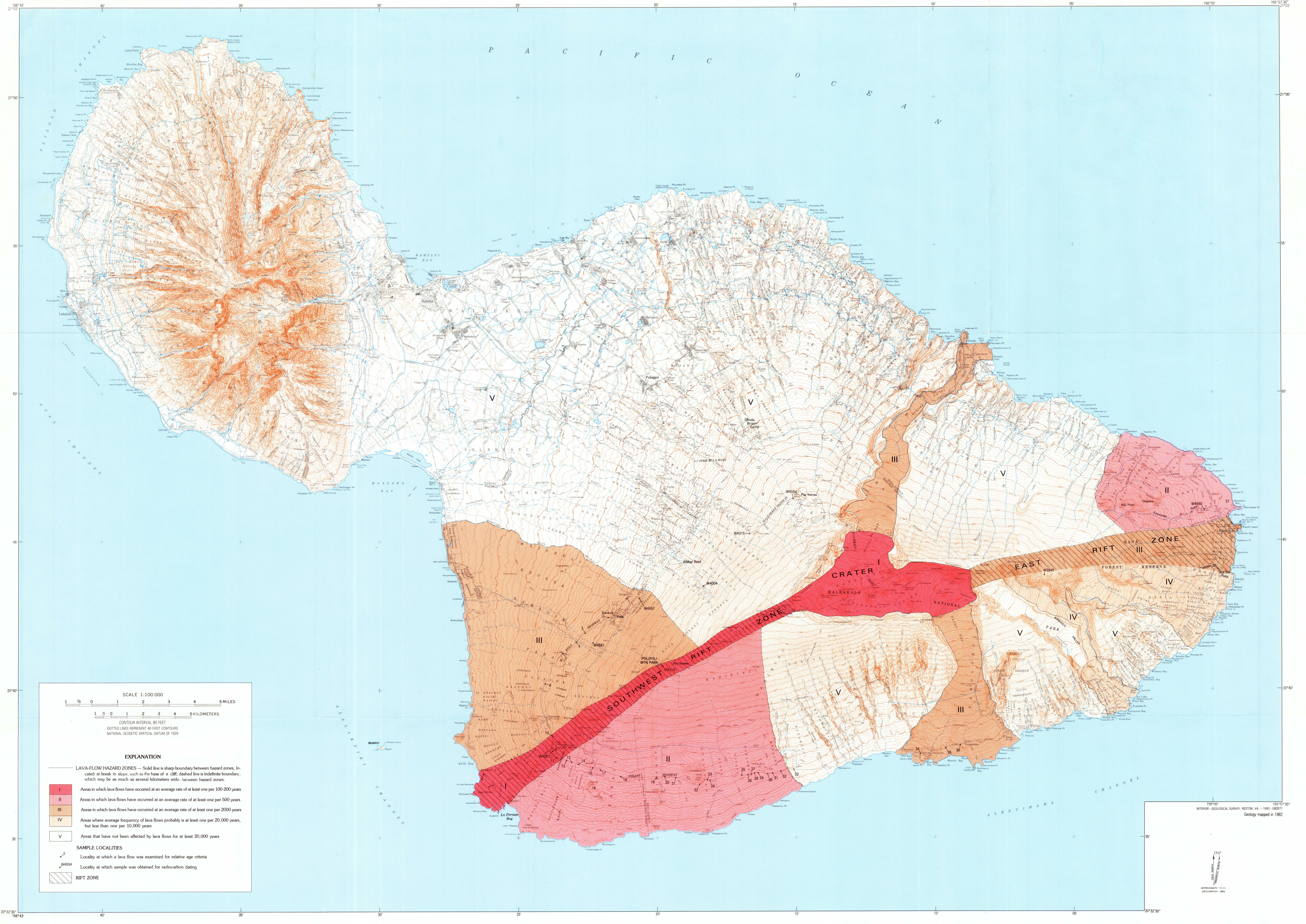
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

MISCELLANEOUS INVESTIGATIONS SERIES
MAP I-1442



SCALE 1:100 000

CONTOUR INTERVAL 80 FEET
DOTTED LINES REPRESENT 40 FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

LAVA-FLOW HAZARD ZONES — Solid line is sharp boundary between hazard zones, located at break in slope, such as the base of a cliff; dashed line is indefinite boundary, which may be as much as several kilometers wide, between hazard zones.

