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A Geologic Evaluation of Proposed Lava Diversion Barriers for the NOAA Mauna Loa Observatory Mauna Loa Volcano, Hawaii

by

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Abstract

Lava flow diversion barriers should protect the Mauna Loa Observatory from flows of reasonable magnitude if properly constructed. The a'a flow upon which the observatory is constructed represents a flow of reasonable magnitude.

Proper construction of the barriers includes obtaining riprap from a zone exterior to the proposed V-shaped barrier so as to produce an exterior relief near 9.2 m for most of the barrier, construction of a channel about 8 m deep and 40 m wide along the east part of the barrier, and proper positioning of an isolated initiating barrier.

Calculations suggest that the barriers should be able to handle peak volume flow rates near 800 m^3/s and possibly larger ones. Peak volume flow rates for the a'a flow upon which the observatory is constructed are estimated to be in the range of 400-600 m^3/s.

Introduction

This document is a geologic evaluation of lava diversion barriers that have been proposed to protect the NOAA Mauna Loa Observatory (MLO) on the north flank of Mauna Loa, Hawaii. It includes some recommendations on general procedures to be used in the construction of the barriers as well as some detailed recommendations. The underlying principles that form the basis for the recommendations are two-fold: lava must be conducted and diverted so that deep, wide channels, along with diversion, are required to produce the desired effect.

Suitably constructed barriers and channels should protect MLO from flows of reasonable magnitudes, such as the a'a flow upon which MLO is constructed. Estimated peak volume flow rates for this flow are in the range of 400-600 m^3/s; but average volume flow rates were probably less. The diversion barriers and channels, if properly constructed, should be able to handle such volume flow rates and, possibly, larger ones.

Lava diversion barriers and their effectiveness have been discussed in the literature, and the matter is controversial (see for examples, Macdonald, 1958; Wentworth and others, 1961). Macdonald (1958) cites examples which indicate that diversion barriers will be effective. Macdonald's evidence suggests to me that suitably designed barriers will work under some conditions. It is clear, however, that the magnitudes of lava flow rates, and their unpredictable variations in time would substantially affect their success.

The field observations, analyses, and preparation of this document were requested by John P. Lockwood of the U.S. Geological Survey's Hawaiian Volcano Observatory, who recommended that lava diversion barriers be constructed to protect MLO. This report is a revision of an informal preliminary report delivered on August 14, 1981.

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The author was competently assisted in the field and office in early August 1981 by Steven R. Browning of Weber High School, Ogden, Utah, who was a student visitor and summer employee at the Hawaiian Volcano Observatory. Extensive logistical support for the field work and geologic information on the area were provided by John Lockwood. K. C. Coulson, Director of the NOAA Mauna Loa Observatory, provided living accommodations at MLO during field work.

Location and Topography

MLO is located on the north flank of Mauna Loa between 3390 and 3408 m in elevation and about 4.44 km north of the rim of North Pit of Mokuaweoweo caldera. As portrayed by the 1/24,000 topographic map (U.S. Geol. Survey, 1956), MLO is located on a broad north-trending ridge about 610 m wide between 3371 to 3414 m. Above this ridge, between 3463 to 3487 m, the axis of a valley, 274 m wide, coincides with the axis of the broad ridge of MLO. Thus, a flow moving down the valley could very well continue down the ridge.

Detailed portrayal of the area around MLO at 1/2000 shows this in greater detail (Plate 1). Here the valley measures 270 m across at the edge of the map, broadens downslope, and divides into two smaller valleys on each side of the ridge. Profiles of channels formed by these valleys are shown in Plate 2 and profile section lines are shown on Plate 1.

MLO is constructed on an a'a flow formed in historic times on a slope of about 7.4°. Edges of the flow generally rise 3-4 m above the surroundings. Locally the rise is only 1-2 m where the flow abuts against ridges and channels of prehistoric flows from a spatter rampart to the east and where lava has been squeezed out of the base of the flow. Local relief of the prehistoric spatter rampart to the east of the a'a flow is about 3-4 m. Broad, subtle ridges and shallow valleys are found west of the a'a.

At the scale-lengths of the hiker and his foot, the surface of the a'a is very rough with 15-cm- to meter-size clinkers and larger blocks set in a matrix of finer fragments.

As shown by the profiles, a flow coming down the valley above MLO would probably, but not necessarily, be confined to the valley. If confined to the valley, the flow would tend to veer toward the northwest but part would probably veer to the northeast. This condition also occurs at profile E-E'. However, a flow which builds its own levees as it proceeds could also continue straight down the ridge. Thus, a flow diversion barrier between profiles D-D' and E-E' would insure that a flow either veers left or right or that it divides and flows on both sides of the barriers. Another important point to be made by the other profiles is that channels to southeast and southwest of the MLO ridge are shallow and poorly defined (see profiles J, L, N and G, I, K, Plate 2). Here, lava spreading or changes in flow direction may occur. An absence of channelways and natural lava diversion barriers is particularly striking to the southeast of MLO (see Profiles M, P, R, and S, Plate 2). Here, a lava flow could go in almost any direction and some shallow depressions are present that might even guide a flow toward MLO.

