CHAPTER III

PREDICTION OF ERUPTIONS

From what has been said, it is apparent that the avoidance of loss of life and property damage during eruptions is heavily dependent on reasonably accurate prediction of the time, place and nature of the eruptions, as well as of the behaviour and course of different sorts of flows and of the distribution and thickness of tephra. The type, severity, and duration of the eruption are at least as important as the time. To date, the best basis for predicting the nature of a coming eruption is by analogy with past eruptions of the same volcano, coupled in some cases with the length of time since the last eruption. Individual volcanoes are likely to continue similar behaviour over many centuries and through many eruptions. Determination of the history of the volcano entails a geologic study, to ascertain the composition and types of lava flows and tephra, the proportion of tephra and its distribution, the presence or absence of domes and deposits of glowing avalanches, ash flows, and lahars, the extent of the flows, etc. Dating of the rocks may give some idea of the frequency of past eruptions. Thorough studies of this sort have as yet been made on only a small proportion of the earth's potentially active volcanoes.

At some volcanoes the length of the repose period since the last eruption gives some indication of the probable nature of the next one. For example, at Hekla, Iceland, a short period of inactivity is apt to be followed by a relatively gentle eruption, whereas a long period of quiet is followed by violent explosion (Thorarinsson, 1967a).

Accurate prediction of the courses of flows demands a good topographic map of the volcano and its surroundings on a reasonably large scale (preferably not less than 1:50,000); such maps are available for relatively few volcanoes.

Prediction of the time of a coming eruption is useful in direct proportion to its precision. General predictions that the volcano is uneasy and may erupt within the next few weeks or months are useful primarily in alerting observers and relief agencies to be ready for action, and persons in the vicinity of the volcano to be ready for evacuation or some other sort of protection whenever more definite warning and instructions are received. It cannot be emphasized too often that false predictions can do a great deal of harm, through the loss of the confidence of the people warned, and hence loss of response to future warnings. In our present state of knowledge some failures must be expected, but it is better to err in the direction of not warning than by issuing large numbers of warnings of events that do not materialize. Brief comments on commonly used bases for prediction of time of eruptions follow.

Periodicity of the volcano can be used in a very general way, if any is detectable. Thus, during the past 150 years summit eruptions of Mauna Loa, Hawaii, have been followed within about 3 years by flank eruptions. But the interval has varied from less than 6 months to 38 months, and some summit eruptions have been followed by another summit eruption rather than by a flank eruption, so that any prediction on this basis is necessarily very imprecise. At most other volcanoes no regular periodicity has been recognized.

A periodicity of events within a single eruption is sometimes recognizable. Thus, during the 1924 eruption of Kilauea, a regularity of this sort made it possible to forecast the time of occurrence of individual explosions and warn of them.

Some observations suggest that eruptions of some volcanoes may be triggered by tidal or other astronomical forces, which are themselves quasi-periodic (Hamilton, 1973; Mauk and Johnston, 1973). During the period from January 1972 to June 1974 there was a marked correlation of eruptions of Ngaurahoe, New Zealand, with tidal maxima, the eruptions tending to precede the maxima by a few days (Michael and Christofell, in press). Other investigators believe they have found direct correlations with phases of the moon (Perret, 1950, p.129; Taylor, 1960).

Some evidence suggests a relationship between tectonic earthquakes and subsequent eruptions, but elsewhere there appears to be no relationship (Berg and Sutton, in prep.; Blot, 1973; Tokarev, 1959; Latter, 1971). Certainly the relationship is yet too vague to be used for prediction.

Some eruptions are preceded by changes in fumaroles or hot springs on the volcano - the appearance of new ones, increases of temperature, or change in the composition of the gases. Thus the 1965 eruption of Taal was preceded by a rise of 11° C in the temperature of the crater lake; and at Aso, Japan, the temperature may rise to the point that the lake boils completely dry before the eruption. But the length of the period of increased temperature ranges from a few days to several years, and in some cases the temperature has returned to normal without any eruption. At other volcanoes, no increase of the temperature of fumaroles has occurred before eruptions (Neumann van Padang, 1963).

At Asama and Mihara volcanoes, Japan, the proportion of sulphur and halogen gases in fumaroles has increased before some eruptions, but before other eruptions and at other volcanoes no increase has been detected. The method appears however sufficiently promising to warrant further investigation, With recent improvements in gas chromatography and electronic transmission of chemical data and temperatures, increased monitoring of fumaroles is indicated.

