Reawakening of Tonga volcano

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After almost 7 years of dormancy, Hunga Tonga-Hunga Ha’apai Volcano (HTHHV) erupted on December 20th, 2021. HTHHV is located in the South Pacific Ocean, 65 km north of Tongatapu, Tonga’s main island. The volcano erupted again violently on January 15th, 2022, causing loud booms that were heard across the Pacific Ocean, ejecting 30 km-high ash clouds into the stratosphere, and triggering severe tsunamis; ash from the eruption caused communication networks to collapse.1 Earthquakes continued to occur frequently in the areas around Tonga, even 20 days after the eruption.

GEOLOGICAL CONTEXT AND ERUPTION HISTORY

HTHHV is a part of the highly active Tonga-Kermadec island arc, which sits along the convergent boundary where the South Pacific Plate is subducting westward beneath the Indo-Australian plate. Active volcanoes are distributed along the western flank of the Tongan Ridge, and the magmas erupted from HTHHV are mainly basaltic andesite and andesite.

The uppermost ignimbrite sequence on Hunga Ha’apai island was dated at AD 1040–1180 and overlies earlier pyroclastic deposits.2 These deposits are spread thinly across Hunga Tonga island and can be correlated geochemically with those found on Tongatapu Island. The 2009 eruption lasted from 17th to 21st March, forming two roughly circular vents and generating new land to the northwest and south of Hunga Ha’apai. The eruption was characterized by 7.6 km-high volcanic ash plumes that posed a hazard to local air traffic. The 2014–2015 eruption occurred between September 19th, 2014, and January 26th, 2015, producing 9 km-high plumes and a circular tephra cone. By January 16th, the eruption had formed new land 1 km wide and 2 km long. The volcano became dormant on January 26th, 2015.

On December 20th, 2021, the volcano emitted a large plume that was visible from Tongatapu, and the eruption increased the size of the island on December 25th. On January 14th, 2022, a subaerial eruption formed a 20 km-high ash plume. Dark pyroclastic deposits were erupted, and pyroclastic flows extended over the

| Volcano name | HTHHV | Tambora | Pinatubo | St. Helens | El Chichón |
|--------------|--------|---------|----------|------------|------------|
| Country      | Tonga  | Indonesia | Philippines | United States | Mexico |
| Highest VEI  | ~5 (2022) | 7 (1815) | 6 (1991) | 5 (1980) | 5 (1982) |
| Bulk deposit volume (km³) | unknown | 110 | 13 | 1.3 | 2 |
| Maximum plume height (km) | ~30 | 44 | 35 | 19 | 32 |
| SO₂ (Tg)     | ~0.4 | 93-118 | ~20 | 1.5 | 7 |
| North Hemisphere summer anomaly (°C) | unknown | -0.4–0.7 | -0.5 | no anomaly | -0.1–0.2 |

Figure 1. A brief diagram of Hunga Tonga-Hunga Ha’apai Volcano (HTHHV) (A) Geological locations of Tongatapu Island and HTHHV. (B) Remnant subaerial shapes of HTHHV historical eruptions. (C) A brief comparison between HTHHV and historical volcanic eruptions worldwide.
surrounding ocean. On January 15th, a violent Plinian eruption occurred that was much more powerful than the previous activity. Its maximum column height was estimated to be up to 30 km, with tephra at the plume top covering an area at least 600 km in diameter.2 There were numerous reports of loud booms being heard after this eruption across Tonga and Fiji, and even in Alaska. Numerous fast-moving, concentric atmospheric waves were detected by satellite, which were unlike anything observed previously.3 Radar surveys before and after the eruption showed that most of the island has been destroyed.

POTENTIAL IMPACTS

The January 15th eruption resulted in tsunami waves 2–15 m high around Tonga. Waves 0.2–2 m high were reported in Australia and Japan, and a nearly 2-m-high tsunami killed two people in Peru, ~10,000 km from the volcano. Because the submarine volcano is constructed from unstable tephra, there is a risk of further collapse that could trigger new tsunamis; therefore, real-time observation is necessary.

In addition to the deaths and injuries caused directly by this eruption, damage due to tephra falls, acid rain, and lahars is also important. Most of the population of Tonga live on Tongatapu, 65 km from the crater. This distance makes direct impact by pyroclastic flows unlikely, however, up to 2 cm of ash covered Tongatapu Island, seriously affecting aircraft access and the restoration of communication networks. Suspended volcanic ash reduced visibility and caused air pollution, including toxic gases that have not yet been quantified. Contamination of drinking water by volcanic ash was a concern because of the release of toxic gases and metals. Acid rain also poses a hazard, and lahars could form without warning— even in the absence of eruptive activity—as rainfall can rapidly remobilize ash.

Much attention has been paid to the potential impact of explosive volcanic eruptions. This is because some historical eruptions have resulted in global temperature changes, including the 1816 “year without a summer” caused by the 1815 Tambora eruption and a global temperature drop of ~0.5°C due to the 1991 eruption of Pinatubo. Preliminary analysis indicates that the HTHHV eruption will not cause significant global climate change without further large eruptions because this eruption released only ~0.4 Tg (1 Tg = 10^12 g) of SO2 into the atmosphere.4 This is much less than was released by the Tambora and Pinatubo eruptions (Figure 1). The maximum column height is similar to that of the 1982 El Chichón eruption, but the latter released 7 Tg of SO2 into the atmosphere, which also suggests that the eruption of HTHHV would be unlikely to cause a global temperature change similar to that caused by the El Chichón eruption (Figure 1). In addition, the Volcanic Explosivity Index (VEI) and the amount of SO2 emitted are no greater than those of the 1980 St. Helens eruption, which had only a localized impact on temperature rather than a significant global effect. Although it is unlikely that the climatic impact from this eruption will be global, HTHHV is within the tropical zone where explosive eruptions are more likely to cause global climate change than those at high latitudes, such as Mt. St. Helens, and the exact climatic impact of the HTHHV eruption remains to be evaluated.

FUTURE ERUPTION RISK

Future eruptions may be forecast by monitoring the HTHHV magma reservoir. Volcanic eruptions can last from several days to several years; for example, the Pinatubo eruption began in March 1991 with small phreatic explosions and the climactic eruption occurred in June, with no major explosive eruptions occurring since then. Major eruptions usually extract large volumes of magma from the magma chamber, and reaccumulating enough magma and energy to supply subsequent major eruptions takes time; however, subsequent minor eruptions may still occur. According to our statistical analysis of historical volcanic records (Figure 1), the VEI of the 2022 eruption of HTHHV could be as high as 5, which could make it the largest known eruption from this volcano. A large amount of magma and energy may have been released from the magma chamber; therefore, an eruption of similar or larger size from the same crater in the near future is unlikely, while low-VEI eruptions (i.e., VEI of 1–2) could occur for years or even decades. It is difficult to make a precise forecast of future volcanic eruptions from HTHHV, as monitoring data are limited. Additional eruptions and pre-eruptive unrest (e.g., geothermal and volcanic degassing) have not been observed after the explosive eruption on the 15th of January,5 although the fact that the precursors of subaqueous eruptions can only be detected remotely makes such determinations uncertain. It is worth noting, however, that earthquakes with a magnitude of >4.0 have occurred frequently in the area around Tonga after the eruption, including a Mw 6.0 event on February 6th, which may indicate ongoing magma activity.

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DECLARATION OF INTERESTS

The authors declare no competing interests.