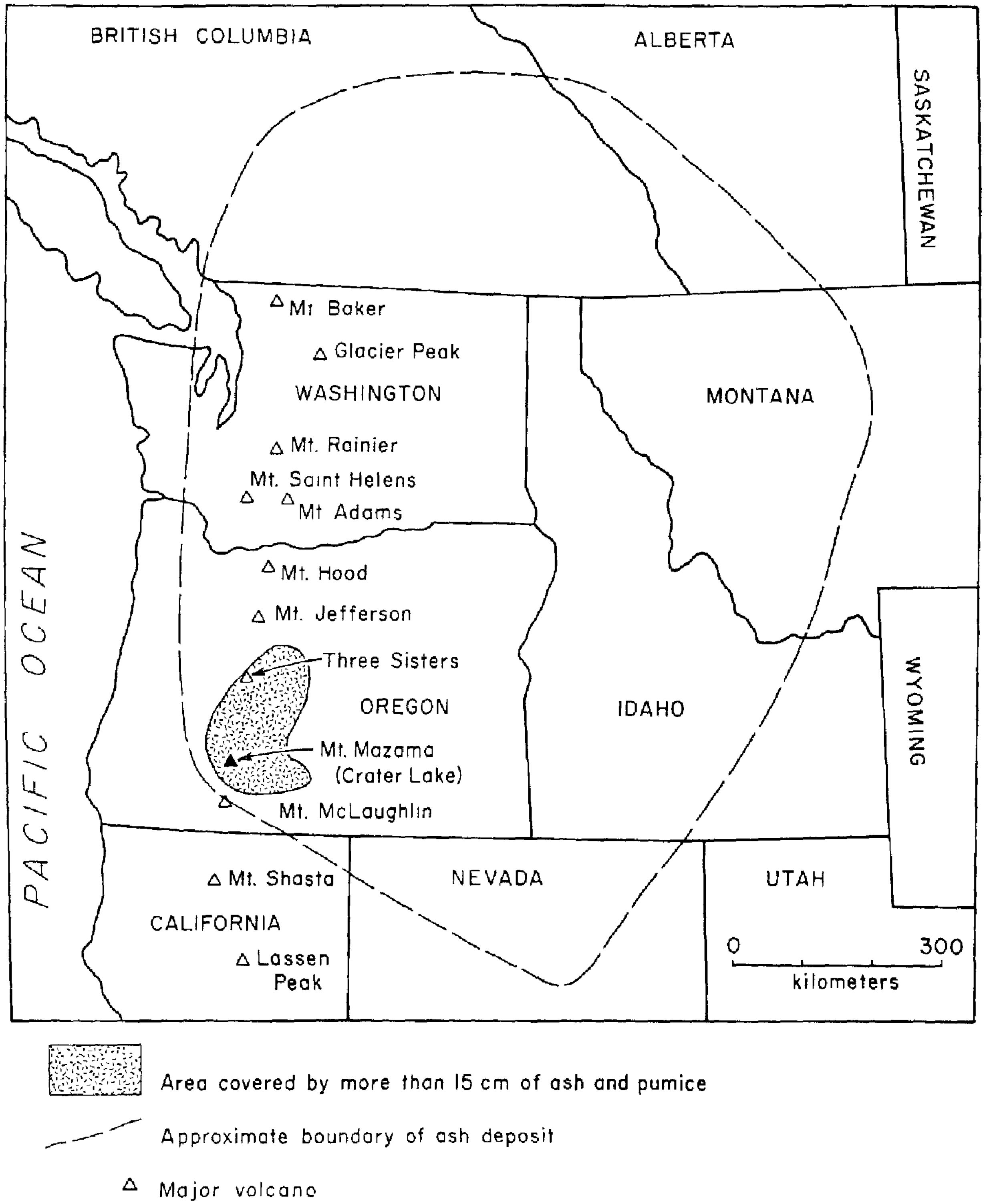

Figure 5. Map showing the distribution of ash from the great eruption of Mt. Mazama, Oregon, about 4,000 B.C.

(After Williams and Goles, 1968).

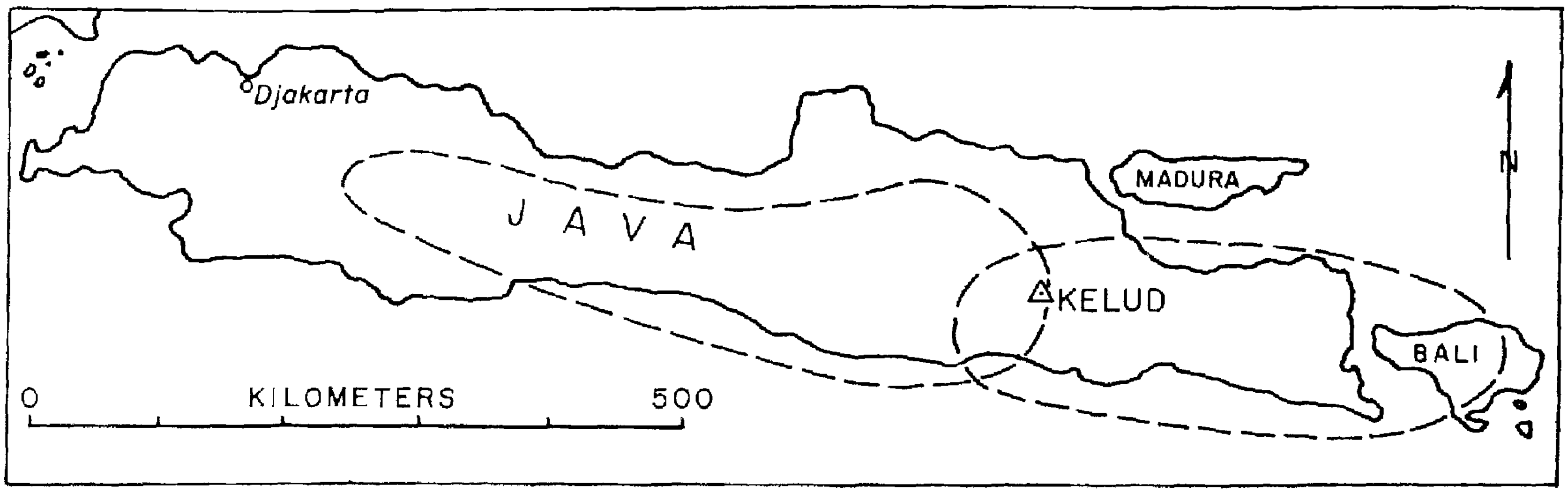

Figure 6. Map showing the distribution of ash (dashed lines) during the 1919 eruption of Kelud Volcano, Java. High-level winds blew the ash westward, and low-level winds blew it eastward.

