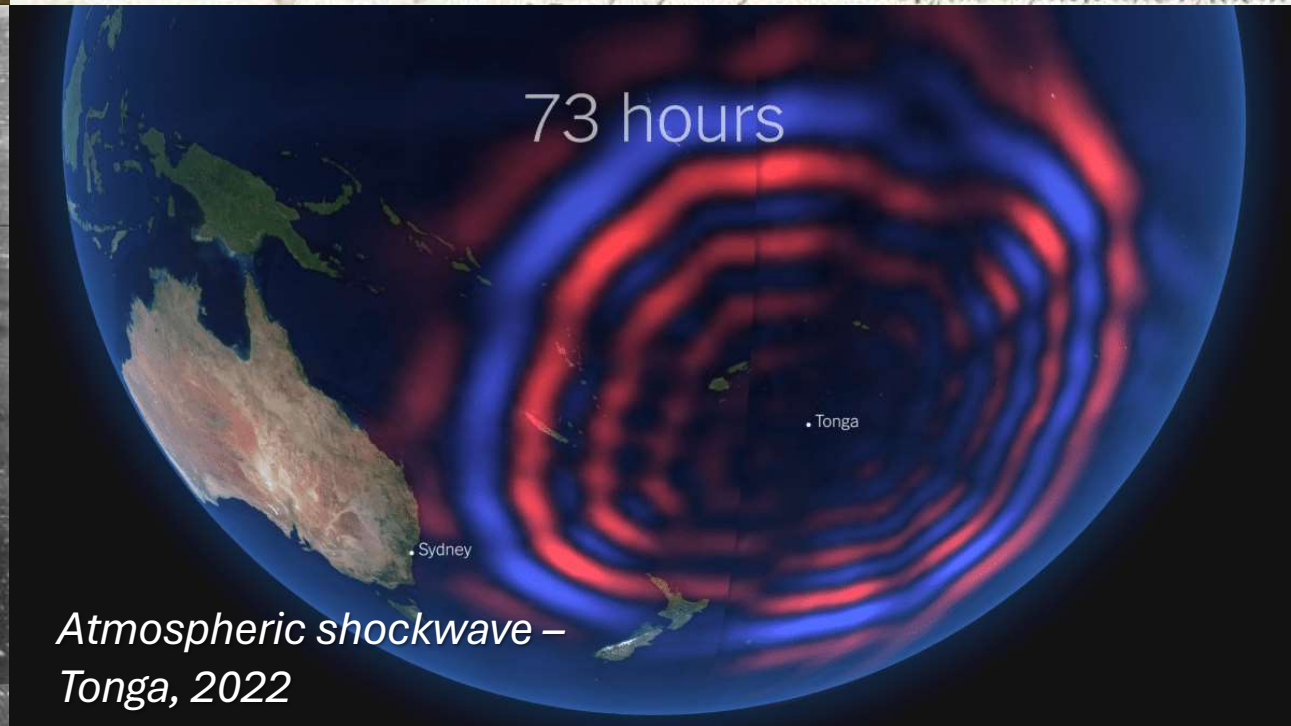
Outer shores of modern Santorini, Greece

“Volcano in the sea” - 1811

HMS Protector surrounded by pumice – Scotia Sea, 1962



Atmospheric shockwave – Tonga, 2022

SMITHSONIAN ASSOCIATES IN PERSON + ONLINE

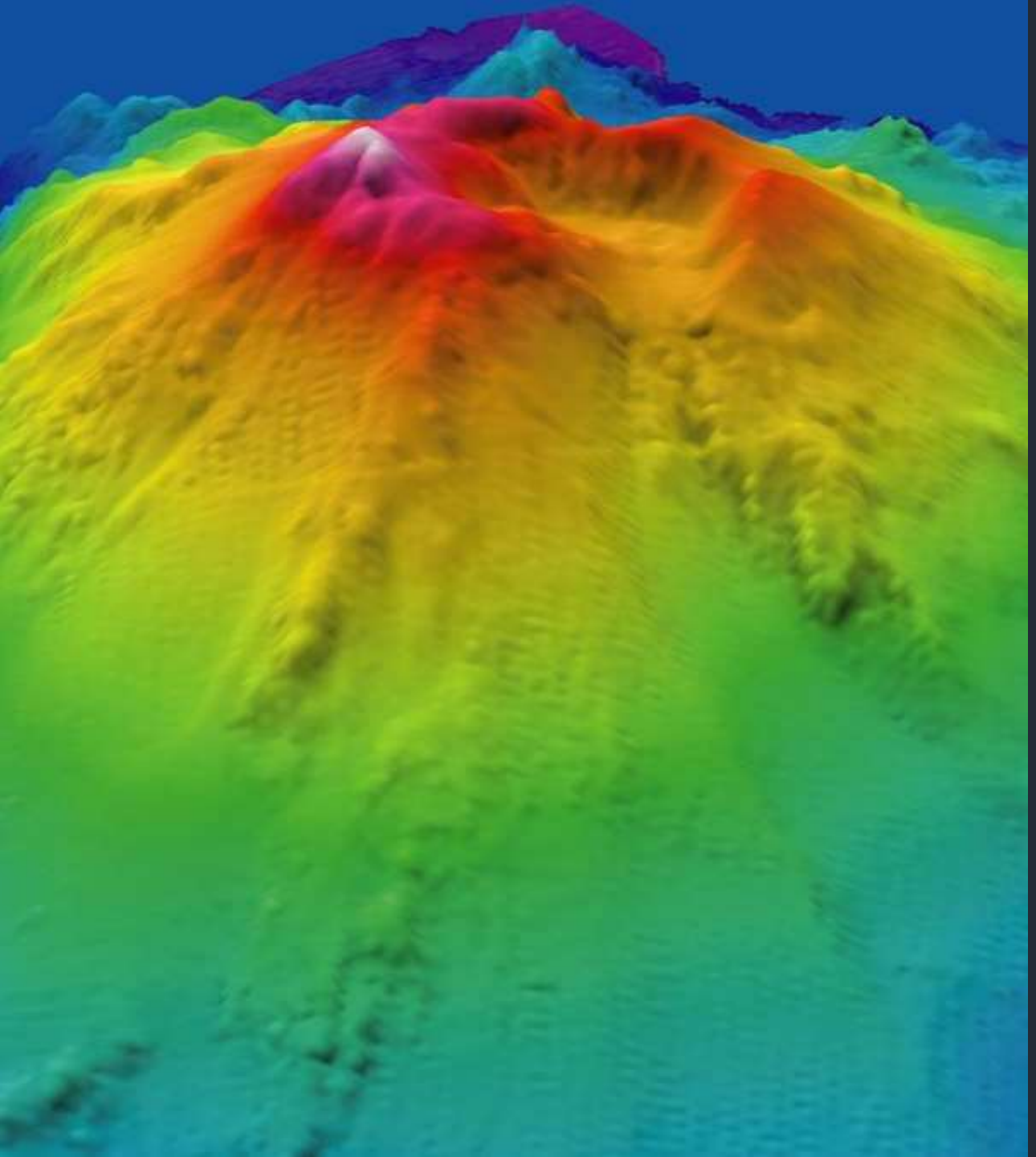
@smitchell_science
@smitchell_sci
@sams_volcano_stories
www.smitchellscience.com

