

can be thousands of times more powerful than the cataclysmic eruption of Mount St. Helens in May 1980, which caused the worst volcanic catastrophe in U.S. history. Fortunately, the volcanic systems capable of wreaking the most havoc are the least likely to erupt in any given time frame.

In 1974, the U.S. Geological Survey (USGS) was designated by Congress to be responsible for volcanic-hazards investigations and to provide "timely warning" of volcanic and related hazards. Effective volcanic-hazards mitigation requires (1) identification and hazards assessments of high-risk volcanoes, (2) systematic monitoring of potentially hazardous volcanoes, (3) fundamental research on volcanic phenomena and monitoring techniques, and (4) active participation of volcanologists in emergency-response planning and public-education efforts. To date, seismic and ground-deformation monitoring of volcanoes still provide the most reliable precursory data, but several other monitoring techniques show promise.

The USGS carries out its Volcano Hazards Program in close cooperation with State and local agencies, and with volcanologists from academia. Although the USGS primarily focuses on U.S. volcanoes, in the 1980's it began to assume an increasing role in providing technical assistance to developing nations in response to major volcanic disasters and crises (for example, El Chichón [Mexico], 1982; Galunggung [Indonesia], 1982-83; Rabaul [Papua New Guinea], 1983; and Nevado del Ruiz [Colombia], 1985). An important component of USGS cooperative studies abroad is the Volcano Early Warning Disaster Assistance Program (VDAP), supported in part by the Office of Foreign Disaster Assistance (OFDA) of the U.S. State Department, which at present largely focuses on volcanic crises and hands-on training needs of volcanologists in Latin America.

Technology already exists to mitigate substantially volcanic and related hazards on a global basis. The challenge lies in marshaling the political will and/or resources—currently lacking—to study and adequately monitor the world's high-risk volcanoes.

POTENTIAL HAZARDS FROM FUTURE ERUPTIONS IN CALIFORNIA

C. Dan Miller

More than 500 volcanic vents have been identified in California. At least 76 of these vents have erupted, some repeatedly, during the last 10,000 years. Past volcanic activity has ranged in scale and type from small rhyolitic and basaltic eruptions through large catastrophic rhyolitic eruptions. Sooner or later volcanoes in

California will erupt again, and they could have serious impacts on the health and safety of the State's citizens as well as on its economy.

The potentially more hazardous eruptions in the State are those that involve explosive eruption of large volumes of silicic magma. Such eruptions could occur at vents in the vicinity of Mount Shasta, Medicine Lake volcano, Lassen Peak, and in the Mono Lake-Long Valley area. Large eruptions could eject pumice high into the atmosphere and produce destructive blasts, debris avalanches, or pyroclastic flows that could reach distances of tens of kilometers from a vent. Eruptions of Mount Shasta and Lassen Peak could produce lahars and floods that could reach distances of hundreds of kilometers. Smaller eruptions would produce similar but less severe and less extensive phenomena.

The hazard is greatest close to a volcanic vent; slopes on or near a volcano and valleys leading away from it will be affected most often and most severely by eruptions. In general, risk from volcanic phenomena decreases with increasing distance from a vent, and for most flowage processes, with increasing height above valley floors or fan surfaces. Tephra from explosive eruptions can affect extensive areas downwind from a vent. In California, prevailing winds will cause the area east of a volcano to be affected most often and most severely. Risk to life and property from ashfall decreases rapidly with increasing distance from a vent, but even thin deposits of ash could disrupt communication, transportation, and utility systems at great distances, and over wide regions.

Volcanic eruptions are certain to occur in California in the future. Though eruptions can be neither prevented nor stopped, risk to life and property can be reduced by avoiding threatened areas and by taking protective measures to reduce the effects when and where vulnerable areas cannot be avoided. Monitoring of volcanic precursors generally can identify the location of impending volcanic activity, even though it often does not pinpoint the nature or timing of an eruption, or even its certainty. Hazard-zonation maps can then be used by public officials to guide decisions regarding land use and access and other hazard-response activities.

RECENT VOLCANISM AND HAZARDS IN THE LASSEN AREA, CALIFORNIA

Michael A. Clynne

Three episodes of volcanism have occurred at Lassen volcanic center in the past 1,100 years. These are the complex eruption at Chaos Crags, the eruptions at Cinder Cone, and the summit eruptions of Lassen Peak in 1914-1917. Each eruptive episode was different. Similar volcanism will reoccur in the future.

