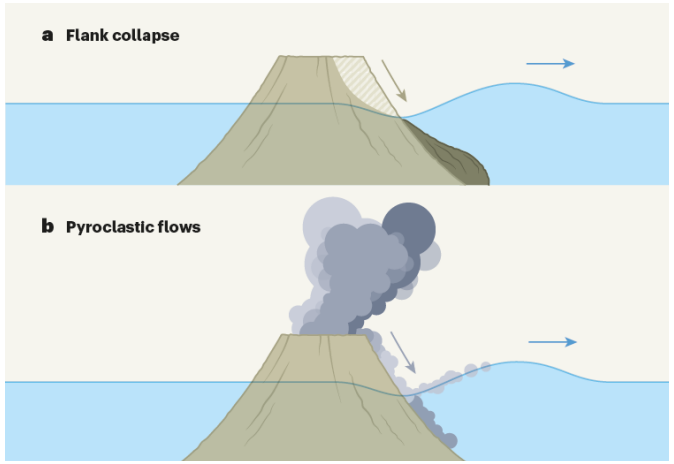
The 2022 Hunga eruption and other SW Pacific volcanic tsunami threats…

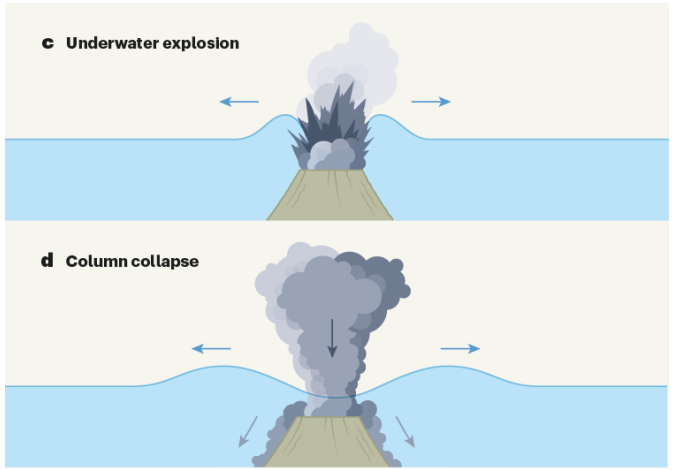
Shane Cronin - University of Auckland

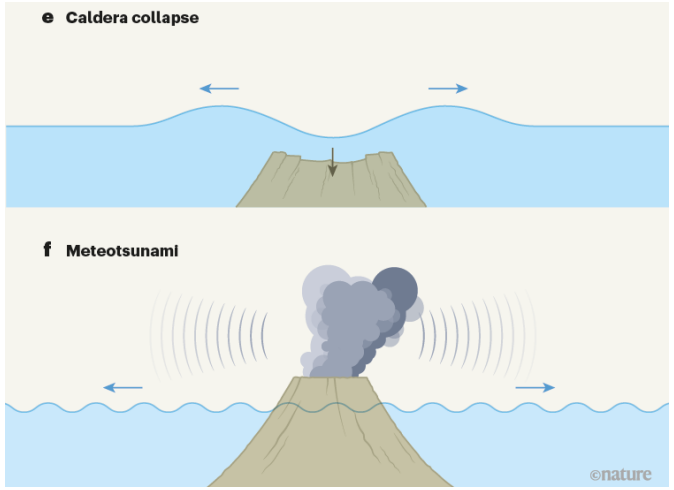
What causes volcanic tsunami

Shallow (<50 m deep) submarine eruptions (Surtseyan)	Mainly small and localized
Landslides or pyroclastic flows entering ocean (Unzen)	Mainly localized and directed
Submarine volcano flank landslides	Less well known, but likely to be directed
Caldera collapse	Unknown until Hunga
Extreme phreatomagmatic explosions in >150 to 500 m of water: • Direct jetting of pyroclasts • Water displacement • Atmospheric pressure waves • Caldera ring-fault fountaining • Dense pyroclastics	Hunga (and Krakatoa) exemplars • Concentric distribution suggests explosion and caldera source • Largest local displacement • Distal tsunami due to atmospheric coupling

Emily Lane https://www.nature.com/articles/d41586-022-01855-0



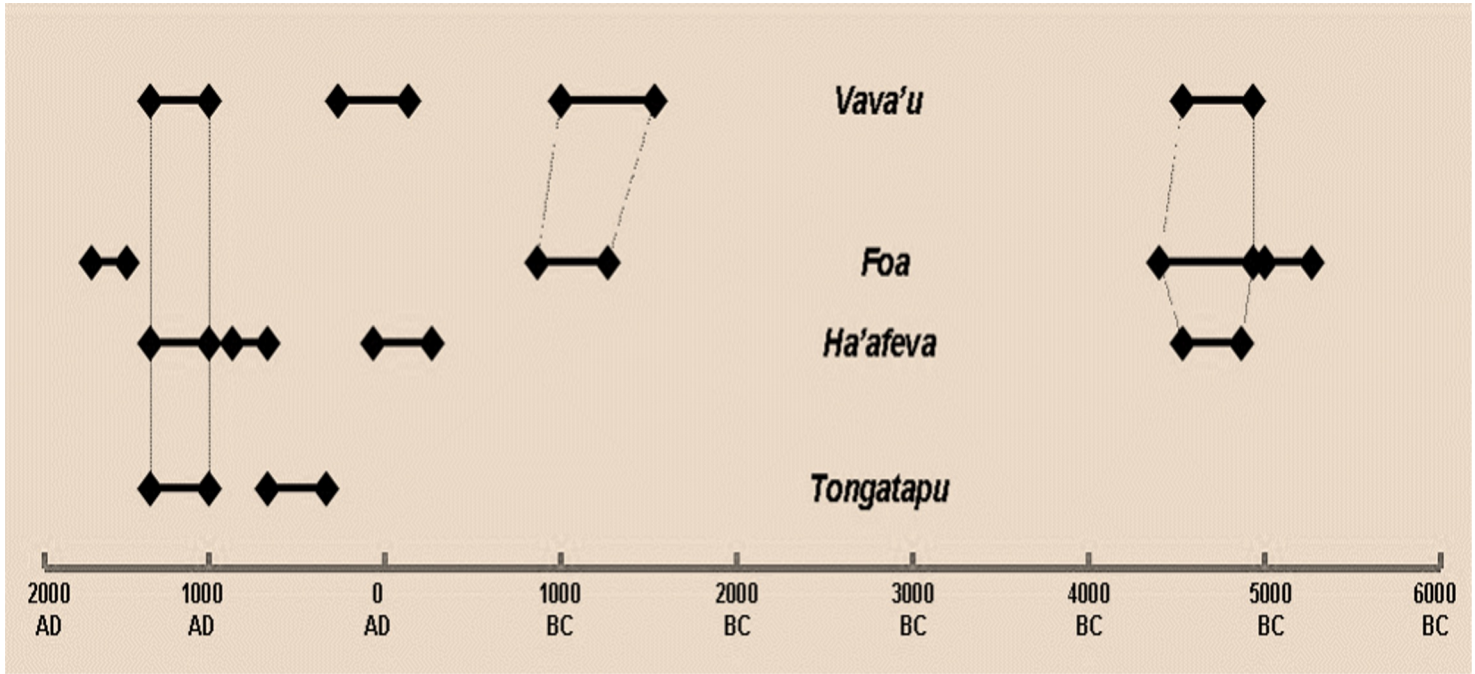


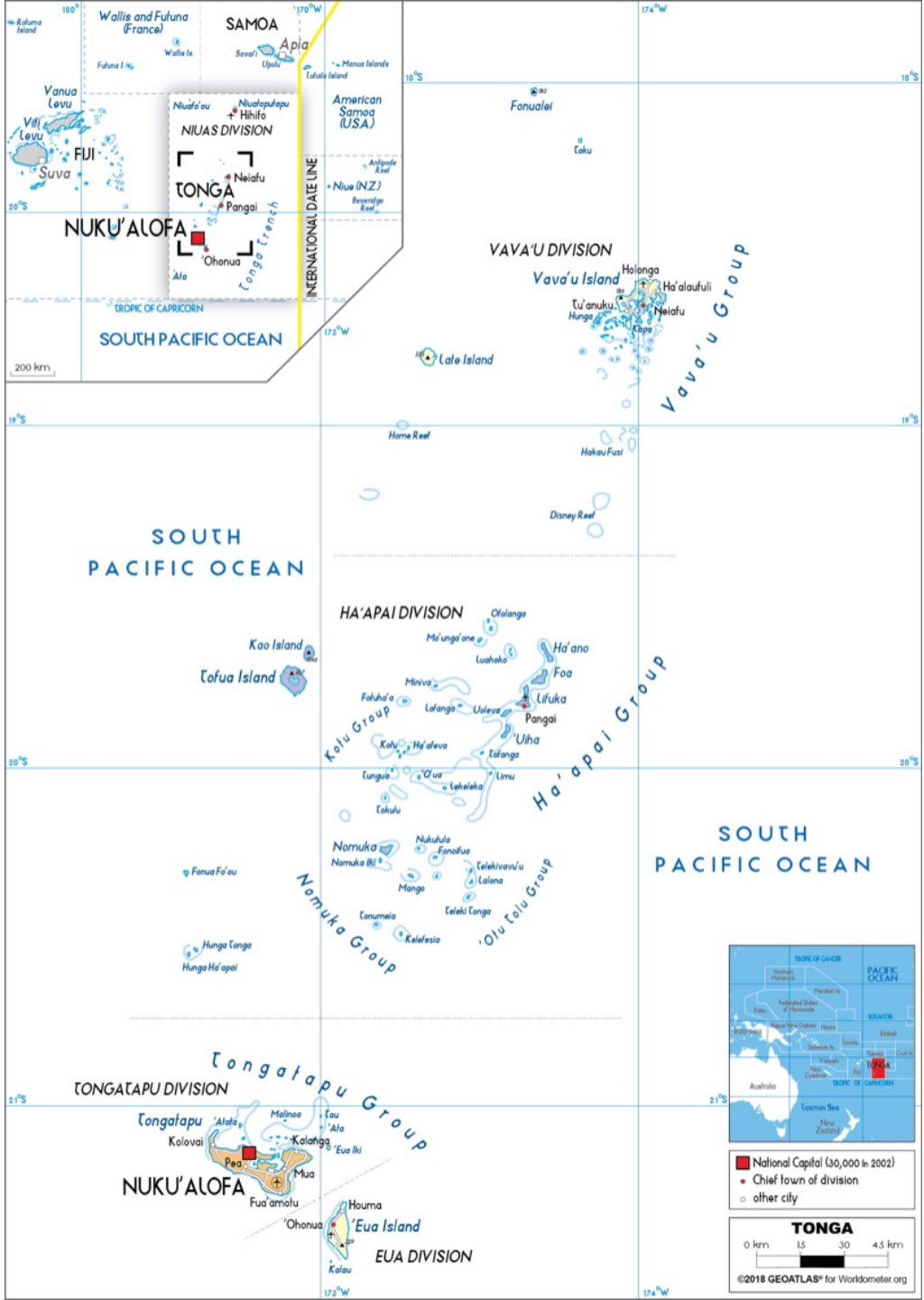


Tonga

35 large eruptions over the last 6.5 ka

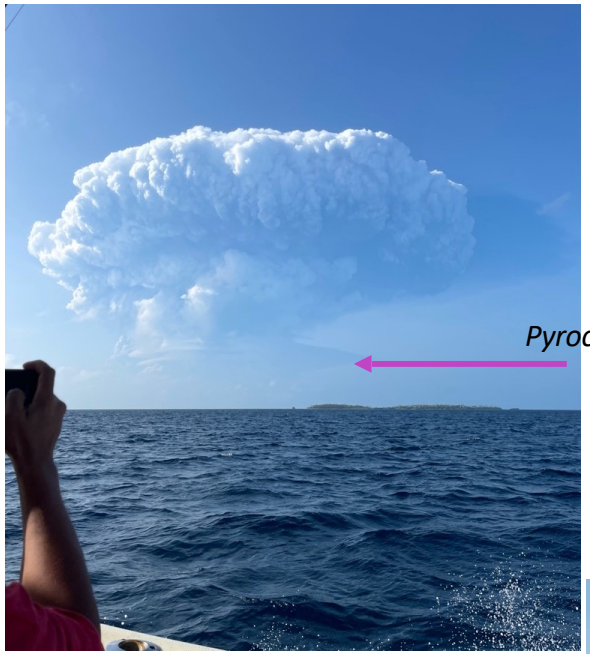
Several major events affected all of the country
PhD on Tonga Holocene Tephrochronology underway
(Annahlise Hall)