Temperature changes may also be detected by infrared remote sensing, from ground stations, aerial photography, or artificial satellites (Fisher, et al., 1964; Moxham, 1971).

Changes in magnetism and in earth electrical currents also may occur before eruptions, presumably because of changes in the heat regime within the volcano. Minakami (1935) has reported rapid changes in strength of earth currents a few hours before individual explosions of Asama, in Japan, but little other work of this nature has been reported. It appears worthy of further investigation. Marked changes in the intensity of the magnetic field were observed before the eruption of a lateral vent (Piip Crater) on Kliuchevskoi, Kamchatka, in 1966 (Gorshkov and Kirsanov, 1968); and a peculiar fluctuation in the vertical component of the magnetic field occurred at Honolulu, 300 km from the volcano, before the 1942 eruptions of Mauna Loa, Hawaii (Macdonald, 1951). An increase in the rate of drift of the magnetic field has been observed several months before eruptions of Mihara Volcano (Rikitake, et al., 1963). Little continuous work has been done on earth currents or magnetic variations at other volcanoes, but the changes reported appear to warrant further studies.

On several occasions animals on and near the volcano have been observed to be uneasy for several days before an eruption. Thus, cattle started to move off Arenal Volcano two weeks before the outbreak in 1968, although persons in the area felt the first earthquakes only two days before the outbreak (Melson and Saenz, 1968). At Kilauea, in 1955, dogs became uneasy and started digging in the ground and snuffling in the holes as though in pursuit of some burrowing animal, about 4 days before the outbreak (Macdonald and Eaton, 1964). Observers could detect no odor of gas or anything else to cause the dogs' uneasiness. However, a seismograph a few miles away was recording hundreds of earthquakes too small for people to feel, and these may have been disturbing the dogs. The sensitivity of some animals to earth tremors that cannot be felt by people is well known. There were no seismographs close enough to Arenál to tell whether the animals there might have been disturbed by small earthquakes. Disturbance of animals should be taken into account, along with any other available signs, in attempting to forecast eruptions.

So far, the most useful geophysical tools for the prediction of eruptions have been ground deformation and earthquakes. More than half a century ago T.A. Jaggar and H.O. Wood recognized cycles of tilting of the surface of Kilauea Volcano, which they attributed to a rise and fall of the summit of the volcano, due to changes of pressure in the underlying magma reservoir (Jaggar and Finch, 1929). Recently, more detailed measurements with improved instruments have confirmed the phenomenon and have indicated that the magma chamber is a complicated sponge-like structure, lying about 3 or 4 km below the surface (Eaton and Murata, 1960), in which the center of swelling migrates from place to place (Fiske and Kinoshita, 1969). Swelling generally reaches a maximum before eruption, then decreases when the magma pressure is relieved by a flank eruption. During summit eruptions little or no deflation may occur, but flank eruptions may so reduce the pressure that collapse of the summit area results. As yet no definite critical amount of swelling can be identified as that at which eruption will take place, though it can be said that the volcano is ready to erupt. The swelling of the volcano is observed by means of tilt-meters, by precise levelling, and by geodometers which measure the changes of length of lines across the summit of the volcano. Mauna Loa also tumesces before eruptions, but the data are far less precise, partly because Mauna Loa has been inactive since the installation of sensitive modern instruments. Tumescence has been observed before eruptions of some other volcanoes, as for instance at Merapi and at Manam, New Guinea (Taylor, 1963). But at others, such as Etna, no swelling has been detected, perhaps because their magma chambers lie too far below the surface (Rittmann, 1963).

Very marked deformations of the ground have occurred at some volcanoes, as for instance at Usu, Japan, in 1943, when the ground was upheaved some 50 m before the beginning of the actual eruption (Minakami, et al., 1951). Uplift of the shoreline preceded the eruption of Monte Nuovo, in the Phlegrean Fields near Naples, in 1538, and may be expected at other coastal and island volcanoes. Instrumental measurements of ground-surface deformation have been thoroughly reviewed by Decker and Kinoshita (1971).

