning about 180 houses and killing 43 people who had ventured into a previously designated hazard zone. Subsequently, lava continued to extrude from the summit crater toward the volcano's east flank. Another collapse event on June 8 swept 5.5 km down the same river valley, burning 210 additional houses. By the end of July, extruding lava had built an elongated dome—500 m long, 150 m wide, and 80 m high—that generated an average of about 10 small pyroclastic flows every day.

Information about Unzen volcano was provided by Japanese scientists and gathered by Steven R. Brantley and other USGS scientists during visits to the volcano that were supported by the Ministry of Construction of Japan for consultation with scientists of the Public Works Research Institute. We thank Dr. Yoshiharu Ishikawa and his colleagues for arranging field trips to Unzen and for many engaging discussions.



Unzen volcano, Japan. Pyroclastic flow races downslope from a lava dome (upper left). The leading edge of the pyroclastic flow is still moving (lower right). Billowing ash rises convectively from the hot flow. In this area, several thousand people abandoned their homes and land due to pyroclastic flows, ash-cloud surges, and lahars. Copyrighted photograph by K. Ohkawa, reprinted with permission.

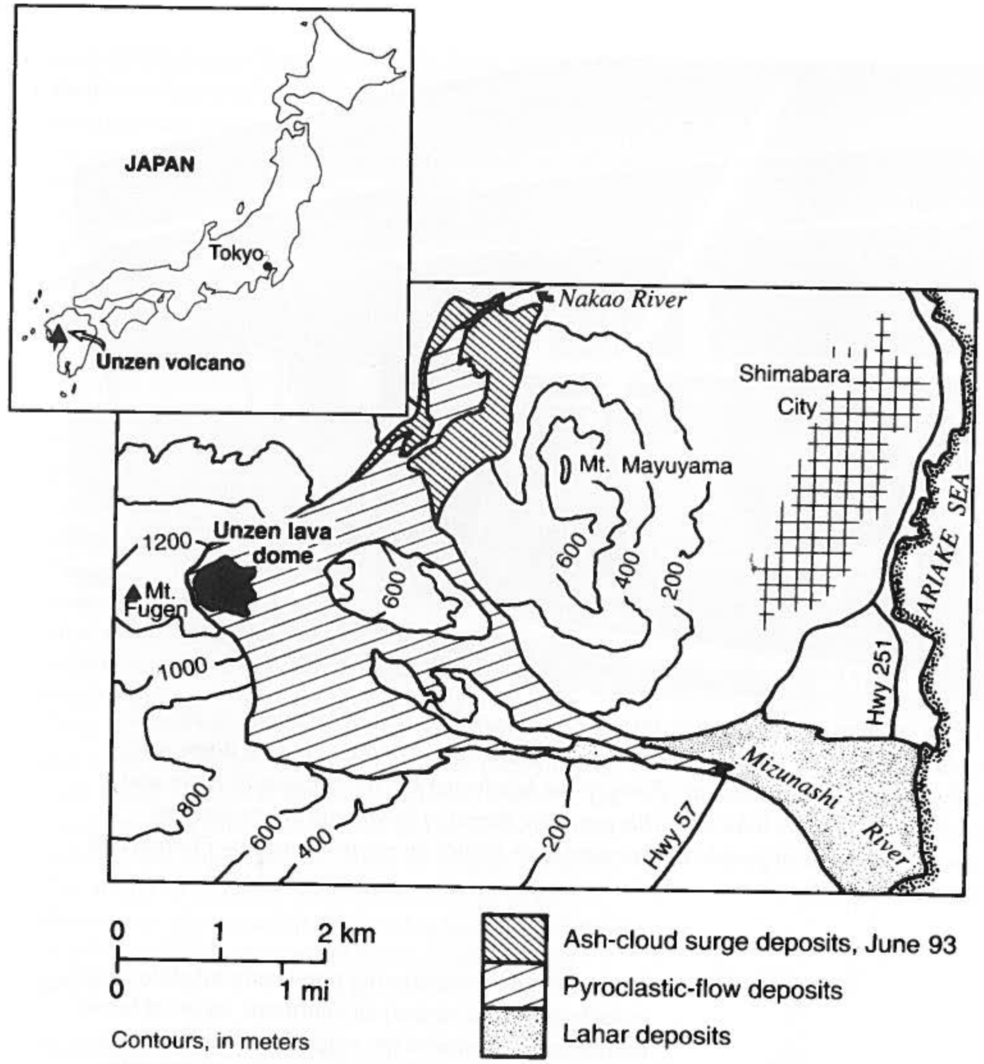
Unzen volcano, Japan. Remnants of a once thriving community, 4.5 km from Unzen, destroyed by ash-cloud surges on June 3, June 8, and September 15, 1991. The ash-cloud surge on June 3 killed 43 people. The surges swept from right to left. Copyrighted photograph by S. Nakada, Kyushu University, reprinted with permission.



