Lava Eruption Disrupts the Puna Geothermal Venture - The Background

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The Kīlauea volcano has been continuously featured in international headlines since it began erupting in May, due to its adverse effects on both local residents and on the only geothermal power plant in Hawai‘i. The lava flow has surrounded the Ormat Puna Geothermal Venture power plant, forcing a shutdown of activities, and the evacuation of thousands from nearby neighborhoods.

Lava Surrounds Geothermal Power Plant

As of the time of publication, Kīlauea Volcano, located on the Island of Hawai‘i (“Big Island”), is still erupting from the summit caldera and from the Lower East Rift Zone (LERZ) in the Leilana Estates and Lanipuna areas. As magma steadily moves from the reservoir to the East Rift Zone and on to the ocean, the area around the caldera continues to experience small explosions, fissure eruptions, and earthquakes.

Remarkably, this is the first time that lava flow has affected operations of a geothermal power plant. The volcanic activity has caused the shutdown of the Puna Geothermal Venture (PGV), a 38 MW installed capacity plant operated by Ormat Technologies Inc. The lava flows surrounding PGV have blocked road access and have prompted officials to shut down the plant and take precautionary measures to prevent lava from reaching the wells. Despite best efforts, three wells have been covered in lava.

Kīlauea Volcano

Kīlauea is a relatively young, basaltic shield volcano east of Mauna Loa Volcano on the Island of Hawai‘i (red deposits in Figure 1). Erupting 34 times since 1952, it is one of the most active volcanoes in the world [1].

The plumbing system of Kīlauea Volcano extends up to 60 km depth and feeds only the volcano [1]. Research by Lin et al. (2014) suggests the presence of a deeper crustal magma reservoir that may supply magma to the deep East Rift Zone [3]. Pietruzka et al. (2016) support this theory, and further suggest that magma intrusion from the summit reservoir into the LERZ is rare and accounts for major volcanic events [4].

The complicated plumbing system at Kīlauea may result in periodic shifts in magma composition. For example, a shift to a more Mg-O enriched magma composition in 1983 suggests a mixing of rift zone stored magma with mantle-derived magma. Furthermore, an eruption hiatus lasting only a few days may cause crystal fractionation and thus change the eruption magma composition [5].
The active lava pond and gas plume of Kīlauea’s summit caldera contribute to the eruption patterns of the volcano. The summit lava lake is directly connected to the summit magma reservoir, controlling the eruptive style (Figure 2)[6]. Initially, an abundant magma supply allows the summit caldera to fill and may eventually produce large lava flows from the summit and from rift zone vents at the caldera floor. However, in the current situation, a low magma supply has caused the caldera to collapse down to the water table, resulting in large steam explosions. As the magma supply re-entered the system, the lava has flowed into the rift zone vents causing effusive eruptions along the rift zone to the east.

Explosive eruptions can occur when
1) magma column drops below water table
2) groundwater interacts with hot rock
3) steam pressure builds then explodes.

![Figure 1: Geologic map of the Island of Hawai’i showing deposits from the five volcanoes on the island. Kīlauea is the easternmost volcano][2]

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The 2018 Eruption

Indications of an impending eruption were noticed as early as April 17 2018 when the United States Geological Survey (USGS) noted pressurization of the magma system beneath Puʻu ‘Ōʻō, a volcanic cone within the Eastern Rift Zone.
of Kīlauea. On April 26, lava overflowed onto the Halema’uma’u crater (a pit crater within Kīlauea) floor at the summit of the volcano \cite{7}. Four days later, the Pu’u ‘Ō’ō crater collapsed, inducing seismicity and deformation down the rift of the vent, and increasing the risk of a Lower East Rift Zone (LERZ) eruption. The increased pressure beneath Pu’u ‘Ō’ō formed a magma pathway from Pu’u ‘Ō’ō crater to the LERZ, and, just two days later, small ground cracks began to open in the Leilani Estates area and the summit lava lake started to drop \cite{8}. Finally, on May 3, a 5.0 magnitude earthquake caused Pu’u ‘Ō’ō to collapse and release an ash plume; a few hours later, an eruption began on the LERZ with a 150m long vent opening and releasing molten lava to the surface \cite{8}. In the following week, LERZ fissures steadily opened up and the summit lake continued to drop; by May 9, there were 15 new fissures and cracks opening.

As magma continues to move from the reservoir to the ERZ, the reservoir pressure continues to decrease and the Kīlauea Caldera floor has subsided further \cite{9}. This subsidence stresses the faults in and around the caldera, causing continuous pulses of seismic activity \cite{9}. A 6.9 magnitude earthquake, the strongest seismic event in Hawai’i since 1975, was recorded on May 11 -- eight days after the start of the eruption.

**Puna Geothermal Venture**

The Puna Geothermal Venture (PGV) is a geothermal power plant operated by Ormat Technologies Inc. and located approximately one mile east of Leilani Estates (Figure 3). Opened in 1992, the power plant manages 11 active wells that reach depths of 6,000 to 8,000 feet. The steam extracted is directed to turbine generators and also used to vaporize a working fluid for a second turbine. The condensed steam is then re-injected into the geothermal reservoir together with the unused brine \cite{10}. With an installed capacity of 38 MW, PGV supplies 25% of Big Island’s electricity, and represents 4.5% of Ormat’s total generating capacity \cite{11, 12}.

**Protecting the Infrastructure**

Due to the proximity of the lava flows, officials decided to shut down PGV on May 3, 2018. Over the next few days and weeks, Ormat personnel worked to shut down all wells, remove flammable materials, and install physical barriers to protect the plant’s infrastructure from lava intrusion \cite{12}.