(After Kemmerling 1921, from Wilcox, 1959).

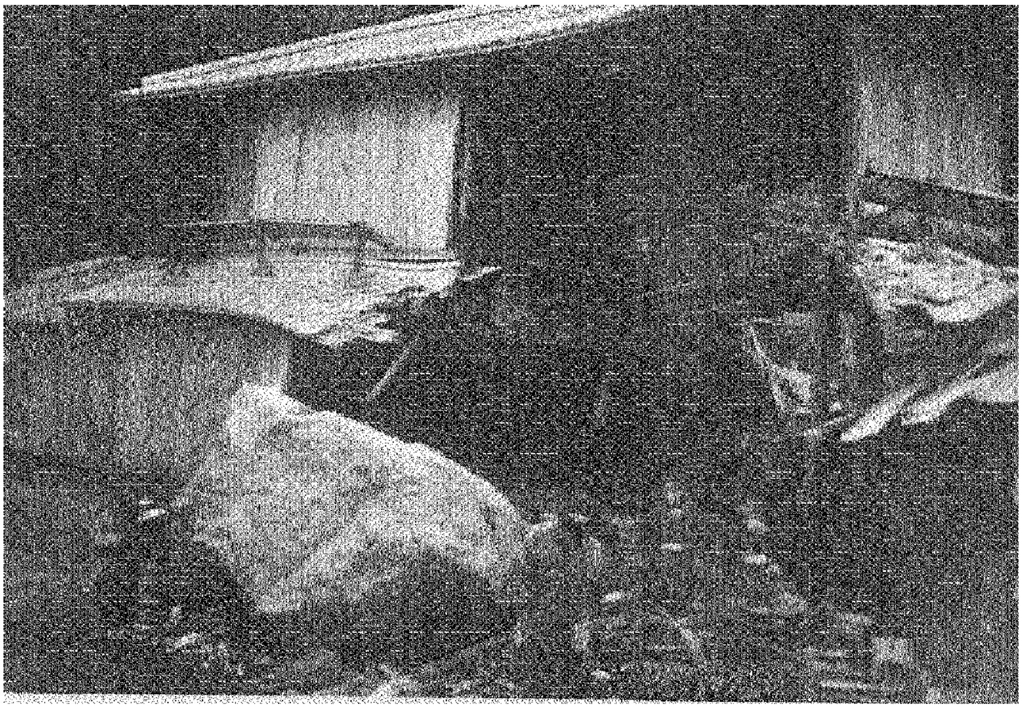

Plate 6. House destroyed by a large lava block ejected from Sakurajima Volcano, Japan, in 1914.

(Source: T.A. Jaggar).

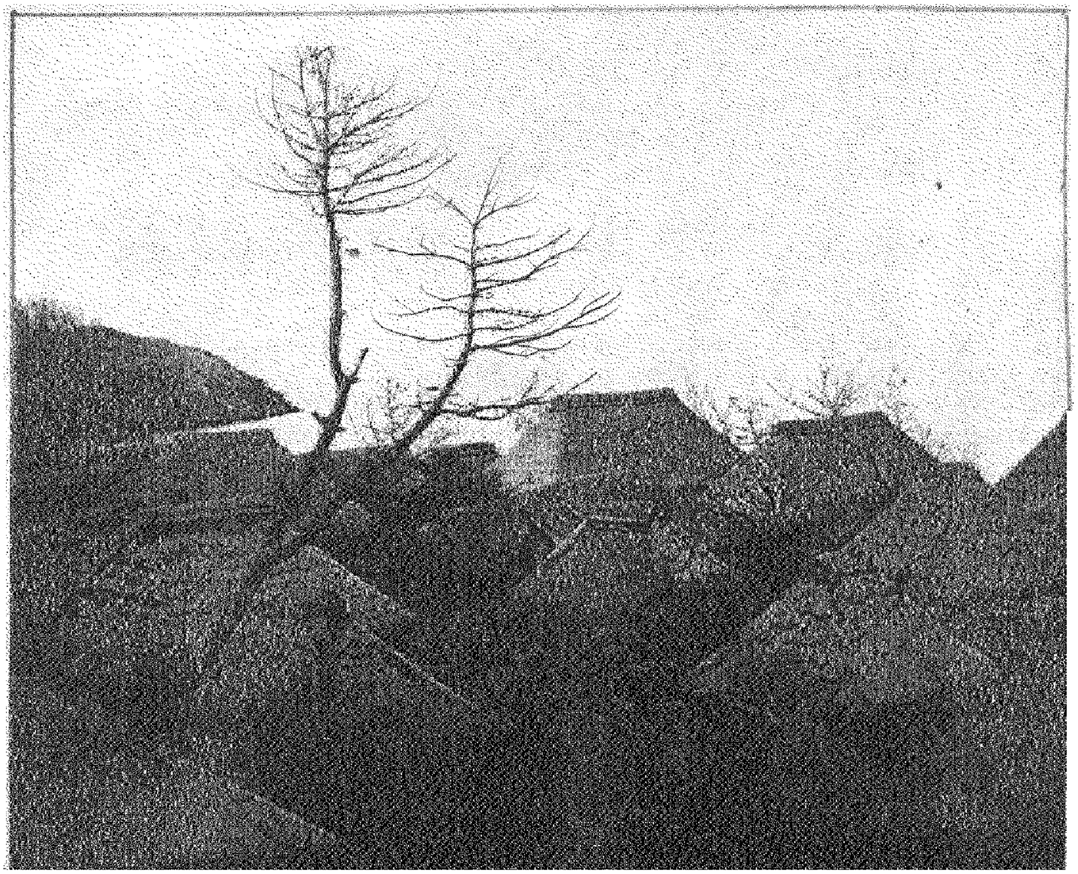

Plate 7. Houses on the eastern slope of Sakurajima Volcano, Japan, buried by ash during the eruption of 1914. Much of the ash has slid off the steeply-pitched roofs.

