Impacts of the mid-15th century eruption at Kuwae caldera, Vanuatu

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Summary: The submarine Kuwae caldera in central Vanuatu has long been suggested to have caused one of the three biggest eruptions in the last 1000 years. Here we present recent findings from at-source analysis of the mid-15th century eruption. These are based on fieldwork taken out on Epi, Tongoa, Tongariki and Emae, covering volcanic stratigraphy, bathymetry of the submarine caldera, and geochemical analysis. One main question that remains is the connection between the event at Kuwae and the global climate perturbation caused by an eruption in 1458 CE.

1 The location

The submarine Kuwae caldera lies in central Vanuatu, around 80 km north of Vanuatu's most populated island of Efate, with little landmass surrounding the caldera.

Of the two islands adjacent to Kuwae, Epi is the larger, stretching away from the caldera (up to 50 km). Tongoa is smaller and reaches only 6 km away from Kuwae. Towards the South, the other Shepherd Islands (Emae, Tongariki, Makura, and others) lie between Kuwae and Efate.

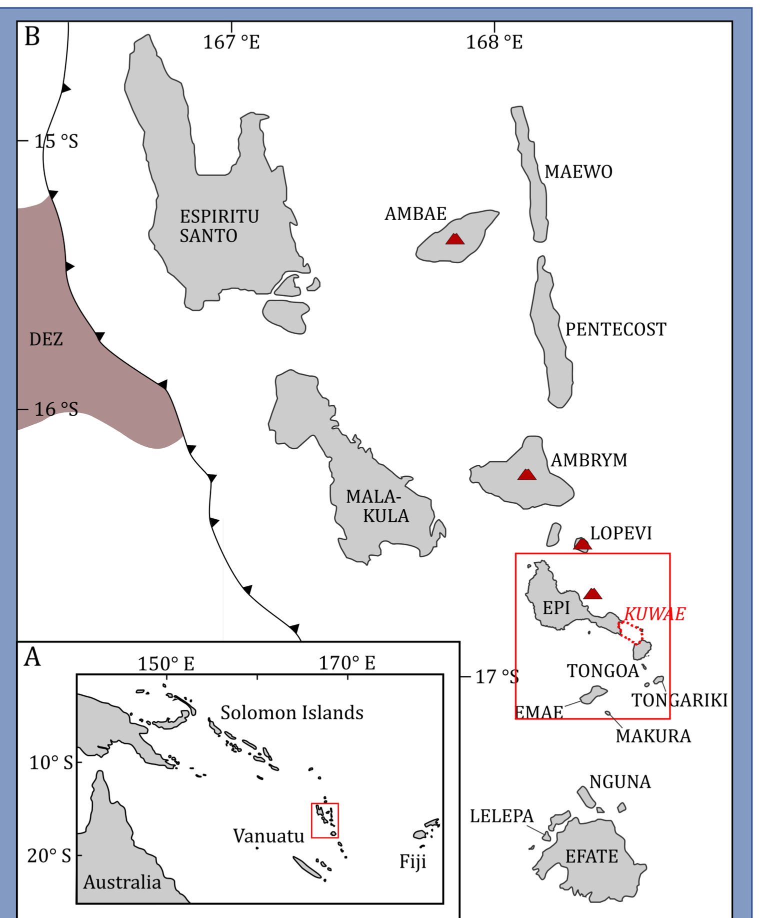

Fig. 1: Location map of Kuwae (study area in red box) within Vanuatu and the South Pacific. Selected volcanoes in the region are marked with red symbols, including the recently active submarine volcanoes of East Epi.

Kerua is a hydrothermal vent within the caldera and produced several eruptions in the last 130 years, the last one being in 1973 & 1974. Every time, a small islet grew out of the ocean, before being quickly eroded. This edifice was reported to reach up to 3 m below sea level in the early 1990s.

The Shepherds have a 3000-year-long history of settlement, with both Polynesian and Melanesian influences, providing a very rich cultural background. Kuwae represents the single most significant event in the Shepherd's human history and is still very present in local customs. Today, around 10,000 people inhabit Epi and the Shepherds.

Fig. 2: Cliffs at the beach at Mangarisu (Tongoa).

The islands are covered by dense rain forests, with only little exposure in the middle of the islands. Work focused on soft-sediment outcrops along the coasts of Epi and Tongoa, as well as selected inland locations.

A bathymetry study was carried out in March 2023, mapping the Kuwae caldera.

