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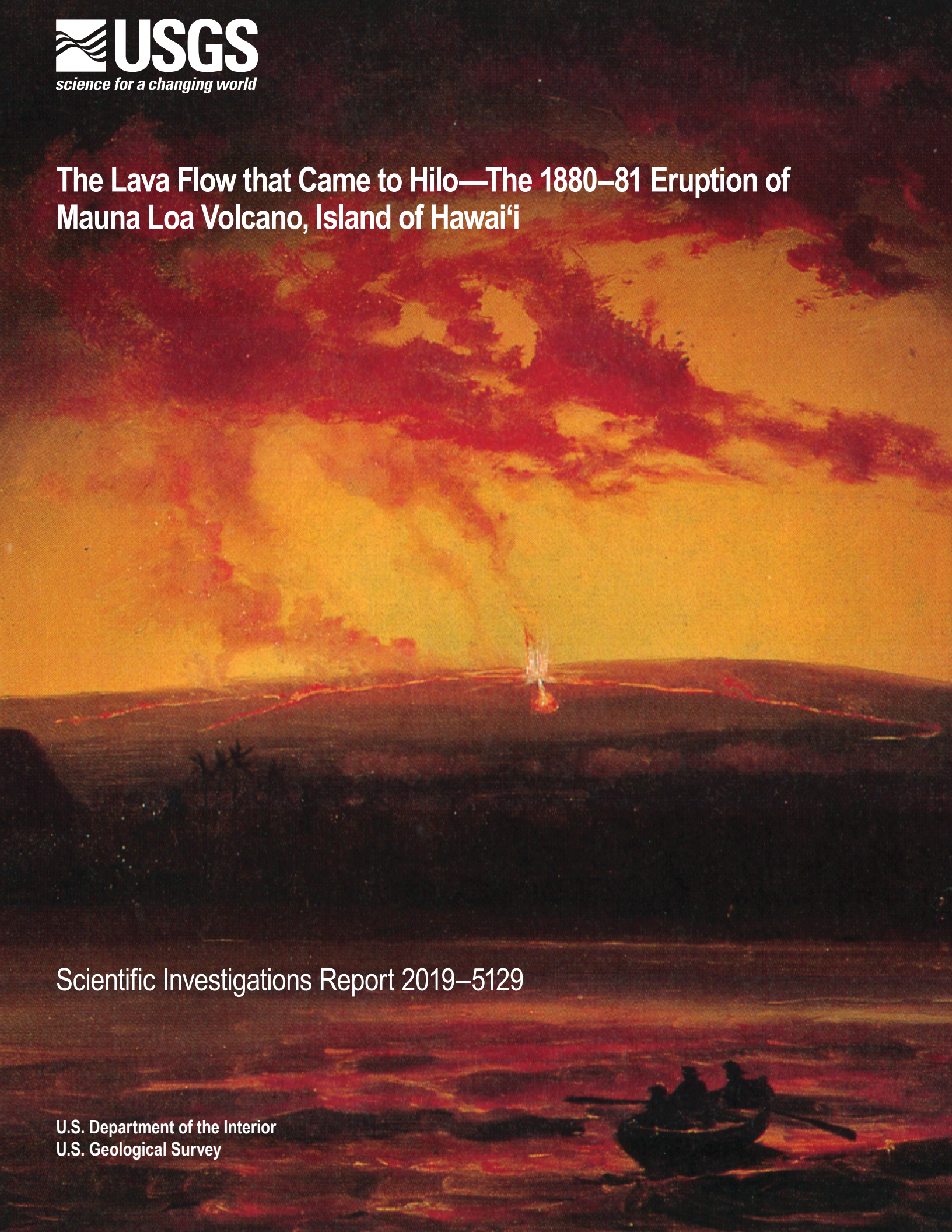
The Lava Flow that Came to Hilo—The 1880–81 Eruption of Mauna Loa Volcano, Island of Hawai‘i



Scientific Investigations Report 2019–5129

U.S. Department of the Interior
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Cover. The 1880-1881 eruption of Mauna Loa produced lava flows that came within about 2 kilometers of the town of Hilo. This painting by Charles Furneaux, "Night View 1880-1881, Eruption from Hilo Bay," illustrates the Ka‘ū (left) and the Kea (right) flows as they would have been in November 1880. The Ka‘ū flow would not have been visible from this vantage, however.

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By Jim Kauahikaua, Ben Gaddis, Ku‘ulei Kanahele, Ken Hon, and Valerie Wasser

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Contents

Figures

Appendix Figures

The Lava Flow that Came to Hilo—The 1880–81 Eruption of Mauna Loa Volcano, Island of Hawai‘i

By Jim Kauahikaua[1], Ben Gaddis[1], Ku‘ulei Kanahele[2], Ken Hon[3], and Valerie Wasser[3,4]

Abstract

The Mauna Loa eruption sequence of 1880–81 consists of two eruptions. The May 1880 eruption in Moku‘āweoweo at the summit of Mauna Loa lasted just a few days and was followed 6 months later by three lava flows that issued from vents along the Northeast Rift Zone. The November 1880 eruption lasted almost a year and one of its flows nearly reached Hilo Bay.

Public reaction in Hilo to the advancing lava flow increased as the lava got closer, but a smallpox quarantine prevented travelers and government officials from leaving Honolulu, the government seat of the Hawaiian Kingdom, until July 1881. In the King's absence, his sister Princess Regent Lili‘uokalani and key officials met in Hilo at the beginning of August to plan a government response. This included the first known plan to use barriers and explosives to divert the lava flow in Hawai‘i. Fortunately, the lava flow stopped before the plan was enacted; however, both Christian prayer and traditional Hawaiian chants and gifts to the Hawaiian deity Pele were offered in the last few weeks of lava activity.

Mauna Loa was again restless in 2019 and the time seems optimum to review this and other Mauna Loa flows, in order to be ready for the next lava flow. Should the next flow threaten developed areas, review of past lava flow threats may provide valuable experience on how the public may best be provided with information.

Introduction

It has been more than a century since Mauna Loa lava came to Hilo, yet there is much to learn about past events. Details from the progress and response to the eruption of 1880–81 (fig. 1) may offer guidance about how to alleviate the threat to Hilo from the next Mauna Loa eruption. Many Mauna Loa flows advanced toward Hilo, but only one flow came close in at least 750 years. As Hilo town boundaries expand westward toward vents within Mauna Loa's Northeast Rift Zone, the chances of an eruption affecting Hilo residents increase.

In 1880, Hawai‘i nei (the Hawaiian Kingdom) was an independent constitutional monarchy under High Chief Kalākaua who was elected king in 1874. His sister, Princess Lili‘uokalani, was his heir. The Kingdom's population of 58,000 in 1878 was predominantly of native Hawaiian descent (more than 47,000) with the remainder being foreign, mostly Chinese laborers and American residents (Thrum, 1881). The larger islands of Kaua‘i, O‘ahu (the seat of government), Maui, and the Island of Hawai‘i were linked by weekly steamer service which also provided the only regular inter-island communication.

In 2010, the population of the State of Hawaii exceeded 1.4 million residents. More than 185,000 of these residents are located in Hawaii County (Hawaii Dept. of Business, Economic Development and Tourism, 2017), the home of Mauna Loa volcano. The Hawaiian Islands are now linked in ways beyond the imaginations of their 19th century residents, but the threat from Mauna Loa has not changed.

Sources of Eruption Information

Information about how this eruption progressed and how it impacted the island's population was compiled from many sources. The primary sources were the weekly newspapers in both English (https://chroniclingamerica.loc.gov/) and Hawaiian (http://nupepa.org/) published in Honolulu on the island of O‘ahu. News from the Island of Hawai‘i was primarily obtained from passengers or letters brought by the weekly steamer. The weekly steamer, *Likelike*, usually left Hilo on Thursday each week and was scheduled to arrive in Honolulu on Sunday morning. All newspapers but the Hawaiian Gazette published on Saturday, so there was a minimum of a nine-day delay for Hilo news to be printed in Honolulu newspapers. The Hawaiian Gazette published its weekly newspaper on Wednesday and was often the first to report new developments.

Eyewitness accounts were preferred but all information was used. Of course, not all reporters were equally experienced in describing volcanic eruptions. Reverend Titus Coan, who had resided in Hilo since 1835 and was the primary documentarian of the volcanic eruptions of both Kīlauea and Mauna Loa volcanoes

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since then, was the most trusted of sources. His letters were frequently published in the American Journal of Science but he also contributed letters to the Honolulu newspapers and shared his observations with family and colleagues via letters (https://hmha.missionhouses.org/). David H. Hitchcock, a lawyer and judge who lived in Hilo since the 1850s, was also a valued source. Iosepa Kaho‘oluhi Nāwahīokalani‘ōpu‘u, or Joseph Nāwahī in the newspapers, was a painter, lawyer, and surveyor born and raised in Hilo, and he also provided both images and detailed reports of the lava flow’s advance on Hilo.

Travel books and personal journals were also good sources of information. Many of these are archived digitally at https://books.google.com/ or https://www.hathitrust.org/. Original journals or good copies of material not found online could sometimes be obtained from the Hawai‘i State archives and the Hawai‘i Mission Houses Museum Archives (https://hmha.missionhouses.org/).

Maps depicting the lava flows produced during this eruption were not available in the newspapers, but maps were made by Hawaiian government surveyors just after the flow stopped, and these are available online at http://ags.hawaii.gov/survey/map-search/. The maps were made by triangulation with equipment that is less accurate than survey equipment available today, but important details can still be obtained when registered to modern maps. These early maps were often the only way to locate place names mentioned in the eruption reports that either no longer exist or are no longer used.

Our final group of sources were images in the form of paintings, sketches, and photographs. This was probably the first Mauna Loa eruption that was widely photographed. Many of the available photographs of the lower end of the lava flow appear to have been obtained sometime after the flow had cooled but, because the lava is heavily overgrown now, the photos of the bare flow surface show valuable details. Artist Charles Furneaux accompanied William Brigham on a trip from the United States to the Island of Hawai‘i in mid-1880. Brigham left a few months later, but Furneaux stayed and visited the Mauna Loa lava flow several times to take notes and make sketches for paintings.

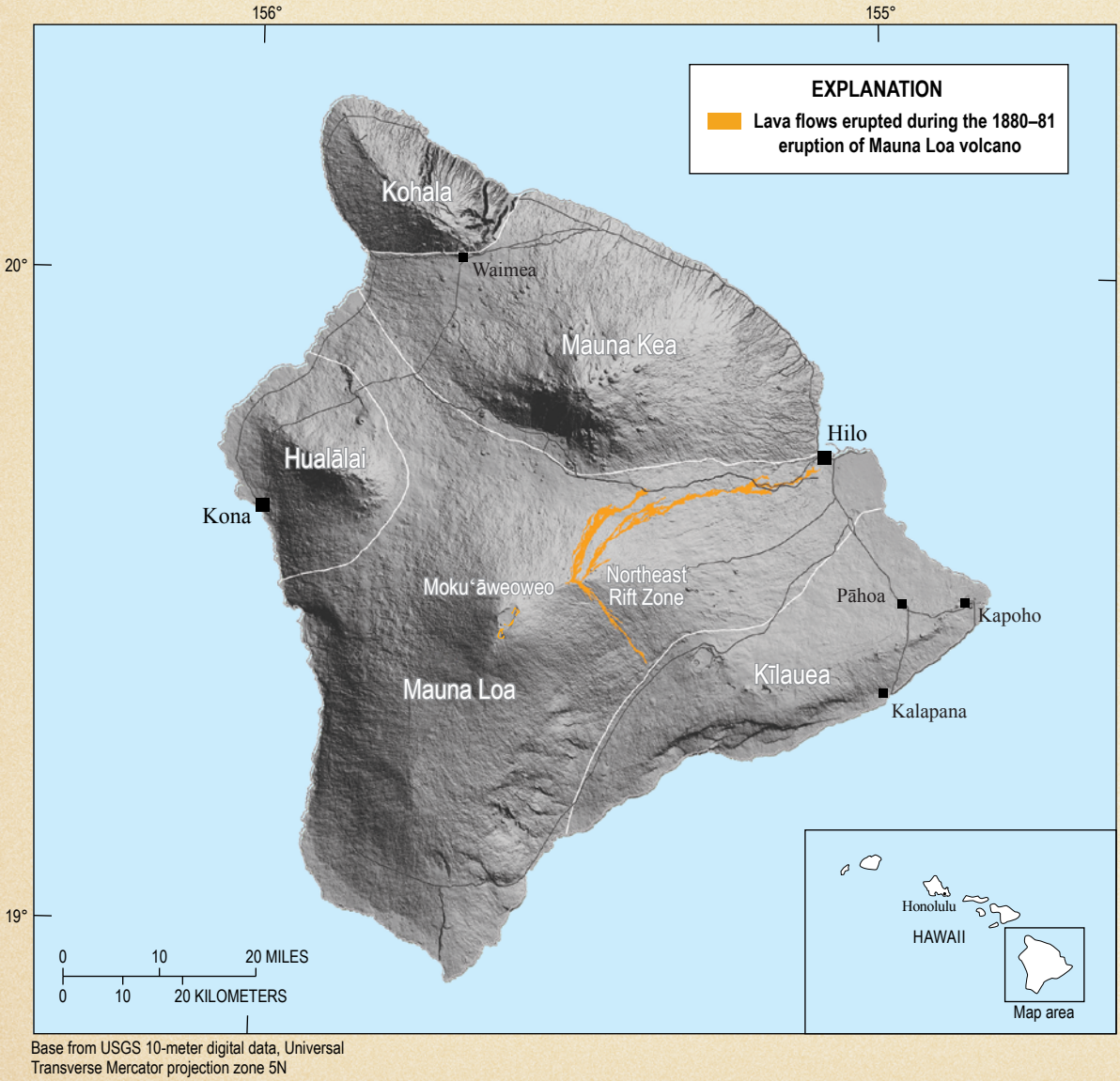


Figure 1. Shaded relief map of the Island of Hawai‘i showing the five volcanoes, the major cities of Hilo and Kona, Moku‘āweoweo (Mauna Loa’s summit caldera), and the lava flows erupted during the 1880–81 eruption of Mauna Loa volcano.

Hilo in 1880

The town of Hilo is located on the east side of the Island of Hawai‘i, the largest island in the Hawaiian Kingdom. In the 19th century, the main foreign settlement was on the west side of Hilo Bay, bounded by the Wailuku River to the northwest, Hilo Bay to the northeast, and the ‘Alenaio gulch to the southeast (fig. 2). The settlement area was about 0.5 km^2 (~120 acres) and had mostly thin, ashy soils suitable for moderate cultivation. Beyond Hilo, sparse settlement, including the Waiākea Sugar Mill, existed along the main road southeast from Hilo. “Hilo Hanakahi, I ka ua Kanilehua” are the first lines of a poetic reference to Hilo by Keola Naumu (Naumu, 1938). Hanakahi was an ancient beloved chief of Hilo and “ua Kanilehua” is a reference to the famous mist-like Hilo rain that nourishes lehua flowers of the ‘ōhi‘a tree.

Directly upslope of Hilo is Mauna Loa, an active volcano on the Island of Hawai‘i. Mauna Loa consists of a summit caldera, Moku‘āweoweo, with its highest rim at 4,169 m (13,678 ft) elevation, and two rift zones extending to the northeast and south-southwest from Moku‘āweoweo (Trusdell, 2012). Hilo has been repeatedly threatened by lava flows that erupted from vents below 3,350 m (11,000 ft) on Mauna Loa’s Northeast Rift Zone and flowed down its north flank (fig. 3). Before 1880, 12 lava flows advanced toward Hilo within the previous 1,500 years but only two reached within 8 km (5 mi) of Hilo Bay (according to the most recent geologic mapping by Trusdell and others, 2017). Those two flows were erupted in the 5th and 7th centuries, well before Polynesian arrival in the 13th century (Rieth and others, 2011). In the early and mid-19th century, flows advanced toward Hilo in 1852 and 1855–56. Neither flow came closer than 8 km (5 mi) from the bay but the latter caused the most concern among residents because it advanced slowly for 6 months before stalling; the eruption continued for another 9 months (Coan, 1883, p. 289–312).