The MLO Flow

Mauna Loa Observatory is constructed on an a'a flow (hereinafter termed the MLO flow) which has been described by Lockwood (1978). It consists of fresh blocky a'a that originated in historic times from a vent 3.5 km south of MLO. The MLO flow is superposed on earlier prehistoric flows of tube-fed pahoehoe, a'a, and pahoehoe from nearby vents. There are a number of lava streams of the MLO flow and the tip of the longest stream, which passes beneath MLO, is about 4.5 km north of the vent from which it originated. Part of the MLO flow was confined to the valley above the MLO ridge where it is about 100 m wide and bounded by levees some 27 m wide; the maximum depth of the 46 m-wide channel between the levees is 4.0-4.5 m. Downslope, the MLO flow splits into two branches. The eastern branch is small and terminates about 500-600 m below the valley; widths, while variable, are typically 50 m. The western branch is about 160 m wide just below MLO and it terminates about 1.5-1.7 km below the valley. In many places the flow is bounded by levees constructed with its own lavas during periods of peak flow. Channels between the levees, which are underlain by MLO lavas, ranged in width from 9 to 50 m and, in depth, from 1.5 to 4.5 m (Table 1).

Geologic observations indicate that the MLO flow is similar to many a'a flows in profile. Measured thicknesses are between 3 to 4 m with 3.6 m being typical. Of this thickness, the uppermost part is composed of reddish blocks, clinkers, and cinders roughly 1.5 m thick. The base of the flow has a variable thickness of massive gray vesicular basalt which probably, in turn, rests upon cinders and clinkers derived from the flow front and subsequently overridden by the flow.

Lockwood (1978) suggested that the MLO flow may coincide with the February 17, 1852 eruption of Mauna Loa described by Rev. Coan. Based on Rev. Coan's estimate of duration and Lockwood's estimate of the length of MLO flow, Lockwood estimates a 2.5 km/hr flow speed. Mapping in progress suggests, however, that the 1852 identity may be in error; an 1832 age is also possible (J. P. Lockwood, personal comm., Aug. 1981).

Natural Lava Diversion

A reasonable qualitative estimate of the expected behavior of a future lava flow is represented by the flow upon which MLO is built. It flowed down a pre-existing channel that coincides with the present one above MLO and was diverted by a linear spatter rampart some 300 m to the south-southeast of MLO. Diversion may have commenced 500 m south of the station (at elevation pt. 3460, Plate 1) where, now frozen, streamlines of lava produce a V-shaped ridge some 2.2 m in height. This diversion probably contributed to the small eastern flow lobe, although most of the lava streamed to the west. Western edges of the western lobe are levees that were constructed by the flow itself. The eastern edge of the eastern flow was clearly confined and diverted by the spatter rampart to the east. Locally, on this eastern edge, the younger MLO flow abuts against loose slabs of prehistoric pahoehoe without disrupting them. A very convincing example of diversion may be seen 240 m southeast of the main building of MLO (see arrow labeled Ƶ, Plate 1). Here, two westerly-trending ridges, about 40 m long and 6 m high, deflected the flow in a westerly direction some 30 to 40 m before it continued its downslope course. The eastern edges of the flow are locally unconfined, so that diversion appears to have been the result of intermittent encounters with steep protrusions of prehistoric pahoehoe. In one place, the older pahoehoe appears to have been almost overridden.

Construction of Barriers

The purpose of artificial lava flow diversion barriers is not to dam the flow but rather to deflect it and create topographic conditions that will permit the flow to spread, slow down, and divide in some places and create conditions for increased flow velocities and rapid transfer of lava in other places. Pressures in the direction of flow (or downslope) are very large and the lavas will pond behind dams until they overflow or rupture them. Pressures of flowing lavas in lateral directions are small compared to those in the downslope direction.

The proposed barrier system to protect MLO includes a V-shaped barrier that points up-slope and a small initiating barrier above the tip of the "V" where the MLO ridge meets the valley above it (Plate 1). In the construction of the V-shaped barrier, endeavors should be made to create a channel not only by construction but also by excavation on the expected flow-ward side of the barrier in order to create the most favorable flow conditions (deep-wide channels). This means that, in most places, riprap for the construction of the barriers should be obtained from the flow-ward side of the barrier. This appears to be, in part, achieveable. In the case of the initiating barrier up-slope, riprap should be obtained from the edges of the MLO flow but not near the valley center because the object here is to initiate spreading, reduce velocities, and encourage dividing. Recommended procedures and sources for riprap are discussed below and shown in Plate 1. Profiles that include the barriers are shown in Plate 3.

