Kīlauea Puts on a "Once-In-A-Century" Show

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Introduction

Kīlauea is the youngest of five basaltic shield volcanoes on the island of Hawai'i, is located to the east of the much larger Mauna Loa volcano, and rose above sea level about 100 ka ago (Fig. 1).

Hawai'i contains the most monitored, and arguably the best understood volcanoes on Earth. This has provided scientists with a good understanding of Kīlauea's recent eruptions in which magma rises from depth and is stored beneath Kīlauea's 4 x 3.2 km summit caldera in an underground reservoir which is connected to a fluctuating lava lake within the caldera. Some eruptions occur at the summit, but these provide only a foretaste of the main lava eruptions that occur elsewhere.

When magma drains from the summit reservoir it magma travels in underground conduits and eventually emerges on the lower flanks of the volcano at a rift zone, where it erupts through fissures. This magma is sometimes stored in other reservoirs along the way. This link between summit magma store and eruptions lower on the flanks of shield volcanoes has been repeated untold thousands of times at Hawai'i and is how such volcanic islands grow. But why is the current eruptive episode a 'once-in-a-century' show?

The current sequence of simultaneous summit and rift zone eruptions is the longest period in at least two centuries that this has been happened. It is also the first time in nearly a century that explosive eruptions have occurred at Kīlauea's summit, allowing study of these eruptions using modern methods. So for these two reasons, the current eruption of Kīlauea is a bit special.

The current Kīlauea eruption

The latest eruption began on the 3rd of May 2018 and at the time of writing (1 June) is still going strong. The summit source is the Halema'uma'u crater that resides within the larger Kīlauea summit caldera, with magma from beneath Halema'uma'u travelling in conduits to the Pu'u 'Ō'ō area (which has a cone, crater, and magma reservoir). See Fig.1. Magma then travels in underground conduits from Pu'u 'Ō'ō into the Eastern Rift Zone where fissure-fed pahoehoe and a'a lava flows and lava fountains have been erupted from at least 24 vents (Fig. 2) (Fig. 3). Lava has either destroyed or caused significant damage to houses in a subdivision called the Leilani Estates (Figs. 1 and 3) and is encroaching on a geothermal plant (Puna Geothermal Venture or PGV, Figs. 1 and 3) that provided up to 25% of the power for the island of Hawai'i. Some lava flows have travelled south from the fissures for 5km in open channels (Fig. 4) and have entered the ocean in several places (Figs. 3 and 5). The hazards associated with activity at the summit, with lava flows, and with the entry of lava into the ocean, are outlined later.

