CIRC. 877

Potential Hazards from Future Volcanic Eruptions in the Long Valley–Mono Lake Area, East-Central California and Southwest Nevada— A Preliminary Assessment

GEOLOGICAL SURVEY CIRCULAR 877

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GEOLOGICAL SURVEY CIRCULAR 877

1982

United States Department of the Interior

JAMES G. WATT, *Secretary*

Geological Survey

Dallas L. Peck, *Director*

First Printing 1982
Second Printing 1983

Free on application to the Branch of Distribution, U.S. Geological Survey, 604 South Pickett Street, Alexandria, VA 22304

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By C. Dan Miller, Donal R. Mullineaux, Dwight R. Crandell, *and* Roy A. Bailey

INTRODUCTION

Recent earthquakes, ground deformation, and increased fumarolic activity in the vicinity of Mammoth Lakes in the southern part of the Long Valley–Mono Lake area of California (fig. 1) have increased the concern over the possibility of a volcanic eruption in the near future, although no one can yet reliably predict either that there will be an eruption, or the time, scale, or specific site if an eruption does occur. This report is a response to that increased concern.

The Long Valley–Mono Lake area has been the site of volcanic eruptions for millions of years. Long Valley itself (fig. 1) is part of a large volcanic depression called the Long Valley caldera, which formed as a result of colossal eruptions about 700,000 years ago. Other volcanic activity within the last few thousand years included explosive eruptions of pumice and formation of lava domes from numerous vents along the Inyo and Mono chains of volcanoes. The most recent eruptions known, from the Inyo chain of vents a short distance north of the community of Mammoth Lakes, consisted of steam explosions that ejected preexisting rock material about 500 years ago and explosive eruptions of rhyolite less than 400 years ago.

Earthquake activity in the Long Valley region began to increase in 1978. In mid-May, 1980, intense earthquake swarms (Ryall and Ryall, 1980), occurred about 10 days before the Mammoth Lakes area was shaken by a historically unprecedented series of earthquakes that included four of Richter magnitude 6 within a 48-hour period (Cramer and Toppozada, 1980). Since that time earthquake swarms, accompanied by spasmodic tremor, have repeatedly occurred underneath a locality referred to as the epicentral site about 3 km (2 mi) southeast of the community of Mammoth Lakes (Ryall and Ryall, 1981; Ryall and Ryall, 1982). The depths at which earthquakes in these swarms originated seem to have become shallower since June 1980 (A. Ryall, oral commun., 1982). These seismic events are thought to have been generated by magma rising under the epicentral site (Ryall and Ryall, 1982; R. Cockerham, oral commun., 1982).

In October 1980, surveying along U.S. Highway 395 across the Long Valley caldera revealed that a preexisting broad uplift, called a resurgent dome, in the western part of the caldera had bulged upward about 25 cm (10 in.) possibly within the previous 2 years (Savage and Clark, in press). Additional geophysical evidence indicates that partially molten magma underlies much of that uplift (Hill, 1976; Steeples and Iyer, 1976; Ryall and Ryall, 1981; Ryall and Ryall, 1982).

In January 1982, increased fumarolic activity was first noticed near the Casa Diablo Hot Springs about 2 km (1 mi) northeast of the epicentral site of the recent earthquakes.

A preliminary interpretation of this evidence is that magma beneath the Long Valley caldera moved upward at about the time of the May 1980 swarm of earthquakes. This caused bulging of the