The eruption of Chaos Crags illustrates a cycle of activity typical of silicic volcanism. Careful study of the deposits of the Chaos Crags indicates that they formed during a complex eruption 1,100–1,000 years ago. Initial activity included formation of a tephra cone, emplacement of two pyroclastic flows, and growth of a dome that plugged the vent. After a quiet interval of 70 years, the dome was destroyed by a violent eruption that emplaced a pyroclastic flow and an air-fall tephra lobe. The violent eruption was followed by the growth of five domes, three of which had hot, dome collapse avalanche events. The Chaos Jumbles formed by a series of three cold rockfall-avalanches that illustrate an additional noneruptive hazard in the Lassen area.

The eruption of Cinder Cone is typical of mafic volcanism in the Lassen area. The Cinder Cone eruptive deposits consist of 4 basaltic andesite lava flows, a complex vent cone, and a widespread ash blanket. Two lava flows erupted before the ash blanket and two followed the ash blanket. All of these erupted over a short time interval 425 radiocarbon years ago.

The eruption of Lassen Peak in 1914–1917 included a diverse series of events that illustrate the destructive potential of snow-covered volcanoes. Mild vent-opening and crater-forming explosions persisted for a full year before the violent explosions of May 19 and 22, 1915. Lava first appeared in mid-May 1915, as a small dome filling the crater. On the evening of May 19, explosive disruption of the still-hot lava dome onto the snow-covered upper slopes of Lassen Peak generated an avalanche, debris flow, and flood that affected downslope valleys for at least 30 mi. On May 22, a subplinian eruption deposited an air-fall tephra lobe. Partial collapse of the eruption column generated a pyroclastic flow that devastated the northern flank of the volcano. Melting of snow incorporated by the pyroclastic flow generated a fast-moving debris flow. Fall of hot tephra onto the snow-covered upper slopes of the volcano generated additional debris flows.

Because these eruptions are fairly young, and their deposits are well preserved, their histories are better understood than those of older eruptions at the Lassen volcanic center. Yet even the deposits of the 1915 eruption of Lassen Peak are being rapidly obscured by vegetation and other natural processes. Erosion, especially glacial erosion, selectively removes unconsolidated volcanic deposits produced by the most explosive and hazardous events. Consequently, the preserved geologic record of older volcanism at Lassen is biased toward resistant deposits such as lava flows and domes produced by less hazardous activity.

Eruptions similar to these described are the types of volcanism most likely to recur. The principal volcanic hazards in the Lassen area are pyroclastic flows and debris flows that would primarily affect valleys peripheral

to Lassen Peak. Avalanches resulting from volcanic activity or nonvolcanic sources also pose a hazard to downstream valleys. Air-fall tephra poses a widespread though less serious hazard. Emplacement of lava flows and domes are an additional, more localized hazard. Fortunately, the Lassen volcanic center is in a national park, and the surrounding area is sparsely populated. However, people now live in areas affected by the Chaos Crags and 1915 eruptions, and the population in the vicinity continues to increase. Continued development in such areas could have serious consequences in the event of future eruptions.

RESEARCH AND MONITORING IN THE LONG VALLEY CALDERA, CALIFORNIA

Malcolm Johnston

The Long Valley caldera forms part of an active volcanic region in the upper Owens Valley that could, as it has in the past, impact this and the surrounding area should an explosive eruption occur. Scientific research in this region has been primarily focused on (1) understanding the structure and evolution of the region through geologic time, and (2) monitoring the present seismic and deformational activity to identify physical processes such as dike injection, magma pressure changes, fault rupture, and so forth, that have preceded eruptive activity of other volcanoes. Techniques from many disciplines (for example, geologic, seismic, magnetic, gravity, telluric, direct drilling, and so forth) have been used to define the detailed structure of the region, eruption types, and occurrence times. Indications of increasing hazard occurred in the early 1980's with a dramatic increase in seismic activity, bulging of the entire caldera, and outward displacement of points around the caldera. While the seismic activity has decreased during the past few years, bulging and straining is continuing at a uniformly high rate of about one part per million per year. This deformation rate is currently the highest in California. The region is presently monitored continuously with arrays of seismometers, strainmeters, tiltmeters, magnetometers, water wells, and so forth. These data are transmitted by radio or satellite telemetry to computers in Menlo Park for rapid (real-time) detection of seismic and deformation events. Horizontal displacement is regularly monitored with a two-color laser geodimeter within the caldera and over the entire region with standard geodimeter techniques. Vertical displacement (uplift) is also regularly monitored with level lines along existing roads, a long-baseline tiltmeter, and by measurements of apparent tilting of Crowley Lake. About 20 inches of uplift, centered on the resurgent dome, has occurred since 1980. Alert criteria have been defined in computer algorithms for detection of both seismic and