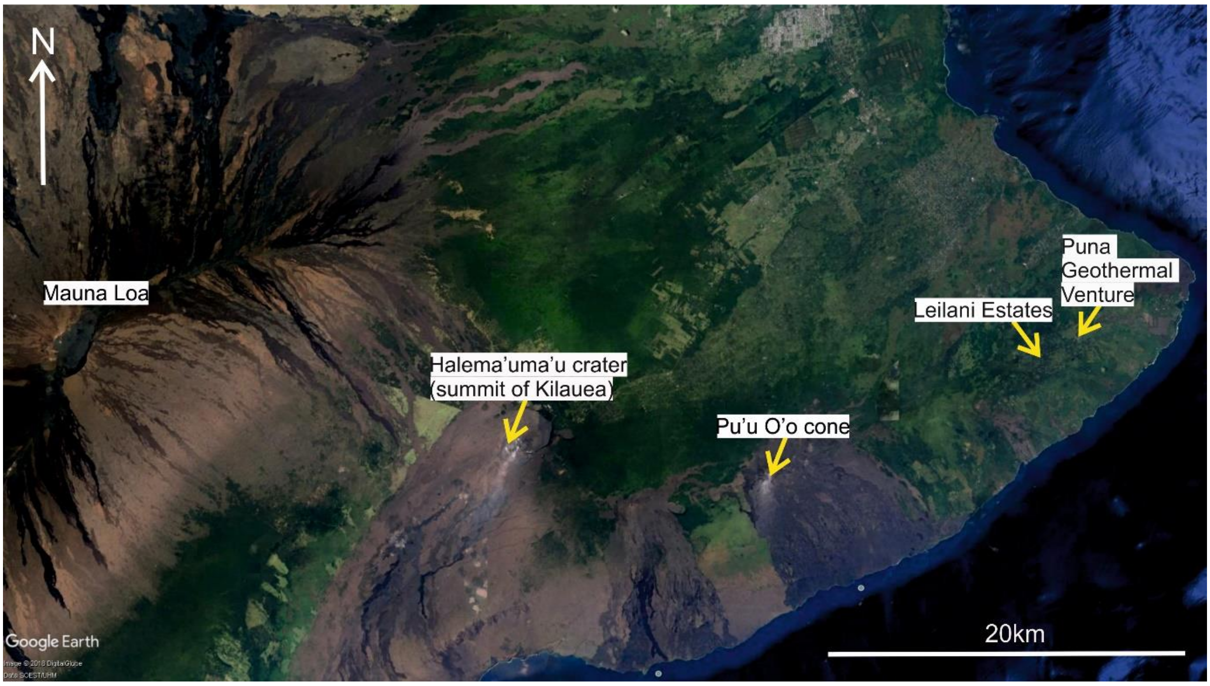

Fig.1. The East Rift Zone of Kīlauea volcano runs from the summit area (Halema'uma'u crater) to Pu'u 'Ō'ō cone to the site of current activity in the lower East Rift Zone, centred in the Leilani Estates area and have encroached on a geothermal energy plant known as the Puna Geothermal Venture (PGV) (image courtesy of Google Earth)

Fig. 2. View to the south-west along the East Rift Zone (ERZ) on May 28th 2018 with active lavas from fissures 16-18 in the foreground. The magma is supplied from reservoirs beneath the summit and the middle of the LERZ, where it travels to the eruption site. At least 24 fissure vents have been active to date (image courtesy of United States Geological Survey/Hawai'ian Volcano Observatory).

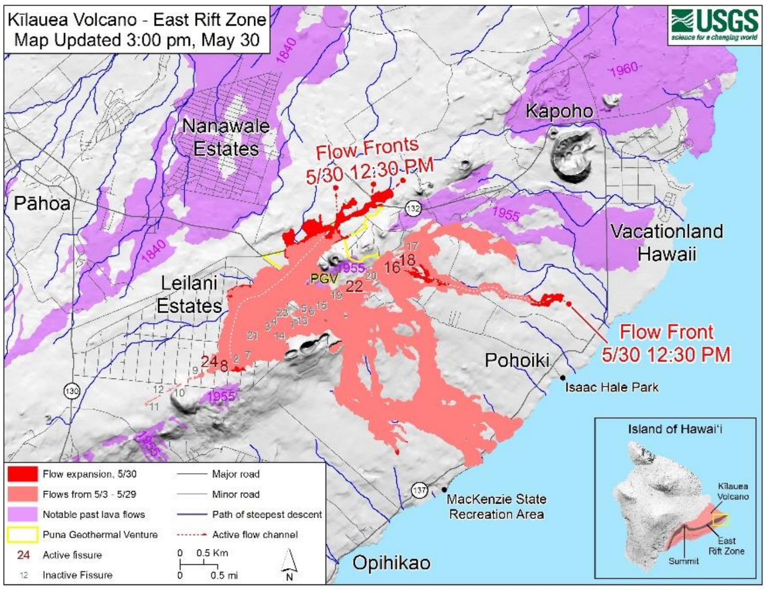

Fig. 3 Map of lava flows erupted from fissures on the Lower East Rift Zone (LERZ) of Kīlauea as of May 30th 2018. Note the geothermal plant (PGV), which is at the time of writing partly covered by lavas from fissures 7 and 8. The area of property damage in the Leilani Estates, where at least 25 homes have been destroyed to date, and the ocean entry points of lavas are also shown. The inset shows the location of Kīlauea on the south-east flank of Mauna Loa volcano, the East Rift Zone and the summit crater of Halema'u ma'u. (map courtesy of USGS/Hawai'ian Volcano Observatory)

Fig. 4. The latest eruption of Kīlauea is dominated by fissure-fed channelized lava flows up to 30m wide that typically bifurcate and anastomose down slope. Note the smoke and flames from burning vegetation and the darker areas which are the cooler margins (levees) and islands between channels.

Islands of old ground that are surrounded by lava but not covered by them are known as "kipuka" in Hawai'ian. (image courtesy of United States Geological Survey/Hawai'ian Volcano Observatory).