I	Areas in which lava flows have occurred at an average rate of at least one per 100-200 years
II	Areas in which lava flows have occurred at an average rate of at least one per 500 years
III	Areas in which lava flows have occurred at an average rate of at least one per 2000 years
IV	Areas where average frequency of lava flows probably is at least one per 20,000 years, but less than one per 10,000 years
V	Areas that have not been affected by lava flows for at least 20,000 years

SAMPLE LOCALITIES

5	Locality at which a lava flow was examined for relative age criteria
W4554	Locality at which sample was obtained for radiocarbon dating
▨	RIFT ZONE

Base from U.S. Geological
Survey, 1957

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA.,—1983—G82071

Geology mapped in 1982

INTRODUCTION

Haleakala volcano, which forms the eastern part of the island of Maui, has erupted many times during the last thousand years, and as recently as 1790. The volcano thus is believed to be only dormant and still capable of erupting again in the future. The geologic history of Haleakala began more than 840,000 years ago, and has been described by Stearns and Macdonald (1942) and summarized by Macdonald and Abbott (1970) and Macdonald (1978). This report considers only the eruptive history of the last few tens of thousands of years. Most eruptions during this period were of basalt lava flows from vents situated along or adjacent to a narrow zone that extends east-northeastward from LaPerouse Bay through the crater of Haleakala, and thence eastward to Hana. Such a linear concentration of volcanic vents is referred to as a rift zone. For the purpose of this report, the rift zone on Maui is subdivided into the southwest rift zone, the crater, and the east rift zone. In addition, some flows were erupted outside the rift zone at vents now marked by cinder cones such as Pimoe and Puu Olai on the southwest side of the volcano.

West Maui also is a volcano, but one so old — 1.15-1.32 million years (McDougall, 1964) — that, for purposes of land-use planning, it probably can safely be regarded as extinct. A few small lava flows on West Maui are substantially younger than the rest of the volcano (Stearns and Macdonald, 1942), but even these bear soils that suggest ages of more than 25,000 years.

PURPOSE AND METHOD OF STUDY

The purpose of this study was to determine the frequency with which various parts of the island of Maui have been affected by the products of volcanism during roughly the last 25,000 years, and to assess the likelihood of future eruptions and their possible consequences. This study assumes that future eruptions on Maui will resemble those of the geologically recent past in both style and frequency. The style of past volcanism has been inferred from lava flows and deposits of volcanic ash, and the frequency of activity has been determined by radiocarbon dating of some of these eruptive products (table 1). Some lava flows for which radiocarbon dates are not available have been approximately dated by comparing the development of time-dependent features, such as degree of weathering and erosional modification, with similar features on flows of known age (table 2).

In addition to the radiocarbon dates cited in this report, Reber (1959) listed dates of 200 ± 15, 590 ± 120, 640 ± 140, and 890 ± 170 on charcoal samples he obtained from tree molds in lava flows along the southwest rift zone. The youngest date was obtained from the Kalua o Lapa flow, at the southwest end of the rift zone. A comparison of the coastline of southwestern Maui charted by LaPerouse in 1786 and by Vancouver in 1793 led Oostdam (1965) to conclude that the Kalua o Lapa flow occurred about 1790.