Unzen volcano, Japan. Buildings destroyed and vegetation burned by ash-cloud surges associated with pyroclastic flows in the Nakao River valley. Only the dilute ash-cloud surge reached this part of the valley floor (foreground). Large lava fragments typical of pyroclastic-flow deposits are visible near the mouth of the narrow canyon below Unzen. Photograph by K. M. Scott, 1993.

Between June 1991 and December 1993 the pattern of eruption — extrusion of lava and frequent collapse of the dome's eastern margin — progressively increased the volcano's potential for wreaking havoc on local residents. By 1992, pyroclastic flows were rushing down a broader sector of the volcano and lahars became commonplace as heavy rains remobilized the hot pyroclastic debris. Reaching beyond areas covered by pyroclastic flows, these lahars swept away bridges and buried roads, precious farmland, and houses with boulders, gravel, and sand.

The actively collapsing margin of Unzen's growing dome changed location many times in response to where magma was rising into the dome and leaking onto the surface. Depending on which margin was active, pyroclastic flows spilled into one of four stream valleys. Scientists devoted much of their attention to



Map of Unzen volcano and areas effected by pyroclastic flows, ash-cloud surges, and lahars. Figure based on a preliminary map prepared in July 1993 by S. Nakada, Kyushu University.

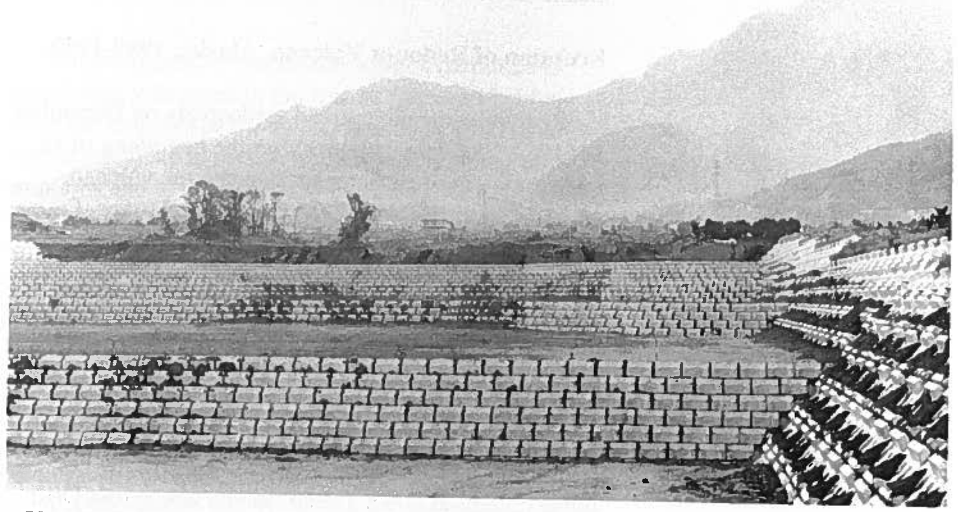
monitoring the dome's active margin to identify which valley was most at risk from pyroclastic flows. For example, two years after the eruption began, pyroclastic flows started cascading northeast into the Nakao River valley for the first time. The most extensive of these flows reached a point 4.5 km from the dome. Fortunately, officials had already ordered residents to evacuate this area in anticipation of these pyroclastic flows.

Unzen volcano, Japan. House destroyed and partially buried by lahars in the Mizunashi River valley. Large rounded boulders are blocks of the new lava dome originally deposited by pyroclastic flows in the headwaters of the Mizunashi River and later remobilized by lahars. In this area, the threat of lahars during rainstorms caused thousands of people to evacuate their homes on many occasions. Photograph by S. R. Brantley.