Many eruptions are preceded by earthquakes. The number felt by persons on and near the volcano ranges from many to none, but when seismographs of at least moderate sensitivity are operating in the area it is generally found that the number of quakes that are too small to be felt, greatly exceeds that of felt quakes. The period of abnormally frequent quakes preceding an eruption ranges from less than an hour to several years, so that unless some more definite relationship has been established at the particular volcano, the advent of seismic activity does not make possible any close prediction of the time of the eruption. Moreover, in detail the pattern of occurrence of the quake is quite variable. Sometimes the number of quakes increases regularly up to the time of outbreak. Thus, before the 1955 eruption of Kilauea there was a continuous increase in earthquake frequency for about 4 months. From an average of about 25 quakes/month on a seismograph of only moderate sensitivity 6 km from the eventual point of outbreak, the number increased to about 60 in November 1954, and to 90 in December. During January the number increased to an average of 6/day, and in early February to

15/day; on 24 February approximately 100 were recorded, on 25 February 300, on 26 February 600, and on 27 February 700. The eruption started early on 28 February. Later swarms of earthquakes made it possible to anticipate the place, and sometimes the approximate time, of new outbreaks during the same eruption. In some other preludes there has been a sharp decrease in the number of earthquakes for a few hours or a few days just preceding the eruption; however, similar decreases may occur at one or more times during the prelude. Still other series of quakes come to an end without any attendant eruption. At Kilauea, series of similar-appearing quakes may occur either during swelling of the volcano, which may lead to eruption, or during the shrinking that results from drainage of magma from the underlying chamber. Tilt measurements make it possible to tell which type of change is going on.

At Asama Volcano Minakami (1959) distinguishes three general classes of earthquakes. Type A quakes originate at depths of 1 to 10 km below the crater, those of type B originate at less than 1 km, and those of the third type result from explosions in and just below the crater. Using an empirical formula based on the frequency of B-type quakes, Minakami is able to assign a probability value for the occurrence of an eruptive episode within the next 5 days. At Sakurajima Volcano, swarms of B-type earthquakes precede groups of explosions by 10 to 15 days (Minakami, et al., 1960). Tokarev (1963) finds that B-type earthquakes start at Bezymianny Volcano some 30 to 50 days before an eruption. Using the principle of the strain-release curves devised by Benioff (1951), he has developed a formula which he has used to predict individual explosive episodes approximately a week in advance. He believes the method can be used at other volcanoes also. It should be tested.

So far, no definite relationship has been found between the number of earthquakes in a prelude, or the total energy released by them, and the magnitude of the subsequent eruption.

Volcanic tremor is a rhythmic vibration of the ground that seems clearly related to underground magma movement, and produces a characteristic regular undulation of the line on a seismogram (Shimozuru, 1971). It appears to be commoner on basaltic than on andesitic volcanoes. Its appearance during an earthquake swarm adds to the probability that an eruption is about to occur; but the period between its appearance and the outbreak of lava is often only a few minutes or less.

Thus there is no single known indicator for the successful prediction of eruptions. The best results have been obtained by combining several different indications. Thus, R.H. Finch combined the rather vague periodicity of Mauna Loa with swelling of the volcano indicated by tilt measurements and an earthquake swarm which migrated along one of the rift zones of the volcano, to make an unusually successful prediction of the 1942 eruption (Macdonald, 1972, p.418).

The present tendency in observing volcanoes is toward elaborate and expensive instrumentation. Where this is not economically unfeasible, much can still be done with simpler means. Mechanical seismographs of moderate magnification are relatively cheap both in capital and in manning costs, and may often be adequate. Simple water-tube tiltmeters also are cheap; measuring the opening and closing of cracks in the summit region gives much the same information as geodometer measurements. Fumarole temperatures can be measured by an observer with an ordinary maximum thermometer. Telemetry saves footwork, but is not indispensable.

CHAPTER IV

VOLCANIC ZONING

The delineation of areas of type and degree of hazard from volcanoes is generally known as volcanic zoning. In several parts of the world attempts are being made to identify which volcanoes are potentially dangerous, and to indicate on maps the areas subject to different degrees and types of risk, but thus far work of this sort has been very limited. Much more should be done, and as rapidly as possible, before catastrophe strikes again. It is the only logical basis for the decisions that must be made when an eruption starts or appears imminent, as to what areas should be evacuated, and for what periods.

The earliest zoning maps appear to have been made by the Volcanological Survey of the Netherlands Indies after the 1919 eruption of Kelud (Neumann van Padang, 1960). The areas indicated as dangerous were chiefly those that had been previously devastated within historic time, and they show clearly the effects of topography on the flows (fig. 18). The work is being continued by the Geological Survey of Indonesia (fig. 19). In recent years similar maps have been prepared for some of the Kamchatkan volcanoes (Gorshkov, G.S., personal communication, 1973). In New Zealand, a general appraisal of volcanic risk has been made for the city of Auckland (Searle, 1964).

