

cutin, three miles to the west. When it approached Parícutin it was moving at a rate of about 100 feet an hour. Another flow on the east side of the cone spread out like a large fan at the base of the volcano. According to Foshag, this one went 1,500 feet in 15 minutes.

While one of these flows was in progress, I had the good fortune to fly over the volcano. At this time the crater was nearly full; lava extending to within 50 feet of the lip. The top of the lava in the crater was congealed, and was broken in large blocks. Ashes were issuing from a vent estimated to be 75 to 100 feet in diameter in the northwest part of the lava field within the crater, but relatively few explosions were seen. Lava was flowing from an opening on the east side of

the cone. This vent was 50 to 75 feet in width and 200 to 300 feet in height. The upper limit was 100 to 150 feet beneath the lip of the crater. The lava coming through the opening was red hot, but it soon cooled and congealed while flowing down the sides of the volcano. The cone was intact above the point of escape of lava, but according to Foshag it subsequently was undermined by the flow.

At this time, June 19th, Parícutin was 1,200 feet in altitude. By late September it had reached a height of 1,500 feet. At that time it was still exploding at about the same rate as when it started, and was showing no signs of dying. In the meantime several other flows of lava had appeared, mostly from within the cone. Parícutin truly is now a full-fledged volcano.

4 Volcanic Hazards in the Cascade Range*

Dwight R. Crandell and Howard H. Waldron

Newspapers recently carried the story that the Vatican had just demoted 90 saints, including St. Januarius. You may recall that his blood is kept in

vials in a cathedral in Naples and that it liquifies several times each year. One of these times is on December 16, which is the anniversary of the 1631 eruption of Mount Vesuvius. According to the newspaper article, St. Januarius has stopped the lava flows from Mount Vesuvius many times, and has repeatedly saved the Neapolitans from countless other catastrophes. Perhaps we should invoke the spirit of St. Januarius, as we discuss geologic hazards, and perhaps he should also be our patron saint.

We are pleased to report that the human casualty rate has been very low, probably nil, from volcanic erup-

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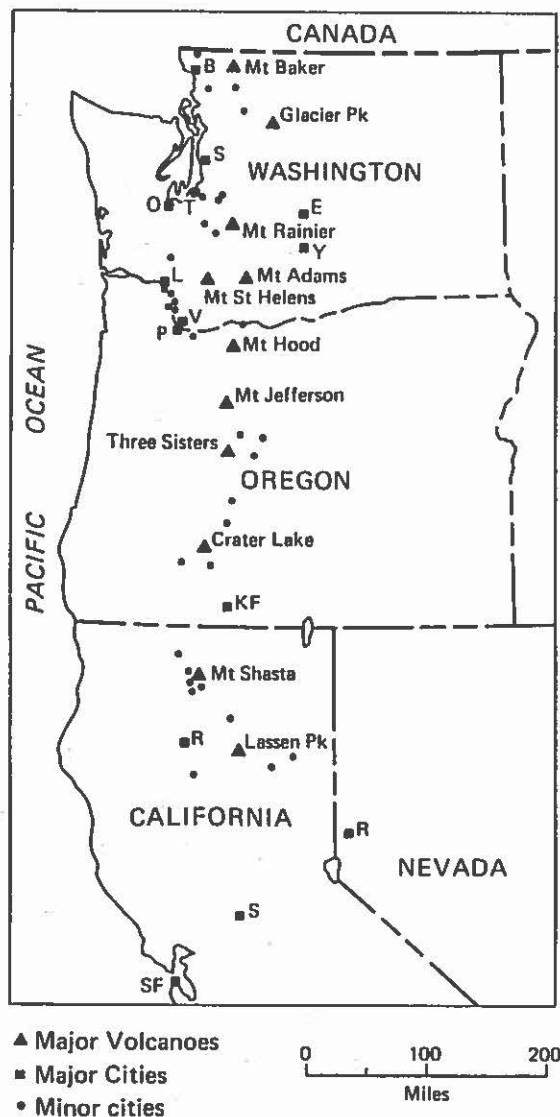


FIG. 1. Index map of Cascade Range, showing locations of major volcanoes, and major and minor cities in their vicinity.

tions in the Cascade Range (Fig. 1) within historic time. There is a report of an Indian who burned his leg against a lava flow from Mount St. Helens in 1844, and in 1914 a man who stood

too close to the erupting crater of Lassen Peak was rather badly injured by a rock that flew out of the crater. But even he is still alive today.

