



# Frequently Asked Questions about Deformation at Kīlauea Summit

USGS–Hawaiian Volcano Observatory  
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At present, the summit of Kīlauea Volcano is undergoing dramatic changes. The caldera floor is subsiding. The rim and walls of Halema'uma'u are slumping inward. Nearby residents feel moderate-sized earthquakes, and see small ash plumes rise from the crater. The responses to these Frequently Asked Questions address the reasons behind the current activity at Kīlauea Volcano's summit and what might happen over the next several months.

## Why is the crater subsiding?

As we have observed from 1983 to present, magma from the mantle rises beneath Kīlauea's summit, passes through the summit magma storage system, and exits towards the East Rift Zone (ERZ). Like a balloon slowly losing air, deflation of the magma reservoir is occurring because magma is departing the summit more rapidly than it is being supplied. These images show the subsidence of the caldera floor and inward slumping of the rim and wall rock at Halema'uma'u on May 19, June 13 and June 28, 2018.



May 19, 2018



June 13, 2018



June 28, 2018

### **When did the subsidence begin?**

Deflation of Kīlauea's shallow summit magma reservoir began in early May. Deflation was triggered by the intrusion of magma into Kīlauea's lower East Rift Zone. Conditions may have also changed in the rift itself, which have enabled increased rates of magma storage (for instance due to rift opening associated with the M6.9 earthquake).

## Will magma fully drain from the shallow reservoir?

Models suggest that the shallow magma reservoir is about 0.2 to 0.7 cubic miles (1-3 cubic km) in size. If the volume lost is approximately 300 million cubic meters, then about 30% of the shallow summit reservoir may have drained into the East Rift Zone at this time. It is also possible that magma could be pulled from other storage areas in the summit.

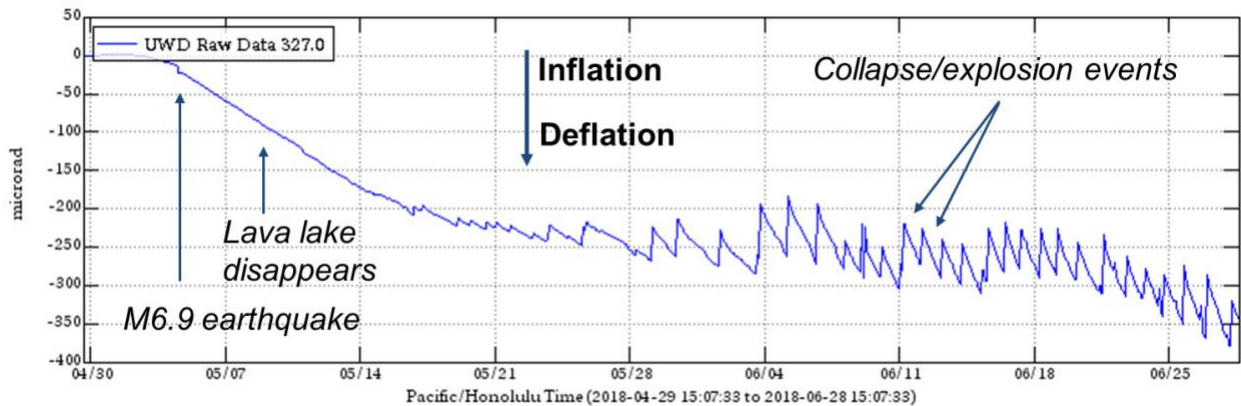
## How much does the crater subside?

Reservoir deflation caused the floor of the caldera to subside at a rate of 2-3 inches per day near the Overlook vent within Halema'uma'u.

## Can you track the changes?

Yes. This graph shows the changes recorded at a GPS monitoring station at the summit (UWD) between April 30, 2018 and June 28, 2018. On April 30, the floor of the Pu'u 'Ō'ō crater collapsed, as subsurface pressure forced open a pathway for magma to travel from Pu'u 'Ō'ō into the lower East Rift Zone. On May 1, deflation began at the summit and on May 2, the lava lake began to drop, disappearing from sight, on May 10, more than 320 m (1,000 ft.) below its high point in late April.