Fig. 5. Lava flow from fissure 22 was the first to reach the ocean in an open channel on the evening of 19th May. Ocean entry is hazardous, as it is typically accompanied by white plumes of water droplets that include hydrochloric acid droplets and small particles of glass (a dangerous phenomenon often known as LAZE) and by small phreatomagmatic explosions that can construct littoral (shoreline) cones. The coast in such areas is also very unstable and large-scale collapses of the land, which are known as bench collapses are common. Collapses occur as waves undercut the lava or as the rubble that formed when lavas enter the sea slumps into deeper water (image courtesy of United States Geological Survey/Hawai'ian Volcano Observatory)

The current Kilauea eruption is just the latest in an almost continuous series of eruptions in the East Rift Zone that began 35 years ago in January 1983 with the formation of Pu'u 'Ō'ō cone (Fig. 1). It was the overflowing of the lava lake at Halema'uma'u crater on April 24th and the collapse of the floor of Pu'u 'Ō'ō on April 30th this year that indicated magma was moving in underground conduits, leading to the fissure eruptions and lavas inundating the Leilani Estates subdivision on the 3rd May. The current eruptions are accompanied by numerous earthquakes and ground deformation (both deflation and inflation) all along the rift zone (including Pu'u 'Ō'ō) and in the Kilauea summit area, and by periodic eruptive activity at the summit. Modelling of activity during May shows that magma is draining from the summit area and from beneath the middle of the rift zone (Pu'u 'Ō'ō) eastwards along the rift, which is what would be expected given past observations etc.

Of the 24 fissures that have been active, up to ten can active on any one day, and the main focus of eruptive activity can fluctuate rapidly. Some of the fissures have generated spectacular lava fountains up to 70m high, most notably fissure 8. The situation is very dynamic, and is monitored 24 hours a day by scientists at the Hawai'ian Volcano Observatory (HVO),. Monitoring methods are diverse, and include airborne and satellite imagery, seismic monitoring, ground deformation monitoring, gas analysis (especially sulphur dioxide concentrations), and thermal analysis.

Fissure-fed lava effusions are commonplace at Kīlauea. This same area of the lower East Rift Zone was inundated with lavas in 1955 (Fig. 3), but for the first time in nearly a century, they have also been accompanied by significant explosions at the summit crater of Halema'uma'u (Fig. 6) caused by the explosive interaction of magma and water, a process called phreatomagmatism. If the explosions include only steam, and no new magma is involved, then they are called phreatic eruptions. Both occur can occur at the summit of Kīlauea, and it is these types of eruptions that make the current eruptive episode particularly special, as volcanologists have a rare opportunity to observe and better understand exactly how they happen at Kīlauea.

Fig. 6. A small phreatomagmatic explosion from the summit caldera (Halema'uma'u) of Kīlauea on May 17th 2018. Such explosions began on May 10th and occurred when lava in the open conduit at the Halema'uma'u lava lake drained below the groundwater level allowing water ingress and collapse of the surrounding walls. Violent steam explosions can eject blocks of the old wall rock but may also include significant amounts of highly fragmented glass derived from magma in the conduit. Prior to 1924 such phreatomagmatic eruptions probably occurred through an open lake of water in the crater. (image courtesy of United States Geological Survey/Hawai'ian Volcano Observatory).

As c.90% of the surface of Kīlauea is composed of basaltic lava flows erupted in the last 1100 years, this may suggest that all of its eruptions have produced lava. However, over the last 2500 years, more than half of its eruptions have in fact been explosive eruptions from the summit area, though it is important to note that the volumes of magma erupted are dwarfed by the huge volumes erupted in the rift zones. These summit eruptions are either phreatomagmatic or phreatic,. Phreatomagmatic and phreatic (i.e. steam only with no new magma) explosions at Kīlauea occur when the floor of a crater such as the present day Halema'uma'u crater, subsides below the level of an groundwater aquifer. This aquifer is about 500m below the caldera rim, and when subsidence goes below 500 m this allows ingress of water into the summit crater, which may be occupied by a lava lake. It may seem unlikely, but a water-filled crater lake can form if the subsidence is deep enough and sufficient water is available, and this occurred prior to 1924.