Pelehonuamea

“Pelehonuamea, often referred to as Pele, is one of Hawai‘i’s dominant female akua of past and present. For those of us here in the islands, it is impossible not to see evidence of Pele’s volcanic impression on our natural and cultural landscape” (Kanahele, 2011). Pele is the Hawaiian deity of the volcano who resides with her family in Halema‘uma‘u at the summit of Kīlauea Volcano and who travels often to Moku‘āweoweo on Mauna Loa volcano and other areas where volcanic activity is occurring. The Hawaiian word, “pele,” is defined as “lava flow, volcano, eruption; volcanic

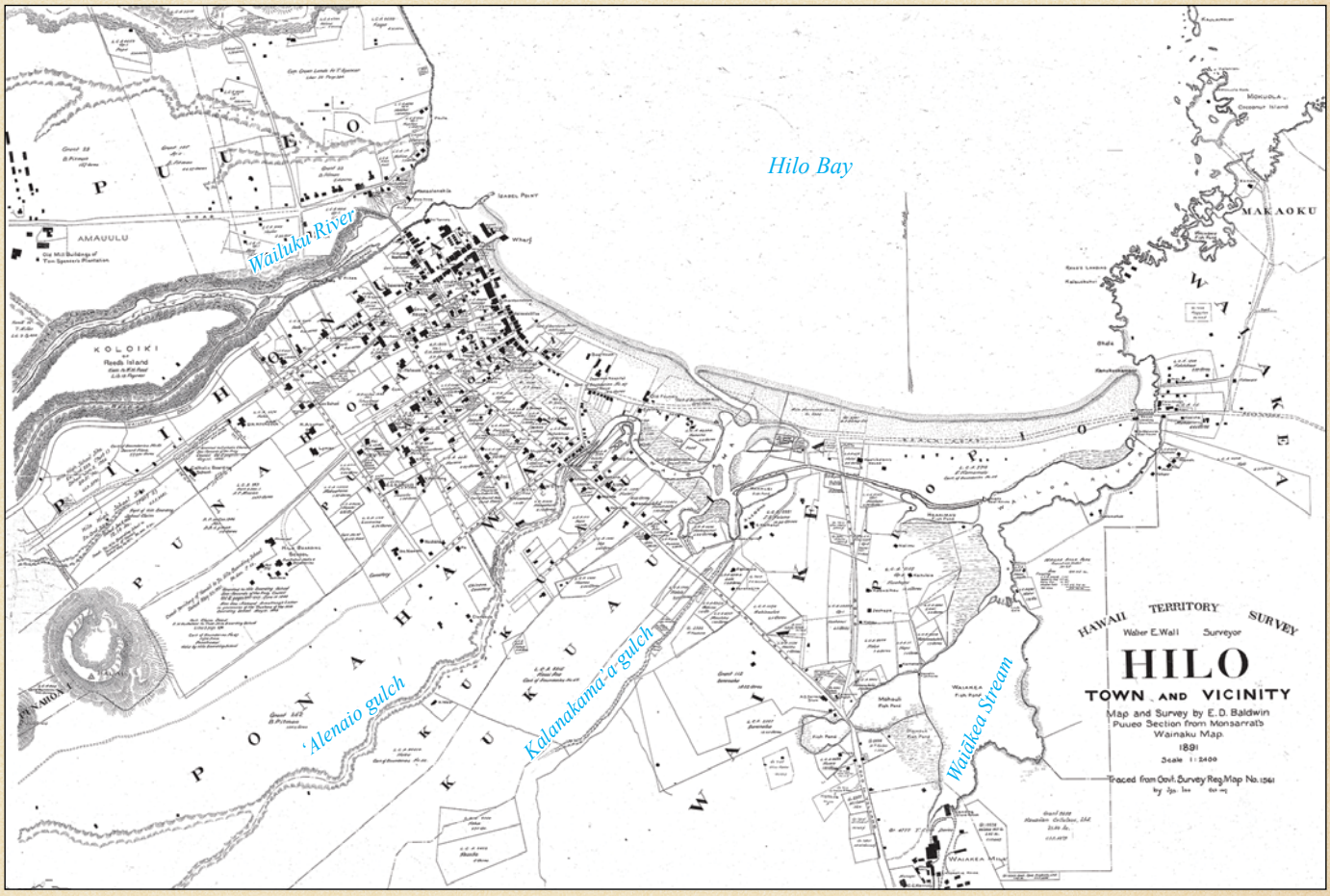
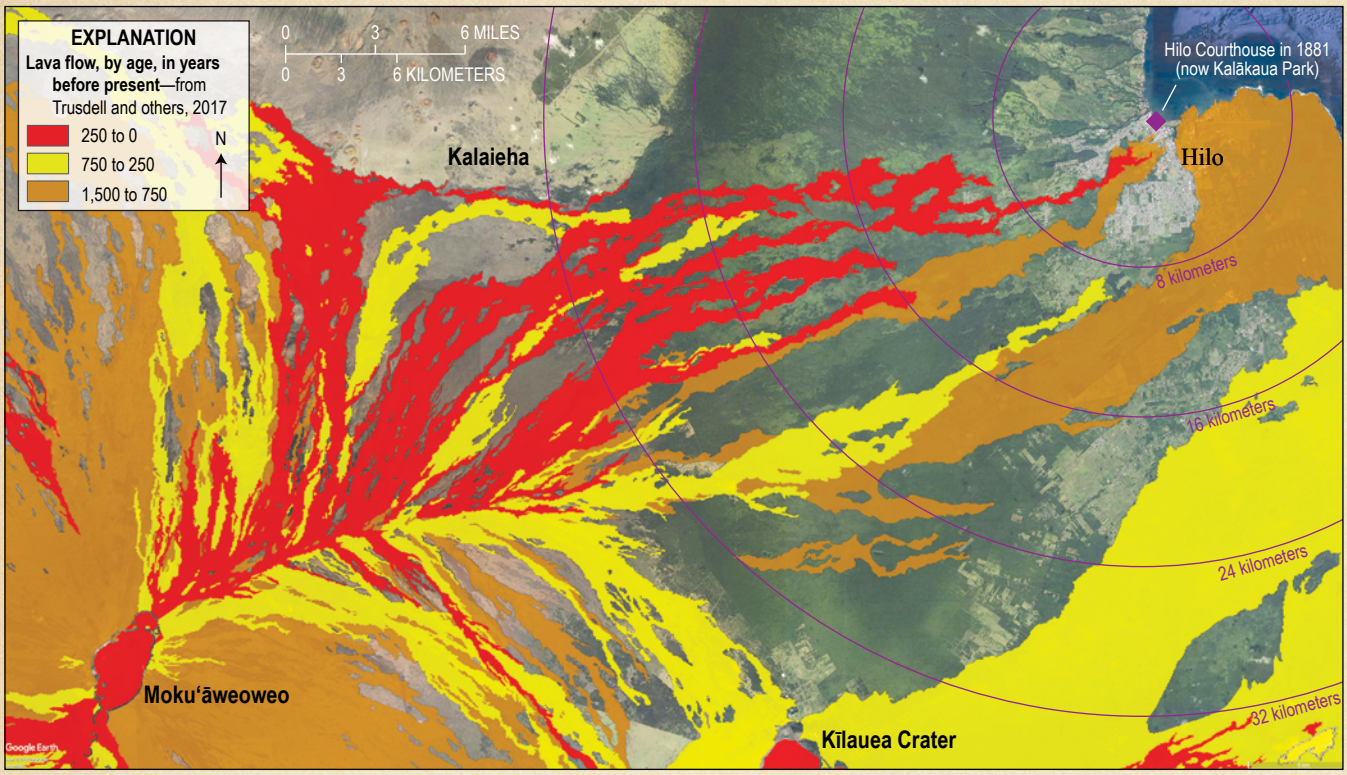


Figure 2. 1891 map of Hilo (Baldwin, 1891b), emphasizing the four main surface water features in 1880 Hilo.



Base map data from Google, DigitalGlobe 2019

Figure 3. Map of Moku‘āweoweo, the northeast flank of Mauna Loa volcano, Hilo, and lava flows erupted within the past 1,500 years (from Trusdell and others, 2017). Circles have radii 8, 16, 24, and 32 km (5, 10, 15, and 20 mi) from the 1881 Hilo Courthouse.

(named for the volcano goddess)" (Pukui and Elbert, 1986). Many eruption reports are infused with Pele references, especially those in the Hawaiian language. In English- and Hawaiian-language newspapers, "Madame Pele" is a personification of volcanic activity. In Hawaiian language newspapers, Pele *is* the volcano, eruption, and (or) the lava flow, depending on the context.

Moku‘āweoweo Eruption May 1, 1880

After the cataclysmic eruption-earthquake-landslide-tsunami event of March and April 1868 (Coan, 1868), Mauna Loa volcano erupted mostly at its summit crater, Moku‘āweoweo, over the next decade with only a single brief non-summit eruption in February 1877 (Coan, 1877). When Mauna Loa volcano erupted again at Moku‘āweoweo on May 1, 1880, residents were excited. A few were worried. Summit eruptions are spectacular sights and, when clouds don't obscure the top of the volcano, they can be viewed from many locations along the coast where most people reside. Moku‘āweoweo is a caldera—a large crater at the volcano's summit—and eruptions generally begin within its walls.

The eruption was visible from Hilo for the first two days before being obscured by a "dense cloud" (Coan, 1880). Later reports from other locations confirmed the eruption as being located within Moku‘āweoweo and producing a 3-km-tall (10,000-ft-tall) towering "column of smoke" by day that was lit by volcanic fires at night (Hawaiian Gazette, 1880a). Premonitory earthquakes were reported in the northeast portion of the island (Whitney, 1880), and Pele's hair—fine strands of volcanic glass spun as molten lava is ejected into the air—were described elsewhere on the east side of the island as "lustrous objects, like hair, were seen, carelessly heaped about Hilo" (Ko Hawaii Pae Aina, 1880).

The eruption was noteworthy in both the English- and Hawaiian-language media. S.P. Kalaau wrote,

> The lava has blazed again on the night of May 1st. We saw that the astonishing elderly woman has returned to her village at Mokuaweoweo. She has shown her exceptional light, it is evident here in Hilo. At dawn, we saw two smokestacks [probably referring to the volcanic gas plumes that looked like smokestack fumes] rising strongly in the atmosphere. The first smokestack fell strongly towards Kona. The second rose straight up. We saw her gray hair scattered on the streets of Hilo (Kalaau, 1880).

In a letter to the editors of the American Journal of Science, Rev. Titus Coan wrote, "Hilo is in a haze of sulphur smoke, and we see the sun as through smoked glass. We have a grand volcanic eruption" (Coan, 1880).

During the nine-day eruption (Hawaiian Gazette, 1880b), at least one adventurous group was able to witness the Moku‘āweoweo eruption from the crater rim. They reported seeing 300-ft lava fountains and a 300+ acre lava lake in the south end of the caldera (Lentz and Goodale, 1880), which was later verified by Hawaiian government surveyor J.M. Alexander (1886b).

After the May eruption ceased, a second expedition to the summit of Mauna Loa was reported by William T. Brigham (1888). Brigham, who had visited Moku‘āweoweo in 1865, returned to Hawai‘i and, with Ahuai, a Hawaiian guide, traveled to Moku‘āweoweo in July, where he saw fresh lava covering the crater floor but no activity: “The bottom of this lateral pit, as of the main crater, was comparatively level, without cones, and gave no indications of the source whence the fresh black lava had issued.” He also noted fresh lava on the crater rim. Ahuai had seen the tops of the lava fountains above the crater rim “as he was lying down some distance from the brink.” Brigham interpreted Ahuai’s observation to indicate a fountain height of nearly a thousand feet.

Alexander’s map of Moku‘āweoweo (Alexander, 1886; fig. 4) located three points of eruption—one at the southwest corner of the caldera and two others near the northeast and southwest caldera rims. Eruptions from vents on the rim may have given the illusion that the fountain height exceeded the height of the crater walls if one viewed them from a distance and assumed that the fountains originated on the floor.

During the subsequent quiescence, earthquakes were felt by Hilo residents in July and August. W.T. Brigham returned to the United States at the end of August. A severe quake was noted on September 25 in Kona, Hilo (Hawaiian Gazette, 1880c), and Kīlauea (Lentz, 1880b), and probably originated beneath Mauna Loa.

Figure 4. J.M. Alexander’s (1886b) map of Moku‘āweoweo with lavas erupted from three vent areas in May 1880. Red circles (added here) denote “points of eruption.” Eruptions from vents on the rim may have given the illusion that the fountain height exceeded the height of the crater walls if one viewed them from a distance and assumed that the fountains originated on the floor, as reported by Brigham (1888).

Northeast Rift Zone Eruption Started November 5, 1880

Mauna Loa erupted again in 1880, and it was first seen as an advancing lava flow at 7 p.m. on November 5 (Saturday Press, 1880). The higher elevations of the volcano were intermittently obscured by clouds and (or) smoke (volcanic gas or vog?), hindering any consistent observations over the next few days from the settled areas nearer the coast. Princess Lili‘uokalani, on her first night of vacation at the Volcano House hotel on the rim of Kīlauea Crater, was awakened at 2 a.m. by hotel staff (on November 6) to see nearby Mauna Loa volcano erupting (Lili‘uokalani, 1898).

The eruption started, not in Moku‘āweoweo where the May eruption occurred, but some distance to the northeast along the Northeast Rift Zone of Mauna Loa (Trusdell, 2012). One of the first observers of the lava flow was Hilo resident David H. Hitchcock (1880b) who was in Waimea on business when the eruption started. Waimea residents reported “a faint light reflected on the clouds above that point of Mauna Loa, which cannot be seen from here, Mauna-kea coming between” starting about 7 p.m. and increasing in brightness overnight. After several attempts to see the eruption by traveling around the west and south sides of Mauna Kea facing Mauna Loa, Hitchcock was finally able to get a full view on November 9.

> I found that the fire had originally broken out away up the mountain side, had flowed along the mountain to where the flow of 1855-6 had broken out, and at the same place again started down and running over the old flow a half mile or so had turned off on the north side of it and then had followed it right down on the north side until it reached what is called the middle ground [relatively flat ground between Mauna Loa and Mauna Kea, also called Aina Hou], and then had turned across the said ground and was flowing over the old ‘aa’ now on the north side of the middle ground (Hitchcock, 1880b).

Hitchcock and his group then visited the toe of the new flow (details in appendix).

> Oh, what a sight that was! Not twenty feet from us was this immense bed of rock slowly moving forward with irresistable [sic] force, bearing on its surface huge rocks and immense bowlders [sic] of tons weight, as water would carry a toy boat. The whole front edge was one bright red mass of solid rock incessantly breaking off from the towering mass and rolling down to the foot of it, to be again covered up by another avalanche of white-hot rocks and sand. The whole mass was at its front edge from 12 to 30 feet in hight [sic]. Along the whole line

Figure 5. “Night View 1880-1881, Eruption from Hilo Bay” by Charles Furneaux; courtesy of the National Park Service, Hawai‘i Volcanoes National Park. The date depicted in the painting was probably November 11, 1880 (Gaddis and Kauahikaua, 2018), and the two flows were probably the Ka‘ū (left) and the Kea (right). The Ka‘ū flow would not have been visible from Hilo Bay so it is shown here probably by artistic license.

> of its advance it was one crash of rolling, sliding, tumbling red-hot rock. We could see no fire or liquid lava at all, but the whole advance line of red-hot stones and scoriae (Hitchcock, 1880b).

Hitchcock's narrative describes a classic ʻaʻā lava flow. We are fortunate to have Hitchcock's observations because he knew the area between Mauna Kea and Mauna Loa very well as a resident of Hilo since the early 1850s who spent a lot of time there. Based on this information, we can estimate that the first flow advanced an average speed of about 6 km/d (3.7 mi/d) in the first few days.

Hitchcock guessed that this flow would not threaten Hilo; however, he speculated that if a pāhoehoe flow followed this ʻaʻā flow and advanced south of the 1855–56 flow, then that pāhoehoe flow might threaten the town. On November 9, the same day that he visited the front of the Kea flow, he noticed that a second flow started southward toward Kaʻū from the same vent area sometime before 2 a.m. (Hitchcock, 1880b). These start dates for the first two flows viewed from the north agree perfectly with those of Volcano House manager W.H. Lentz, who viewed the events from the south side of Mauna Loa (Lentz, 1880a).

The second recorded expedition to the saddle area between Mauna Kea and Mauna Loa was led by Wm. B. Oleson, headmaster of the Hilo Boys School and a recent arrival to Hilo, in mid-November (Oleson, 1880). Being a newcomer, Oleson's descriptions of his track and locations that he passed were sometimes inaccurate, as pointed out by Hitchcock in his report of the third expedition (Hitchcock, 1880a). What can be gleaned from Oleson's report was that the initial southbound flow was diminishing in activity and that he most likely visited the beginnings of the third (Hilo) flow between the 1852 and the 1855 flows.

A third expedition was mounted during the last days of November. David H. Hitchcock was asked to guide Professor W.D. Alexander, Surveyor General of the Kingdom of Hawaiʻi, to the new Mauna Loa flows in the saddle area (Baldwin, 1953). They first visited the northbound (Kea) flow that Hitchcock had described earlier in the month and found it hot but inactive, only having moved a few hundred yards since November 9. They then turned back toward Hilo and visited the third (Hilo) flow, an ʻaʻā flow that started from Mauna Loa's Northeast Rift Zone at a slightly lower elevation than the first two flows and that had advanced 20 km (12 mi) in about 20 days. The second, southbound (Kaʻū) flow was also inactive (Hitchcock, 1880a).

The arrival in Honolulu of the steamer from Hilo in late November brought the news that

> . . . the cresting of the demigoddess of the pit continues in several places on Hawaiʻi, and her beauty is liberated as the glow climbs up the walls of heaven. Her brilliance was seen from all over the island and even as far as the Maui group, the dark nights were shining this winter season. The gentle creeping continues in the fiery earth canals [na auwai ahi maluna o ka aina; probably lava channels]; it is indeed on the side turning towards Puna. Fear nearly descended on some people living where her raging fires turned towards the land (Ka Elele Poakolu, 1880).

Smoke and Vog Noted

Volcanic gas emissions, a major concern during the 1983–2018 Puʻu ʻŌʻō eruption of Kīlauea, and smoke from burning forests were also a concern for this eruption. Long-time volcano observer H.M. Whitney lamented, ". . . the eruption on Mauna Loa . . . continues, enveloping the whole of Hawaii in a dark atmosphere of smoke, which renders it difficult to see headlands or hills distinctly more than two or three miles in any direction" (Whitney, 1880). G.W.A. Hapai (1880) described being on a boat making stops along the shore of the Island of Hawaiʻi on November 17 and said, "The vast land of Hawaii was covered by 'ka uwahi Pele' [vog], making it impossible to see the shore, our prow was led by the magnet of the mariner's compass." At least one ship bound for Honolulu from San Francisco encountered "smoky appearance of the sky" 290 km (180 mi) to the east of the Island of Hawaiʻi (Pacific Commercial Advertiser, 1880a), which was probably volcanic fume from the 1880 vents located above the thermal inversion layer being blown eastward by high-elevation wind currents.

At this time, there was little concern about these flows. In mid-November, Whitney (1880) pointed out that, with multiple flows active, "the divided stream must greatly diminish the quantity of lava flowing into either section." Without good maps, most distance estimates were guesses perhaps based on travel times to the flow and back to Hilo. Best guesses put the flow moving toward Hilo at a distance of 26–32 km (16–20 mi).