The sawtooth pattern that begins May 16 and becomes more pronounced after May 28, are separate collapse/explosion events. After each event, there is a short period of time when the crater inflates slightly (the blue line goes up), but the overall trend is for continued deflation (the blue line goes down).



## What is the crater size now, compared to what it was before April 30, 2018?

Since May 16, 2018, the depth of the crater has more than tripled and the diameter has more than doubled. The dramatic changes are visible in this aerial photo of Halema'uma'u taken on June 18, 2018.



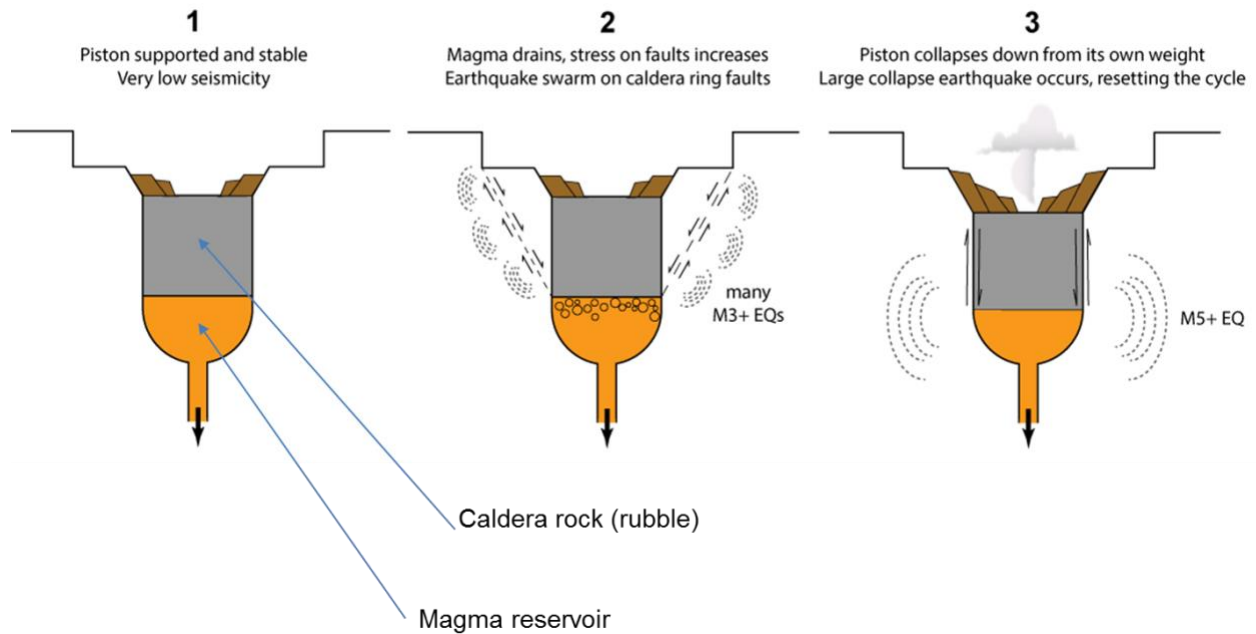
Aerial photo of Halema'uma'u June 18, 2018

### What are the collapse events?

The mechanism producing the collapse events is not well understood. We infer that withdrawal of magma towards the ERZ continually works to reduce pressure in the shallow reservoir. When the reduction in pressure becomes too great, the rock that forms the floor of Halema'uma'u and parts of surrounding Kīlauea Caldera slump down into the shallow magma reservoir in a collapse event. The rock which slumps down into the reservoir replaces pressurized gas and magma that has migrated into the ERZ. After slumping, reservoir pressure abruptly increases (as measured by ground deformation instruments). Similar processes have been observed during caldera formation at other volcanoes. In this way, magma evacuation is accompanied by relatively non-hazardous slumping and enlargement of Halema'uma'u, rather than sudden large-scale collapses and more powerful explosions.