At Mayon, in the Philippines, a permanent danger zone has been established, with a radius of 6 km from the summit of the mountain. During the 1968 eruption additional zones of danger from lahars were established, and their boundaries modified according to changes in the eruptive conditions (Fernandez, 1971).

After the destruction of the village of Kapoho by the eruption of Kilauea in 1960, the present writer prepared for the Hawaii Better Business Bureau an appraisal of the degree of risk from lava flows along the eastern part of the east rift zone of Kilauea, and later a similar appraisal was made for a major land owner of the risk on the southern and western parts of the island of Hawaii. The likelihood of destruction of any given small piece of land within a 30-year period (the average length of life of a wooden house in that climate) was calculated within successive zones of distance from the vents along the rift zones, on the basis of the proportion of the land within each zone that had been covered by lava within historic time — about 150 years. The data are inadequate for a sound statistical analysis, but they at least give a rough idea of the degree of risk. Recently, a more detailed study has been made by D.R. Mullineaux of the U.S. Geological Survey, but the results have not yet been published.

About 20 years ago mapping of the surficial deposits on and near Mt. Rainier, Washington, by geologists of the U.S. Geological Survey, led to the recognition of hazards, particularly from lahars, in that area (Crandell and Waldron, 1956). This, in turn, has led to the study of several other volcanoes, with appraisal of the potential risks from each (Crandell and Mullineaux, 1967, 1970; Crandell and Waldron, 1969), and the publication of a map of hazard areas near Mt. Rainier (Crandell, 1973). A simplified version of the map is given in figure 20. The study of other Cascade volcanoes and the preparation of hazard maps for them is continuing.

