DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

MISCELLANEOUS GEOLOGIC INVESTIGATIONS
MAP I-836

VOLCANIC HAZARDS

MUDFLOW AND FLOOD HAZARD ZONES

High risk — *Valley-floor areas in which there could be a high degree of danger from relatively small but frequent mudflows and floods*

Moderate risk — *Valley-floor areas which could be covered by a mudflow as large as the Electron Mudflow, in valleys in which mudflows have been relatively frequent*

Low risk — *Valley-floor areas which could be covered by a mudflow as large as the Electron Mudflow, in valleys in which mudflows have been relatively infrequent, and areas in the other valleys which might be subject to flooding*

TEPHRA (airborne rock debris) HAZARD ZONES

H — High risk — *Areas in which there could be a high degree of danger to human life and property from asphyxiation, falling rock fragments, and accumulation of tephra*

M — Moderate risk — *Areas in which there could be a low degree of danger to human life and a moderate degree of danger to property from falling rock fragments and accumulation of tephra*

L — Low risk — *Areas in which there could be a low risk of damage to property from accumulation of tephra, but virtually no direct risk to human life*

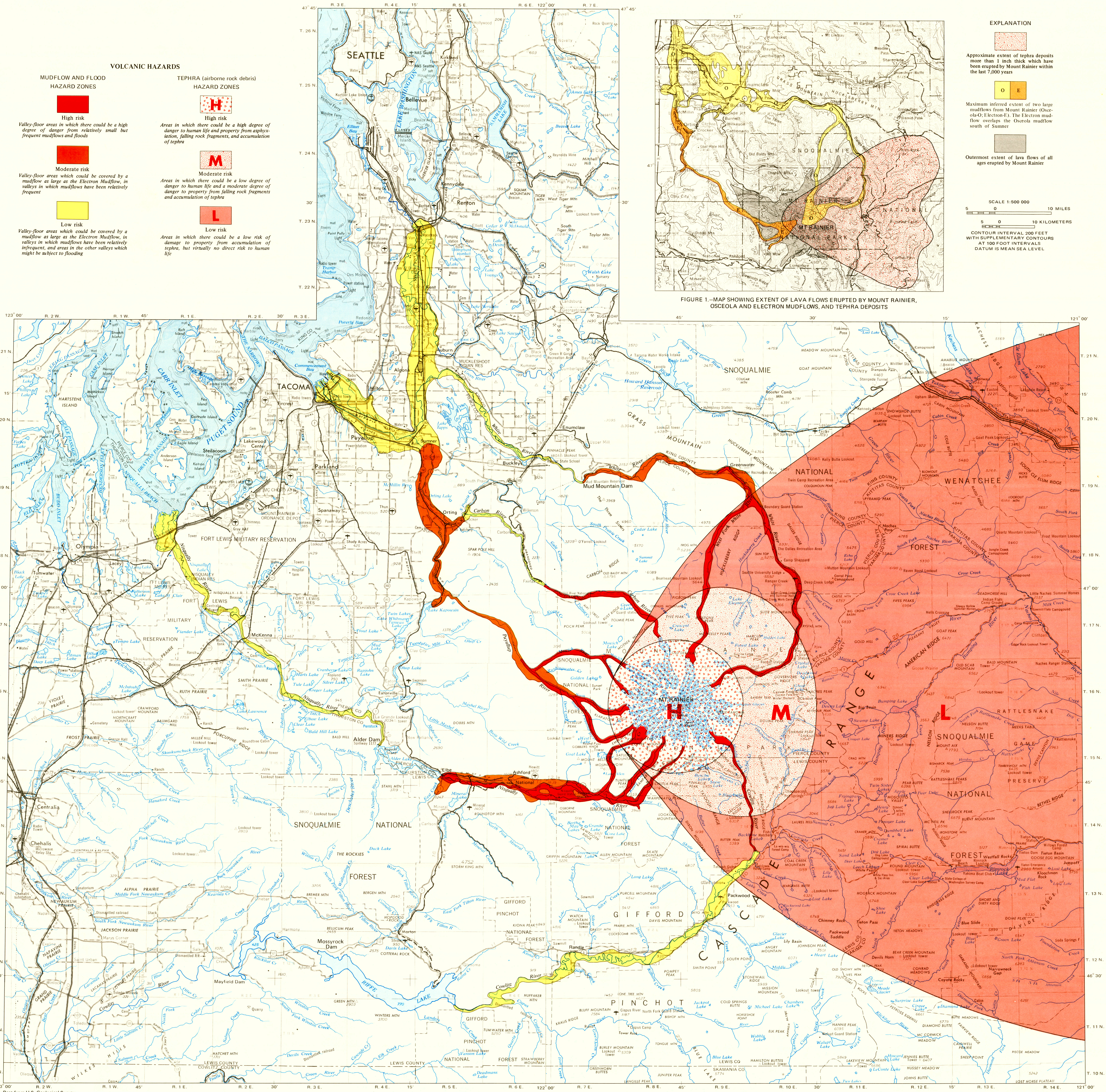

FIGURE 1.—MAP SHOWING EXTENT OF LAVA FLOWS ERUPTED BY MOUNT RAINIER, OSCEOLA AND ELECTRON MUDFLOWS, AND TEPHRA DEPOSITS

INTRODUCTION

Mount Rainier is a dormant volcano which might endanger the lives of thousands of people when it again becomes active. The last significant eruptive activity of the volcano was between 120 and 150 years ago, and several minor eruptions were reported during the late 1800's. Mount Rainier will almost surely erupt again some time within the next few hundred years, but at present there is no way to predict when. It is possible, however, to forecast some of the effects an eruption will have if it is assumed that future volcanism will be of the same type and on the same scale as that which has occurred repeatedly during the last 7,000 years. This sample period of 7,000 years was chosen because the volcano's behavior during this period is better known than is its earlier history.

Conceivably, an eruption of Mount Rainier could occur which would be of a different type and on a vastly more violent scale than any of those of the recent past, and which could cause a major disaster in the surrounding region. Such a catastrophic eruption might resemble the one at Mount Mazama in southern Oregon, which preceded the collapse of the volcano to form the basin of Crater Lake about 6,600 