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# One Hundred Years of Volcano Monitoring in Hawaii

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In 2012 the Hawaiian Volcano Observatory (HVO), the oldest of five volcano observatories in the United States, is commemorating the 100th anniversary of its founding. HVO's location, on the rim of Kīlauea volcano (Figure 1)—one of the most active volcanoes on Earth—has provided an unprecedented opportunity over the past century to study processes associated with active volcanism and develop methods for hazards assessment and mitigation. The scientifically and societally important results that have come from 100 years of HVO's existence are the realization of one man's vision of the best way to protect humanity from natural disasters. That vision was a response to an unusually destructive decade that began the twentieth century, a decade that saw almost 200,000 people killed by the effects of earthquakes and volcanic eruptions.

## *The Destructive Decade*

In 1902 an eruption of Mount Pelée on the Caribbean island of Martinique changed the way scientists around the world viewed natural disasters. Despite months of precursory signs, political officials assured the population that there was no cause for alarm. On the morning of 8 May, however, a violent eruption killed 30,000 residents. Just hours earlier, an eruption at La Soufrière volcano, on St. Vincent island, only 100 miles away, killed nearly 1700 people.

Within a week the U.S. National Geographic Society sent an expedition to both volcanoes to document the eruptions and the destruction. One of the expedition members was Thomas A. Jaggar Jr. (Figure 2), a geology instructor from Harvard University. After several weeks of study, Jaggar concluded that resettlement should not be allowed "until the governments of the islands are willing to establish permanent experiment stations to protect and warn the inhabitants" (*The Evening News*, San Jose, Calif., p. 5, 6 August 1902).

Over the next 8 years, Jaggar visited the scenes of several devastating eruptions and earthquakes around the world, always reaching the same conclusion: Rather than study disasters after they occur, observatories must be established to document any precursory behaviors that could foretell future large volcanic and seismic events. "I think if we could get…a properly endowed laboratory for the study of earth movements,…we might be able in a few years to make earthquakes and volcanoes ordinary risks for insurance, and also succeed in preserving a great many