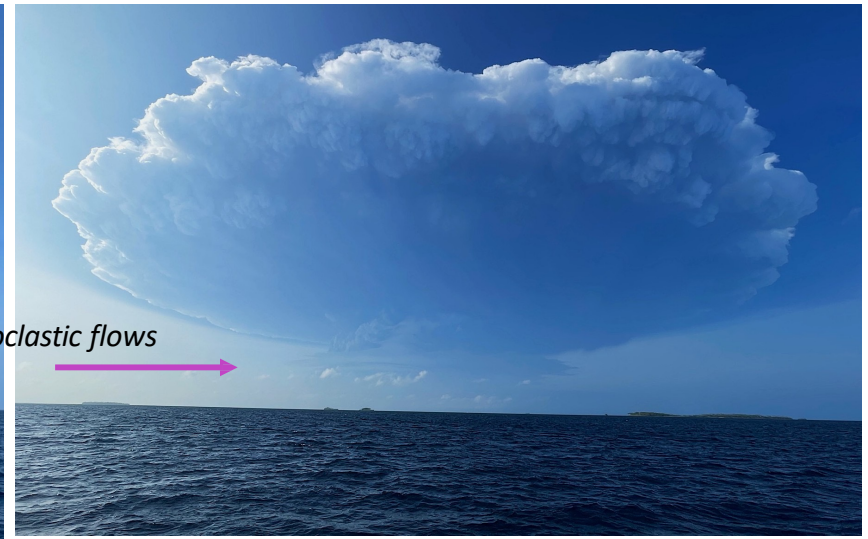


HUNGA ERUPTION (15 JAN 2022)

0411 UTC first eruption ”normal”



0418 Sudden upsurge in energy



0425 rapid plume expansion and huge pyroclastic flows

0432 Sonic booms

1733 (0433) Tsunami approaching north Tongatapu (west hit already with first wave)

Steam rich plume
Collapsing margins
Little evidence of ash in the plume

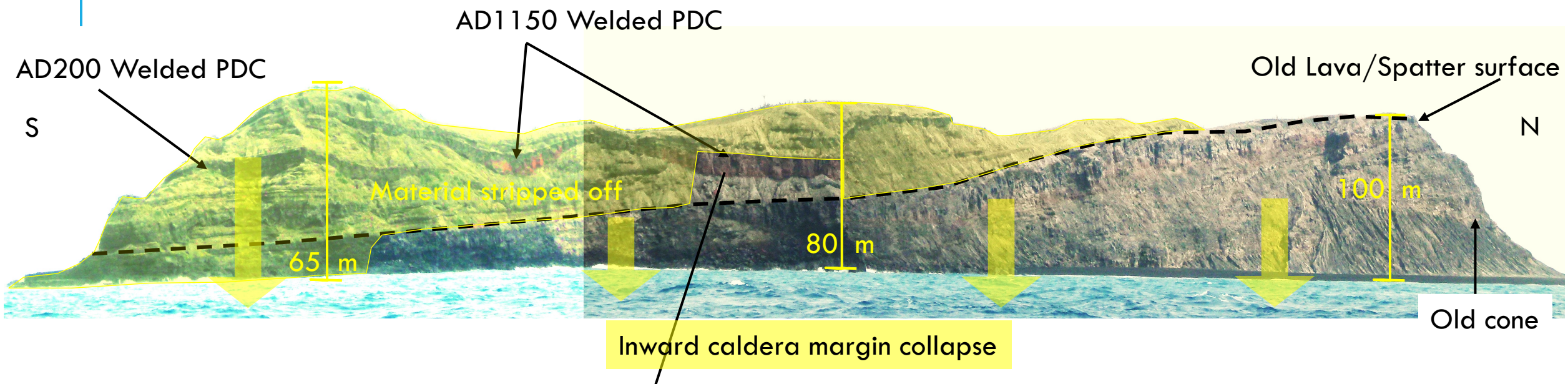
0500 Ashfall on Tongatapu


View from Ha’tafu as first tsunami arrived 04:25 UTC


15 Jan 2022 3.35 pm
1.5 hours before climactic eruption
MAXAR
Planet Labs

Hunga Ha'apai

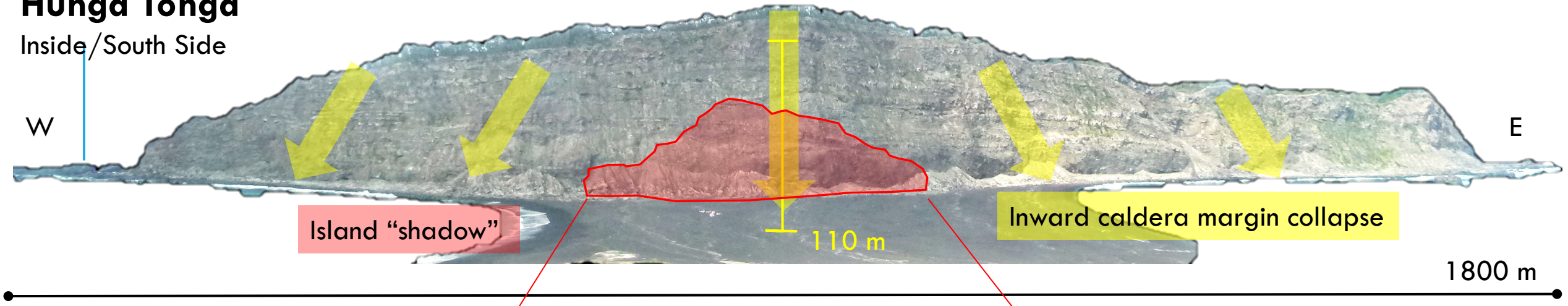
Caldera-side



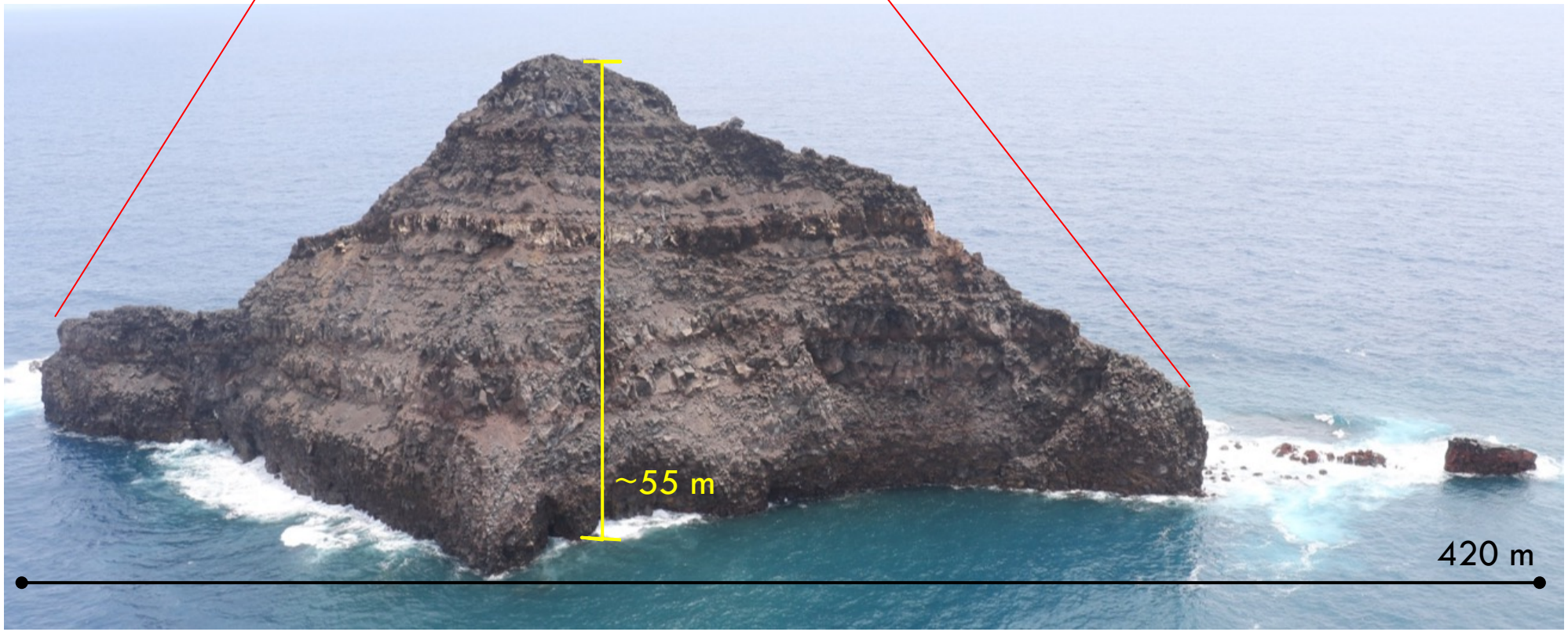
Inward caldera margin collapse

Hunga Tonga

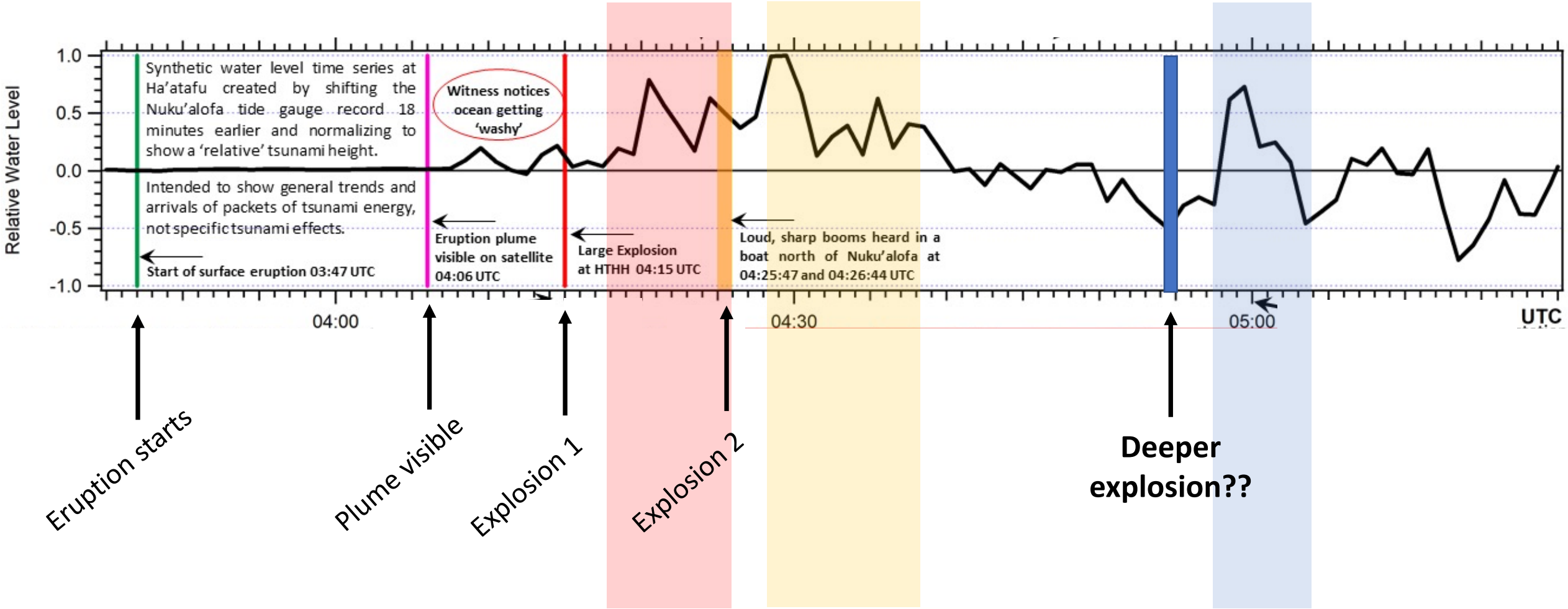
Inside/South Side



This caldera-margin face has completely collapsed inward and the remaining island is a fragment of the northern (outer) flank