(Source: T.A. Jaggar).

The darkness and poor visibility are harder to combat. They are due partly to the shutting out of daylight by the ash-laden atmosphere, and partly to a decrease in the transparency of the air because of the load of fine particles in suspension. During the most violent explosion of the 1956 eruption of Bezymianny, Kamchatka, the air became so opaque at Kliuchi, 24 km from the volcano, that even with electric lights on, and with flashlights, men had to feel their way along the streets to get home (Gorshkov, 1959). During the 1912 eruption of Katmai, Alaska, at Kodiak, 160 km from the volcano, it was impossible to see a lighted lantern held at arm's length.

The intense electrical storms that frequently develop in the ash cloud may make radio communication impossible, and cause severe noise and spontaneous ringing of bells on telephone circuits. Some fires are started by lightning.

The blanket of ash may be several metres thick near the volcano, and several centimeters thick as much as 100 km away (fig.7). At Kodiak, in 1912, the ash is reported to have been more than 25 cm thick. Ash a few centimetres deep may kill grass and other forage, and even lesser amounts may cause serious trouble to grazing animals. The ash is ingested along with the grass, and may accumulate in the animal's digestive system, causing death. Over a somewhat longer period, the abrasive ash may wear away the animal's teeth to the point that it cannot eat, and dies of starvation. Poisonous substances in or on the ash may also cause death. The effects of fluorine during the eruptions of Hekla are discussed later. For all these reasons, it may be necessary to move cattle out of the area temporarily, or feed them on stored or imported feed. Ash is generally washed off grass within a few months, and sometimes much less, after the eruption; destroyed pasture usually becomes re-established within a few months to a few years. In rarer instances, however, trouble may be long lasting. In New Zealand, cobalt poisoning in sheep was traced to an ash layer of prehistoric age, and the animals had to be removed permanently from the area underlain by this ash.

Heavy ash loads often break the branches of broad-leafed trees, and may do serious damage to fruit and nut orchards. This can be averted to some extent by shaking the ash from the trees from time to time. Conifers, with their adaptation to winter snow loads, commonly suffer much less. Deeper ash piling up around the boles of trees may kill them. At Paricutín, Mexico, within the area where the ash was more than one meter deep (fig. 8) even the largest trees were killed. Many of them can be saved by digging the ash away from their trunks.

Some damage to crops may be surprisingly indirect. Thus, near Parícutin sugar cane was killed by an infestation of cane borers, because the ash had destroyed another, predatory insect that normally kept the population of stem borers at a low level. During the eruption of Cerro Negro in Nicaragua in 1971, the cotton harvest was lost over a wide area because of damage to the harvesting machines by ash deposited on the cotton bolls.

The greatest volcano-induced disaster in history resulted from the eruption of Tambora, on Sumbawa Island, in 1815. The eruption, which is commonly rated as the most violent during historic times, buried the nearby parts of Sumbawa with ash and pumice to a depth of 1.5 to 20 m, and on Lombok Island, 140 km west of the volcano, the ash was 50 cm thick (fig. 9). The widespread destruction of crops resulted in a famine which is said to have killed more than 80,000 people. During the Laki eruption of 1783, a combination of ash fall and sulphur gases destroyed forage crops and caused the death of half of the cows and three-fourths of all the sheep and horses in Iceland (Thorarinsson, 1970). The resulting famine killed a fifth of the human population.

