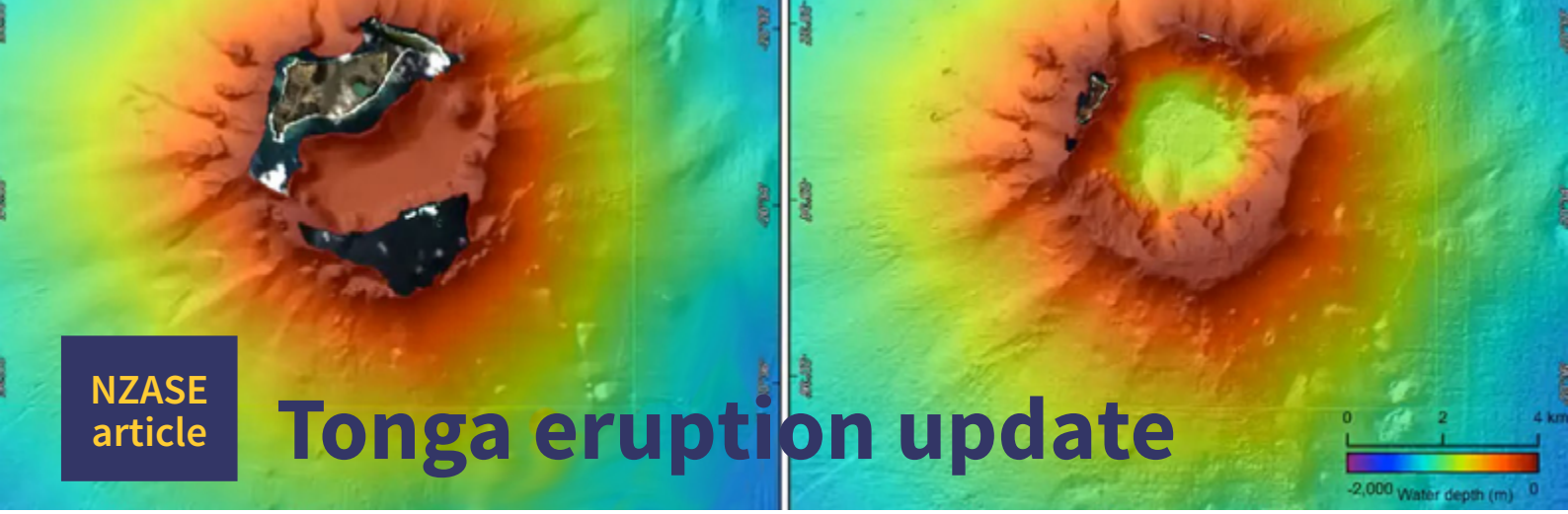


NZASE article

Tonga eruption update

On January 12, 2022, at 4.47 pm, the Hunga Tonga – Hunga Ha'apai (HTHH) volcano erupted violently for 11 hours. This was the biggest eruption seen worldwide in 140 years, and the first with such a wide array of measuring instruments available. Scientists have pored over the data and now have a better understanding of the processes involved. NZASE's Mike Stone adds to last year's article with what we now know.

The scientists

Because of Tongan people's urgent needs after the eruption, as well as COVID travel restrictions, it was difficult for overseas scientists to get immediate access to the islands for detailed study of the eruption.

However, University of Auckland volcanologist, Professor Shane Cronin, had already gained permissions and laid the ground work for a scientific trip due in March 2022. He used this trip to train local scientists and worked with them to gather evidence – rock and ash samples, and tsunami-related measurements and observations.

The icebreaker of the Korea Polar Research Institute, passing on its way home from Antarctica, was able to sample the sea floor between Fiji and Tonga. Other scientists gathered and analysed data from sensors around the world.