TABLE 1.—*Radiocarbon dates from lava flows and volcanic ash on Maui*

Sample no.	Radiocarbon date[1] (years)	Description of sample and location[2]
W-4560	490 ± 70	Charcoal from ash directly beneath lava flow exposed on north side of Kawaipapa Gulch about 0.45 km (0.25 mi) upstream from Hana Highway
W-4297	920 ± 70	Charcoal from soil on cinders directly beneath lava flow exposed on north side of Piilani Highway about 1.35 km (0.75 mi) road distance south of Ulupalakua
W-4554	2530 ± 50	Charcoal from red ash at ground surface in cut along Haleakala Highway 0.3 km (0.2 mi) southwest of summit of Puu Nianiau
W-4314	3900 ± 60	Charcoal from soil directly beneath lava flow exposed in roadcut 0.5 km (0.3 mi) south of spur road to Polipoli Mountain Park, and 0.6 km (0.35 mi) west-southwest of Puu Keokea
W-4561	4070 ± 90	Charcoal from soil directly beneath lava flow exposed on north side of gully 2.1 km (1.3 mi) south-southwest of Keokea; outcrop is 0.9 km (0.5 mi) southeast of Kula Highway and about 250 m west of a private road
W-4557	8650 ± 90	Charcoal from black ash beneath lava flow exposed in cut along private road 0.3 km (0.2 mi) north of road junction designated 3402 on Puu o Kali quadrangle map, 1.5 km (0.9 mi) northeast of Keokea Park
W-3945	9400 ± 300	Charcoal from beneath lava flow in upper part of east rift zone at an altitude of about 5465 ft, near south boundary of Hana Forest Reserve, on north rim of Kipahulu Valley[3]
W-4754	12,760 ± 120	Charcoal from soil on cinders beneath lava flow that forms a ledge in the floor of Haneoo Gulch about 150 m upstream from highway bridge, 2 km (1.2 mi) south of Hana
W-4004	22,550 ± 400	Charcoal from beneath lowest ash bed in cut along Walker Road 6.4 km (4 mi) road distance from junction with Upper Kula Road
W-4315	26,800 ± 400	Charcoal from beneath uppermost ash bed in cut along Haleakala Highway 0.6 km (0.4 mi) west of Puu Pahu
W-4785	38,000	Charcoal from fine reddish-brown ash mixed with angular rock fragments (colluvium), stratigraphically beneath horizon of sample W-4004; from cut along Walker Road about 5.9 km (3.7 mi) road distance from junction with Upper Kula Road

[1] Radiocarbon dates cited were determined in the laboratory of the U. S. Geological Survey under the supervision of Meyer Rubin
[2] Sample localities are plotted, with sample number, on the map
[3] Sample collected by Heather Fortner and submitted for dating by G. A. Macdonald

TABLE 2—*Known and inferred approximate ages of selected lava flows on the flanks of Haleakala*[1]

Flow no.[1]	Lava type[2]	Oxidized color[3]	Weathered rind thickness[4] (mm)	Local relief[5]	Slopes[6]	Drainage[7]	Approximate age(yr)[8]
1	A	10YR6/6–8	1	N	Mostly G Locally K	Mostly T	8650*
2	A	10YR6/6–7/8	1.6	N	Mostly G Locally K	Mostly T	>10,000 <20,000
3	A	7.5YR6/6–10YR6/6	0	Locally L to M	Mostly G Locally K	Mostly T	4070*
4	A	10YR6/6	0	N	G	T	>10,000 <20,000
5	A	7.5YR6/8	0	Locally L to M	G, locally K	Mostly T	>10,000 <20,000
6	A	10YR7/6	1	N	G	T	>10,000 <20,000
7	A		0	H	K	I	200
8	A-P	10YR6/4	0	H	K	I	>200 <900*
9	P	10YR5/4	0	n.d.	K	I	900*
10	A-P	10YR5/6	0	H on aa	K	I	900*
11	P	7.5YR6/6	0	n.d.	G	T	<10,000?
12	A	2.5Y6/4	0	H	K	I	< 1000?
13	A	10YR6/4	0	H	K	I	<10,000?
14	A	10YR6/6	0.2–0.3	N	K	I	<10,000?
15	P	7.5YR5/6	1	N	K	T	<10,000?
16	A-P	7.5YR5/6–2.5Y6/4	0	H	K	I	About 1,000?
17	A-P	10YR5/6	1	N	G	T	About 10,000?
18	A	10YR6/6	0.4	H	K	I	1000-2000?
19	A	10YR6/6	1	Locally H	K	T	< 20,000 <10,000?
20	A	10YR7/8	2	Locally L to M	K	I	<10,000?
21	P	10YR6/6	1	n.d.	K	I	<10,000?
22	P	10YR6/6	1	n.d.	K	I	<10,000
23	A	2.5Y7/4	0	H	K	I	< 1000?
24	P-A	10YR6/8–7/6	0.5	Locally L to M	K	Mostly I	<10,000?
25	P	5YR5/8	5	n.d.	G	T	>20,000?
26	A	5YR3/4	6	N	G	T	>20,000?
27	P	10YR5/6	0.5	N	G	T	<10,000?
28	A-P	10YR7/6	1.5	L	K	T	<10,000?
29	A-P	10YR6/8	0.5	L	K	Mostly I	<10,000?
30	A-P	10YR7/6	1	M	K	I	<10,000?
31	A-P	7.5YR5/6	3	N	G	T	>10,000
32	P	7.5YR5/8	2	Mostly N Locally L	G	T	>10,000?
33	A	5YR5/8	4	N	G	T	>20,000?
34	A	2.5Y6/4–10YR6/6–8/8	?	H	K	I	>1000 <10,000?
35	A	2.5Y6/4	0	L	K	I	>1000 <10,000?
36	?	5YR5/8	3	N	G	I	>20,000?
37	A	10YR5/4	0.5	Locally H	K	I	500*
38	P-A	Black	0	N	G	T	12,760*

