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Kīlauea—an Explosive Volcano in Hawai‘i

Kīlauea Volcano on the Island of Hawai‘i, though best known for its frequent quiet eruptions of lava flows, has erupted explosively many times in its history—most recently in 2011. At least six such eruptions in the past 1,500 years sent ash into the jet stream, at the cruising altitudes for today's aircraft. The eruption of 1790 remains the most lethal eruption known from a U.S. volcano. However, the tendency of Kīlauea's 2 million annual visitors is to forget this dangerous potential. Cooperative research by scientists of the U.S. Geological Survey, Smithsonian Institution, and University of Hawai‘i is improving our understanding of Kīlauea's explosive past and its potential for future violent eruptions.

Kīlauea Volcano, on the Island of Hawai‘i, is best known for its frequent sustained eruptions of lava flows and lava fountains, which are gentle enough that they can be observed and enjoyed from close range. Occasionally, however, Kīlauea erupts explosively, hurling out rocks and plumes of fine pulverized material. Several small explosions occurred in 2008 and 2011, like this one on October 12, 2008, but much larger explosive eruptions have occurred in past centuries, sometimes with deadly consequences. Inset shows a large block thrown out of Halema‘uma‘u Crater during an explosive eruption on March 19, 2008.

Kilauea…has not always been the tame creature of today.

Hitchcock, C.H., 1909, Hawaii and its Volcanoes, p. 167

At 2:58 a.m. on March 19, 2008, a gaping, glowing hole, visible from the U.S. Geological Survey's (USGS) Hawaiian Volcano Observatory (HVO) 1.8 km (1.1 mile) away, opened in the floor of Halema‘uma‘u Crater almost beneath the visitor overlook. A scientist working all night at HVO heard and felt nothing. Just after dawn, three geologists drove to investigate. Thick, sulfurous fume blowing across the road 500 m (yards) downwind from the hole obscured visibility. The driver, knowing the road was straight, tightly gripped the steering wheel and crept ahead. Crunch, bump—oh no, must have driven off the road! Then came the sudden realization that the car was still on the road but was lurching over rocks blown out of the crater. This was how the first explosive eruption at the summit of Kīlauea since 1924 was discovered.

Later in 2008 and then in 2011 eight more similar events took place. All were tiny by comparison to explosive eruptions in Kīlauea's past, but they jarred the public into realizing that Kīlauea could be explosive. Long considered a "milquetoast" of a volcano, erupting only photogenic lava fountains and flows, Kīlauea has the capability of quickly turning violent. Its eruption of 1790 killed a large number of people (estimates, all made decades afterwards, range from about 80 to more than 5,000) within a few hundred meters of where the Jaggar Museum and the adjacent Hawaiian Volcano Observatory stand today. And, in 1924, a too-adventurous accountant was killed while photographing the largest in a 17-day series of explosive eruptions at the volcano's summit.

Although they are not its usual style, Kīlauea produces explosive eruptions about as often as does Mount St. Helens in Washington State—several periods of multiple explosive events every millennium. Those at Kīlauea are generally smaller in volume and in area affected, but their risks are substantial. More than 5,000 people a day visit Kīlauea's summit, where most of the explosive eruptions take place, and hundreds live nearby. A busy highway now passes through the area where so many died in 1790—a tragedy that, by itself, makes Kīlauea historically the most lethal of all volcanoes in the United States.

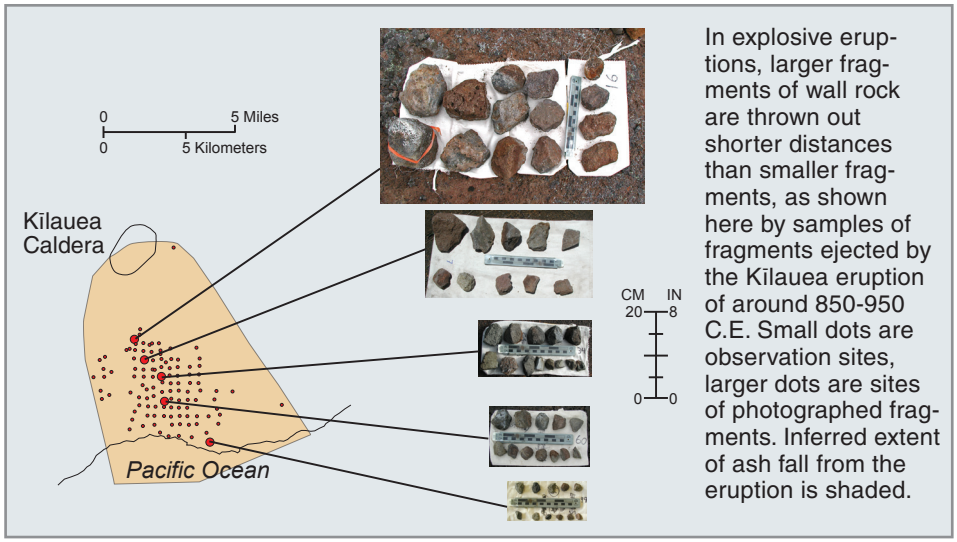
What Is the Nature of Explosive Eruptions at Kīlauea and How Large Can They Be?