2 Local and regional impacts in the Shepherds and Vanuatu

Topography:

Chiefly titles before the eruption at Kuwae do not contain 'Tongoa' as a name – the name of the island used to be Kuwae, a continuous land mass between Epi and Tongoa. The eruption produced a 12-by-6 km gap between the two islands, with the Kuwae caldera filling this 56 km^2 space.

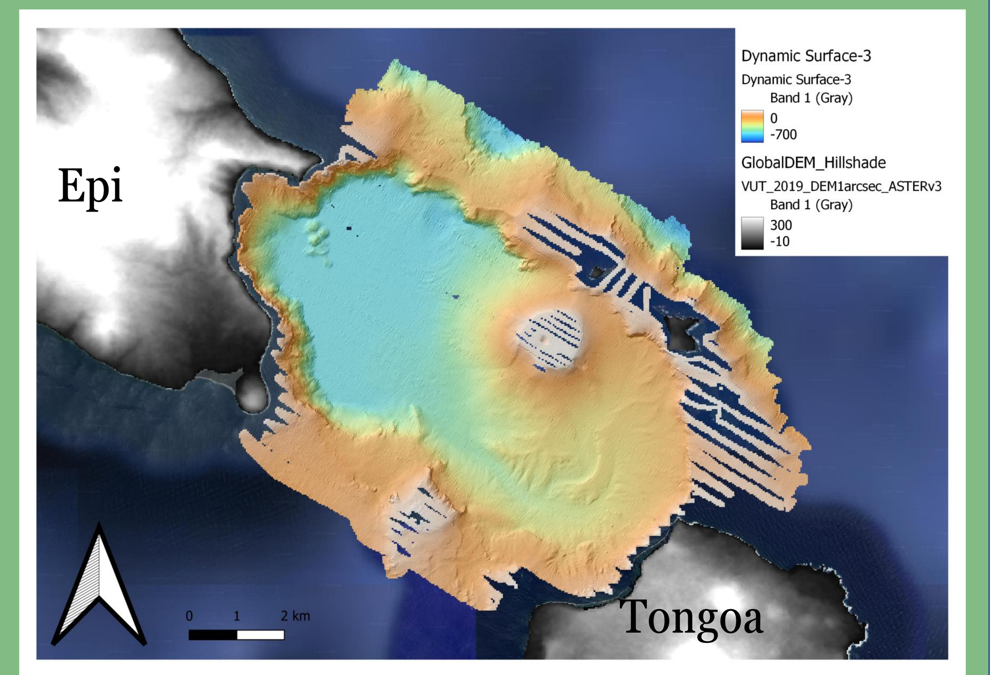

Fig. 3: Preliminary bathymetric map of the Kuwae caldera, with rainbow colours showing seafloor depth below sea level and greyscale showing on-land topography. The shallow area within the caldera is the smaller submarine cone of Kerua.

Earthquakes:

Strong earthquakes shook the area before the activity. Evidence can be found in soft-sediment faults below the Kuwae deposits. These earthquakes are described in local narratives of the event, describing earthquakes increasing in intensity before the eruption. This warned locals of the upcoming activity, enabling them to evacuate the island.

Volcanic effects:

First, a 4 cm ash fall covered the local area. Afterwards, a Plinian plume was built, covering Tongoa with up to 3 m of lapilli fall, while Epi shows up to 0.8 m – the difference suggesting that the plume mainly travelled south. Following, pyroclastic flows travelled over all of Tongoa and large parts of Epi, devastating both. Basal pyroclastic flow deposits at Tongoa are full of charcoal in all sizes (including whole tree logs), emphasizing the amount of devastation. Further pyroclastic flows then filled in valleys (up to at least 30 m), completely altering the pre-existent landscape.

While there likely was a chance to survive on the northern side of Epi, people closer to Kuwae (especially on Tongoa) would not have been able to do so.

