



# Hawaiian oral tradition describes 400 years of volcanic activity at Kīlauea

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## ABSTRACT

Culturally significant oral tradition involving Pele, the Hawaiian volcano deity, and her youngest sister Hi'iaka may involve the two largest volcanic events to have taken place in Hawai'i since human settlement: the roughly 60-year-long 'Ailā'au eruption during the 15th century and the following development of Kīlauea's caldera. In 1823, Rev. William Ellis and three others became the first Europeans to visit Kīlauea's summit and were told stories about Kīlauea's activity that are consistent with the Pele–Hi'iaka account and extend the oral tradition through the 18th century. Recent geologic studies confirm the essence of the oral traditions and illustrate the potential value of examining other Hawaiian chants and stories for more information about past volcanic activity in Hawai'i.

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## 1. Introduction

Kīlauea is one of the most active and intensively studied volcanoes on Earth. Most attention has been paid to the dynamics of its eruptive and related seismic activity that, for almost 100 years, has been monitored geologically, geophysically, and geochemically. Several excellent studies notwithstanding, less interest has been paid to past eruptive behavior, in large part because the written historical record at Kīlauea goes back only to 1794 C.E. (Vancouver, 1798; Archibald Menzies, cited in Hitchcock, 1909) and, in practical terms, only to 1823 C.E. (Ellis, 1825).

Polynesians, currently thought to have arrived in Hawai'i in 800–1000 C.E. (Masse and Tuggle, 1998; Hunt and Lipo, 2006), lacked a written language but had a rich oral tradition (Vansina, 1985) maintained in story, chant, and dance. This tradition has been little used by modern scientists, however, because it is couched in thick poetic metaphor and is incompletely translated. The oral tradition contains unique descriptions of past events and attitudes about those events that deserve modern interpretation.

I make a start in this paper by interpreting an important series of chants and stories regarding Pele, the volcano deity, and her youngest sister, Hi'iaka, in terms of the two largest volcanic events to have taken place in Hawai'i since human settlement: the roughly 60-year-long 'Ailā'au eruption (Clague et al., 1999) during the 15th century and the following development of Kīlauea's caldera. I believe the Pele–Hi'iaka oral tradition describes elements of those events that have only recently been recognized by volcanologists.

Rev. William Ellis and three other missionaries, who in 1823 became the first Europeans to visit the summit of Kīlauea, were given

important information by their guides about the volcano that is consistent with the Pele–Hi'iaka oral tradition and describes summit eruptive activity up to 1823. In this paper, I interpret in a modern context what Ellis (1825) was told, some of which has been previously overlooked or, in my opinion, misinterpreted.

The oral tradition and history together describe, in general terms, 400 years of eruptive activity at Kīlauea that, until very recently, were poorly understood by modern scientists. In the past few years, volcanologists have started to decipher this period of time (1400–1800 C.E.) at Kīlauea and have found remarkable correspondence between the oral record and the results of modern research.

### 1.1. Methods and caveats

Many versions of the Pele–Hi'iaka oral tradition exist, and, for someone who does not know the Hawaiian language, they present a bewildering array of inconsistency and ambiguity. I take most of my interpretations of the oral tradition from an English translation made by Nathaniel Emerson (1915) and prepared during several decades in the late 19th century from interviews with, and writings of, Hawaiian elders. I believe Emerson's version, which he termed a "myth," is more likely to have minimal post-European-contact influence and to show less natural evolution than contemporary versions. But, given the likelihood of considerable variation in the chants and stories among the different islands or even the communities on one island, probably no one "correct" version exists. Future workers will modify my interpretations depending on the version of the oral tradition they accept. Nonetheless, I believe the basic story of the 'Ailā'au lava flow and the ensuing collapse of Kīlauea's caldera will be relatively consistent, because it forms the fundamental background to the stories and chants.

Modern spellings and diacritical marks are used in this paper except in direct quotes, where original spellings and lack of diacritical marks are honored.