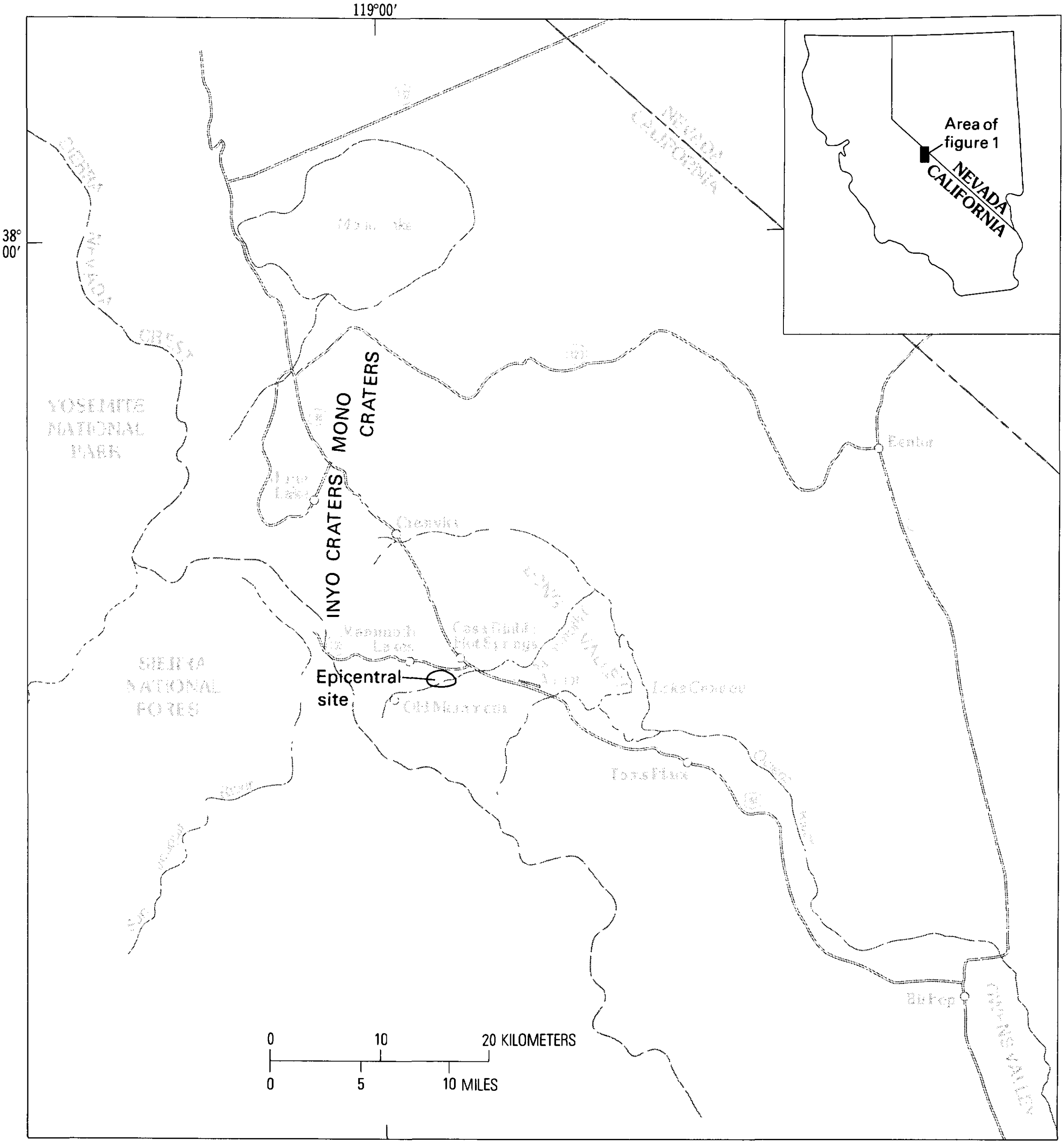


FIGURE 1.—Index map of the Long Valley–Mono Lake area, east-central California and southwest Nevada.

resurgent dome and opened fractures at depth in the southern part of the caldera (R. A. Bailey and R. Cockerham, written commun., 1982), which allowed a tongue of magma to move toward the surface beneath the epicentral site. It cannot be determined whether this magma will reach the surface and cause an eruption, or will cool and solidify beneath the surface.

This report, revised from U.S. Geological Survey Open-File Report 82–583 (Miller and others, 1982), describes potential volcanic hazards and areas that could be affected by eruptions in the

Long Valley, Inyo Craters, and Mono Craters areas. An investigation to provide data for a more comprehensive volcanic hazards assessment for the Long Valley–Mono Lake area is underway, but only partially completed. Thus, this preliminary assessment is based mainly on the results of extensive research on the Long Valley volcanic system by Bailey and other U.S. Geological Survey scientists (see, for example, Bailey, Dalrymple, and Lanphere, 1976), about 5 weeks of fieldwork by Miller, and published reports and unpublished data of other Federal, State, and university scientists.

ERUPTIVE PRODUCTS AND THEIR EFFECTS

Future eruptions are most likely to consist of one or more of the types of activity that have occurred before in the Long Valley–Mono Lake region. Past eruptions in that region include explosive eruptions that produced chiefly silicic (dacitic to rhyolitic) ash falls, pyroclastic flows, and pyroclastic surges of small to large volume, and relatively nonexplosive eruption of silicic lava domes and basaltic lava flows. Any of these eruptive events could cause floods and mudflows, especially if the area adjoining an active vent is covered with snow. Volcanic gases are emitted during eruptions, and also during dormant intervals.

ASH FALLS

Volcanic ash and larger fragments are ejected upward above a vent by explosive eruptions, which may range from blasts that last only a few seconds to explosively rapid, continuous rushes of fragment-laden gas that continue for hours. Such rock fragments can be projected high into the air; as winds carry them away, large fragments fall close to the vent, whereas the smaller particles are carried farther, forming a lobe-shaped blanket leading away from the vent. Layers of ash may be thick near the volcano but become thinner with increasing distance. Thus, the expectable effects of ash are greatest where it is thickest near the volcano, and decrease with increasing distance.