Hawaiian-language writers noted that the Kea and the Hilo flows were advancing through the district of Hilo. One of the great Hawaiian sagas tells of attraction and conflict between Pele, the Hawaiian volcano deity, and Kamapuaʻa, a pig-god from Oʻahu, that was resolved by Pele dividing the island between them—Pele took Puna, Kaʻū, and Kona districts and provided Kamapuaʻa with Kohala, Hāmākua, and Hilo—to avoid future conflict (Kameʻeleihiwa, 1996). In 1880, Pele was again trespassing by erupting lava flows in Kamapuaʻa's Hilo district; several writers jokingly suggested taking western legal action against Pele for this transgression (Hapai, 1880; Kakaiana, 1880).

By the beginning of December 1880, the first two lava flows (Kea and Kaʻū branches of the 1880–81 eruption) were inactive and all erupted lava was feeding the third (Hilo) flow that continued advancing in a general northeast direction toward Hilo (Thrum, 1882; Coan 1881a). All flows were described as ʻaʻā in November with no pāhoehoe (Hitchcock, 1880a).

During the month of December, multiple observers confirmed that the flow sources were northeast of Mokuʻāweoweo from at least two distinct locations (J.A.M., 1880a). In addition, the Hilo flow continued to advance slowly toward Hilo and, during the month, was estimated to be 26–32 km (16–20 mi) from the town (J.A.M., 1880a, 1880b).

Also during December, Kalākaua, King of the Hawaiian Islands, commenced a tour of the coastal communities on the Island of Hawaiʻi for the purposes of recreation and assessing the sanitary conditions of his people (Pacific Commercial Advertiser, 1880c). Kahunas (Hawaiian spiritual leaders) stated that "if the King would visit the scene of the eruption, Pele's wrath would be stayed" (Pacific Commercial Advertiser, 1880b); however, no such royal visit was recorded.

Hilo Flow Continues Advancing into 1881

In January 1881, Rev. E.P. Baker hiked up to the summit crater of Mauna Loa, Moku‘āweoweo, located the source of the flows at a cinder cone called Pukauahi to the northeast, and confirmed that Moku‘āweoweo was not erupting (Baker, 1881b). The Hilo flow was pāhoehoe (J.A.M., 1881a) about 23–24 km (14–15 mi) from Hilo (Ko Hawaii Paeaina, 1881a).

Non-volcanic events in the kingdom started to complicate any government response to increasing distress caused by the active lava flow heading toward Hilo. In December 1880, quarantines were imposed on passengers who originated on the U.S. West Coast, where smallpox was raging (Carter, 1880). In addition, on January 20, 1881, Kalākaua made known his intentions to travel abroad, designated Princess Lili‘uokalani as Regent in his absence (Green, 1881), and departed on January 22, 1881 (Pacific Commercial Advertiser, 1881c).

Despite the quarantine and mandatory inoculation policies, smallpox succeeded in infecting several Honolulu residents so, on February 14, a further quarantine was imposed on inter-island travel—no passengers or baggage could be transported from O‘ahu to any other island (Carter, 1881). This policy effectively isolated residents of the Island of Hawai‘i and prevented tourists and residents from visiting the Mauna Loa eruption.

The Hilo flow continued to advance. In the first two weeks of February, newspaper articles reported that the flow was estimated to be 14 km (9 mi; J.A.M., 1881b) and 18 km (11 mi) from Hilo, remaining on the south side of the 1855–56 lava flow (Severance, 1881). The latter article also suggested that the older flow would present a barrier making it “impossible for the lava to get down into the town of Hilo.”

At least one Hilo resident was frightened enough to start packing to leave, but most people were not yet worried (J.A.M., 1881b). Two articles suggest that vog continued to be a problem. Hilo was “darkened by the smoke of the volcano” in early February (Ka Nupepa Kuokoa, 1881a) and coughing increased, possibly due to the duration of wind blowing from the south (Ka Nupepa Kuokoa, 1881b).

Images of the eruption and its lava flows were made by Hilo native Joseph Nāwahī after his wedding to Emma ‘Aima Ai‘i in Hilo on February 17, 1881. The couple spent their honeymoon at the Volcano House the following week, where Joseph made several landscape sketches that were preserved in the Volcano House Register (Nāwahī, 1881e). The first is a sketch of the

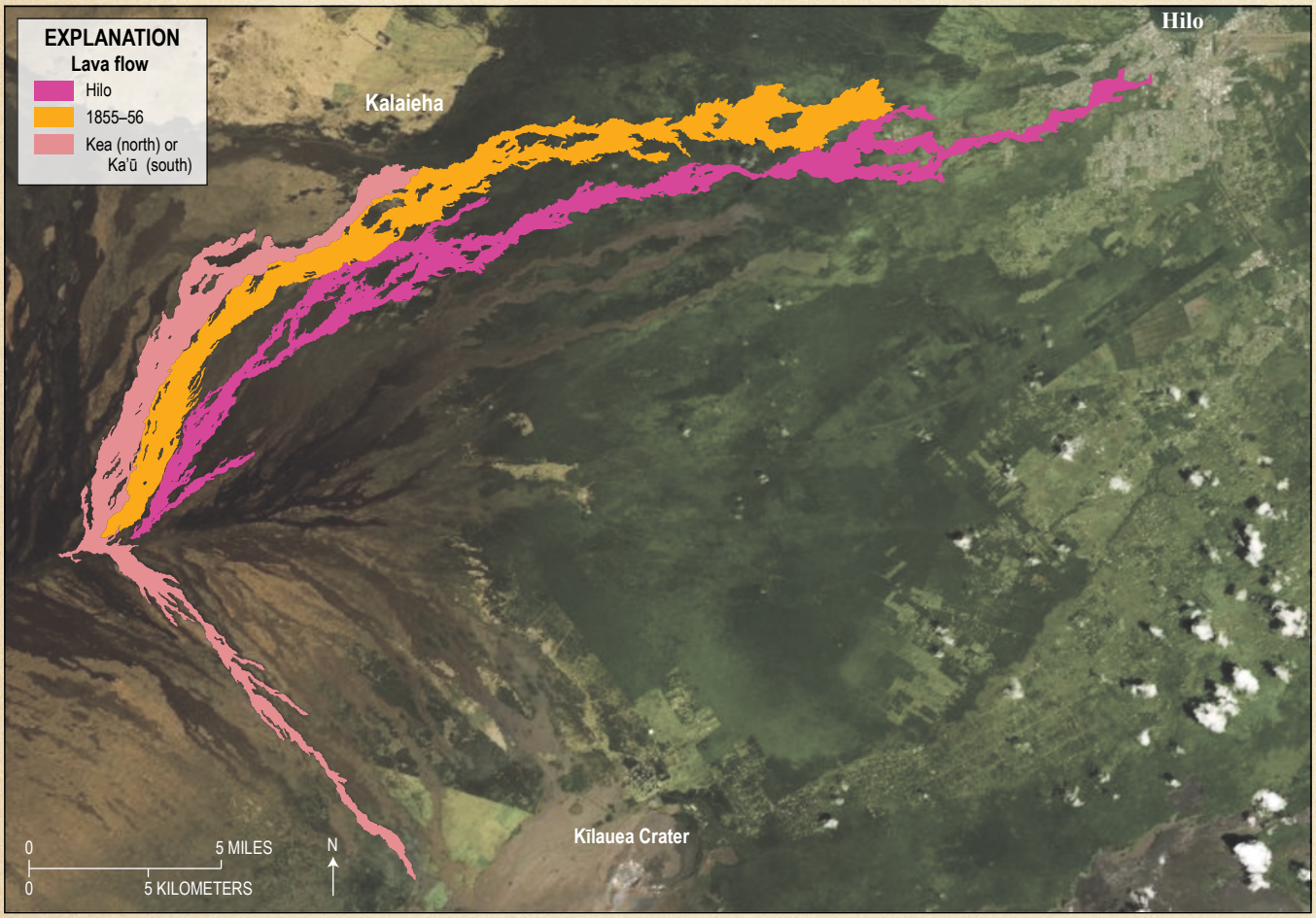


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Figure 6. Map of the three flows produced by the 1880–81 Mauna Loa Northeast Rift Zone eruption. The lighter-pink-colored flows (Kea and Kaū flows) were only active in November 1880, while the dark red/purple Hilo flow continued active for almost a year. The 1855–56 lava flow is shown in brown.

Northeast Rift Zone of Mauna Loa from the south and shows two volcanic plumes and the suggestion of a flow coming from the left plume, probably from Pukauahi, the source of the first two lava flows (fig. 7). The right plume probably marks the source or path of the Hilo flow through the forest on the other side of the ridge.

A second sketch by Nāwahī (fig. 8) shows a single plume from high on Mauna Loa and additional smoke sources just behind Hilo town. The low hills are probably the Hālaʻi Hills just behind the main part of Hilo. This scene was sketched in the Volcano House Register while the newlyweds were honeymooning there (40 km or 25 miles away from Hilo), so this image was from Nāwāhī's memory. The viewpoint is similar to a painting of Hilo done by Nāwahī in 1868.

Through March and early April, the flow continued to advance slowly along the south edge of the 1855–56 flow through the forest above Hilo, and various people estimated the distance to Hilo to be between 10 and 13 km (6 and 8 mi) (Nāwahī, 1881c, d; Coan, 1881b; Baker, 1881a). The first actual measurement located the lava flow 6.5 mi from Hilo in mid-April (Wetmore, 1881) where it had split near the toe of the 1855–56 lava flow. A month later, Furneaux (1881) reported seeing three branches, and Baker (1881a) explained the sequence of the splitting: ". . . the stream ran north-east and cooled, then east and cooled, then south-east and continued on." The northernmost (Hilo or Laumaia) branch was advancing around the toe of the 1855–56 flow, possibly threatening Hilo town.

Figure 7. Sketch of the Northeast Rift Zone of Mauna Loa from the Volcano House, showing two volcanic plumes and the Kaʻū flow branch (Nāwāhi, 1881e).

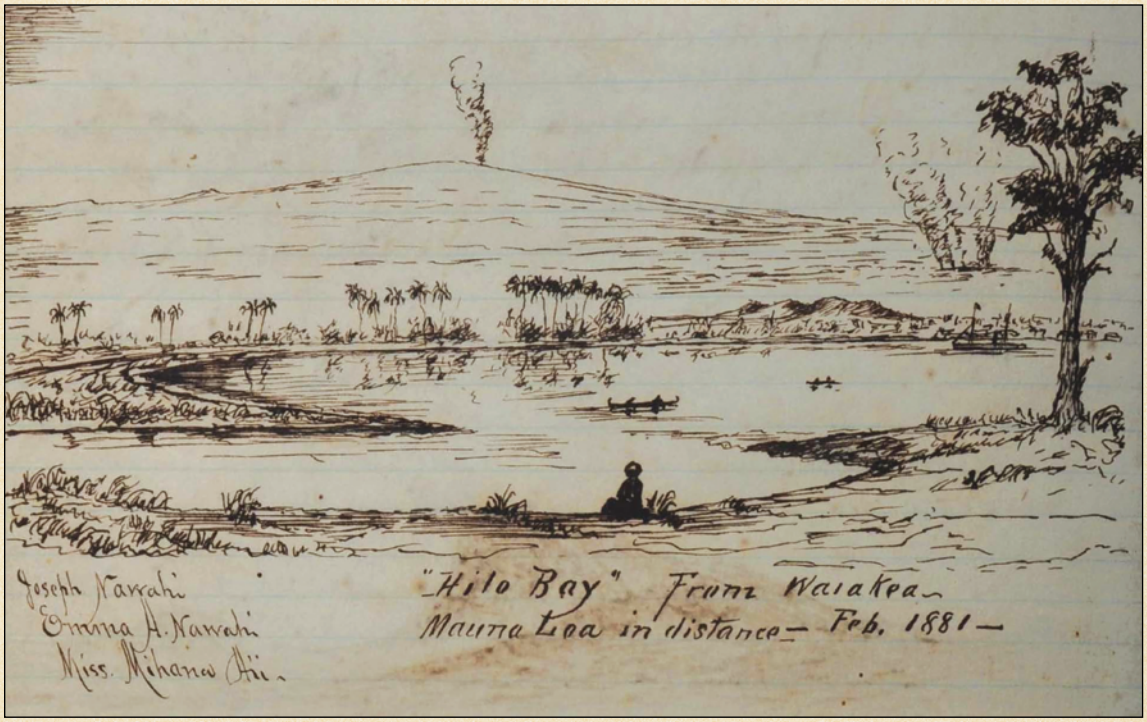


Figure 8. Sketch looking southwest showing the Hilo flow advancing toward Hilo town in February 1881. The smoke marking the flow front is above and to the right of Hālaʻi hill just behind Hilo town (Nāwāhi, 1881e).

> On the Sabbath morning, June 26th, the appearance of the lava was clearly seen downslope of the forest and it has left its forest home, where it has sullied for over seven months. As it flowed in the gulch directly towards Kalanakamaa and Alenaio with Kukuau, it affixed its gray banners [smoke plumes?] and waved them in the sky, and the town knows that with those banners, the lava has exited downslope of the forest (Wahinehuhu, 1881a).

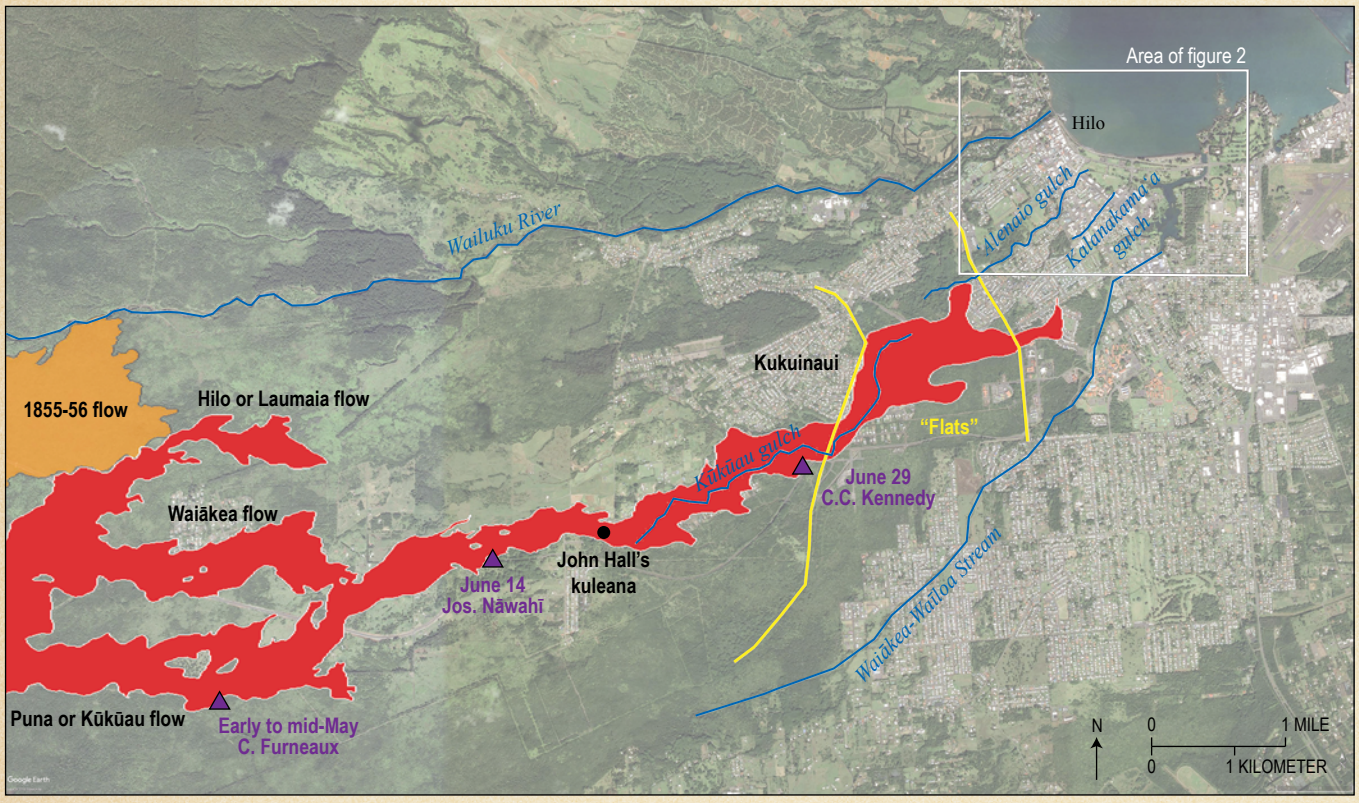
The southeast branch continued to advance toward Hilo. On June 28, Titus Coan (1881b) estimated that the southeasternmost branch was less than 5 mi from Hilo, while Nāwahī (1881b) measured 6,140 yards (5.6 km or 3.5 mi) to the flow from his house (which was another half-mile to Hilo Bay). Two days later, the flow advanced into Kūkūau gulch (fig. 9) to a point 4 km (2.5 mi) from Hilo, passing, but not consuming, the kuleana [homestead] of guide and bird catcher John Hall (sometimes referred to as Keoni Holo), the outermost resident above Hilo (J.A.M., 1881c).

David H. Hitchcock (1881b) described watching the flow enter Kūkūau gulch, then stall, followed by another breakout farther upslope:

> By Saturday [June 25] noon it had run a mile and was just above John Hall's house on the south side. On Monday morning [June 27] it was reported to have reached the flats [past Hall's home], back of Halai Hills . . . We rode up to it before dark and found that the stream was entirely confined to the gulch and intensely active . . . About midnight we noticed a diminution in the activity of the gulch flow and soon saw a bright red glare above the tree tops mauka [inland or west] of us and were presently startled by the burning gas bursts and the crackling and falling of the trees somewhere above us. The whole sky above us was lined with the light of burning trees and shrubs. . . we made the attempt to reach the scene of the great activity and succeeded by going up the south side of the gulch some quarter of a mile. . . The on coming [sic] overflow had swept over the banks of the narrow gulch and was flowing like water into a dense grove of neneleau and guava trees.