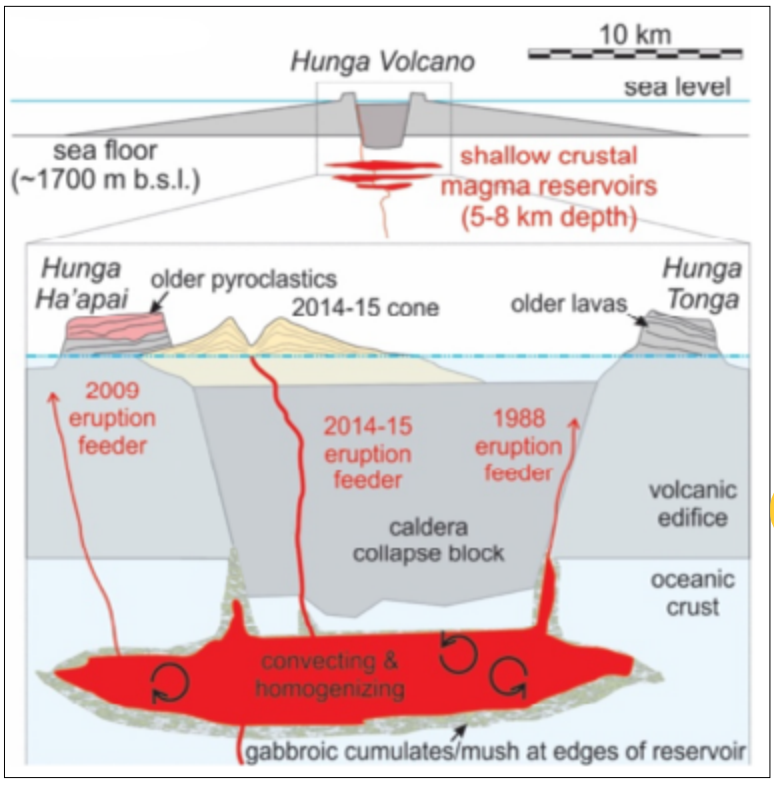
A trove of scientific papers had been released by the one-year anniversary, the work of more than 70 scientists.

The HTHH crater and caldera before and after the 2022 eruption. By Sung-Hyun Park/ Korea Polar Research Institute, CC BY-SA.

Before the 2022 eruption

The kingdom of Tonga is a collection of volcanic islands, part of a subduction zone extending north-northeast of Aotearoa. At this convergent boundary the Pacific plate dives under the Indo-Australian plate.

HTHH is one of many submarine volcanoes in this region, rising 2000 m from the sea floor. On January 14, 2022, parts of the rim extended above the sea surface as two visible, connected islands, Hunga Tonga and Hunga Ha'apai. The rest of the volcano top was 150 m under the sea, flat and about 6 km wide. This is a caldera where past eruptions have emptied the bulk of the magma in the volcano until it collapsed in on itself.



Sketch of the HTHH caldera and of the conceptual model of the volcano plumbing geometry, after the 2015 eruption, modified from Brenna et al., 2022.

Under the water

The 2022 eruption destroyed most of the two visible islands and excavated a hole 4 km wide and 1 km deep, as shown by sonar mapping of the volcano by Tongan and New Zealand scientists. So the caldera has deepened

Comparison of HTHH to other eruptions, by km³ of erupted material. NIWA.

by 850 m. The 9.5 km³ material expanded once erupted, depositing about 12-14 km³ of ash, rock and debris.

After the magma had been pumped out, the caldera collapsed, allowing seawater to breach the walls, meet the molten magma and explode.

However, the scale of this eruption suggested there was more to it than just a large volume of magma and its interaction with seawater.

NIWA's research vessel *Tangaroa* and a remote robot surveyed the seafloor, collecting samples. The texture and isotopic chemistry of the erupted material showed a mixture of different types of magma.

Only about 10% of the ejecta came from the old volcano; the rest was new magma from three different sources deep underground. The mixing caused a strong reaction for two reasons.

Volatile substances formed a gassy magma foam, which vigorously pushed out the magma at the start. But also, this andesitic magma had fairly low viscosity and that meant magma could be rapidly forced out through narrow cracks in the rock.

Seawater then poured in through those cracks and met magma at 1,150°C. This caused two strong explosions 30 and 45mins after the first eruption, each decompressing the gassy magma.

The ejected material fell back into the sea creating pyroclastic flows: hot and fast currents of lava, ash, gas and volcanic debris. This material spread at least 80 km wide and 30 m deep, breaking and then covering multiple fibre-optic cables on the sea floor.

The heavily forested Nomuka Iki Island before and after the tsunami overwash. Google Earth, Maxar Technologies.

In the air

The eruption sent a cloud of ejected materials 58 km high, unprecedented in the modern era. This was detected in the stratosphere by ozone monitoring instruments on NASA's S-NPP satellite.