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## 2. Interpretation of the Pele–Hi'iaka oral tradition in terms of volcanic events

In the words of Emerson (1915), “The story of Pele and her sister Hiiaka stands at the fountain-head of Hawaiian myth and is the matrix from which the unwritten literature of Hawaii drew its life-blood.” What follows is my interpretation of only those events described in Emerson's translation that bear on possible volcanic activity. These events form the important background of the stories and chants but by no means are what they are all about. A series of beautiful hula and chants created by Pualani Kanaka'ole Kanahale and Nalani Kanaka'ole tells the Pele–Hi'iaka saga; a version of this presentation, *Holo Mai Pele*, was adapted for the *Dance in America* series on the Public Broadcasting System and is available on video cassette and in book form (Kanahale, 2001).

### 2.1. Synopsis of the story

Pele and her retinue of sisters and other relatives arrived in Hawai'i at the northeast end of the island chain (Fig. 1) and looked for a home, where the ground was hot. She failed to find a suitable place on the island of Kaua'i but found a man named Lohi'au whom she wanted for herself. Pele continued down the island chain, looking for a home but keeping Lohi'au in mind. She finally reached the island of Hawai'i and, at the summit of Kīlauea, found a home in a crater at the top of the volcano. The crater became known as Kalua o Pele (the pit of Pele). Pele displaced 'Ailā'au, “eater of the forest,” a god who previously controlled Kīlauea (Westervelt, 1916; Varez and Kanahale, 1991).

After becoming settled, Pele asked each of her sisters to go back to Kaua'i to fetch Lohi'au for her. Every sister declined except the youngest, Hi'iaka'aikapoliopole (generally shortened to Hi'iaka), who agreed to bring back Lohi'au for Pele. But in return, Hi'iaka asked Pele not to destroy her beloved forest of 'ōhi'a lehua (a native tree) in Puna (the district stretching from Kīlauea's summit to the east tip of the island; Fig. 1) while she was away. Pele promised that she would not destroy the forest provided that Hi'iaka returned in a certain time (40 days, according to Kane, 1987; Varez and Kanahale, 1991).

Hi'iaka and a companion (Wahine'ōma'o) then traveled to Kaua'i, experiencing many significant adventures along the way, including a likely hurricane in Pana'ewa forest just outside Hilo. They eventually reached Kaua'i and found Lohi'au, but he was dead. It took Hi'iaka and Wahine'ōma'o some time to bring Lohi'au back to life, but they were successful.

Eventually they started back down the island chain with Lohi'au. They landed at Ka'ena Point on the island of O'ahu (Fig. 1), and Hi'iaka climbed to the top of Pōhākea in the Wai'anae Range. Looking down the chain to Kīlauea, she could see that her beloved 'ōhi'a lehua forest was on fire. With all her adventures and sidetracks, Hi'iaka's return

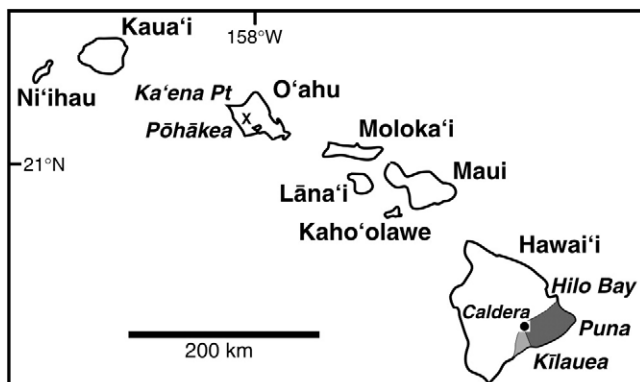


Fig. 1. Map of principal islands in Hawai'i. Kīlauea is shown as shaded portion of Island of Hawai'i, and Puna District is portrayed by darker shade.