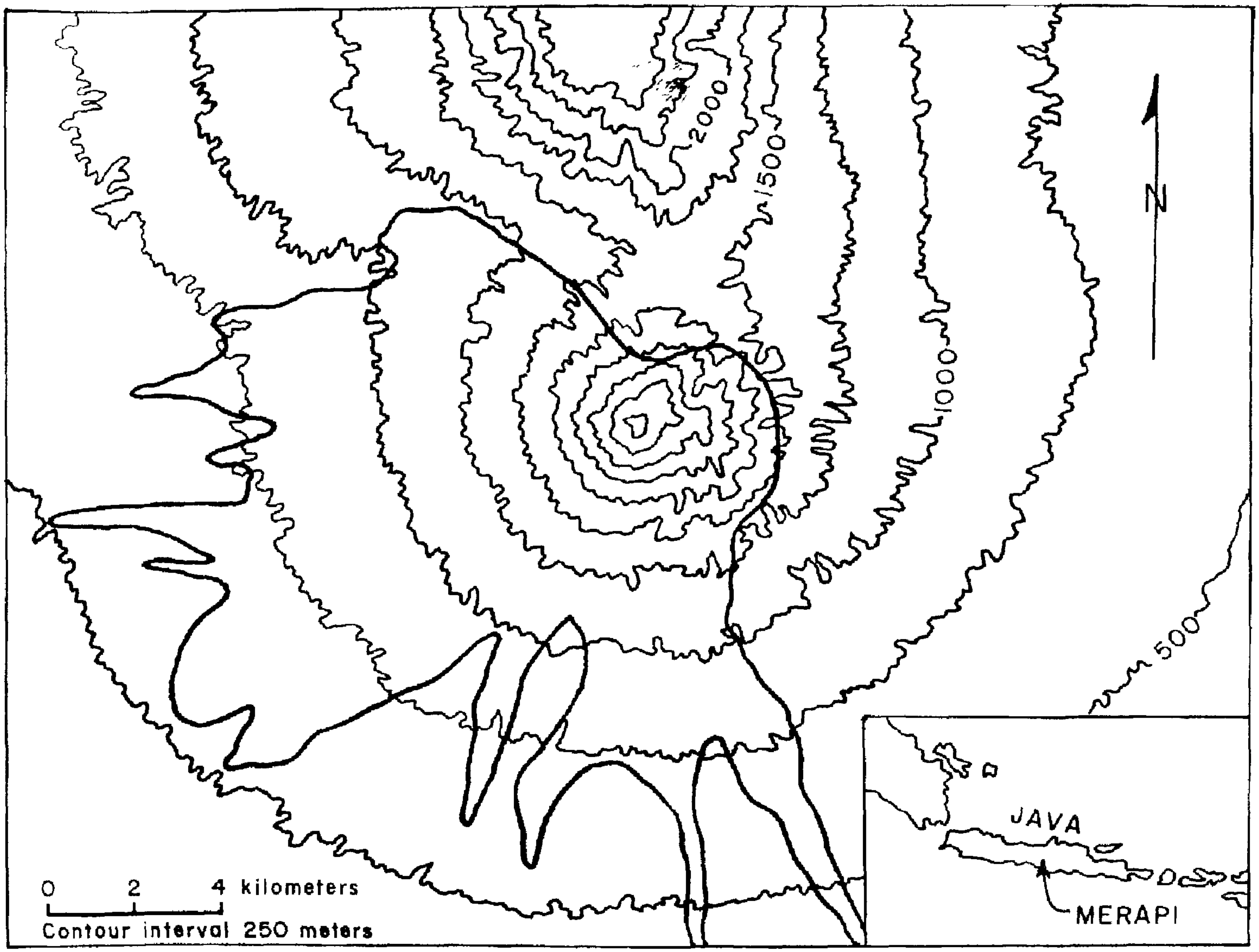


Figure 18. Map of Merapi Volcano, Java, showing the zone of danger from glowing avalanches as designated by the Netherlands Indies Volcanological Survey about 1934.

(After Neumann van Padang, 1960).