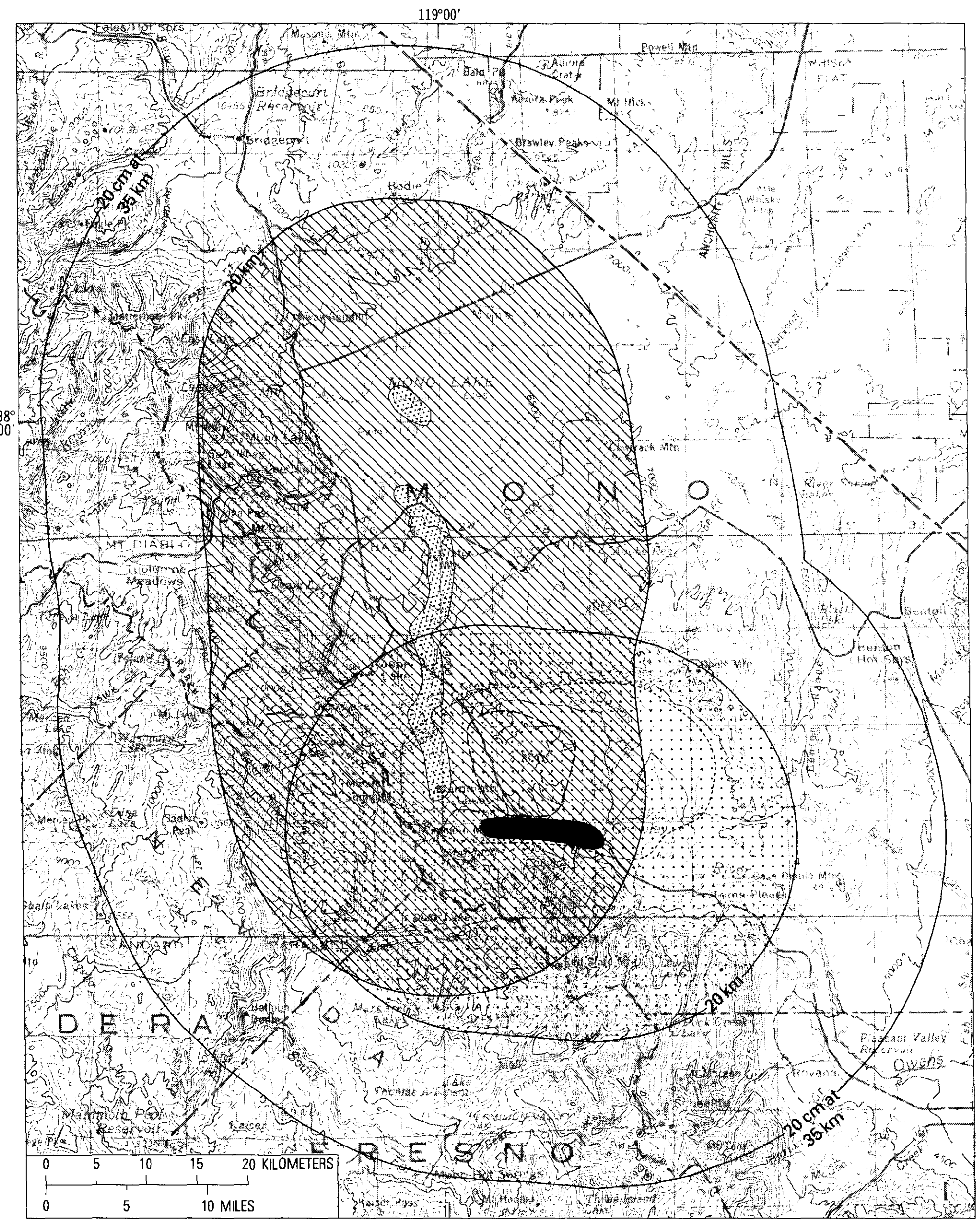
Ash falls generally endanger property more than human lives. Ash endangers human health chiefly by its effect on respiratory systems. A lesser hazard exists from toxic gases which may accompany the ash. Impact of large rock fragments thrown from the vent by explosions can endanger people and property near an erupting vent, and hot rock fragments can start fires. Danger from such rock fragments can extend as much as 10 km (6 mi) from the source vent. Thick ash accumulations can cause roofs to collapse and, especially if wet, can shut off telephone and electric-power service by breaking transmission lines. Lightning typically accompanies clouds of ash, and may interrupt telephone, radio, and electrical services and start fires. Ash fall can reduce visibility, producing darkness during daylight hours, and halt air, rail, and highway traffic; and deposits on the ground can block roads. Ash can disable motor vehicles and other machinery by clogging air filters and causing rapid wear of moving parts. It can also cause short circuits in electrical systems and electronic equipment, clog filters in water- and air-supply systems, and incapacitate these and sewer systems by plugging collection, treatment, and distribution systems with accumulations of ash.

During an ash fall, people generally should stay indoors and avoid ash inhalation by breathing through commercial dust filters or moistened cloths. Eyes should also be protected as much as possible. It may be possible, but generally is inadvisable, to attempt to evacuate an area during an ash fall. Mechanical equipment can be protected by being covered and allowed to remain idle; if such equipment is used, filtration of air, water, and fuel can reduce the effects of abrasive and corrosive ash.

PYROCLASTIC FLOWS

Pyroclastic flows are relatively high-density masses of hot, dry rock fragments mixed with hot gases; the flows move like fluids along the ground surface at high speed outward from a volcanic vent. Such pyroclastic flows commonly reach temperatures of hundreds of degrees Celsius and speeds of 50-150 km/hr (30–90 mph). They generally follow valleys or other depressions but can have enough momentum to overtop hills or ridges in their path. Clouds of hot ash that commonly precede or accompany pyroclastic flows may, depending on wind conditions, affect areas as much as several kilometers wide adjacent to the margins of the flows.

