COOPERATOR REPORT TO: HAWAI`I VOLCANOES NATIONAL PARK

Preliminary Analysis of Current Explosion Hazards at the Summit of Kīlauea Volcano

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May 8, 2018

Introduction

We examine here the possibility and potential impacts of future explosive events from within Halema`uma`u. In particular, the potential for the summit lava lake surface to drop to or below the elevation of the groundwater table, estimated to be 460 m (1500 ft) below the caldera floor, raises the strong possibility of explosions caused by interactions of groundwater and hot rock which would impact the summit area. This document reviews current activity, describes a credible set of circumstances that could produce such explosions, examines hazards and their extent, and discusses uncertainties. It is meant as a guide for managing risk in the Kīlauea summit region.

Background

Kīlauea Volcano's summit lava lake is directly connected to its summit magma reservoir. As pressure in the reservoir decreases, the surface height of the lava lake also decreases, and vice versa. The elevation of the lava lake surface is measured by laser rangefinder, thermal camera, and other methods.

Current Activity

After repeatedly overflowing onto the floor of Halema`uma`u in late April, the surface of Kīlauea's lava lake began to drop on May 2, 2018. Around the same time, deflation of Kīlauea's magma reservoir was detected by the summit tiltmeter network. The rate of lava lake subsidence increased slowly but over the last three days of available data has remained relatively constant at roughly 2 meters (6½ ft) per hour. From its height at 1,025 m above sea level on May 2 to the most recent estimate at 9:00 pm on May 6, the lava lake surface dropped a total of more than 200 m (660 ft). Measurements have become more difficult to make as the surface has dropped farther from monitoring instruments, but thermal camera imagery indicates continued lowering of the lake surface since that time, and tiltmeters at Kīlauea's summit also indicate a steady depressurization of the summit magma reservoir.

Outcome of Concern

Assuming the lake surface continues to drop at its current rate, we can extrapolate forward in time. Such an extrapolation is associated with very large uncertainty, as the system may change in unexpected ways. But it guides our thinking about potential outcomes. **At the current rate of decline, the lava lake may drop below the water table near the end of this week (Figure 1)**.

Such a condition was associated with explosive activity at the summit of Kīlauea Volcano in the past. In February 1924, for example, lava drained from Halema`uma`u Crater and by early May 1924 had dropped below the water table. Collapse of the crater walls, and influx of groundwater into the conduit to Halema`uma`u, caused repeated explosions between May 11 and 27, 1924. These explosions threw rocks more than 25 cm (10 inches) in diameter (maximum size about 2 m [6½ ft]) for more than 1 km (0.6 miles) from the vent. Ash from the explosions fell from North Hilo to beyond Pāhala, pea-size rocks were reported to have fallen at the Volcano House, and gravel-size rocks were deposited 3 kilometers (2 miles) southwest of Halema`uma`u.

Potential hazards

For management purposes we can define two types of hazard zone for future Halemaʻumaʻu explosions:

A. *Ballistic Projectile Zone*. A zone of extreme risk, in which large projectile-like rocks travel on cannonball-like paths outwards from the vent in all directions. The chance of fatalities and severe injury within this zone is high. For practical purposes a projectile size limit of 10 cm (4 inches) can be taken as the outer edge of this zone.
B. *Ashfall Zone.* This zone is located primarily downwind from the vent where smaller particles (ash to centimeter-size) fall. Debris falling in this region is unlikely to threaten human life, but it can heavily impact transportation, infrastructure and utilities. Visibility can be low, cars can lose traction on roadways, water supplies can be contaminated, machinery can be damaged by abrasion and corrosion, power transformers can short out, and prolonged exposure can result in respiratory problems. Some of these problems

can persist for days or longer after an eruption stops, as wind resuspends ash. A more complete discussion of ash impacts can be found here: https://volcanoes.usgs.gov/volcanic_ash/

In the Projectile Zone, risk depends on the size of the projectiles, so we typically plot contours of rock size to make hazard projections (Figure 2). In the Ashfall Zone the risk increases with ash thickness and with meteorologic conditions (wind affects visibility and ash infiltration into mechanical and electronic components, and wetness affects road traction and weight of ash fall on structures) so we typically plot ash thickness for scenarios or past events on a map (Figure 3).