years ago. During that eruption, hot masses of pumice rushed down valleys to distances of as much as 40 miles, and pumice erupted high above the volcano was carried by wind over a region of more than half a million square miles. If this kind of eruption occurred at Mount Rainier, property damage and loss of life could be high. However, the possibility that this kind of eruption will occur at Mount Rainier within the next few centuries is so remote that the extreme cost and major changes in land use that would be required to protect the public from such an event seem unwarranted. It is more practical, instead, to plan for the kinds of eruptions and other geologic events which have occurred in the past 7,000 years and which almost surely will occur again.

The chief hazards from such future eruptions will be mudflows and floods moving along valley floors and fallout of tephra (airborne volcanic-rock debris) in areas downwind from the volcano. Future lava flows probably will not extend beyond the flanks of the volcano, but mudflows and floods may be caused by rapid melting of snow and ice by lava. Avalanches of rock debris could bury valley floors, but these probably would reach only a few miles beyond the base of Mount Rainier.

MUDFLOWS

Mudflows can be especially dangerous because of their possible large size, their ability to travel many miles, and the speed with which they can move. At other volcanoes, mudflows are reported to have traveled at speeds of 20 to 55 miles per hour. Mudflows on steep slopes generally leave only a veneer of mud behind even though they destroy vegetation and man-made structures in their path. On gentle slopes they move more slowly and may bury the land under tens of feet of mud and rock debris. Mudflows can cause severe damage to water-storage reservoirs and dams; flood farther downstream can result from the displacement of water by mudflows.

FREQUENCY.—At least 55 different mudflows of various sizes have left deposits in the valleys that head on Mount Rainier. During the last 7,000 years the upper Nisqually River drainage basin has been affected by mudflows at an average rate of at least 1 per 270 years, the upper White and Puyallup River basins by at least 1 per 430 years, and the upper Carbon and Cowlitz River basins by no more than 1 per 1,000 years. These average minimum rates, however, do not mean that the mudflows occurred at regularly spaced intervals. Few, if any, large mudflows might have occurred during a period when the volcano was dormant, but many probably were formed during relatively short episodes of volcanic activity.