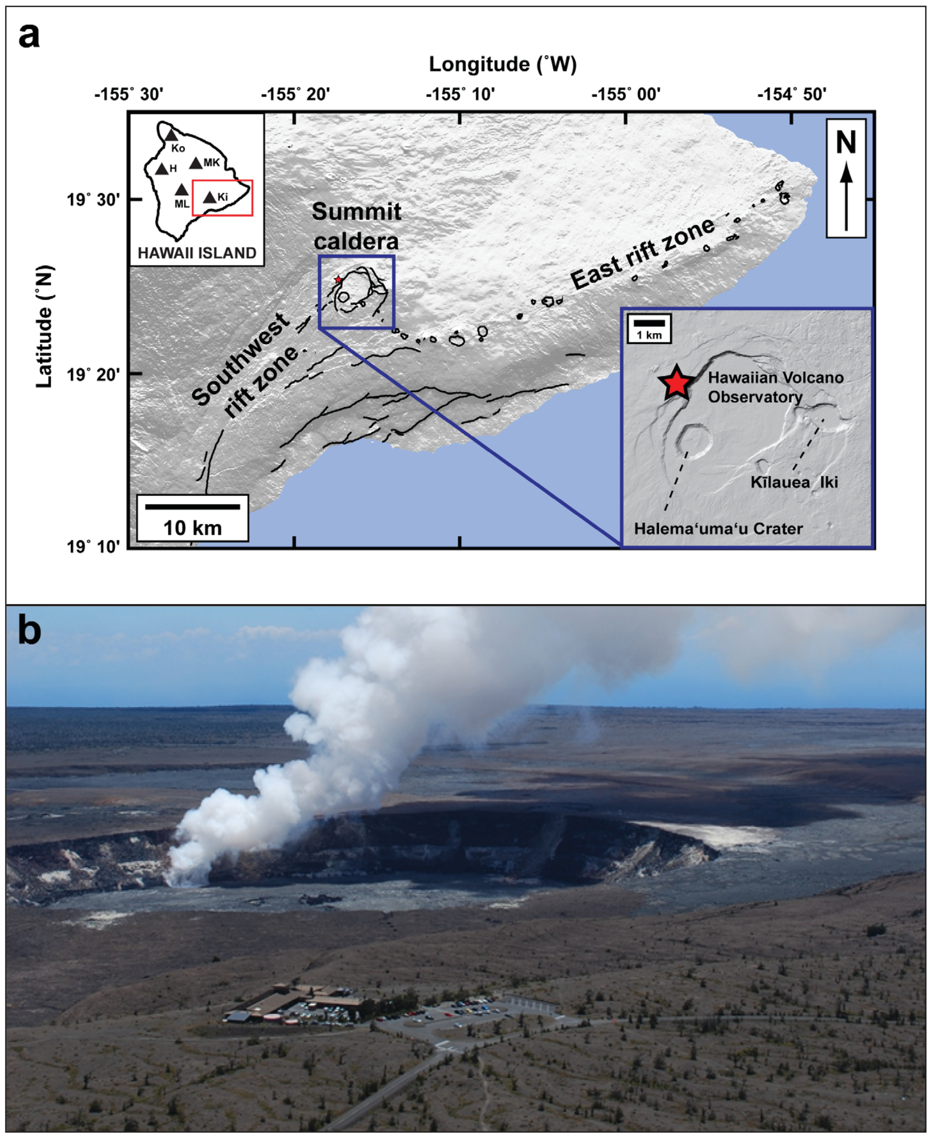


*Fig. 1. Location of the Hawaiian Volcano Observatory (HVO). (a) Shaded relief map of Kīlauea volcano. Inset at top left gives locations of the five volcanoes that make up the Island of Hawaii (Ki, Kīlauea; ML, Mauna Loa; MK, Mauna Kea; H, Hualālai; Ko, Kohala). Kīlauea's summit caldera and two rift zones are marked. Red star indicates the HVO. Major faults and craters are outlined. Inset at bottom right shows close-up view of Kīlauea's summit. (b) HVO is located on the east rim of Kīlauea caldera and affords an excellent view of Halema'uma'u crater and the currently active summit eruptive vent, in the background. U.S. Geological Survey photo taken 3 September 2008.*

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human lives" (*The San Francisco Sunday Call*, San Francisco, Calif., p. 5, 24 June 1906).

### *The Founding of HVO*

In 1909, Jaggar, then with the Massachusetts Institute of Technology (MIT), traveled to Japan to study the progress made in that country toward the establishment of earthquake observatories and to visit two active Japanese volcanoes. During a stop in Hawaii on his way to Japan, he spoke to interested Honolulu businessmen about establishing an observatory at Kīlauea volcano on the Island of Hawaii. They were enthusiastic and pledged financial support that led to a deal between the businessmen and MIT and to Jaggar's promise to return to Hawaii later that year.

Academic and familial duties did not allow Jaggar to return to Hawaii as quickly as he had promised. Monitoring instruments were purchased in 1910, but by early 1911 the Honolulu supporters were growing restless. Jaggar enlisted American volcanologist Frank Perret, then working at Vesuvius in Italy, to lead an advance effort to study Kīlauea in July 1911. By the time he returned to Italy in October, Perret had gathered enough data to publish seven scientific papers in the *American Journal of Science*. Jaggar returned to Kīlauea on 17 January 1912 and began continuous observations of volcanic and earthquake activity, the core functions of what would become the Hawaiian Volcano Observatory.

HVO was operated by the Hawaii Volcano Research Association (the Honolulu businessmen) with supplemental funds from private donations through MIT until 1919, when its operation was transferred to the U.S. Weather Bureau. In 1924, HVO was transferred to the U.S. Geological Survey (USGS). The Great Depression greatly reduced federal spending, and HVO was temporarily transferred to the National Park Service in 1935 before being returned to USGS in 1947.

### *Beginnings of Volcano Observation and Research*

Although one of Jaggar's strengths was meticulous documentation of eruptive and earthquake activity, he also began early geophysical monitoring by installing seismometers when HVO was founded. Jaggar and seismologist H. O. Wood recorded the occurrence of earthquakes and seismic tremor that preceded and accompanied Hawaiian volcanic activity, complementing the work of Japanese volcano seismicity pioneer Fusakichi Omori and solidifying the relation between earthquakes and volcanism.

The earliest seismometers installed at HVO were also sensitive to ground tilt, providing the first record of deformation of Hawaiian volcanoes. HVO scientists correlated tilt with changes in volcanic activity in the 1920s, while repeated leveling surveys indicated that the caldera area was rising and subsiding.

*Fig. 2. Thomas A. Jaggar Jr. in his study inside the first HVO building in 1925.*

With the help of HVO staff, scientists from the Carnegie Laboratories sampled gases from Kīlauea and confirmed that volcanic emissions consisted primarily of water vapor, carbon dioxide, and sulfur dioxide exsolved from magma during ascent to the surface. Gas samples collected at Kīlauea in 1912 were among the first high-temperature volcanic gas emissions ever analyzed, and additional samples obtained by Jaggar in 1918–1919 continue to be an important resource for studies of volcanic degasing.

The persistent lava lake within Halema'uma'u crater during the first 13 years of HVO's existence also allowed close study of lava level variations, circulation, and degasing. Both Perret and Jaggar concluded that lava lakes are actually filled with degasing lava foam [*Perret,* 1913]. Exsolution of gases upon magma ascent drives circulation, and degasing drives lava fountains.

Although HVO was set up ostensibly to study volcanoes, Jaggar's original purpose was to protect human life and property from all natural hazards. For example, he and seismologist Ruy Finch developed an early method for predicting the timing of tsunami waves in Hawaii based on the arrival times of teleseisms [*Finch,* 1924]. The Aleutian Island earthquake of 3 February 1923 afforded the first formal tsunami forecast, saving many lives and much property while establishing the basic forecasting method for future efforts.