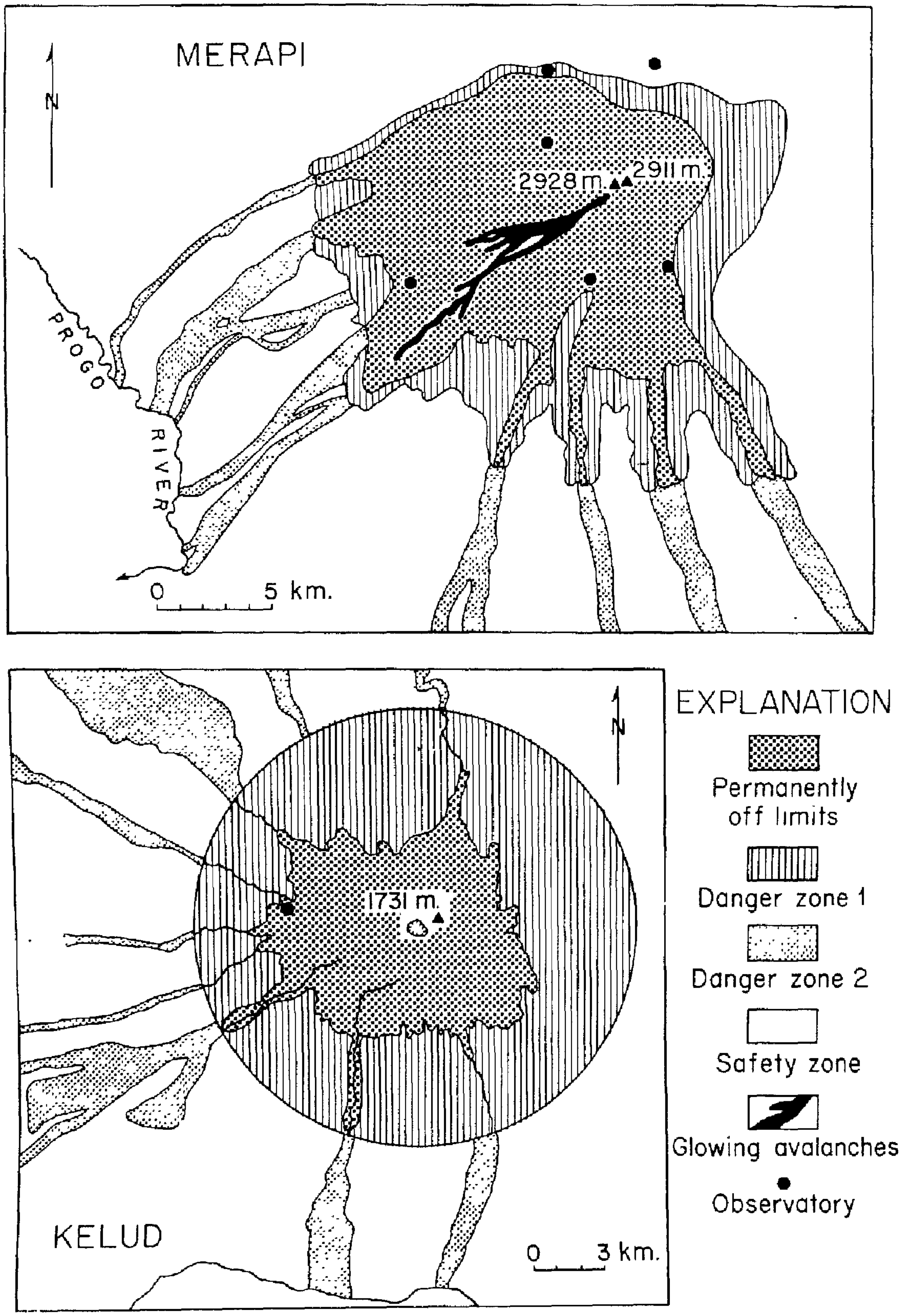


Figure 19. Maps of the areas around the volcanoes Merapi and Kelud, in Java, showing danger zones. The maps are simplified from ones prepared by the Geological Survey of Indonesia. The inner zone is dangerous even in minor eruptions, and persons are advised not to live within it at any time. (Compare figure 18). Zone 1 is dangerous during big eruptions, and zone 2 is endangered by lahars. (After Suwa, 1973).