Technically, even lava fountains are explosive eruptions. For the purpose of this fact sheet, however, an eruption at Kīlauea is considered to be explosive if fragments of broken rock from the vent walls (called "wall rocks") are ejected, generally but not always accompanied by fresh shreds and droplets of magma (molten rock). Lava fountains at Kīlauea eject only fresh magma particles and so are not considered explosive; in contrast, the explosive eruption of March 19, 2008, threw out only wall rocks.

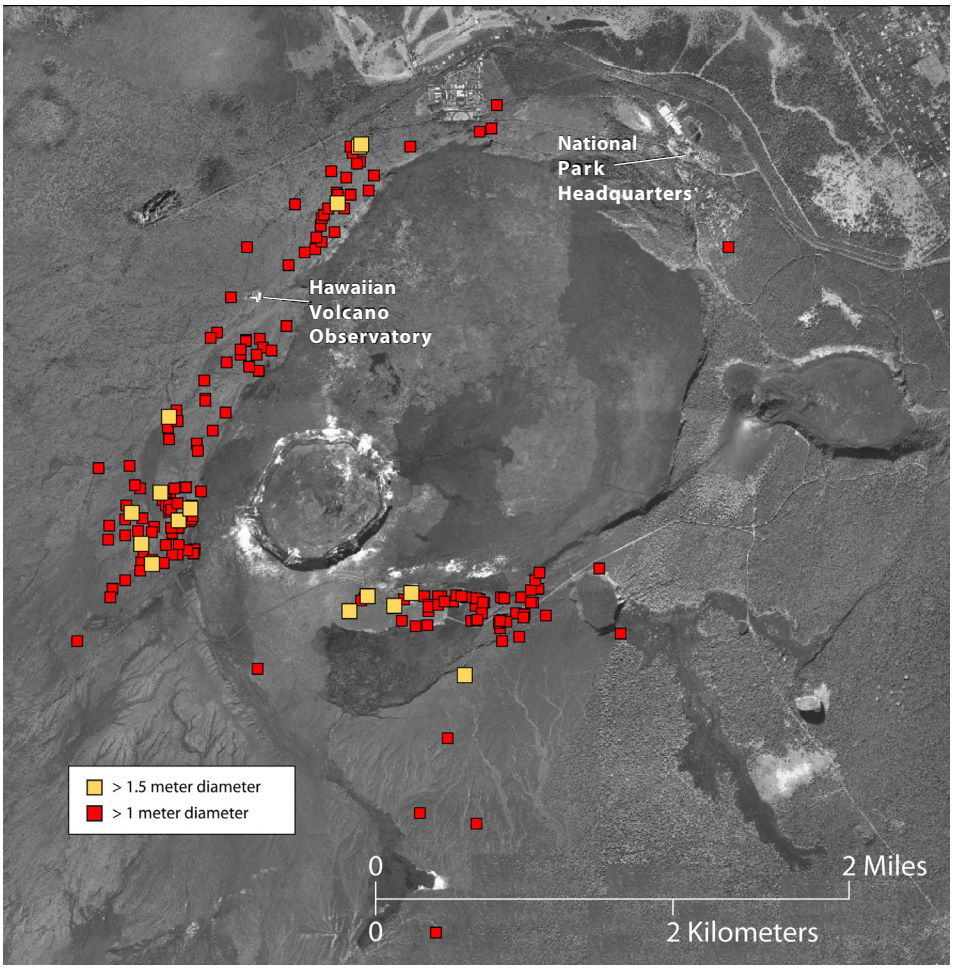
Most explosive eruptions at Kīlauea are relatively small, but they can be hazardous to people and infrastructure. The pulverized wall rocks (and magma droplets) fall as volcanic ash around the vent and downwind. During heavy ash fall, breathing is difficult, and the weight of ash, especially when wet, can cause roofs of buildings to collapse. Such hazards are mainly of concern to people

near the summit area, but more distant effects can also be substantial. In 1924, ash falling 40 km (24 miles) from the summit shut down a railroad, and a layer of ash amounting to 4.9-7.4 tonnes/hectare (2-3 tons/acre) accumulated 30 km (18 miles) away, contaminating grass used for livestock feed. The 2008 explosive eruptions were much smaller than those of 1924, creating a hazard only directly adjacent to the vent. Such tiny eruptions could have happened many times in the past but their record may be overlooked today because they left such limited, transient deposits.