So, we really cannot evaluate the di-

mension of volcanic hazards in the Cascade Range by the past casualty rate or by the amount of past property damage, as we can with some other geologic hazards. I think we will all agree that it's our good fortune to have volcanoes that are pretty tame. At least they are today!

This very lack of repeated eruptions in the Cascade Range is a problem in itself, for it is very difficult to predict the behavior of a volcano that has never been observed to erupt. For example, Arenal volcano in Costa Rica had been dormant for hundreds of years; in fact, it was thought to be extinct. But it erupted violently on July 29, 1968 with very little warning and killed more than 70 people in nearby villages. A year ago, if someone had asked which Costa Rican volcano might erupt next, Arenal probably would not have even been on the list; and, naturally, nothing was known about what kind of eruption could be expected.

Likewise, we don't know which of the Cascade volcanoes will be the next to erupt, but by means of a hazards evaluation study at a given volcano, we can predict some of the effects if that volcano were to erupt. We do this by finding the deposits of past eruptions, by dating these deposits, and by inferring what they mean in terms of kind, extent, and frequency of volcanic activity. We then assume that future eruptions most likely will follow the same pattern.

Before going any farther, however, we need to go into a little background on volcanoes so that you'll understand some of the terminology we will use later on. The best way to start is by mentioning some of the kinds of eruptions, or other processes caused by volcanism, that might be dangerous.

These are lava flows, eruptions of volcanic ash, eruptions of hot avalanches of volcanic ash and rock debris, and the formation of mudflows and floods due to an eruption. There are other volcanic processes, but we will limit our discussion to these four types.

Lava flows are the streams of molten rock that come from volcanoes. They are confined chiefly to valleys and other low areas. They may move at greatly different speeds, but most are so slow that people can easily get out of their way as they approach. The indirect effects of lava flows might be very dangerous. In fact, they may be much more dangerous than the direct effects. For example, lava flows might start forest fires or if the lava moves out onto snow and ice, it might cause very rapid melting and produce floods or mudflows.

In a *volcanic ash eruption*, great quantities of rock fragments and dust are blown high into the air by repeated explosions. And then the wind takes over. The fragments may be solid rock or pumice. Pumice is a volcanic rock full of bubbles and so light in weight that it can be transported great distances by wind for hundreds, even thousands, of miles.

Hot avalanches of ash and rock debris are a little harder to visualize. Sometimes a large volume of hot, dry fragments is blown from a crater by a volcanic explosion. The mass then avalanches down the side of the volcano, trapping air and heating it and becoming very mobile; gaining speed, it may move several miles beyond the base of the volcano. The rock fragments themselves may be giving off hot gas, which cushions and lubricates the debris so it acts just like a flow of fluid material. Such avalanches may

move at speeds of 35 to more than 70 miles an hour. The temperature in the avalanche, and in the cloud of smoke and dust that rises above and accompanies it, may be hundreds of degrees centigrade, so that everything in its path is incinerated. The initial eruption of Arenal volcano in Costa Rica in July, 1968 produced one of these hot avalanches and clouds, which swept down into nearby villages. Two days later, another hot avalanche and cloud erupted just as a rescue party was moving in jeeps into the devastated area, and eight more people were killed.

The last process we'll consider is that of *floods and mudflows*. You all know what a flood is. A mudflow is simply a flood of wet mud and rock debris—it looks very much like wet concrete carrying boulders. Mudflows very commonly form on the sides of active volcanoes, chiefly because these steep slopes are frequently mantled with loose rock debris that is very unstable. When this material becomes mixed with water from rain or melting snow, or from the spillover of a crater lake, it may form a mudflow which will move many miles downstream at speeds of several tens of miles an hour.

Now, which of these volcanic events might present the greatest danger to the most people, if one of the Cascade volcanoes were to erupt? We believe that ash eruptions and mudflows are the two greatest hazards.

The degree of hazard from an ash eruption depends on the amount of material blown out, the rate and duration of the eruption, the strength and direction of the winds blowing at the time of the eruption, and also the distance people are from the volcano. On May 22, 1915, the most violent of a

long series of eruptions of Lassen Peak in northern California sent a column of volcanic ash at least six miles into the air. Ash was deposited from this cloud as it drifted eastward into Nevada, and some fell as far east as Winnemucca, 100 miles downwind. But, fortunately it was a very brief eruption and only a relatively small amount of material was blown out.