Pyroclastic flows are especially dangerous because of their speed, high temperature, and possible long travel distance. They generally destroy life and structures in areas they cross by impact, incineration, or burial. Pyroclastic flows moving



EXPLANATION

FEATURES OF THE LONG VALLEY CALDERA

- - - - - - Outline of Long Valley caldera floor

— — — Outline of resurgent dome within the Long Valley caldera

AREAS INFERRED TO BE POSSIBLE SITES OF FUTURE ERUPTIONS

Area of explosive silicic vents active during the last 10,000 years

Potential vent area indicated by seismicity since 1980 and by proximity to the Long Valley ring-fracture system

HAZARD ZONES FROM ERUPTIONS OF THE SIZE AND CHARACTER OF THOSE THAT HAVE OCCURRED WITHIN THE LAST 10,000 YEARS IN THE LONG VALLEY-MONO LAKE AREA—The following hazard zones are drawn around relatively likely sites of future eruptions. During a future eruption, the appropriate hazard zone would be that part of the zone shown on the map that is circumferential to the erupting vent or vents

Flowage-hazard zone around existing explosive vents—Areas adjacent to and within 20 km (12 mi) of volcanoes or vents subject to eruption of pyroclastic flows and clouds of hot ash, pyroclastic surges, lava flows, and domes, and, at some vents, mudflows and floods. Some parts of the hazard zone have not been affected by geologically recent events, but could be affected in the future

Flowage-hazard zone around possible future vents inferred from seismicity—Areas adjacent to and within 20 km (12 mi) of possible future vents at or near the epicentral location of earthquake swarms since 1980 and along a part of the caldera ring-fracture system. Areas within this zone are subject to eruption of pyroclastic flows and clouds of hot ash, pyroclastic surges, lava flows, and domes, and, at some locations, mudflows and floods

20 cm at 35 km — Ashfall-hazard zone—Areas within 35 km (22 mi) of potentially erupting vents subject to ash accumulations of 20 cm (8 in) or more downwind from a vent. In general, thickness of ash accumulations gradually decreases with increasing distance from a vent

FIGURE 2.—Map of potential volcanic hazards in the central part of the Long Valley–Mono Lake area.

over snow or into water can generate hot mudflows, secondary steam explosions, and waves in water bodies. The paths of some pyroclastic flows that originate on the sides of domes can be anticipated, but other pyroclastic flows can be caused by the fallback of material in vertical-eruption columns and can move radially outward in many or all directions. Because of the speed with which pyroclastic flows can be generated and with which they can move, the most effective mitigative measure is to evacuate people from zones that are likely to be affected.

PYROCLASTIC SURGES

Pyroclastic surges are relatively low-density, cloudlike mixtures of rock particles and gases that move at high speed outward from volcanic vents. Hazards presented by pyroclastic surges include severe abrasion, impact by rock fragments, and deposition of ash and coarser material. Structures can be damaged or destroyed by a surge moving along the ground surface at high speed. High temperatures of some surges create an added hazard. Pyroclastic surges move at speeds similar to those of pyroclastic flows, and can also be lethal to all forms of life. The speed of surges is so great that escape is not possible once they have been generated, and only windowless, airtight, and fireproof structures of substantial strength would protect people in the path of a surge. The most practical mitigative measure is to evacuate people from zones that are likely to be affected.

LAVA DOMES AND FLOWS

Lava domes and flows result from relatively quiet eruption of molten rock that piles up over a volcanic vent, or flows away as a molten stream. Lava domes and flows seldom threaten human life directly because their slow rate of movement usually allows people to move out of their path. Furthermore, lava flows typically move along predictable paths determined by local topography. Basalt lava flows may reach distances of more than 50 km (30 mi) from their sources, but because of their greater viscosity, silicic lava extrusions typically produce short, thick volcanic domes and flows that seldom move as far as 5 km (3 mi).

The principal hazard associated with formation of a dome results from pyroclastic flows, and from rock fragments thrown out by explosions. The flanks of growing domes typically are unstable, and often collapse to form pyroclastic flows that may move outward beyond the dome. During periods of active dome growth, areas within a distance of at least 5 km could be endangered by such pyroclastic flows, and this distance would progressively increase as a dome grew higher.

FLOODS AND MUDFLOWS

Eruptions at vents in areas covered with snow may cause hot mudflows as hot rock debris mixes with snowmelt, or floods that may become mudflows as they incorporate rock debris. Floods and mudflows can threaten people and structures, and block evacuation routes along valley floors. Because of their high density, mudflows can carry large and heavy objects such as vehicles and bridges. Reservoirs downvalley from an active vent can trap floods and mudflows, but water displaced from them can become a hazard if the reservoirs are already full. For this reason, lowering the level of a reservoir such as Lake Crowley to accommodate floods and mudflows is advisable if an eruption appears to be imminent, and if products of that eruption could melt large volumes of snow in the drainage basin above the reservoir. General paths of floods and mudflows can be predicted because they follow valleys and other depressions, and people can escape by moving upslope. Those that occur at night or at other times of poor visibility are especially dangerous because their approach may not be observed. Floods generally move at speeds of less than 25 km/hr (15 mi/hr), but mudflows can move at least as fast as 50 km/hr (30 mi/hr).