The chance that future mudflows will directly affect a certain segment of a valley decreases with distance from the volcano. Although mudflows have occurred fairly often in the upper Nisqually, White, and Puyallup River drainage basins within the last 7,000 years, the White and Puyallup River valleys in the Puget Sound lowland have each been directly affected by only one mudflow during the last 7,000 years. The last mudflow to reach beyond the mountain front along the Nisqually occurred before the last major glaciation of the lowland and thus is more than 15,000 years old.

RELATION OF MUDFLOWS OF VOLCANIC ACTIVITY.—Many of the large mudflows of the recent past seem to have occurred during periods when Mount Rainier was active, and the mudflows probably were caused by some kind of volcanism. The largest mudflows were formed when huge masses of rock debris and wet clay avalanched from the top and sides of the volcano. These masses became mudflows tens to hundreds of feet deep and traveled many miles downvalley. Other mudflows were not directly related to volcanic activity, but were caused by the saturation of loose rock debris by rain or melting snow, or by the release of a body of water held in a glacier. Such mudflows can occur with little or no warning, but they seldom involve more than a few millions of cubic yards of rock debris and thus are a serious hazard only in the upper parts of valleys that head on the volcano.

The Osceola Mudflow (fig. 1) is the largest known mudflow from Mount Rainier and is one of the largest mudflows in the world. It covers an area of at least 125 square miles in the Puget Sound lowland and has an estimated volume of about 2.6 billion cubic yards, or a little more than half a cubic mile. Radiocarbon age determinations on wood in the mudflow show that the Osceola occurred about 5,700 years ago. The mudflow was formed during a period of volcanic activity, and originated when the upper part of the volcano slid off, or was pushed off, to the northeast. The volcanic rock in that part of Mount Rainier had previously been softened and extensively altered to clay by steam and other gases. No comparably large areas of altered rock are visible on the volcano today, so the chance of another mudflow as large as the Osceola seems slight.

A much smaller mudflow, the Electron Mudflow (fig. 1), is an example of the largest mudflow that might occur within the next few centuries. Hence, in part, it forms the basis for differentiating mudflow and flood-hazard zones on the map. The Electron Mudflow was formed about 600 years ago and moved 35 miles down the Puyallup River valley. It is as much as 16 feet thick in the valley near Orting, and has an estimated volume in the lowland of about 200 million cubic yards. There is no direct evidence of volcanic activity when the Electron Mudflow occurred, and it possibly resulted from slides of altered rock on the volcano that were triggered by a volcanic explosion that was not accompanied by new tephra or lava.

DEGREES OF RISK.—The relative degree of risk from future mudflows is shown for each major valley and is rated as high, moderate, and low, depending on distance from the volcano, on height of areas above the river, and on the frequency with which parts of a valley have been affected in the past. The zones of different risk grade into one another, and the lesser-risk zones are in a downvalley direction or at a greater height above a river. A similar gradation exists within each zone. These ratings are based on the assumption that no mudflow will be larger than the Electron Mudflow.

REDUCING THE RISK.—Ways of reducing the potential risk to human life or property include developing plans for the evacuation of valley floors during eruptions or upon notice of a mudflow, and zoning the valley floors to prevent the building of homes and other structures within potentially high-risk areas. In addition, if time permitted, existing reservoirs in some valleys could be drained and used to trap a mudflow and prevent it from reaching a densely populated area.

Evacuation of valley floors in time to prevent loss of life from a mudflow requires a communications system by which residents can be quickly warned of a mudflow moving toward them. The effectiveness of such a warning will depend, in part, on the interval between receipt of the warning and the arrival of the mudflow. Large mudflows like the Electron probably move at speeds between 10 and 25 miles per hour; thus, only a short time might elapse between the first recognition of a mudflow and its arrival at a populated area. Because of this, valley floors near the volcano should be evacuated as soon as eruptive activity begins.

