

Feasibility of a Lava-diverting Barrier at Hilo, Hawaii¹

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THE SUBJECT of the value and possibility of protecting Hilo Harbor and vicinity from devastation by a lava flow from Mauna Loa is again being given thoughtful consideration by the residents of Hawaii. Those who must weigh the pros and cons of this matter need information, part of which can best be appraised by geologists and engineers. From the geologists' appraisal should come answers to questions such as the following: How often might protection from a lava flow be needed? Is it physically possible to divert a lava flow with a man-made structure? What are the necessary dimensions of such a structure? Of what should it be built? What is its expected useful life?

Various references to cost have been made. Some say that a barrier is justified, regardless of cost; others hold to a strict accounting of supposed risk against cost, amortization, and other factors. These opposed views are widely separated. Many risks could be reduced by astronomical spending, but such spending may be beyond reasonable relation to contemporary life or even to capacity of the community to pay. Though opinions may differ greatly, the criterion of economic justification cannot be ignored altogether.

Much has been written on the subject of a lava barrier for Hilo. The latest and most comprehensive review and discussion is by Gordon A. Macdonald (1958). His greatest emphasis is laid on the matter of a barrier system to be constructed across the slope above Hilo to divert the course of an approaching lava flow. He concludes that a system of barriers can divert the course of a lava flow.

The conclusions reached in this report differ in this matter from those expressed by Macdonald because different evaluations are made of the same few facts available for appraisal.

Among the most important of these different evaluations, this report concludes that the minimum condition for the successful functioning of a diversionary system is the construction of a channelway adequate to conduct the lava flow along the chosen route behind the barrier system. An adequate channel may exceed 2 mi. in width with rock excavation in excess of a 400-ft. depth along the upslope margin, even with a barrier 60 ft. high along the downslope margin. Facts needed to design the channel system and to appraise the amount of funds that can prudently be invested in it are imponderable—facts such as the volume of flow to be expected and the probable frequency of hazard. In the face of such imponderables, a downslope diversionary system is unrealistic; it would seem prudent to rely on, and plan for, defensive actions that can be taken during an eruption, such as causing distributary flows at or near the vent.

FORECASTING ACTIVITY

The waxing and waning of volcanic activity shown in the geologic history of Mauna Loa makes it impossible to give a dependable prediction of the *probable* hazard to Hilo from lava flows. The *possible* hazards cover a great range: Hilo might be obliterated by another eruption from the same vicinity as the prehistoric eruptions that formed the Halai Hills (see Fig. 1); or it is possible that no future lava flow will ever reach Hilo. Since Hawaiian oral history began, perhaps about A.D. 1100, only one lava flow from Mauna Loa, that of 1881, reached the vicinity of Hilo.

It is natural to predict future events on the premise that events of the best-known past will be repeated; in this instance, the history of Mauna Loa's activity since 1843. How disastrously wrong such a prediction can be was emphasized by the eruption in 1960 of the Kilauea lava flow in Puna. After the devastating flow in 1955, no further outbreak in that region was to

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be expected for several decades, based on the spacing of recent known eruptions: 1740?, 1793?, 1840, and 1955 (Macdonald, 1941). Forecasts of Mauna Loa activity based on an even shorter period of time may be equally wrong; in fact, an inspection of a longer record shows that the activity of Mauna Loa waxes and wanes in a manner that gives no useful basis for predicting the frequency of future activity. In the 180 years since 1780 there have been 20 lava flows from the flanks of Mauna Loa; in the preceding 600 odd years covered by Hawaiian oral traditions there apparently were no lava flows from Mauna Loa; and, representing activity previous to A.D. 1100, 60 different ancient cinder cones can be found that indicate flank eruptions that took place over an unknown span of time. There is no geological basis for predicting how long the present epoch of frequent eruption may last; it may continue or it may have run its course.

The evidence for the dormancy of Mauna Loa during about 600 years covered by Hawaiian oral history is considered here in some detail, as it has not had the attention in the literature that it deserves. It consists of the evaluation of observations by early explorers and of geologists and evaluation of Hawaiian oral history and mythology.