By late June 1881, Hilo residents were getting nervous and that affected real estate prices. On June 25, two lots of Hilo land were auctioned with sales at prices well below their pre-eruption value (Hawaiian Gazette, 1881a). On July 2, the acting governor of the island, Rev. F.S. Lyman, decreed,

> In view of the danger impending this part of the Island from the lava flow, it is hereby recommended, that, on Wednesday the 6th day of July, all places of business in the town and district of Hilo, be closed



Base map data from Google, DigitalGlobe 2019

Figure 9. Map showing the flow's advance on Hilo from May to June 1881. This detailed map shows several locations mentioned in the text: the "flats" (area between two yellow lines), Kalanakamaʻa, ʻAlenaio, and now-lava-filled Kūkūau gulches (light blue lines and labels), May flow branch names, Kukuinui kukui grove, Wailuku River, John Hall's kuleana (homestead), and Hilo town (boundaries of Baldwin, 1891b, shown in detail in fig. 2). Background is Google Earth image of present-day Hilo.

> from 11 A. M. until 3 P. M and that all persons who believe in an Almighty God look to him especially on that day, and so far as practicable, assemble in their several places of worship for that purpose, if so be He may be pleased to avert the threatening calamity, or prepare us for the result (Pacific Commercial Advertiser, 1881b).

Rev. Coan felt that the fasting and prayer approach was successful in halting the 1855–56 lava flow and had no reason to doubt that it would work again. In 1857, he wrote an essay on the subject which concluded, "That the lava stream which so long hung like a flaming sword over us, and which flashed so fearfully in our faces would have been arrested within five miles of our dwellings, and that, within seven miles of us, it should, for nine long months, have boiled and raged, … had there been no prayer, no fear, no fasting and no recognition of an Almighty God …" (Coan, 1857).

However, despite the call to prayer, the southern of the three flow branches continued down the Kūkūau gulch and, when it reached relatively flat terrain below 400 ft elevation, split again. The northern branch, called the Hilo flow, was reported to be very active and continued to advance down Kūkūau gulch to within 3.7 km (2.25 mi) of Hilo by July 7; the southernmost branch, called the Waiākea flow, was 7 km (4.5 mi) from Hilo but was nearing the Waiākea Sugar Mill (J.A.M., 1881d).

Destruction of John Hall's Kuleana on July 11

After being spared by the first pass of lava flow down a neighboring gulch at the end of June, the homestead of Keoni Holo, or John Hall (fig. 9), was destroyed (fig. 10) when the flow broke out well behind the front (described by D.H. Hitchcock above), filled what remained of Kūkūau gulch, and spread laterally beyond its edge (Kennedy, 1881b). In the process, the breakout consumed John Hall's house and property on the gulch edge (Hawaiian Gazette, 1881c), despite his supplications to the Hawaiian volcano deity Pele (Hawaiian Gazette, 1881b).

> In the letter of a native paper *Elele Poakolua* curious illustration of native superstition. The devastating lava had been for some time threatening the homestead of one Keoni Holo [John Hall], an old native, who had lived for thirty years on a pleasant Kuleana of about twelve acres, flourishing with well irrigated taro patches, potato patches, and choice fruit trees, within a short distance of Hilo. Keoni had faith that, although great Pele might not heed the prayers of foreigners, she would be touched by the offerings of a true keiki [son] of the soil. He offered his choicest pig to the advancing flood of fire, crying out: Aloha

Figure 10. The remains of John Hall's homestead that was destroyed on July 11, 1881, above Hilo. Photo courtesy of the Lyman Museum.

> o Pele. Mohai ia oe o Pele. Hail to thee, O, Pele. Receive my gift, O, Pele. And the dread goddess responded, with a puff of steam and a crackling flow of blood red fire, that smothered the squeak of the poor porker. Again Keoni stood before the advancing tide of fire; and offered chickens, ohia fruits, ohelo berries and a lock of his hair; but Pele was not to be coaxed by Keoni. Her cohorts of red wrath moved onward, licked up with a moments fizzle the flowing taro patches, crackled through the orchard, and with a flash and a flicker rolled over the old man's once smiling homestead; leaving overspread above the site, the burning floor of an inferno, a surface of twisted, serpentine folds, and coils of glassy black lava (Pacific Commercial Advertiser, 1881a).
>
> Five or six miles inland from our town there nestled, some twenty years ago, a quiet hamlet. There was a school-house in the place; and the land produced taro, potatoes, bananas, and other fruit-trees. The scenery was of enchanting beauty. But the population passed away; and of late years only one house remained on this lovely spot. Its occupant was reputed an inveterate heathen [Keoni Holo or John Hall?]. He belonged to the ancient class of native physicians or medicine men. When the burning flood struck the forest behind his house, he is said to have hoisted his flag in front of the slowly advancing lava, and to have forbidden it, in the name of the ancient gods of his race, to pass that flag. But onward came the flood, regardless of the edict. From time to time the heathen doctor was compelled to remove his flag to the rear, planting it nearer and nearer to his house; and at last the lava expelled him and his friends, and rolled over house, garden, and field, leaving a grisly pile of black lava over all. One circumstance in the case was curious. The lava stream surrounded a single kalo-plant, growing on an islet of eighteen inches in diameter, and on another one twice as broad, a single banana plant. They have survived the heat and are growing finely, the only green things left in the garden from which the idolater was driven (Coan, 1882).

Details of the Lava Flow and its Dynamics Emerge

During June and July when the lava flow was within easier reach of adventurous residents, observations were more frequent and perplexing. The lava flow didn't advance steadily but rather in pulses. Observers returning from the flow would alternately report its advance or its quiescence.

This behavior was best summarized by Titus Coan (1882):

> The surface of it soon hardens; the lavas below are sealed within a rigid crust that confines them on every side. Their onward progress is thus checked for hours or days. But as the tremendous pressure of the stream behind increases, the crust is rent, and the liquid lava bursts out and gushes forward or laterally for a hundred, five hundred, or a thousand feet or more, as the case may be. The surface of this extruded mass cools and stiffens in turn, again confining the living lava; then, with the pressure from behind, there is a fresh rupture in the confining shell. While the lava is held in check as I have described, the uninitiated visitor will pronounce the flow to have ceased. But it is only accumulating its forces. The lava presses down from the source, until suddenly the hardened crust is ruptured with a crash, the lava moves forward again, and a new joint is added to the covered way.

The pressure described by Coan is hydrostatic, provided by lava flowing in a conduit from the vent source to the toe of the flow. The conduit is variously described a "tunnel" (Baldwin, 1953), "viaduct," or "pyroduct" (Coan, 1882) and skylights (often called "blowholes" in the 1880 accounts) into the conduit, formed by collapses of the roof where one could look in to see lava passing through at high speed, were a major curiosity (for example, Hawaiian Gazette, 1881c).

Residents observed active lava running within water stream courses resulted in the streams running boiling water (Hawaiian Gazette, 1881c).

> Some of our streams are beginning to run boiling water; it is a mistake to suppose that when the lava enters and fills up a gulch it dries up the stream; the water continues running under the lava. As proof of the heat, a little dog which followed its owner up to the flow the other day, plunged into a pool and had all the hair taken off in a second, it died almost immediately (Hawaiian Gazette, 1881b).

Nāwahī (1881b) also described the scene on July 7:

> On this day I saw a stream flowing atop the pahoehoe, its water boiling creating steam columns in many places, countless tiny waterfalls rushing down the steep hills with the steam. Blistering bubbling water is tossing about in the spaces of the pahoehoe that is spreading in the river. . . When you touch the surface of the water, it is hot, but underneath where you sit is cool, and because of this, you can mix the water to your desired temperature, and when the water is stirred up, you can dive into the water and go down to the cold.

On July 20, the Hilo flow was advancing down Kūkūau gulch and began filling a small pond where, for the hour and a half it took the lava to completely fill the pond, many people viewed the spectacle (Hall, 1881). Artist Furneaux and photographer Menzies Dickson captured the scene in their respective media (fig. 11).

By July 25, the Kūkūau flow was nearly 2.25 mi from the sea as measured by chain (Hawaiian Gazette, 1881e). Two days later, this branch was less than 3.45 km (2.15 mi) from the sea (Wahinehuhu, 1881b). On August 4, Kawainui (1881) reported,

The nearest branch that is creeping towards the village is the branch of Kalanakamaa, and I estimate that only a half-mile remains before it roars on the government road of Kukuau. It is believed that the boundary where this lava is flowing will be the sea, because it is no longer believed that it will extinguish since it is so near. The families who are living where the lava is descending have taken their provisions from their homes and they are remaining in their homes until the very last moments in their own homes.

Figure 11. *A*, One of eight sequential photographs obtained by photographer Menzies Dickson on July 20, 1881. (Courtesy Lyman Museum.) *B*, Charles Furneaux painting of the July 20 cascade. (Courtesy Hawai'i Volcanoes National Park, catalog number HAVO 808.)

Quarantine Lifted; Help (and Tourists) Arrive from Honolulu

After 5 months, the smallpox quarantine order barring travel from O‘ahu was lifted and royalty, government officials, and tourists flooded into Hilo on the next two weekly steamer trips, according to the published passenger lists.

Beniamina (1881) was one of the first tourists to arrive in Hilo on July 21 and, after clearing himself with health officials, he rented a horse and inspected the flows:

> The area where the Lava was flowing is roughly 20 to 30 feet downslope of Kuikuinui, a kukui grove near the Kalanakamaa gulch; the lava was flowing in this gulch, its width 45 feet perhaps over the areas where the water would flow. Its distance was just a half-mile southeast from the famous hill named Halai. Its flow was similar to the pouring of hard poi from the barrel that it was stored, or syrup/molasses that was cooked in a vacuum pan and poured into tubs/tanks before entering Drying Machines. Its raging fire was similar to the fires of the Blacksmith preparing to beat out metals until flattened, heating one's cheeks, making it impossible for a visitor to stand long within 5 to 6 feet of where the lava was flowing, its burning is visible, and its rumbling heard as it entered the pools of water, sounding like sonorous puffing and blowing.

Beniamina (1881) also defined the drainage in which the lava was flowing:

> Kalanakamaa gulch [what some were calling Kūkūau gulch] runs from the mountain to the Northeast, on a diagonal path towards Kukuau for Waiakea, downslope of where the lava is spreading, the Kalanakamaa gulch has a branch descending into an area called Alenaio. It is believed that if the flow of the lava reaches this branch, and flows along Alenaio, then some wooden houses standing near this branch will be damaged. The distance from these branches until the government road in Kukuau leading to the Crater is less than three-quarters of a mile, but more than half-mile. If my calculations were correct, if the flow continued descending with this strength every day, then, Madame Pele would've passed the government road this past Thursday, July 28th, and she would take a long break to eat the fat anae and limu pahee of Waiakea for her dinner.

He returned to Honolulu on the next steamer on July 28.

The tourists almost overwhelmed Hilo. Hospitality, or ho‘okipa, was fundamental to the Hawaiian way of life (Fong, 1994) and, also, a Christian virtue. Without any hotels to speak of, Hilo residents opened their homes to the flood of visitors:

> Our friends at Hilo, are having a somewhat hard experience, the lava-flows threaten not only to burn them out of house and home, but the shoals of visitors, sight-seers &c., must be eating them up. There exists, so far as we know, not any hotel, or even restaurant in Hilo. Parties of two, three, or a dozen, go 'to see the flow' and Hilo's hospitality helps them, but really our excursionists ought to have some sort of delicacy in taking a meal here, or borrowing a horse there, and so on. The dwellers in Hilo are to be thanked by the general public; not only no panic, no shutting up and running away, but the usual open-hearted, open-handed hospitality even when destruction seemed to be near their doors (Saturday Press, 1881c).

The incoming flood of visitors included two notable travelers on two separate steamer trips—Princess Luka Ke‘elikōlani and Princess Regent Lili‘uokalani. The two royal women were the result of different royal heritages and life choices. Princess Ke‘elikōlani was the last of the Kamehameha line who inherited much of the Kamehameha lands, honored ancient Hawaiian traditions, and, despite knowing English well, spoke only in the Hawaiian language (Silva, 2006). Lili‘uokalani was the sister of elected King Kalākaua, heir to the throne, and the Regent in his absence abroad who had adopted Christianity at an early age (Lili‘uokalani, 1898) and spoke both Hawaiian and English.

Princess Ke‘elikōlani Arrives in Hilo on July 28

Princess Luka Ke‘elikōlani, also known as Princess Ruth, probably arrived in Hilo on July 28 (Hawaiian Gazette, 1881b). Few details were reported for the Princess's activities while in Hilo until she set up camp on Pu‘uhonu, the westernmost of the three Hāla‘i hills behind Hilo (fig. 12), by August 2:

> Luka Keelikolani, a native-born chief, is now in Hilo, relaxing with her people. She went on her first trip to lovingly greet the chiefess of the mountain at 3pm, August 2nd. And it was heard that she had a few treasured gifts to give to the chiefess of the mountains. Many went on the royal mother's sightseeing expedition, and they spent the night atop a hill. Tents were erected on that hill and she relaxed atop Haili throughout the day and night in order to see the activities of the woman of the crater, and because the view at night is more splendid (Hoaai, 1881a).

> On the 2nd, her Excellency, Princess R Keelikolani began her sightseeing ascent to Puuhonu; prisoners were the ones to pull her atop a carriage. The Road Superintendent of Hilo made a suitable road to the top of Puuhonu hill so the carriage could arrive there; tents are atop Puuhonua [sic], and when looking at its lights they look like balloons atop the hill. . .. The lava has neared Puuhonu, the third of the hills of Halai. (Kalana, 1881b).

Joseph Nāwahī (1881a) reported the same with a different means of transportation for the princess: "R. Keelikolani ascended on horseback from town; seven horses pulled her cart." Note that these letters were all written on August 4, the day that the steamer sailed from Hilo.

Princess Keʻelikōlani was not there as a sightseer; she wanted to respectfully ask Pele, the Hawaiian deity of volcanoes, to spare Hilo and go home. In an August 4 letter from a Hilo newspaper correspondent (J.A.M., 1881e), the Princess was reported to have thrown "some of the best brand of brandy into the lava." Oliver Stillman, her bookkeeper who traveled to Hilo with the Princess and Simon Kaʻai, recollected many years later that she approached the lava flow (probably the Hilo flow in the Kūkūau or ʻAlenaio gulch), prayed to Pele to go back home, offered her brandy, the Princess's red handkerchief and many other handkerchiefs, and prayed again. "The flow stopped at that point and did not flow a foot farther" (Palmer, 1924, p. 48–49); however, Mr. Stillman did not mention a date. Another eye-witness to Princess Keʻelikōlani's actions was Herbert Purvis. "Herbert returned to Kukuihaele [Hāmākua District north of Hilo] after witnessing this remarkable event, and immediately told his family in a letter home of the amazing effect of Princess Ruth on the lava flow, or the coincidence of events" (Hedemann, 1994); unfortunately, this letter was not located.

The north (Hilo) lava flow that was headed down the ʻAlenaio gulch stopped on August 6 (Pacific Commercial Advertiser, 1881e). The date of Princess Keʻelikōlani's ceremony was not noted but it must have been after August 4, no more than two days before the ʻAlenaio flow stalled; however, the event has become legend and, in the various versions of the story, the flow stops immediately after the Princess' offerings (Palmer, 1924) or, more commonly, by the next morning (Honolulu Advertiser, 1947). Hawaiians concluded that Princess Keʻelikōlani stopped the flow, which sparked concern amongst the missionaries of a return to "paganism" (Baker, 1881a), otherwise known as Hawaiian beliefs prior to western contact.

Figure 12. Photo of the flows probably looking southeast from Puʻuhonu (see fig. 14). The photo was almost certainly taken some time after the flows stopped. Note the lack of smoke and dead vegetation around the flow's edges and the cattle grazing unconcerned near the flow. The Kūkūau flow in the foreground is headed down the ʻAlenaio gulch while the distant Waiākea flow was advancing down and filling the Kalanakamaʻa gulch. See figure 9 for locations. Courtesy Lyman Museum.

There are a few bits of news about the Princess' movements in the Hawaiian-language newspapers between August 2 and 4 (necessarily curtailed because of the weekly steamer's departure on the 4th) but there is little mention of her in English-language newspapers until well after she returned to Honolulu. Her name could not even be found in the list of passengers on steamships returning to Honolulu from Hilo, nor was it mentioned that she was a guest at the birthday party for Princess Regent Liliʻuokalani in Honolulu on September 2; however, Hawaiian-language newspapers reported that her adviser, Simon Kaʻai, gave a speech at Kaipalaoa, the Hilo wharf, on August 25 (Kalana, 1881a) and that Princess Keʻelikōlani was leaving Hilo in a few weeks, accompanied by Kaʻai (Ka Nupepa Kuokoa, 1881c). Combining the two newspaper stories suggests that the Princess and Kaʻai stayed in Hilo for about a month before returning to Oʻahu.

Princess Regent Liliʻuokalani and Kingdom Officials' Lava Diversion Meeting on August 4

Movements of the Princess Regent were more completely reported. Princess Regent Liliʻuokalani, the Royal Hawaiian Band, and government officials left Honolulu on the next steamer arriving in Hilo early on the morning of August 4 (Pacific Commercial Advertiser, 1881a). During the day, many of the visitors, including the Princess Regent, found transportation and guides and visited the flows that were still advancing on the town. On August 4, the Hilo flow was directly south of Puʻuhonu in the ʻAlenaio gulch, the Waiākea flow had reached the Kalanakamaʻa gulch gradually creeping toward the shore, and, as mentioned, Hilo was flooded with tourists (Nāwahī, 1881a).