The parts of valley floors near Mount Rainier which have been covered most frequently by mudflows are not yet densely populated. Because of the potential hazard, great caution should be exercised in developing areas that are less than 30 feet above river level on the valley floor upstream from Elbe in the Nisqually River valley, and at least as far downstream as Greenwater in the White River and West Fork valleys. The continued use of the upper Puyallup River basin west of Mount Rainier National Park solely as a tree farm seems compatible with the potential risk. The lack of many mudflows in the upper Carbon and Cowlitz River valleys suggests that the risk of large mudflows there is appreciably less than in the other valleys.

Mud Mountain Dam (earthfill) in the White River valley and Alder Dam (concrete arch) in the Nisqually River valley could trap much or all of a mudflow as large as the Electron Mudflow. The impact by a mudflow tens of feet deep moving at a speed of 20 miles per hour down the floor of an empty reservoir might endanger a concrete dam. If the reservoir were full, a mudflow would probably move like a density current down the reservoir floor, and would be moving more slowly when it reached the dam. The mudflow would, however, displace an equivalent volume of water which could cause a flood downstream from the dam. The danger of such a flood seems greater than the danger of a mudflow destroying a dam by impact; thus, a nearly empty reservoir is regarded as a lesser hazard than one which is full or nearly full.

At the first sign of eruptive activity, reservoirs downvalley from the volcano should be lowered or drained as quickly as would be consistent with public safety. The reservoir created by Mud Mountain Dam is used to control floods on the White River, and thus is kept empty most of the time. The reservoir is designed to store 106,000 acre-feet of water, which is equal to about 171 million cubic yards, and it could contain a mudflow having nearly the volume of the Electron Mudflow in the Puget Sound lowland. The reservoir behind Alder Dam has a usable capacity of about 179,000 acre-feet, or about 289 million cubic yards. The reservoir typically is kept at its highest levels during summer months, but high levels also are attained at other times of year when there is excessive runoff from storms or melting snow. Although the reservoir's upper 80,400 acre-feet of storage could be discharged at a rate of as much as 70,000 cfs (cubic feet per second), this rate would cause a major flood in the lower Nisqually River valley. The maximum flood on record, which occurred in 1959, had a discharge of 20,700 cfs several miles downstream from Alder Dam. If a more reasonable discharge rate of 40,000 cfs is assumed for the upper 80,400 acre-feet of storage, 179,000 acre-feet could be drained in about 12 days, but an additional 9 days would be required if an inflow of 2,000 cfs occurred during the drawdown period (Donald Richardson, U.S. Geol. Survey, unpub. commun., 1973).

Riffe Lake, in the Cowlitz River valley, lies beyond the expectable maximum extent of a mudflow no larger than the Electron. Even so, partial drawdown of the reservoir should be considered in the event of an eruption of Mount Rainier, especially if the eruption occurred on the southeast flank of the volcano.

FLOODS

Floods probably caused by eruptions of Mount Rainier have formed coarse deposits of sand and gravel in the upper parts of some valleys that head on the volcano, and some of these floods may have extended many miles down the valleys. If similar floods occur in the future during times of dry weather, they may affect only the parts of the valley shown in the high-risk zone on the map. If, however, they occur during times of excessively high rainfall, or during rapid melting of snow due to meteorological conditions, their effects may extend far downstream. Because of this possibility of flooding, some valley floors beyond the probable extent of a mudflow like the Electron are shown to be in a low-risk zone.

TEPHRA (Airborne volcanic-rock debris)

Three of the 10 or more tephra eruptions of Mount Rainier within the last 7,000 years deposited at least 1 inch of material over elliptical areas 20-25 miles eastward from the volcano (fig. 1); winds carried smaller amounts many miles farther.

The zones of relative risk to human life and property shown on the map are based on the particle size, thickness, and distribution of tephra from past eruptions, on the prevailing wind directions, and on the assumption that any tephra eruption within the next few centuries will not be much larger than those of the recent past.