Tsunami timeline - Tongatapu

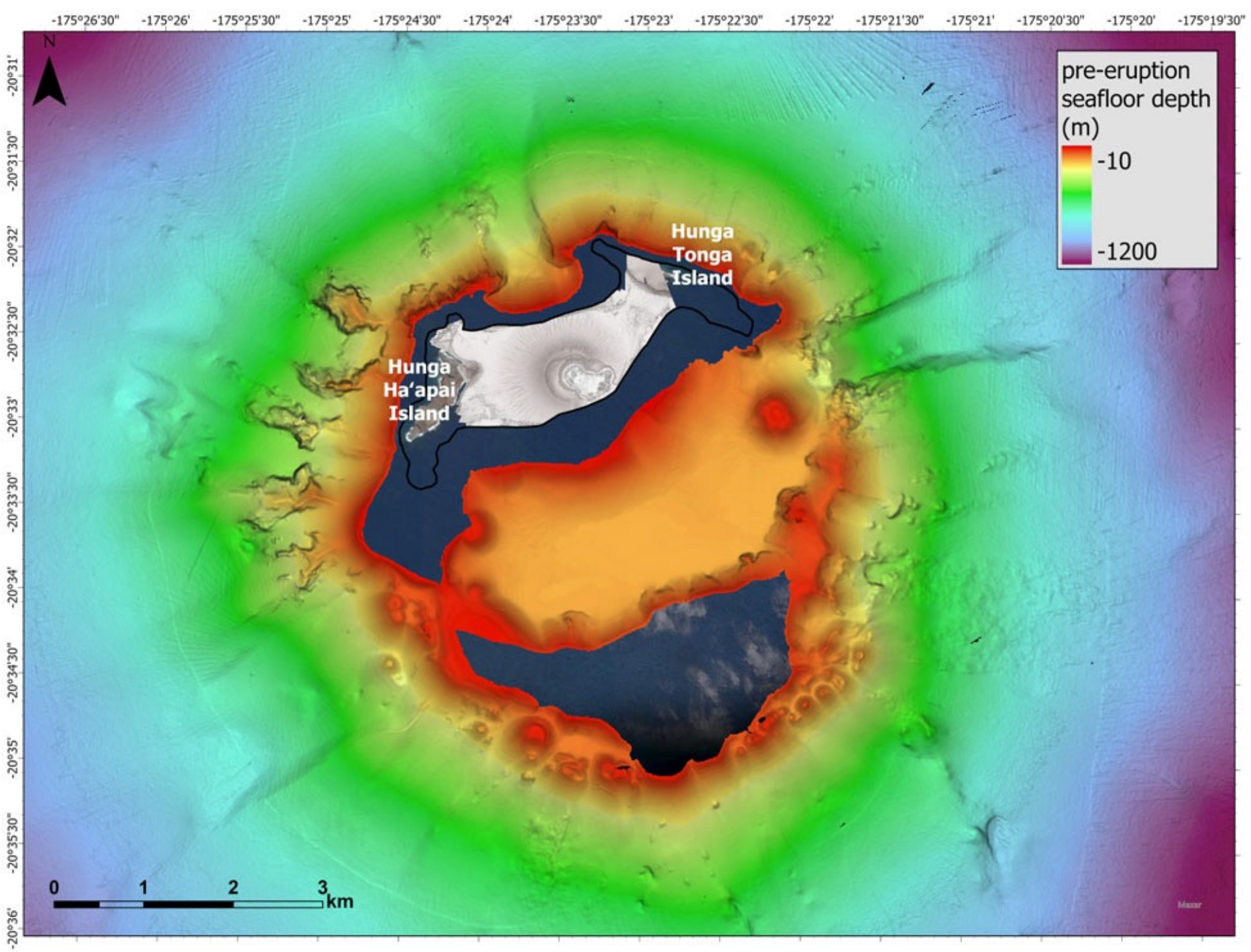


Borrero et al., 2022

Pre-eruption

Combined
bathymetry
2015 UoA
&
2016 RVFalkor

2015 UoA drone
DEM



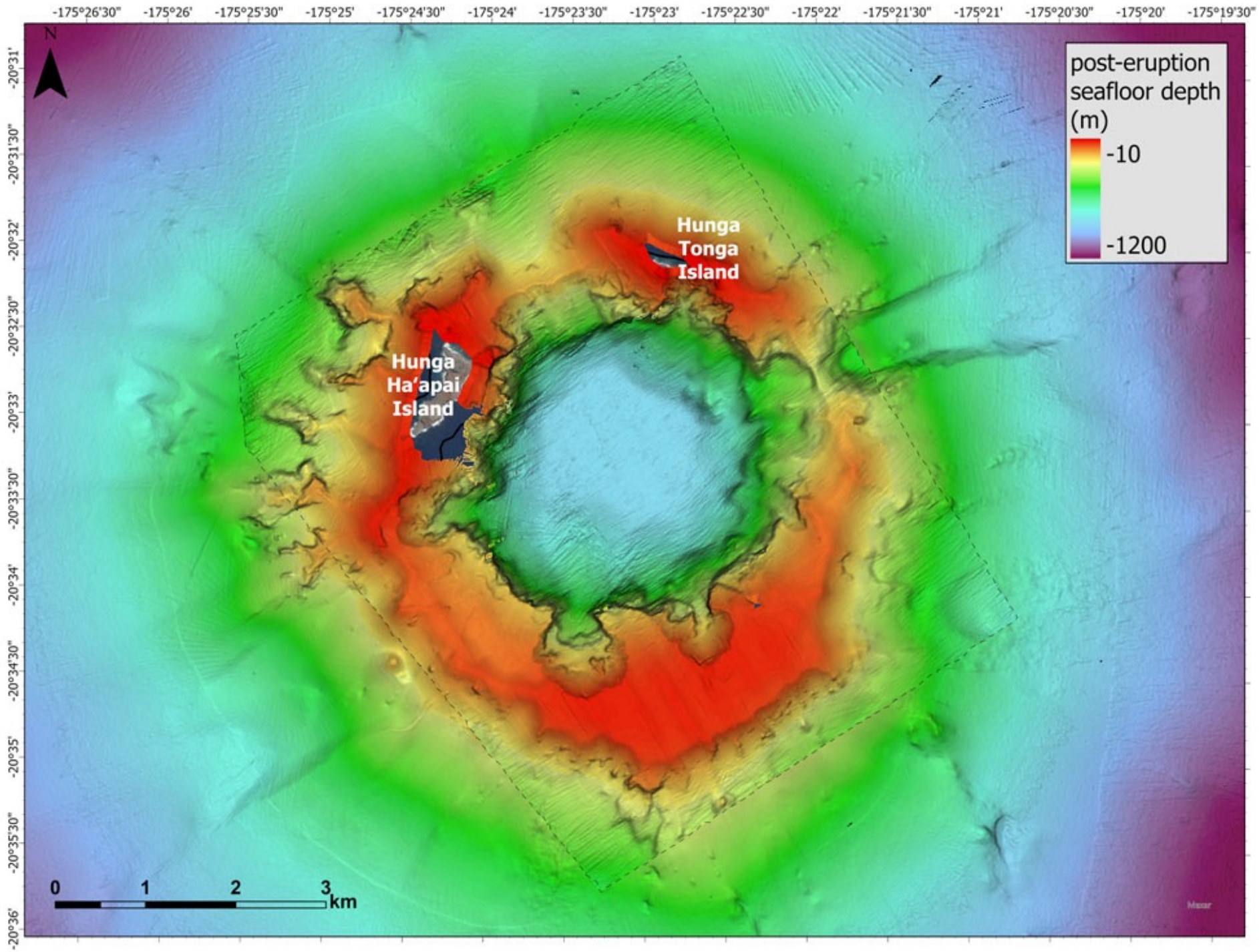
Post Eruption

2022 UoA + Korpri Bathymetry

100 m+ pyroclastic infill in crater floor

Deep ring faults imaged, steepest in Nth

Demagnetized zone in the north



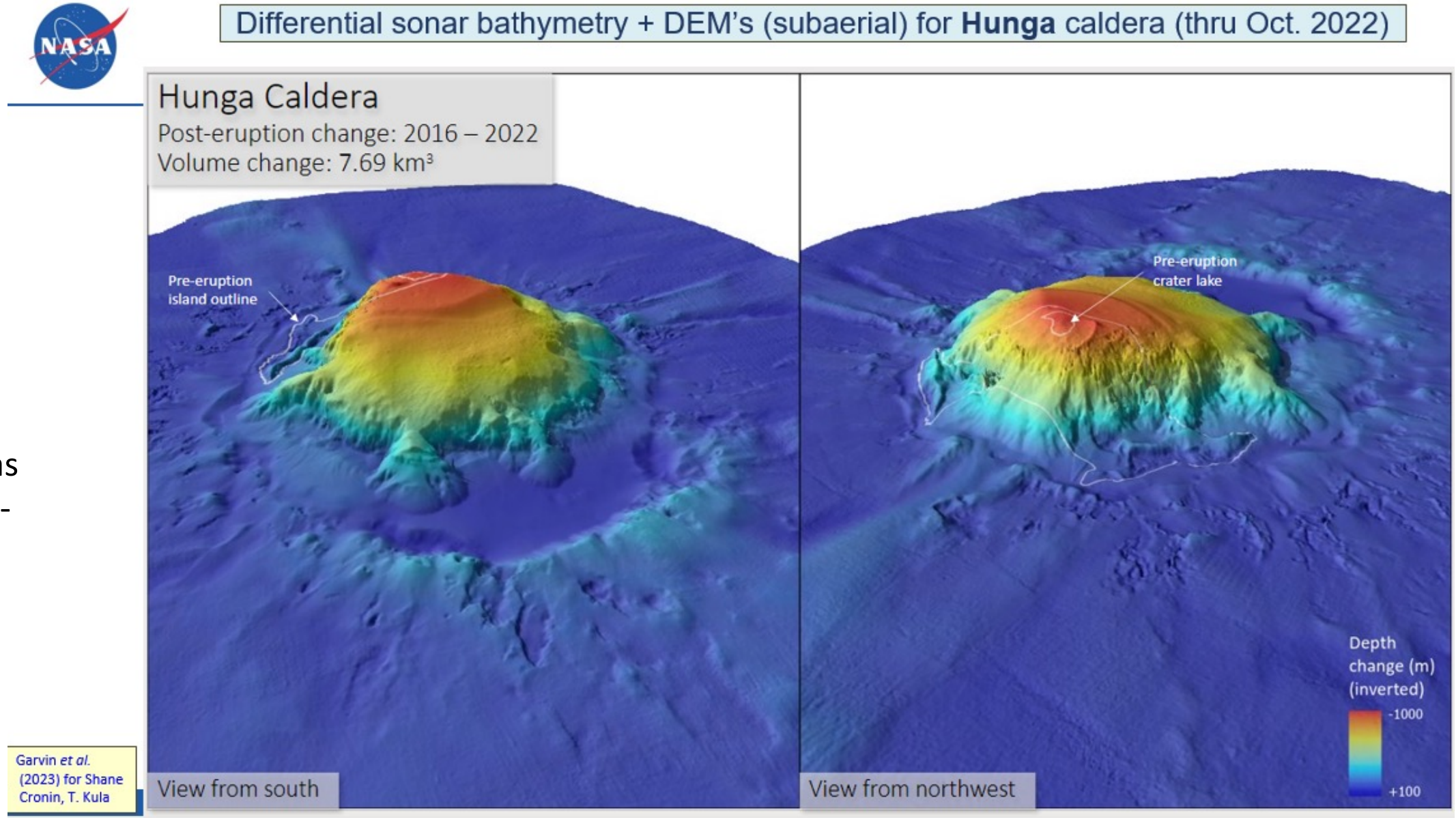
Volume change

7.7 km^3 for caldera

Up to 100 m sediment infill (0.2-0.3 km^3)