VOLCANIC GASES

Volcanic gases are emitted without rock material from small vents called fumaroles, and they generally accompany molten or solid rock fragments expelled during eruptions. Volcanic gases usually consist predominantly of steam, accompanied by carbon dioxide and compounds of sulfur and chlorine. Minor amounts of carbon monoxide, fluorine and boron compounds, ammonia, and other compounds are found in some volcanic gases. Distribution of volcanic gases is mostly controlled by the wind; gases concentrated near a vent rapidly become diluted as they are carried downwind.

Volcanic gases can affect eyes and respiratory systems of people and animals and thus endanger life and health. Accumulation of heavier-than-air

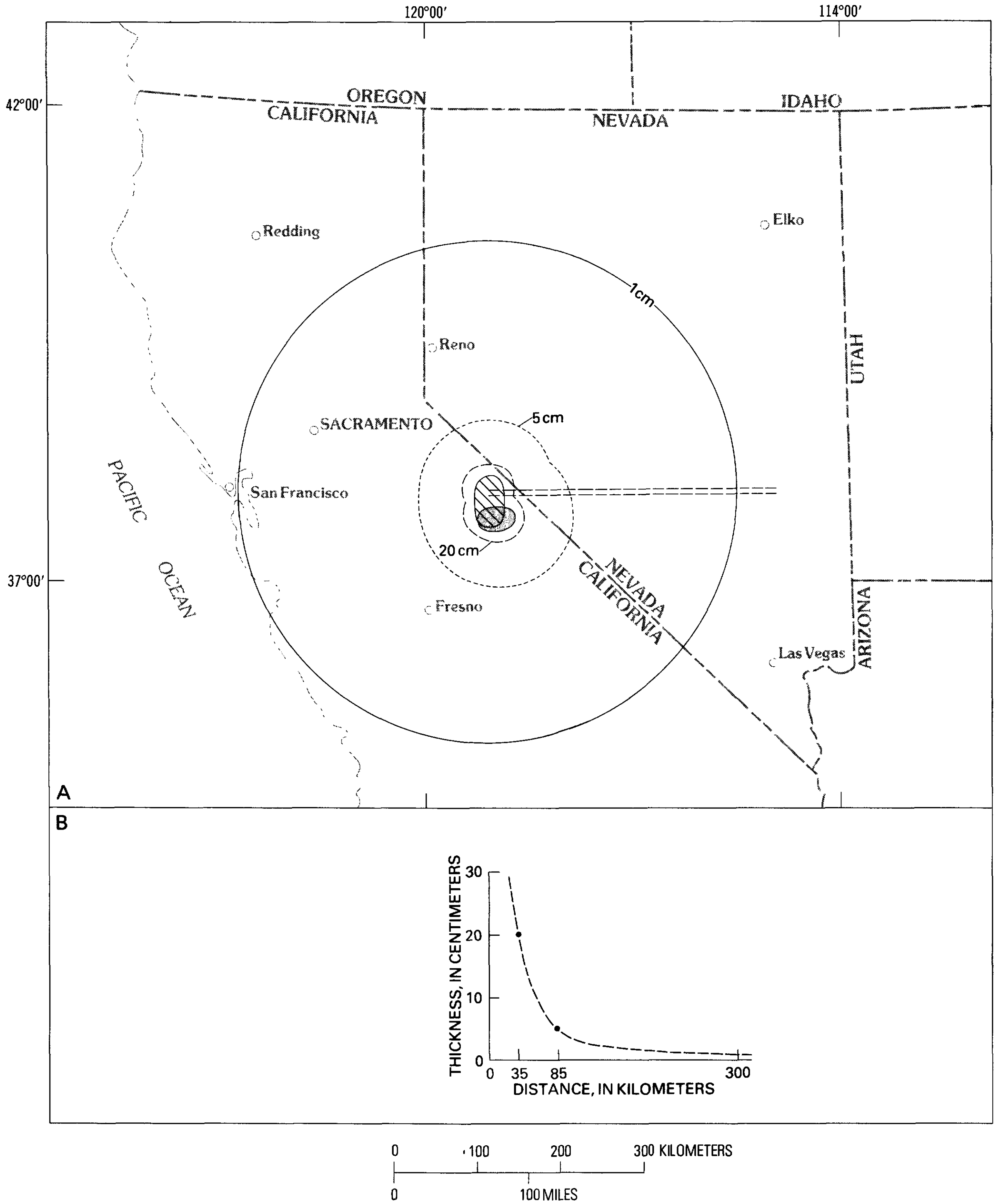


FIGURE 3.—Potential hazards from airfall ash. *A*, Hazard zones for air-fall ash from recognized potential vent areas in the Long Valley–Mono Lake area. Diagonal line and stipple patterns show flowage-hazard zones out to a distance of 20 km (12 mi) from recognized potential vents, as shown in figure 2. Lines surrounding those areas represent potential ash thicknesses of 20 cm at 35 km (dashed line), 5 cm at 85 km (dotted line), and 1 cm at 300 km (solid line) (8 in. at 22 mi, 2 in. at 53 mi, and ½ in. at 185 mi). Hazard from air-fall ash is greatest near source, and decreases as thickness of deposit decreases. *B*, Possible thickness and distance relation for ash of a volume of approximately 1 km^3 (¼ mi^3) erupted from a vent at the north end of the Mono Craters chain, and carried eastward along the double line shown in figure 3*A*.

gases such as carbon dioxide in depressions can suffocate people or animals. Gases can also corrode metals and destroy crops and other vegetation. Even where dilute, volcanic gases can have a noticeable odor and can harm plants many tens of kilometers downwind from a vent.