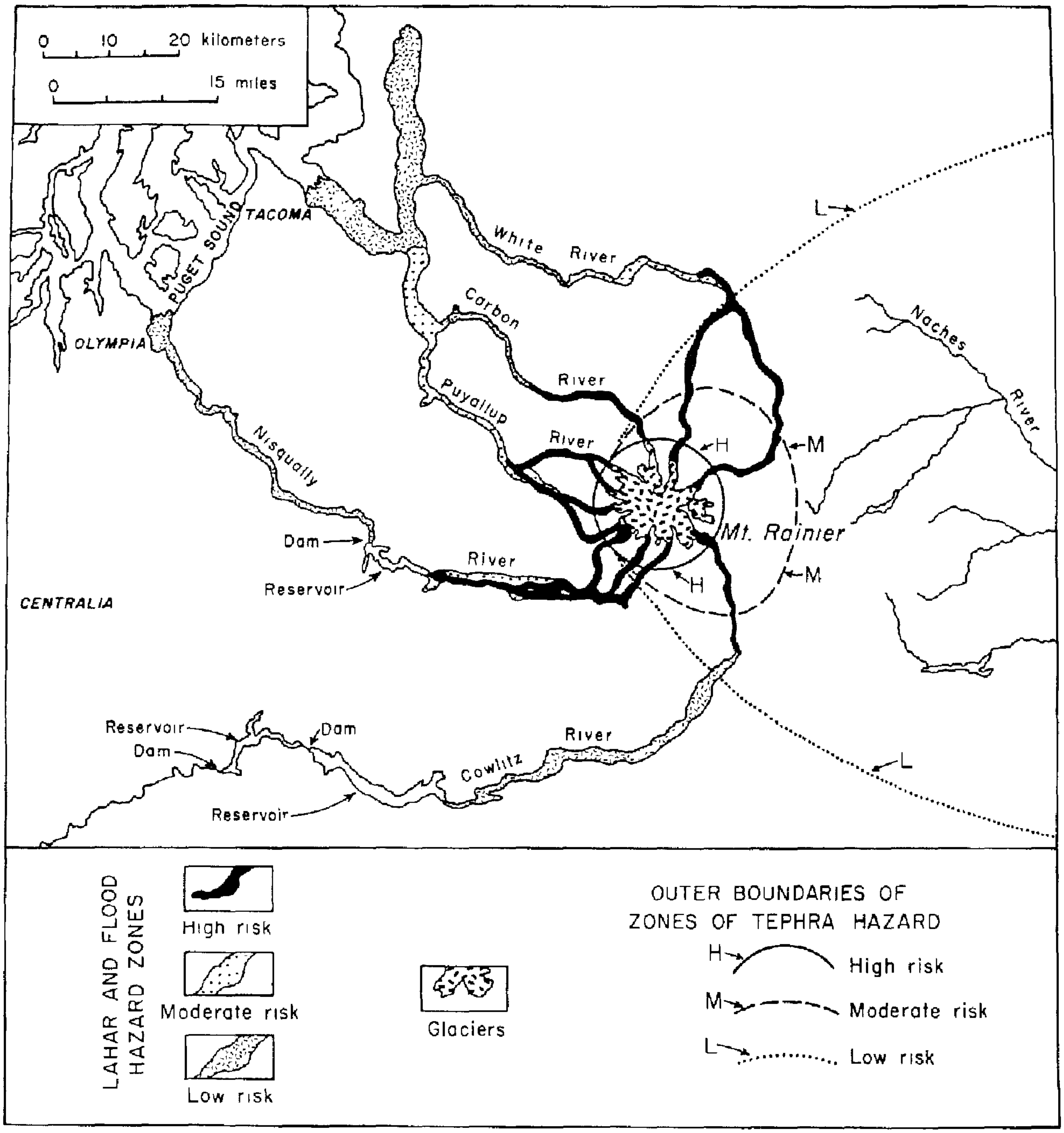
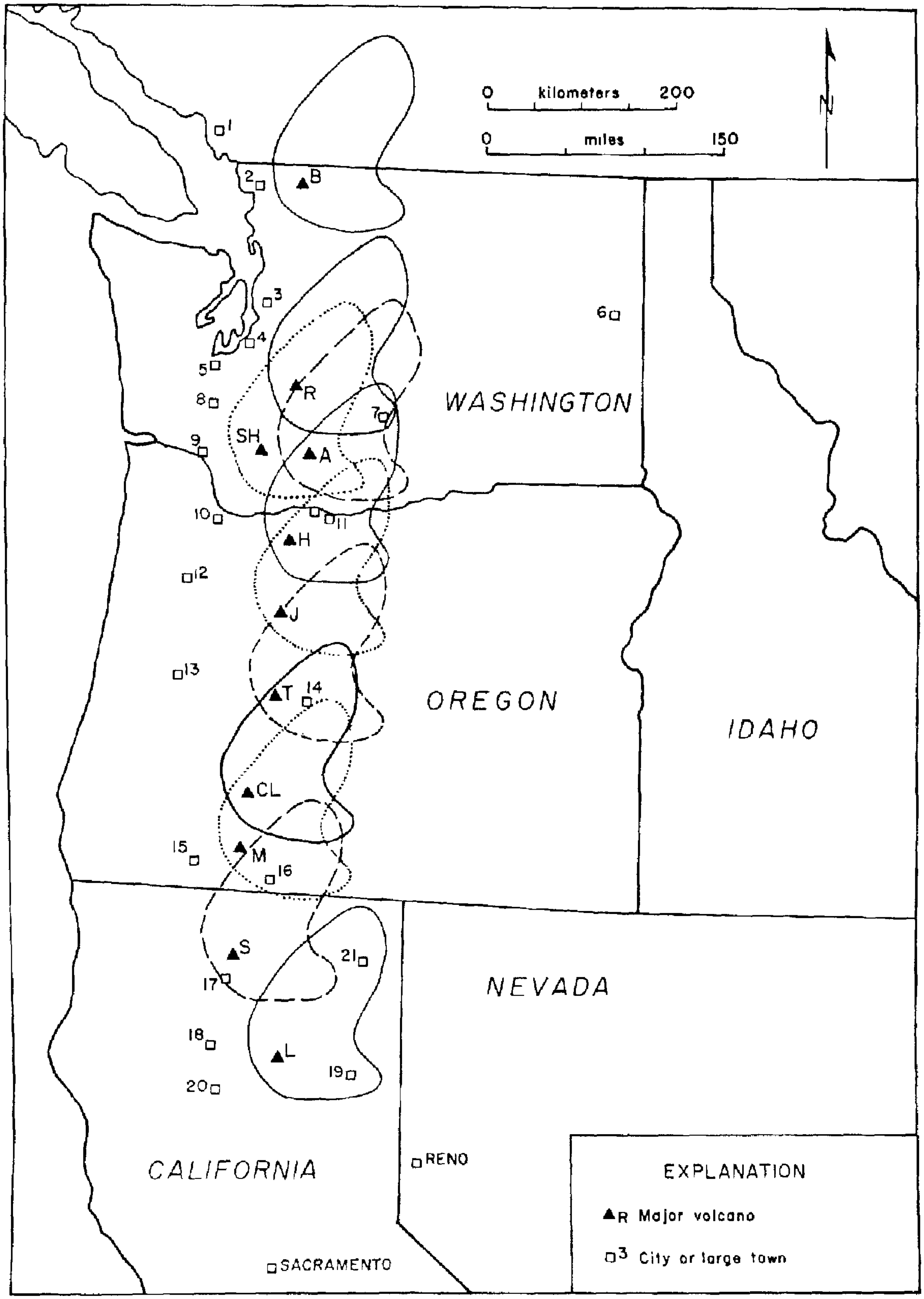


Figure 20. Map showing zones of danger in the vicinity of Mt. Rainier, Washington. (Simplified after Crandell, 1973).