[1] Each number refers to a separate lava flow; the location of the corresponding number on the accompanying map is the site at which relative age criteria were observed.
[2] A, aa (flow with rough blocky surface); P, pahoe oe (flow with smooth ropy surface).
[3] Colors of soils were determined from Munsell Soil Color Charts published by Munsell Products, Baltimore, Md.

Color notation	Soil-color names	Color notation	Soil-color names
2.5Y6/4	Light yellowish brown	7.5YR6/6-6/8	Reddish yellow
2.5Y7/4	Pale yellow	10YR5/4-5/6	Yellowish brown
5YR5/3	Reddish brown	10YR6/4	Light yellowish brown
5YR5/8	Yellowish red	10YR6/6-6/8	Brownish yellow
7.5YR5/6-5/8	Strong brown	10YR7/6-7/8	Yellow

[4] Maximum thicknesses measured on surfaces exposed to weathering. Inferred ages: <1 mm, 10,000 yr; 1–2 mm, 10,000 yr?
[5] H, 2 m or more, inferred age <1000 yr. M, 1–2 m; L, <1 m and N, none >1000 yr. n.d., not determined on pahoehoe flows.
[6] K, constructional, inferred age <10,000 yr; G, graded, smooth, >10,000 yr.
[7] I, interior, inferred age <10,000 yr; T, through-going gullies present, >10,000 yr.
[8] Asterisks identify lava flows dated by radiocarbon; inferred ages of other flows are based on relative age criteria.

PRODUCTS OF VOLCANISM AND POTENTIAL HAZARDS

The chief products of future eruptions on Haleakala will be volcanic ash and lava flows; other possible products include volcanic gases and rock debris carried by pyroclastic surges. These eruptive products and their possible consequences are described in the following sections.

VOLCANIC ASH

Explosive eruptions throw lava fragments above a vent, after which the coarser material falls back close to the vent, where it may form a cone, and fine material is carried away by winds. These fragments are classified by their size: particles less than 4 mm (0.15 in.) in diameter are ash, those 4-32 mm (0.15-1.25 in.) are cinders, and larger fragments are blocks or volcanic bombs. Distribution and thickness of ash beyond the source vent are controlled by the volume of the material erupted and by the speed and direction of winds blowing during the eruption.

From youngest to oldest the sequence of ash and lava flows on the west flank of Haleakala volcano is:

Black cindery ash near crater rim
Lava flows (nos. 7, 9, 10 in table 2)
Red ash (about 2500 yr old)
Lava flows (nos. 1-6 in table 2)
Ash (>8650, <22,000 yr old)
Ash (about 22,000-27,000 yr old)
Older lava flows

The oldest ash deposits are well exposed in cuts along Walker Road. There, beds of fine to coarse cindery ash form a deposit that increases in thickness southeastward from about 2 to 6 m (6.6-19.7 ft) between the 3800- and 6400-ft contours (a distance of 3 km — 1.9 mi). Individual beds of ash also increase in number and in grain size. As many as 15 discrete beds of medium to coarse ash were noted in a single outcrop. A sample of charcoal from directly beneath the lowest well-defined layer of coarse ash in the deposit had a radiocarbon age of 22,550 ± 400 years (sample W-4004). Charcoal from a similar sequence of beds along the Haleakala Highway had a radiocarbon age of 26,800 ± 400 years (sample W-4315). This sample was taken from the upper 10 cm (4 in.) of a soil beneath the uppermost well-defined bed of ash in a roadcut.