Members of Captain Cook's expedition in 1778–79, particularly John Ledyard who attempted to climb the mountain, noted that Mauna Loa was a volcano and described features on the slopes "... that had every appearance of past eruption and fire. . . . But there is no tradition among the inhabitants of any such circumstance" (Hitchcock, 1909: 61–62).

Archibald Menzies, the botanist on one of Vancouver's expeditions, climbed to the summit crater of Mauna Loa in February, 1794; he contrasts "the Mountain" Mauna Loa with "the Volcano" Kilauea in his descriptions (Hitchcock, 1909: 68–72).

William Ellis, a British missionary who knew the Polynesian language, explored Hawaii in 1823 and queried the Hawaiians about volcanic activity. They had no oral history of lava flows from Mauna Loa but reported that Kilauea had been active from "time immemorial" and that some part of the lands of Kau and Puna had

been devastated by a lava flow during the reign of every King (Hitchcock, 1909: 163–164).

The United States exploring expedition under Captain Wilkes spent nearly a month on the summit of Mauna Loa in the winter of 1840–41, having traversed the northeast ridge in the ascent (at that time, only one of the known historic eruptions had broken out from this region). They reported that the whole area was of lava, chiefly of very ancient date (Hitchcock, 1909: 83).

A large area of the southwest ridge of Mauna Loa was explored by R. H. Finch of the U.S. Geological Survey during December, 1925. He observed, "The lava on the southwest flank of Mauna Loa may well be divided into two ages: recent (within the last 100 to 150 years, say), and old. Lava flows of various ages showing a uniform gradation in weathering between the oldest and newest flows are not to be found" (Finch, 1925: 90).

There is thus some geologic evidence for a considerable period of dormancy of Mauna Loa, implied by the lack of mention of Mauna Loa flows in Hawaiian oral history. Moreover, recent seismological evidence that Kilauea's lava rises from a zone about 60 km. beneath the region between the Kilauea caldera and Mauna Loa's northeast rift zone raises the possibility that both volcanoes are fed from the same source and that when one is in a period of unusual activity the other erupts infrequently. Such alternation in activity between the two volcanoes over century-long intervals is suggested by the historic evidence quoted above.

However, the Hawaiians were well aware of the fact that Mauna Loa was a volcano; many of their myths describing the activities of the demigods were explanations of volcanic features they found on the slopes of Mauna Loa. Pre-Hawaiian lava flows on the southwest slope are explained in the legend of "Na Pu'u o Pele" (Westervelt, 1916: 22–26); the lava flows that bank against the north slope of Mauna Kea were, to the Hawaiians, evidence of legendary conflicts between Pele and the snow-goddesses (Westervelt, 1916: 62); and the most recent lava flow in the forest south of Hilo was, to them, a record of the battle between Hi'iaka and Pana-'Ewa (Westervelt, 1916: 96–103). In

contrast, the lava island in Hilo Bay called Coconut Island was fished up from the sea by the demigod Maui (Westervelt, 1916: 28), apparently not associated in Hawaiian minds with the demigods to whom they attributed volcanic phenomena.

DIVERSION SYSTEM TECHNICALLY POSSIBLE

All who have considered the problem have agreed that a solution to containing a lava flow does not lie in impounding lava behind a dam; the topography is not favorable and the total amount of lava that would need to be stored cannot be estimated. The solution is sought, therefore, in some manner of diverting the course of flow. A lava flow following a natural channel can be entirely diverted along a chosen alternate channel if one fundamental condition is met—the artificial channel must be able to carry the lava away from the point of interception as rapidly as it is delivered there by the natural flow.