Construction of test barriers suggests that a reasonable estimate of the angle of repose for a barrier is near 37-38 degrees (Anon., 1977). For a barrier 20 m wide, the corresponding height is near 7.7 m and the corresponding volume of riprap required is 77 m^3 per m of length of barrier. Two test pits which were excavated in the upper surface of the MLO flow and geologic observations suggest that a bulldozer can obtain at least 1.5 m of riprap from the upper part of the flow. Assuming that no volume change will occur in transfer of material from the upper surface of the flow to the barrier, 77 m^3 per m of barrier length could be obtained from distances about 51.4 m from the barrier (51.4 m x 1.5 m = 77 m^2). As shown on Plate 1, about one-half of the material can come from each side of the barrier. This procedure will increase the channel depth by 1.5 m and the total relief to 9.2 m.

If it turns out that the bulldozers can obtain more than 1.5 m depth of riprap from the area adjoining the flow-ward sides of the barriers, this should be done. In other words, obtain as much riprap material from the expected flow-ward sides of the barriers as is possible. In order to achieve the angle of repose on the flow-ward sides of the barriers, they should be topped off using riprap from the interior of the barriers.

Rip-rap for the leading edge of the V-shaped barrier should come from the edges of the MLO flow and not the center. The object here is to allow the flow to spread, slow down, and branch (see Plate 1, areas AA and BB) until it reaches the barrier, where deep channels will accelerate the lava and conduct it past MLO.

An isolated initiating diversion barrier upstream will help initiate flow diversion and again, riprap should come from the edges of the MLO flow in order to encourage flow spreading, reduced velocities, and branching. The initiating barrier should be sub-parallel to the axis of symmetry of the V-shaped diversion barrier and offset 10 m east of this axis (see arrow labeled W on Plate 1). This should create a slight bias for flow to the west where barrier channels are wider and deeper.

One area of concern exists between elevations of 3410 to 3430 meters along the east side of the east barrier (Plate 3). Here the combination of the barrier and local topography results in a narrow shallow channel some 80-90 m wide and an average depth of 4.0 m. Because channel depths are about the same as the thickness of the MLO flow, the channel may become clogged and overflow the barrier at this location. The constriction is partly the result of two ridges which produced some deflection of the MLO a'a flow (see arrow labeled Z, Plate 1). These ridges should be dozed down as much as possible to produce a channel 8 m or more deep and 40 m wide. This will permit rapid flow of lava past the barriers. This applies elsewhere along the east edge of the east barrier.

Flow Capacity of Barriers

In order to assess the protection capacity of the proposed barriers, the expectations for velocities and volume flow rates for lava flows are calculated for parts of the MLO flow, the proposed diversion paths, and compared with those reported in the literature. It should be realized that the flow rates represent model dependent peak volume flow rates and that the average of flow rates in time may be considerably less. The comparison of peak volume flow rates for the MLO flow with those expected for the barriers should reduce some model dependent uncertainties. The comparisons indicate that the barriers should handle a flow the size of the MLO flow or possibly a larger one.

Model for Lava Flows

In the following section, flowing lava is assumed to behave as a Bingham plastic. Bingham plastics are characterized by yield strengths and plastic viscosities. This is in contrast with a Newtonian fluid which is solely characterized by a viscosity. As with a Newtonian fluid, the average velocity of flow in a wide channel increases with the depth of fluid, the fluid density, and the gradient and decreases with increased viscosity. The difference between Bingham and Newtonian fluids is the yield strength which results in a velocity of zero when the thickness of the fluid is less than some critical value. The yield strength can also give rise to levees, but levees can also arise for a number of other reasons. Levees will restrict the lateral extent or width of the flow.

In the cases considered here, the flow is laminar with modified Reynold's numbers (Moore and Schaber, 1975) much smaller than 2000. Thus, the question of turbulent flow is not considered further.

The principal value in the approach used is that field observations of flow rest thicknesses and topographic gradients are used to estimate yield strengths that existed when the hot lava flow stopped moving. The yield strengths are then related to plastic viscosities that existed when the hot lava was flowing using an empirical model. Peak flow velocities are then calculated using a variety of geologic situations. General procedures are outlined below. It should be realized that these procedures, equations, etc. are currently being tested and will be revised at a future date. They do appear to give reasonable results, however.

Yield Strength

The yield strength (τ_y) is a property of the flowing lava. Shear stress (τ) on a surface parallel to the flow surface at a distance (d) below the flow surface is:

$$\tau = \rho g \, d \sin \theta$$

where τ is shear stress (Pa),
ρ is the lava density (kg/m^3),
g is the acceleration of gravity (m/s^2),
d is a distance below the surface of the flow (m),
sin θ is the topographic gradient, and
θ is the slope angle.