As well as plumes of ash, an enormous aerosol and water cloud rose into the stratosphere. A microwave instrument on NASA's Aura satellite detected 150 Tg of water vapour, which came from seawater superheated by the erupting magma.

The water vapour layer had a colder temperature than is normal at this height, due to enhanced infrared radiative cooling. The water vapour sat above the aerosol layer and the two slowly moved apart.

This eruption was so big it created several types of sound waves. Audible sound (0.01 – 20 Hz) was detected in Alaska, 10,000 km from its source. Severe disruptions were detected in the ionosphere.

And it also generated a Lamb wave, a special and rare type of atmospheric pressure wave, which has a large amplitude and very low frequency. This infrasound wave travelled four times around the Earth in the six days after the explosion, similar to the 1883 Krakatoa eruption. Seismometers showed this Lamb wave also had an impact on the sea, pushing the tsunami more strongly, so that it was bigger and arrived much earlier than expected.

Tsunami

In 2022, news mediareported one main wave of tsunami reaching outlying islands, but the devastation suggested this was not the whole story.

Scientists hitched rides on local boats to conduct foot surveys on many islands, measuring distances and elevations along transects, which could then be cross-referenced with satellite and drone imagery. Two key measurements were the tsunami runup (highest height above sea level) and inundation (the distance it travelled inland).

On the islands worst affected, they observed trees and soil stripped off the land, laying the coastal coral bare. In other places, there was evidence of piles of debris, trees denuded of bark and leaves, and mud deposited on structures. In 2023 scientists found many of the Tongan people from these islands still traumatised, terrified by loud noises and the threat from the sea.

Scientific evidence showed two small tsunami waves arrived initially, measuring just a few metres high. These were linked to the two large explosions at 30 and 45min after the start. Tongans took this as a warning to evacuate from the coast and seek higher ground. A much bigger tsunami arrived a bit later.

The weather station on the west coast of Tongatapu was attached to a cell-phone tower 13 m above sea level. It collected data every 10min and uploaded it on the hour to a satellite. The last data was transmitted at 6pm, suggesting the larger tsunami must have arrived shortly after its last transmission. The tower was later found more than 200 m inland.

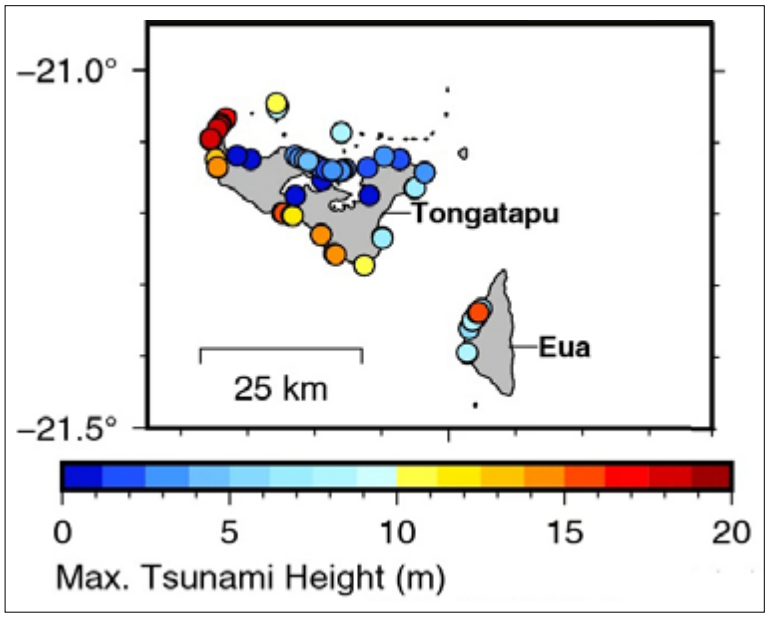
This last, larger tsunami, fuelled by the Lamb wave in the atmosphere, travelled at a speed of 500 km/h. It completely overran some of the low-lying islands, and caused extreme erosion. Evidence suggested runups of up to 20 m and inundations of 1,000 m in some places, with 5 m runups and 18 m of inundation in others.

So there were two small tsunami, caused by the volcano itself blowing up, and a third more destructive tsunami that resulted from the pressure shockwave it generated.

Four people were killed in this massive event. Why so few?