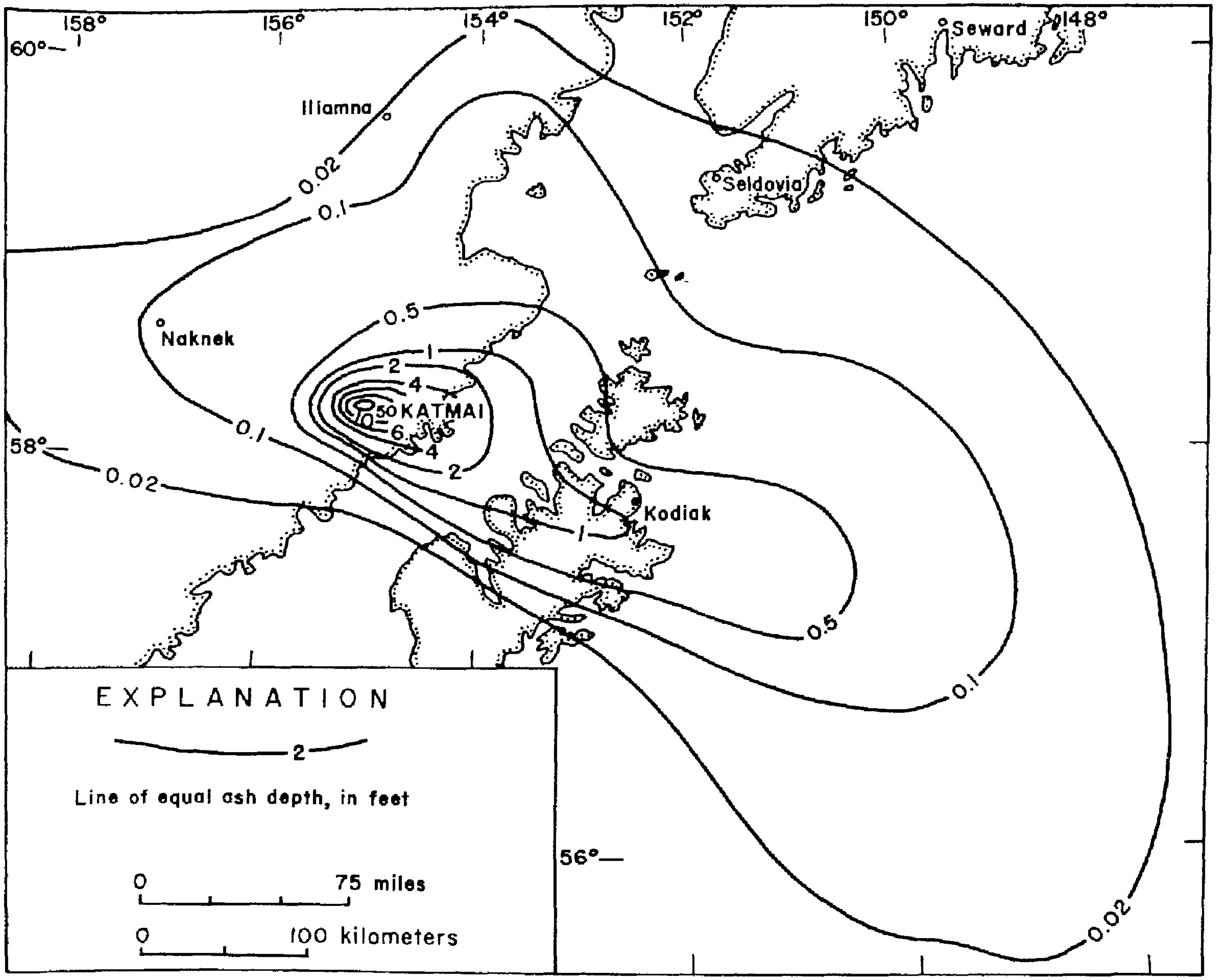

Figure 7. Map showing the distribution of ash from the eruption of Katmai Volcano, Alaska, in 1912 (from Macdonald, 1972, modified after Wilcox,1959)

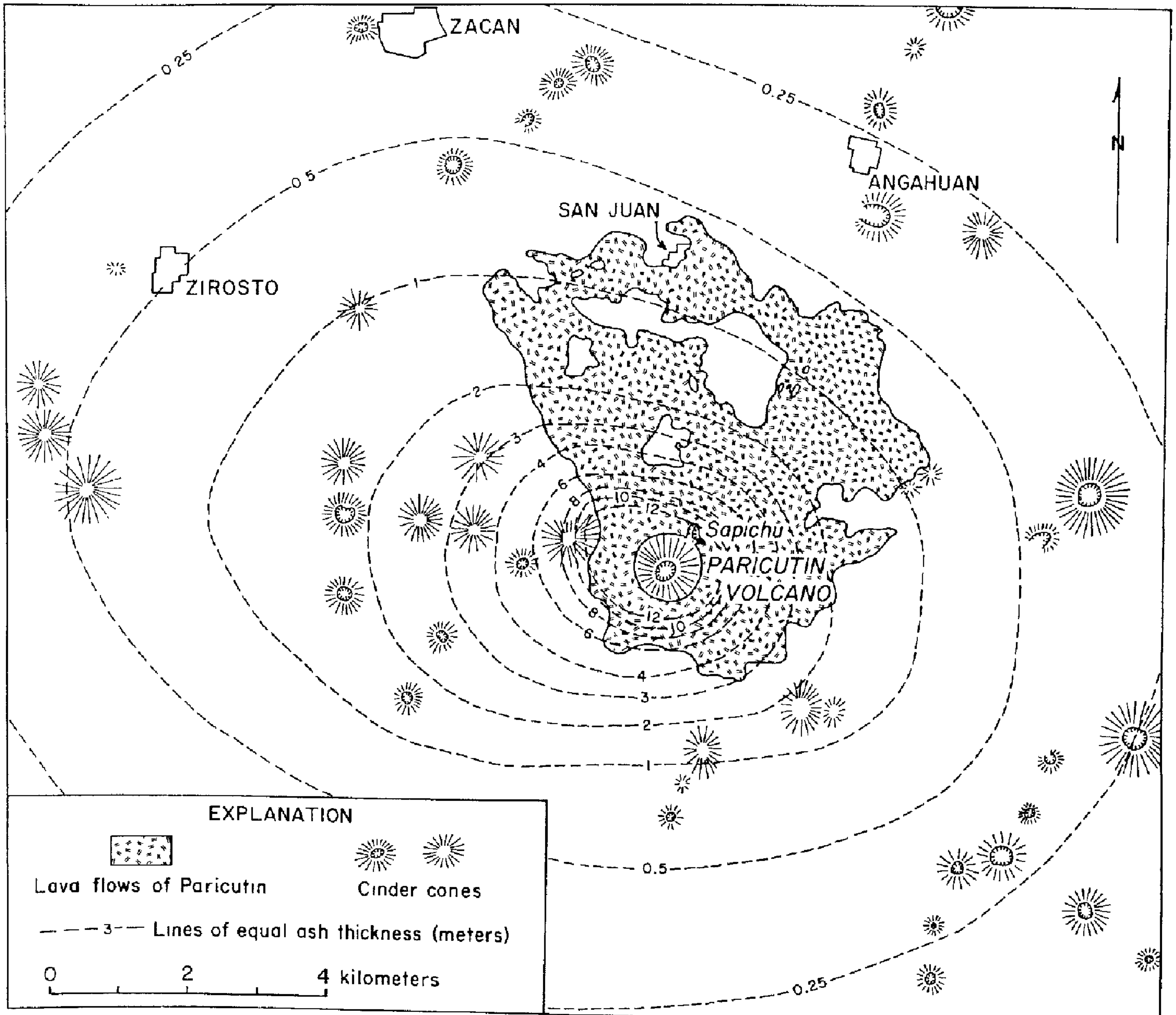

Figure 8. Map of the environs of Paricutin Volcano, Mexico, showing the distribution of lava flows and ash. (From Macdonald, 1972, after Williams, 1950)