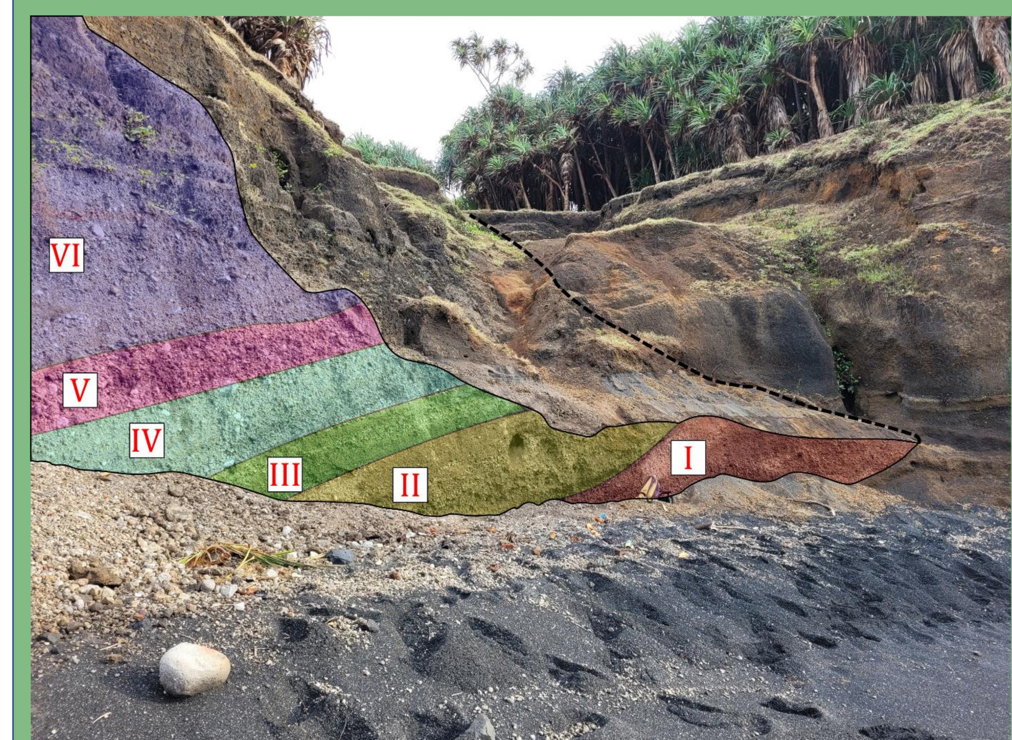

Fig. 4: Stratigraphy at Mangarisu (Tongoa), showing 6 different layers. I is the initial lapilli fall, while II to VI are various pyroclastic flow deposits.

Tsunami:

Tsunami deposits can be seen on Tongoa, with runup heights of at least 12 m at Kurumambe and Mangarisu. These immediately overlie the deposits of the valley-filling pyroclastic flow, suggesting tsunami generation through entrainment of pyroclastic flows into the sea, as suggested for similar eruptions elsewhere. On Emae, 20 km to the south of Kuwae, tsunami deposits (beach sand, mixed with corals and lapilli) can be found as high as 15 m asl.

3 Discussion of global impacts

Large volcanic eruptions can eject volcanic gases and aerosols (mainly ash) into the atmosphere, causing a global climate effect. Global interest in Kuwae was piqued by paleoclimate signal, indicating at least one major eruption in the 1450s CE – on a similar scale as the 1815 CE eruption of Tambora, making it one of the biggest three events of the last 1000 years. The 1458 CE signal shows up in paleoclimate datasets, incl. tree rings, corals, and ice core-based reconstructions (see e.g., Sigl et al., 2015). The temperature effect might have been up to 2.5 °C, with cooling detectable for several years.

Kuwae has been linked to the 1458 peak since the early 1990s, but the connection between the local event at Kuwae and the global event in 1458 CE could never be made convincingly. This can only be tested once the eruption at Kuwae is understood at source, in terms of (a) its total volume, (b) its plume characteristics, (c) the total amount of emitted sulphur, and (d) its timing.