Underwater Volcanoes

Dr. Samuel Mitchell
University of Bristol
Volcanologist / Marine geologist

sam.mitchell@bristol.ac.uk

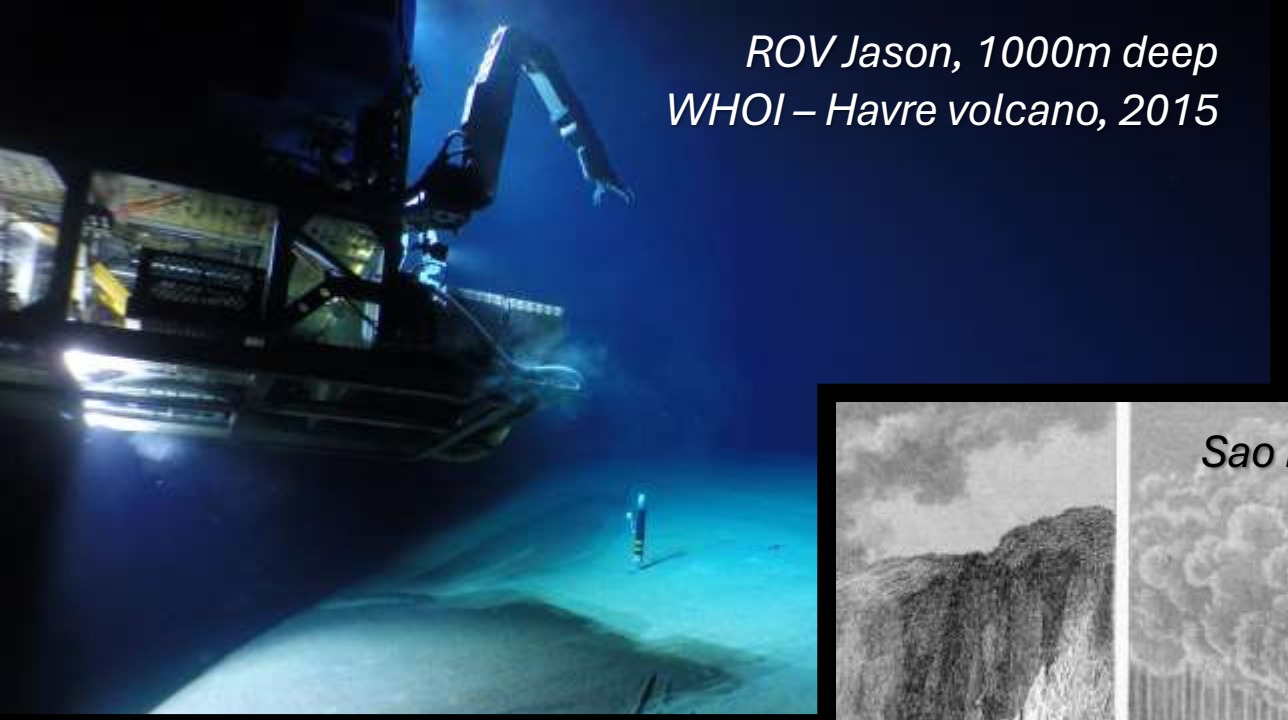
Smithsonian Associates Lecture Friday, September 6, 2024