The direct hazards associated with such eruptions are mainly from impact of dense and heavy rock fragments as well as pumice, from accumulations of tephra on the surface, and from fine material and volcanic gases in the air. Large blocks may be thrown with great force in any direction from the crater by the eruption. The danger from impact injury from large blocks of rock could be great on the flanks of the volcano, but would be very small outside Mount Rainier National Park. Blocks 2-4 feet across from past eruptions have been found 5-8 miles from the summit of the volcano. The largest fragments seen at the park boundaries, in contrast, are only about 2-3 inches across.

Fine tephra and volcanic gases in the air, especially if hot, can endanger people, animals, and machinery. These products of an eruption are strongly controlled by winds and are mostly limited to areas downwind from the crater. The hazards decrease rapidly in severity downwind, so that beyond a distance of 10-15 miles tephra is more likely to cause maintenance and repair problems than to directly threaten human life. Specific hazards include breathing of fine tephra or gases resulting from the eruption; burns from falling rock fragments; reduced visibility on highways and for aircraft; loading of roofs that might cause collapse, floods of tephra-laden water from heavy rainfall accompanying the eruption; acidity and turbidity caused by tephra falling into streams and reservoirs; and corrosion of metals by acids carried by tephra.

The direction and distance from a volcano that fine tephra travels is determined by the direction and strength of winds between the vent and the height reached by the tephra. The likelihood of tephra being carried in a certain direction depends on how often winds above the vent blow in that direction, and on how long the eruption continues. The Puget Sound lowland is shown to be outside the low-risk zone of tephra fallout because at all altitudes above Mount Rainier that are likely to be reached by an eruption cloud, winds blow most often in an easterly direction. The chances are small that tephra would fall in the area bounded by Chehalis on the south and Seattle on the north. This sector lies WSW (west-southwest) to NNW of the volcano; thus, winds blowing from an ENE-SSE sector could carry tephra toward densely populated areas in the lowland.

In order to assess the chances of this occurring, high-altitude wind data were examined from records obtained at a weather station (Quillayute) near Forks, Wash., about 150 miles northwest of Mount Rainier, which is the nearest station from which such data are available (Winds Aloft Summary of the Air Weather Service, U.S. Air Force, available from the National Climatic Center, Asheville, N. C.). These records are based on two observations daily for the period 1950-1970, and show percent of winds averaged by month, from 16 points of the compass and at various altitudes. Data for altitudes of 18,000, 30,000, 40,000, and 53,000 feet were selected because of the probability that eruption clouds would reach some zone between these limits. During October through January, winds at these altitudes, combined, blew from the ENE-SSE sector no more than 3 percent of the time. From February through April, and during July through September, winds blew from the same sector as much as 6.7 percent of the time, and during May and June as much as 10 percent of the time. It should be noted that these percentages include winds at all recorded velocities; thus, the percent of strong winds blowing from this sector is even smaller. These data suggest that there is little chance that tephra erupted by Mount Rainier would affect Seattle, Tacoma, Olympia, and other populated areas west and northwest of the volcano. However, fallout of tephra could affect communities that are northeast to southeast of Mount Rainier, such as Cle Elum, Ellensburg, and Yakima. The problems at such distances of 45 to 60 miles should be mostly with maintenance of facilities and effect of tephra on crops and vegetation.

LAVA FLOWS

The large lava flows of Mount Rainier (fig. 1) are all older than the last major glaciation, and some may be hundreds of thousands of years old. Those erupted within the last 7,000 years have been small and confined to the top and upper slopes of the volcano. Even if lava were to be erupted from the flank of Mount Rainier, it probably would be stiff and sluggish, and would move at a speed of less than 5 miles per hour. Thus, there is little danger of a lava flow covering a campground before campers could safely leave.

The indirect effects of a lava eruption are a much greater potential hazard. If lava were erupted at the summit, its first effect would be to melt snow and ice in the summit craters. Downward movement of this water to meet molten rock could lead to steam explosions that might rupture parts of the summit of the volcano and cause landslides. Bodies of water in the summit craters could also be thrown out or suddenly drained by the rupture of the sides of the summit cone. In either case, floods would surely result from the large amount of water that would rush down the flanks of the volcano.