In addition to destroying previously inhabited areas, pyroclastic flows created an enormous apron of loose fragmental deposits on the volcano's steep east side. The apron has filled the headwaters of streams with many tens of meters of debris. Combined with destabilization of old debris on Unzen's upper slopes owing to the death of vegetation, these deposits are a ready source of loose debris for generating lahars during rainstorms. Heavy rainfall, commonly exceeding 1 cm/hr in this area, readily erodes this material to form destructive lahars. Between August 1992 and July 1993, lahars triggered by heavy rains damaged about 1,300 houses. Each period of heavy rain required sudden evacuation of several thousand residents along the Mizunashi and Nakao rivers.

Japanese officials have worked hard to ensure public safety by developing an efficient warning system and evacuation plan. They have also sought to minimize destruction from lahars by building "countermea-

Unzen volcano, Japan. Deep gully on the north side of Unzen eroded in older volcanic deposits during periods of heavy rain in 1991–1993. Note bare limbs on trees alongside the gully, which is at least 15 m deep. Death of vegetation by pyroclastic flows and ash-cloud surges promoted erosion of older pyroclastic-flow deposits on the volcano's steep slopes. Photograph by K. M. Scott.



Unzen volcano, Japan. Concrete-lined sediment basin in the Mizunashi River valley downstream from Unzen. Widely used in Japan as a "countermeasure" to mitigate the destructive effects of lahars as well as non-volcanic debris flows, this basin is one of three at Unzen built to trap sediment carried by lahars. After the basins fill with sediment, workers excavate the material to make room for subsequent lahars. Photograph by S. R. Brantley.

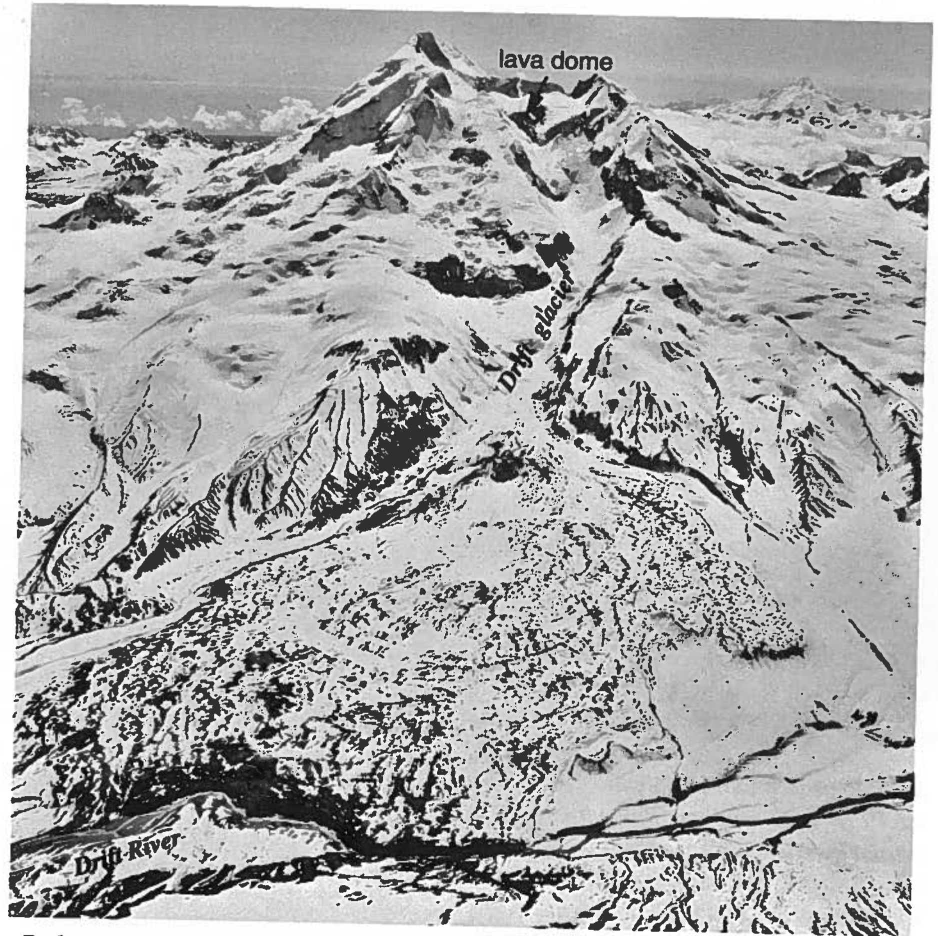
sures" designed to trap sediment and channelize the flows as much as possible. Countermeasures along the Mizunashi River include three sediment basins lined with interlocking-concrete blocks and a series of discontinuous dikes along both sides of the main channel. The dikes funnel most of the flows down the main channel while allowing some material to spill around their margins. When the sediment basins and areas around the dikes fill with debris, workers excavate the debris with heavy equipment to make room for the next series of lahars.