One of the major risks from Cascade volcanoes, as from similar volcanoes elsewhere, is damage by air-borne ash. Prediction of the areas that might suffer in this manner requires the preparation of maps showing the extent and thickness of possible ash falls from each volcano, with various intensities of eruption and various directions and strengths of both upper- and lower-level winds (Crandell and Waldron, 1969). Figure 21 is an example.

Other agencies and groups are becoming concerned. Thus, geological studies have recently led to the closing by the National Park Service of one major campground near Mt. Lassen, California, and opening of a new one in a safer area. A report on volcanic hazards has recently been prepared for the legislature of the State of Washington (Cullen, 1974), to aid in planning for future land use.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SACRAMENTO
EXPLANATION
R Major volcano
3 City or large town

Figure 21. Map showing the location of the major volcanoes of the Cascade Range in northwestern United States, with superposed on each the pattern of ash distribution during the eruption of Mt. Mazama about 4,000 B.C. Compare figure 5. (After Crandell and Waldron, 1969). The letters and numbers indicate respectively the volcanoes and some of the cities of the region, as follows: A - Mt. Adams, B - Mt. Baker, CL - Crater Lake (Mt. Mazama), H.-Mt. Hood, J - Mt. Jefferson, L. -Mt. Lassen, M - Mt. McLaughlin, R - Mt. Rainier, S - Mt. Shasta, SH - Mt. Helens, T - Three Sisters; 1 - Vancouver, 2 - Bellingham, 3 - Seattle, 4 - Tacoma, 5 - Olympia, 6 - Spokane, 7 - Yakima, 8 - Centralia, 9 - Longview, 10 - Portland, 11 - Hood River and The Dalles, 12 - Salem, 13 - Eugene, 14 - Bend, 15 - Medford, 16 - Klamath Falls, 17 - Dunsmuir, 18 - Redding, 19 - Susanville, 20 - Red Bluff, 21 - Alturas.

CHAPTER V

THE ROLE OF THE VOLCANOLOGIST

The volcanologist should play a dual role. He should be both scientist and humanist. On the scientific side, he must gather, analyse, and interpret the data, and attempt to predict the time and type of the eruption, and the nature and extent of the damage from it. Prediction can be considered pure science, in that the degree of its fulfilment constitutes a test of the accuracy of the data and their interpretation and of the understanding of the volcanic mechanism. Obviously, it also has its very practical side, since a successful prediction can mean a great saving in property and lives. The volcanologist must publicize his prediction, even at the risk of damage to his scientific reputation should he be wrong, and the basis for the prediction must be fully explained. Furthermore, the prediction and explanation must be made in plain language that can be understood by non-scientists. Specialized scientific terms and jargon must be avoided.

The volcanologist must develop the ability to work with non-scientists — the government officials and representatives of disaster-relief organizations — to understand their problems and needs and to make them aware of what sort of information he can supply, its basis, and its limitations. He must also establish a rapport with residents of the areas concerned, not only with community leaders, but with the populace as a whole. They must come to know him, and he them. He must understand their feelings and reactions, their behaviour under stress, and try to lighten the stress by gaining their confidence. Panic is one of the most dangerous possibilities in any situation of potential danger. Indeed, it can turn a situation that would otherwise not have been serious into a disaster. If the people have confidence in the volcanologist, and he takes the pains to explain to them, in their own language, just what the situation is and what risks are involved, the likelihood of panic can be much reduced. People show great ability to face dangerous situations with equanimity if they understand the situation. It is the unknown or not understood danger that terrifies. This has been pointed out by Perret (1950, p. 151-153) and it is amply borne out by experience. The mere presence of the volcanologist can inspire confidence and calm the situation.

There should, however, be a definite limit to the responsibilities of the volcanologist, and this should be understood by the general public. Thus, although it is his job to try to forecast a dangerous situation, it should not be his responsibility to order an evacuation. That should be done by a designated government official, on his advice. He should advise on the relative safety of evacuation routes, but the actual evacuation should be directed by officials of the police or disaster-relief agencies, following previously prepared plans insofar as possible. He should advise of the feasibility of diverting flows, by barriers or by bombing, but the execution of the diversion should not be on his order. Economists should weigh the cost of the operation against the value of the property that may be saved; the probable legal implications should be considered by lawyers, and so on; on the advice of all, the decision to divert the flow should be made by a high government official designated to assume the responsibility.

Not all scientists are psychologically fitted to deal with the human side of volcanology, and they should not attempt it. There is ample place for them in collecting the scientific data and interpreting it. Otherwise, with the best of intentions, they may soon alienate the people they are trying to help. Others, who are better suited, should make the contacts with the community.

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