The lower part of a younger cindery ash is interbedded with the upper part of the oldest deposit; this younger ash crops out at many places southwest of the community of Keokea. It thickens and coarsens southward toward the southwest rift zone, where it is several meters thick. Although the ash itself has not been radiocarbon dated directly, it is older than a lava flow that is 8650 ± 90 years old (sample W-4557).

A still younger deposit of red ash is present on the west flank of Haleakala from Keokea northeastward at least as far as Puu Nianiau. It was not seen, however, in cuts along the road to the Olinda Prison Camp, northwest of Puu Nianiau. It typically occurs in lens-shaped masses that are as much as 25 cm (10 in.) thick. The ash is present near the crater rim along Halemauu Trail, but was not found within the crater. Charcoal from the red ash had a radiocarbon age of 2530 ± 50 years (sample W-4554).

A deposit of black cindery ash can be seen above the red ash in cuts along the Haleakala Highway, upslope from the boundary of Haleakala National Park. This black ash increases in thickness toward the west rim of the crater, where it is 40-60 cm (16-24 in.) thick, and is one of three or more beds of black ash that are widely distributed within the crater. Intervals between the deposition of the black ash beds within the crater are represented by thin zones of soil oxidation at the tops of the lower two beds.

Potential hazards from eruptions of ash include its smothering effect on vegetation and its abrasive and corrosive effects on machinery. Ash can harm people and livestock when inhaled and ingested. Falling ash reduces or may entirely obscure visibility and halt local aircraft traffic; fallen ash more than a few millimeters thick can impede automobile traffic. The fall of ash is usually accompanied by lightning that may disrupt telephone and radio communication and, by infiltrating transformers, interrupt electrical service. Ash can carry acids and may adversely affect natural vegetation and damage or kill agricultural crops.

Heavy rainfall during or after an eruption of ash can cause floods of ash-laden water that may bury or cut roads and sweep away bridges and other structures. Ash-rich flood deposits are present adjacent to gullies at the west base of Haleakala both north and south of Kihei.

LAVA FLOWS

Most eruptions on Maui have produced lava flows. Those of recent geologic age have ranged in length from a few hundred meters to some that extended from the upper parts of the southwest rift zone downslope to the coast, a distance of as much as 15 km (9.3 mi).

Lava flows erupted at vents along the southwest rift zone range in age from about 200 years to more than 20,000 years. Lava flows numbered 1 through 7 (table 2) are all younger than the 22,550-26,800-year-old ash that blankets the west slope of Haleakala, as well as the cindery ash that locally overlies the old ash. Thus, flows have moved into the area north of the rift zone at an average rate of at least one per 3000-4000 years during the last 22,000 years. The youngest of these flows is about 4000 years old. At least six other flows were erupted from vents within the southwest rift zone during the last 1000 years. The average rate of lava-flow eruptions in the rift zone during that period probably has been one per 150-200 years. The largest of these recent flows is also the youngest; it occurred about 1790 (Oostdam, 1965).

The average rate of eruptions in the east rift zone is not known, although it seems to have been at least one per 10,000 years. The youngest dated flow on the east side of Haleakala, which originated at a vent between Olopawa and Puu Puou, a short distance north of the rift zone, is about 500 years old (W-4560, table 1).

The lava flows on the crater floor of Haleakala have not been directly dated. In order to limit the ages of these flows, 11 of them (map units hp through hka of Macdonald, 1978) were searched for the presence of the red ash that is about 2500 years old. This ash occurs on the west crater rim, and should be present on lava flows within the crater if those flows are older than the ash, but the ash could not be found on the 11 flows that were examined. Ten other flows on the crater floor were not examined, but according to Macdonald they are of the same general age as those on which the red ash is apparently absent. In addition, beds of black ash within the crater represent at least three separate eruptions since the red ash was deposited about 2500 years ago. These relations suggest that the average rate of eruptions within the crater during this time span has been at least one per 100 years, and of lava-flow eruptions, at least one per 120 years. The age of the last eruption within the crater is not known.