That evening, the Princess Regent held a preliminary meeting to discuss "whether anything could be done for the town, to save it from impending destruction" (Viator, 1881b). The Minister of Foreign Affairs, W.L. Green, was appointed chairman of the committee seeking solutions. Building many small walls to turn the flow away from valuable properties was suggested by Rev. F.S. Lyman. Sugar plantations were willing to supply the labor if the government would provide the tools, lumber, and a weekly food allotment to the laborers who would also build small shelters for those displaced by the lava flow. The consensus of the meeting, which was attended by Caucasian government officials, the Princess Regent, and House of Nobles member J.M. Kapena, was that "it was the duty of the Government to take the necessary steps to attempt to save Hilo." Mr. Kapena "was certain the natives would heartily co-operate and render all the assistance in their power. They would be pleased at seeing the efforts of the Government to take care of them." The steamer which carried this group to Hilo was held until a letter summarizing the results of this meeting could be written and sent back to Honolulu with A.S. Cleghorn (Viator, 1881b). It is unclear which natives Kapena was representing because he resided on Oʻahu.

> It was revealed during the speech of the Crown Princess inside Haili Church in Hilo on the evening of August 6th that she ordered her Husband [J.O. Dominis], the Minister of Foreign Affairs [W.L. Green] and other influential figures of the nation to support the belief regarding the seriousness of the lava spreading atop the village of Hilo, and that several buildings should be built at a separate site from the center of town as an area to house any remaining furniture and for families perhaps who are homeless due to the covering of the volcanic fire, the lava. They decided to order the government body and the Superintendent Public Works to personally go to the lava bed and to support any activity to control the damage from the lava over the devastated village. While we were in Hilo, we saw the arrival Mr. Stirling with his tools meant to detain the long descent of the lava into the village. Included among his battalions that were meant to combat the lava are strong explosives called dynamite in English. It is similar to the dynamite [we are familiar with], however it is stronger than dynamite. Never before in the history of the world has lava been extinguished with man-made hand tools, but Mr. Stirling is going with his implements of war to battle with Pele. If he should extinguish the lava with his implements of war, then he will be famous, but if not, handheld tools will be proven useless in the face of the lava, since it is said that fire is the element that is incomparable (Ko Hawaii Pae Aina, 1881b).

Lili'uokalani planned to stay in Hilo until the steamer returned on Thursday of the following week (August 11) on its weekly circumnavigation of the southern ports of the island. Until then, she remained in Hilo, visited the lava flow several times, was entertained at the houses of prominent Hilo residents, and attended church (Viator, 1881a). The Royal Hawaiian Band accompanied the Princess Regent and entertained Hilo residents several times during this week. The performances included the introduction of a new song, "Hilo March," composed by Joseph K. Ae'a, a band member, upon learning of the Princess Regent's request for the Band to join her in Hilo (Elbert and Mahoe, 1970, p. 50–51). The song was a tribute to Hilo and doesn't mention the lava flow threat.

Princess Regent Lili'uokalani boarded the steamer with her companions and the band at 8 p.m. on August 11 and continued around the island visiting her subjects at various stops before returning to Honolulu to celebrate her birthday on September 2 (Viator, 1881a).

Keaweamahi (1881) gave an excellent assessment lava of activity during week of the Princess Regent's stay in Hilo:

> Here are the impressions that we can recall about the lava above Laumania, that fire descends in a direct line towards shore, then it will completely sweep through Piihonua, Waianuenue, Wailuku River, and half of the homes along Waianuenue Avenue, before hitting Kaipalaoa (the coastal area at the foot of Waianuenue Avenue], however, I can say that this fire is very far from the village, it is up in the inland forested region where it is pushing down ohia and koa, perhaps 6 miles away from town. I will set aside my discussion of this fiery branch rooting through the forest.
>
> I can also report on the fire that spread throughout Kukuinui and consumed the home of Keoni Holo, swallowed whole by Pele, this is the fire that is surging like water on the Puna side of Puuhonu and Halai Hill, and running (like water) in the low-growing lehua groves of Mokaulele and the hala of Upeloa. This fire warmed the village and caused everyone to think that Kukuau would sink under if the fire were to cover it up. There are two branches descending to shore. The first is descending along the Alenaio Stream, its goal being Waiolama.
>
> When I departed Hilo for Honolulu, the flow front was on the Puna side of Puuhonua, its descent a gradual movement, I have estimated the distance of this fiery branch from that lava until Kukuau street that goes to Kau, is about 1 mile, it has slightly extinguished but there is fire inside of the pahoehoe.
>
> The second of the fiery branches is flowing on the branch near Kalanakamaa and Kalepolepo, this is the branch nearest to shore, and when calculating the distance of this fire, it is only half mile until the road going to Kau, and the Mill of Waiakea, this is the lava that will destroy Waiakea and other places (Keaweamahi, 1881).

Kennedy Built Rock Walls, Judge Severance Dug a Moat and Built an Embankment to Divert Lava

During this same period, at least two groups constructed their own barriers. C.C. Kennedy, manager of the Waiākea Sugar Mill threatened by the Waiākea flow, built

> a short piece of wall, just the width of the ravine. The lava reached there last Saturday night [August 6]; in the morning it was within about a foot of the top, it has been running there ever since, the lava has piled up [inflated] several feet higher than the wall, but has not advanced one inch to go on or over it. The lava worked over a knoll at the lower end of the wall and continued down this ravine. The second wall has now been put up, the whole length of the low place. The lava had reached it . . . [on August 10] (Hawaiian Gazette, 1881c; fig. 13).

The Hilo flow was proceeding down the ʻAlenaio gulch. Titus Coan, who lived in Hilo, wrote in his autobiography that "Judge Severance dug a moat around the Hilo prison, with an embankment seven or eight feet high," hoping to avert the necessity of a jail evacuation (Keaweamahi, 1881; Ko Hawaii Paeaina, 1881b; Coan, 1882); however, Coan did not record any preparations for his own home. Hilo jail was less than 100 m (330 ft) from the ʻAlenaio gulch while Rev. Coan's residence was more than 400 m (1,300 ft) away.

Government Aid Arrived on August 11 Just as the Flow Stopped Advancing, but the Eruption Continued

On the morning of August 11, the steamer arrived with the requested tools, supplies, and food needed to build lava barriers. In addition, Mr. Stirling of the Hawaiian Government Survey was onboard with some strong dynamite (Hawaiian Gazette, 1881b) and immediately inspected the Hilo and Waiākea flows. His plan was to use the explosives to blast open the lava conduit near the source, hoping that it would start another flow that could be directed away from town while stalling the progress of the original (Hawaiian Gazette, 1881f); however, there was no longer any need to execute this plan.

Both flows had behaved sluggishly during the previous week (J.A.M., 1881f) and the one headed down the ʻAlenaio gulch stopped on August 6 (Pacific Commercial Advertiser, 1881e) while the more southerly flow headed down Kalanakamaʻa gulch was finally pronounced dead on several different days: August 9 (W.E.C., 1881; Baldwin, 1953), 10 (J.A.M., 1881g), 11 (Coan, 1881d; J.A.M., 1881g; Hawaiian Gazette, 1881f; Martin, 1979, p. 168) or August 12 (Kahiehie, 1881). The flow had stalled before only to start up again, so the population was hopeful but unconvinced of its demise until the flow remained stationary for several days.

Rev. Titus Coan summed up the flow's end (Coan, 1881a): "Some say the wall stopped the flowing, some say that the offering of our old governess, Ruth's brandy, gin, food and cloth have pacified the Fire Goddess."

When Did the Eruption End?

The toe of the lava flow never reactivated after August 12, much to the relief of Hilo residents, but for the next couple of weeks, lava was found active several miles behind the flow front (for example, Castle, 1881; Hitchcock, 1881a). These observations suggest that the eruption was not over but that activity was weakening and receding from the flow front. Gas was still visibly venting from the flow's source on Mauna Loa (Kalana, 1881a).

The continuing eruption became of little concern to Hilo residents once the flow terminus was dead, but at least two

Figure 13. Post-eruption photo of one of the Kennedy rock walls. Note the hala (pandanus) trees of the ʻŪpeloa grove through which this lava flowed and in which the rock wall was built. See figure 14 for locations. Courtesy of Lyman Museum.

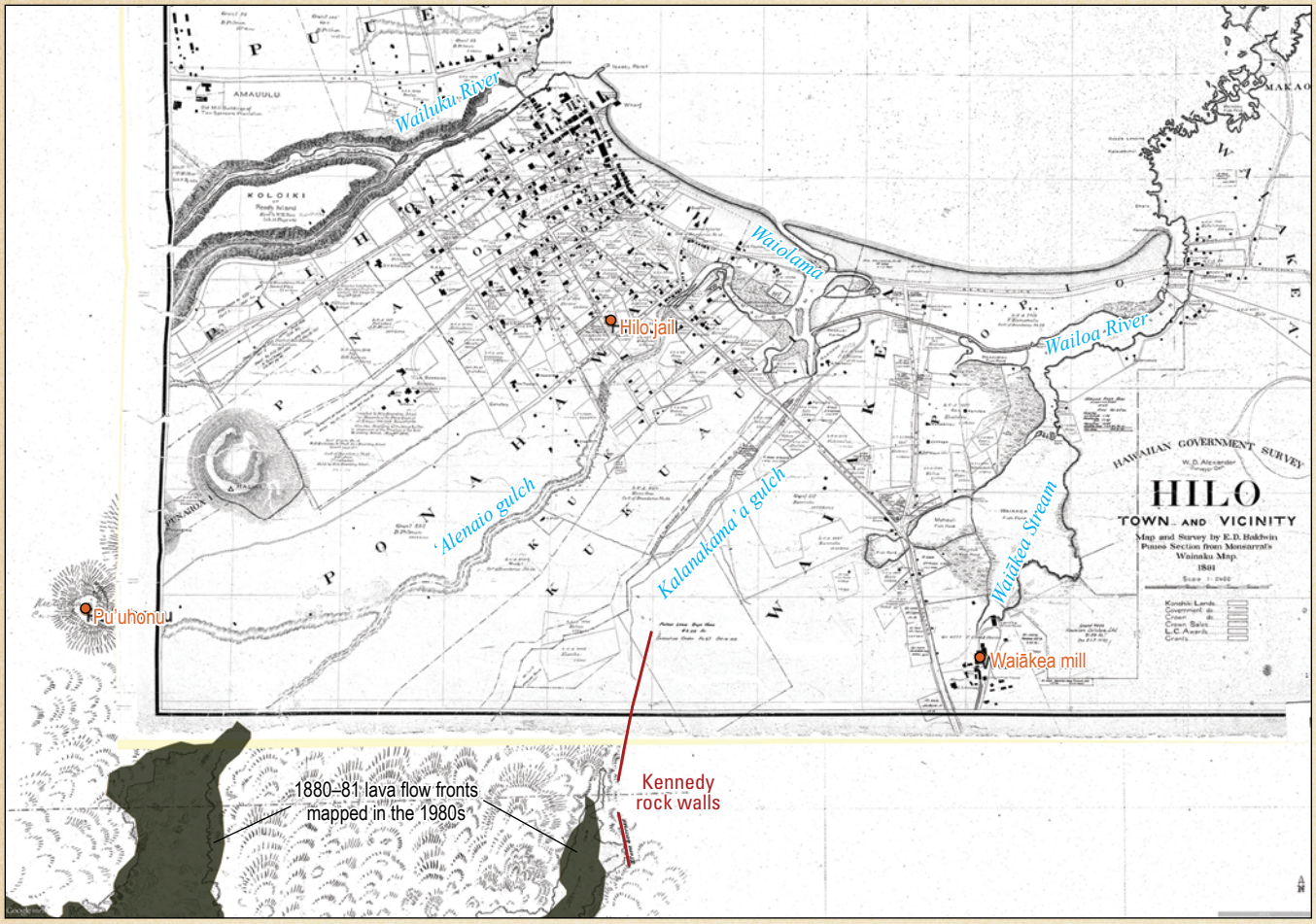


Figure 14. Map of Hilo around 1890 and the lower extent of the flows showing the Kennedy walls and the Hilo jail. The black, filled polygons in the lower left corner of the figure are the flow fronts of the 1880–81 lava as mapped in the 1980s (Trusdell and others, 2006). The Hilo map (Baldwin, 1891b) is laid over a map of the lowest part of the 1880–81 flows right after they stalled on August 1881 (Lawrence, 1881). Note “Waiākea Mill” on Waiākea Stream in the lower right corner of the 1891 map.

observers recorded the eruption’s delayed demise. David H. Hitchcock (1887) recollected that although the 1880–81 lava flow stopped in August, it was still active on the side of Mauna Loa until the middle of November. Capt. Dutton, who arrived in Hawai‘i in 1882, reported that the “eruption ... lasted until October, 1881” (Dutton, 1884, p. 154–155).

Commemoration of the End of the Lava Flow Threat

After months of growing anxiety, the people of Hilo were grateful to be spared. On September 2, they met and agreed to establish a memorial institute to “afford the people of Hilo village and district the privilege of newspaper, magazine reading, writing, museum and art collection rooms, and public library” in commemoration of the cessation of the flow (Saturday Press, 1881b).

Governess Kekaulike set aside two days, September 18 and 19, “to praise the Almighty God for His kindness and Compassion in saving the village of Hilo from His Lava’s fiery wrath” (Hoaai, 1881b). Services included the reading and singing of a hymn about the lava in Hilo. The event was commemorated a year later in August 1882 by a large lū‘au staged in the Kūkūau gulch immediately in front of the now-cooled lava flow (Ulumaialii, 1882). The end of the lava flow threat was agreed by all to be celebrated annually; however, the 1882 lū‘au was the last such celebration noted by Honolulu newspapers.

Kalākaua returned to Hawai‘i in late October (Hawaiian Gazette, 1881d) and, on his birthday on November 16, delivered a short speech recognizing the smallpox epidemic and touting his trip around the world (Pacific Commercial Advertiser, 1881d). He did not mention the Hilo lava flow in his speech, but he did visit it on a December trip to Hilo (Saturday Press, 1881a).

Conclusions

The purpose of a detailed reconstruction of this eruption and lava flow threat to Hilo is to learn how the lava flow behaved, how it impacted the town of Hilo and its people, what measures were taken to mitigate its effects, and how we might be able to better mitigate the effects of the next lava flow threat. It's useful to look at conclusions that were drawn at the time and what we can conclude from the viewpoint of the present with another century of experience with Mauna Loa.

The 1880–81 Eruption Sequence Started with the May 1880 Eruption in Moku'āweoweo

"All historically recorded Mauna Loa eruptions started in the summit area, and approximately half have stayed in the summit" (Trusdell, 2006). Most summit and rift zone eruptions are separated by minutes to several days. The May 1880 eruption occurred only in the summit caldera, while the later eruption in November was from Northeast Rift Zone vents and was not accompanied by summit caldera activity. The period between these two phases of the eruption was about 6 months, making it the longest summit-rift-zone eruption lag in the recorded history of Mauna Loa volcano.

W.T. Brigham (1888) reported that, at the time of his July 1880 ascent of Mauna Loa, he felt that the May eruption was the "avant courier" of a great eruption; however, there was no recorded mention of this forecast at the time of his July visit, only his report of the trip several years afterward. Brigham left the Kingdom of Hawai'i for the United States at the end of August 1880—two months before the Northeast Rift Zone eruptions started.

Three Different Mauna Loa Northeast Rift Zone Vents Erupted the 1880–81 Lava Flows

In 1882, geologist Clarence Dutton (1884, p. 133) visited the source area for the three 1880–81 flows and found that each was erupted from different vents. The westernmost vent erupted the Kea flow and the easternmost erupted the Hilo flow.

> The uppermost of these large vent holes gave rise to a stream of lava of enormous dimensions which flowed more than half a mile wide down the northern slopes of the mountain, reaching nearly to the base of Mauna Kea and spreading out on the intervening plain between the two great volcanoes, ... This constituted the first part of the eruption and flowed for about three weeks [Kea branch]. Soon afterward another vent opened along the same line of fissure about a mile further down the mountain slope and gave issue to the Kau branch of the flow, which has a length of about 10 miles and a width varying from half a, mile to a mile and a quarter. Still again along the same line of fissure and about half a mile further down the slope broke out the principal branch of the eruption which flowed down the northern side of the mountain into the intervale between Mauna Loa and Mauna Kea, then deflected to the right and flowed eastward to within half a mile of the town of Hilo. The length of this branch of the flow is about 45 miles and the width vary from half a mile to 3 miles. No cone was formed at any of the three upper orifices (Dutton, 1884).

Dutton's descriptions of the source vents are particularly valuable because the upper two vents were overrun by later eruptions. Vent migration away from the summit during the eruption was common and also occurred during the 1935, 1942, and the 1984 Mauna Loa Northeast Rift Zone eruptions.

'A'ā is Followed by Pāhoehoe During an Eruption

The 1880–81 eruption of Mauna Loa again demonstrated the general progression of 'a'ā flows at the beginning of the eruption transitioning to pāhoehoe flows with time. "The first flow of 1881 outbreak was aa, which changed to pahoehoe; the pahoehoe flowing from the source over the aa. The change probably took place when the fire seemed to cease. The pahoehoe came out of a long crack, which can readily be made out today. The lava must have poured out quietly, otherwise a cone would have been built" (Hawaii's Young People, 1901); this last observation matches those of Dutton (1884). The note about "when the fire seemed to cease" probably refers to what one saw from a distance. While 'a'ā flows were active, their channels would have been seen as bright, incandescent streams at night. The transition to pāhoehoe internalized more of the incandescence in lava conduits so that, from a distance, only spots of light from individual breakouts might be visible in the dark. The Hilo flow was first reported to be pāhoehoe early in January 1881 (J.A.M., 1881a). This general sequence has been established as typical for lava flows erupted from Mauna Loa and Kīlauea volcanoes. 'A'ā lava flows form at high eruption rates, usually in the initial stages of an eruption, while pāhoehoe lava flows form at lower eruption rates later in the eruption sequence (Rowland and Walker, 1990).