A similar long-term eruption scenario is possible at Mount Hood in Oregon. Dome collapses and lahars at Mount Hood would require public officials and residents to wrestle with the similar issues regarding evacuations, even though the area around the volcano is much less developed than at Unzen. Complicating the hazard scenario at Mount Hood is the presence of snow and ice, which ensure that lahars would be triggered directly by some dome collapse events. The collapse of several domes at Alaska's Redoubt Volcano in 1990 provided insight into the generation and effects of such lahars. This eruption also drew critical attention to hazards to aircraft posed by eruption clouds downwind from the volcano and to the danger from an ash-cloud surge that can move well beyond the edge of a pyroclastic flow.

Eruption of Redoubt Volcano, Alaska, 1989-1990

Redoubt Volcano erupted explosively on December 14, 1989, less than 24 hours after the beginning of an intense swarm of earthquakes beneath the volcano, which is about 180 km southwest of Anchorage. From a new vent blasted through the ice-filled summit crater, a 10-km-high eruption column spread ash to the northeast. Ash from several subsequent explosive eruptions blanketed much of southern Alaska. By December 22, pasty lava began oozing from the vent and a new lava dome rose.

On January 2, 1990, this initial dome was destroyed by two strong explosions and a collapse event. The dome collapsed down a deep canyon and across Drift glacier on the north flank of Redoubt. In the next four months, a succession of lava domes grew in the crater and then were subsequently destroyed, chiefly by gravitational collapse. The resulting pyroclastic flows swept over Drift glacier, cut huge channels in the glacial ice,



Redoubt Volcano, Alaska. A faint vapor plume rises from the 1990 lava dome in the breached summit crater. Numerous dome-collapse events melted snow and ice from Drift glacier to form lahars between January and April in 1990. Iliamna Volcano can be seen in distance on right. Photograph by D. Richardson, Bureau of Land Management.

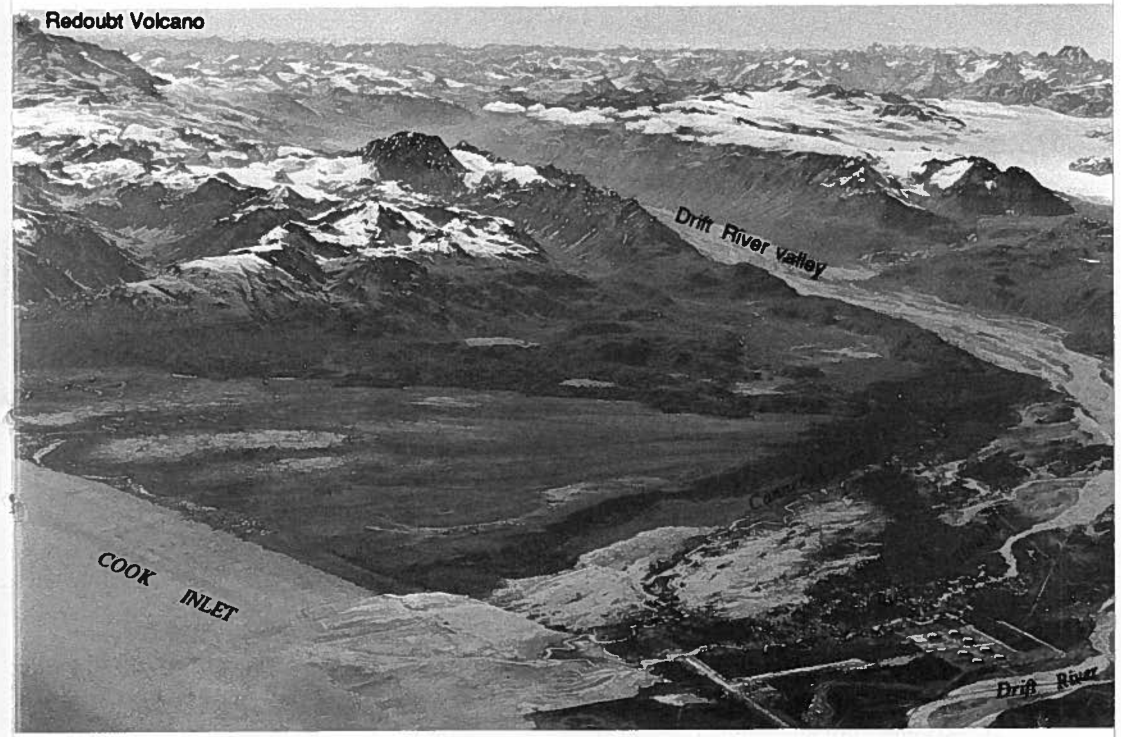
and reached distances 6–8 km from the crater. Many of the pyroclastic flows melted sufficient snow and ice to form lahars that reached Cook Inlet about 40 km to the east.