1. Can you name any underwater volcanoes?

2. How many do you think there are?

3. How many have been captured erupting on camera?

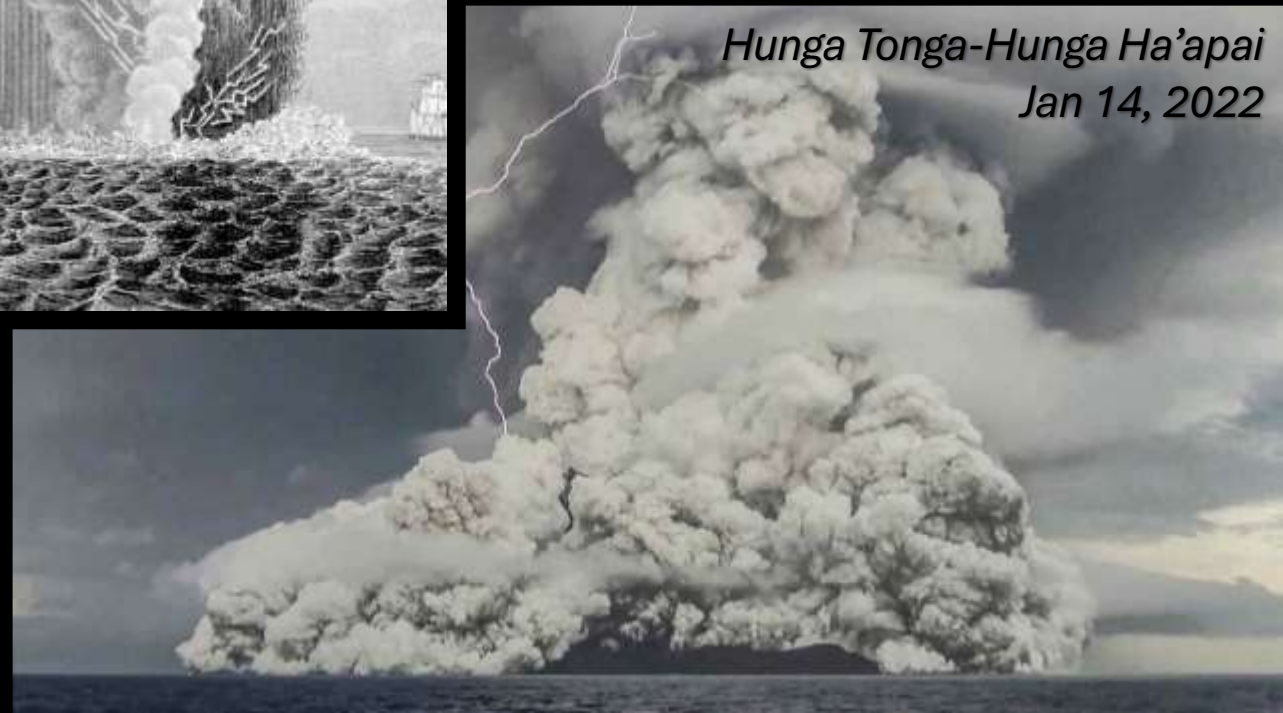


ROV Jason, 1000m deep
WHOI – Havre volcano, 2015

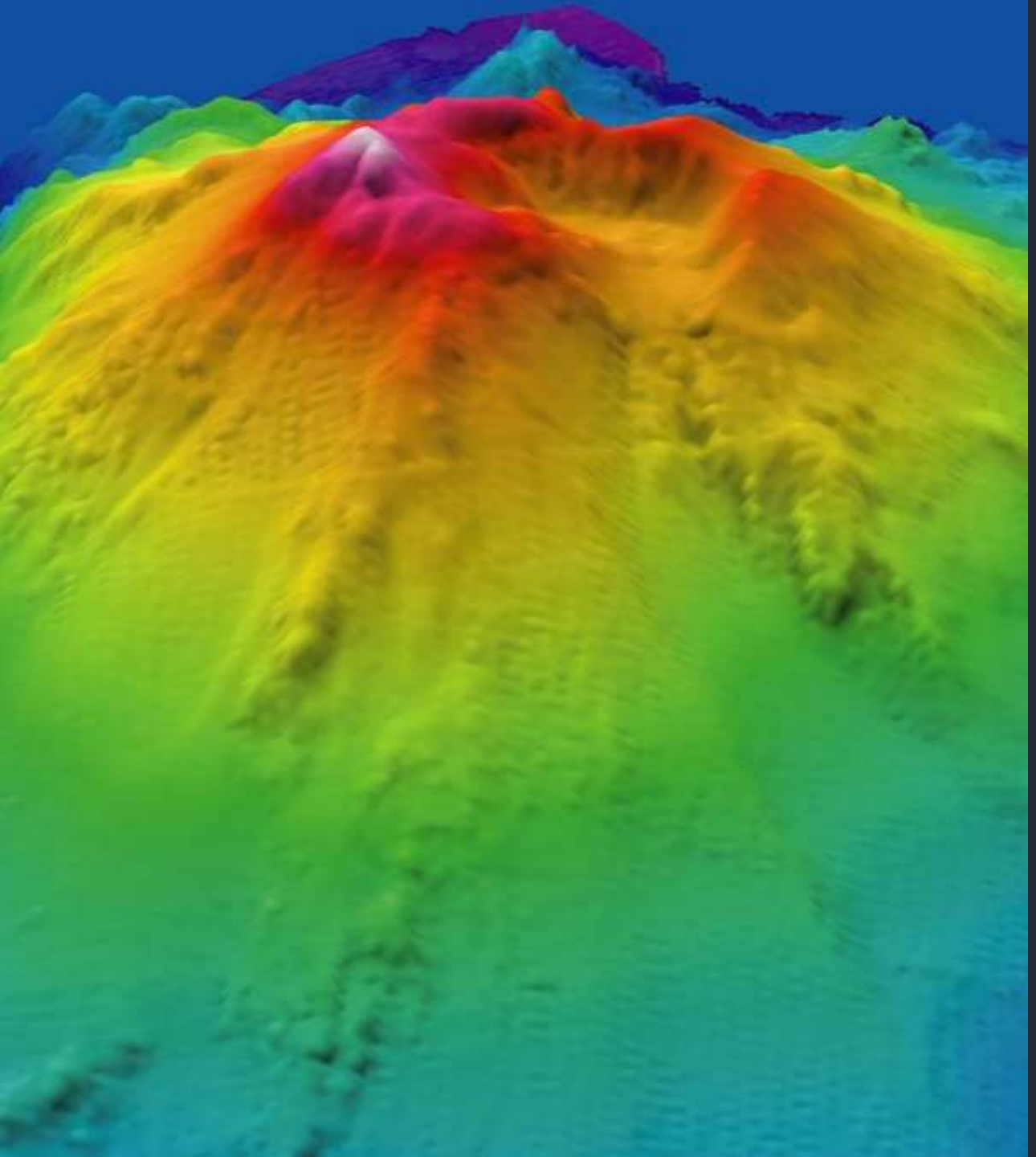