Also note southern rim has dropped by ~30-50 m

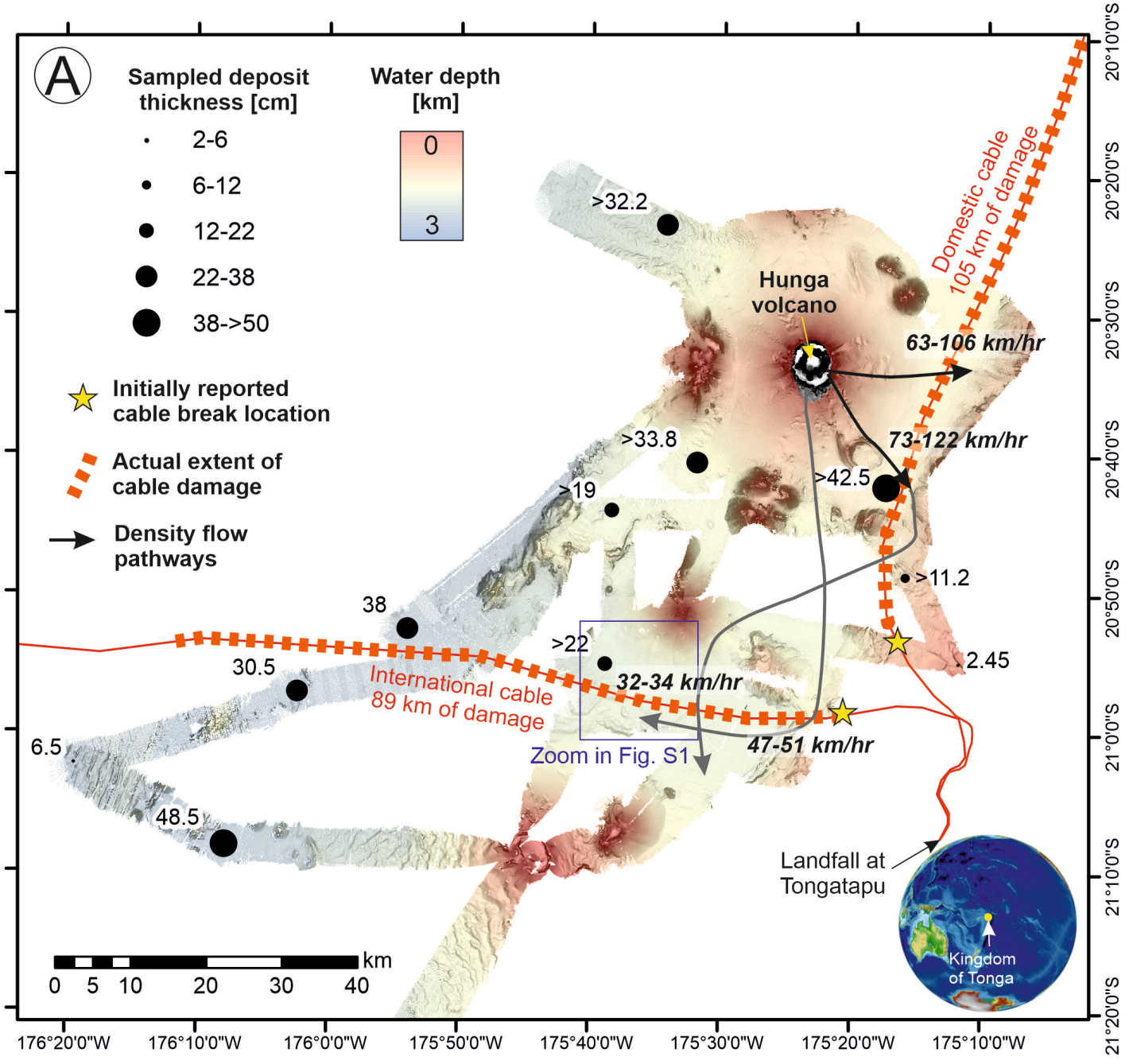
Uncertainty ~0.5 km^3



Submarine gravity flows

Very Fast
Broke internet cables
Long runout >90 km, suggests long-term high rates of feeding