Wilcox (1959) noted that although it is not possible to prescribe complete protective measures, a properly fitted industrial gas mask with acid-type filter is best for protection from volcanic gases, and that where such special equipment is lacking, a dampened cloth has been found to be a practical expedient. Airtight goggles can lessen effects on eyes. Wilcox also recommended renewing the effectiveness of a wet cloth by rinsing, because the action of the wet cloth is to trap the acidic gas in the moisture of the cloth (Wilcox, 1959, p. 443).

HAZARD ZONES

The location of epicenters of recent earthquakes suggests that if an eruption occurs in the near future, the vent is likely to be in the southern part of the Long Valley–Mono Lake area. Nevertheless, an eruption might occur instead in some other nearby area that has been volcanically active in the recent geologic past, especially along the Mono Crater and Inyo Crater vent systems. Thus, hazard zones (fig. 2) have been drawn around both the epicentral site and the Mono-Inyo vent sites.

Although future eruptions of lava domes and flows are expectable, explosive eruptions are the chief concern. Explosive eruptions that are considered possible in the Long Valley–Mono Lake area include steam-blast eruptions that produce no magma, eruptions that produce widely variable volumes of silicic magma as pumice, and even a catastrophic eruption of an immense volume of material such as occurred about 700,000 years ago (Bailey and others, 1976; Wood, 1977).

Steam-blast (phreatic) eruptions like those of the Long Valley–Mono Lake area are produced when rising magma heats subsurface water. They may occur without other volcanic activity or may be followed by eruptions of magma. Rock fragments thrown out by such explosions could fall as far as 10 km (6 mi) from the vent, and windborne ash could fall on areas at distances of many tens of kilometers. Such steam explosions could also produce pyroclastic surges, which may move outward at great speed as far as 10 km (6 mi) from their source vents. A steam-blast eruption up through a lake could also cause large waves, and subsequent floods and mudflows. Effects of steam-blast eruptions are expected to be less extensive than those from explosive eruptions of magma; thus hazard zones for steam-blast eruptions are not differentiated in figure 2.

Figures 2, 3, and 5 depict hazard zones for explosive eruptions comparable to two such eruptions that have occurred at Long Valley in the past: (1) explosive eruptions of moderate volume (on the order of 1 km^3, or ¼ mi^3) from the vicinity of recently active vents and from the vicinity of the epicentral site east of Mammoth Lakes; and (2) an eruption of the volume of the catastrophic eruption that occurred about 700,000 years ago, originating from the southern part of Long Valley. The discussion of hazard-zone maps is followed by an explanation of hazard-zone boundaries.

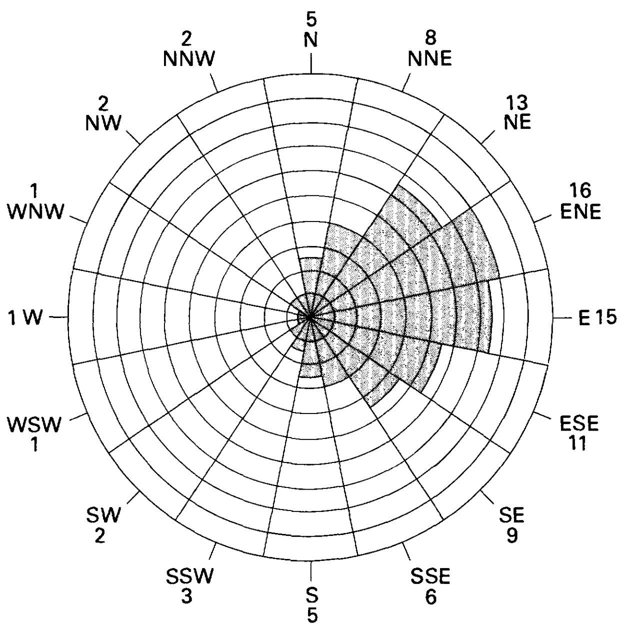


FIGURE 4.—Average percentage of time, annually, that winds at six altitudes from about 3000 to 16,000 m (10,000 to 53,000 ft) blow toward wedge-shaped sectors centered on 16 principal compass directions above Las Vegas, Nev. Percentages for the same altitudes above Oakland, Calif., west of the Sierra Nevada range, are similar. Percentages are rounded to nearest whole number. Data from Winds Aloft Summary of the Air Weather Service, U.S. Air Force, available from the National Climatic Center, Asheville, N.C.