One pyroclastic flow triggered by a dome collapse spawned an unusually energetic overriding ash-cloud surge that ultimately reached a distance of 12 km from the crater. When this surge encountered a steep, 700-m-high ridge about 8 km north of the vent, it had sufficient momentum to climb the ridge and

Lava dome at Redoubt Volcano, Alaska. This 350-m-wide dome was extruded during the 1989–1990 eruption. Below the dome, the erosive action of pyroclastic flows caused by dome collapses stripped away upper Drift glacier and exposed the underlying bedrock. The summit of Redoubt Volcano (elev 3108 m) can be seen in upper left. Photograph by D.E. Wieprecht.

continue on for another 4 km. The hot mixture of gas and ash-sized and gravel-sized rock debris burned and abraded small willow trees on the ridge and drove the ends of broken branches at least 1 m into the snow.

We do not know why this ash-cloud surge traveled so much farther than the others. Clearly, some dome-collapse events can trigger pyroclastic flows with attendant ash-cloud surges that can travel several kilometers beyond the average distance. Such rare, but large, collapse-triggered surges at both Unzen and Redoubt volcanoes emphasize the need for scientists and public officials to be conservative when outlining hazardous areas.



View of Redoubt Volcano, Drift River valley, and Cook Inlet. During the volcano's 1989-1990 eruption, several lahars swept more than 40 km down Drift River and into Cook Inlet. An oil-loading terminal near the river (storage tanks, lower right) was partially inundated by two of the lahars. Due to channel aggradation, Drift River changed course repeatedly, shifting from one side of the terminal to the other side. Photograph by S. R. Brantley.

Redoubt Lahars Close Oil Terminal

Lahars triggered by melting snow and ice from dome collapses at Redoubt Volcano caused a temporary shutdown of an oil-storage and tanker-loading terminal at the mouth of Drift River. They also interrupted operations at 10 oil platforms in Cook Inlet. The platforms produced about 30,000 barrels of oil per day before the eruption. Parts of the oil-storage facility were inundated by water almost 1 m deep from a lahar during the eruption on January 2, 1990. Sedimentation by subsequent lahars caused the active channel of the river to shift many times as it flowed across the broad alluvial plain on which the terminal was built.

Head of canyon in Drift glacier on Redoubt Volcano. The canyon was eroded into glacial ice by hot pyroclastic flows from dome collapses. As shown at upper left, the glacier is mantled by several meters of pyroclastic-flow deposits. Helicopter in foreground indicates scale. Photograph by T.P. Miller.