The stress at the base of the flow (τ_b) is obtained when d is equal to the thickness of the flow during flow (H). A flow comes to rest when the shear stress (τ) is less than the yield strength (τ_y) at all depths. Since τ is a maximum at the base of the flow,

$$\tau_y = \rho g H_y \sin \theta$$

where τ_y is the yield strength of the flow (Pa) and
H_y is the rest thickness of the flow (m).

With subsequent cooling, the yield strength increases but the rest thickness remains the same.

For the vicinity of MLO, thicknesses are usually between 3 and 4 m, and the average topographic gradient is 0.129 (slope = 7.4°). Using an acceleration of gravity of 9.8 m/s^2, density of 2200 kg/m^3, and a typical rest thickness of 3.6 m, the yield strength is 10 kPa. A yield strength of this magnitude is common for flows elsewhere on Mauna Loa (Moore and others, 1978). On a gradient of 0.06, the rest thickness would be 7.6 m and, for a gradient of 0.02, the rest thickness would be 23.2 m. Thus, the Bingham plastic model would roughly account for observed flow thicknesses from Mauna Loa, on gradients near 0.06 above Hilo, where the slowly moving a'a flow of 1942 was near 7 m thick (Macdonald, 1943). The distal end of the 1977 Kalapana flow from Kilauea Volcano attained a thickness of 14 m (Moore, R. B. and others, 1980) on a gradient near 0.05 and the 1950 Kaapuna flow was 15 m thick near the point where it entered the sea (Macdonald, 1953).

Plastic Viscosity

The relationship between plastic viscosity and yield strength used in this report is an assumed, empirical one based on limited information (Moore and Schaber, 1975). Analogy is made between the plastic viscosities of water-clay slurries, which behave as Bingham plastics, and lava flows. The volume fractions of solids of slurries are inversely related to the logarithms of the plastic viscosities and yield strengths. For lavas, similar properties may be attained because of entrained solids and crystals. The combine assumed relationships between plastic viscosities and yield strengths of lavas yield:

$$\eta_p = 82.1\, \tau_y^{0.524}$$

where η_p is the plastic viscosity (Pa·sec)
τ_y is the yield strength (Pa)

Thus, if a yield strength can be established from the observed rest thickness of a flow, the plastic viscosity can be estimated.

As an example, the average topographic gradient (sin θ) near MLO is 0.129 and the corresponding thickness of a Bingham plastic flow is 3.6 m. This indicates the yield strength was near 10 kPa and the plastic viscosity was 10 kPa·sec (10^5 poise).

Effects of Temperature

Field observations indicate that both the plastic viscosities and yield strengths vary with temperature. Direct measurement of molten lava in Makaopuhi lava lake (Shaw and others, 1968) indicate the lava has a plastic viscosity near 0.9 kPa·sec and a yield strength near 0.1 kPa at a temperature of 1132°C. Inferred plastic viscosities and yield strengths of the July 1974 flow near Keanakako'i (Kilauea), inferred to be cooler, are 2.3 kPa·sec and 0.6 kPa (Moore, H. J. and others, 1980a) while those of the 1977 Kalapana flow ranged from about 2 kPa·sec and 0.4 kPa near the Pu'u Kia'i vent, where the lava was hot, to 13 kPa·sec and 15 kPa near the tip, where the lava was cooler (Moore, H. J. and others, 1980b).

Flow Velocity

For a Bingham plastic in the laminar flow regime, the upper part moves as a slab, which has the highest velocity, and the lower part has the normal velocity distribution for laminar flow. In this basal part, velocity increases from zero at the base of the flow to the velocity of the slab at the base of the slab. The equation for average flow velocity is:

$$\bar{V} = \frac{H^2 \rho g \sin\theta}{3\eta_p}\left[1 - \frac{3}{2}\frac{\tau_y}{\tau_b} + \frac{1}{2}\frac{\tau_y^3}{\tau_b^3}\right]$$

while that of the slab is:

$$V_s = \frac{\rho g \sin\theta}{\eta_p}\left[\frac{H^2}{2} + \frac{H_y^2}{2} - H_y H\right]$$

where H is the thickness of the flow during flow
H_y is the rest thickness of the flow
η_p is the plastic viscosity
τ_y is the yield strength
τ_b is the stress at the base of the flow
ρ is the density of the flow
g is the acceleration of gravity
θ is the slope angle.

Average flow velocities and slab velocities decrease as τ_b and H decrease and become zero when $\tau_b = \tau_y$ or $H = H_y$. This is illustrated in figure 1.