The graphic below is a generalized cross-section of what the crater and shallow magma reservoir might look like. The rock of the crater floor is represented as a piston, supported by the magma reservoir beneath it. Initially, it is stable and there is very low seismicity. But as magma drains, stress on the faults increases and the number of earthquakes increases. The piston collapses downward from its own weight. A large collapse earthquake occurs and a plume can result.

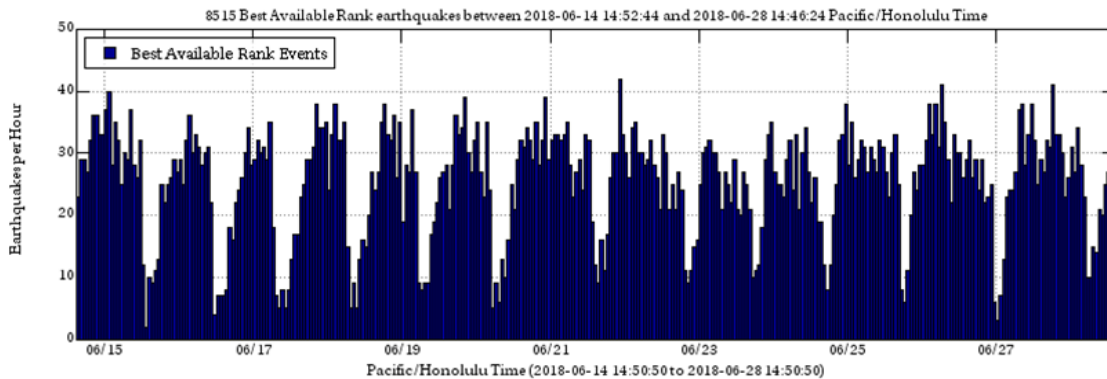




### Is there a pattern to the collapse/explosion events?

The exact location and timing of earthquakes and collapse/explosions cannot be predicted. But, if recent patterns continue, earthquake activity increases gradually over the course of an individual swarm, culminating in a collapse/explosion event semi-regularly with repose periods (time between events) of roughly 1 to 2 days. After the event, earthquake activity drops rapidly before gradually increasing again.

This graph is the number of earthquakes per hour, from June 15 to June 28, 2018. Whenever one of these events happens, the earthquake activity drops dramatically (represented by a lower bar on the graph), then earthquake activity picks up gradually as rock material slumps inward and downward toward the magma reservoir. Stress builds until there is a large collapse/explosion seismic event and the cycle repeats.



## **How strong are the earthquakes?**

As many as 40 earthquakes per hour have been recorded during earthquake swarms preceding collapse/explosion events. Most of these are small and cannot be felt by people, but magnitude 3 and larger earthquakes do occur at increasing rates through the course of individual swarms. Overall, more than 500 earthquakes per day have been recorded in the Kīlauea summit region during recent weeks. Felt event rates have exceeded 30 earthquakes per day at and around the summit.