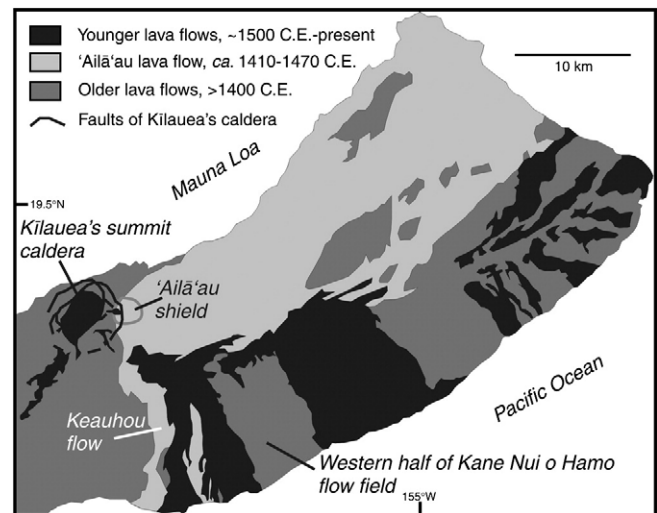


Fig. 2. Map of eastern part of Kīlauea, showing 'Ailā'au lava flow and its relation to Kīlauea's summit caldera. Keauhōu flow is southern branch of 'Ailā'au flow. Kane Nui o Hamo flow field, mentioned in text, is older than, and unrelated to, 'Ailā'au flow.

had been delayed past the allotted 40 days. Pele imagined that Hi'iaka and Lohi'au were having a romantic liaison and, enraged, set fire to the forest.

Hi'iaka was understandably upset but nonetheless continued the canoe trip back to Hawai'i with Lohi'au, remaining faithful to Pele despite temptations. They finally landed at Hilo, walked to the summit of Kīlauea, and there, in full view of her older sister, Hi'iaka made love with Lohi'au. Now it was time for Pele to be upset. So what did she do? She killed Lohi'au and threw his body into Kalua o Pele. Hi'iaka then dug furiously to recover the body. She dug deeper and deeper. Rocks were flying, and she was warned not to dig too deeply or water would come in and put out the fires of Pele.

In the end, Hi'iaka finally did get back with Lohi'au, and they are together today, at least in spirit.

### 2.2. Interpretation

The two elements of the story that I believe can be interpreted in terms of volcanic events are the destruction of Hi'iaka's 'ōhi'a lehua forest and the furious digging by Hi'iaka for the body of Lohi'au.

The extensive forest loss suggests a large lava flow, and Holcomb (1987) identified such a flow, which he named the 'Ailā'au flow (Fig. 2). Lava erupted from a vent just east of Kīlauea's summit and built the 'Ailā'au shield; Nāhuku (Thurston lava tube), a favorite visitor attraction in Hawai'i Volcanoes National Park, is in this shield. The lava flow (called flows by previous workers, but erupted essentially continuously, so I assume only one flow) covered most of Kīlauea north of the east rift zone and reached all the way eastward to the coastline; one or two streams even spread southward from the shield to the sea (Fig. 2). Clague et al. (1999) estimated its area as about 430 km<sup>2</sup> and its dense-rock-equivalent (DRE) volume as 5.2±0.8 km<sup>3</sup>.

This lava flow is the largest to be erupted from Kīlauea, and probably in all of Hawai'i, since Polynesian settlement. If any flow were to be commemorated in oral tradition, this should be the one, because the destruction of such a large area of forest would have impacted Hawaiian life in many ways.

Clague et al. (1999), through careful analysis of calibrated <sup>14</sup>C ages and paleomagnetic data, concluded that the eruption of the 'Ailā'au flow lasted about 60 years and ended in about 1470 C.E. The morphology of the pāhoehoe suggests slow emplacement by lava tubes, and large tubes are known in the flow; one, the Kazumura, is 65.5 km long—one of the longest known lava tubes (Allred, 2001; <http://caverbob.com/usalong.htm>).