For natural lava flows, "paleo" peak velocities can be estimated in places that allow an estimate of thickness during flow (H). One such situation occurs where lava once flowed in leveed channels formed by the flow. Here the thickness at the time of peak flow is taken as the sum of the present channel depth and rest thickness. Thus, a flow with a rest thickness (H_y) of 3.6 m on a topographic gradient of 0.129 would have a peak average velocity of 2.2 m/s (7.9 km/hr) and a slab velocity of 2.7 m/s (9.7 km/hr) when the channel depth is 4.4 m (H = 8 m).

Lava with a constant viscosity and yield strength will flow at a constant velocity as long as the supply of lava from the vent is constant and sufficient to maintain a constant flow thickness (H) in the channel. The lava will flow at a reduced velocity when the supply of lava is reduced provided that the supply is sufficient to maintain the flow thickness (H) at a value larger than the rest thickness (H_y). When the supply of lava stops, the velocity of flow will steadily decrease as the flow thickness (H) decreases to the rest thickness (H_y).

Flow Rates of MLO Flow

As part of the field observations, channel depths were measured along the course of the MLO flow from the vicinity of the Mauna Loa road above MLO down to the elevation of MLO; widths of the channels were measured on 1/11,400 scale color photographs (see Table 1). Flow thicknesses (H) were then taken as the sum of the channel depth and the nominal rest thickness (H_y = 3.6 m) in order to calculate a peak average velocity in the channel. The product of the flow thickness, the channel width, and the peak average velocity represents the estimate of the peak volume flow rate (Table 1). It should be clear that the channels may not be rectangular as assumed and that flow rates may be too large in some cases. To offset this fact, the largest flow rates obtained are discarded from the accepted estimate of peak flow rates below.

Using the nominal conditions outlined in the previous section, peak average velocities ranged from zero to 8.3 km/hr (2.3 m/s). For the channels above MLO, peak average velocities ranged between 3.6 to 8.3 km/hr (1.0 to 2.3 m/s) with 5.8 km/hr (1.6 m/s) being typical. Estimated peak volume flow rates ranged between 286 to 864 m^3/s with 548 m^3/s being typical.

Farther down near the location of the point of the proposed barrier, velocities were in the range of 1.0 to 5.1 km/hr (0.28 to 2.4 m/s) and volume flow rates were 34 to 411 m^3/s with 220 m^3/s being typical. Because the flow was split into two channels, a total flow rate near 440 m^3/s is implied.

Near the end of the east lobe of the flow, the last determinations of channel velocities were 1.0 to 1.8 km/hr (0.28 to 0.49 m/s) and volume flow rates were 25 m^3/s.

Thus, the peak volume flow rates of the MLO a'a flow appear to have been of the order of 400-600 m^3/s, and peak average velocities were as large as, roughly, 6 km/hr (1.7 m/s). These are estimates of peak values and, during actual flow, volume flow rates and velocities may have been less than this much of the time. Clearly, the final rates and velocities are zero.

Flow Rates Around Proposed Barriers

The amount of lava that might be handled by the diversions barriers depends on the properties of flowing lava and the sizes of the channels produced by the barriers. Properties of the flowing lava are the same as those used for the MLO flow (τ_y = 10 kPa; η_p = 10 kPa·s). Sizes of the channels produced by the barriers were obtained by the construction of profiles that include the approximate relief of the proposed barriers (Plate 3; lines of sections corresponding to the profiles are shown on Plate 1). Channel widths were constrained by lava levees, 3.6 m high, that reach the same elevations as the barriers in each profile (Plate 3) because the yield strength indicates that lava less than 3.6 m thick will not flow.

A rather approximate method was used to calculate volume flow rates because of the complex geometry of the channels produced, uncertainties in the lava flow model, and similar uncertainties for the MLO flow. In the approximate method, each area of channel in the profile that was 20 m wide and 8 m or more deep was assigned a volume flow rate of 350 m^3/s (i.e. $\bar{V}$ x area = 2.2 m/s x 160 m^2) and each area of channel in the profile that was 20m wide and 6 to 8 m deep was assigned a volume flow rate of 80 m^3/s (i.e. $\bar{V}$ x area = 0.7 m/s x 120 m^2). Occasionally, parts of a section were included. The total volume flow rate for a given profile is then the sum of the flow rates of each section in the profile.

The results of the approximate solutions are shown in Plate 3 where it may be seen that flow rates that could be handled are largest upstream and diminish steadily downstream. For the western barrier, volume flow rates that could be initially handled are in the range of 1200 to 1800 m^3/s but in the lower part, due west of MLO, they drop to about 800 m^3/s. This value is considered to be the maximum flow rate that can be handled if the flow has a yield strength of 10 kPa, a plastic viscosity of 10 kPa's, and if it passes by the western barrier. Much larger flow rates could be handled if the viscosity and yield strengths were smaller.