Marine life on pumicestone

Sao Miguel, Azores, 1811

Deep sea coral, Galapagos Islands
HOV Alvin, 2023



Hunga Tonga-Hunga Ha'apai
Jan 14, 2022



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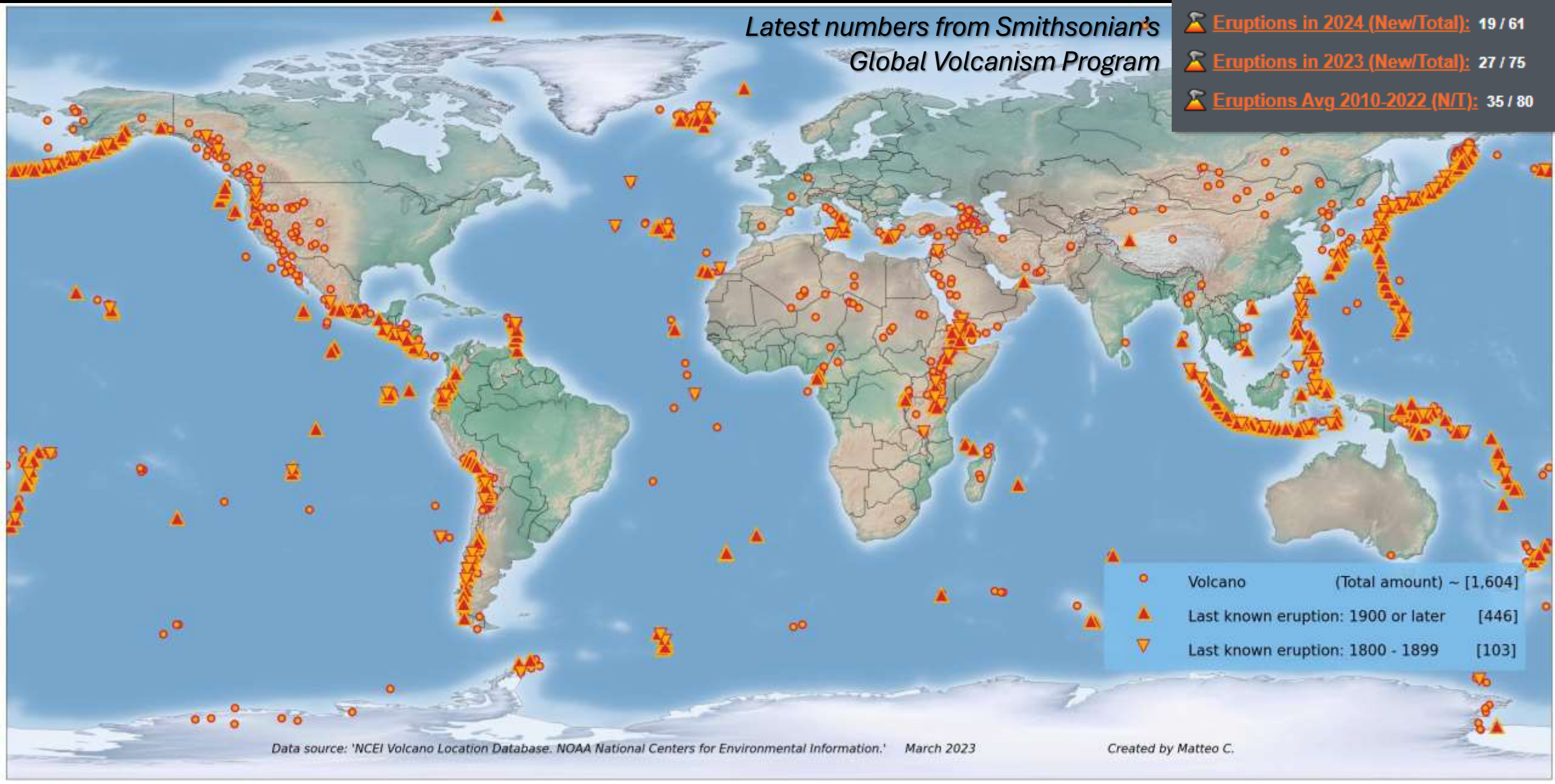
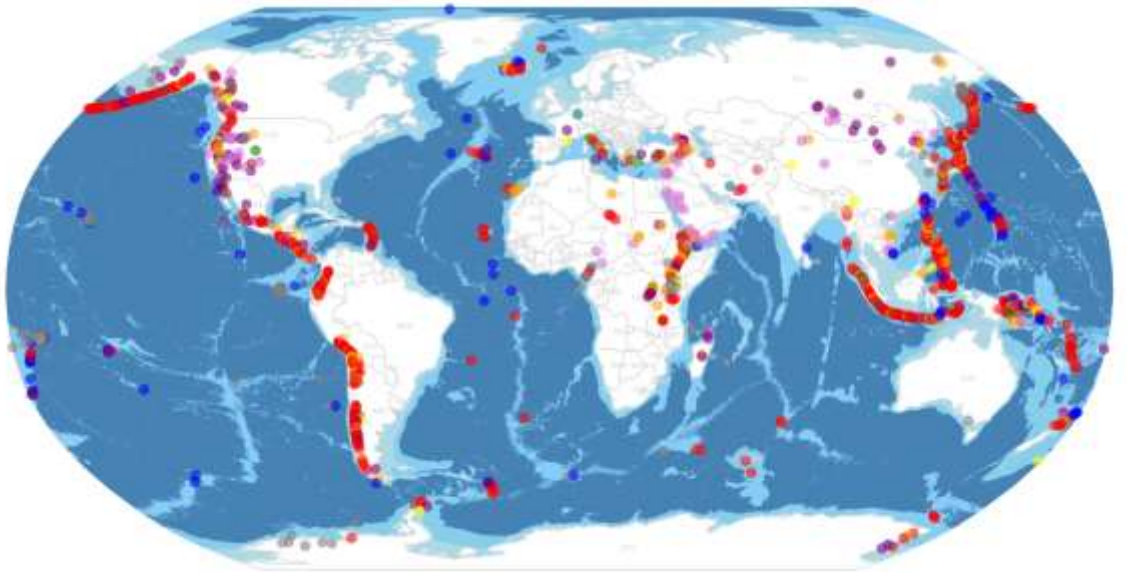