I suggest that Hi'iaka's digging for Lohi'au's body metaphorically describes the initial formation of Kīlauea's modern caldera. The "flying" rocks probably record explosions associated with the collapse, and the warning about water implies that the "digging" reached substantial depth. Explosive deposits are not interbedded with the lava flows that formed the Observatory shield, the edifice built at the summit of the volcano before the caldera formed, so it is unlikely that the digging took place during the formation of the shield. And, if we are to believe the relative timing of events in the oral tradition, the digging postdates the 'Ailā'au flow, which ended in about 1470 C.E., some 100 years or so after the summit shield had formed (D.A. Swanson and J. P. McGeehin, unpublished <sup>14</sup>C ages). The *Current understanding* section below provides more information about the formation of the caldera.

### 3. Interpretation of what Ellis was told in 1823

Rev. William Ellis and three accompanying missionaries were the first Europeans to visit the summit of Kīlauea and provide a written account of its volcanic activity. Born in London in 1794, Ellis was sent by the London Missionary Society to the Society Islands in 1817 and soon became fluent in the local language, Tahitian. He moved to Honolulu in 1822, where he quickly learned Hawaiian, a language resembling Tahitian, transcribed the language into a Roman alphabet, and became the first European to preach in Hawaiian. In 1823, he led a 2-month trip around the Island of Hawai'i, mostly on foot, to identify sites for future missions. Owing to his language skills, he was able to converse fluently with the people he was exploring, most of whom had never before seen a westerner. He was a missionary but also an ethnographer, interested in the culture without damning it as heathen.

Ellis and his group reached the summit of Kīlauea on August 1, 1823, about halfway through their journey around the island. His Hawaiian guides told him (Ellis, 1825) that Kīlauea

... "had been burning from time immemorial... and had overflowed some part of the country during the reign of every king that had governed Hawaii: that in earlier ages it used to boil up, overflow its banks, and inundate the adjacent country; but that, for many kings' reigns past, it had kept below the level of the surrounding plain, continually extending its surface and increasing its depth, and occasionally throwing up, with violent explosion, huge rocks or red-hot stones. These eruptions, they said, were always accompanied by dreadful earthquakes, loud claps of thunder, with vivid and quick-succeeding lightning. No great explosion, they added, had taken place since the days of Keoua..."

Much can be read into these words. I interpret them to mean the following:

The Hawaiians told Ellis that the summit of the volcano had been active during the entire time that kings had ruled the island, probably about 800 years or so. There had been a change, however. Lava erupted at the summit used to flow into the surrounding forest, probably during the time that Kīlauea's summit shield was constructed (and 'Ailā'au, eater of forests, held sway), between about 1000 and 1350–1400 C.E. on the basis of unpublished <sup>14</sup>C ages (D.A. Swanson, J.P. McGeehin, and others, unpublished data). But, "for many kings' reigns past," a caldera had existed that kept lava from spreading outward, perhaps undergoing episodic subsidence as lava moved across its floor. Explosions occasionally took place, but no great one had occurred since November 1790 (Cahill, 1999), when an explosion killed part of Keōua's army, on its way to do battle with Kamehameha for control of the island; the number of victims is variously estimated as about 80 (Ellis, 1825), approaching 400 (Desha, 2000, p. 279), almost 800 (Desha, 2000, p. 280), and 5405 (Douglas, 1834).

As an aside, the renowned botanist David Douglas (1834) reported a far higher number of fatalities, 5405, in a letter written shortly before his mysterious death in a pit-trap for wild bulls on the island. His account has not been generally accepted owing to obvious errors, such as a date of 1787 for the explosion, but he gives his source of information as the last of the "Priests of Peli (sic)... who witnessed the scene." With current knowledge, it is not possible to discredit his account.

From this interpretation of what Ellis was told, one can estimate when the caldera first formed based on the length of time meant by "many kings' reigns past." This cannot be done with much accuracy, however. If "many" means 10–15 rulers, then, for generations lasting 20 years (Hommon, 1975) or 25 years (used by the B.P. Bishop Museum, according to Hommon, 1975), the caldera would have formed in the range of 1440–1600 C.E. Even with these rough calculations, it becomes evident that the end of the 'Ailā'au eruption and the formation of the caldera were not separated by more than 100–150 years or so, and possibly much less. Thus what Ellis was told is broadly consistent with the Pele–Hi'iaka oral tradition that little time elapsed between the eruption of the flow and the collapse of the caldera.