Much more powerful eruptions occurred in the more distant past. One large explosive eruption at Kīlauea's summit 1,000-1,200 years ago sent golf-ball-size dense wall rocks to the south coast of the island, 18 km (11 miles) away. One block 24 cm (9.5 inches) across and weighing 4.43 kg (9.7 lbs) fell 5 km (3 miles) from the vent. Several other large explosive eruptions, including the deadly one in 1790, produced volcanic ash that blew southeast, east, and northeast of the summit, as recognized from the distribution of the ash deposits. Dispersal of ash in those directions could not have resulted from the normal trade wind, which blows from the northeast, or the less common south wind. Instead, such easterly dispersal implies that the eruption columns penetrated high into, or even above, the west winds of the subtropical jetstream, which in Hawai'i blow year-round at altitudes of 4-17 km (13,000-56,000 feet). Volcanic ash drifting at these altitudes poses a clear hazard to modern aircraft—a chilling prospect never dreamed of a few years ago for Hawaiian volcanoes.



In explosive eruptions, larger fragments of wall rock are thrown out shorter distances than smaller fragments, as shown here by samples of fragments ejected by the Kīlauea eruption of around 850-950 C.E. Small dots are observation sites, larger dots are sites of photographed fragments. Inferred extent of ash fall from the eruption is shaded.



The deadly explosive eruption of Kīlauea in 1790 hurled numerous large blocks of rock—more than 1 meter (more than 3 feet) in diameter—out of the caldera, some as far as 2 kilometers (1.4 miles) beyond the rim.

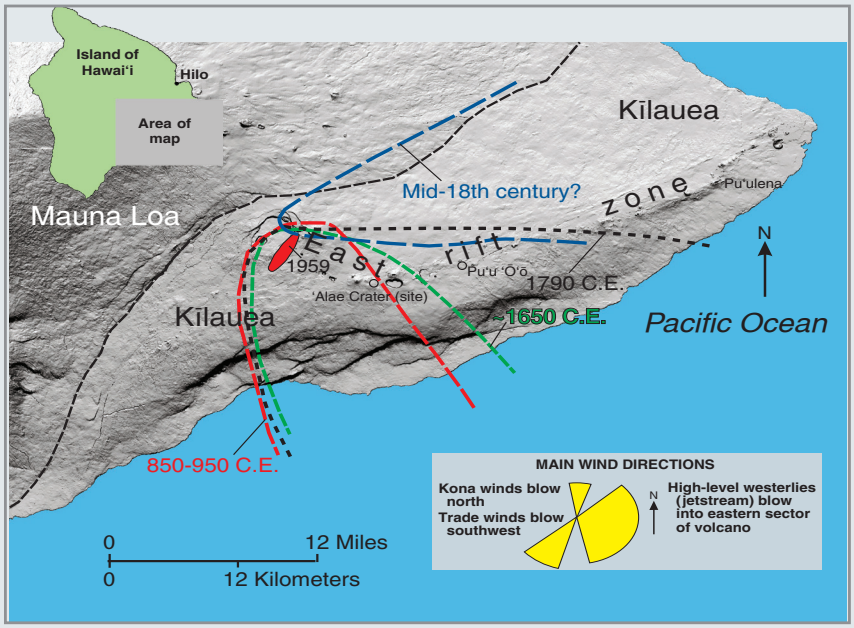
Explosive eruptions of Kīlauea between 1500 and 1790 included the occurrence of at least a dozen fast-moving, ground-hugging clouds of ash, rock, and volcanic gas. Such "pyroclastic surges" are among the most dangerous of all volcanic phenomena—speeding at hurricane velocities and having temperatures of several hundred degrees Celsius. Ongoing research indicates that a surge probably caused the deaths in 1790. Surge deposits have been recognized as far as 3.5 km (2.1 miles) outside the summit caldera (the 4 km by 3 km volcanic depression within which lies the vent of Halema'uma'u Crater).