Redoubt Eruption Clouds Disrupt Air Traffic

During the largest explosive eruption on December 15, 1989, a Boeing 747 en route from Amsterdam to Anchorage with 231 passengers unknowingly flew into Redoubt's eruption cloud about 240 km downwind from the volcano. As the pilot attempted to climb out of the cloud, tiny ash particles ingested by the engines melted to form a glassy deposit that impeded air flow and stalled all four engines. After gliding steeply for 8 min and losing 4,000 m of altitude—and with only 2,000 m of ground clearance remaining—the crew was able to restart the engines. The plane landed safely at Anchorage, but this near tragic encounter galvanized action among commercial and military operators, aircraft manufacturers, and Federal agencies to prevent future volcanic-ash encounters. Aircraft successfully avoided direct contact with subsequent eruption clouds, but ash lingering in the atmosphere led to a higher than usual rate of window glazing and greater engine wear.

Anchorage International Airport, a busy refueling stop and cargo-transfer center for flights between Asia and Europe. In 1989-90, dome collapses at Redoubt Volcano, 180 km southwest of Anchorage, generated eruption clouds that intermittently interfered with air traffic. Photograph by Mark Sok, Anchorage International Airport, reprinted by permission.

Between January and April 1990, each of the dome-collapse events at Redoubt Volcano formed eruption columns that rose at least 8,000 m above sea level. Downwind, the eruption clouds caused multiple ash falls in Kenai and Soldotna, resulting in darkness during daylight hours, local power outages, school closures, and cancellation of sports and cultural events.

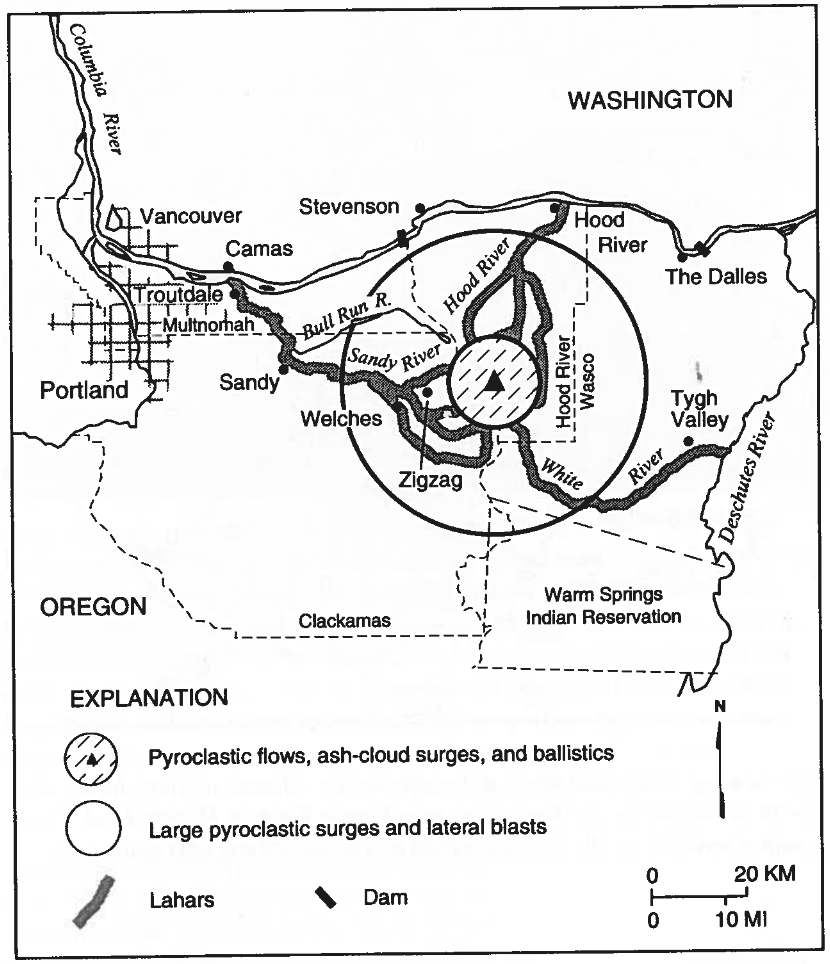
Dome Eruptions at Mount Hood

Visitors viewing Mount Hood from the south are impressed by the extensive, triangular-shaped apron of rock debris tapering upward to Crater Rock. Individual lava rocks in the apron are more than 5 m in diameter. Hikers on the Timberline Trail, which cuts across the debris apron and descends into several deep canyons, find the secret of the debris apron and Crater Rock. The debris apron is composed of tens of layers of fragmented lava, some several meters thick. The layers are