The average gradient of such a diversion channel will, of necessity, be considerably less than the average gradient of the natural slope across which it is constructed. To offset the unfavorable loss of gradient, the built channel must offer less obstruction in its floor, such as irregularities and vegetation, and provide space for a greater cross-section of flow. It is not enough to consider that a cross-section of a diversion channel is adequate by allowing an added area to compensate for the reduced gradient on the basis only of gravity flow of a liquid. Allowance must be made also for the capacity of the lava flow to transmit enough heat to maintain its liquidity. This differential term in the equation works against a wide flow, even though its greater width might sufficiently compensate reduced depth for water. If these conditions are met, the channel will direct the movement of the flow, and the barrier need only confine the downslope margin, not act as a dam across the flow.

However, if lava behind the barrier is ponded to a considerable depth (50 ft. or so), the possibility that it might inject itself through the barrier or its foundation cannot be overlooked.

Such an engineering accident was responsible for the early failure of a barrier constructed during the 1960 eruption of Kilauea.

DESIGN OF THE DIVERTING SYSTEM

The designer of a system of structures to divert flowing lava must know the probable maximum rate of delivery of lava that can be expected to enter the system. Here again, geologic experience cannot predict the probable requirements, it can only point out the possible maximum load. If the outbreak takes place within 10 or 15 mi., lava may be expected to enter the system at a rate of about 25,000,000 cu. yd/hr, based on the observations made on the Mauna Loa eruption of 1950, the most voluminous eruption that has been sufficiently documented (Finch and Macdonald, 1953). Should the designer anticipate the voluminous load from a nearby eruption? What are the data upon which to make the decision?

The pre-Hawaiian lava flows that form the south shore of Hilo Bay (see Fig. 1) appear to have come from vents along the lower part of the northeast rift, according to current studies of recent air photographs and some reconnaissance field identifications. The topographic ridge built by these and similar eruptions is the south boundary of the topographic trough that slopes into Hilo Bay. Any future eruption along this rift line below an altitude of about 3,500 ft. will lie on the south side of the ridge, and its lava flows thus would be directed away from Hilo Bay; an eruption along this zone above about 3,500 ft. will be more than 15 mi. from Hilo. Any source vent closer to Hilo than 15 mi. would have to break through the flank of Mauna Loa considerably to the north of the zone of old cinder cones that mark the lower part of the northeast rift. However, Stearns and Macdonald (1946: 70) reasoned that the vents in Hilo (Halai Hills) lie on a branch of the northeast rift, and Macdonald restated the supposition in 1958 (p. 259). An eruption on any part of this supposed branch of the rift zone will be in the trough leading to Hilo; such an eruption must be expected geologically, even though there are no existing vents along this line between Hilo (Halai Hills) and a point 22 mi. from Hilo at