Represent >11 km^3 of pyroclastic deposit

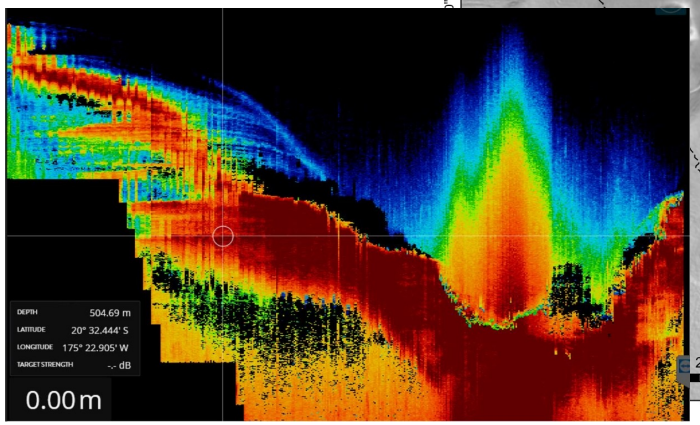


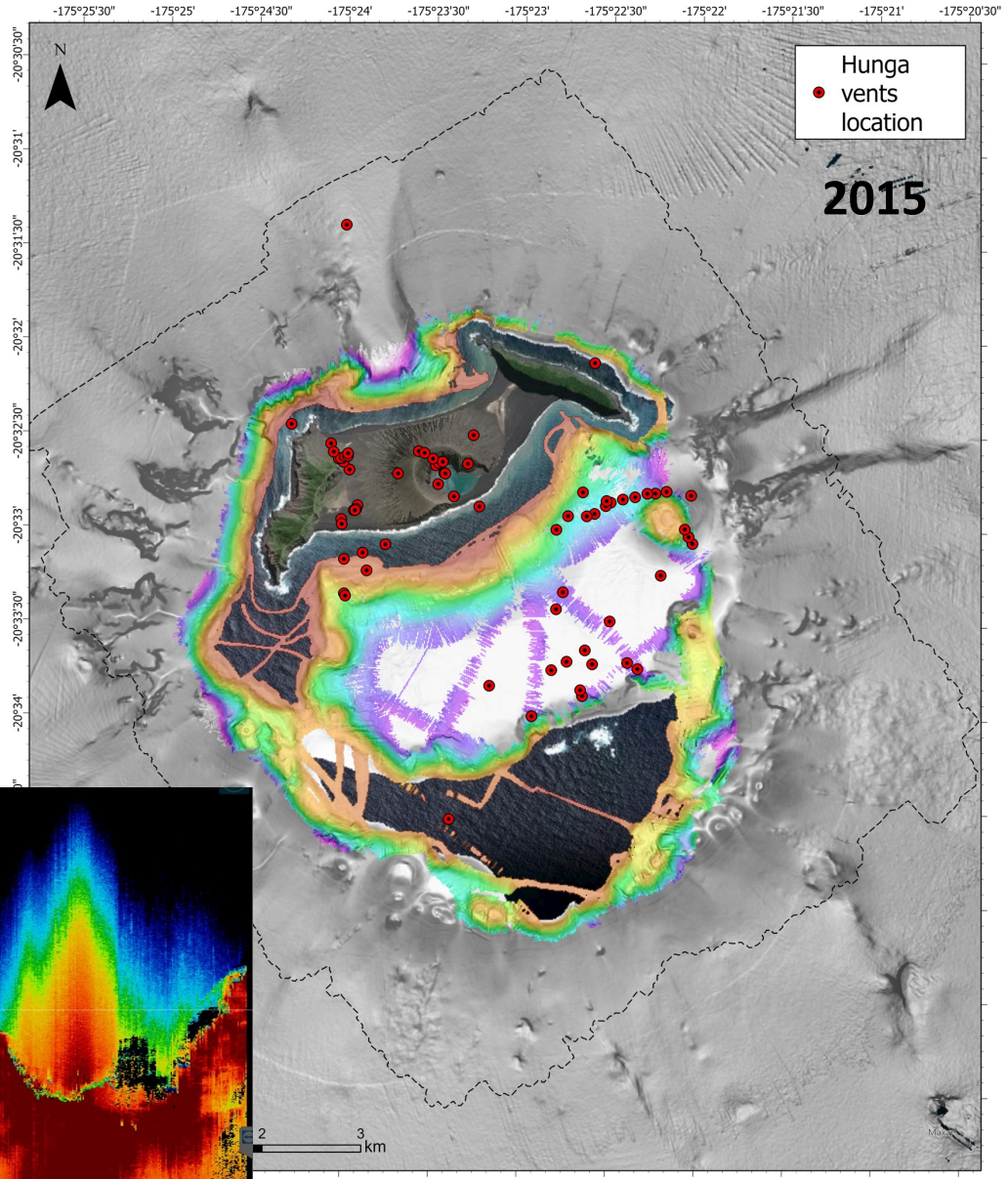
Mike Clare et al., in review

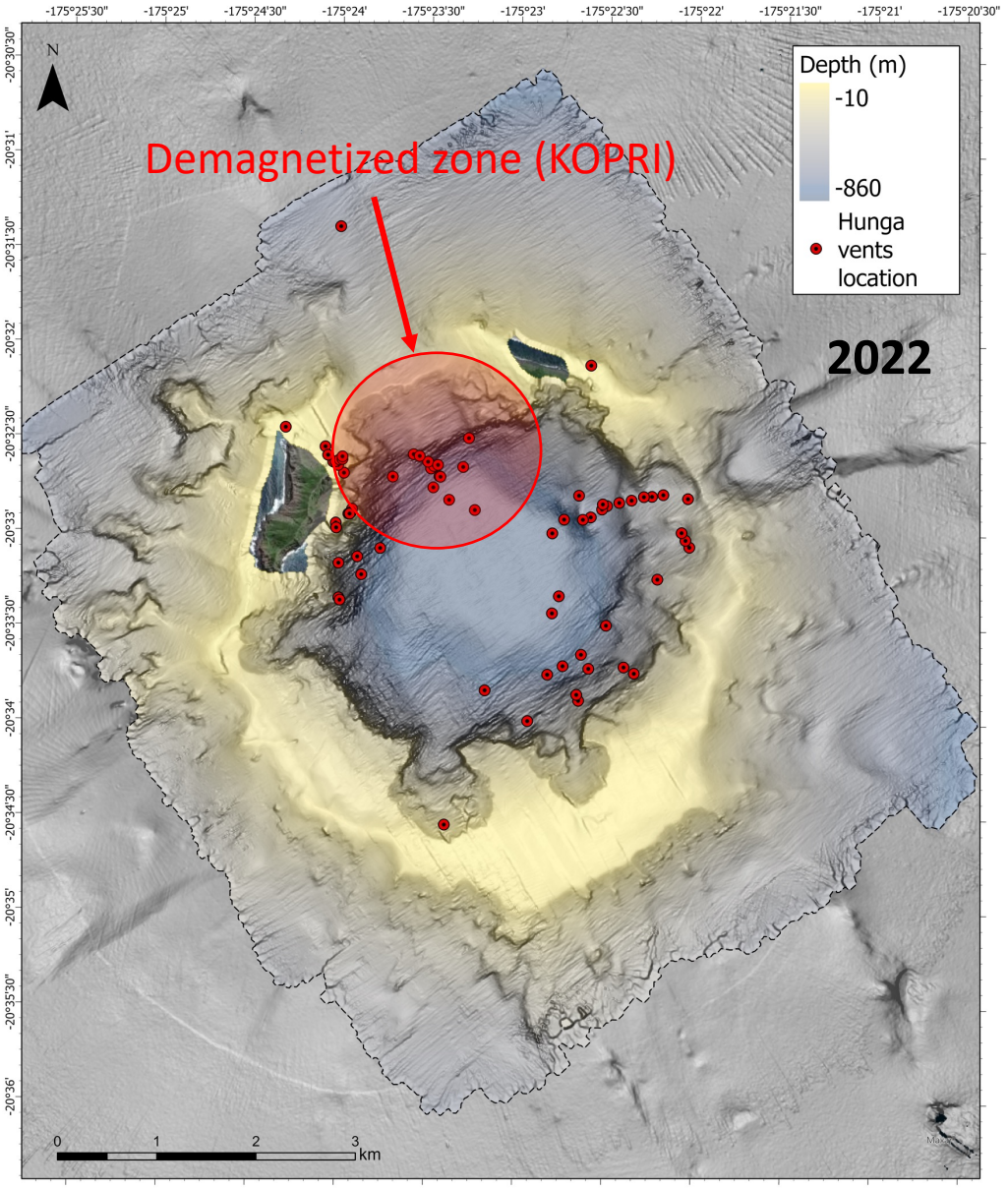
Vent patterns (post-eruptive submarine vents superposed on 2015 and 2022 bathymetry)

Northern area was an important conduit

Caldera wall vents during the PDC phase?



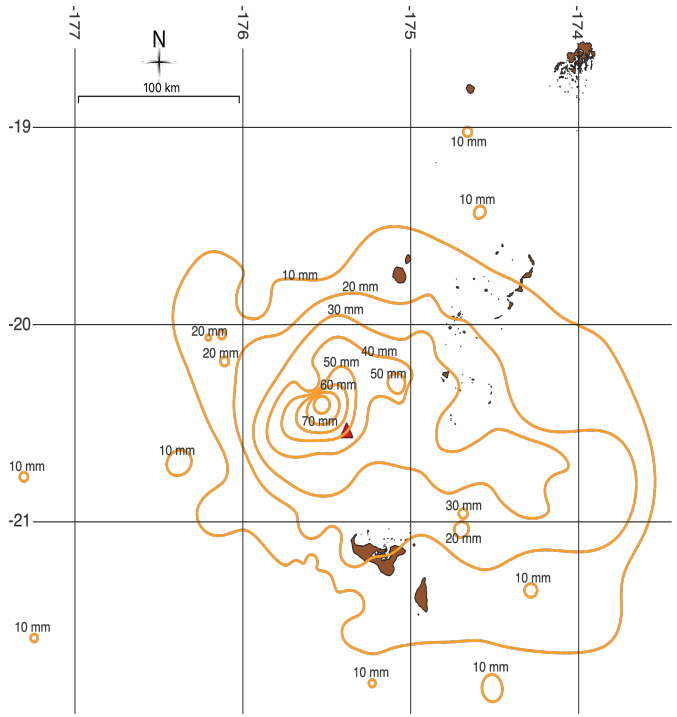


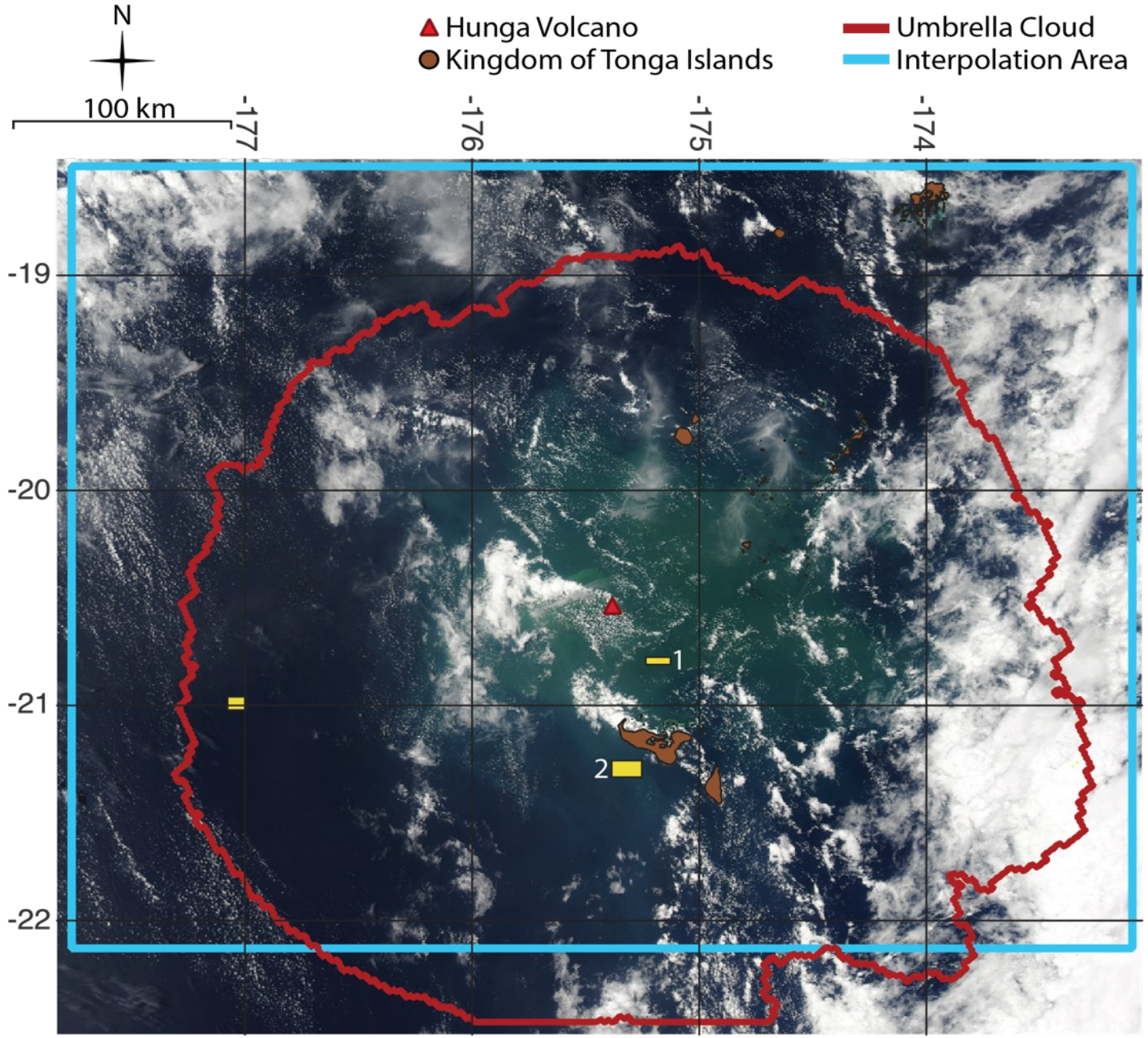


Fallout volume estimates

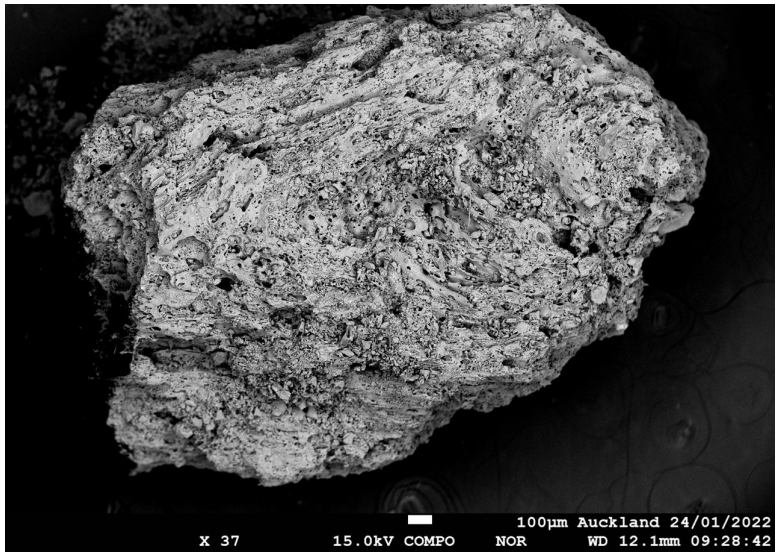
Mastin et al., in prep
Using Plumeria model
~1 km^3 of fall

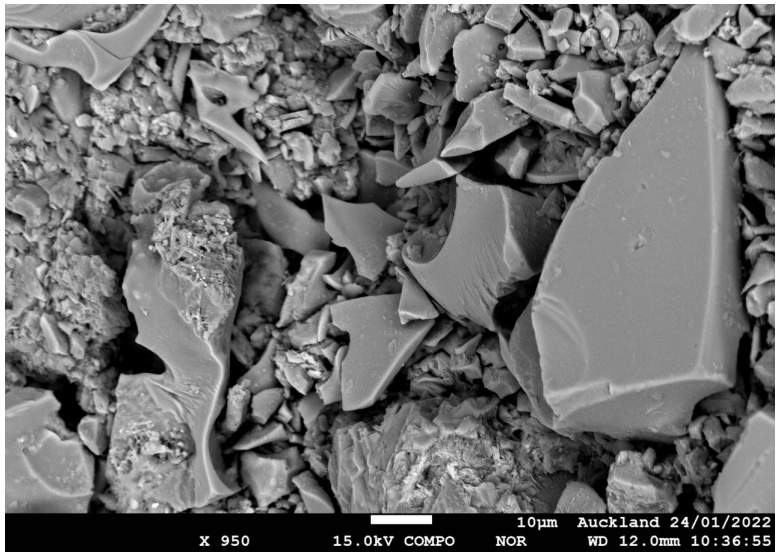
Kelly et al., in review
Using ocean discoloration
~1.5 km of fall