Jack Lockwood (written commun., 2019) found no 'a'ā anywhere on the surface of the Hilo flow and points to the lack of a cinder/spatter cone around the vent of the Hilo flow, common on vents erupting 'a'ā flows, as further evidence that this vent erupted only pāhoehoe lava. We can only note Jack's observation along with the eyewitness reports to the contrary and allow for the possibility that the lengthy eruption of pāhoehoe may have covered all signs of the earliest 'a'ā including any near-vent structures.

The Formation of Pyroducts or Lava Conduits Necessary for Long Flows

Rev. Titus Coan first observed molten lava flowing in subterranean tunnels as he hiked up his first active Mauna Loa pāhoehoe flow in 1843; he coined the term "pyroduct" to describe them:

> The lava on which we were treading gave indubitable evidence of powerful igneous action below, as it was hot and full of seams, from which smoke and gas were escaping. But we soon had occular [sic] demonstration of what was the state beneath us; for in passing along we came to an opening in the superincumbent stratum, of twenty yards long and ten wide, through which we looked, and at the depth of fifty feet, we saw a vast tunnel or subterranean canal, lined with smooth vitrified matter, and forming the channel of a river of fire, which swept down the steep side of the mountain with amazing velocity. The sight of this covered aqueduct or, if I may be allowed to coin a word, this pyroduct—filled with mineral fusion, and flowing under our feet at the rate of twenty miles an hour, was truly startling (Coan, 1844).

The same conduits were observed in the pāhoehoe flows of 1855–56 (Coan, 1856) and 1859 (Lyman, 1861).

The importance of pyroducts or lava conduits was reaffirmed in 1881, as many observed lava flowing within these subterranean tunnels or conduits downhill clearly supplying new lava to the toe of the flow.

> For the last two months nearly, has this flow poured down the mountainside, and it seems to make for itself a tunnel or casing, of cold lava, whilst this heated molten rock flows in a sort of tube of its own construction. This casing, or tube, or tunnel, of cooled lava is so impervious a non-conductor of heat, that we see red-hot, sometimes white-hot lava which has traveled over five and thirty miles without giving off its heat; but the moment it is exposed to the action of the atmosphere its heat is given off and it becomes a solid hard slate-colored surface. Now if this great conduct were broken up the lava flow might be taken in hand as it were, rendered a little more tractable (Saturday Press, 1881c).

Not only were the conduits recognized, their function was understood well enough so that the use of explosives was planned to disrupt the conduit. If the conduit could be opened far enough behind the lava flow front to rob the existing flow, it could feed a new flow at a greater distance from Hilo and stall the existing, more threatening flow. This general idea was tried during the Mount Etna eruption of 1669, when pickaxes were used by citizens to open the lava conduit (Scrope, 1862), so it is possible that some in Hawai'i were aware of that effort and wanted to try it in Hawai'i. More recently, the same basic method was used, with explosives instead of pickaxes, to successfully divert Etna lava flows in 1983 and 1992 (Barberi and Carapezza, 2004).

Today, lava conduits and flows are routinely monitored for assessment of hazards posed. Experimental methods have been used to track the volume rate of lava flowing through the conduits as a measure of the vigor or health of the lava flow (Kauahikaua and others, 1996).

The Long- and Short-Term Advance Rates of the Kea and Hilo Flows

The Kea flow was about 24 km (15 mi) long when David Hitchcock approached it on November 9; it had advanced very quickly at a rate of about 24 km in 4 days (d) or 6 km/d (3.7 mi/d). This is the about the same average advance rate observed for the Mauna Loa 1984 lava flow from its lowest vent before its supply was diverted from its channel by upstream breakouts (Lockwood and others, 1985).

The total length of the 1880–81 Hilo flow was about 47 km (29 mi), and it had an average advance rate of about 5.5 km (3.4 mi) per month, a little slower than the 1855–56 flow that advanced 40 km in 6 months at an average rate of 6.7 km/month (4.2 mi/month). Over the last 40 days of its activity, the Hilo flow advanced almost 5 km at an estimated average rate of 3.8 km/month (2.4 mi/month); however, the flow did not advance steadily during the last 2–3 months. Coan reported that the daily advance rate varied between 100 and 500 ft/d which is equivalent to 0.9–4.6 km/month (Coan, 1882).

The sporadic advance of pāhoehoe was unexpected and only became evident when the flow advanced through the forest surrounding Hilo, allowing it to be easily accessed. The non-steady advance was not interpreted as a hopeful sign that the flow was slowing. "The advance of the flow has been all along fitful, irregular, and by alternate starts and halts, so that we do not feel inclined to congratulate the people of Hilo and the kingdom in general, on the improved prospects, judging from the cessation of advance at the foot, so much as from the reported changes of appearances at the fountain head" (Saturday Press, 1881c).

At least two observers noted a possible periodicity to the surges: "These pulsations have occurred, so far, about every other week, and perhaps may so continue till this volcanic eruption is finished; if so, perhaps the coming week may bring startling news of a renewed progress. That activity still continues under the surface is more than demonstrated by what is seen through various vents" (Hawaiian Gazette, 1881c). "In the eruption of 1880-1881, when the lava was flowing from Mauna Loa toward Hilo, and the front end of the flow was many miles from the source upon Manna Loa, it was noticed that the stream would sometimes come to an entire standstill and then break out with renewed vigor at Intervals. These were Intervals of about a month" (Lyons, 1902).

The lava flow eventually stopped advancing, but the vent and upper parts of the flow probably remained active for another

2 or 3 months. This pattern was similar to the Mauna Loa 1855–56 lava flow, which advanced toward Hilo for 6 months before it stalled. The vent and upper portions of the lava flow remained active for another 9 months until the eruption ceased (Coan, 1882, p. 289–312). Coan suggested that the ʻaʻā flow stalled but that a pāhoehoe flow advanced slowly behind the stalled ʻaʻā front until the eruption ended. For the 1880–81 lava flow, the ʻaʻā phase lasted less than 1 month, and the pāhoehoe flow was active for possibly 10 months.

The sporadic stop and start of the 1880–81 lava flow is also very similar to that observed for pāhoehoe flows that inundated Kalapana, Hawaiʻi, in 1990, where lava flow inflation was studied for the first time (Hon and others, 1994), and the flow that approached the town of Pāhoa in 2014–15 (Poland and others, 2016; Patrick and others, 2016). Inflation occurs when the lava conduits are completely full and crustal growth continues both above and below the molten lava stream, causing the lava surface over the conduit to rise or inflate. Once the internal fluid pressure exceeds the strength of the crust, a breakout occurs and possibly forms a new lava conduit. This behavior does not necessarily occur in the period just before the end of lava flow activity, but it sometimes heralds a decrease in lava supply to the flow front, as in Pāhoa in 2014–15.

Public Reaction to the Lava Flow Threat

As the threat increased, more people collected their valuables and moved away to the homes of friends or relatives. Until the Princess Regent arrived on August 4, the government did not have a plan to accommodate refugees from the lava flow. The highest civic authority on the island was Rev. F.S. Lyman who was Acting Governor while Governess Princess Kekaulike was on Oʻahu. He, along with fellow clergy stationed in Hilo, instituted the day of prayer and fasting on July 6.

Real estate values dropped, as shown by the one report of a land auction on June 25 (Hawaiian Gazette, 1881a).

Public Perception of Mechanical Diversion Efforts

Many commented about the untested rock walls and their possible effectiveness; the comments ranged from supportive to derisive. A few examples follow:

> Messrs. Kennedy and Richardson have been very busy all this week building a wall along the side of the ravine at a low place where the lava might run down, cutting off their railroad track just beyond Mr. Kennedy's house where the trestle spans the ravine, they first put up a short piece of wall, just the width of the ravine. The lava reached there last Saturday night [August 6]; in the morning it was within about a foot of the top, it has been running there ever since, the lava has piled up several feet higher than the wall but has not advanced one inch to go on or over it. The lava worked over a knoll at the lower end of the wall and continued down this ravine. The second wall has now been put up, the whole length of the low place. The lava had reached it when I was there yesterday [August 10] (Hawaiian Gazette, 1881c).

> We have built a good deal of stonewall. One place we put up for a trial 4 feet high and 3 feet thick, just in front of the lava to give it a good test; well, it never touched the stones to put it out of its place, but when near to the level of the stone it actually rose 7 feet above and did not come over (Kennedy, 1881a).

> Due to the Waiakea sugar mill owners' anxiety at the approach of the lava towards their existing assets, they have attempted to build a tiny rock wall either to look at the lava's demolition or ascend over that rock wall. During that attempt, I witnessed the lava's flow toward that wall and touch that rock wall, but it didn't cause the wall to tumble, and it didn't tread over that wall, but the lava did circle around its sides and mound up into tall pahoehoe piles on the side where it flowed from. That wall then looked small in comparison and was like a tiny child under a pahoehoe mound. Recently, the sugar mill owners of Waiakea have reattempted to build a long rock wall makai of the tiny rock wall described above, the intent was to cause a division where the lava is descending. The height of that wall is over 6 feet, and I have seen the lava descend and touch that wall, however it did not climb over the wall, it did however flow at the base of that wall on a route that the owners believed it would travel (Ulumaialii, 1881).

> A good deal of sport has been made of a stone wall which, as is generally believed, was built across the front of the 1881 flow. But this wall was only built across the head of a small branch of the flow which was working its way towards the Waiakea mill. It was clear that the flow was nearly exhausted. Two small branches had been sent out on either side — that near the Halai Hills had ceased to flow, but the other crept on. The wall was built along a rise where a shallow water run made a sharp turn. The wall was evidently intended to keep the lava in this water run, which it was following. … It is about a hundred yards in length, and, … is a very well built wall. The wall was never tested, for the flow followed the water run. However, the lava pushed up close to the wall, just touching and rising above it at one of the salients (Hawaii's Young People, 1901).

> Here is a surprising fact, the sugar plantation haole of Kapunakea [C. C. Kennedy and crew] have constructed a large wall in order to block the strength of the lava. Burst into laughter (Kalana, 1881b).

What We Learned from Revisiting the 1880–81 Lava Flow

Social Bias in 1881 Reporting

The available English- and Hawaiian-language newspapers were apparently pro-missionary. Although they did not openly condemn Princess Ke‘elikōlani and her efforts to stop the lava flow via ancient rituals (perhaps because of her social position), they did look down on commoners who made offerings to Pele at the leading edge of the lava flow.

> The activity of the people before the Lava—Even in this enlightened era, there are many people who call Pele a God, and because of this, some have gone with gifts for Pele, saying ‘Here is a Gift, may you all return to the mountain’; some worship before Pele with awa, rum, and pig atop a water spring, and give their offerings to Pele, requesting that Pele spare the water spring and return to the place from whence she came. Here is what Pele did, the pig was devoured by the fire of Pele, the awa and fish, the spring was filled with rock piles, and Pele did not return mountainward, Pele is continuing her march to sea, a half mile remaining. I have witnessed these activities of man firsthand, Hawaiians wasting time during this Christian age (Keaweamahi, 1881).

> Hawaiian superstition in regard to the fiery goddess Pele is curiously illustrated at Hilo these days. The crowds who daily visit the flow make many offerings to the enraged deity, largely in the shape of coin, small and large, which are thrown on the surface of the flowing mass. But it is interesting to observe that most of the offerers stand by to watch and see that no avaricious looker on extracts the coin till Pele has melted it into herself (Hawaiian Gazette 1881c).

This bias suggests that the newspaper accounts were not objective insofar as reporting the viewpoints of all Hawaiians. While they did not publicly condemn Princess Ke‘elikōlani, they carried only minimal news of her whereabouts and deeds during her visit to Hilo in 1881.

Modern journalism tries to incorporate multiple points of view and even encourage the reporting of Hawaiian views as the host culture (Corrigan, 2014; Associated Press, 2018).

The Three Branches of the Mauna Loa 1880–81 Lava Flow Were Not Always Mapped Correctly

For more than a century after the eruption, only one or two of the three flows and were portrayed in maps until Rowland and Walker (1990) and the geologic map of the Island of Hawai‘i (Wolfe and Morris, 1996) were published. From the 1892 map of Baldwin to the geologic map of Stearns and Macdonald (1946), the lava flows on the north flank of Mauna Loa were variously identified as from the eruptions of 1855–56, 1899, or partially from 1880–81. Using the detail of historical accounts (for example, Hitchcock, 1880a), the contemporary place names on early maps (such as Baldwin, 1891b), and geochemical lava-flow fingerprinting techniques, we were able to identify the Kea flow amongst all flows in the area of the Humu‘ula saddle (appendix). Even Capt. Dutton (1884, p. 156–157), who had correctly identified the three flows from a vantage point at the vents, didn’t recognize the Kea flow when he came up against the lower end of it on his way from Hilo to the summit of Mauna Kea: while traveling west on the 1855–56 lava flow, “… we found ourselves confronted by a high barrier of clinkers stretching far out towards Mauna Loa on the left and plunging into the forest on the right. Turning sharply to the right the trail crosses several spurs of this ridge of clinkers and at length leaves the lava field and enters the forest.” His words describe exactly the path of the old Saddle Road (prior to the construction of the Daniel K. Inouye Highway), around the toe of the Kea flow.

The Lava Flow Followed and Filled Stream Channels, Erased Locations, and Added New Ones

The 1880–81 lava flow changed the way that surface water drained into Hilo Bay. Prior to 1881, there were four stream courses that drained into Hilo Bay—The Wailuku River, the ‘Alenaio and the Kalanakama‘a gulches that both drained into the Waiolama ponds before flowing to the sea, and Waiākea Stream that flowed via the Wailoa River to the sea (see fig. 14). The tendency for lava flows to use stream channels logically results in changes to drainage patterns, and the 1880–81 lava flow was no exception. The Hilo flow completely filled ‘Alenaio (Kūkūau) gulch above 73 m (240 ft) elevation thereby cutting off some tributaries of the Wailuku River and diverting their flow into the ‘Alenaio drainage. The Waiākea flow partially filled the Kalanakama‘a gulch and diverted water to either the ‘Alenaio gulch or the Waiākea Stream. The result was that Kalanakama‘a gulch was abandoned and only used as a land boundary after 1881 (Lyman, 1901) and increased flow went into the ‘Alenaio gulch which, to modern times, has repeatedly flooded despite multiple efforts to contain the flow during the rainy season (Lockwood and Buchanan-Banks, 1981).

Lava flows bury surface features, destroying places and erasing their names. Kūkūau or Kalanakama‘a gulch, Kukuinui grove, ‘Ūpēloa (hala grove), and Mokaulele (an ‘ōhi‘a grove whose lehua are famous in legends and chants; Pukui, 1983, #2252) were inundated by the 1880–81 pāhoehoe flow. The hala trees that must have made up the ‘Ūpēloa grove can be seen in many of the lava photos (for example, fig. 12); the ‘Imiloa Astronomy Center was able to preserve part of the grove on its grounds (‘Imiloa Astronomy Center of Hawai‘i, 2015). The Mokaulele name was carried on only as a 1940s development along Mohouli Street in Hilo, built over the toe of the Waiākea flow (fig. 15; Murray and Fernandez, 1947). Waiola spring, important enough to induce Hawaiian residents to ask Pele to spare it, was also covered (Keaweamahi, 1881).

The lava flow also created a new location. Kaumana Cave is now a popular tourist site and a Hawai‘i County Park, where visitors can explore a part of the lava conduit system that supplied lava to the advancing front during the summer of 1881 (County of Hawai‘i, 2005). The opening, or skylight, to the main cave was also a tourist curiosity when the flow was active; visitors could see lava “rushing along two or three feet below” the opening (Hawaiian Gazette, 1881c).

The two lava flows immediately west of Hilo provided a good path for a cross-island road. Prior to the emplacement of the 1855–56 and 1880–81 flows, the path west from Hilo to the base of Mauna Kea was a difficult one over mostly swampy, densely forested ground (Dutton, 1884). The lava flows that threatened Hilo later offered an ideal path westward. In 1881, the upper end of Kaumana Road, near where John Hall’s residence was located, was covered by the 1881 pāhoehoe; today, Kaumana Drive (formerly Kaumana Road) connects with almost 10 km of State Highway 200 built on the 1881 pāhoehoe flow. The highway continues west for another 20 km built on the adjacent 1855–1856 lava flow.

The lower reaches of the 1881 pāhoehoe flow are now densely wooded with ‘ōhi‘a trees and are not recognizable as a recently active lava flow without a geologic map. Hilo residents are surprised when the extent of the 1881 flow into Hilo is revealed (fig. 15).

Lava Diversion in Hawai‘i was First Tried in 1881 and Is Controversial Today

The 1881 plans for lava diversion by the Kingdom and the private efforts to build barriers were the earliest known attempts at lava diversion in Hawai‘i. The barriers were built in front of the advancing flow to deflect lava away from valuable resources and explosives were planned to disrupt the lava flow supply near its source. The residents of Catania, Sicily, had tried with hand tools to divert a flow from Mount Etna in 1669 (Scrope, 1862), but that effort was unsuccessful because the residents of Palermo, a town that would have been endangered by a diverted flow, chased the Catanians away.

Today, lava diversion is still controversial—the Hawaiian community generally prefers not to interfere with lava flows (for example, National Public Radio staff, 2014); however, 1881 newspapers did not report any reactions to the lava diversion plans. Hawaiian Monarchy, in 1881 represented by Princess Regent Lili‘uokalani, supported lava flow diversion with methods that included blasting the lava conduit with dynamite, building rock barriers, and invoking Christian prayer. We don’t know the views of Kalākaua or of Hawaiians native to the Island of Hawai‘i; J.M. Kapena, who assured the August 4 meeting attendees that the natives would be grateful, resided on O‘ahu. There were no Hawaiians from the island noted as attending the meeting.