HAZARD ZONES FOR ERUPTIONS OF MODERATE VOLUME

Explosive eruptions of moderate magma volume (as much as about 1 km^3, or ¼ mi^3) at the Mono Craters have produced extensive pyroclastic flows and ash falls. Pyroclastic flows produced during such eruptions of the last 10,000 years, for example, have traveled at least 15 km (9 mi) from their source vents. This distance, plus an additional margin of safety of 5 km (3 mi), is the basis for the 20-km-radius flowage-hazard zone shown in figures 2 and 3. This zone has been drawn around vents that have been explosively active in the last 10,000 years and includes areas that might be affected by pyroclastic flows during future eruptions of moderate volume. A similar flowage-hazard zone extends outward to a distance of 20 km (12 mi) from a linear area of possible future vents near the south margin of the Long Valley caldera. That area, defined by frequent earthquakes since May 1980, begins at the epicentral site of recent earthquake swarms within the caldera and extends eastward about 12 km (7 mi) along the south margin of the caldera.

Downwind deposits of ash produced by an explosive eruption of moderate volume from the Mono Craters probably could reach thicknesses of at least 20 cm (8 in.) at a distance of 35 km (22 mi), and 5 cm (2 in.) at 85 km (53 mi) (fig. 3). These estimates of potential ash thicknesses are based on deposits of ash from past eruptions at other volcanoes that involved volumes of as much as about 1 km^3 (¼ mi^3). The anticipated outer limit of ash 20 cm (12 in.) or more thick is shown in figure 2 at a distance of 35 km (22 mi) from all likely sites of future vents. Only part of an ash-fall hazard zone would probably be affected by any single ash fall; the part affected would be determined by the wind direction or directions during an eruption. It is not possible now to predict wind directions that will exist at the time of a future explosive eruption. However, records suggest that on an annual basis the winds in the Long Valley–Mono Lake area at altitudes where most ash is transported, between 3000 m and 16,000 m (about 10,000 and 52,000 ft), blow toward a sector between N. 45° E. and S. 45° E. more than 50 percent of the time, and more than 80 percent of the winds blow toward some easterly direction between due north and due south (fig. 4). Areas in these directions from a vent thus have a greater chance of being affected than do other areas.

HAZARD ZONE FOR AN ERUPTION OF VERY LARGE VOLUME

The explosive eruption of very large volume that occurred at Long Valley about 700,000 years ago resulted in immense pyroclastic flows and clouds of airborne ash. Pyroclastic flows of hot pumice buried an irregular area of at least 1500 km^2 (580 mi^2) in and adjacent to the Long Valley–Mono Lake area to depths of tens to hundreds of meters. One lobe of these pyroclastic flows extended southward down the Owens Valley to a distance of at least 65 km (40 mi) from its source area, while others traveled down the San Joaquin River and other drainages west of the Sierra Nevada crest and may have reached the Central Valley of California. The pyroclastic flows probably moved at speeds of several hundreds of kilometers per hour, which permitted them to cross topographic barriers many hundreds of meters high. The eruption also produced voluminous airborne ash that was carried eastward by winds across the United States, resulting in ash deposits as much as 100 cm (40 in.) thick at a distance of 120 km (75 mi), 40 cm (16 in.) at 200 km (125 mi), and 15 cm (6 in.) at 500 km (300 mi). Lesser but appreciable thicknesses probably were deposited all across the United States.

The hazard zone shown in figure 5 is based on the possibility that as much as 1 m (3.3 ft) of airborne ash could be deposited anywhere within the zone and that pyroclastic flows could extend to that distance. Devastation from such an eruption could be severe to total within any part of the circle shown on the map at distances of as much as 120 km (75 mi) from the center of the Long Valley–Mono Lake area. As with smaller eruptions, the directions of thickest ash fall would be determined by wind directions at the time of the eruption. Even upwind, however, pyroclastic flows of hot pumice could completely devastate much of the area within 120 km of the vent, especially along valleys.

The likelihood of a future eruption as large as this cannot be calculated with data now available; such an eruption would be much more damaging but far less likely than a smaller eruption. An eruption of that volume is tentatively regarded as much less probable than an eruption involving a volume of a few cubic kilometers or less.

A catastrophic eruption of a volume like that of 700,000 years ago has occurred nowhere in the world during historic time, so the kinds and timing of precursory events and the full range of possible consequences cannot be anticipated.

HAZARD-ZONE BOUNDARIES

Flowage-hazard zones on the accompanying figures enclose areas that may be affected by future explosive eruptions of the volume of the two events used as models. The outer boundaries of the zones are generalized and enclose minimum areas that would be endangered by eruptions like those of the two models used. Within these zones, relative hazard generally decreases with increas-