Two eruptions, the 19 March 2008 and the 1924 explosions, provide information about the scale of hazards for (1) small and (2) moderate Halemaʻumaʻu explosions.

1. SMALL EVENT: 19 March 2008. This small event began the current 2008–2018 summit eruption. The Projectile Zone extended radially outwards for a distance of 300 m (1000 feet). The Ashfall Zone extended at least 1.5 km (1 mile) downwind (to the southwest).

2. MODERATE EVENT: 1924. The Projectile Zone extended 1 km (0.6 miles) to the north and south of the Halemaʻumaʻu Crater rim, less to the east and west. The Ashfall Zone extended at least 30 km (20 miles) from Halema'uma'u, in a variable pattern indicating complex winds over an extended period of time. Dispersal toward the southwest would be expected during normal trade winds, but winds can vary with daily meteorology. The U.S. Geological Survey is running twice-daily simulations of ashfall dispersal under current conditions for hazard planning (Figure 4).[1]

Less likely but more hazardous scenarios do exist. If the pressure in Kīlauea's shallow magma reservoir greatly decreases, it is possible that the ground surface in a broader area above the reservoir would begin to collapse along faults into the evacuated space. This process is distinct from the reduction in lava lake surface height described above, and will require a greater degree of depressurization. This scenario does not seem likely at the present. In 1924, the ground above the reservoir subsided several meters without inducing a collapse—far more subsidence than has been recorded during the current activity. Larger eruptions are also known to have occurred in the late 18th century. **However, there is no evidence at present that would suggest an eruption as large as those in the late-18th century is likely in the short term.**

[1] https://vsc-ash.wr.usgs.gov/ashgui/#/publicresults/MNL-1025775/DEP

Uncertainties

Many aspects of this analysis have a high degree of uncertainty. In particular,

1. *Time when the lava column reaches the water table*. The current rate of lava subsidence (~2 m/hr) is derived from only five days of observations. We do not fully understand why the magma reservoir is steadily draining, or how long it will continue to drain. The subsidence rate will likely change in coming days, but when, how much, and whether the rate will increase or decrease are all unknown. The rate may or may not be directly impacted by changes in the ongoing lower East Rift Zone eruption. The depth of the water table is also known only from observations in a research well located 1.5 km (0.9 mile) south of the lava lake. Details of the water table in the immediate vicinity of the lava lake are not well known.

2. *How long until water begins to interact with hot rock.* As rock around the conduit cools, water will migrate towards the conduit; the duration of this process is not known.

3. *Whether or not conditions will produce explosions*. Explosions are believed to require pressurization as water is heated to steam by magma. Crater walls may collapse and block the conduit, causing pressurization of steam. Alternatively, rapid mixing could produce steam and increase pressure even when confinement is poor. These processes are not well understood globally, and the timing of their occurrence (if they do occur) may be impossible to predict.

4. *How large the explosions will be.* Above we have outlined the two most credible scales for future explosions, that is, small and moderate events.

5. *How long such explosions can continue.* Individual explosions may last minutes to tens of minutes. Episodes of historical explosive activity have lasted days (in 2008) to weeks (in 1924). Repeated episodes have persisted for longer only when the caldera floor was below the water table.

Conclusions

Interaction of magma, hot rock, and groundwater as the Halema`uma`u lava lake recedes deeper into the volcano is likely and has the potential to produce sudden and largely unpredictable explosions. Individual explosions may be brief (minutes) but may occur in sequences or clusters lasting weeks or longer. This process could begin as early as mid-May 2018 and may result in intermittently hazardous conditions in and around the summit of Kilauea Volcano.

The onset of such activity will likely be abrupt and follow quickly after some triggering event; for example, collapse and blockage of the deepening crater. It is not certain that the Hawaiian Volcano Observatory will receive signals in monitoring data (earthquakes, tremor) that suggest the onset of this activity. Once the lava level reaches the groundwater elevation, the onset of continuous ashy plumes or a sequence of violent steam-driven blasts may be the first sign that activity of concern has commenced.