Figure 2 shows an area covered by a pumice eruption at Crater Lake about 7,000 years ago. This was a catastrophic eruption. The pumice blanketed an area of several hundreds of thousands of square miles in the northwestern United States. The patterned area was covered by six inches or more of pumice, and the outer line shows the total area of the ash fall. The 6-inch fallout area has been superimposed on other volcanoes to give an idea of the area that might be most seriously affected if a similar type and scale of eruption should occur at any of them.

What are the actual hazards from volcanic ash? Breathing ash is like breathing in a duststorm; it's hard on the respiratory system as well as the eyes. Close to the volcano there may be also toxic fumes such as sulphur dioxide. Ash will destroy vegetation, including crops. It will reduce visibility for both highway and air travel, and aircraft could be damaged by flying through clouds of volcanic ash. Surface water supplies will be contaminated, both by sediment and by a temporary increase in acidity, although this acidity may go away within a few hours after the ash eruption stops. Roofs may be overloaded. A 1-inch ash fall, for example, will load a roof

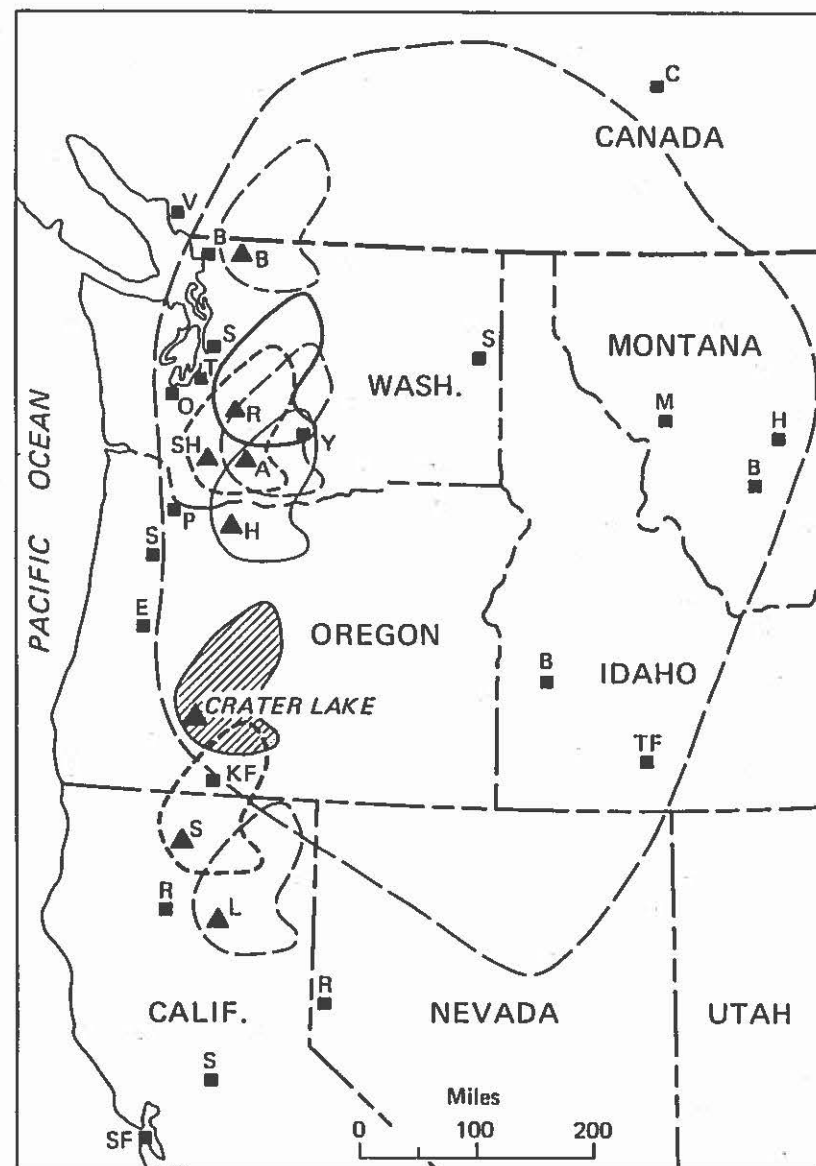


FIG. 2. Map of Cascade Range, showing area covered by pumice eruption at site of Crater Lake about 7,000 years ago. The outer line shows maximum limits of ash fall; inner line (pattern) shows area covered by 6 inches or more of pumice. The same 6-inch thickness line is shown superimposed on the other major volcanoes of the range. Data from reports by Howel Williams and H. A. Powers and R. E. Wilcox.