Figure 15. Photo looking south from the intersection of Popolo Street and Mohouli Street in Hilo. The two lobes (white arrows) between the street and the rockwall/fence are toes from the Waiākea lobe of the Mauna Loa 1880–81 flow very near where C.C. Kennedy built his rock barriers.

Hawaiian protests about diversion efforts were reported in the Honolulu newspapers during the 1935 Mauna Loa eruption when aerial bombing was tried: “Pele should not be disturbed . . . This bombing is a folly. It will do more harm than good. If Pele makes up her mind to come to Hilo it is not for man to dissuade her by artificial methods. She cannot be stopped that way” (Honolulu Star Bulletin, 1936). A sociological study of victims of the 1960 Kapoho eruption of Kīlauea Volcano found strong opposition to the use of bombs amongst the Kapoho Hawaiian community but less opposition to the use of barriers (Gregg and others, 2008).

Modern day conflicts usually find the Hawaiian community on the Island of Hawai‘i most vocally opposed to lava flow diversion efforts supported by the State and Federal government. Hawai‘i County government has been more receptive to the cultural concerns about diversion. In 1990, when a Kīlauea lava flow slowly destroyed the village of Kalapana, Hawai‘i County Civil Defense officials stated that “diversion attempts, once it has been determined they are technically feasible, will only be attempted if such efforts are acceptable to area property owners, do not jeopardize the property of others, and are worth the cost to the community. . . all those factors could probably come into play only if lava were to threaten a major community-wide resource, like a hospital, harbor or airport” (Honolulu Advertiser, 1990). As recently as 2014 when a Kīlauea lava flow threatened the town of Pāhoa, County officials stated that they weren’t considering diversion because it was not historically successful nor was it culturally sensitive (Lincoln, 2014). Local farmer Jerry Konanui explained, “We learn what our kupuna [ancestors] taught us: This aina [land] belongs to kuku (tutu) Pele, and men cannot control Mother Nature” (Honolulu Star Advertiser, 2014).

The Next Lava Flow to Threaten Hilo

As mentioned at the beginning of this paper, only three Mauna Loa lava flows have advanced within 8 km of Hilo Bay in the past 1,500 years. As the outer limits of Hilo expand upslope (and closer to Mauna Loa’s Northeast Rift Zone vents), the lava flow threat increases.

In 1881, the residence at the highest elevation (about 300 m) was that of John Hall (near Kaumana Cave), and it was overrun by lava. Most of the other residences were nearer Hilo Bay and they remained untouched. Today, there are several subdivisions with hundreds of homes farther upslope than John Hall’s 1881 residence and closer to future Mauna Loa vents. The highest subdivision, called Kaumana City (about 600 m or 2,000 ft elevation), is located within the arms of the April–May 1881 lava branches and just below the toe of the 1855–56 lava flow. Future upslope development puts residents at increased hazard. While there are three flows within 8 km of Hilo Bay, there are another five that have advanced within 16–17 km (10–11 mi) of the bay in that same period. One of those flows (1984) made the distance in 5 days!

It is possible that an ‘a‘ā lava flow will advance quickly after an eruption starts and, at rates of about 6 km/day like the 1880 Kea flow and the 1984 Mauna Loa flow, could be in the upslope neighborhoods of Hilo within a week; however, it is more likely that a slower pāhoehoe flow, like the 1880–81 Hilo flow, will advance toward Hilo for several months before directly threatening homes and businesses.

Vog will most certainly be an issue during the next Mauna Loa eruption, whether lava flows threaten Hilo or not. Volcanic fumes from Mauna Loa vents at about 2 km elevation (the thermal inversion layer) will be moved by upper level winds, which typically blow to the northeast. Gases from lower elevation vents will follow surface winds, which are most often toward the southwest but can be blown northwest up the island chain by southerly winds (Lyons, 1899).

As the flow approaches Hilo subdivisions, the topic of lava flow diversion will come up and its relative advantages and disadvantages will be argued. Hopefully, past lava diversions in Hawai‘i and elsewhere will be studied in detail to see whether any of the techniques might be a wise choice for Hilo. Ultimately, it is a matter for public officials to decide.

Mechanical barriers have been tried in both Hawai‘i and Italy with only temporary success at delaying the flow’s advance. In Hawai‘i, rock barriers were built to divert or slow Kīlauea East Rift Zone lava flows erupted in 1955 and 1960. Gordon Macdonald, a strong proponent of lava barriers, built upon this partially successful experience to suggest the best construction techniques for lava barriers to protect Hilo (Macdonald, 1958, 1962); however, Wentworth and others (1961) disagreed and concluded that effective barriers require much more complex, and expensive, construction techniques: “In the face of such imponderables, a downslope diversionary system is unrealistic; it would seem prudent to rely on, and plan for, defensive actions that can be taken during an eruption, such as causing distributary flows at or near the vent.”

The Italian experience on Mount Etna has been very similar. During the 1983, 1991–93, and 2001 eruptions, various methods were tried. Barberi and Carpezza (2004) concluded that rock dams orthogonal, and diversion barriers at high angles, to the lava flow’s path were successful with different goals. The orthogonal dams, like the ones that Macdonald used in 1960, were meant to slow the flow’s advance. The high-angle diversion barriers, like Macdonald’s barriers in 1955, deflected the lava away from critical structures. In 1992, explosives opened a lava conduit near its vent on Mount Etna, diverting the supply of lava into a new path and stopping the original flow.

But each of these methods was only deemed successful when the lava flow either stopped or its supply decreased enough to no longer threaten infrastructure and diversion was no longer needed. None of the techniques were able to remove the threat without constant monitoring and continued diversion efforts until the flow stopped. Rev. Lyman hinted at this when, in 1881, he “… spoke of the progress of the flow, he had examined the ground that it was likely to go over carefully, he thought there was a possibility of diverting the flow by throwing up embankments. Not one large embankment, but many smaller ones. The course of the flow should be carefully watched, and the embankments thrown up at various points to meet it” (Viator, 1881b). Any diversion plan would require constant monitoring and adaptation of the diversions to keep the lava flow from becoming a threat. As such, any commitment to lava

flow diversion is necessarily of unknown duration or expense when started.

Many of today's Hilo residents are not aware of the history of the 1880–81 eruption of Mauna Loa and the resulting lava flows that threatened their hometown. Time and verdant Hilo vegetation have obscured most traces of the great lava flow. But that eruption experience should be remembered and understood as we plan the future of Hilo in the 21st century.

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Appendix. Identifying the First Lava Flow Produced During the Mauna Loa 1880–81 Eruption

The identity of the first (most northwestern) of the three lava flows produced by 1880–81 eruption of Mauna Loa has been displayed incorrectly in maps and publications produced in the century after the eruption. Even though it was finally identified correctly in the Geologic Map of the Island of Hawai‘i (Wolfe and Morris, 1996), there was some lingering doubt (Hawaiian Volcano Observatory, 2015). This appendix summarizes two arguments by which we positively identify the first, or Kea, flow from this eruption.

Eyewitness Account

After the eruption started on November 5, 1880, David H. Hitchcock approached the flows from Waimea, around the west side of Mauna Kea, and described flow first to the east along the Northeast Rift Zone and then, from the source of the 1855–56 lava flow, north toward Mauna Kea along the north side of the 1855–56 flow. He was able to get to the edge of the active ‘a‘ā lava flow on November 9. At that time, there was a narrow east-west flow, called the “old flow” of unknown date, along the southern base of Mauna Kea that made a good landmark.

“We took the track from Kalaeeha to Kipukaahina and then followed down the Hilo road from the old Bullock’s Head to where it turns down into the big Kipuka above Halealoha at the foot of the descent … We crossed the old flow for about 1000 feet and then stood on the very edge of that flowing river of rock” (Hitchcock, 1880a).

In the summer of 1891, surveyor Erdman Dwight Baldwin triangulated locations and made a detailed map of the saddle area between Mauna Kea and Mauna Loa volcanoes (Baldwin, 1892). He located several key cinder cones on the slopes of Mauna Kea and extending south from the base of that volcano. He also located a few points along nearby lava flows, trails, and locations mentioned in Hitchcock’s approach to that first flow. Much of the southern portion of Baldwin’s map on the lower slopes of Mauna Loa was filled from perspective sketches he made from vantage points on Mauna Kea (figs. 1.1, 1.2).

Baldwin’s map of the saddle area (fig. 1.1; Baldwin, 1891a) identifies several lava flows, from west to east: “Ke‘āmuku flow,” “Flow of 1843,” the northern tip of the “Kalaieha branch of 1880–81 flow,” the “Flow of 1855 ‘a‘ā”

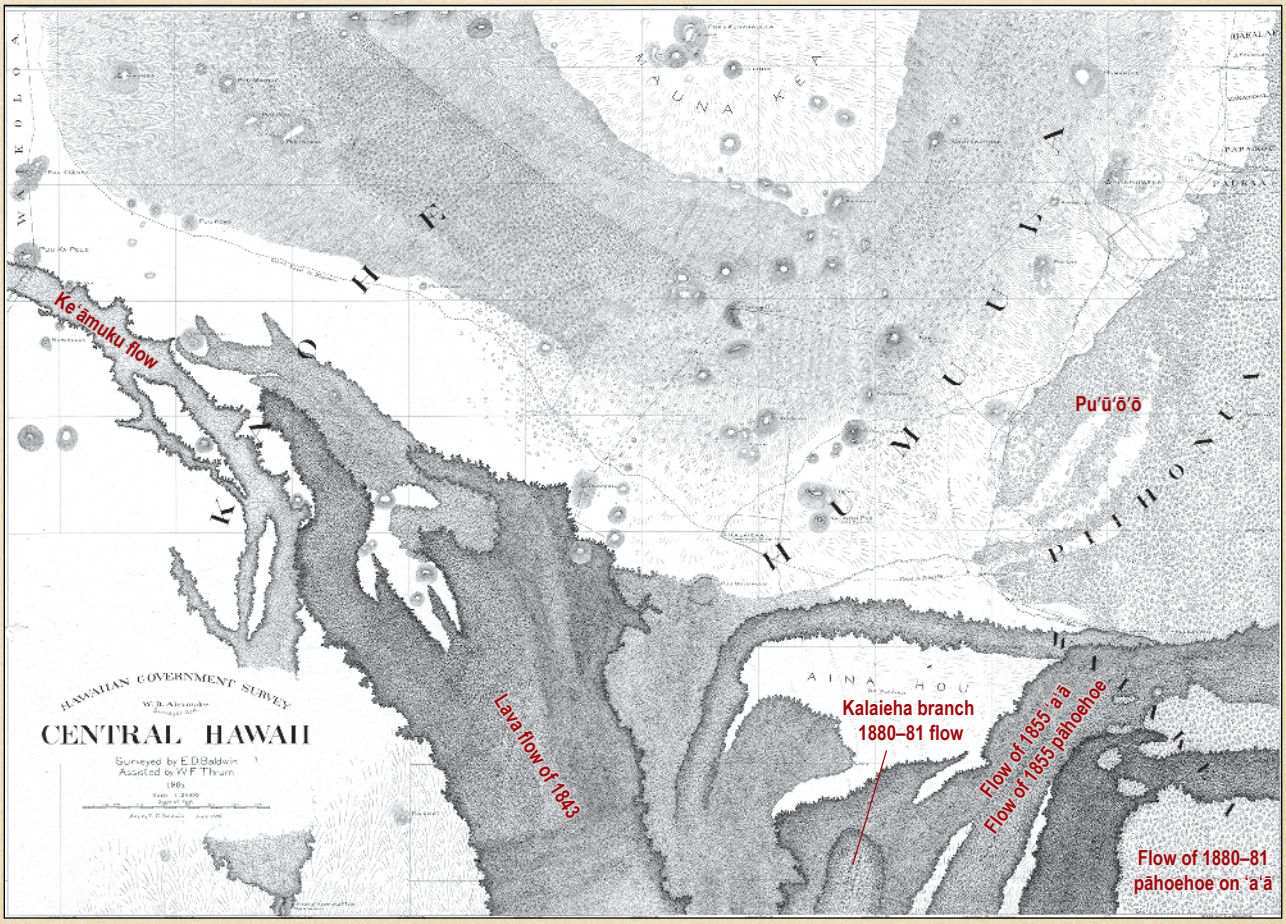

Figure 1.1. Baldwin’s (1891a) map of the saddle area. (Labels use modern spelling for his labels for the various lava flows.)

and “Flow of 1855 pāhoehoe,” and the “Flow of 1880–81 pāhoehoe on ‘a‘ā.” The latter is the Hilo branch of the Mauna Loa 1880–81 flows. The Kalaieha branch in Baldwin’s map doesn’t extend across the ancient ‘a‘ā flow (east-west flow at the base of Mauna Kea) where Hitchcock reports approaching it when active. Baldwin’s field notes (1892) don’t reveal his source for these lava flow labels.

In fig. 1.2, Baldwin’s sketch of the north slope of Mauna Loa from Pu‘u‘ō‘ō (shown in fig. 1.3) shows, from left to right, “81 flow” (Hilo branch of the 1880–81 flows), “Pahoehoe 55 (the 1855–56 lava flow), “Branch 81,” presumably the Kea or Kalaieha branch, wholly on top of the “aa 55” up to the Northeast Rift Zone, and the “old flow” that comes down to the base of Mauna Kea and flows east (to the left). The Ke‘āmuku and 1843 flows are sketched to the right (west).

The flow labeled “aa 55” by Baldwin is the same as the Kea branch ‘a‘ā of the 1880–81 flows, and the narrower pāhoehoe flow on top of it is also part of the 1880–81 flows portrayed by Wolfe and Morris (1996).

If D.H. Hitchcock’s eastward route is tracked on the Baldwin (1891a) map (fig. 1.1), Hitchcock’s path places him within 1,500 ft of the north edge of a lava flow labeled “Flow of 1855 ‘a‘ā ” on Baldwin’s map; however, the northwest edge of the Mauna Loa 1880–81 flow of Wolfe and Morris (1996), shown as a gold outline, agrees with Hitchcock’s track details. Therefore, Baldwin’s labeling of that flow as being erupted in 1855 is partially incorrect, although the southeastern part of the flow does match later mapping of the 1855–56 lava flow.

On the evening of the previous day (November 8), Hitchcock described “another stream of lava start from the fountain head and run right along the top ridge of the mountain for about two miles and then apparently stop.” He may have described the second lava flow, called the Ka‘ū branch, which advanced south (away from him) toward Kīlauea Volcano and the Volcano House and out of his direct sightline.

Judge Hitchcock was a very credible witness who was raised by missionary parents on the island Moloka‘i, moved to Hilo in the 1850s, and was a frequent visitor to, and traveler through, the saddle area. “I am an old kamaaina up there and know of what I am writing,” Hitchcock says near the end of his July letter (Hitchcock, 1880b). His detailed letter was the key to positively identifying that first (Kea) flow.

Maps for the Next Century were Based on Baldwin’s 1891 Flow Misidentification

Of the three flows identified by eyewitnesses, only the Ka‘ū and Hilo branches were usually shown on later maps. This is understandable because the Ka‘ū branch was easily visible from almost anywhere on the southeast side of Mauna Loa, including the Volcano House on the north rim of Kīlauea Caldera. The Hilo flow was visible and traceable from Hilo and, while the first flow (the Kea branch) was only visible at a distance from Hilo and points on the northwest side of the island when it was active, it lasted less than one month

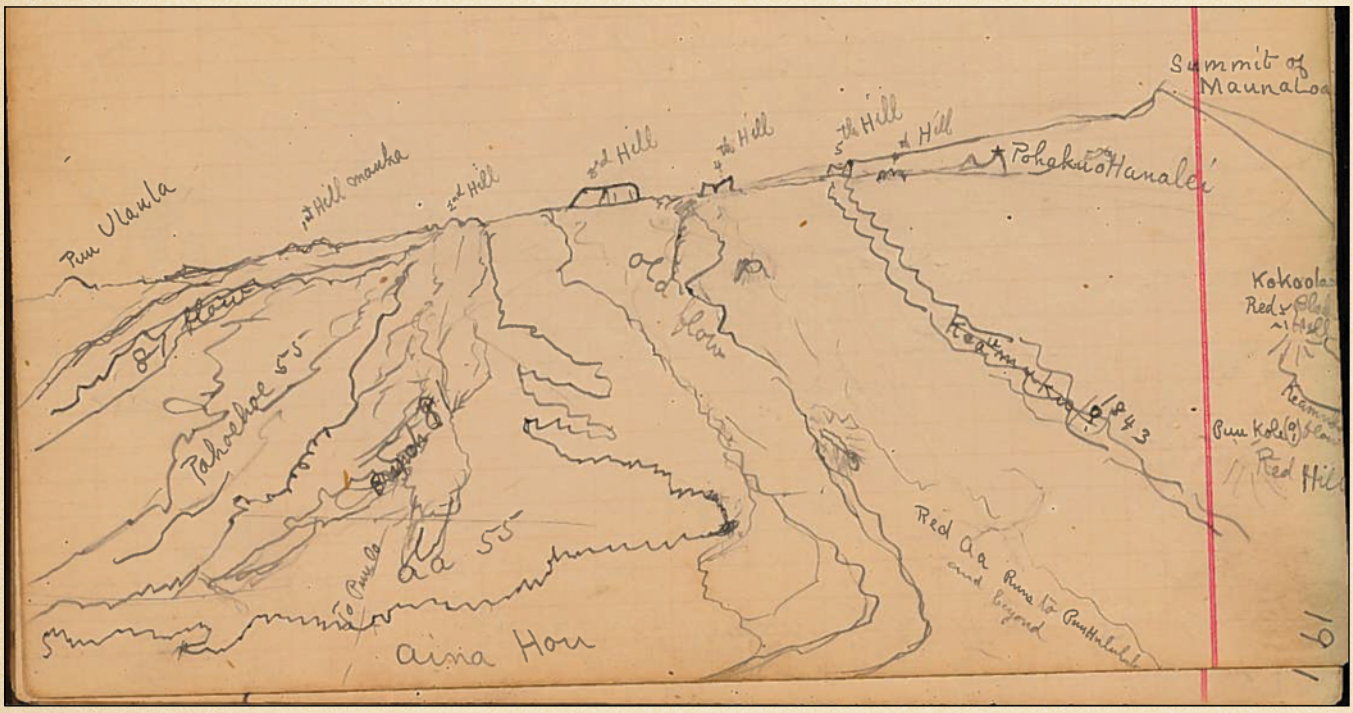

Figure 1.2. Sketch of the view to the south of the Mauna Loa northeast flank from the east base of Mauna Kea, which was used to sketch the southern portion of Baldwin’s map of the saddle area (Baldwin, 1891a; sketch from page 19, E.D. Baldwin Field Book 323).