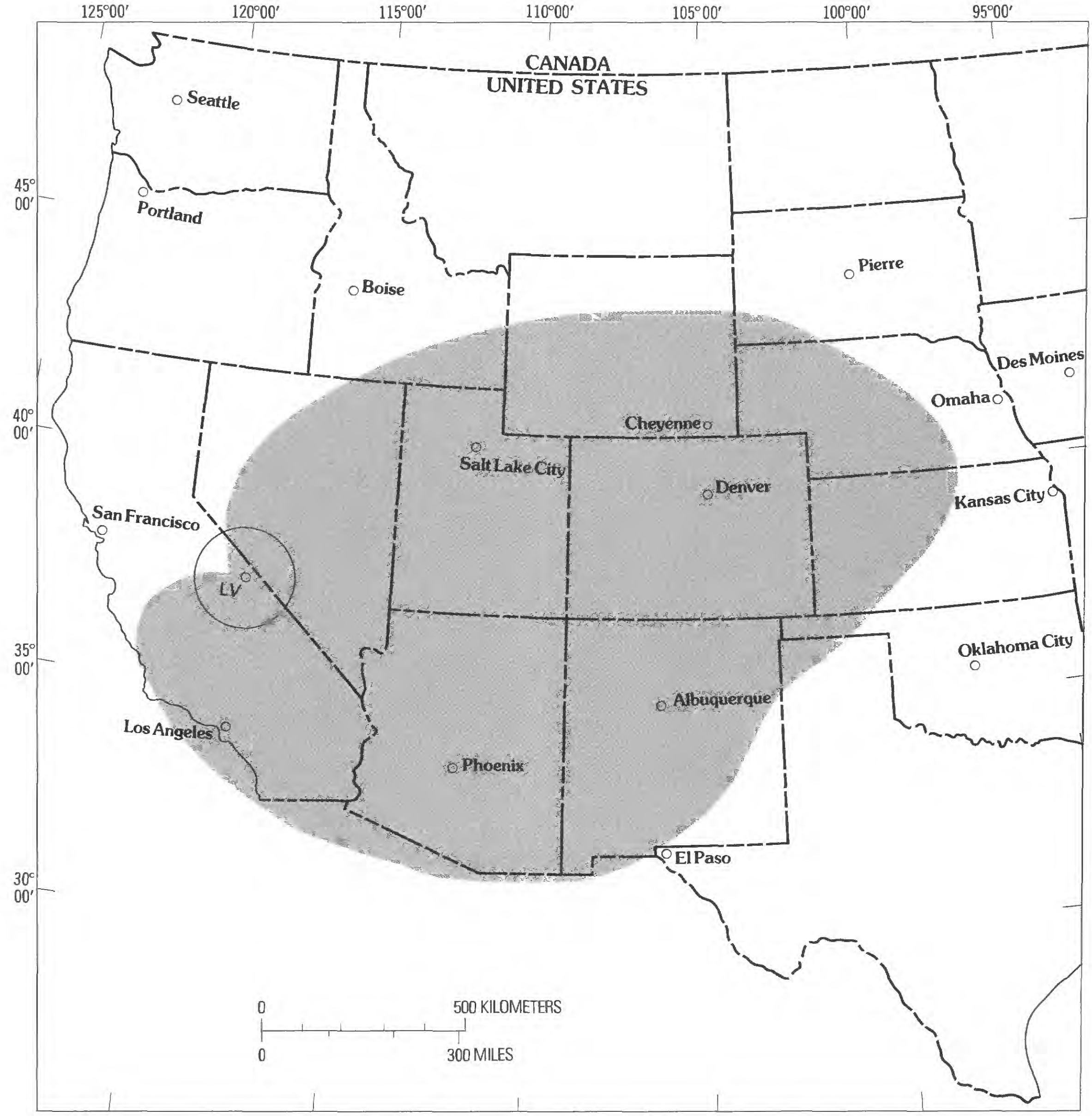


FIGURE 5.—Distribution of Bishop ash beds from eruption at Long Valley caldera (LV), as shown by Izett, Obradovich, and Mehnert (1982). Pattern encloses sites of identified Bishop ash beds; ash must also have been deposited beyond the extent shown (Izett and others, 1982, p. 5). Thickness of ash beds judged to be unreworked at distances of 550 km (340 mi) and 820 km (510 mi) from the source vent suggests that the Bishop ash at the easternmost boundary shown was less than 1 cm (½ in.) thick. Circle at 120 km (75 mi) from the center of the Long Valley caldera encloses area subject to accumulation of 1 m or more of airfall ash downwind during a future eruption similar to that which produced the Bishop ash. Hot pyroclastic flows could occur anywhere within this area and could extend even farther down valleys that head in this area.

ing distance from a vent and with increasing height above valley floors or basins. The positions of the hazard-zone boundaries do not reflect topographic relief, because (1) pyroclastic flows and surges can overtop topographic barriers in their paths, (2) associated clouds of ash can affect areas, including high ground, many kilometers wide adjacent to pyroclastic flows, and (3) pyroclastic flows travel farthest down valleys and along other depressions, but the maximum distances to which they might extend are not known.

Thus, the outer boundaries of flowage-hazard zones shown in figures 2 and 3 are smooth curved lines that disregard topography and should be interpreted only as a "generalized" outer limit of one level of hazard. It should be understood that flowage phenomena may extend beyond the zone boundary, and possibly even reach onto adjacent topographically high areas.

Ash-hazard zones are not assigned zone boundaries comparable to those for flowage hazards. Hazardous flowage events have geographic limits, even though they may be difficult to predict. No comparable limits exist for the extents of ash-fall deposits, which simply diminish with increasing distance downwind. Moreover, people a d different kinds of structures, machines, and vegetation have different tolerances for ash. An ash fall that might not endanger a healthy person could seriously affect a person with breathing problems. Thus, the graph (fig. 3*B*) shows potential ash thicknesses at various distances from possible vents (compare fig. 3*A*), and can be used to anticipate possible effects on people or various kinds of property and vegetation. Descriptions of some of the effects that resulted from the 1980 eruptions of Mount St. Helens have been published. (See, for example, Warrick and others, 1981; Schuster, 1981.)

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