Until recently, this reading of Ellis had been overlooked, though Holcomb (1987, p. 337) came close, and the caldera was assumed to date from 1790, the year of the fatal explosion that was thought to have accompanied the deposition of the entire Keanakāko'i Ash, a thick tephra unit found around and within the caldera. Clearly here is an example where oral tradition and the information garnered by Ellis could have been used long ago to have assigned a much earlier age to the caldera. Moreover, the sporadic explosions described to Ellis would have suggested prolonged deposition of the Keanakāko'i rather than only in 1790.

Ellis was told another story about one of these earlier explosions, this one involving Pele. Kamapua'a, an erstwhile suitor of Pele who was piglike at one moment and humanlike at another, visited her home. "When she saw him standing on the edge of the crater, she rejected his proposals with contempt, calling him a hog, the son of a hog." A fight ensued, Pele was forced back into her home, and Kamapua'a poured water that almost filled the crater and put out Pele's fire. However, "Pele and her companions drank up the waters, rose again from the craters, and finally succeeded in driving Tamapuaa into the sea, whither she followed him with thunder, lightning, and showers of large stones." This is a wonderful metaphor for an explosive eruption, perhaps one involving groundwater or exceptionally heavy rain and suggesting the presence of a caldera lake. Repeated explosions such as this might be responsible for the concept that Pele has a volatile, often violent temper.

This story has often been interpreted to mean that a lava flow, not an explosion, chased Kamapua'a away from the summit, and the flow has been credited to either the Keauhou branch of the 'Ailā'au flow (Holcomb, 1987) or to an older flow, the Kane Nui o Hamo, erupted from one or more vents on the east rift zone more than 10 km east of the summit (Masse et al., 1991, p. 48). If a lava flow is indeed indicated by the story (together with an explosion), I believe the Keauhou is the more reasonable, both because it is of the appropriate age for the oral traditions interpreted in this paper and because the source of the flow was at Kīlauea's summit, where Kamapua'a was causing the trouble. In contrast, the Kane Nui o Hamo vent is at least 10 km from the summit and is unlikely to have been where Kamapua'a was trying to douse the fires of Pele. The fact that Ellis was told this story when he was at Kīlauea's summit also suggests that the summit was where the water was poured. Finally, the Keanakāko'i Ash is the only tephra deposit at Kīlauea's summit younger than 1000 C.E. that indicates explosions powerful enough to have chased Kamapua'a to the sea. No such explosive deposits are associated with the Kane Nui o Hamo flow field.

#### 4. Current understanding

The Pele–Hi'iaka oral tradition and the stories told to Ellis may seem frustratingly vague and imprecise to modern scientists, but ongoing research at Kīlauea shows them to be consistent with new data about the age of the caldera and the Keanakāko'i Ash. This work is nearing completion and will be described in later papers, but the essence can be given here.

Kīlauea's caldera formed between about 1470 and 1500 C.E., as judged from stratigraphic and calibrated <sup>14</sup>C evidence (Swanson, 2003; Swanson et al., 2004). The outermost fault on the eastern side of the caldera cuts the 'Ailā'au shield (Fig. 2) and therefore is younger than about 1470, the estimated date that the shield stopped erupting. Vitric and lithic–vitric tephra, dated at about 1500 C.E. on the basis of several calibrated <sup>14</sup>C ages, mantles the main caldera faults at several places, so the faults must be older than about 1500.

This evidence indicates that the caldera formed in the time range expected from the oral accounts—just after the 'Ailā'au eruption and in the range of 1440–1600 C.E. inferred from what Ellis was told. The caldera clearly did not form in 1790, as has been commonly thought (Decker and Christiansen, 1984; Holcomb, 1987), and it is even unlikely that there was substantial downdropping of its major faults then, to judge from the lack of a description of major subsidence or dreadful earthquakes in the stories told to Ellis.