Mount Hood, Oregon. These interbedded deposits of pyroclastic flows and lahars are exposed in Little Zigzag Canyon on the southwest side of Mount Hood. A series of dome collapses at the site of Crater Rock formed these deposits about 1,500 years ago. Note size of the lava blocks in the deposits; man standing on snow at bottom of photograph shows scale. Photograph by D.R. Crandell.

deposits of pyroclastic flows and lahars formed by dome collapses. Crater Rock is the most recent of a series of lava domes that grew and collapsed during two periods of activity, one about 1,500 years ago and the other only about 200 years ago.

At Mount Hood, the abundance of deposits related to dome collapses and the rarity of evidence for other types of volcanic activity indicate that the most likely type of eruption in the future will be the growth and collapse of another dome, probably at or near the site of Crater Rock. As indicated by the debris apron, future dome collapses will produce pyroclastic flows and overriding ash-cloud surges, the largest of which could travel as far as 10 km or more down the volcano's south and west flanks. When pyroclastic flows melt snow and ice, or when an intense rainstorm erodes newly emplaced deposits, lahars will race down one or more drainageways, including Still Creek and the Sandy, Zigzag, Salmon, and White rivers.



Volcanic hazards at Mount Hood, Oregon. This map shows river valleys that are subject to the effects of lahars originating at Mount Hood during growth and collapse of a new lava dome. A dome growing at the site of Crater Rock in the future would trigger lahars that travel east, south, and west. A dome growing high on a different side of the volcano would cause lahars to travel north. The shaded inner zone is shown in detail in the next figure (p. 266). The outer zone is subject to the effects of large pyroclastic surges or lateral blasts like the one that occurred at Mount St. Helens on May 18, 1980.

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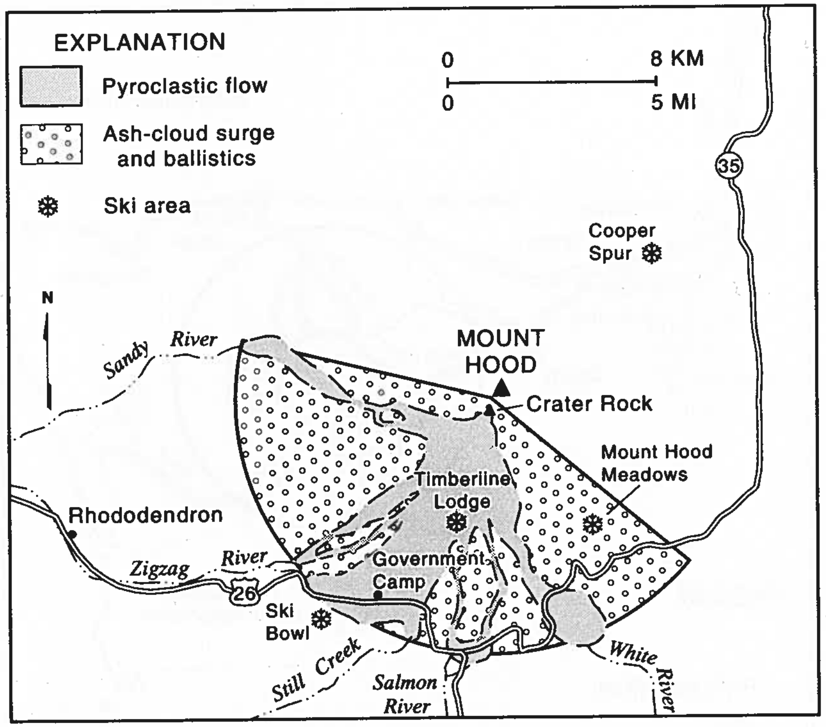

Map showing areas most likely to be affected by volcanic activity during the growth and collapse of a lava dome near Crater Rock on Mount Hood. Dome growth elsewhere on the volcano would direct the activity east and north.