Latest numbers from Smithsonian's Global Volcanism Program
Current Eruptions (16 Aug 2024): 45
Eruptions in 2024 (New/Total): 19 / 61
Eruptions in 2023 (New/Total): 27 / 75
Eruptions Avg 2010-2022 (N/T): 35 / 80
Volcano (Total amount) ~ [1,604]
Last known eruption: 1900 or later [446]
Last known eruption: 1800 - 1899 [103]
Data source: 'NCEI Volcano Location Database. NOAA National Centers for Environmental Information.' March 2023
Created by Matteo C.

The World Map of Volcanic Activity

Countries/territories/U.S. states/Russian territories which experienced volcanic eruptions in 2023

[1] U.S. territory [2] French Overseas Department [3] India
[4] Australia [5] British Overseas Territory
As of Nov. 15, 2023
Source: Smithsonian Institution Global Volcanism Program

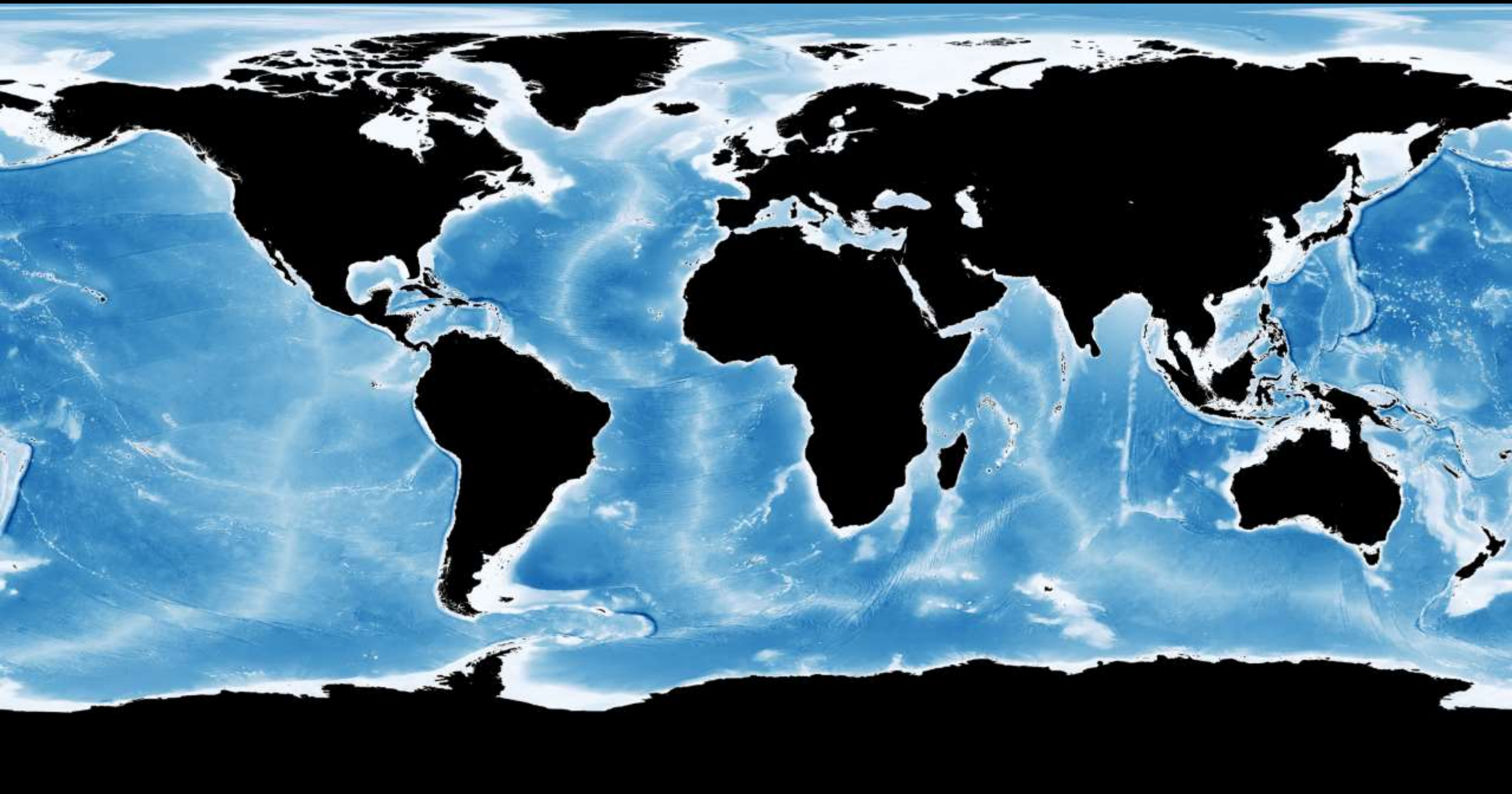
statista

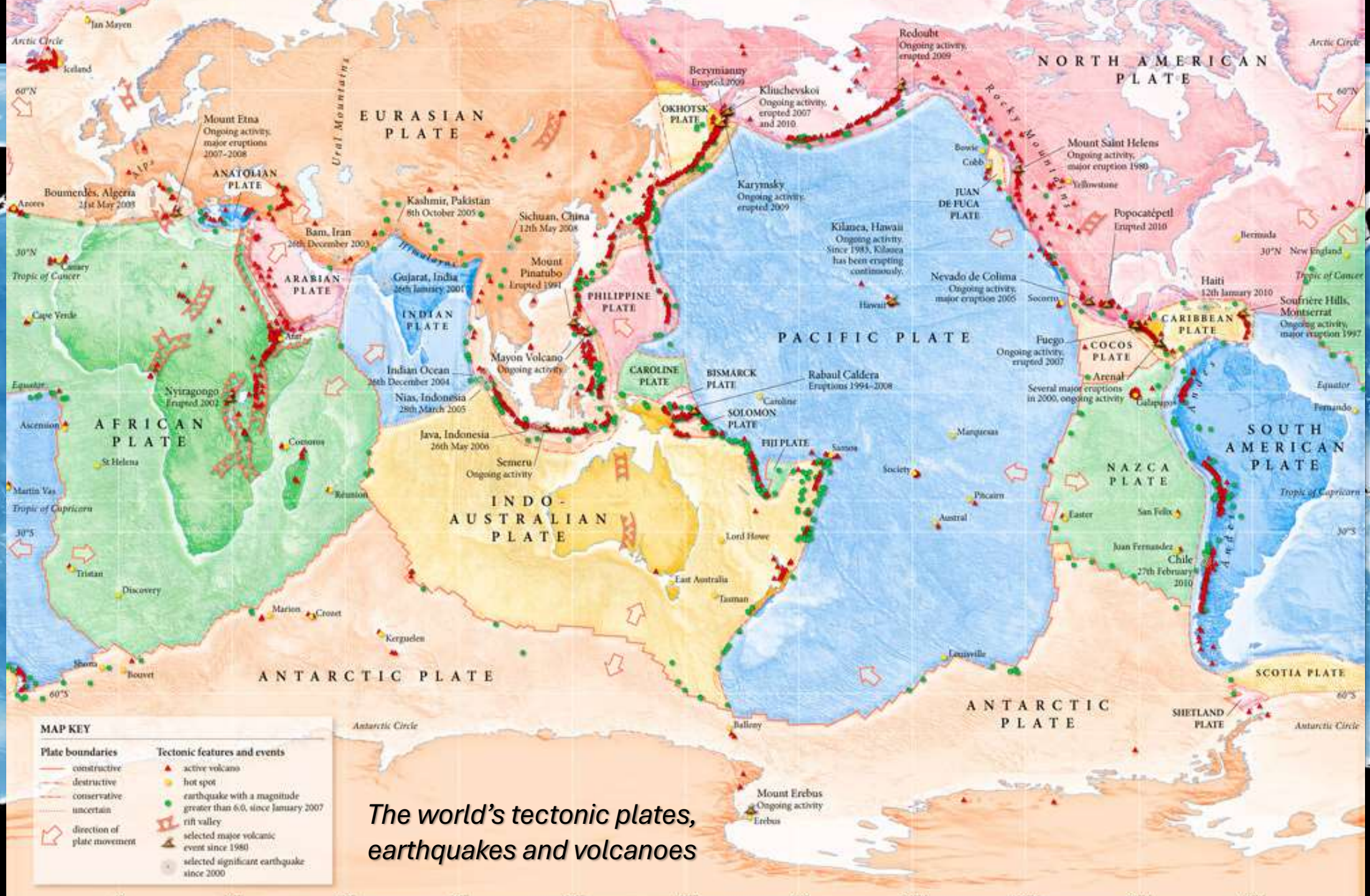


Volcano Types in this Map

Shield Volcano	Strato Volcano	Caldera	Cinder Cone
Pyroclast	Explosion	Complex volcano	Lava
Maars	Fumarole	Submarine	Volcanic
Other			