Although explosive eruptions at Kīlauea are infrequent in human terms, they are not rare geologically. Besides the eruption of 1924, significant explosive eruptions occurred repeatedly during a 300-year period between about 1500 and 1790, and also repeatedly between about 500 and 1000 C.E. Many deposits of older explosive eruptions are known but poorly understood. The eruptions appear to occur in clusters, during times when a deep caldera exists at Kīlauea's summit. This is clear for the 1500-1790 and 500-1000 periods. The 1924 events, however, don't fit this picture easily.

Not all of Kīlauea's explosive eruptions take place at the volcano's summit. Several hundred years ago, blocks of wall rock were ejected from 'Alae Crater (now buried by recent lava flows) and from Pu'ulena, both on the east rift zone (a zone of fractures and eruptive vents trending east from the summit area). Even Pu'u'Ō'ō, site of an ongoing eruption on the east rift zone since 1983, had small explosive eruptions in 1987, 1991, and

ASH DISPERSION BY THE JETSTREAM

Some large explosions from Kīlauea's summit in the past have sent eruption clouds so high that they entered the west winds of the jetstream. As a result, their ash deposits were dispersed mainly in easterly directions. Shown here are the known distributions for explosive eruptions in 850–950 C.E., about 1650 C.E., in the mid-18th century (?), and in 1790 C.E. By contrast, the spectacular lava fountains of the 1959 eruption, the largest in the past 200 years, only sent material some hundreds of feet into the air, where it was dispersed to the southwest by the prevailing low-level trade winds (shown by solid red oval). Although the on-land extent of the ash deposits is fairly well known, except for the mid-18th century deposit, all those ash layers extend offshore for unknown distances.



1996 and tiny bursts in 2008 and 2009; these eruptions were similar in size to those at the summit in 2008.

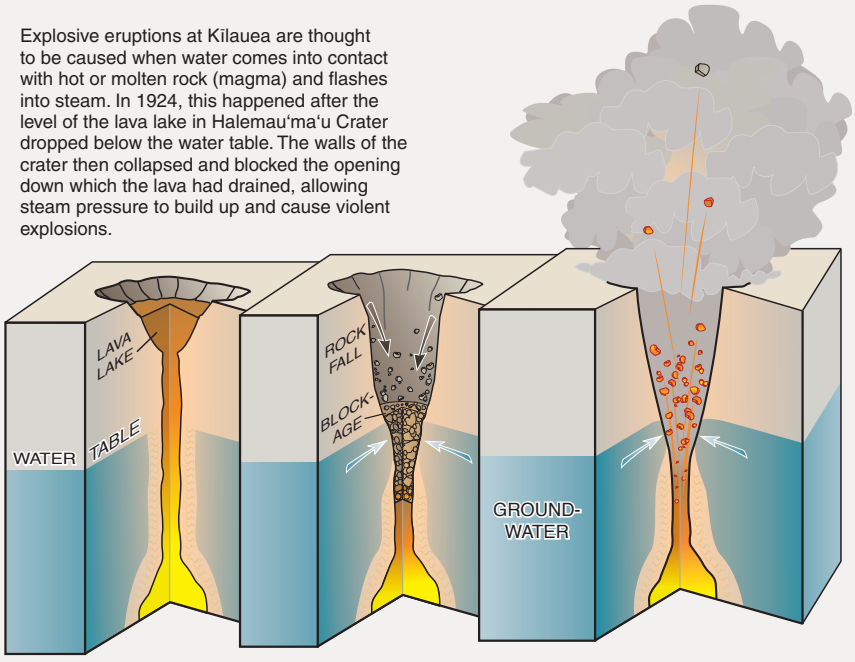
What Causes Kīlauea's Explosive Eruptions?

Groundwater or surface water probably has played a major role in most of Kīlauea's explosive eruptions. If water is heated under pressure and the pressure then relieved, it can flash into steam, rapidly expanding and providing the propellant for explosive eruptions. Scientists theorize that, when the caldera is deep enough to be at or below the water table (the level below which rocks are saturated with water), water can seep into the vent and explosive eruptions can take place. The water table is currently about 500 m (1,640 ft) below the floor of the caldera. If the caldera collapsed to about that level—as it did around 1500 C.E., probably remaining there until 1790—explosive eruptions could likely occur. In 1924, geologists noted that lava drained from Halema'ma'u Crater to a depth apparently below the water table; rock falls from the collapsing walls of the crater dammed rising steam, pressure built up, and explosive eruptions occurred.