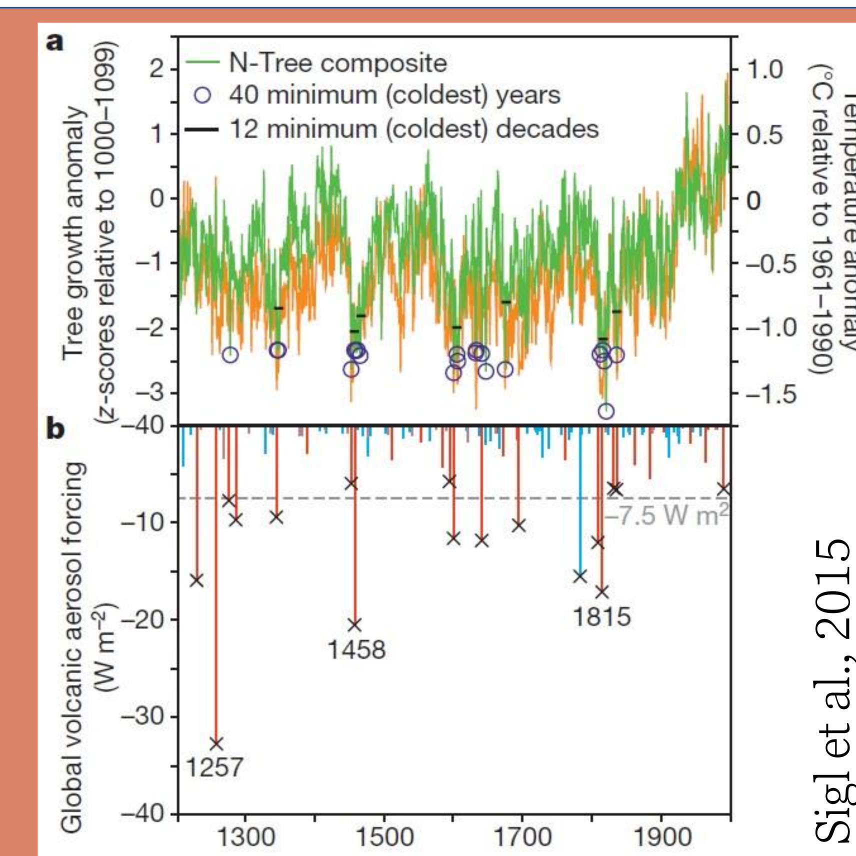

Fig. 4: Paleoclimate data showing the largest events within the last 800 years (Sigl et al., 2015).

Bathymetry:

Based on the newly obtained bathymetric data, the volume of the modern caldera is around 17 km^3. There is no large intra-caldera structure indicating overlapping collapses, thus a complete collapse during the mid-15th century appears likely. Within the caldera, the submarine vent of Kerua has grown in the last 600 years, currently building up from ~450 m to 11 m bsl. The total volume of Kerua is estimated at around 2 km^3.

Additional potential for volume lies in sediment infill after the latest caldera collapse and pre-existent topography. The sediment infill is estimated at up to 225 m, based on seismic reflection data collected during earlier studies. Reconstruction of the pre-existent topography heavily relies oral history, indicating heights above sea level. On both Epi and Tongoa, the caldera walls stick out >200 m asl.

Parameter	Thickness	resulting volume
Kuwae caldera volume	-	17 km^3
Sediment infill	100 - 200 m[a]	5.6 - 11.2 km^3
Pre-existent topography	0 - 100 m[a]	0 - 5.6 km^3
Kerua volcano volume	-	1.9 km^3
Total collapse volume[b]	-	24.5 - 35.7 km^3

[a] All thicknesses are estimated and averaged over the whole caldera.
[b] Very preliminary numbers - should be treated cautiously.

Tab. 1: Estimations for caldera collapse volume, based on the volume of the Kuwae caldera itself, the amount of sediment infill, the elevation of the pre-existent topography (above sea level), and the volume of Kerua volcano, which has grown inside the caldera since its last major eruption

Overall, the collapse volume is likely between 24 and 36 km^3 dense rock equivalent, see Tab. 1. However, further analysis of the record remains. The upper end of the range would put eruption at Kuwae on par with the 1815 Tambora event.

Plume and material characteristics:

While most of the deposits found within the Shepherd Islands around Kuwae are made up of pyroclastic flow deposits, fall layers can be found on Epi, Tongoa, Tongariki, and Efate. Thickness and particle size result in early estimates of plume heights between 40 and 55 km asl, easily reaching the stratosphere. This would allow for ash to spread globally, including both poles, depositing material on ice sheets in Greenland and Antarctica.

Total amount of emitted sulphur & Timing:

While we have collected samples for both, we only have preliminary data for sulphur concentrations and await radiocarbon dating analysis of ~40 samples collected at Kuwae. Following further analysis, we will be able to provide more detailed information.

Conclusions: Locally, the eruption at Kuwae had devastating consequences. The islands of Epi and Tongoa were devastated by pyroclastic flows that reached at least 30 km away from the caldera. Tsunamis affected the Shepherds, with ash fall reaching Efate. Questions remain concerning its global impact and studying further parameters at source (mainly total amount of emitted sulphur and timing of the event) is essential for answering these.

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