Experts from the geothermal energy community, including personal from the USGS, University of Hawai’i at Hilo, Ormat geologists and engineers, a wireline company and equipment suppliers, were brought in to help with the effort. Ormat also deployed a “mudman” who advised on the well quenching process. Charlene L. Wardlow, who oversees the Northern District of the California Division of Oil, Gas, and Geothermal Resources (DOGGR),
was recruited by the Hawai‘i Emergency Management Agency to join their Geothermal Task Force to secure PGV wells from potential lava intrusion. Wardlow described the process in an interview on June 20, 2018: “Usually a geothermal well can be quenched by pumping cold water; however, the intrusion of the 2000°F magma nearby and on the surface changed the wells’ behavior and [the water] didn’t work well at first on some of the wells.” According to Wardlow, the operators of PGV were able to collect downhole temperature and pressure measurements before the lava had entered the facility. One of the wells had measured temperatures of 100°F greater than normal, even at 2500 ft depth. In addition to salt water, this well had to be quenched with a mud-barite mixture, which is intended to generate a ceramic seal upon exposure to high temperature conditions.

The team also encountered problems due to delays in equipment delivery (especially bridge plugs) to the islands. “Overnight mail doesn’t exist [on Hawaii],” noted Wardlow. As soon as the bridge plugs arrived, they were installed in the wells to isolate the lower part of the wellbore. “Ultimately, the wells were quenched and bridge plugs were run into the production wells using a wireline unit.” This quenching operation, which involves injecting water so that the hydrostatic pressure exceeds the pressure of the volcanic stream below, is essential for ensuring the mechanical integrity of the wells. By May 21, all the wells were quenched and sealed with metal caps.

Meteorological conditions were monitored throughout this process, as the eruptions were emitting large amounts of sulfur dioxide (SO₂) and hydrogen sulfide (H₂S) gas. To date, three wells, an equipment warehouse, and switchyard and access roads have been covered with lava[13]. “It is an island in between the active lava flows,” said Wardlow. PGV was built on high ground in order to mitigate risks from potential eruptions, and this strategic placement has mostly saved the plant from destruction (Figure 4). Dr. Nicole Lautze, Director of the Groundwater & Geothermal Resources Center at the University of Hawaii, hopes that people will appreciate the success of Ormat’s mitigation measures: “This eruption has shown that infrastructure on topographically high locations along Kilauea’s East Rift Zone can survive eruptions along the rift, and [that] the mitigation measures initiated by PGV/Ormat worked. More broadly, the eruption demonstrates that there will be value in finding geothermal across the state, including in locations less prone to natural hazards.”

**Geothermal Power Plants and Other Natural Disasters**

The future of PGV is difficult to assess as the eruption continues. Although most commercially producing geothermal power plants are built near or around volcanic centers, this is the first time geothermal operations have been interrupted by volcanic activity, so there are no case histories from which to draw comparisons or adopt compatible countermeasures. However, this is not the first instance when a geothermal power plant has had to endure threat from and damage by natural disasters: nearby geothermal plants survived...
the disastrous earthquake and tsunami during the 2011 Fukushima Daiichi nuclear disaster; Typhoon Haiyan led to the decommissioning of three geothermal power plants in Tacloban City, Philippines in 2013; cooling towers at a geothermal power plant in The Geysers in Northern California were damaged by wildfires in 2015[14].

**Hawaii’s Energy Future**

The State of Hawai‘i has recently vowed full reliance on low-carbon power in the near future, after Governor David Ige signed and passed a bill (H.B. No. 623) in 2015 to set a 100% renewable portfolio standard by 31 December 2045[15, 16]. Hawai‘i is the most fossil-fuel-dependent state in the United States of America largely due to geographic isolation, but it is also one of seven states with utility-scale geothermal production[15]. The PGV plant, the lone geothermal energy source of the state, has been a steady contributor of renewable energy since the early-to-mid ’90s. As mentioned previously, geothermal energy has most recently accounted for about a quarter of total electricity supply for Big Island. Coincident with improvement of solar and wind energy implementations, dependence on petroleum has decreased by ~12% from 2005 through 2016[15]. In order to meet the renewable standard by the 2045 deadline, Dr. Lautze believes that more test wells are needed on other Hawaiian islands to determine viable locations for development: “Geothermal is the only viable baseload renewable energy source. There is a lot of talk about solar and storage here, but the fact is that issues with long-term storage remain. To me, geothermal is key.”

**Conclusion**

Despite general uncertainty and upcoming challenges involving PGV, there is optimism amidst the concern: the wells could be re-opened and operations begun again within two to three years. This phenomenon is a ‘first’ for the geothermal industry. Mass communication of ensuing events and underlying science have signified the integral role of geothermal energy to local parties and have alerted geothermalists worldwide to adapt from such a situation, should this ever happen again. Although this eruption has caused a hiatus in energy production at PGV, the media coverage it received has revealed the need for careful and elaborate emergency response for geothermal plants in active volcano zones. The minimal damage to the facility proves that with clever design (built on high ground) and quick action to threats, geothermal energy may and will continue to be a stable source of baseload energy. Increasing geothermal baseload capacity throughout the Hawaiian Islands will reduce the negative effects of temporary shutdowns, which must be expected when facilities are built next to and depend on such powerful natural systems like Hawaii’s Kilauea volcano.

[15] https://www.eia.gov/state/?sid=HI