The Keanakāko'i Ash (McPhie et al., 1990), comprised of vitric, lithic, and mixed vitric and lithic deposits of ash to block size and totaling as much as 13 m in thickness, formed from multiple eruptions during a 300-year period beginning in about 1500 and ending in about 1790 (Swanson et al., 2004). It is the deposits of the two oldest Keanakāko'i tephra eruptions that mantle the caldera faults and constrain the minimum age of the caldera.

The evidence for the age of the Keanakāko'i is developed from numerous calibrated <sup>14</sup>C ages as well as from physical stratigraphy, including three or four widespread erosional unconformities between successive deposits, pure ash beds interlayered with reworked wind-blown vitric ash in sand dunes, and archaeological evidence that Hawaiians built stone structures during periods of calm between explosions.

The 300 years of episodic explosive activity is much longer than what most late 20th-century workers interpreted (Decker and Christiansen, 1984; McPhie et al., 1990; Mastin, 1997). These researchers believed that most or all of the Keanakāko'i was the product of a strong eruption during 1790, when the fatal explosion took place. The recognition of three centuries of sporadic explosive activity has come about slowly through careful work during the past decade. If we had paid close attention to what Hawaiians told Ellis in 1823, the acceptance of repeated explosions over many years would have come more easily.

Interestingly, early 20th-century geologists recognized that only the upper part of the Keanakāko'i was produced in 1790, though they were uncertain of the age of the older tephra deposits (Hitchcock, 1909; Sidney Powers, 1919; Finch, 1925; Stone, 1926; Finch, 1942; Howard Powers, 1948). Their interpretations were close to those put forth in this paper and consistent with the oral traditions.

#### 5. Discussion

If my interpretations are correct, it is fair to say that volcanologists were led astray by not paying close attention to the Hawaiian oral traditions. Had we looked for geologic evidence to test the traditions, rather than ignoring them, we probably would have realized much sooner that formation of the caldera closely followed the eruption of the 'Ailā'au flow and that both took place centuries before 1790. There is a lesson here, plain to see.

But, it is difficult to interpret anecdotes, particularly those cloaked in thick poetic metaphor. We are used to thinking scientifically, not metaphorically, when we tackle volcanic problems.

I found it useful in my thinking about the oral traditions to distinguish between what scientists can and can't do. We can ask questions, and often do a good job of answering them, when they are of the *what*, *when*, *where*, and *how* type. But, we can't address the questions of *why*. That is ultimately a religious query.

We often confuse *how* and *why* but should strive to keep them separate. In a society not versed in our modern scientific approach, the important question is *why*, not *how*. That society wants to know why X happened so that it can appease the deity that was responsible. A scientist might say that the caldera collapsed because magma emptied from a reservoir, but a member of the society in which Pele was influential might say that the caldera collapsed because Hi'iaka dug deeply for the body of Lohi'au. The end result is the same, but how one thinks about the problem is different. They are, in some sense, two versions of the same reality.

Oral traditions dealing with volcanoes in Hawai'i implicitly ask and overtly answer the *why* question in terms of Pele. If we volcanologists take the traditions seriously, we stand a good chance of learning about the *what*, *when*, and *where* questions, and answering those first three questions is often very helpful in addressing the more important *how*.

The interpretations put forth in this paper bear on the long-standing question of when Pele arrived in Hawai'i. Current thinking is that Polynesians arrived in Hawai'i in 800–1000 C.E. (Masse and Tuggle, 1998; Hunt and Lipo, 2006), several hundred years later than was thought by scientists for most of the 20th century. Pele, however, is generally considered (without much evidence) to be a late-comer, arriving after the period of discovery and occupation, and my interpretation of the Pele–Hi'iaka oral traditions supports that view. An already well-entrenched Hawaiian society existed when she arrived from the South Pacific. Lohi'au was already on Kaua'i, and 'Ailā'au was sending lava into forests from the summit shield of Kīlauea.