Figure 1.3. Closeup of Baldwin's (1891a) map of the saddle area showing the path traveled by D.H. Hitchcock (blue line) before crossing the "old flow" to stand "on the very edge of the flowing river of rock." The outline of the Kea branch of the 1880–81 flow (modified from Wolfe and Morris, 1996) is in orange.

and, thereafter, all attention focused on the threatening flow approaching Hilo.

Graphics were not typical in newspapers of the day, and the earliest map of the flow appeared in a story about the Mauna Loa eruption of 1887 (fig. 1.4; Hawaiian Gazette, 1887). In that map, six individual lava flows were depicted from the 1855, 1859, 1868, 1881, and 1887 eruptions of Mauna Loa and the 1840 eruption of Kīlauea. The single lava flow labeled "1881" was shown extending from near the summit of Mauna Loa to very near Hilo Bay—the Hilo flow. Later newspaper maps were not much more detailed.

Every map made between 1891 and 1996 (Donn 1901; Baldwin, 1903; Macdonald, 1945; Stearns and Macdonald, 1946) used surveyor Baldwin's mistaken flow identities. The first map to portray these flows as described by D.H. Hitchcock was that of Wolfe and Morris (1996).

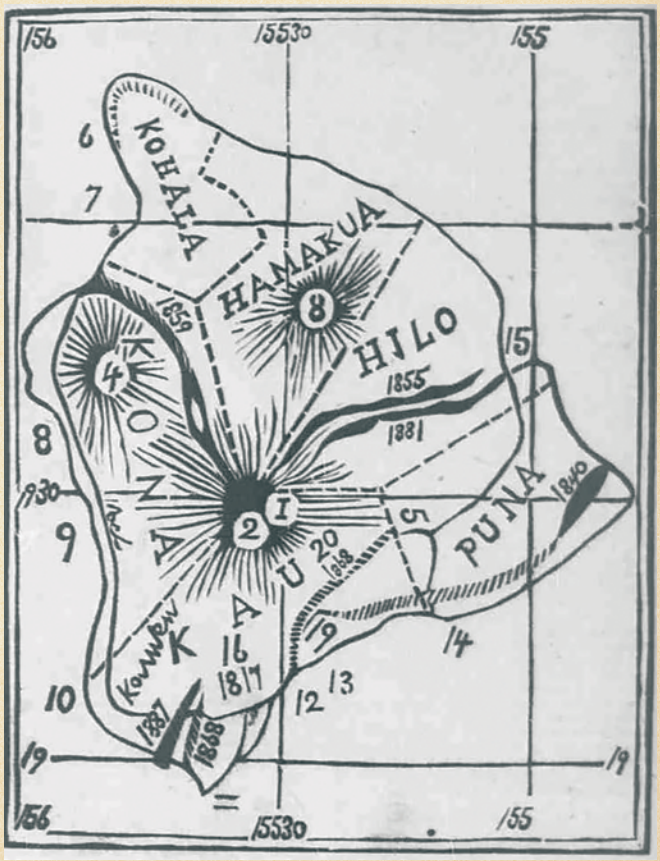

Figure 1.4. Map of the Island of Hawai'i showing recent lava flows (Hawaiian Gazette, 1887). Lava flows are identified by year. Other locations are identified by number, for example, "15" is Hilo.

Geochemical Fingerprinting of North-Slope Mauna Loa Lava Flows

To confirm the eyewitness accounts, the northwestern flow of the three 1880–81 Mauna Loa flows in Wolfe and Morris (1996) was temporarily designated as a “mystery flow” and we sought to independently identify its nearest geochemical matches using a method that’s successfully matched Hawaiian adze basalt flakes with their source quarries (Mills and others, 2011).

During the summer of 2016, we collected samples from the 1899, the 1855, and the Hilo branch of the 1880–81 lava flows (as shown in Wolfe and Morris, 1996) as well as the “mystery flow” which had been identified variously: as the November 1880 Kea flow by eyewitnesses (Hitchcock, 1880b), an 1855–56 flow (Baldwin, 1891a), an 1880 flow (Wolfe and Morris, 1996), and an 1899 flow (USGS 1928 Humuula topographic quadrangle; Stearns and Macdonald, 1946). We planned to run these samples through an energy dispersive X-ray flourescence (EDXRF) machine operated by the Geology Department, University of Hawai‘i at Hilo, to see if unique geochemical flow identities could be found.

While the flows were nearly indistinguishable in hand sample and thin section, the EDXRF results for zirconium (Zr) and strontium (Sr) showed discernible differences (fig. 1.6). The “mystery flow” samples were indistinguishable from the 1880–81 Hilo branch and clearly distinct from the 1855–56 and 1899 lava flow samples. This clarified identity was provided to authors of the most recent map of Mauna Loa’s north flank (Trusdell and Lockwood, 2017).

This clarification also brought up at least two new questions. First, are the later pāhoehoe flow geochemically distinct from the initial ‘a‘ā flow? Except for the 1855–56 samples, data from each of the sampled 19th and 20th century flows clustered tightly with no discernible geochemical differences between pāhoehoe and ‘a‘ā samples. The 1855–56 analyses were not clustered tightly, however, and pāhoehoe and ‘a‘ā samples appeared distinct from each other.

Second, were the various ‘a‘ā and pāhoehoe lobes of the 1880–81 flow really part of that flow? The narrow flow lobe immediately west of the 1880 Kea flow (“mystery flow W”) was originally mapped as part of that flow, but is geochemically most like the 1855–56 ‘a‘ā lava. These results suggest that the November 1880 (Kea) lava flowed over the 1855–56 flow northward and then ran down its west side, as D.H. Hitchcock described, and that the upper part of the 1855–56 lava flow field may be almost twice as wide as it is currently mapped (fig. 1.7).

Finally, the samples from the distal end of the November 1880 (Kea) flow were slightly different from those at mid-distance from the vent, but the distal samples are still more similar to the mid-distance 1880–81 sample than to lavas from flows of other years. This may have been a contaminated sample, as the area was recently excavated for a parking lot. Resolution of this issue, however, is beyond the scope of this paper.

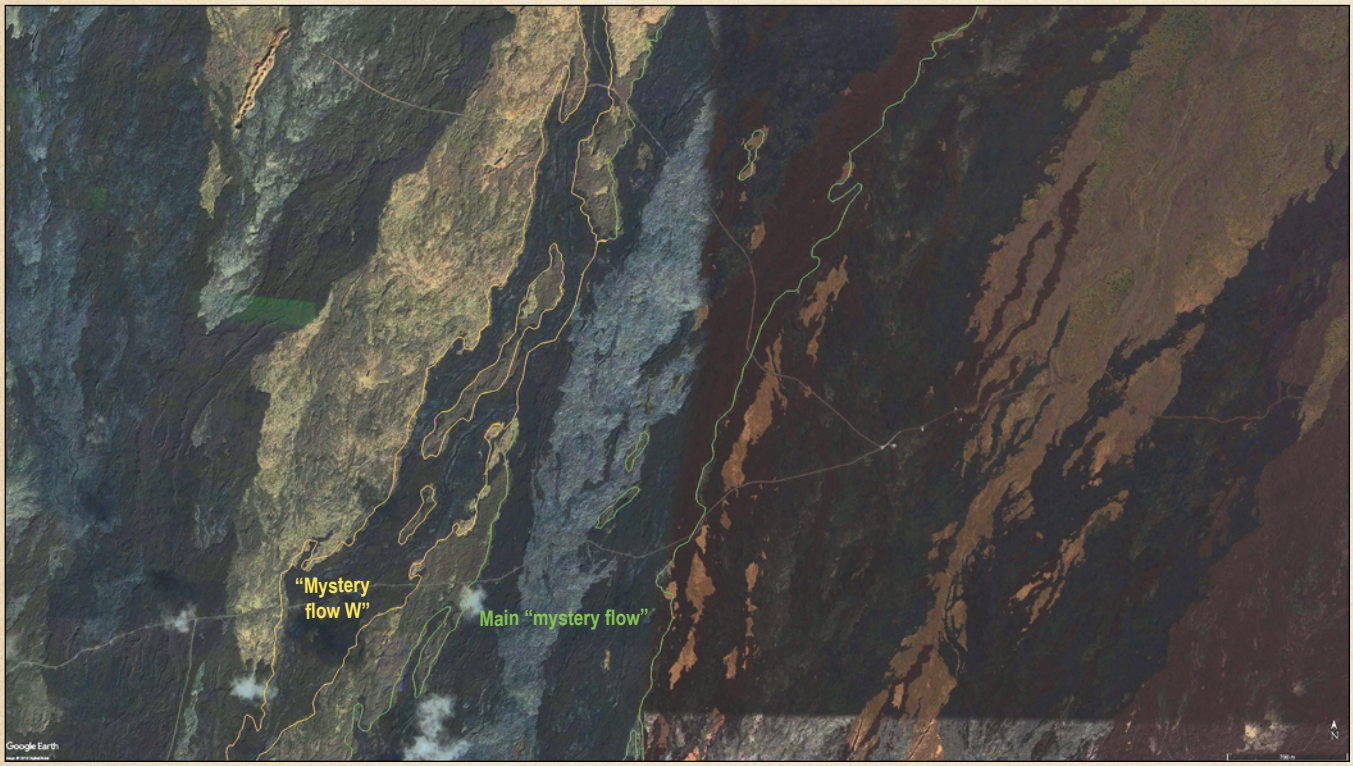

Figure 1.5. Google Earth satellite photo of the area near the Mauna Loa repeater station. Yellow lines outline the “mystery flow W” and green outlines the main “mystery flow.” Within the main “mystery flow,” the brownish material nearest the flow edges is ‘a‘ā and the gray material down the center is pāhoehoe lava.

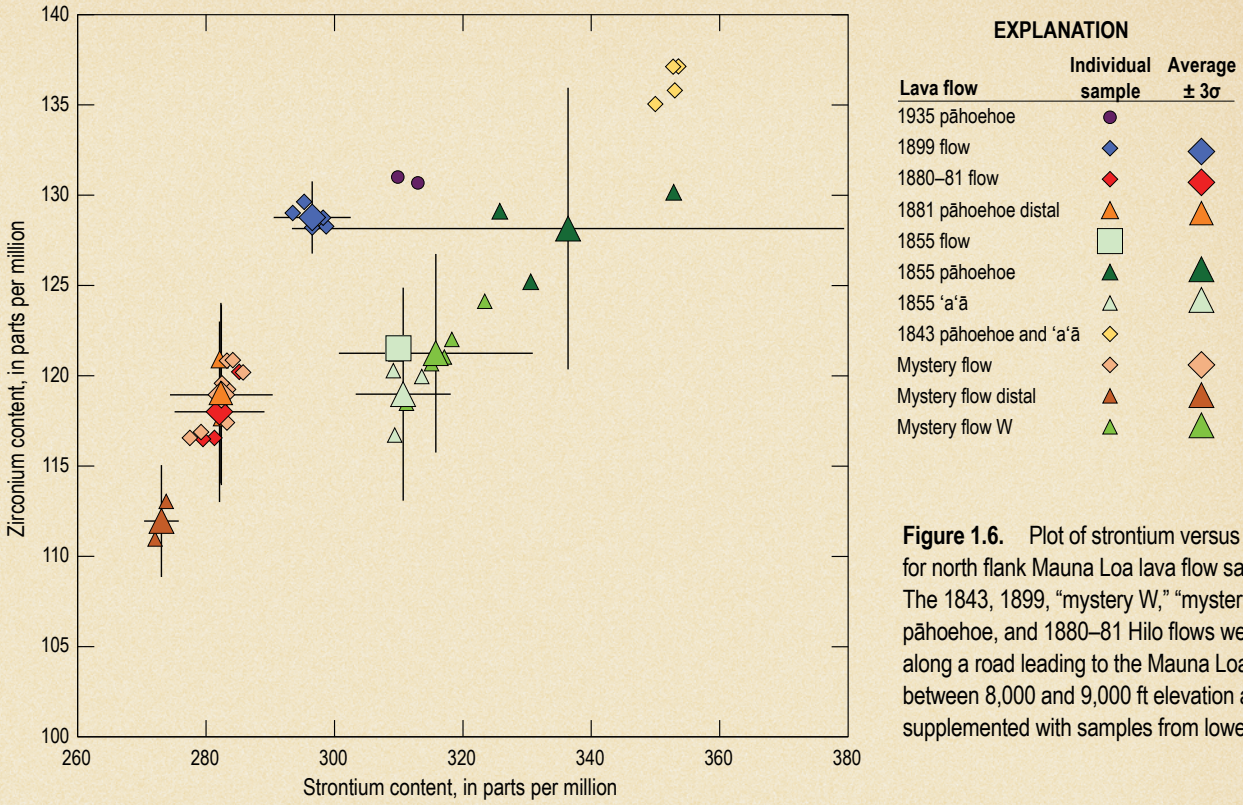

Figure 1.6. Plot of strontium versus zirconium for north flank Mauna Loa lava flow samples. The 1843, 1899, "mystery W," "mystery," 1855 pāhoehoe, and 1880–81 Hilo flows were sampled along a road leading to the Mauna Loa Observatory between 8,000 and 9,000 ft elevation and supplemented with samples from lower elevations.

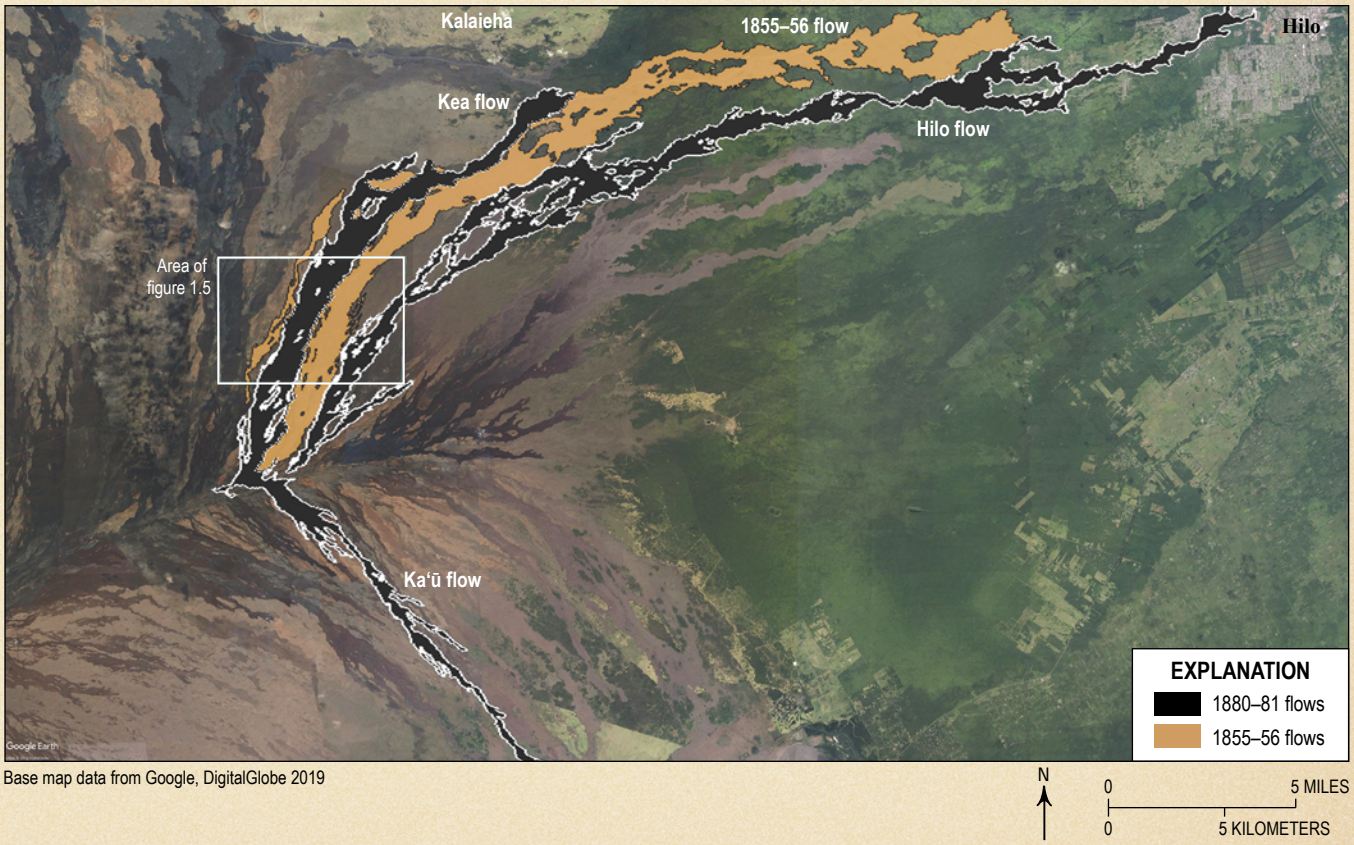

Figure 1.7. Map of the 1880–81 flows (black with white outlines) and the 1855–56 flows (tan) after geochemical identification (and some interpolation).

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