Figures

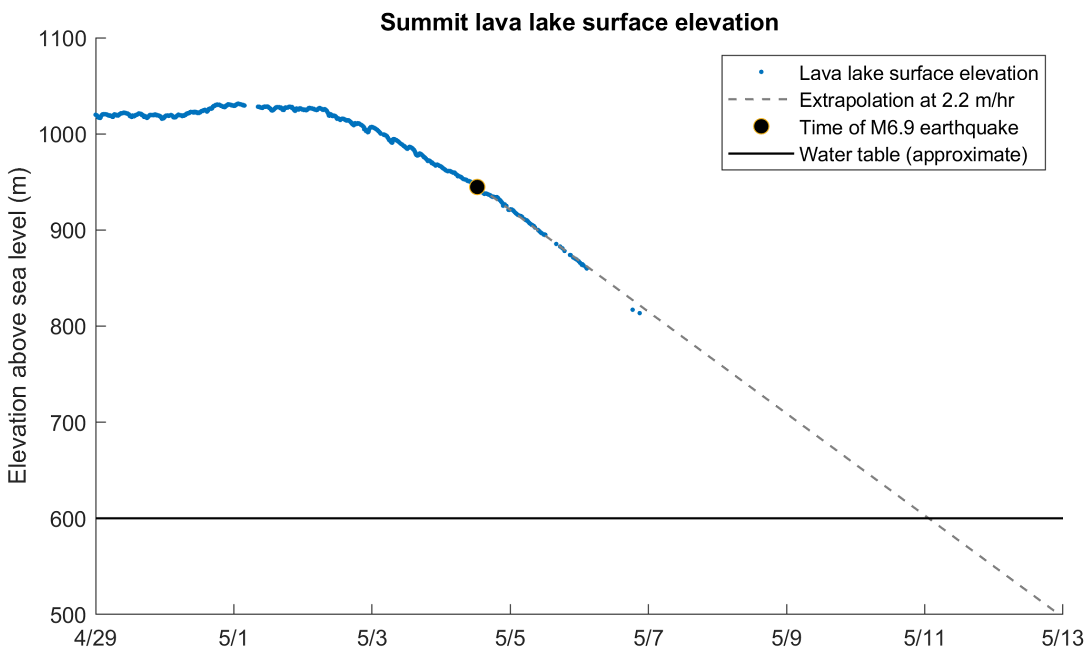

Figure 1: Elevation of Kīlauea's lava lake surface as a function of time, with extrapolation into the future at a rate of subsidence of 2.2 meters per hour (approximately its rate from the time following the M6.9 earthquake to the present). The water table at roughly 600 meters a.s.l. is indicated by the black horizontal line. At 2.2 meters per hour, the lava lake surface could reach the water table within the next several days, although such an outcome is far from certain. The water table around the lava lake is also likely complex, and its elevation there is only approximately known.