Jaggar was also an early advocate of emergency preparedness and lava flow diversion. Communities had to be ready for eruptions with plans for evacuating and for securing major community assets and infrastructure. These functions are now a standard responsibility of local governments in Hawaii and elsewhere. Jaggar experimented with lava flow diversion, working with the U.S. Army to bomb the vent area of Mauna Loa's 1935 eruption with the intent of robbing the supply of lava from the advancing flow. The tactic was tried again during the 1942 Mauna Loa eruption, but neither effort was a clear success.

Jaggar was forced to retire from the National Park Service in 1940, when he had already worked 2 years beyond the mandatory federal retirement age thanks to waivers signed by President Franklin Roosevelt. He used retirement as the opportunity to continue geologic research with the University of Hawai'i until his death in 1953.

### *Advancements in Understanding How Hawaiian Volcanoes Work*

In the 1950s, HVO's capabilities increased significantly as a result of the efforts of Jerry Eaton, who, during 1953–1961, designed and installed a telemetered, electronic seismic network. He also built and deployed a network of water tube tiltmeters around Kīlauea to more accurately track subsurface magma storage and movement. These new data provided the basis for the first general model of how Hawaiian volcanoes work [*Eaton and Murata,* 1960], a study that is the foundation for all models of Kīlauea's magma plumbing system.

Another important contribution made by HVO scientists to the volcanology community was the discovery of flank instability. Deformation measurements in the 1960s showed that Kīlauea's south flank was moving seaward by many centimeters per year, suggesting the possibility of future damaging earthquakes. These results [*Swanson et al.*, 1976] were in press when a magnitude 7.2 earthquake occurred beneath the south flank on 29 November 1975, causing two deaths and millions of dollars in damage.

The pervasiveness of flank instability in Hawaii was demonstrated during the 1970s, when exploration of the seafloor around the Hawaiian Islands revealed large offshore landslide deposits [*Moore et al.*, 1994], possibly a result of the same instability that had been discovered on Kīlauea's south flank. In the decades since, several other island volcanoes have been found to have suffered flank failures, including La Réunion in the Indian Ocean and the Azores and Canaries in the eastern Atlantic Ocean.

Frequent eruptive activity at Kīlauea since the 1950s has afforded outstanding opportunities to study lava flows. Eruptions within Kīlauea Iki crater in 1959 produced a deep lava lake that was repeatedly drilled as it solidified through the late 1980s, providing unique data on the cooling and crystallization of magma bodies [e.g., *Helz*, 2009]. Long-lasting rift zone eruptions at Kīlauea during 1969–1974 and from 1983 to the present have provided opportunities to study lava flow emplacement, demonstrating, for example, how flow texture and transport are affected by temperature, effusion rate, surface slope, and other factors [e.g., *Peterson and Tilling*, 1980], critical input to understanding lava flow hazards.

Most recently, studies of tephra layers and stratigraphic relationships around Kīlauea caldera have revealed alternating periods of explosive and effusive behavior, changing the way scientists think about the destructive potential of supposedly benign basaltic shield volcanoes. It is interesting to note that the formation of Kīlauea's caldera and subsequent explosive eruptions may have been recorded in the plot of the saga of the Hawaiian volcano deity Pele and her sister, Hi'iaka [*Swanson*, 2008], relating volcano evolution to native Hawaiian oral traditions.

Over the past century, HVO scientists have documented almost 50 Kīlauea eruptions, 12 Mauna Loa eruptions, an intense seismic swarm (probably an intrusion) beneath Hualālai volcano, and dozens of strong earthquakes. Most notable of these were the explosive eruptions of Kīlauea in 1924, which ended years of persistent lava lake activity at its summit; the long-lived eruptions within Kīlauea's east rift zone (Mauna Ulu and the current eruption that started in 1983); the Mauna Loa eruption of 1950, during which lava flows advanced more than 20 kilometers from vent to ocean in just a few hours; and the 1975 *M* 7.2 earthquake beneath Kīlauea's south flank.

### *HVO in 2012*

HVO currently hosts a staff of 25 scientists and support personnel in addition to student and community volunteers. The observatory monitors six Hawaiian volcanoes and more than 200 kilometers of rift zones for earthquake and volcanic activity using geophysical, geological, and geochemical instruments installed on the islands of Hawaii and Maui. Recent funding provided by the American Reinvestment and Recovery Act has allowed for modernizing instruments and telemetry, and HVO is now well positioned for future monitoring and research efforts, which will include studies of geophysical manifestations of Hawaiian volcanism and tectonism, dynamics of lava lakes and surface flows, and hazards posed by volcanic gases. The research potential of Hawaiian volcanism will be the primary topic of discussion at an AGU Chapman Conference in Hawaii during 20–24 August 2012 (http://www.agu.org/meetings/chapman/2012/dcall/).

In 1912, Jaggar was one of just a few scientists working to understand active volcanoes. In the century that followed, volcano research around the world grew, involving academic institutions and government agencies as hazards due to increasing development near active volcanoes and ash-aircraft interactions have invigorated awareness of volcanic impacts. Hawaiian volcanoes continue to be some of the most accessible and active in the world. These reasons—the same ones that attracted Jaggar to Kīlauea—will ensure that volcano monitoring and research continue to thrive in Hawaii during HVO's next 100 years.

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