Lava flows can originate at a point source, such as at a vent marked by a cinder cone, or along a fissure perhaps hundreds of meters in length. Fissure eruptions are most likely to occur along a rift zone. The paths of lava flows can usually be predicted as soon as an eruption begins, but their lengths will depend on the volume of lava erupted. Flows move in a generally downslope direction, but they may cross a slope at a slight angle. The formation of tunnels (lava tubes) or ridges (levees) along the margins of flows, tends to keep flows from spreading and permits them to move farther and faster than unconfined flows. Lava may flow at speeds of more than 50 km/hr (about 30 mi/hr) on steep slopes and where confined by levees or tubes, but generally moves from less than 1 m/hr (3.3 ft/hr) to a few hundred meters per hour on gentle slopes and flat surfaces. The chief danger from lava flows is burial and incineration of combustible materials, so they threaten immovable structures and other property. Except on steep slopes, they rarely endanger people because of their relatively slow speeds and predictable paths.

GASES

Most eruptions are accompanied by copious emission of gases, the most voluminous of which typically is water vapor. However, harmful gases may also be produced, such as carbon dioxide, carbon monoxide, hydrogen chloride, and compounds of sulfur and nitrogen. Gases emitted during future eruptions at vents in the crater of Haleakala may accumulate and form lethal concentrations unless dispersed by winds. Gases emitted at vents along the rift zones or elsewhere on the flanks of the volcano, are more likely to drift away and quickly become diluted, but can form toxic concentrations in depressions. Dilute gases probably do not constitute a threat to human life or health during exposures of no more than a few hours, but can cause lung irritation and adversely affect health if there is continuous exposure for longer periods. Continued exposure to dilute gases can also harm crops and other vegetation.

STEAM EXPLOSIONS AND PYROCLASTIC SURGES

The upward movement of molten rock into water-saturated rocks commonly causes steam explosions that produce vertical eruption columns and, in some cases, pyroclastic surges that move laterally away from the vent in all directions not constrained by topography. Pyroclastic surges are cloudlike mixtures of fine to coarse rock debris, air, and usually steam or water, that move along and just above the ground surface at hurricane speeds. Although speeds of from 50 to as much as 300 km/hr (30-187 mi/hr) can be inferred from the vertical heights ascended by some pyroclastic surges, they seem to lose their energy quickly during movement, rapidly decelerate, and typically stop within distances of less than 10 km (6 mi) from the vent. The temperature of surges is variable; the presence of water in many surges implies temperatures under 100°C.

Deposits of steam explosions and pyroclastic surges have not been described on Maui, and were not found during this study, although they occur on both Oahu and Hawaii. The island of Molokini, about 4.5 km (2.8 mi) off the southwest coast of Maui, consists of beds of solidified fine to coarse ash (tuff) that contain blocks of basalt (Palmer, 1930). Molokini seems to have been constructed by explosive eruptions, and the bedding in the resulting deposits resembles that of deposits on Oahu and Hawaii that have been attributed to pyroclastic surges.

People subjected to pyroclastic surges almost surely will be killed or severely injured. Other effects of such surges include partial or total destruction of structures by rock debris moving at high speeds, and deposition of ash and coarser rock debris.

EARTHQUAKES AND GROUND DEFORMATION

Earthquakes in the Hawaiian Islands can be of both volcanic and nonvolcanic origin. Those of volcanic origin are caused by the subsurface movement of molten rock. Swarms of such earthquakes that occur at progressively shallower depths may precede an eruption by days or weeks and, if detected and correctly interpreted, provide a warning of an impending eruption. Most such earthquakes are relatively weak and can be detected only by seismometers, but a few may be strong enough to be felt and to cause local damage.

In addition to causing earthquakes, subsurface movements of molten rock can cause local bulging, subsidence features, and ruptures of the ground surface. These features are most likely within rift zones, and usually will trend parallel to those zones.