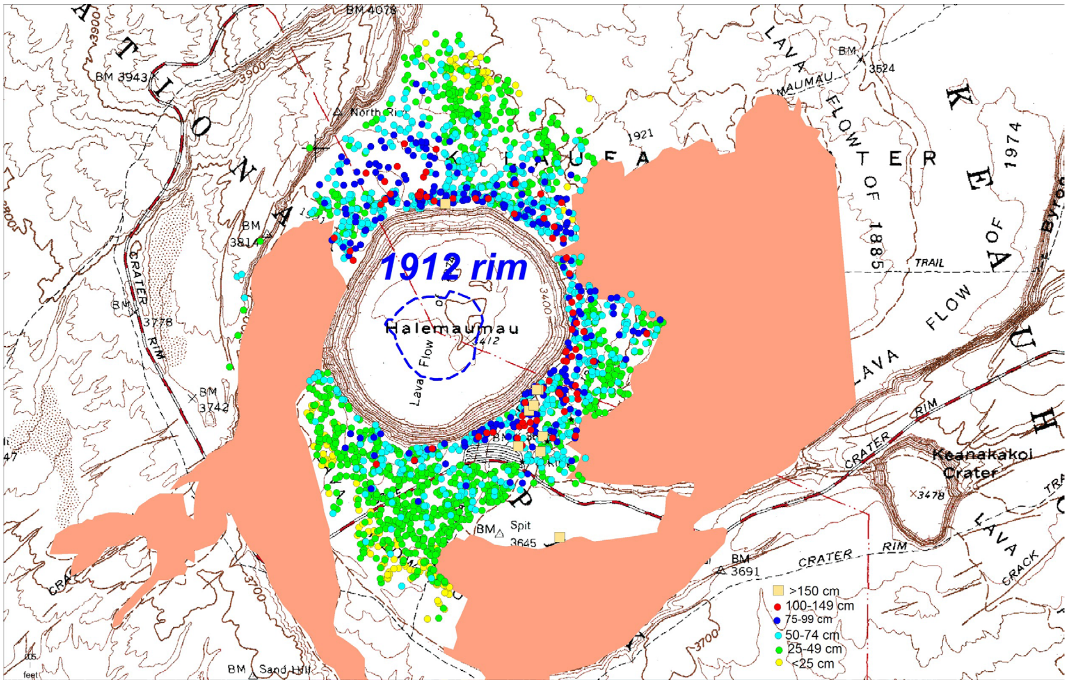

Figure 2: Projectile Zone for the 1924 eruption at Kilauea. Dots are individual projectiles between <25 and >150 cm in diameter Collectively, they define a hazard zone of extreme risk with a radius of approximately 1 km (0.6 miles). Orange color indicates post-1924 lava flows, which bury any earlier ballistic rocks. Ballistic rocks fell in the white area just southeast of the crater but cannot be distinguished today from older rocks owing to human activity after 1924.

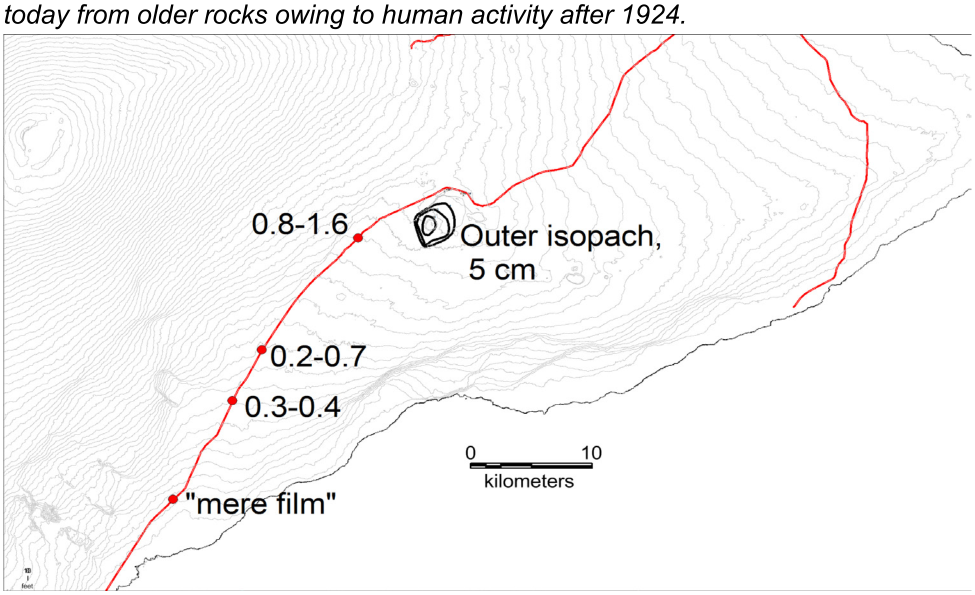

Figure 3: Ashfall Zone for 1924. The red line encloses the large and complex region of ashfall. Numbers are thicknesses measured by Thomas Jaggar soon after the 1924 eruption. Units are centimeters. We know that in fact the Ashfall Zone was much larger than indicated here as reports indicate that ash was dispersed northward, as far as North Hilo. An isopach is a line of equal ash thickness.