- On January 14 the government had issued a tsunami warning. The wave did not eventuate, but it put people on alert.
- Since the 2009 Samoan tsunami there had been a strong education programme about the danger of tsunami, the signs to watch for and what to do, so many families had a plan.
- There were few tourists, who had little experience of or education about tsunami.
- The sonic boom, ash clouds and darkening skies warned Tongans to leave the coast.
- The early arrival of moderate tsunami waves meant people had evacuated before the largest and most destructive waves landed.

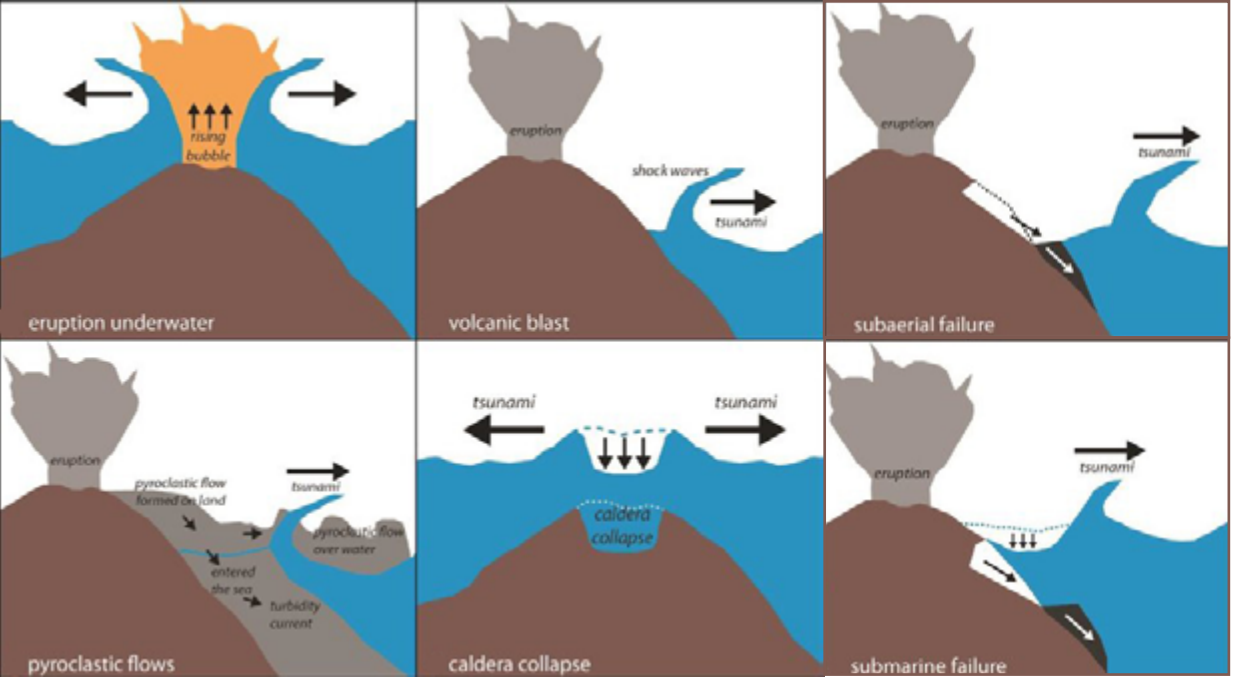
Summary data plots of maximum measured tsunami heights in two islands south of HTHH.



The future

The results of this detailed scientific study showed that the Tongan eruption was enormous, unique, complex and very hazardous. We know lots about volcanoes on the land, but little about submarine volcanoes.

Such research can be expensive and time-consuming, but the potential hazards seen in the Tongan eruption make it imperative that we do more to understand the threats. We need seismic and infrasound sensors in the right places and a range of satellite observation tools. The low number of deaths also showed the importance of education.



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Thanks to teacher Ross Stephen and scientist Graham Leonard for their critique.

Ngā Kupu

Hūnga puia – Volcanic eruption
Kōhaupapa – Stratosphere
Mātai puia – Volcanology
Ngaru oro – Sound wave
Puia – Volcano
Puia koeko – Cone-shaped volcano
Pungarehu – Ash
Rere tipua – Pyroclastic flow
Tainiwhaniwha – Tsunami
Tawhā – Caldera
Tokarewa – Magma
Wairehu – Water vapour.

From Paekupu