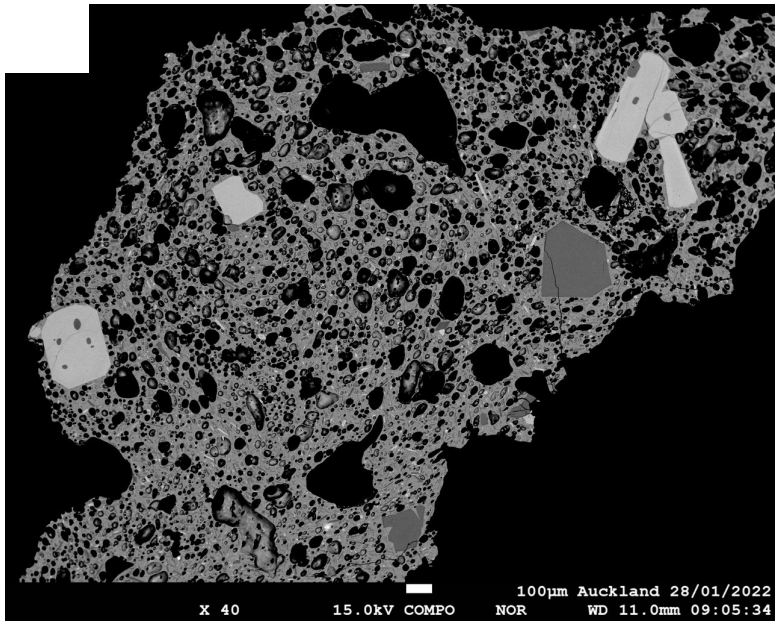


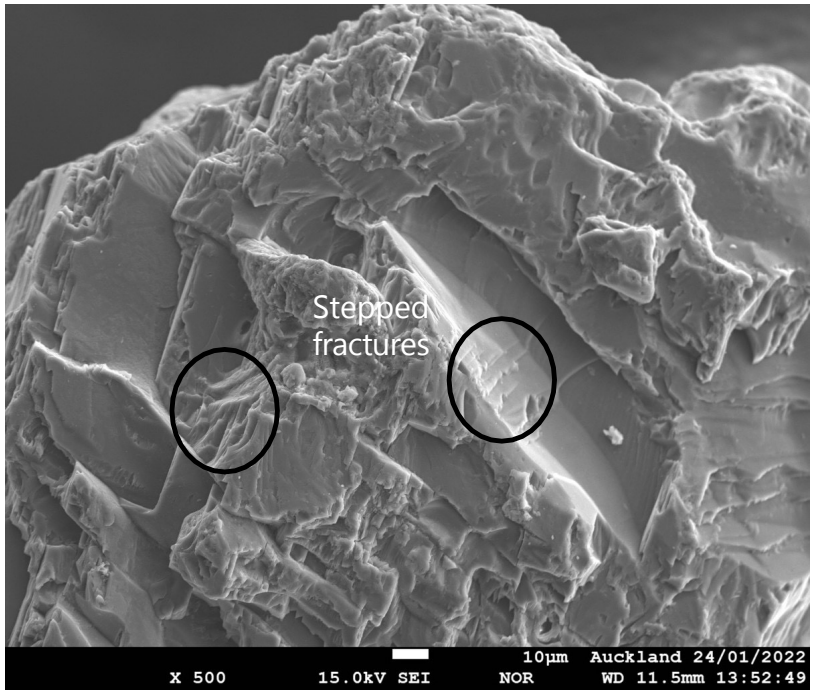


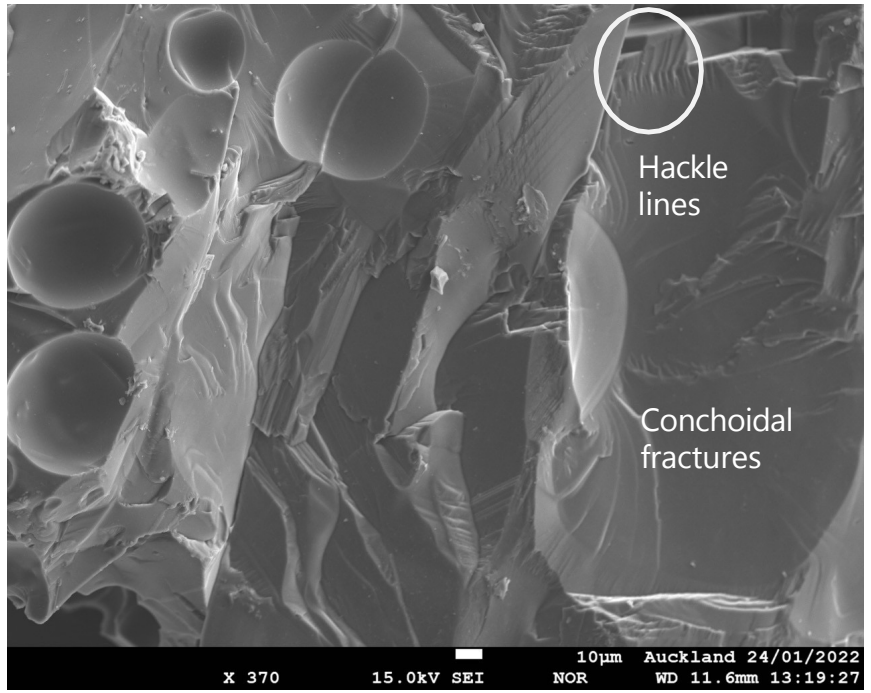
Explosive magma-water interaction evidence









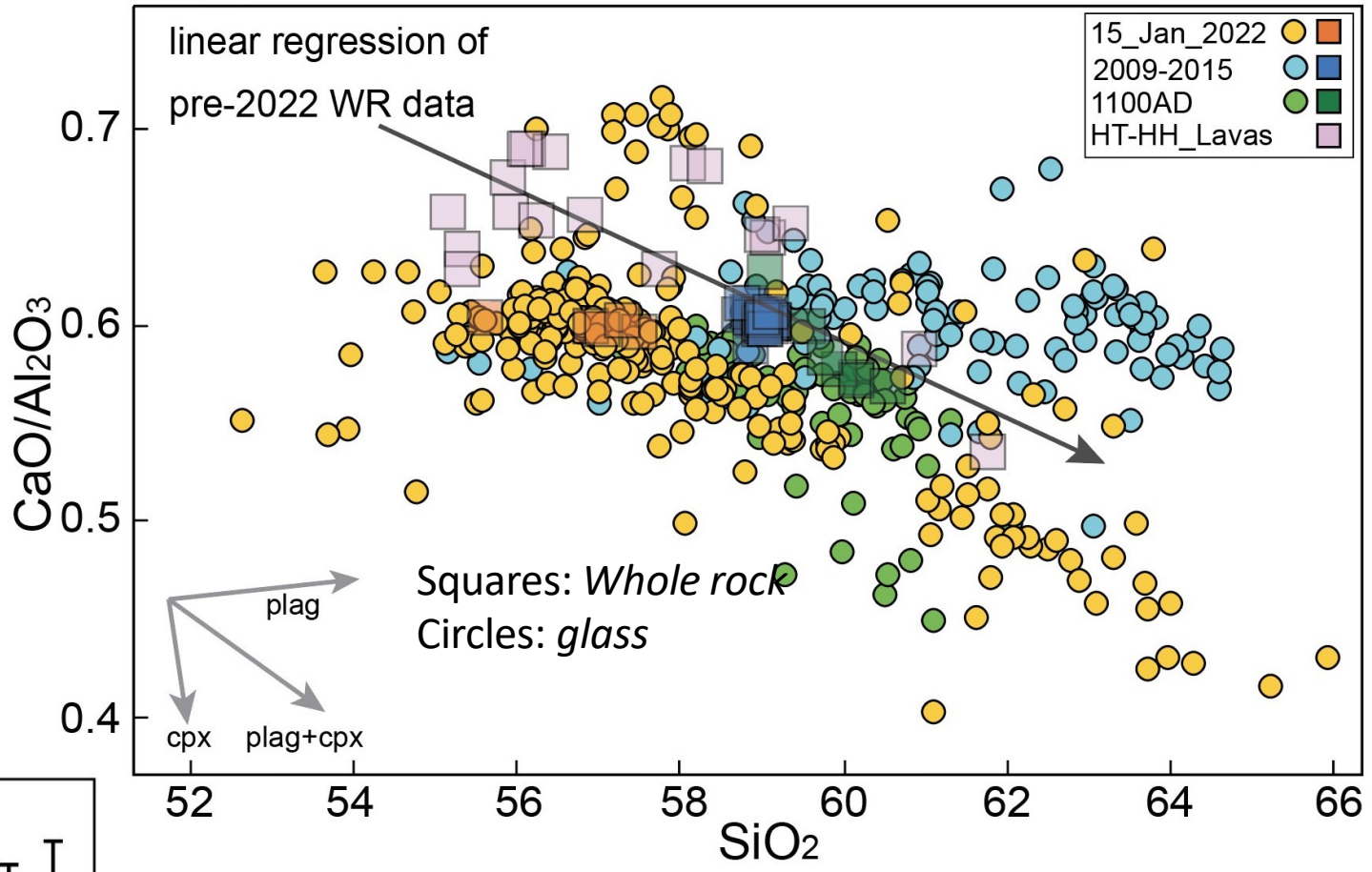


Pumice textures:
Variable vesicularity
Coated in fine-ash
Isolated vesicles

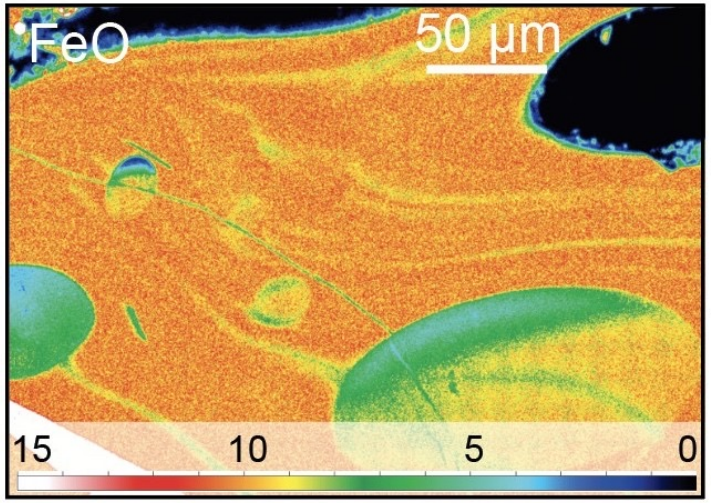
Massive glass:
Blocky:
- Stepped fractures
- Conchoidal fractures
- Hackle marks:

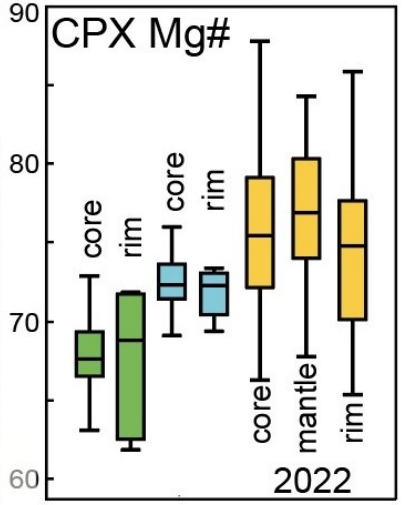
Mingled and Mixed Magmas

- Whole rock composition similar to past
- mixing and mingling to micron scale
- Mineral core and rim-zoning shows rapid assembly of mafic and evolved (andesitic) pyroxenes and feldspars