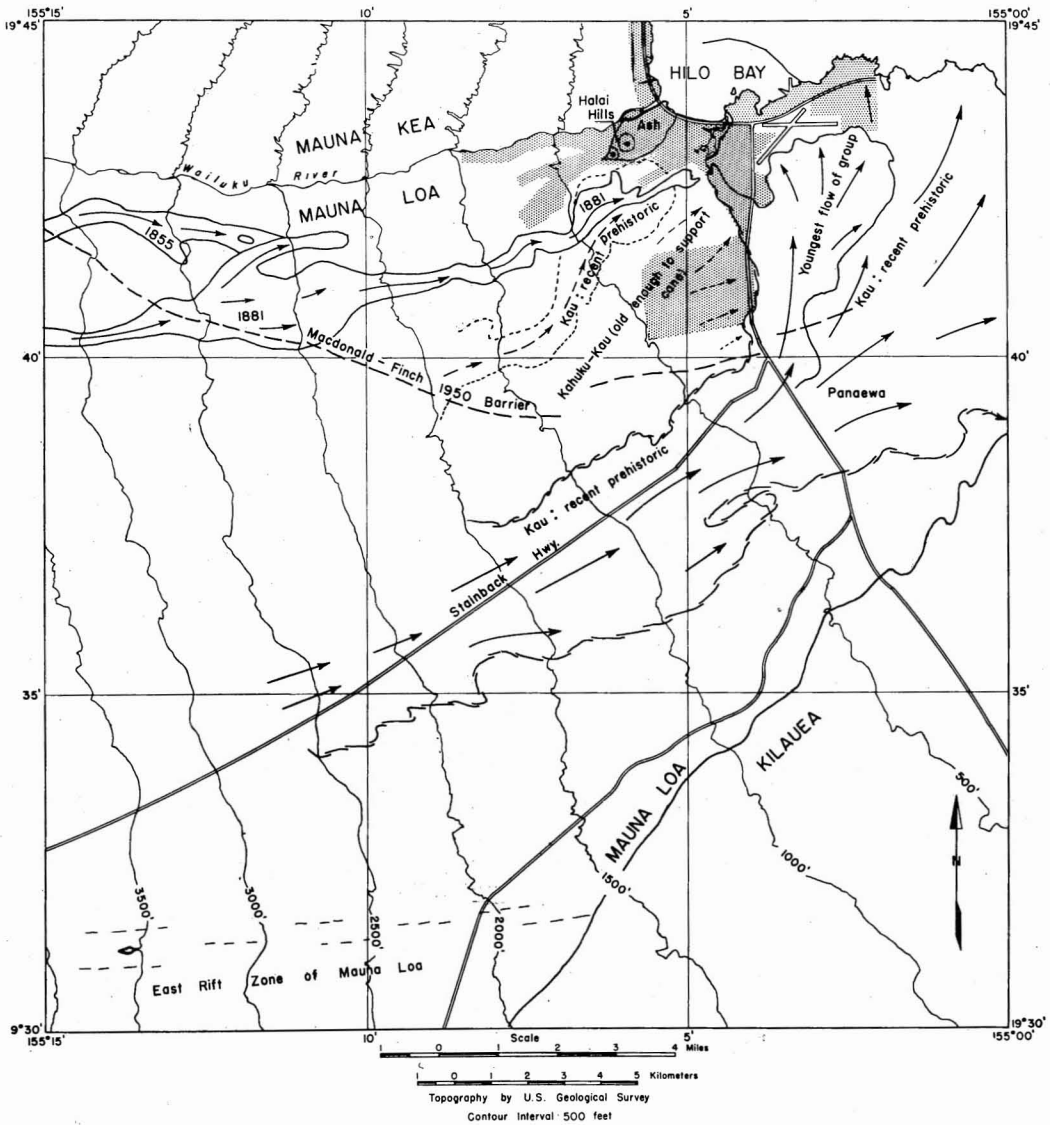


FIG. 1. Map of the vicinity of Hilo, Hawaii, showing historic and recent prehistoric lava flows from Mauna Loa that approached Hilo Bay. Shaded area represents present extent of the city of Hilo.

an altitude of 6,800 ft. Even if it is assumed that the reasoning of Stearns and Macdonald is incorrect (and there is no compelling geological basis for such an assumption), and that the supposed branch of the rift zone does not exist, there remains strong geologic precedent for an outbreak through any flank area away from a

known rift zone. Of the 72 known flank eruptions, 18, or one-fourth, have broken through the mountain flank several miles away from any known rift zone. The eruption of 1877, above and in Kealakekua Bay (Hitchcock, 1909: 115), broke out as far from a rift zone as it is possible to be. There has been no eruption, in

the past, within 15 mi. upslope from the probable site of a diversion structure, but there is no known geologic reason why an eruption may not break through in this area. A reasoned decision about the necessary barrier design cannot be made on such data; the decision must be based on other considerations.

Another, and completely unrelated, problem of design for which no geologic or engineering solution is possible rises from certain characteristics of a lava flow (Wentworth, 1954). Every flow of lava inevitably sends out distributary flows from time to time and from place to place along its course, as one way of responding to frequent large fluctuations in the amount and rate of eruption of lava at the source vent. Therefore, it may be expected that more than one flow of lava will enter the channel of the diversion system during any one eruption. Inasmuch as mobile lava becomes immobile rock as soon as it cools slightly, a considerable amount of any lava that enters the channel system will solidify there and form an obstruction in the channel. Thus, any subsequent flow of lava that enters the channel system at a point up grade will have to override this obstruction in order to keep on moving down grade. If the channel system has been built with enough capacity, the overriding flow will be contained and the system will continue to function; if the system has too small a capacity at this point, the barrier wall of the channel will be overrun at the obstacle and the diversion system will fail to function.