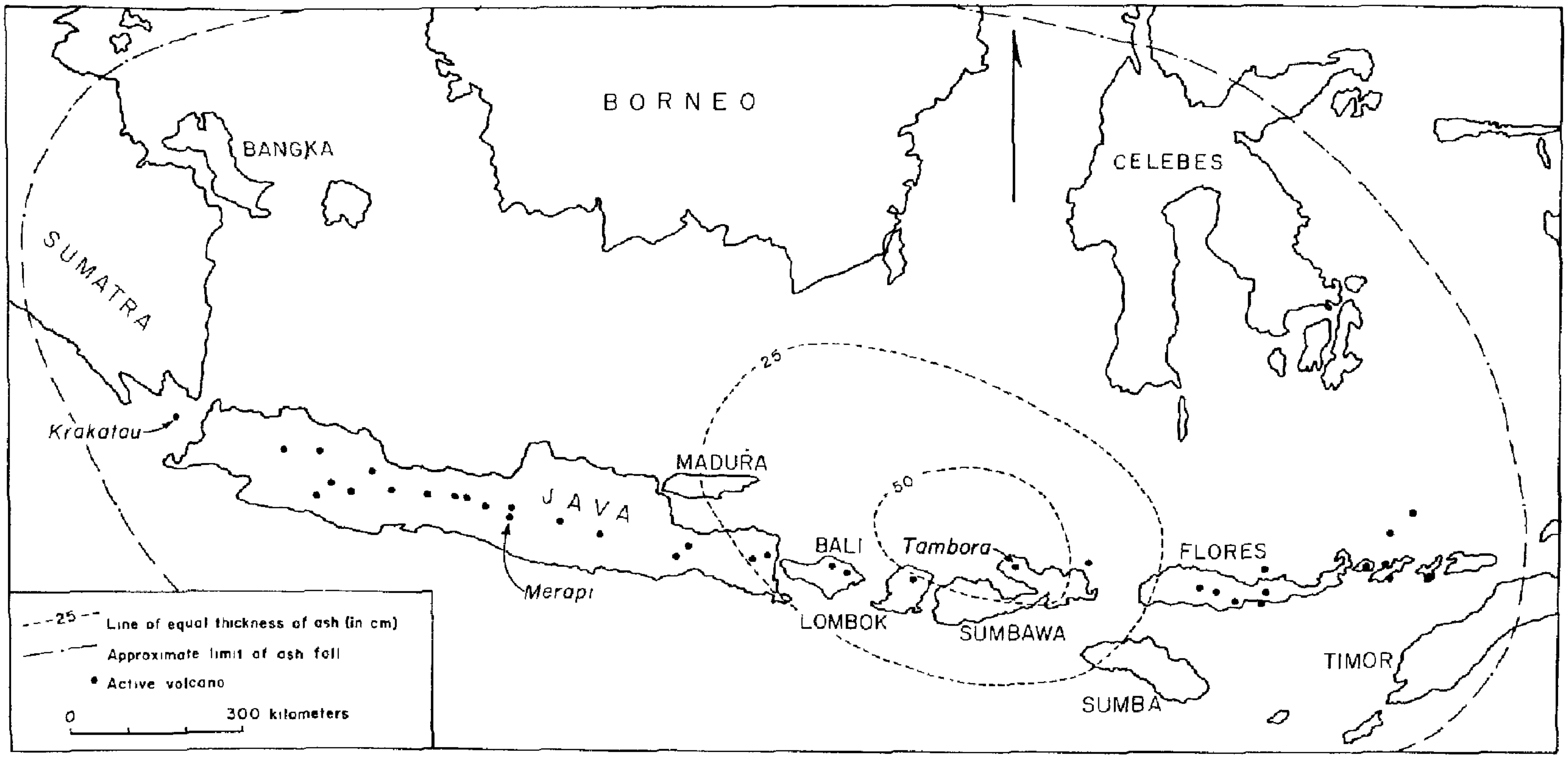

Figure 9. Map of part of Indonesia, showing the distribution of ash from the great eruption of Tambora Volcano in 1815.

(After Petroeschevsky, 1949.)

Heavy ash falls may disrupt water supplies by clogging streams and wells, or filters in water systems, and water may become acid from leaching of the ash. During the Katmai eruption the people of Kodiak had to be supplied with water from ships in the harbour; and during the eruption of Irazú, Costa Rica, in 1963, ash suspended in river water clogged the filters in the water works of the city of San José. Suspended ash can be removed from piped water by a temporary filter, or even a cloth bag tied over the faucet. As soon as the possibility of a dangerously heavy ash fall becomes apparent, sufficient water to serve essential needs for several days should be stored indoors. Ash washed from the streets of San José during the Irazú eruption blocked the storm drains, causing flooding during subsequent rains. In such circumstances, drains should be cleared as soon as possible to prevent flooding.

Ash on hillsides may slide, destroying vegetation, buildings, or even animals. Watch should be kept for dangerously unstable accumulations, if visibility permits, and it may be desirable to evacuate certain areas.

In long-continued ash-making eruptions, such as that of Paricutín, which lasted for 9 years, it may often become necessary to evacuate people and animals from the badly affected areas. The same may be desirable in the case of shorter, more violent eruptions. However, this may not be possible without an accurate prediction of the approximate time and nature of the eruption and the area affected. Once the eruption has started, evacuation may become extremely difficult or impossible, because of poor visibility, and perhaps blocked highways. It is probably better under such circumstances for people in the badly affected area to remain in their houses, with a supply of stored water and with windows and doors closed, except for necessary brief trips outside to clear the ash from roofs and drains. The phase of extreme violence in such eruptions does not usually last more than a very few days.