Pele arrived in time to dislodge 'Ailā'au and take control of Kīlauea before the eruption of the huge 15th-century lava flow (unfortunately and misleadingly also named 'Ailā'au [Holcomb, 1987]; if my interpretation is correct, the deity 'Ailā'au was no longer at Kīlauea when the flow was erupted). Pele probably was not present during the eruptions that built the shield at Kīlauea's summit; at least, those eruptions are not clearly ascribed to her in the oral traditions. This reasoning suggests an arrival some time in the late 14th century, several hundred years after the islands first started to be populated. This date is somewhat later than that of about 1175 C.E. estimated by Kalākaua (1990), which itself is considerably after Polynesians first came to Hawai'i. Fornander (1996) also appears to place Pele's arrival long after that of the earliest Polynesians, though he presents no clear evidence supporting this interpretation.

Masse et al. (1991) reached a different conclusion by interpreting the Kane Nui o Hamo flow field as the flow that Pele may have used to get rid of her erstwhile suitor, Kamapua'a. Holcomb (1987) named the flow field and estimated its age to be in the range of 500–750 B.P., and Masse et al. (1991, p. 48) narrowed the range, in calendar years, to approximately 1300–1375 C.E. by using interpretations of genealogy. If this is correct, Pele could have been on the island at least a few decades earlier than I propose. As I pointed out earlier, however, the Kane Nui o Hamo flow field is unlikely to be the subject of the Pele–Kamapua'a story, owing to the location of its vent far east of Kīlauea's summit.

Kamapua'a was likely on the island long before Pele (Fornander, 1996) and perhaps even before the Kane Nui o Hamo flow field was emplaced. 'Ailā'au, the eater of forests, likewise precedes Pele and probably dates from the 350–400-year-long time during which lava flows built the large Observatory shield at Kīlauea's summit and destroyed surrounding woodlands, between about 1000 and 1350–1400 C.E. (Holcomb, 1987; Neal and Lockwood, 2002; D.A. Swanson and J.P. McGeehin, unpub. data). Pele was the latecomer, in my interpretation, replacing 'Ailā'au as the volcano deity and having on-again-off-again affairs with the older, ever-virile Kamapua'a.

The chants about Hi'iaka's journey that strongly influence my interpretation may have been composed sometime in the 16th century, likely soon after the collapse of the caldera, before the events that preceded the collapse were lost from memory. During the composition, the 60-year duration of the 'Ailā'au eruption must have been telescoped into a few weeks or months. That may trouble some skeptics, but time often seems to be the first reality lost in oral traditions and in poetry in general.

## 6. Conclusions

The oral tradition of Pele and Hi'iaka tells of the eruption of the 'Ailā'au lava flow during the 15th century and the collapse of Kīlauea's caldera at the start of the 16th century.

The stories related to Ellis indicate that the caldera existed for "many kings' reigns past," interpreted as some 200–300 years before 1790. Those stories also tell of sporadic explosions from the caldera during that time.

Hawaiian oral traditions are rich sources of eruption information and deserve much closer examination than I can give, preferably by one familiar with both volcanology and the Hawaiian language.

The interpretations of the chants and the stories told Ellis—that Kīlauea's caldera is both older than previously thought and the site of sporadic explosions during a 300-year period—are at odds with previous interpretations based on incomplete geologic understanding. More recent geologic work shows that the oral traditions are broadly consistent with the improved understanding. We geologists were somewhat sidetracked by not taking the oral traditions into account.

From a hazards perspective, it is important to know that Kīlauea erupts explosively more often than once thought. It is important to know that the caldera formed, with only minor explosion, following a long-lasting eruption. This is the kind of information that the oral traditions provided before the recent geologic studies confirmed them. Interpretation of oral traditions is clearly important to understanding the past, providing ideas to pursue in the field, confirmation of geologic observations that may be inconclusive, and, at times, suggestions of events whose geologic record may be obscured by later eruptions or even completely missing.

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