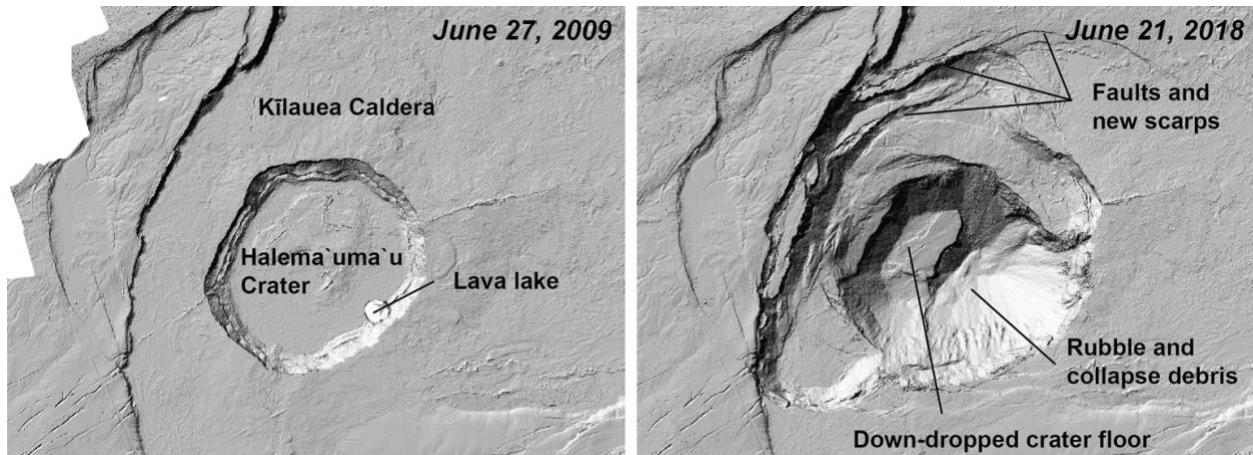
The energy release during collapse/explosion events is equivalent to earthquake magnitudes of low- to mid-magnitude-5. These types of events emit most of their energy at low frequencies and so are not felt as strongly as typical non-volcanic M5 earthquakes. Regardless, shaking can be strong and possibly damaging near the summit.

Strong earthquakes can occur at any time, and the risk of these events is larger now due to ongoing stress changes in and around the caldera. These earthquakes will not necessarily occur during swarm seismicity or in association with CE events, may be large, and may happen outside of the caldera.

## **How have the collapse/explosion events changed with time?**

Early collapse/explosion events (before late May) ejected ash and gas to heights above 25,000 feet and large rock fragments several inches in size to the area immediately surrounding the vent. Observations and preliminary models suggest that these explosions may have been caused not by interaction of magma with groundwater, as previously believed to have occurred at Kīlauea in 1924, but rather by exsolution, expansion, and explosive release of gases which were dissolved in the magma.

At the end of May, collapse of rock from surrounding crater walls blocked the Overlook vent (which formerly contained the lava lake) and changed the character of summit activity. Since then, background gas emissions at the summit have greatly decreased, collapse/explosion events generally have produced only weak ash plumes that do not rise higher than 6000 feet above the crater rim, and no ballistic fragments are known to have been ejected. Although the plumes have become less vigorous, these more recent events have been preceded and accompanied by larger amounts of seismic shaking, and reservoir pressurization (as measured by ground deformation instruments) during the events has increased. The character of subsidence at the summit has also changed, with deformation becoming more localized around Halema'uma'u crater but occurring at a higher rate. At the current time, subsidence of the caldera continues at a high rate due to magma withdrawal from the Halema'uma'u magma reservoir.



Comparison of the topography of Halema'uma'u Crater in 2009 (left) and on June 21, 2018 (right). The 2018 data, from a photogrammetric survey of Kīlauea's summit by the U.S. Department of Interior (DOI) Unmanned Aircraft Systems' (UAS) Kīlauea response team, show the topography of Halema'uma'u as of June 21. Extensive cracking and faulting has occurred around the crater, and the crater has enlarged through collapses of wall rock. The depth of the crater floor has increased by more than 350 meters (1100 feet) since early May. Limited UAS flights into the summit occur with permission and in coordination with Hawai'i Volcanoes National Park to collect data needed to updated hazard assessments, all of which are shared with emergency managers. Image courtesy of U.S. Geological Survey and Office of Aviation Services, DOI, with support from HVO and Hawai'i Volcanoes National Park.