by about an additional ten pounds per square foot. This means perhaps a 7-ton load on a roof with a surface area of 1,500 square feet. Rainfall will increase the load, because the rain will soak into and saturate the ash. If rainfall is heavy, ash might be carried by running water into gutters, storm drains, and sewers, and it could also block streets; it may also run as mudflows if enough of the ash becomes saturated.

The U. S. Geological Survey Bulletin 1028-N, by Ray E. Wilcox, discusses the effects of volcanic ash falls; it will be a very useful reference when we have the next volcanic ash eruption here in the United States.

The other volcanic event of high potential hazard is that of mudflows and floods. The volcanoes in the Cascade Range are especially dangerous in this respect because most have a perennial snow cover, which can be melted readily by a lava flow or by a hot avalanche or by some other volcanic process. Mudflows are especially dangerous because they move at very high speeds. Generally speaking, they can move faster than water floods, and they can travel tens of miles down valley floors if they have enough volume.

Consider the unfortunate Indian who was standing at the townsite of Enumclaw in western Washington (Fig. 3) about 5,000 years ago. He was probably looking in wonder at the clouds of steam and ash rising from mighty Tahoma, the mountain he called God, and which we call Mount Rainier. Although he probably felt safe at his distance of 25 airline miles from the volcano, he didn't realize that a wall of mud hundreds of feet deep was rushing down the White River valley to-

ward him. When he first saw the mudflow, it was still a mile away, but it was moving about 20 miles an hour.

What do you suppose the reaction would be today of the present citizens of Enumclaw in a similar circumstance? Probably the same as the Indian's—run like hell! But the only way to get out of the way of a mudflow as large as this would be by a car headed in the right direction. The right direction would be toward high ground, and this is not necessarily the direction that highways go.

We wish to point out an important difference between mudflows and floods. Floods are generally preceded by heavy rain and by gradually rising rivers. People normally can get out of the way, unless the flood is caused by a dam failure or some other sudden event. When the flood recedes, the water drains away and the danger is over, whereas, in the case of a mudflow, the mud remains forever. For example, the mudflow beneath the townsite of Enumclaw (Fig. 3) is still there, tens of feet deep. The town of Herculaneum, in Italy, five miles from the foot of Vesuvius, now lies beneath a volcanic mudflow, or rather a succession of three volcanic mudflows that total 80 feet deep, formed during the eruptions of 79 AD.

Volcanic mudflows, especially the really big ones, can occur with little or no warning. Most are likely to start during an eruption, when the volcano is hidden by clouds of smoke, steam, and ash. The upper parts of valleys heading on volcanoes, therefore, should be watched very carefully during an eruption in order to take advantage of what little warning there might be, before a mudflow comes down into a populated area.