The east barrier can handle about 1500 m^3/s initially but the amount rapidly decreases to about 130 m^3/s near profile KB-K' (Plate 3) because of the topographic reliefs of ridges and the proposed barrier converge in a downslope direction (see Plate 1, arrow labeled Z). Additionally, sources for riprap from the MLO flow are not as large in this area as those for the western and upper parts of the barriers. If the local relief could be changed in this area by excavation on the flow-ward side of the barrier to produce a channel 40 m wide at the base and 8 m deep, the flow capacity could be increased from 130 m^3/s to 700 m^3/s.

Effusion and Volume Flow Rates

It may be of some interest to examine effusion rates of lava flows published in the literature because the barriers, if properly constructed as discussed above, should be able to handle peak volume flow rates of about 800 m^3/s on the west side and 700 m^3/s on the east side (in a channel 40 m wide and 8 m deep). Effusion rates published in the literature should be viewed cautiously, however, because they depend on the time or duration used in the calculations. Average effusion rates, obtained by dividing the total volume of flows of an eruption by the duration of the eruption, are less than about 600 m^3/s (Walker, 1973). Malin (1980) reviewed information on Hawaiian flows and calculated "actual effusion rates" which were obtained by dividing the total volume of a flow by the estimated time that the flow was fed with lava and thus active. According to this analysis, only 5 of 87 historic flows had effusion rates greater than 800 m^3/s with the largest rate being 1800 m^3/s (Malin, M. C., written communication, 1981). For Mauna Loa, 5 of 42 flows had effusion rates greater than 800 m^3/s. The time used in calculating the effusion rate is of critical importance so that it is of interest to examine the problem in more detail. For the 1942 Mauna Loa flows, Walker (1973) arrives at an average effusion rate of 55 m^3/s. "Actual effusion rates" of 68 m^3/s are used by Malin (1980) for the 1942 flow between 914 and 2900 m in elevation on the northeast flank of Mauna Loa, but he allows that it might have been as large as about 120 m^3/s because the flow moved 20 km in 100 hours, although it was actually fed for 220 hours (Malin, M. C., written communication, 1981). This same flow was examined while it was active (Macdonald, 1943; Finch and MacDonald, 1953). The velocity of lava flowing through a channel 3.7 m deep and 15.2 m wide was estimated to be 24 to 32 km/hr. These velocities, combined with the channel area, would yield volume flow rates near 380 to 500 m^3/s but they are probably too large because the velocity is greatest at the surface and zero at the base of the channel. A nominal reduction in flow rate of 2/3 would yield 253 to 333 m^3/s. The tip of the 1942 flow, estimated to be 6.1 to 7.6 m thick and about 800 m wide, was moving at 0.091 to 0.150 km/hr. This gives a volume flow rate between 123 and 253 m^3/s. The variations suggest that "actual effusion rates" may be somewhat smaller than peak volume flow rates observed in channels and moving flows.

It is possible to calculate an "actual effusion rate" for the MLO flow that is more or less equivalent to those of Malin (1980). The volume of lava below the main channel at 3480 m elevation (Plate 1) is about 0.674 million cubic meters. If the velocity was, in fact, 2.5 km/hr, about 2420 seconds would have elapsed until the farthest tip reached its final position 1680 m below the main channel. This yields an "actual effusion rate" of 280 m^3/s. Roughly, 15 of the 87 Hawaiian flows had "actual effusion rates" 250 m^3/s and larger, and 11 of 42 flows of Mauna Loa had effusion rates greater than 250 m^3/s.

Based on the rather crude estimates of volume flow rates above, it appears that MLO should be reasonably well protected from a future flow by the proposed barriers. Both the data and flow model make it difficult to place precise numbers on the protection afforded.

Summary

1. Properly constructed lava diversion barriers should protect Mauna Loa Observatory from lava flows comparable to the flow upon which it is constructed. Volume flow rates that could be handled by the barriers may be as large as 700-800 m^3/s, and possibly more.

2. Proper construction includes (a) obtaining 1.5 m, or more, riprap from a zone about 26 m wide exterior to the V-shaped barriers so as to produce exterior relief near 9.2 m or more, (b) obtaining riprap from flow edges away from the center of the natural channel upslope of the tip of the V-shaped barriers, (c) producing a channel about 8 m deep and 40 m wide along the eastern barrier east and southeast of MLO, and (d) proper positioning of the isolated initiating barrier upslope of the V-shaped barrier.

3. There could be flows that are too large for the barriers, but these seem to be improbable.

4. Although not discussed in the text, the barriers may not protect MLO from all eruption events such as "radial vents" (Lockwood, 1978) that could pass close to, or through, the barriers. Such eruptions are extremely rare, however.

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Table 1. Data used to calculate "paleo" velocities and volume flow rates of MLO a'a flow. Rest thickness (H_y) was 3.6 m, acceleration of gravity (g) was 9.8 m/s^2, density (ρ) was 2,200 kg/m^3, and topographic gradient (sin θ) was 0.129.