### Could groundwater cause an explosive eruption?

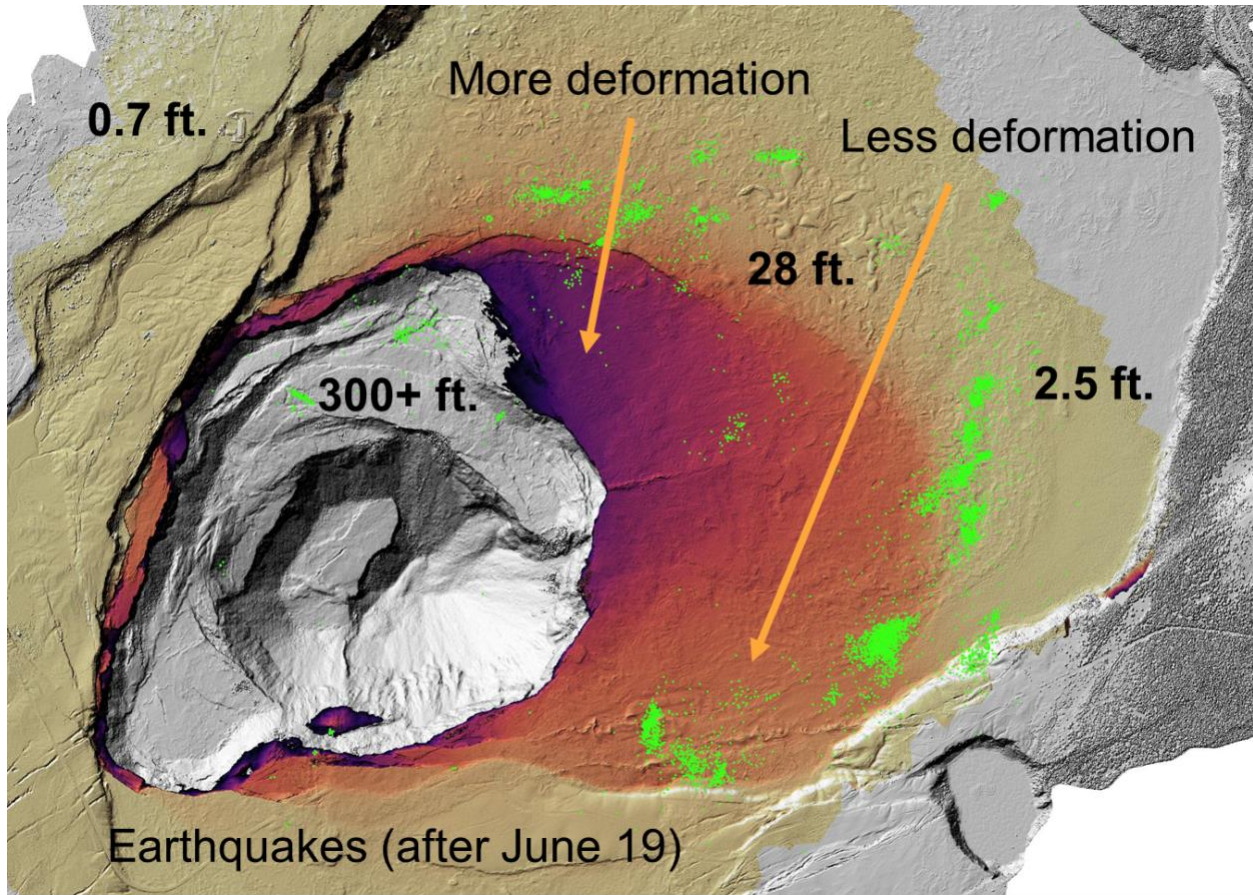
After the lava lake drained, there was concern that the groundwater could enter the emptying conduit to produce an explosive eruption. But the explosions that occurred in May were likely triggered by gases coming off the magma and not the interaction of groundwater with hot rock. Some theoretical hydrologic models suggest it might take two months for groundwater to enter an empty conduit, because of the residual heat in the area. While it is still possible groundwater may trigger an explosion eruption, there are no indications at this time that this will occur.

### How wide is the area that “feels” subsidence?

The subsidence is occurring within the Kīlauea Caldera, with the most dramatic changes at Halema'uma'u and, to a lesser extent, the caldera floor to the northeast. As the reservoir deflates, cracking and slumping is gradually engulfing a broader extent of Kīlauea Caldera (as observed in high rates of ground deformation and propagating cracks around Halema'uma'u); this process will likely continue to enlarge Halema'uma'u and may involve larger slump blocks..