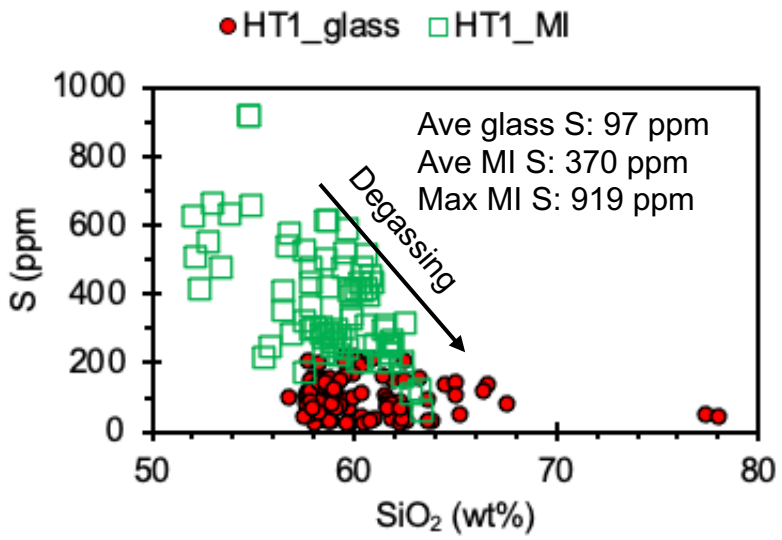
Mingled glass + collapsed vesicles

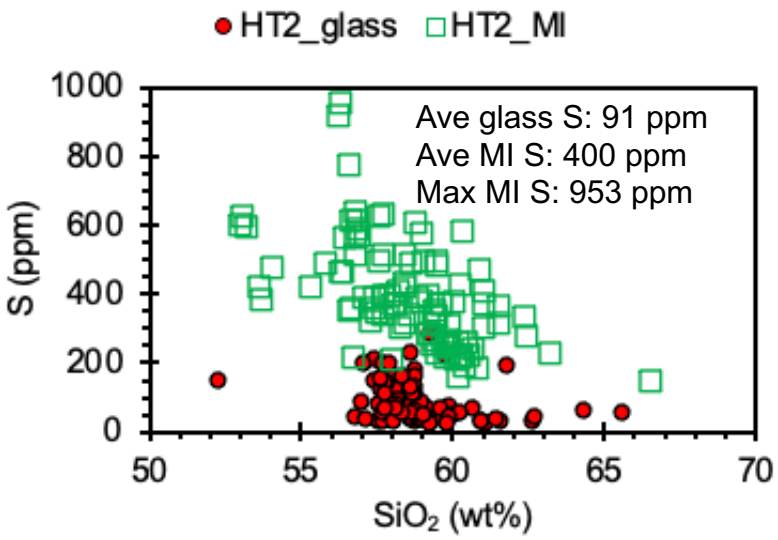


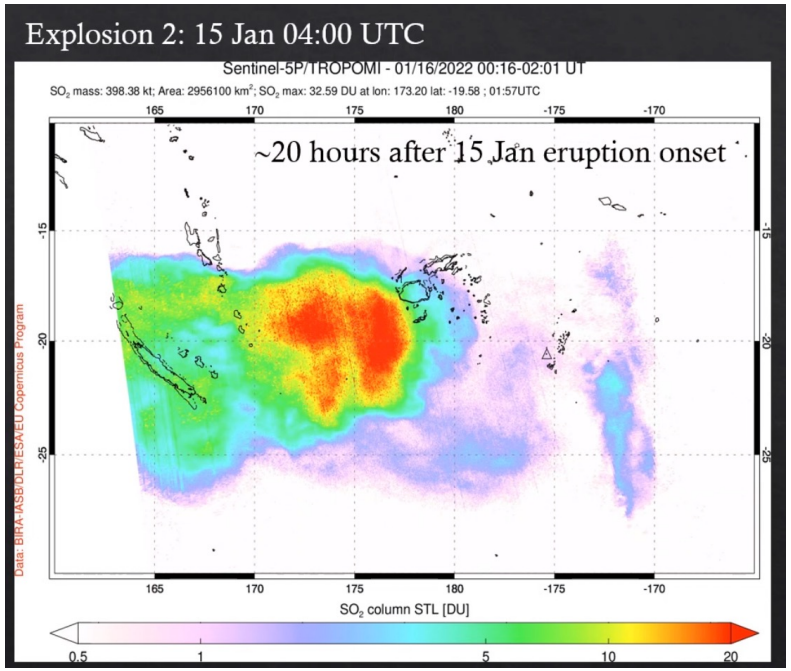


Wide mineral composition range

Sulphur outputs







Total magma mass >14 billion Tg (magma volume = 7+/-0.5 km^3; density = 2000 kg/m^3)

Total S loss was 24 Tg SO_2 (1991 Pinatubo eruption (VEI 6) released 20 Tg SO_2 (Bluth *et al*., 1993)

Satellite estimates recorded only 0.4-0.5 Tg in atmosphere (Carn et al., 2022)

>97% of SO_2 went into the ocean with gravity currents or was released earlier?

Hunga eruption

- New basaltic-andesite magma invaded the Hunga reservior to start the eruption
- Eruption began from the north vent at ~03:47 UTC
- Ring-faults were activated, allowing seawater contact with magma within the edifice.
- Intense pressurized water-magma interactions caused an extreme form of **phreatomagmatic** explosions for ~40 min
- Caldera collapsed began by at least 04:15, possibly step-wise
- Radial/concentric dense boiling-over plumes occurred from multiple vent sites for ~2 hours
- Explosions + collapse of debris on upper submarine flanks and direct fountaining of pyroclastic material generated submarine gravity currents and tsunami
- High plume heights were generated by volatilization of sea water and an atmospheric “thermal” plume with little ash content

THE UNIVERSITY OF AUCKLAND
Te Whare Wānanga o Tāmaki Makaurau
NEW ZEALAND

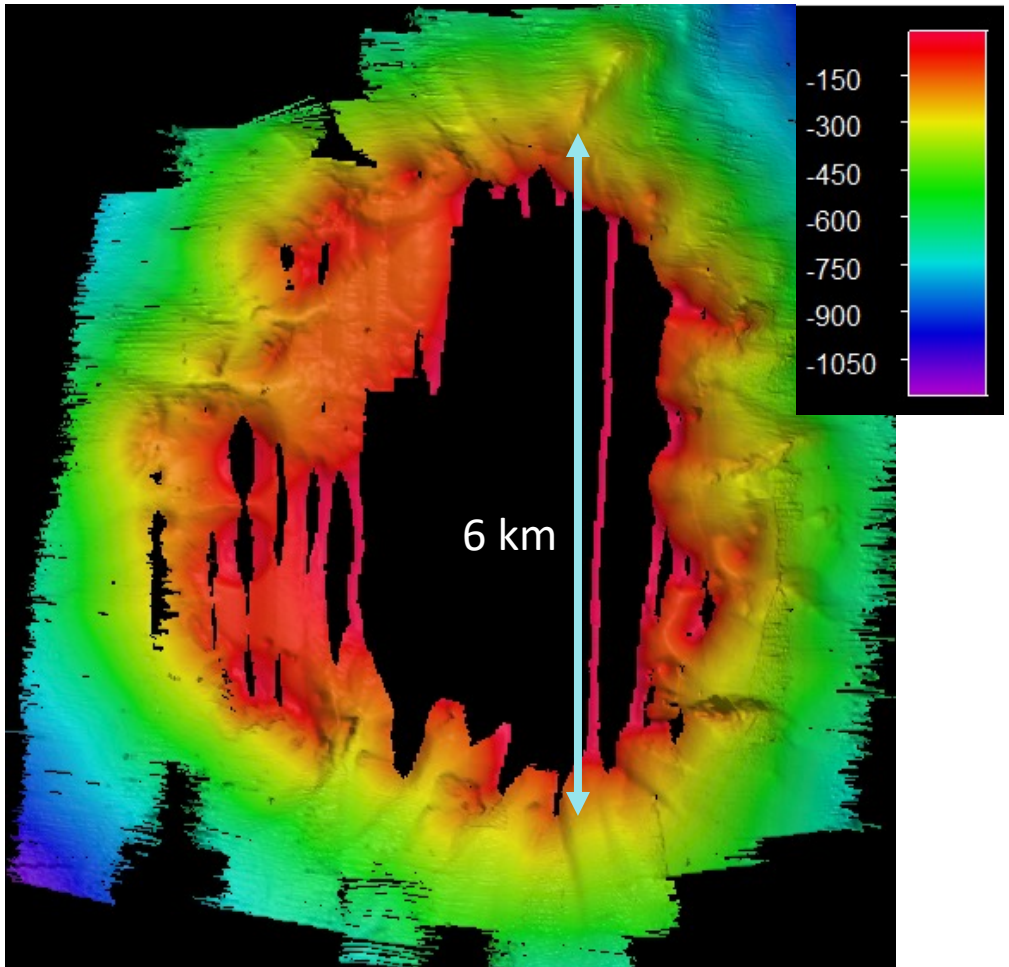
TONGA GEOLOGICAL SERVICES
MLNR TONGA

Other important tsunami concerns in Tonga:

Lateiki, Home Reef, Tofua – all caldera systems with a history of large eruptions

Fonuafo'ou 20 km north of Hunga

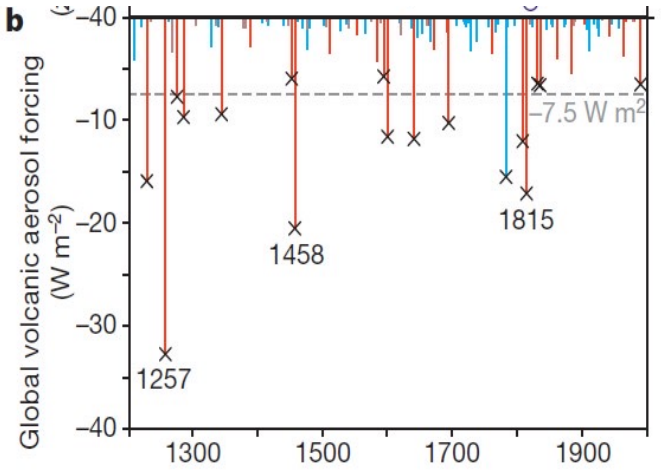
- Similar dimension and caldera structure Historical activity (1930s)
- Summit only 10-50 m below sea level
- Unknown composition



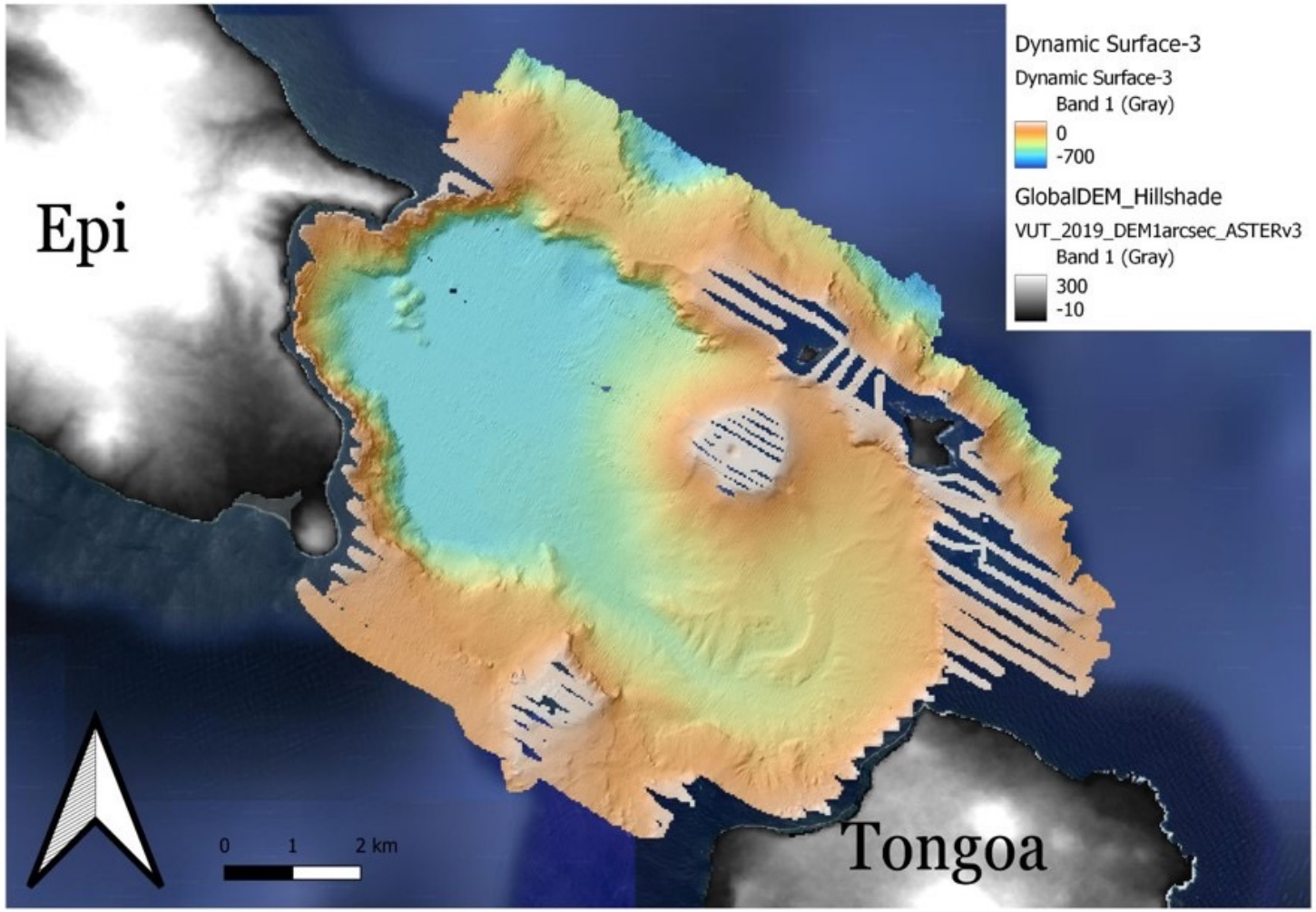
Important tsunami concerns in Vanuatu

Kuwae Caldera

- New UoA bathymetry (in prep)
- Dacite-rhyolite composition
- PhD student Soenke Stern
- >20 km^3 Caldera (3 times size of Hunga!)
- Responsible for mid-15th Century climate cooling