	Location of Channel	Channel Depth m	Flow Thickness (H), m	Channel Width m	Area m^2	Average Velocity (V) m/s	Volume Flow Rate m^3/s	Remarks
1.	1.2 km upslope of station	2.7	6.3	29	180	0.87	160	One of two feed channels
2.	1.0 km upslope of station	2.9-3.6	6.5-7.2	46	302-334	1.0-1.5	301-503	Main channel
3.	0.8 km upslope of station	2.9-4.2	6.5-7.8	44	286-344	1.0-2.0	286-693	Sum of two channels
4.	0.7 km upslope of station near edge of Plate 1	4.0-4.5	7.6-8.1	46	353-376	1.8-2.3	648-864	Main channel
5.	0.5 km upslope of station near barrier tip on Plate 1	1.5-2.5	5.1-6.1	49	278-297	0.3-0.8	83-224	Some of lava deflected to east and east lobe
6.	0.5 km upslope of station to east of barrier tip on Plate 1	3.0-3.5	6.6-7.1	41	268-289	1.1-1.4	285-411	Flow rates of 5 and 6 should be added for total rate
7.	0.2 km south-west of station	2.0	5.6	9.3	52	0.5	26	Flow stopped 0.3 km to north
8.	0.2 km east of station	1.5	5.1	17	89	0.3	25	Flow stopped 0.2 km to north

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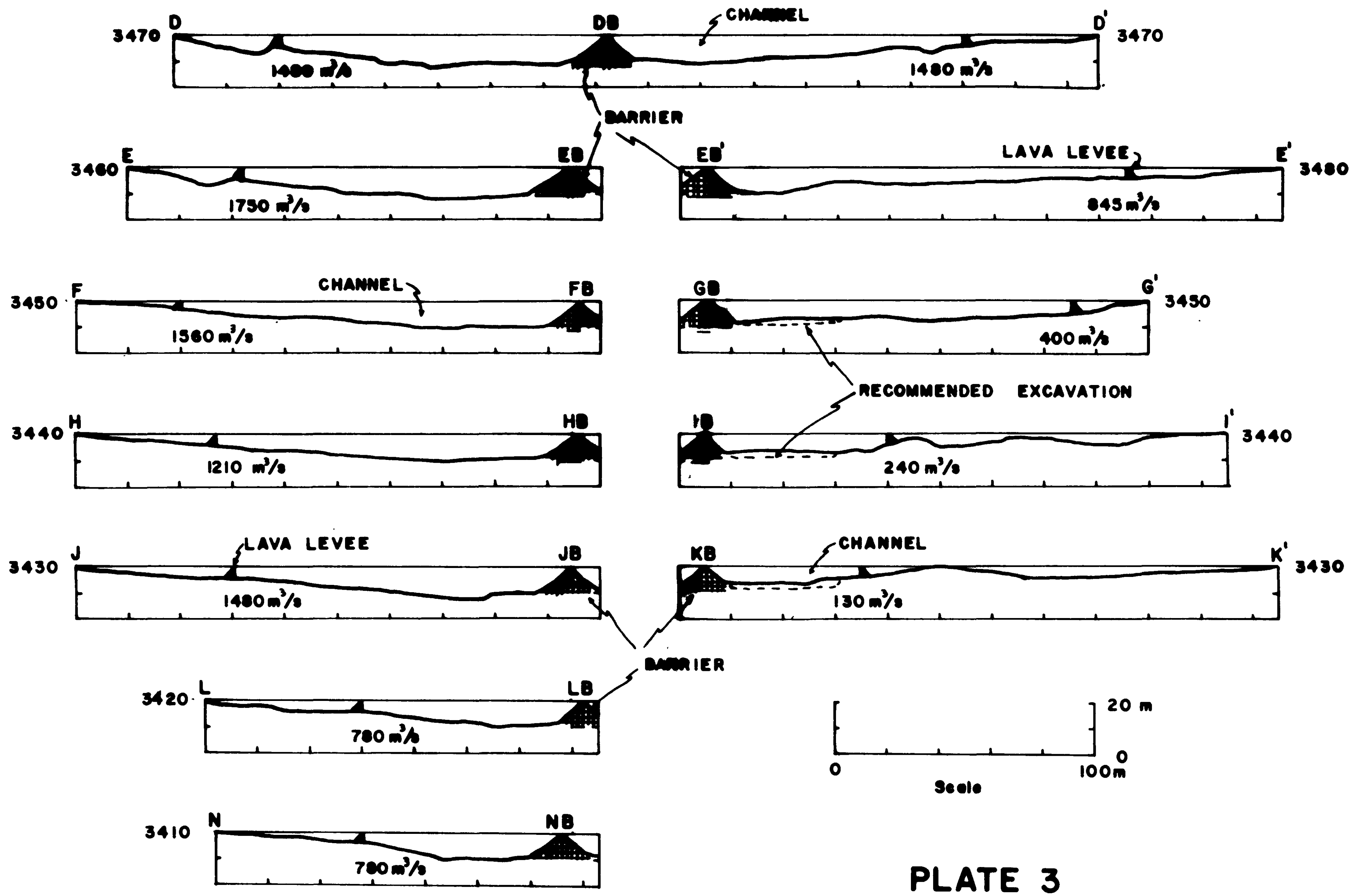