At the designing stage of an adequate diversion system, it is obviously impossible to anticipate the point at which a future first lava flow will enter the system, to estimate the magnitude of the obstruction that it will form, or to appraise the amount of lava that may have to pass over the obstruction. The designer can cope with this situation only by overdesigning the entire system. He can only guess how much to overdesign:—twofold?—tenfold?

In considering design of barriers and diversion channels, the tendency of liquids adjacent to a dam to cause uplift pressure and to burrow through should be realized. To allow for such tendency is standard practice in designing dams, because some have failed in this way. Lava bar-

riers have also failed in this way, as was recently observed in some instances at Kapoho. However, in the case of a massive barrier built of well-compacted rock and soil, this is thought to be a very remote contingency because of the cooling effect. Lava might retain liquidity through tenuous openings for a distance of 200 or 300 ft. but would seem unlikely to do so through 1,000 ft. or more except in a pre-established tube. Such an accident is not entirely dismissable, however.

SAMPLE ESTIMATES OF DIVERSION CHANNEL DIMENSIONS

We can neglect for the moment the imponderable matter of overdesign and consider the dimensions required to convey two sample lava flows that may be assumed to move as simple flow units.

The average natural gradient of the trough that leads to Hilo, which must be intercepted by the diversion system, is between 250 and 300 ft/mi. The diversion channel probably could be laid out with an average gradient of no more than 200 ft/mi. Estimates of the velocity of movement of lava flows on comparable low gradient can be made from published descriptions of previous flows. The hot, mobile lava near the vent of the 1954 eruption of Kilauea (Macdonald and Eaton, 1954) moved at rates not less than 400 yd/hr. A channel designed to move 25,000,000 cu. yd. of hot, mobile lava at this velocity would need to provide space for a flow cross-section of 63,000 sq. yd. If a containing barrier on the downslope margin of the channel were built high enough to give an average depth of flow of 20 yd. in the channel, the width of the channel would be 3,150 yd. (approaching 2 mi. wide), and the maximum rock excavation at the upslope margin would be greater than 400 ft.

A different example: the relatively cool and viscous lava of the 1926 flow that destroyed the beach village of Hoopuloa (Hawaiian Volcano Observatory, 1926) moved at rates not less than 60 yd/hr. A similar relatively cool flow from a distant vent reaching the diversion system at a rate of 2,000,000 cu. yd/hr would require a channel cross-section of nearly 34,000 sq. yd. to

carry the load at 60 yd/hr velocity. Assuming an average depth of 20 yd., the width of channel required is about 1,700 yd. (1 mi.) and the up-slope would exceed 200 ft.

These examples have neglected the overdesign necessary to accommodate the transportation of distributary flows.

CHANGING THE MOVEMENT PATTERN OF LAVA FLOWS BY BOMBING

It has long been understood by observers of Hawaiian lava flows that the course and progress of a flow can be radically altered by breaching the levee bank of the main feeding channel. Macdonald (1958) presents an excellent discussion and evaluation of the matter which need not be repeated here. He concludes that efforts to divert the flows by bombing should be made in the event of a threat to Hilo, but that a barrier system also should be constructed as insurance against failure of the bombing effort, particularly in the event that a voluminous, fast moving flow would overrun the area before bombing could be carried out. However, it would seem from the discussion in previous paragraphs that an artificial diversion system of dimensions adequate to cope with a voluminous, fast moving flow would be expensive beyond prudent economic justification. Thus, it would seem that the hazard of being overrun by lava is one that must be accepted and lived with, perhaps analogous to the acceptance of earthquake hazards by Tokyo and cities in other earthquake areas.

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