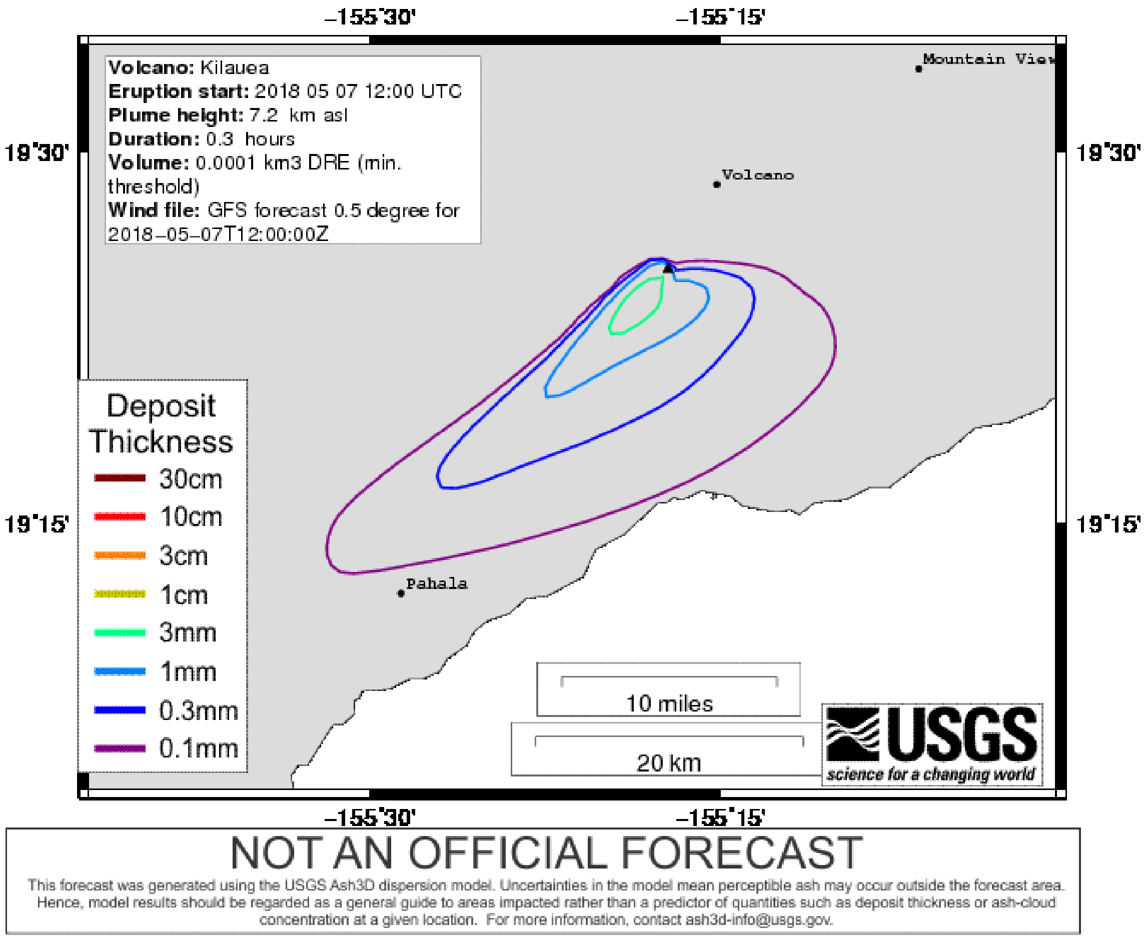

Figure 4: Model output showing possible extent and thickness for a plausible explosive event from the Kilauea summit should phreatic explosions commence. Contours show expected deposit thickness under wind conditions of May 7, 2018 (1200 UTC). The assumed plume height, duration, and erupted volume used in the simulation are listed in the legend. In this case the maximum thickness is predicted to be less than 1 cm (<0.5 inch) at a distance of less than 5 km (3 miles) from the vent.