Powerful explosions that can eject dense blocks (from collapsed crater walls) several metres across up to 1 km away are driven by the heating and rapid flashing of the water to steam (a 1000-2000 times increase in volume). These explosions can also , produce significant volumes of volcanic glass shards produced when magma is rapidly cooled and fragmented. In some of these summit explosions, ground-hugging pyroclastic surges (dilute pyroclastic density currents) can be produced. It has been suggested that rapid injection of magma into water may be necessary to generate some of the largest phreatomagmatic explosions at Kīlauea.

The most violent explosion of this type was recorded around 1790AD when at least 80 Hawai'ians, belonging to the army of a Keōua (a rival to the King of the Hawai'ian islands, Kamehameha) lost their lives, probably due to dilute pyroclastic density currents.. The deposits from this eruption are included in a formation called the Keanakako'i Ash, which still covers much of the summit area of Kīlauea, is locally up to 10m thick, and even preserves human footprints of Keōua's army. The next significant phreatomagmatic explosion at the summit region was almost a century ago, over a period of 18 days in May 1924, which also generated dilute pyroclastic density currents (Fig. 7) and ejected blocks weighing as much as 7 tonnes a distance of 1km from the summit. A photographer was the only fatality during the 1924 eruption.

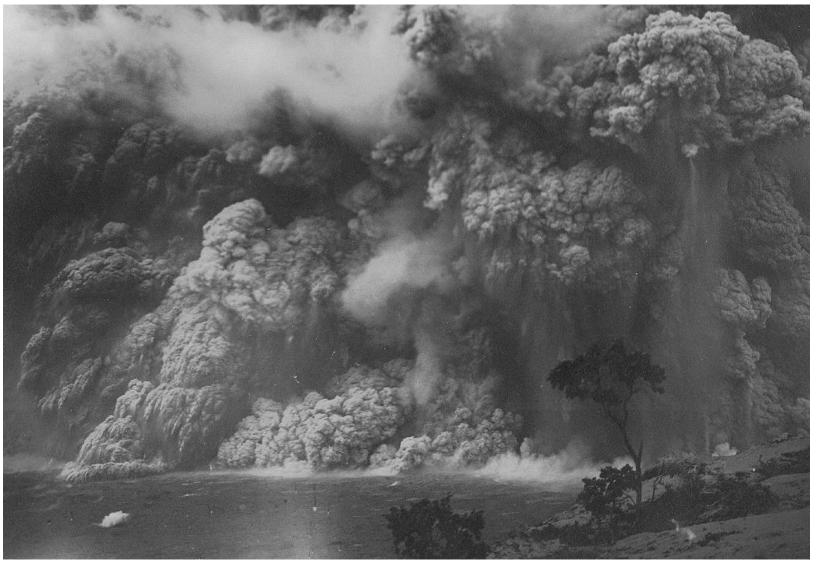

Fig. 7. Pyroclastic density currents flowing away from the base of a plume of ash during the 1924 phreatomagmatic eruptions at the summit of Kīlauea. A similar eruption but large volume eruption around 1790 killed at least 80 Hawai'ians (image courtesy of the Bishop Museum, Hawai'i)

During the current activity, phreatomagmatic eruptions began on May 10th as magma drained from the summit and the floor of Halema'uma' subsided by about 200m. To date, no pyroclastic density currents have occurred, but they remain a possibility, and importantly phreatomagmatic eruptions at Kīlauea may be hard to predict as they typically do not display significant precursor seismic activity. Plumes of ash reached as high 9km on May 17th and have been associated with large ballistic blocks in the summit region, so pyroclastic density currents have to be considered as a potential future hazard at Kīlauea.

Hazards

As the island of Hawaii is one of the most monitored and studied volcanic islands in the world, and has produced broadly similar eruptions since historical records began, the hazards from its eruptions are well known. Consequently, unless something atypical happens or people ignore warnings, Hawaii is considered a relatively 'safe' place to visit and study. The huge caveat here is that it is 'safe' only if people act responsibly, as well as acting upon advice given by relevant professionals (i.e. staff from the Hawai'ian Volcano Observatory, Hawai'ian Civil Defence and Hawai'i Volcanoes National Park).

So what hazards is Kīlauea capable of producing, what have we seen so far during this eruption, and what hazards may yet appear? These may be broken down into three broad hazard zones – the summit, the fissure vents and associated lava fields in the East Rift Zone, and points at which lava enters the ocean.