The problems involved in evacuation, especially in poor countries, have been pointed out by Bonis and Salazar (1974). Commonly, there are no facilities to house and feed the displaced persons, and no funds to pay for their sustenance or to purchase feed for livestock. Furthermore, the loss of income to the evacuated workers may be a very serious problem for a period much longer than that of the actual eruption. These things should be considered in any plans for evacuation, either by national governments, or by international relief agencies.

Although they are temporarily destructive, ash deposits are potentially fertile. Natural revegetation may take place within a few months in the tropics, and within a few years in colder climates. Return of vegetation can be speeded by ploughing or discing to break up any crust that has formed, and also by artificial seeding. The latter can improve the quality of the pasture over what would develop naturally. Where the ash is not too thick, it may be desirable to mix it into the underlying topsoil by deep ploughing. Studies should be made to determine what, if any, additional fertilization is desirable. Locally, it is possible to clear the ash from small garden areas. This was done, for instance, after the 1779 eruption of Sakurajima, in Japan.

A newly-recognized phenomenon of ash eruptions is the base surge. Base surges form in the presence of abundant fall-out around the base of some volcano explosion columns, just as they do around the stem of the mushroom cloud of an atomic blast. They were first recognized in the 1965 eruption of Taal, Philippines (Moore, 1967). Examination of photographs, records, and the ash deposits themselves indicate that they have occurred also in many earlier eruptions, particularly in low-temperature hydro-explosions. Ring-shaped clouds of suspended ash spread outward with great speed, eroding the surface near the vent and depositing at greater distances. In the inner zone trees may be uprooted or broken off, and buildings razed. Farther out, remaining trees are heavily sand blasted, but not burned. At Taal, a kilometre from the vent (fig. 10), as much as 15 cm of wood was eroded from the tree trunks on the side toward the volcano, but the opposite side of the trunks was almost unaffected. In the outer zone the trees were plastered with mud, and cross-bedded dunes of ash as much as 2.5 m thick were deposited. The surges travelled across the surface of Lake Taal, on to its outer shores, to a distance of about 6 km. Fortunately, casualties were few, but in a more violent eruption of the same volcano in 1911 about 190 persons and more than 1,300 animals were killed.

The behaviour of base surges resembles in many respects that of glowing avalanches, described later, and the effects also are similar except for the difference in temperature. Probably their destructive effects can only be lessened by prediction of their occurrence long enough in advance to allow evacuation of the area. Where the volcano is known to have produced them in the past, they may be anticipated in the future.

Base-surge deposits can be used agriculturally in much the same way as air-fall ash deposits, except that more smoothing of the hillocky surface may be necessary.

Ash flows

In some eruptions of gas-charged magma, only a relatively small proportion of the material is thrown high into the air by explosion. Much of the ash resulting from disruption of the rock froth remains suspended in a cloud which spreads outward close to the ground surface, producing an ash flow. In most such flows disruption of the rock froth is incomplete so that along with the ash particles, there are many fragments of pumice, from a few millimetres to many centimetres across. The gas between the ash particles is still expanding, due partly to heating of air entrapped by the advancing flow, and partly to continued release of gas from the fragments themselves. The expanding gas holds the fragments apart, so that solid friction is largely eliminated, and the cloud advances with great speed, in many cases exceeding 200 km/hour. The driving force is largely gravity, so that, like that of any dense fluid, the flow is largely directed by topography, travelling down slope and along valleys. Locally, however, the high velocity may result in the flow climbing opposing slopes, conceivably to heights of several hundred metres. Ash flows commonly come to rest, even at distances of tens of kilometres from their vents, still so hot that the glassy fragments in the central part of the mass become welded together, and pumice fragments in the central part are flattened and compacted to thin disks of obsidian. The rock mass formed by an ash flow is known as ignimbrite. Single ignimbrite layers have been traced for more than 160 km, and have volumes of more than 1,000 km 3/.

Ash flows can issue from vents at the summit of big composite cones, or from fissures on the sides of the cone, and apparently also from fissures not directly associated with any large cone. Many of them are parts of Plinian eruptions, such as the one that formed Crater Lake, in Oregon, about 6,000 years ago (Williams, 1942), or that of Bezymianny in 1956 (Gorshkov, 1959).

The great speed and often great volume of ash flows make it impossible to control them in any way. Lessening their destructiveness in the future depends on recognition of magmatic conditions in the volcano that may lead to them, and prediction of the eruption long enough in advance to permit evacuation of the endangered area.