As shown in this Digital Elevation Model of the caldera, the area of subsidence is enlarging toward the northeast, broadening Halema'uma'u, but deformation is still located within the confines of the Kīlauea Caldera. The colors are the elevation changes from 2009, as compared to June 28, 2018. The purple area shows more deformation and the lighter colors indicate less deformation. The small clusters of dots are the earthquakes, which are occurring toward the east where stress is concentrated.





### Could part of the caldera floor collapse?

It is possible that a large section of the Halema'uma'u wall could abruptly collapse into the crater. Because a broad region east and northeast of Halema'uma'u is currently subsiding, it is difficult to predict how large such a collapse might be or its impact on the explosion hazard. Most likely, such an event would generate only strong seismic shaking and a robust ash plume.

### How long will the subsidence and collapse/explosion events continue?

The most likely activity for the immediate future (over the next two months) is continued subsidence of Kīlauea Caldera, episodic slumping into a widening Halema'uma'u crater, felt earthquakes (some large enough to be damaging), and small to intermediate ash plumes that remain below 10,000 feet above sea level.

Deflation of Kīlauea's summit storage system is occurring in response to the removal of magma at a higher rate than the reservoir is being resupplied from its deep mantle source. If summit magma is predominantly feeding eruptive activity in the LERZ rather than filling storage space (independently of the LERZ eruption), then summit activity should cease soon after the LERZ eruption ends. The duration of the ongoing LERZ eruption cannot be predicted, and at this time output appears steady.



Historical eruptions in Kīlauea’s LERZ in 1955 and 1960 lasted 88 and 38 days, respectively. It is also possible that magma will continue to fill storage space in the rift zone, so that summit subsidence will continue even after the LERZ eruption ends. Alternatively, summit subsidence may greatly slow or even stop if the LERZ eruption decreases in vigor, or a new pressure equilibrium is obtained between the summit and LERZ. For these reasons it is not possible to forecast the duration of summit subsidence. It is most likely that it will continue for weeks to months, and it is possible, although less likely, that it will continue longer.

## **What are the primary hazards from the current activity at Kīlauea’s summit?**

Should activity continue as described, primary hazards of concern are:

- (1) Damaging earthquakes (potentially exceeding equivalent M5);
- (2) Ash plumes, ashfall (associated with collapse/explosion events and large rockfalls);
- (3) Large and sudden collapses into the expanding Halema`uma`u crater;
- (4) Ground cracking and continued rockfall activity along steep caldera walls; and
- (5) Vog (although sulfur dioxide output is approaching low pre-2008 levels).

Residents should continue to be prepared for strong seismic shaking in the vicinity of the caldera (see <https://www.shakeout.org/hawaii/>). During earthquakes drop, cover, and hold on.

With over six weeks of heightened seismic activity, structures are in some cases already weakened from strong earthquakes. Ongoing earthquake activity can damage these further, especially close to the summit in the National Park and Volcano Golf Course areas. Ground cracks, rockfalls, and damage to roads, trails, rock walls, buildings, utilities, and water pipes may also occur.

## **How is information shared with the public and other officials?**

The USGS–Hawaiian Volcano Observatory (HVO) is the lead scientific agency in this disaster and provides the bulk of information used to identify hazards. The HVO is monitoring the situation 24 hours a day and maintains constant contact with the Hawaii County Civil Defense Agency to provide timely accurate information for your safety. HVO also coordinates monitoring efforts with Hawaii Volcanoes National Park.

## **How will we know when the hazard has passed?**

Hazards may remain present at the summit for months or longer even after subsidence and related strong seismicity stops. Earthquakes will likely occur at elevated but decaying rates, ground cracks may worsen, and rockfalls continue. Also, based on historical patterns, the summit will eventually re-inflate; this process will be associated with its own set of hazards, not specifically addressed here.

## **Will magma return to Halema‘uma‘u?**

Most definitely yes, although it may take years for lava to reach the surface at the summit after activity stops in the lower East Rift zone.