PLATE 3

PROFILES OF CHANNELS PRODUCED BY BARRIERS

LOCATIONS OF PROFILES SHOWN ON PLATE I
ESTIMATED VOLUME FLOW RATES ARE IN m^3/s

by Henry J. Moore, 1982

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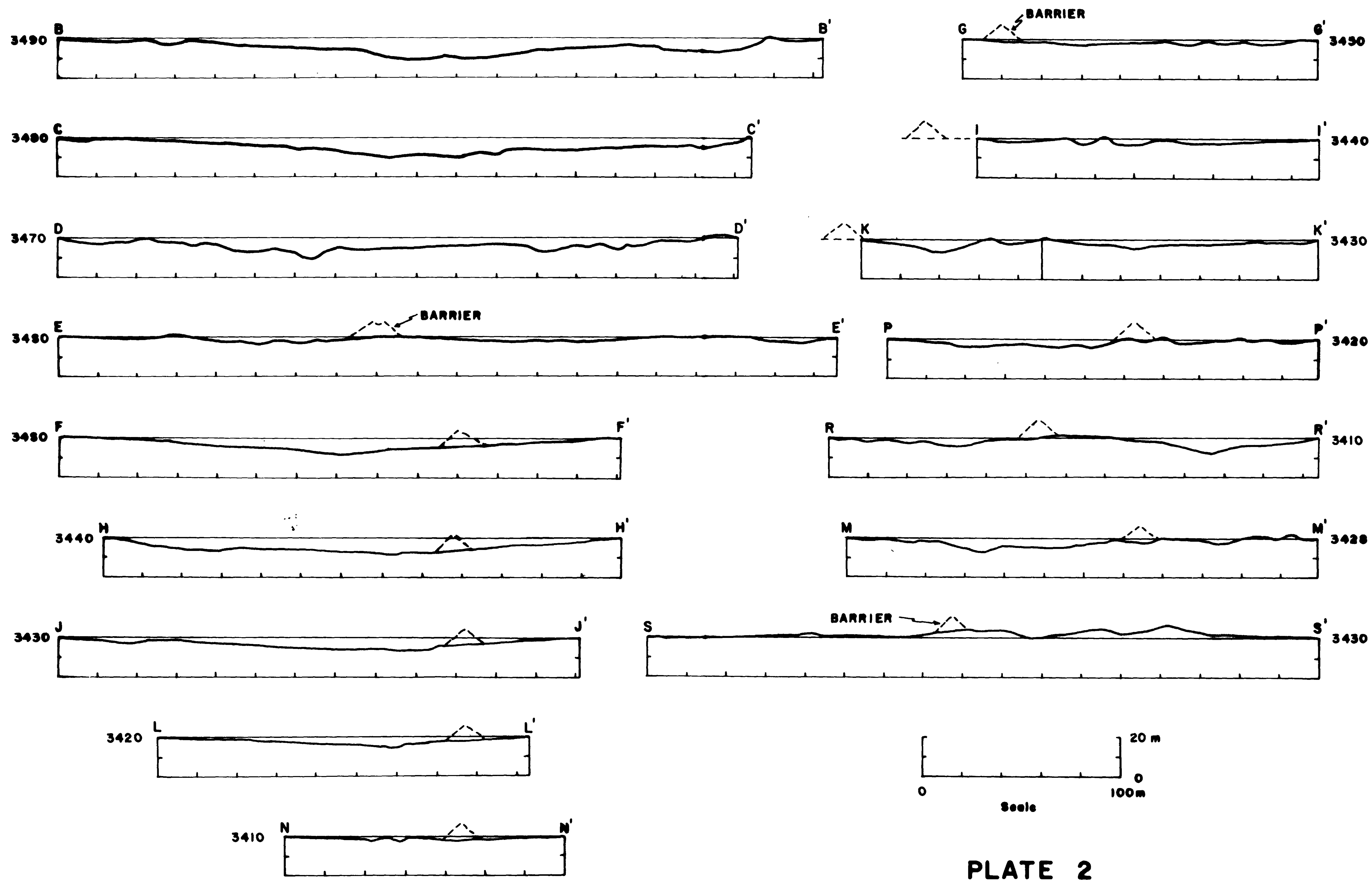

PLATE 2

TOPOGRAPHIC PROFILES

LOCATIONS OF PROFILES SHOWN ON PLATE I

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