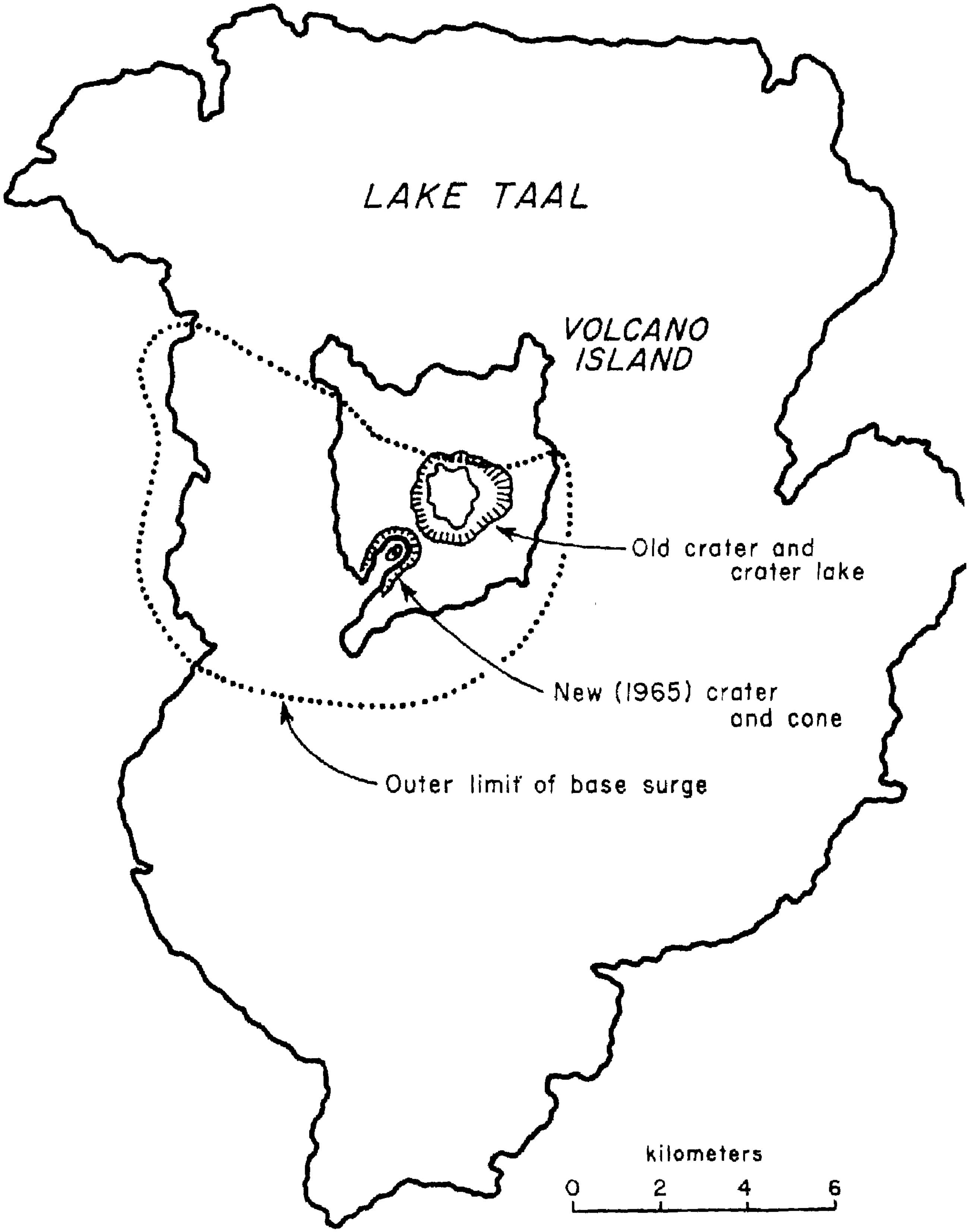

Figure 10. Map of the Lake Taal, Philippines, showing Volcano Island, the location of the vent of the 1965 eruption, and the extent of the base surges during that erupti (From Macdonald, 1972, after Moore, 1967).

However, just what premonitory signs should be looked for is highly uncertain, and more occurrences of the flows coupled with continuous observation of the volcanoes before their eruptions are needed before we can hope for much success in prediction. Unfortunately for such observations, but very fortunately for the inhabitants of volcanic districts, ash flows have been rare during historic time and probably will continue to be so in the future.

Since ash flows are largely topographically controlled, the major destruction by them will be along valleys; and since small ones are more likely than large ones, the damage will probably be restricted to areas near the volcanoes. The ash flow in the Valley of Ten Thousand Smokes, Alaska, in 1912, travelled 22 km, and those at Crater Lake travelled nearly 60 km. (fig.11). However, destruction may not be limite to the area buried by the flow. As in the case of glowing avalanches, a relatively dispersed cloud of ash above the flow may extend considerably beyond the margins of the main flow, and may do considerable damage. Until we know more about them, if an ash-flow eruption is anticipated all of the mountain and a zone several tens of kilome wide around its base should be evacuated.