Sigl et al., 2015



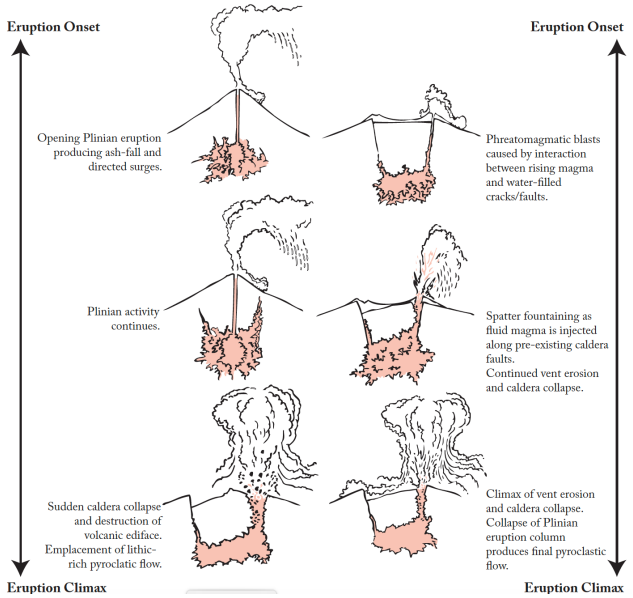
Also, **Gaua** a possible additional explosive system

Yenkahe/Siwi - Tanna

Two major caldera forming events and…

Steady state Yasur volcanism And uplift in caldera indicates basaltic andesitic magma is accumulating

Firth et al., 2015, 2021 and Ukstins et al in prep.



Waisisi

White Sands

Sulphur bay

Port Resolution

Yasur

Shark Bay

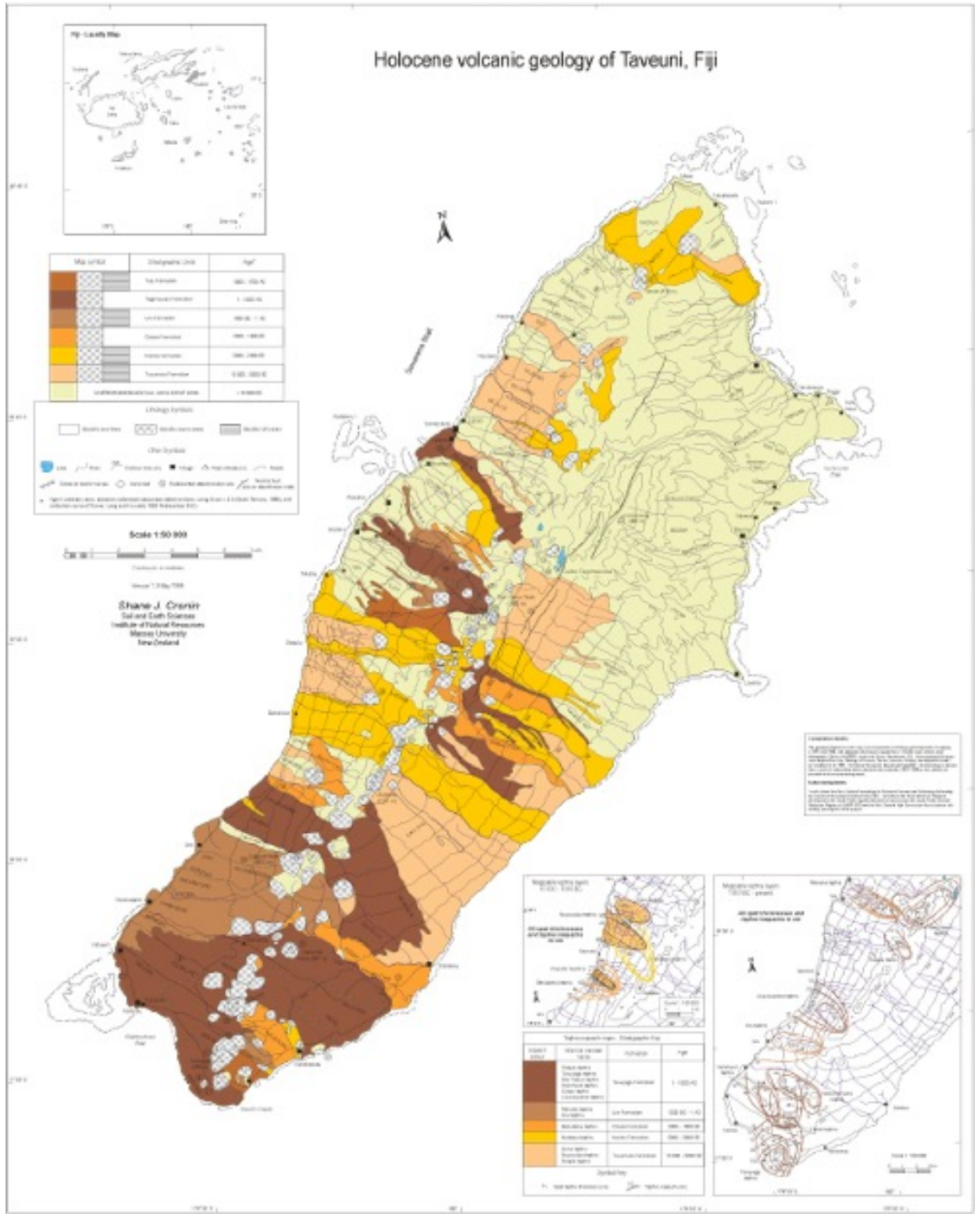
Small volcano within a BIG one
Yenkahe/Siwi Caldera

Important Tsunami concerns in Fiji

Kadavu – andesite to dacite, debris avalanches, domes, pyroclastic flows, last 1-3 ka, most recent <1680AD (south and facing Suva)

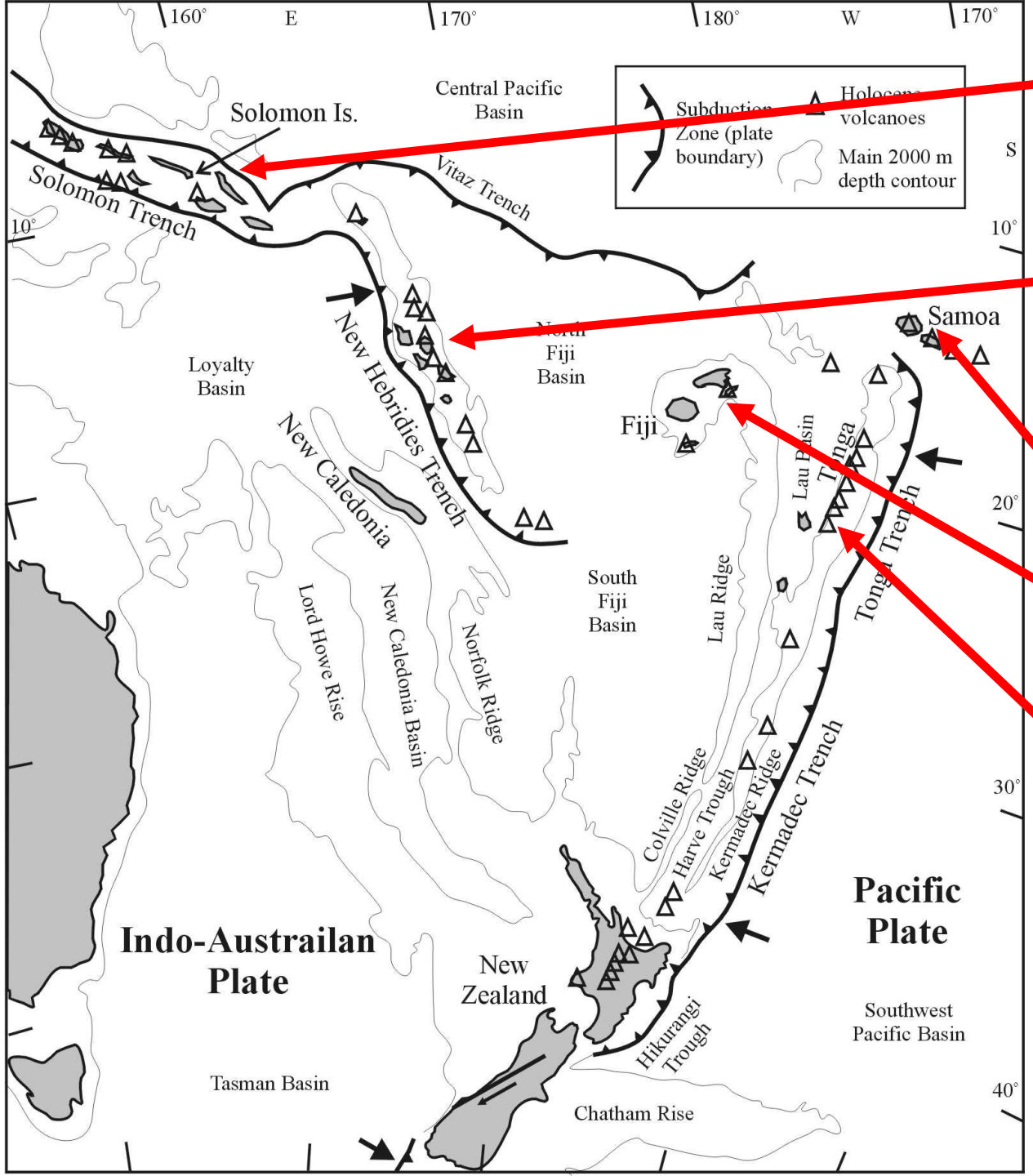
Taveuni – alkali basalt, >100 eruptions over last 10,000 years, most recent ~1700AD

(sorry no big active calderas here – bula vinaka!)



Some of the most concerning volcanoes in the region

The ones that worry me the most are caldera or stratovolcano systems – especially those capable of mafic explosive caldera-forming eruptions…



Savo, 1840's, Kavachi

Yasur/Yenkahe
Kuwae
Lopevi
Ambrym
Ambae
Gaua

8 ka to recent

Matavanu, 1905-11

Taveuni, 1450-1560AD
Kadavu, 1630-80AD

Nuiafo'ou
Fonuelei
Late
Home Reef
Late-iki
Kao
Tofua
Fonuafo'ou
Hunga
W-Ttpu

AD 1000 to 1640AD