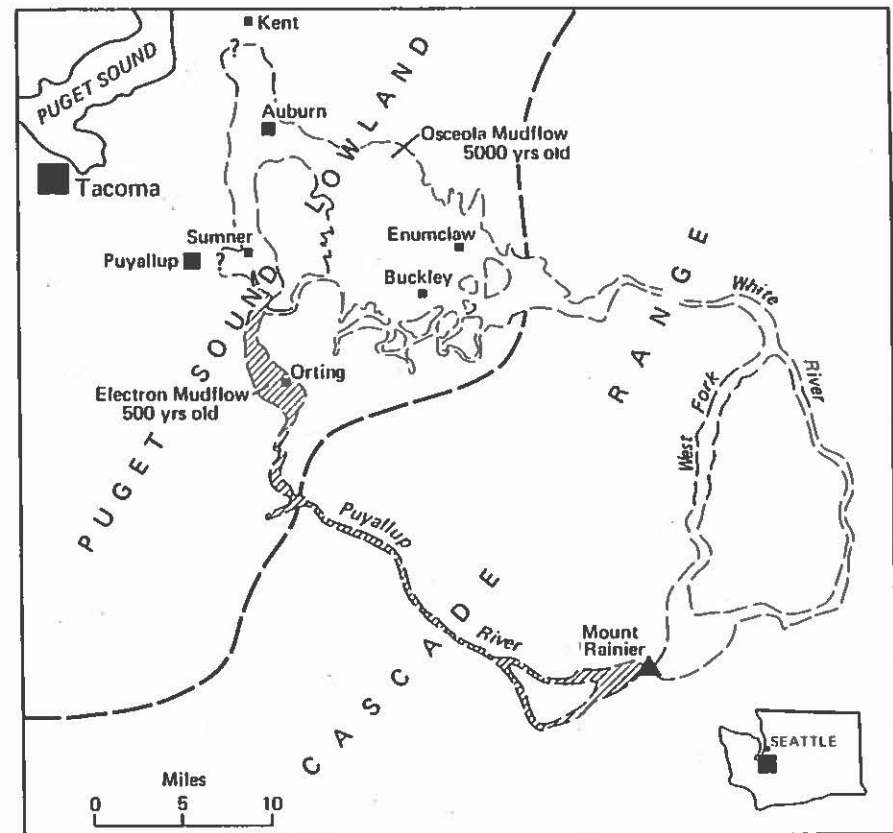


FIG. 3. Map of Mount Rainier and vicinity, showing extent of the Osceola Mudflow in the White River valley and the Electron Mudflow (pattern) in the Puyallup River Valley.

Now, we wish to appraise briefly four potentially dangerous volcanoes in the Cascade Range, which are, from north to south (Fig. 1), Mount Baker, Mount Rainier, Mount St. Helens, and Mount Shasta. These are not necessarily the only volcanoes that are potentially dangerous, or even the ones most likely to erupt next, but possibly they would threaten the largest number of people if they did erupt violently.

Very little is known about the frequency of volcanic activity at Mount Baker within the last 10,000 years, but we do know that it has erupted lava flows and volcanic ash several times. Minor eruptions of smoke or ash were reported by observers in 1843, several times between 1853 and 1859, and again in 1870. Unfortunately we know so little about Baker's behavior that we can't yet realistically assess the poten-

tial hazards there. We do suggest, however, that the chief hazard might be related to a pair of reservoirs at the southeast base of the volcano. These reservoirs are Lake Shannon and Baker Lake, which have a combined length of 18 miles. Downstream from these hydroelectric reservoirs are communities on the floor of the Skagit River valley that have more than 15,000 inhabitants. A large flood or mudflow down the east side of Mount Baker seemingly would threaten the lakes and the downstream communities as well. If a mudflow or flood raised the reservoir level very rapidly, faster than the spillways could accommodate the overflow, spillover across the dam itself could occur, with disastrous results.

Going south, we come to Mount Rainier. We know quite a lot about the past behavior of this volcano. Our studies there are described in Geological Survey Bulletin 1238, entitled *Volcanic Hazards at Mount Rainier*, Washington. These studies show that within the last 10,000 years there have been at least 55 large mudflows, several hot avalanches of rock debris, at least one period of lava flows, and at least 12 eruptions of volcanic ash. The last major eruption was about 2,000 years ago; it involved an eruption of lava and of pumice, and there were also several large mudflows. This extensive eruptive record doesn't necessarily mean that Rainier has been more active than Baker, but only that we have a lot more information about it. Within historic time, many eruptions on a minor scale were recorded in the 1800's, but only one produced pumice. This eruption occurred between about 1820 and 1855—we can't date it any more

closely than that. The last reported eruption of steam and smoke was in 1894.

If we assume that Rainier will continue to behave as it has during the last 10,000 years, the principal hazard will be from mudflows down valley floors. These might consist of a few million cubic yards of mud and be confined to the valley floors very close to the volcano, but there is also a possibility of a huge mudflow, like the Osceola, which covered the present site of Enumclaw. This would be a major catastrophe, comparable to or worse than the great 1902 eruption of Mount Pelée in the West Indies, which killed nearly 30,000 people. The most hazardous areas in the region around Mount Rainier, with respect to mudflows, are the low areas—the valley floors. Just how far down valley the hazard may extend depends on the size or volume of future mudflows.