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If we consider the events at Unzen and Redoubt Volcano as a guide, a future dome at Mount Hood could grow episodically over an extended period of time, perhaps months or several years. Numerous pyroclastic flows, ash-cloud surges, eruption clouds, and lahars can be expected during such dome growth. Areas likely to be affected by pyroclastic flows and lahars include major resorts, numerous businesses, bridges and highways, regional utility lines, and hundreds of private homes. Local, State, and Federal officials will need to make many decisions when the volcano begins to show signs of unrest. Will U.S. Highway 26, an

important highway connecting Portland with central Oregon, be closed? Will residents of Government Camp be evacuated and for how long? Which areas of the Mount Hood National Forest, an important recreational area used by several hundred thousand people each year, will be closed to the public? How will commercial aviation cope with the threat of eruption clouds along several major air routes?

These questions will not be easy to answer in view of the inconvenience and economic losses that some of these decisions are likely to cause. Furthermore, decisions regarding public access and evacuations will have to be made in the face of scientific uncertainty as to exactly when pyroclastic flows or lahars will be triggered and how far they will travel. Making matters worse, a large quantity of sediment derived from pyroclastic flows and lahars is likely to cause river channels in the affected basins to aggrade, change course, and migrate across valley floors. The economically important shipping channel of the Columbia River will also be impacted.

Anticipating an Eruption at Mount Hood

The scenario we describe for a future eruption at Mount Hood is based on the geologic record of its most recent eruptions and a comparison with observed dome eruptions at Unzen and Redoubt volcanoes. Experience with these recent eruptions suggests a range of warning time—from less than 24 hours to as long as one year—that we might expect between the onset of volcanic unrest and first eruption.

Japanese scientists monitoring Unzen first detected anomalous earthquake activity beneath an area 13 km northwest of the volcano in November 1989. One year later, the locus of earthquake activity migrated directly beneath Unzen and a series of small explosive eruptions began a few days later on November 17, 1990. The lava dome was extruded on May 20, 1991, and the first pyroclastic flows began four days later.

At Redoubt Volcano, scientists of the Alaska Volcano Observatory identified a rapid increase in the number of earthquakes beginning only 24 hr before the first explosive eruption on December 14, 1989. A lava dome appeared on December 22 and the first collapse event occurred 11 days later.

Similar sequences of precursory earthquakes at Mount Hood would be detected immediately. With support from the USGS, scientists from the Geophysics Program at the University of Washington monitor seismic activity at Mount Hood. Three seismometers are presently located within 15 km of the summit and are supplemented by an extensive regional seismic network. At the first sign of significant earthquake activity near Mount Hood, scientists will install additional seismometers and initiate other monitoring activities. For example, benchmarks placed high on the volcano in 1980 will be resurveyed; significant changes in these benchmark positions can mean that magma is rising toward the surface. Furthermore, scientists plan to measure sulfur dioxide and carbon dioxide gas emissions from the volcano.

When unusual activity is observed at Mount Hood in the future, scientists will immediately notify govenment officials and the public. According to the existing emergency-notification plan developed after the eruption of Mount St. Helens in 1980, the U.S. Forest Service will serve as the primary dissemination agency for emergency information. As the volcano's activity changes, USGS scientists will provide updated advisories and meet with local, State, and Federal officials to discuss the hazards and appropriate levels of emergency response.

Additional Reading

For a more complete description of the 1989–1990 eruption of Redoubt Volcano, of problems concerning volcanic ash and aviation safety, and of activity that could accompany future eruptions of Mount Hood, the reader may consult the following publications:

Brantley, S.R. (ed.), 1990, The eruption of Redoubt Volcano, Alaska: December 14, 1989–August 31, 1990, U.S. Geological Survey Circular 1061, 33 p.

Casadevall, T.J., 1994, Volcanic Ash and Aviation Safety: Proceedings of the First International Symposium on Volcanic Ash and Aviation Safety, U.S. Geological Survey Bulletin 2047, 450 p.

Crandell, D.R., 1980, Recent eruptive history of Mount Hood, Oregon, and potential hazards from future eruptions, U.S. Geological Survey Bulletin 1492, 81 p.

Till, A.B., Yount, M.E., and Riehle, J.R., 1993, Redoubt Volcano, Southern Alaska: A hazard assessment based on eruptive activity through 1968, U.S. Geological Survey Bulletin 1996, 19 p.

The above publications can be ordered from the U.S. Geological Survey; Information Services; Federal Center Box 25286; Denver, CO 80225 (303) 236-7477.