Severe earthquakes in the Hawaiian Islands typically are of nonvolcanic origin and are probably caused by movements along faults at depths of tens of kilometers below sea level. Others are caused by subsidence of large sectors on the flanks of volcanoes. Severe local or distant earthquakes sometimes cause seismic sea waves (tsunamis) that devastate coastlines. Earthquakes can also trigger landslides on moderate to steep slopes, and these slides can bury and displace buildings as well as roads.

DISTRIBUTION OF HAZARDS

LAVA-FLOW HAZARD ZONES

Areas on the map were assigned to five lava-flow hazard zones on the basis of inferred frequency of eruptions as determined from radiocarbon dates and relative age criteria. Zones on the map that show no specific localities of radiocarbon samples or relative age criteria were examined to determine the relative age of lava flows from the degree of soil development and amount of erosional dissection. Lava-flow hazard zones are numbered I to V in order of decreasing hazard. It should be emphasized that any one lava flow in the future would affect only a portion, and perhaps only a very small portion, of one of these hazard zones. Data are not available at present for predicting the frequency with which all parts of a hazard zone will be affected by future lava flows.

Hazard zone I consists of areas in which lava flows have occurred at an average rate of at least one per 100-200 years. This zone includes the crater of Haleakala, where the inferred average frequency of flows has been at least one per 120 years during the last 2500 years, and the southwest rift zone, where the average rate has been at least one per 150-200 years during the last 1000 years.

Hazard zone II comprises areas in which lava flows are known or inferred to have occurred at an average rate of at least one per 500 years, and in which the last lava flow occurred less than 1000 years ago. This hazard zone includes a sector south of the southwest rift zone, and one north of the east rift zone.

Hazard zone III includes areas in which lava flows have occurred at an inferred average rate of at least one per 2000 years, and in which the last flow occurred within the last 10,000 years. This hazard zone includes valleys that extend from the crater to the coast, an area north of the southwest rift zone that includes a lava flow about 4000 years old, and the east rift zone. The east rift zone is included in hazard zone III because of the presence of one lava flow known to be about 9400 years old (table 2). The only other dated flow in this rift zone is about 12,760 years old. The rate of lava flow eruptions along the east rift zone may be less than one per 2000 years.

Hazard zone IV comprises areas in which the average frequency of lava flows is inferred to be less than one per 10,000 years but at least one per 20,000 years; the last lava flow in these areas probably occurred more than 10,000 years ago.

Hazard zone V includes areas that have not been affected by lava flows for at least 20,000 years.

The relative danger from future lava flows increases progressively toward the respective rift zones in hazard zones III and IV, and in the part of hazard zone II that lies on the southwest flank of Haleakala. The potential hazard from future lava flows is approximately equal throughout zone I and in the part of zone II that is northwest of Hana.

HAZARD AREAS ASSOCIATED WITH PYROCLASTIC SURGES AND ASHFALLS

Hazard zones are not defined on the accompanying map for pyroclastic surges and falls of volcanic ash. Nevertheless, the possible distribution of such future events can be suggested. If steam explosions occur and cause pyroclastic surges, areas within a radius of 10 km (6 mi) of the vent could be seriously affected. This distance is based on the effects of such surges at three basaltic volcanoes elsewhere in the world during historic time, which affected areas 6-9 km (4-5.5 mi) from the vents (Rotomahana, New Zealand, in 1886: Nairn, 1979; Taal, Philippines, in 1965: Moore and others, 1966; Kilauea, Hawaii, in 1790: Swanson and Christiansen, 1973). The probability of an area being affected, as well as the severity of effects, decreases progressively outward from a vent. Because of the loss of energy as they moved uphill, pyroclastic surges might not extend as far upslope as downslope from a vent, but on flat areas they probably would reach roughly the same distance in all directions.

For the purpose of hazards zonation, vents near or beneath sea level and those in areas of high groundwater table are regarded as susceptible to pyroclastic surges during explosive eruptions. Thus, the most likely locations of such vents are near the coastline along the southwest and east rift zones. In addition, eruptions elsewhere on the windward, relatively wet side of Haleakala probably are more likely to be accompanied by steam explosions and pyroclastic surges than are eruptions at vents on drier parts of the island.