Summit

The main hazards arising from summit activity are explosive phreatomagmatic eruptions that are unpredictable in timing, power, and duration, and which can eject large blocks beyond the crater rims. . They may also be accompanied by raining down of smaller particles of hot glass (tephra) and more rarely, by pyroclastic density currents. These hazards would typically be restricted to 1km or less from the summit, but they could be more widespread. The summit area and rift zones can also generate significant amounts of VOG (volcanic fog), particularly during eruptions, which is fog mixed with volcanic gases, the most dangerous of which is sulphur dioxide gas. VOG may cause serious respiratory problems and its distribution is closely monitored during and between eruptive events. Monitoring wind directions and strengths and how they vary at different altitudes is a vital part of the work HVO.

Lava eruptions in the rift zones

Some of the hazards of eruptions in the East Rift Zone are shared with the summit hazards, such as potentially lethal VOG and/or and respiratory problems caused by fine volcanic glass particles, particularly in areas downwind of large fire fountains (such as from fissure 8) which have produced friable of glass, known as Pele's hair. The lavas themselves are of course highly dangerous because of their high temperatures, and it would be a fool who tried to stand too close to an active lava channel as the banks built up around the sides of the channel are often unstable. Because lava flows in a liquid-like manner, a common assumption is that if someone fell in they would sink and drown. However, lava is in fact over twice as dense as a human body and so a body falling into a lava channel would actually 'float' and burn violently: definitely not a good way to die.

As lavas are travelling through vegetated and forested areas, interactions with vegetation and soil can also trigger methane blasts – these can throw rocks, soil, and tree debris for tens of metres, but are more commonly seen as blue flames, especially at night. Flammable and hazardous materials have been removed from the PGV geothermal plant, and the site has been evacuated and closed down, so it is hoped that there is now little danger if lava does override the geothermal wells and plant.

Lavas entering the ocean

Lava flows are also entering the ocean, and this is well known to be associated with a number of serious hazards. When mere dribbles of lava are entering the ocean, this can seem to be a benign and gentle process. However, when lava enters the ocean at substantial flow rates, and especially if the seawater is trapped in a lava tube for example, it is quite a different matter. Here, the chemical reactions that occur along with the extreme fragmentation of lava into small glassy particles produce what is called a laze (lava haze). It sounds innocuous but is in fact a fine acid mist (hydrochloric acid) mixed with tiny glass particles and water droplets. This is very irritating to the eyes and respiratory systems of anyone standing downwind. The lava entering the ocean typically fragments and forms a steeply-dipping pile of rubble that extends for hundreds of metres below the waves, and comprises rock fragments, some intact lava flows, broken fragments of lava flows, but is mostly composed of glassy fragments of various sizes. This rubble pile and the overlying lavas which advance across it is called a lava delta, and is the main mechanism by which most basaltic oceanic islands grow laterally.   Collapses of this unstable lava delta can happen swiftly, as the waves undercut the overlying lavas or as the rubble slumps into deeper water. These collapses are called bench collapses and can lead to phreatomagmatic explosions known as littoral (shoreline) explosions, as hot lava and hot rocks encounter trapped water which flashes to steam – again releasing large amounts of energy that is capable or blasting cooled and molten fragments for hundreds of metres. Occasionally, waves of scalding water (again formed by interactions between water and hot lava/rock) can wash onshore. So, even when only a few dribbles of lava are gently plopping into the ocean and give the impression that there's little danger, sudden collapse of the lava delta lurking beneath the waves offshore can soon turn this seemingly benign scene into a hellish one.

People have lost their lives in each of the three hazard zones mentioned above. Serious and lesser injuries have also occurred. The authorities provide regularly updated information on where not to go, what precautions to take, when to evacuate, and so on. If you are lucky enough to visit Kīlauea during an eruption then follow their advice, but do enjoy one of the most spectacular sights our planet has to offer

Further Information

https://volcanoes.usgs.gov/volcanoes/kilauea/status.html

https://volcanoes.usgs.gov/volcanoes/kilauea/monitoring_kilauea.html

PGV (Puna Geothermal Venture): https://www.Hawai‘ianelectric.com/clean-energy-Hawai‘i/clean-energy-facts/renewable-energy-sources/geothermal/puna-geothermal-venture-(pgv)

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