Effusive and explosive cycles at Kilauea: what do they mean?

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About 17%—250 km² (95 mi²)—of Kīlauea's subaerial surface has been covered by lava flows since 1800.
Locations of $^{14}C$ dates for lava flows
Calibrated $^{14}$C ages, lava flows

- Probably 3-4 flows
- Probably 1-2 flows
- One flow for ca. 60 yr

Year (BCE negative)

- Wolfe & Morris (1996); Clague et al. (1999); D.R. Sherrod (unpub.)
- Fiske et al. (2009; unpublished)
Uwēkahuna, incl. Kulanaokuaiki Tephra

Stratigraphically older than ash

Keanakākoʻi Tephra

Stratigraphically younger than ash

Many observed lava flows
Uwēkahuna, incl. Kulanaokuaiki Tephra

Stratigraphically older than ash

Stratigraphically younger than ash

Edifice-building lava flows dominant 40% of past 2500 y
Episodic explosive activity dominant 60% of past 2500 y
Edifice-building lava flows dominant 50% of past 1400 y
Episodic explosive activity dominant 50% of past 1400 y
Deep caldera

- Most Kīlauea explosive eruptions are phreatomagmatic or phreatic and are thought to be generated at or below the water table.
  - Water table today is ca. 615 m below caldera rim.
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- This implies the existence of a deep caldera during the long periods of tephra production
  - Possibly repeated small collapses, but the caldera seldom if ever filled, according to the $^{14}$C ages
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  - Water table today is ca. 615 m below caldera rim
- This implies the existence of a deep caldera during the long periods of tephra production
  - Possibly repeated small collapses, but the caldera never filled, according to the $^{14}$C ages
- Magma supply rate to the surface was much smaller than today's rate of ca. 0.11 km$^3$/yr
  - Otherwise, caldera would have filled in several decades
Approximate magma supply rate to ground surface:
- 200 BCE-1000 CE, $2.5 \times 10^{-4}$ km$^3$/yr
- 1000-1500 CE, $2.2 \times 10^{-2}$ km$^3$/yr
- 1500-1800 CE, $5 \times 10^{-4}$ km$^3$/yr
- 1800-2012 CE, $2.6 \times 10^{-2}$ km$^3$/yr
Implications of low surface magma supply with deep caldera

- Not obvious why there should be a relation between deep caldera and low surface magma supply if caldera formed by relatively shallow draining of reservoir (eruption, east-rift intrusion)
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Where, then, does the magma go?
Implications of low surface magma supply with deep caldera (cont.)

- One alternative: “bottom-up” cause of caldera collapse
- A leak in the deeper part of the conduit, or severely decreased magma supply, might cause the shallow reservoir system to empty downward, like pulling the plug in the bathtub
  - If these conditions persisted for centuries, an explosive cycle could result
- Downward emptying relates low or zero magma supply rate to caldera formation and is consistent with observations
Implications of low surface magma supply with deep caldera (cont.)

- Rather than the conduit draining down to the mantle beneath the crust, magma could be redirected onto the seafloor or as intrusions into the deep volcano or the oceanic crust.
- This would allow the plume magma supply itself to remain about the same, even though only a little lava erupts onto the island surface.
Destruction of magma reservoir

- Magma withdrawal may collapse much of the shallow reservoir, whether a network of dikes and sills or a single chamber
- It may take centuries to rebuild the shallow reservoir and initiate an effusive cycle
  - This rebuilding could have been aided by thick tephra deposits in the bottom of the caldera—material easily removed by thermal or physical erosion, or stoping, to create cavities
  - The Keanakākoʻi Tephra, for example, is >11 m thick on south rim of caldera. It could be several times thicker in center of caldera
Quarrying preferentially in tephra forms cavities in which magma resides, moves, fractionates, etc.

Schematic cross section of caldera during dominantly explosive period

Magma conduit, perhaps partly a stack of filled cavities developed in previous tephra deposits
Before reestablishment of the reservoir, relatively unusual melt compositions may appear as tephra during explosive eruptions.
**MgO-rich, and fractionated, vitric ash**

- Primitive magma may erupt before reservoir is fully reestablished
  - Vitric ash with nearly 13% MgO in Kulanaokuaiki (Tim Rose) and ≥11% in Keanakāko‘i (Ado Mucek)
  - Such high MgO glass is otherwise very rare at Kīlauea’s summit and may appear either when the summit reservoir is bypassed (Kīlauea Iki) or absent

- Magma bodies isolated from throughput may fractionate and eventually erupt liquids rich in incompatible elements
  - TiO$_2$ >3% and K$_2$O >0.7% in Kulanaokuaiki
  - TiO$_2$ up to 4.7% and K$_2$O to 0.9% in Keanakāko‘i
Microbeam vitric ash analyses by Tim Rose
Plots modified from Adonara Mucek, senior thesis, University of Hawai‘i, 2012

Microbeam glass analyses by Ado Mucek and Mike Garcia
Hazard implications

- Once Kilauea enters a major period of episodic explosive activity, we can expect several centuries of behavior very different from that of today.
- The summit region, including adjacent communities, would be subject repeatedly to explosive activity, including tephra falls and pyroclastic density currents (PDCs).
- The recurrence interval of such periods cannot be reliably estimated.
Possible areas of fatalities

Possible locations of three groups that likely suffered several hundred fatalities in November 1790, caused by a pyroclastic density current.
A PDC can go in any direction from its vent. Circle shows maximum length of future surge like one of those in 1790, depending on eruption direction. GC, Golf Course subdivision, VV, Volcano Village; ML, Mauna Loa Estates.
Holcomb cycle

- Robin Holcomb first proposed cyclic activity of Kīlauea in 1987
  - The proposal was ahead of its time and fell on deaf ears
- The cycles we identified benefit from far more $^{14}C$ ages, the ability to calibrate them to calendar dates, and a better geologic map than Robin had
- To honor his foresight, we propose the name Holcomb cycle for the repeated eruptive behavior at Kīlauea
 Might other hotspot basaltic volcanoes have cycles of effusive and explosive behavior?

- Each shield has to be studied in its own right
- A large number of $^{14}C$ ages for lava flows is probably necessary to discover any cyclic effusive activity
- Explosive deposits are comparatively small and poorly preserved at Kīlauea, easily removed outside the caldera by wind and water
  - If other volcanoes have small explosions and similar environmental problems, recognizing cyclic explosive activity can be a big challenge
- I doubt that Kīlauea is unique, but it may be hard to show that it isn’t
Summary

- For 60% of the past 2500 y (50% of past 1400 y), Kīlauea has been in two long periods of episodic explosive activity when a caldera penetrated the water table
- Magma supply to Kīlauea’s surface decreased by ~2 orders of magnitude during these periods
- Caldera collapse may be a “bottom-up process,” reflecting decreased or redirected magma supply
- Relatively MgO-rich magma can erupt before a shallow reservoir is reestablished. Isolated bodies may fractionate and erupt compositions rarely seen in flows
- The cycles are probably episodic, not periodic; no single recurrence interval can be applied to the Holcomb cycle
Implications of low surface magma supply with deep caldera (cont.)

- There are many problems with emptying the supply conduit
  - Walls would collapse into empty conduit
  - How could mantle melting and magma supply from the source approach zero quickly?
- It seems more likely that melting continues and magma is diverted away from the shallow reservoir during periods of a deep caldera and explosive activity
  - In other words, the supply of magma to the surface drops but the supply coming from the melting source may remain about the same