Separate hazard zones are not shown for volcanic ash because of several variables that are difficult to anticipate, such as the location of future vents, the direction and strength of winds during eruptions, and the volumes erupted. Source vents are most likely to be somewhere within hazard zone I during future eruptions, but could occur outside that zone.

The 2500-year-old red ash could serve as a model for the distribution and thickness of ash that could result from explosive eruptions within the crater of Haleakala. The red ash was deposited on the flank of the volcano at least as far west as the highway between Pukalani and Keokea, and is as much as 10 cm (4 in.) thick along the Haleakala Highway at a point 9 km (5.5 mi) west-northwest of the crater rim.

The hazard from ash is proportional to the amount that falls, and decreases progressively away from its source in the direction of winds blowing during the eruption. Prevailing winds below about 3050 m (10,000 ft) in the Hawaiian Islands are from the northeast, but they are more persistent from this direction in summer than in winter. From about October to April, the islands may be affected by strong southerly, southwesterly, or northerly winds associated with storms. The directions of surface winds are influenced to a variable extent by local surface topography.

If an explosive eruption occurs, monthly averages of wind directions at various altitudes, available from the National Weather Service, may be useful in calculating the probability that ash will fall in a specific sector on the island.

PREDICTING ERUPTIONS AND MITIGATING HAZARDS

Eruptions are usually preceded by days or weeks of earthquakes that can be detected by seismometers, and some of which may be strong enough to be felt. The beginning of an eruption may be marked by the appearance of cracks in the ground, from which steam and other gases are emitted. Initial eruptions often are explosive, and fragments of lava accumulate to form a rampart or cone around the vent. Flowing lava may appear within minutes or hours of the initial outbreak. The appearance of an active vent should be regarded as an immediate hazard warning to people in the vicinity and in areas downslope and downwind from the vent. Areas as much as 8 km (5 mi) from the vent could be affected by falling cinders and ash that could accumulate to depths of at least 10 cm (4 in.); these areas also could be affected by gases. People in areas that could be affected by ash, gases, and lava flows should leave by a safe evacuation route, or be prepared to leave on short notice. If an eruption occurs, the National Weather Service should be asked to predict the directions ash and gases will be carried by winds.

People in areas where ash is falling should seek shelter in a building or a vehicle. Some protection is provided by breathing through a cloth, preferably one moistened with water. People should not walk or drive into depressions near a vent because of possible accumulations of heavier-than-air toxic gases. In general, it is advisable to remain indoors, breathe as little ash as possible, and restrict movement during an ashfall, although civil authorities may advise evacuation in some circumstances.

Although lava flows move downslope, their courses can be modified to some degree by walls or embankments, but construction of containment or diversionary structures may not be practical. If part of a flow is constrained by levees or a tube, the use of explosives to destroy the constraint could divert the flow to another path. Neither of these measures, however, insures success.

The speed of pyroclastic surges is so great that escape is not possible after they begin. If steam explosions occur, the only effective safety measure will be the immediate evacuation of zones that are likely to be affected. If an eruption begins either onshore or offshore near the coast, it should initially be assumed that steam explosions and pyroclastic surges will occur. As the eruption progresses, it will become apparent whether such events are a potential hazard.

THE FUTURE

Haleakala volcano on Maui has been quiet for nearly two centuries, yet the inferred average rate of eruptions on the volcano as a whole has been nearly 1 per 100 years during the last 1000 years. Although this eruptive history suggests that an eruption could occur on Haleakala within the next hundred years, there is as yet no way to predict a specific time or place of the next eruption.

Rapid expansion of locally intensive land use has occurred on the island during the last decade, and is still continuing during a period of volcano dormancy that may be about to end, if the recent eruptive history of Haleakala is a reliable guide. Therefore, the possibility of eruptions should be considered in planning future land developments on the slopes of the volcano, and especially within or near hazard zones I and II. With the limited data now available, it is not possible to calculate the statistical probability that specific parts of hazard zones will be affected by an eruption during the expectable lifetimes of existing or planned structures. Nevertheless, there is cause for concern that land development will continue to expand toward zones of relatively high hazard, and will increase the potential economic and social impacts of future eruptions.

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[1] Articles recommended for further reading are indicated by an asterisk.

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1983

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