To give you some idea of volume, we'll consider a few mudflows that have occurred in the past. One mudflow, which occurred about 6,000 years ago, contained about 800,000,000 cubic yards of material; it flowed down the White River valley for about 30 miles. Eight hundred million cubic yards is the equivalent of a square mile piled to a depth of 775 feet. The Osceola Mudflow (Fig. 3) occurred about 5,000 years ago. It contained a little more than 2½ billion cubic yards, that is, just a little more than half a cubic mile of material. The Osceola Mudflow covered an area of about 125 square miles in the Puget Sound Lowland in an area where at least 30,000 people now live. The Electron Mudflow (Fig. 3) occurred only about 500 years ago. It involved a little more than 200 million cubic

yards and reached about 35 miles from the volcano; between 2,000 and 3,000 people live on the surface of this mudflow today.

Two of the valleys that head on Mount Rainier are now blocked by dams. The White River valley, northwest of the volcano, is blocked by Mud Mountain Dam, built by the Corps of Engineers for flood control. It is generally kept empty and has a capacity of about 170 million cubic yards. In the Nisqually River valley, 20 miles west of Mount Rainier, Alder Dam impounds a hydroelectric reservoir with a capacity of about 375 million cubic yards, or 332,000 acre feet. Either dam or reservoir could contain most or all of a mudflow like the Electron, if the reservoir were empty, but neither would have much effect on a mudflow as large as the Osceola.

Fifty miles southwest of Mount Rainier is Mount St. Helens. This is a relatively young volcano which may have been formed entirely within the last 10,000 years. About 2,000 years ago a series of big mudflows, lava flows, and hot avalanches moved south from the volcano into the Lewis River valley. Mudflows also went down the Toutle River valley, west of the volcano, probably at least as far as Longview and Kelso. Mount St. Helens erupted frequently during the 1800's; many of these eruptions were actually observed in the period 1843 to 1857. Jack H. Hyde, of Tacoma Community College and the U. S. Geological Survey, recently has started a hazard-evaluation study of Mount St. Helens.

Our main cause for concern with Mount St. Helens is the presence of three large lakes—hydroelectric reservoirs—which occupy 25 linear miles of

the Lewis River valley. Imagine the effect if an 800 million cubic yard mudflow were to move into the upper reservoir in a period of a few hours. This could set up a chain reaction that could cause half a million acre feet of water to spill over each successive dam. Downstream, below the mouth of the Lewis, more than 40,000 people live on the flood plain of the Columbia River. The city of Portland is just 20 miles upstream from the mouth of the Lewis River and essentially at tidewater. We feel that Mount St. Helens, therefore, is a possible threat to Portland and many smaller communities, especially if the volcano should erupt and send a very large mudflow, avalanche, or lava flow into these reservoirs.

Mount St. Helens seems to have been the biggest pumice producer of the Washington volcanoes. The biggest eruptions occurred about 3,500 and about 450 years ago. The one 3,500 years ago left two feet of pumice at a distance of 50 miles from the volcano, and the winds spread some of it northward into Canada. The eruption 450 years ago also deposited pumice to the north-northeast, but it was only about five inches thick at a distance of about 50 miles. During both of these eruptions winds were blowing toward the north-northeast, and the sites of the present large towns were missed by the pumice falls. This is a coincidence that wouldn't be counted on in any future eruption.

The Geological Survey is now working on the volcanic hazards at Lassen Peak in Lassen Volcanic National Park. The hazards there seem to be chiefly a local problem, for we see very little effect of the eruptions of Lassen beyond the limits of the park or a zone

very close to the park. So, if future eruptions follow the same pattern, we anticipate that their effects will also be limited in extent.

The Geological Survey also plans to start an appraisal of the volcanic hazards of Mount Shasta very soon. We know very little about the nature or frequency of volcanism at Shasta within the last 10,000 years, although we know there have been lava flows and ash eruptions within that period of time, and a hot avalanche may have extended down into the townsites of Weed and Mount Shasta. Much of the volcano is bordered by aprons of mudflow deposits, but we do not know how extensive they are. Although it is premature to predict future hazards from Mount Shasta, we're concerned with the possibility that a very large mudflow might extend 35 to 40 miles down the Sacramento River valley to Lake Shasta. Lake Shasta covers an area that is smaller than that now covered by the Osceola Mudflow. We can only speculate about the effects of an extremely large volcanic mudflow moving into Lake Shasta and causing the lake to spill over.