Lava erupted onto snowfields or glaciers on the flank of the volcano also would cause rapid melting which would lead to floods or mudflows on valley floors. Such floods, however, probably would not seriously affect valley floors beyond the limit of the high-risk zone.

AVALANCHES OF ROCK DEBRIS

Avalanches of rock from a volcano can be caused by volcanic eruptions or by earthquakes. Avalanches of newly erupted hot rock debris have swept down the flanks of Mount Rainier a few times during the last 7,000 years and have covered valley floors within about 3 miles of the base of the volcano. Such avalanches are especially dangerous because of their speed and their destruction of all life in areas they cover. Hot avalanches at other volcanoes have been known to move at rates of 35 to more than 75 miles per hour. People should leave valley floors near the volcano at the first sign of an eruption because of the possibility that hot avalanches, as well as mudflows and floods, might occur.

The falls of large masses of rock from cliffs can also cause swiftly moving avalanches of rock debris, like those that started on Mount Rainier in 1963 and moved more than 4 miles down the White River valley. Those rockfalls may have been triggered by a steam explosion. Valley floors within a few miles of the base of the volcano could be buried by rockfall-avalanches in the event of a strong earthquake or volcanic explosion.

VOLCANO MONITORING

A volcano can be monitored in several ways in order to detect the upward movement of molten rock that precedes an eruption. This molten rock causes earthquakes within the volcano which can be detected by instruments; at other volcanoes, an increase in the number and strength of quakes has been followed by an eruption. The instruments now being used to detect and record earthquakes at Mount Rainier include standard seismometers and a seismic-event counter which records only quakes that are stronger than a predetermined magnitude. Data from these instruments are relayed by radio to the University of Washington for recording and interpretation.

The thermal state of a volcano can be monitored by temperature-measuring devices (thermistors) placed in steam vents and areas of hot rock, and infrared radiometers which detect heat. If molten rock should rise toward the surface slowly, changes in the number, position, and temperature of steam vents and areas of hot rock might be detected before an eruption. Mount Rainier is now being monitored by infrared radiometer from an aircraft once or twice a year.

ADDITIONAL READING

Crandell, D. R., 1971, Postglacial lahars from Mount Rainier volcano, Washington: U.S. Geological Survey Professional Paper 677, 74 pages. A study of the age, extent, and origin of more than 55 postglacial lahars (mudflows and debris flows) from Mount Rainier, and a discussion of the potential hazard of similar phenomena in the future.

Crandell, D. R., and Mullineaux, D. R., 1967, Volcanic hazards at Mount Rainier, Washington: U.S. Geological Survey Bulletin 1238, 26 pages. A discussion of the eruptive history of the volcano during the last 10,000 years and the anticipated effects of similar future eruptions.

Crandell, D. R., and Waldron, H. H., 1969, Volcanic hazards in the Cascade Range, *in* Geologic hazards and public problems: Office of Emergency Preparedness, Region 7 Conference Proceedings, Santa Rosa, California, May 27-28, 1969, pages 5-18. A nontechnical description of the kinds of hazards presented by volcanic eruptions and a brief review of the recent eruptive history of Mount Rainier and several other volcanoes in the Cascade Range.

Wilcox, R. E., 1969, Some effects of recent volcanic ash falls with especial reference to Alaska: U.S. Geological Survey Bulletin 1028-N, pages 409-476. A discussion of ash falls resulting from eruptions in historic time and their effects on public health, buildings, agriculture, and transportation.

INDEX MAP OF WASHINGTON

SCALE 1:250 000
5 0 5 10 15 20 25 MILES
5 0 5 10 15 20 25 30 35 KILOMETERS

Base from U.S. Geological Survey Wenatchee, 1957; Seattle, Hoquiam, and Yakima, 1958

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POTENTIAL HAZARDS FROM FUTURE ERUPTIONS OF MOUNT RAINIER, WASHINGTON

By
Dwight R. Crandell
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For sale by U.S. Geological Survey, price 75 cents