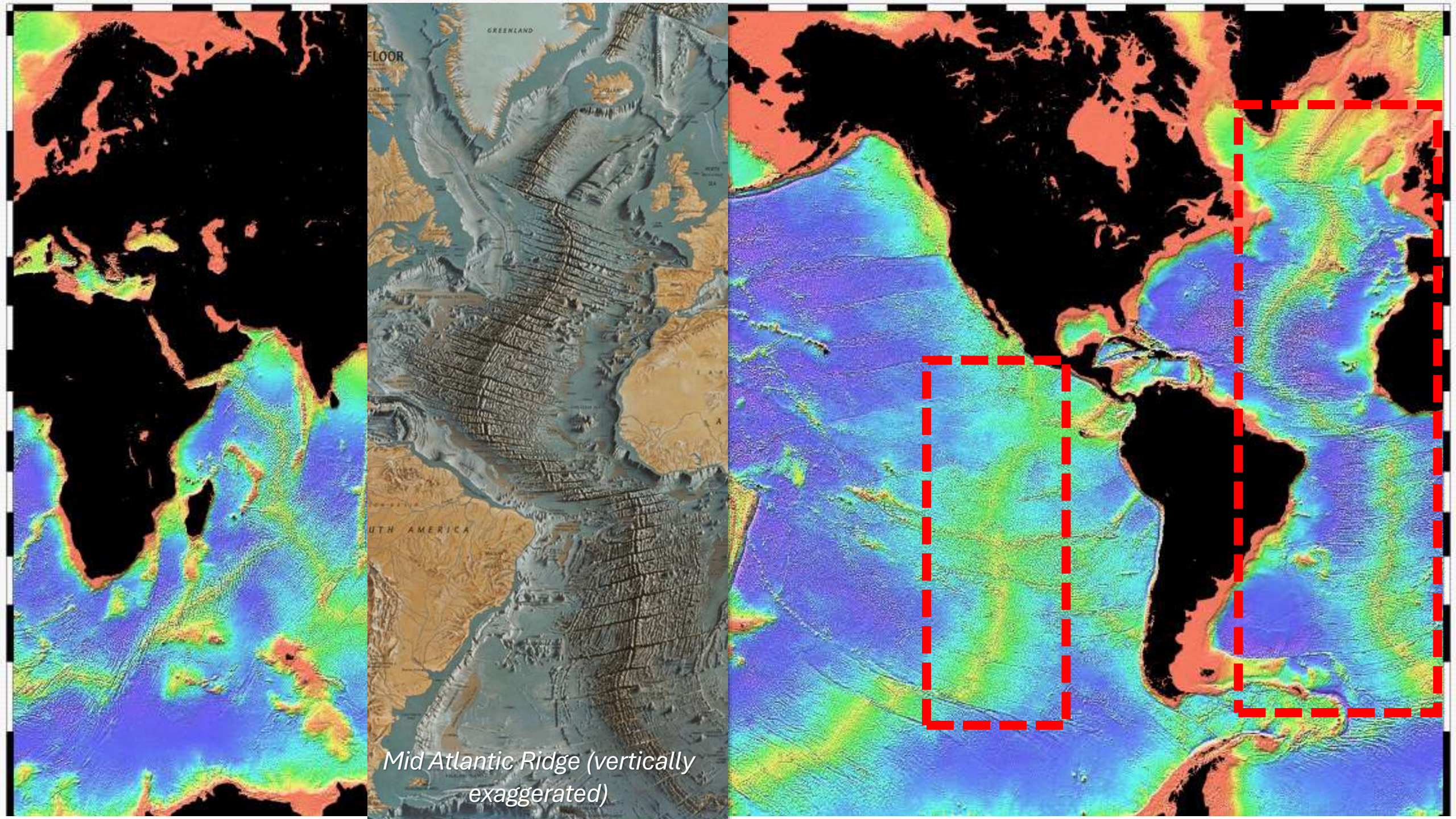
Volcanoes erupting in August 2024





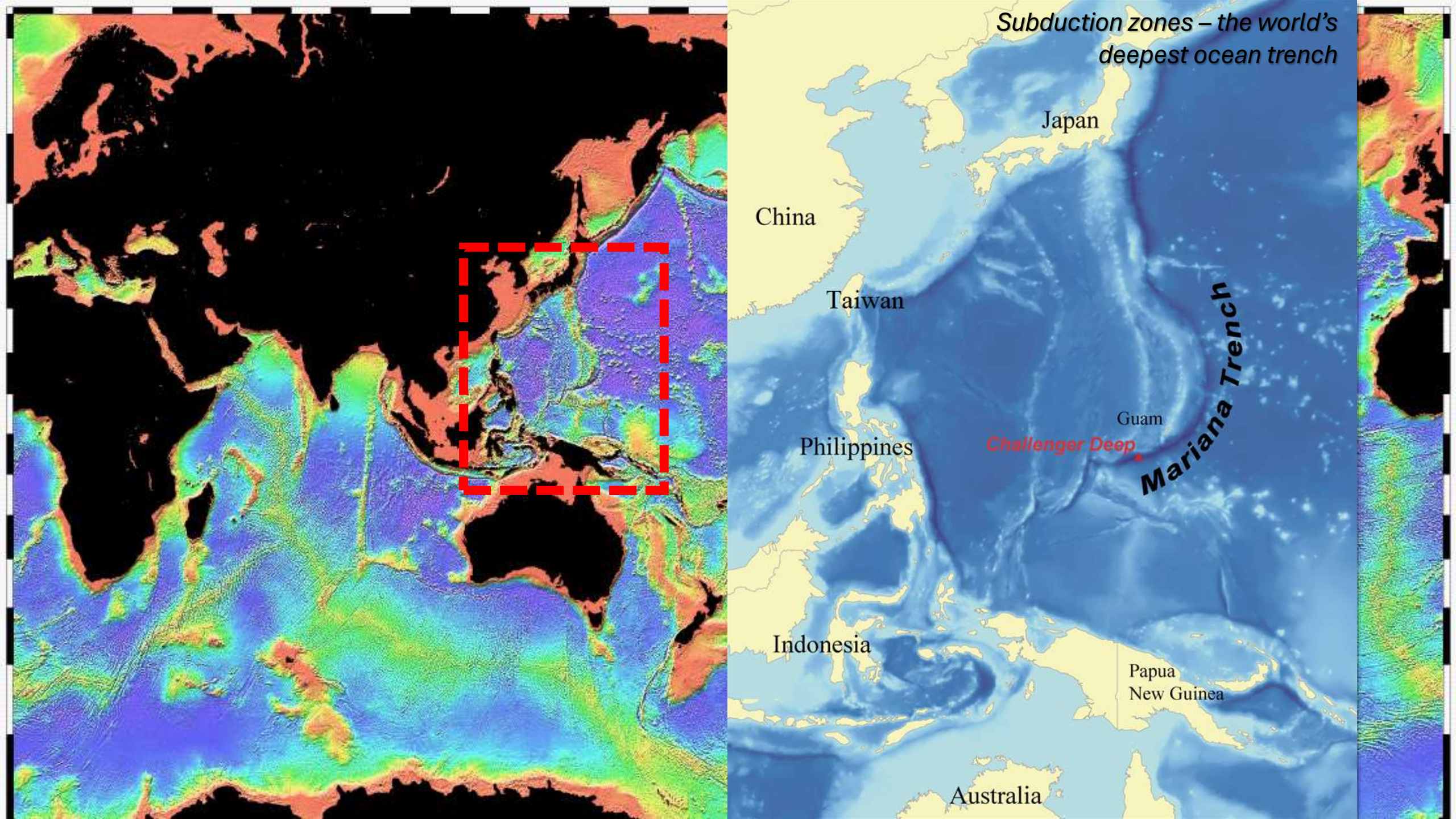
The world's tectonic plates, earthquakes and volcanoes