In this brief discussion of some typical volcanoes in the Cascade Range, you may have noticed a possible hazard common to each—large reservoirs within the reach of volcanic mudflows. We have read the geologists' reports on some of the damsites. The fact that there was a volcano upstream was recognized and was considered, but it was also noted that volcanic activity had been on a minor scale in historic time, and the geologists concluded that there seemed to be little or no cause for concern. Perhaps not, but we wish to suggest that the length of historic time in the case of Cascade volcanoes may not

be long enough a sample. In order to reach a meaningful conclusion, one must sample at least the last few thousand years of a volcano's history to decide whether it does or does not constitute a hazard to a reservoir.

We will conclude by mentioning a few problems and making a few suggestions. One problem when the next eruption occurs will be that of moving people out of the danger zones. People who are camping near the volcano can usually leave easily, unless roads and bridges are destroyed by mudflows and floods. We might note in passing that very few bridges near any of these volcanoes could accommodate a very large flood, and none of them could accommodate a catastrophic mudflow.

If an eruption occurred without any warning, and there were casualties, it might be dangerous to rush in with a massive rescue operation, because an even bigger eruption might follow. We suggest that the initial rescue operations be kept to an absolute minimum—just large enough for the immediate job.

Water supplies downwind are very vulnerable from an ash eruption. People should be advised to store water as soon as possible, and, if they don't leave the area, to remain indoors during falls of ash.

There is the danger of forest fires caused by volcanism. They might be much more difficult to fight during an eruption because of the reduced visibility, and roads might be impassable.

We believe that some volcanoes should be monitored, especially those that are potentially dangerous—monitored with seismographs, tiltmeters, and by periodic aerial infrared sensing to detect temperature changes on the volcanoes.

We suggest that reservoir drawdown should be considered immediately if an eruption should start at an upstream volcano. We take some satisfaction in noting that the presence of a dam is not all bad. The reservoir could accommodate a flood, if drawdown had been accomplished in time, and a dam could also impound a mudflow permanently even though this might not have been the purpose for which the dam was constructed. But this is one way in which a mudflow could be kept out of a populated area. It is better to trap the mudflow than to chance overtopping, or perhaps destroying, the dam.

Editor's note: In 1972 the U. S. Geological Survey reported significant advances in monitoring potentially dangerous volcanoes in the Cascade Range. Seismometers were installed on Mt. Baker, Mt. Rainier, Mt. St. Helens, and Lassen Peak, and data were telemetered either to Menlo Park, California, or to the University of Washington. Seismic-event counters were also installed, and radio signals from these counters were relayed via the ERTS-1 satellite. A tiltmeter was installed on Lassen Peak, and a geodimeter network was established at Mt. St. Helens. Experiments involving continuous monitoring of fumarole activity by infrared imagery from aircraft and by recording temperatures of fumaroles was also initiated. Dwight R. Crandell reports, however, that the Geological Survey's program of monitoring the volcanoes of the Cascade Range is much reduced over what it was in 1972 (personal communication, 1974). As a precautionary measure, the National Park Service closed the Manzanita Lake visitor facilities in Lassen Volcanic National Park. Lassen Park, however, remains open to visitors.

5 Iceland Chills a Lava Flow

Richard S. Williams, Jr., and James G. Moore

Williams, R. S., Jr., and Moore, J. G., 1973, Iceland Chills a Lava Flow, *Geotimes*, v. 18, pp. 14-17. Reprinted by permission of the authors and the American Geological Institute. The authors are on the staff of the U. S. Geological Survey. Williams spent Feb. 7, 1973, on Helmaey, and Moore was there from May 3 to 5. This report is based on their observations, information from the Icelandic Ministry for Foreign Affairs, Icelandic scientists' reports through the Smith-

We also wish to emphasize that comprehensive studies are desirable before other dams are built in the Cascade Range—studies in which volcanic hazards are appraised in terms of the life-time expectancy for the reservoir.

Finally, when an eruption does occur, and we think it is inevitable, we hope that the news media will work with geologists and the Office of Emergency Preparedness in informing the public of what could occur and what the hazards might be, so that if people refuse to leave a potential danger zone, at least they will know enough to leave their cars parked headed in the right direction.

sonian Institution's Center for Short-Lived Phenomena, and published scientific reports. Icelandic scientists and officials provided logistical support and discussions of scientific and engineering aspects.

One of the most destructive volcanic eruptions in the history of Iceland seems to be waning, but only after