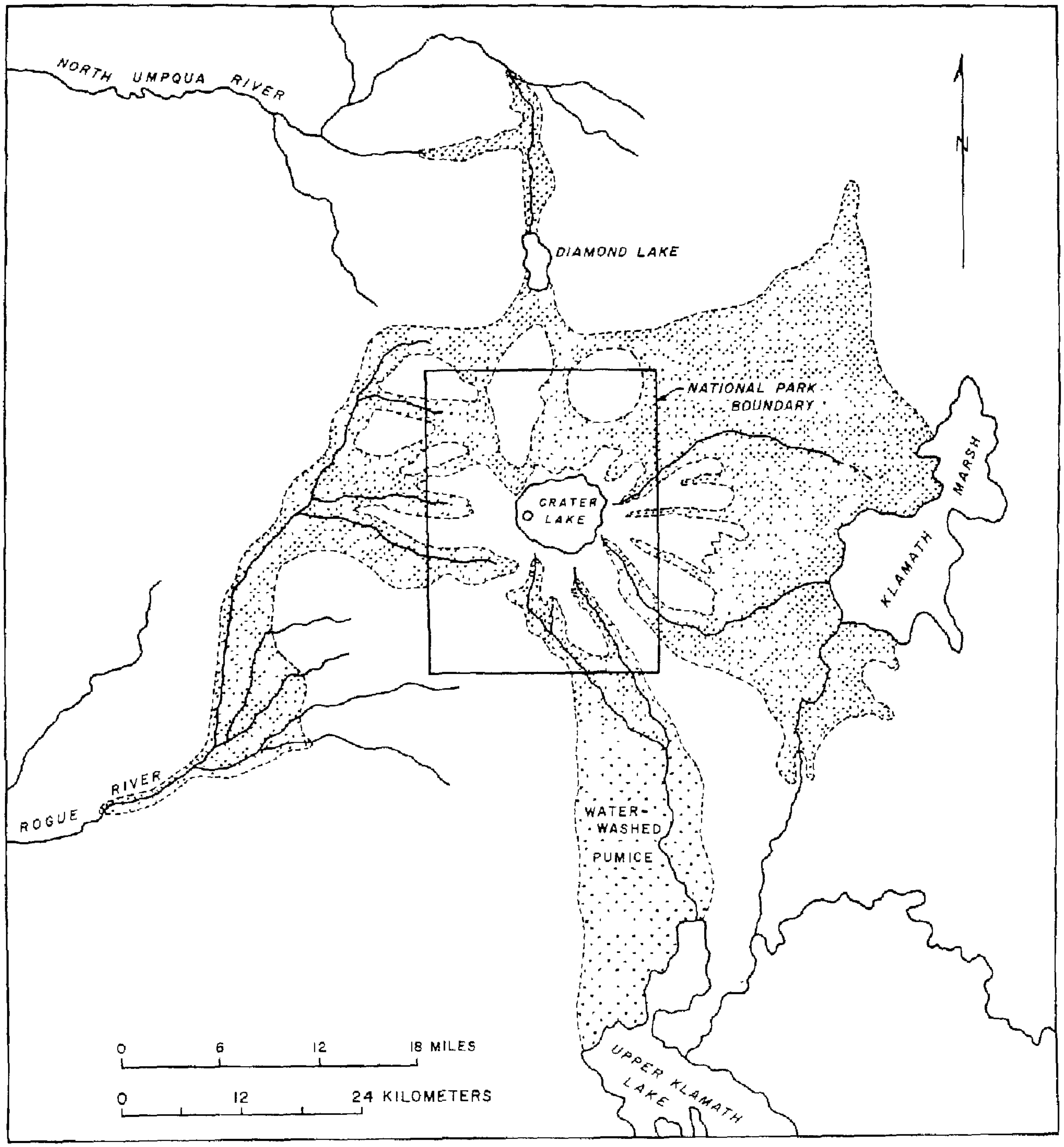

Figure 11. Map of the area around Crater Lake, Oregon, showing the distribution of glowing avalanche deposits (stippled) from the eruption of Mt. Mazama about 4,000 B.C.

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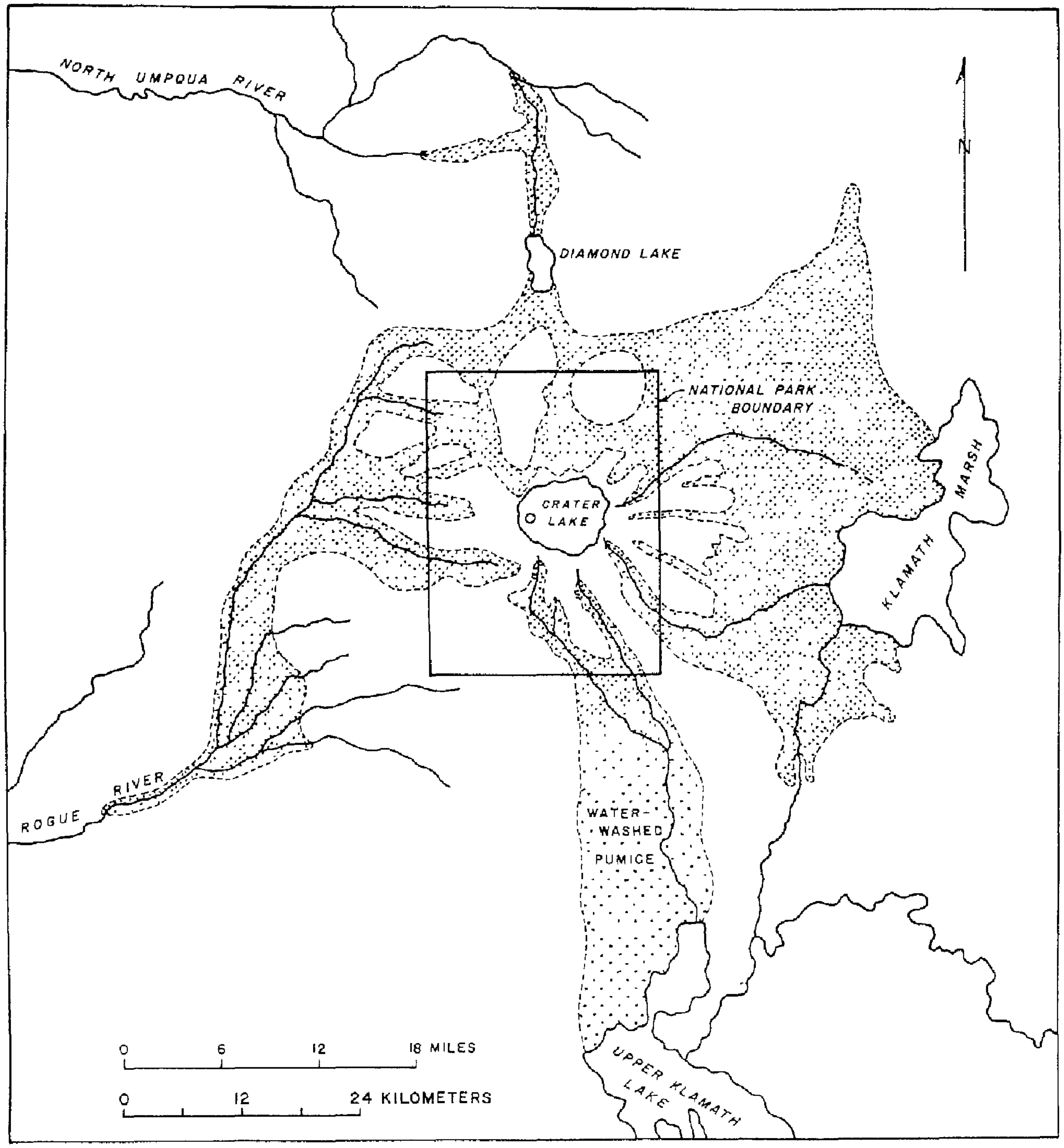

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