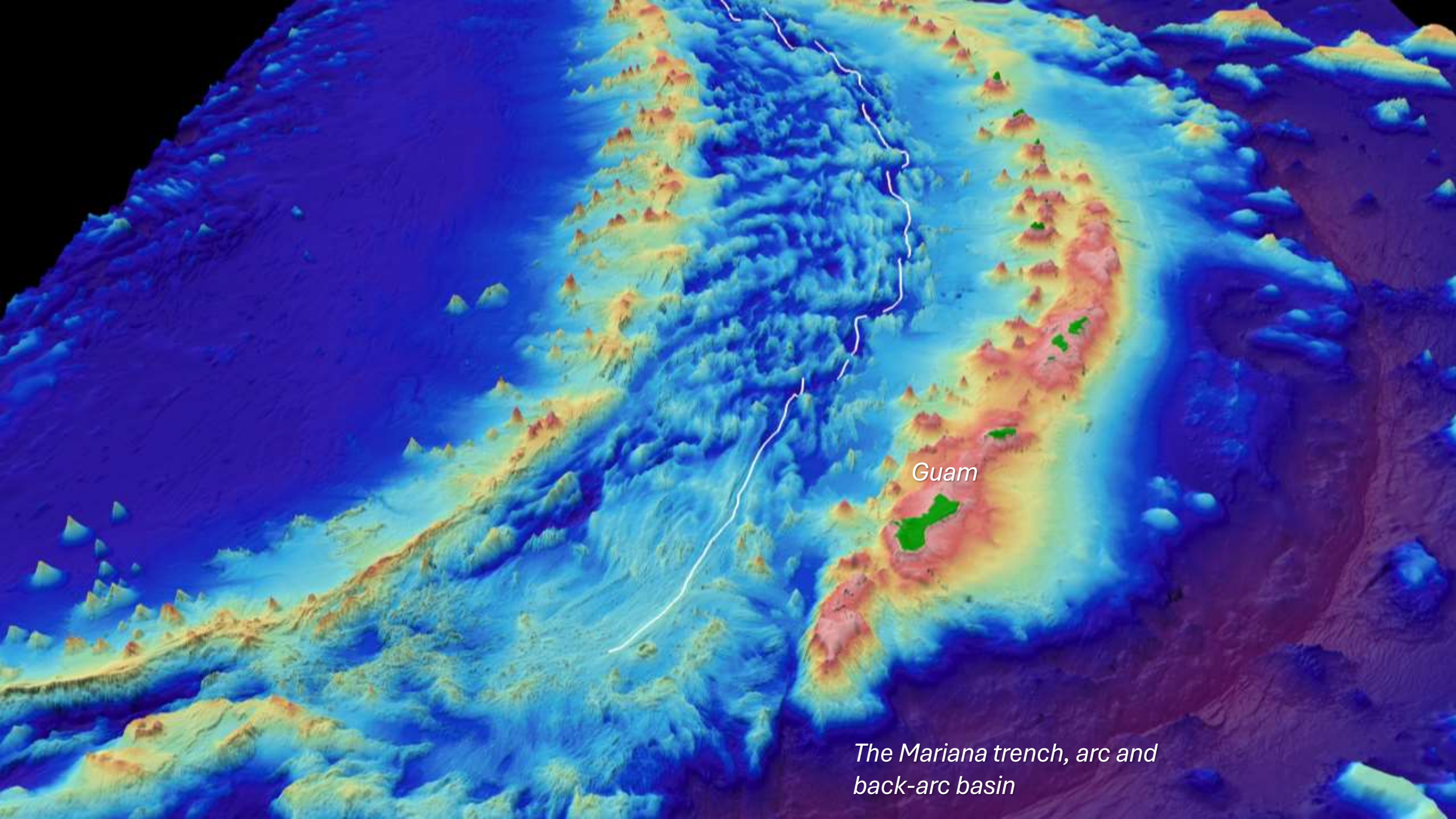
Volcanoes in the ocean



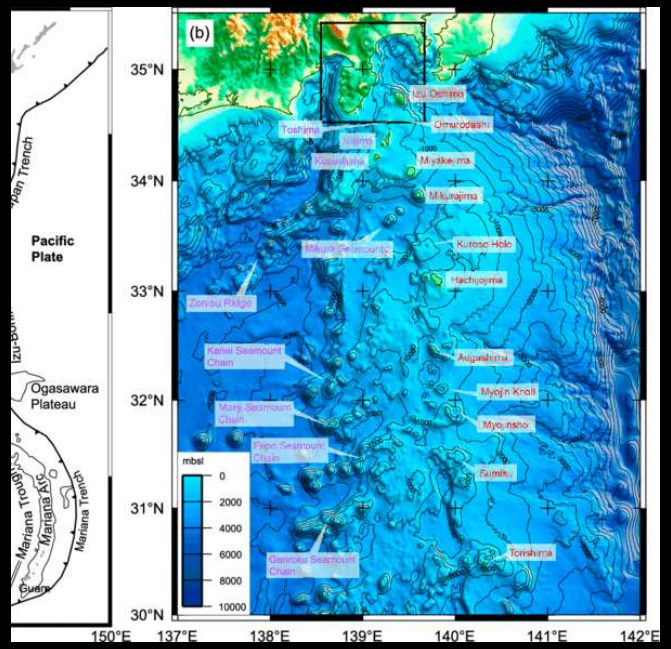
Mid Atlantic Ridge (vertically exaggerated)

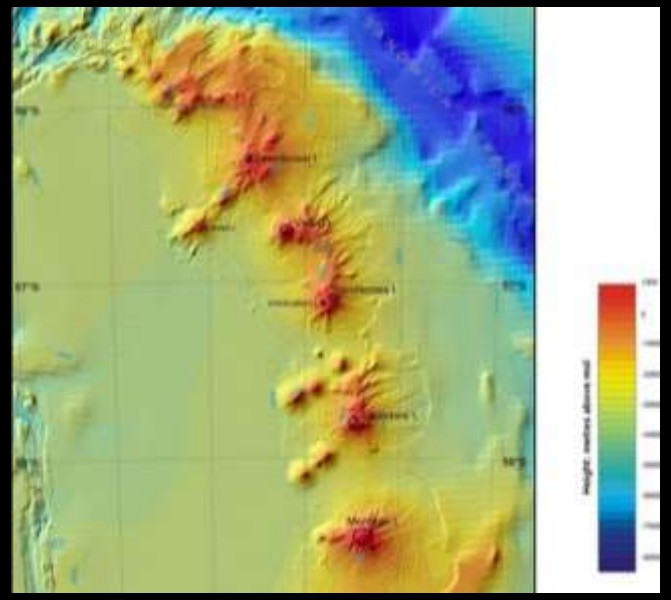
The Hawaiian Islands down to the seafloor

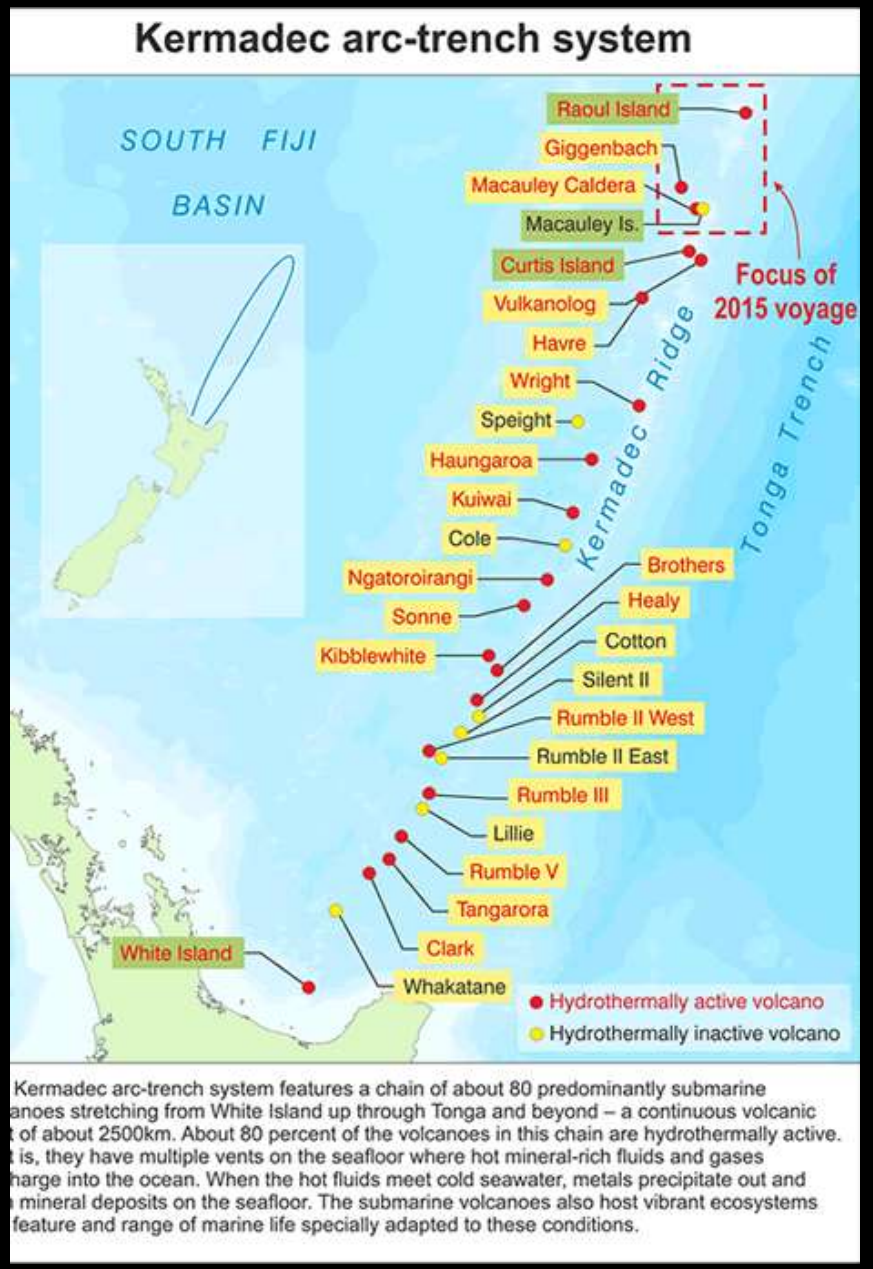

Subduction zones – the world's deepest ocean trench
Japan
China
Taiwan
Philippines
Guam
Challenger Deep
Mariana Trench
Indonesia
Papua New Guinea
Australia