Not all of Kīlauea's explosive eruptions may be related to groundwater, however. The summit explosive eruptions of 2008, and likely also those at Pu'u'Ō'ō, were apparently propelled by gas carried by, and released from, magma independent of groundwater. The very powerful eruption around 800-1000 C.E. carried up fragments of almost solidified magma that was apparently crystallizing at a depth of 5-6 km (3-3.5 miles) when the eruption began. At such depths, carbon dioxide (CO_2) is bubbling from the magma, and perhaps a buildup in CO_2 pressure triggered that explosive eruption.

WHAT CAUSES EXPLOSIVE ERUPTIONS AT KĪLAUEA?

Explosive eruptions at Kīlauea are thought to be caused when water comes into contact with hot or molten rock (magma) and flashes into steam. In 1924, this happened after the level of the lava lake in Halemau'ma'u Crater dropped below the water table. The walls of the crater then collapsed and blocked the opening down which the lava had drained, allowing steam pressure to build up and cause violent explosions.



Can Explosive Eruptions Be Foreseen?

Could we forecast future explosive eruptions at Kīlauea? Whenever the bottom drops out of the caldera, or of a crater (like Halema'ma'u) within it, explosive eruptions become a realistic possibility. But explosive eruptions driven mainly or exclusively by magmatic gas may be harder to anticipate. The explosive event in March 2008, for example, was foreseen in only the most general way as a possible outcome of increased summit unrest (increased seismicity and gas output)–and everyone was surprised by the form it actually took. Deep-seated pressure buildup, such as might

ASH DEPOSITS FROM KĪLAUEA'S EXPLOSIVE ERUPTIONS

This exposure of layered ash beds on the south side of Kīlauea Caldera consists of more than 11 meters (36 feet) of deposits from explosive eruptions between 1500 and 1790 C.E. White numbers identify two events whose eruption columns reached the jet stream: (1) eruption of about 1650; (2) eruption of 1790, the deposit of which lies on the ash bed that elsewhere bears human footprints.

Inclined ash beds in pyroclastic surge deposit probably dating from the deadly 1790 eruption. Such surges are common explosive deposits at Kīlauea and would be deadly to anyone in their path. The knife rests on a massive fine ash bed, the surface of which is indented by thousands of human footprints west and southwest of the caldera.

SIX EXPLOSIVE ERUPTIONS WITH JETSTREAM COLUMN HEIGHTS COMPARED WITH THE LARGEST 2008 ERUPTION (BOLD).

Date	Dispersal direction	Volume, cubic km (cubic mi)	Material[1] ejected	Geologic unit of deposit
Nov 1790	ESE	0.02 (0.005)	Wall-rock lapilli and ash	Keanakāko‘i Tephra
Mid 18th century(?)	ENE	?	Wall-rock lapilli and ash	Keanakāko‘i Tephra
Mid-late 17th century	SE	<0.01? (<0.0025?)	Fine wall-rock ash	Keanakāko‘i Tephra
~1650	SE	0.015 (0.003)	Scoria with wall rock	Keanakāko‘i Tephra
850-950 C.E.	SE	0.02 (0.005)	Scoria with wall rock	Kulanaokuaiki Tephra
400-640 C.E.	SE	?	Scoria with wall rock	Kulanaokuaiki Tephra
Sept. 2, 2008	**SW**	**0.0000008 (0.0000002)**	**Wall-rock lapilli and ash**	**2008-present summit eruption**

[1]The general term for fragmental volcanic material is tephra. Tephra particles less than 2 mm (0.08 in) in diameter are called ash; particles between 2 mm and 64 mm (2.52 in) are called lapilli; the term scoria refers to very crystal-rich tephra of ash and lapilli size.

occur before a CO_2-driven explosive eruption, would be very difficult to detect with current monitoring capabilities.

As volcanoes go, Kīlauea is a pretty safe place, generally producing lava fountains and lava flows quietly when it erupts. Once in a while, however, it will erupt explosively. That is when the volcano becomes the most hazardous and when lives could be lost without prompt, proper warnings and actions. USGS scientists working out of HVO, and their collaborators from the Smithsonian Institution, the University of Hawai‘i, and other organizations, continue to closely monitor Kīlauea and study how the volcano works. Improved understanding of its workings will enable better protection of the public from the hazards of Kīlauea’s occasional explosive episodes.

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