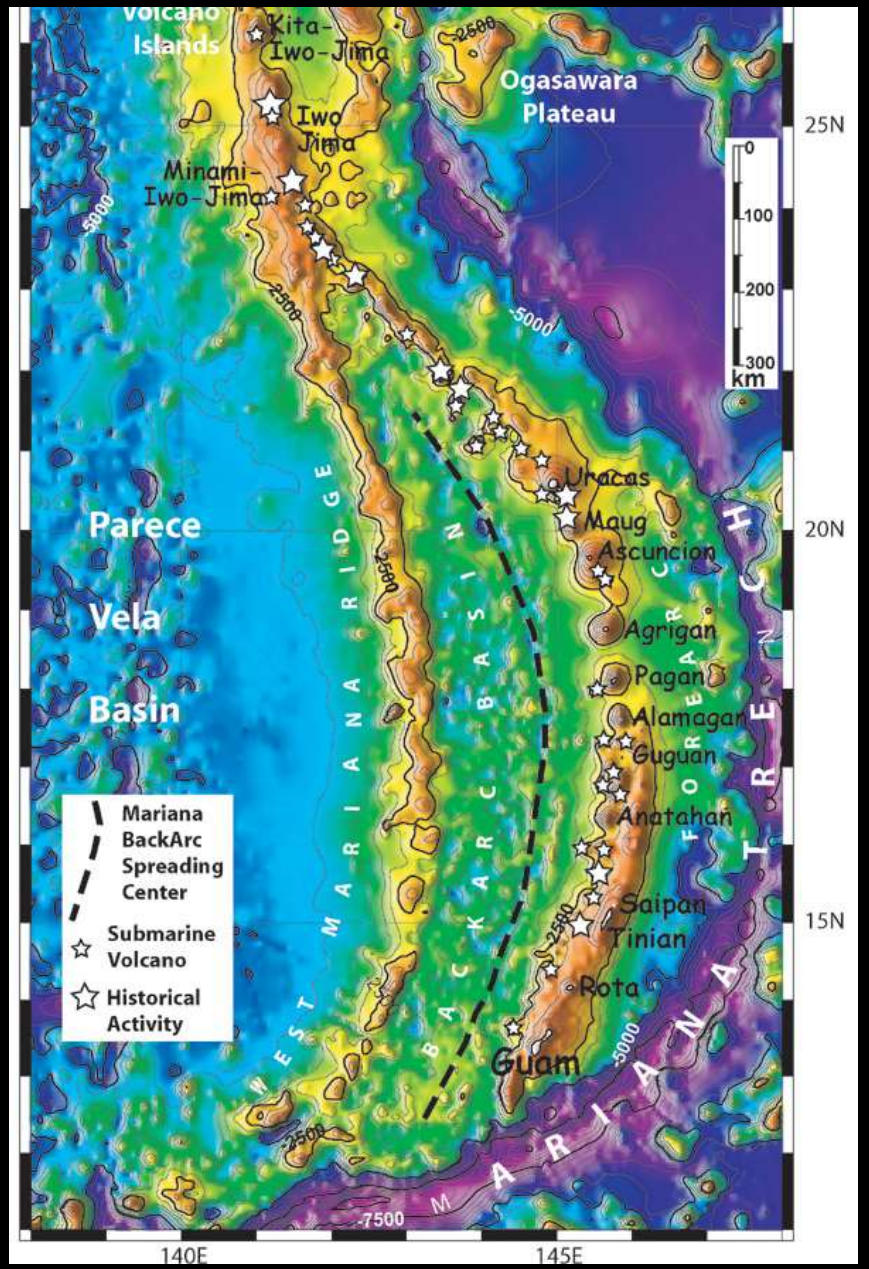
The Mariana trench, arc and back-arc basin



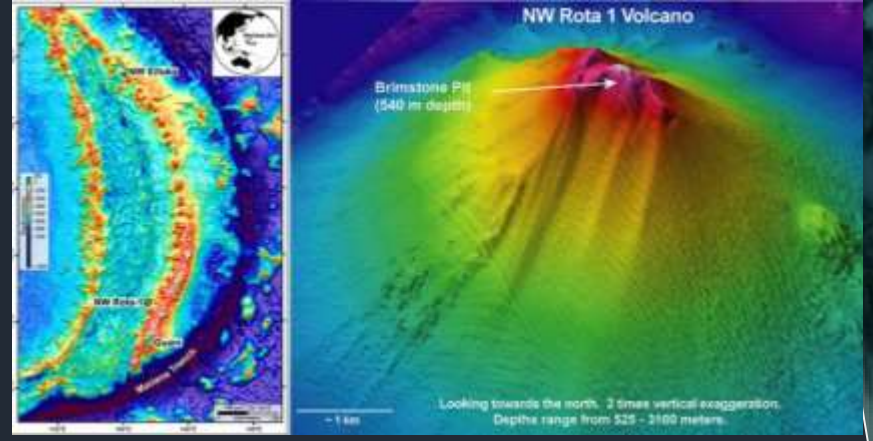




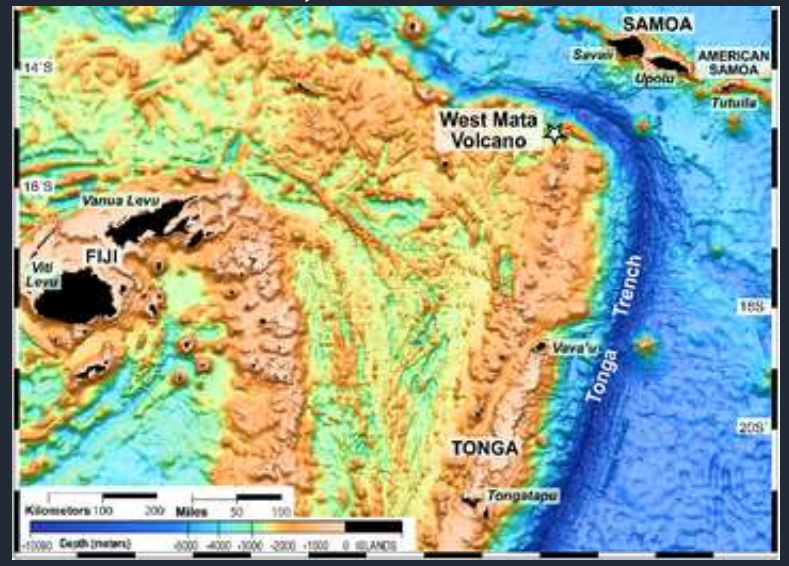
Kermadec arc-trench system features a chain of about 80 predominantly submarine anoes stretching from White Island up through Tonga and beyond – a continuous volcanic t of about 2500km. About 80 percent of the volcanoes in this chain are hydrothermally active. is, they have multiple vents on the seafloor where hot mineral-rich fluids and gases harge into the ocean. When the hot fluids meet cold seawater, metals precipitate out and mineral deposits on the seafloor. The submarine volcanoes also host vibrant ecosystems feature and range of marine life specially adapted to these conditions.



Subduction zone volcanic arcs: Izu-Bonin (TL), South Sandwich Islands (BL), Kermadecs (M), Mariana (R)

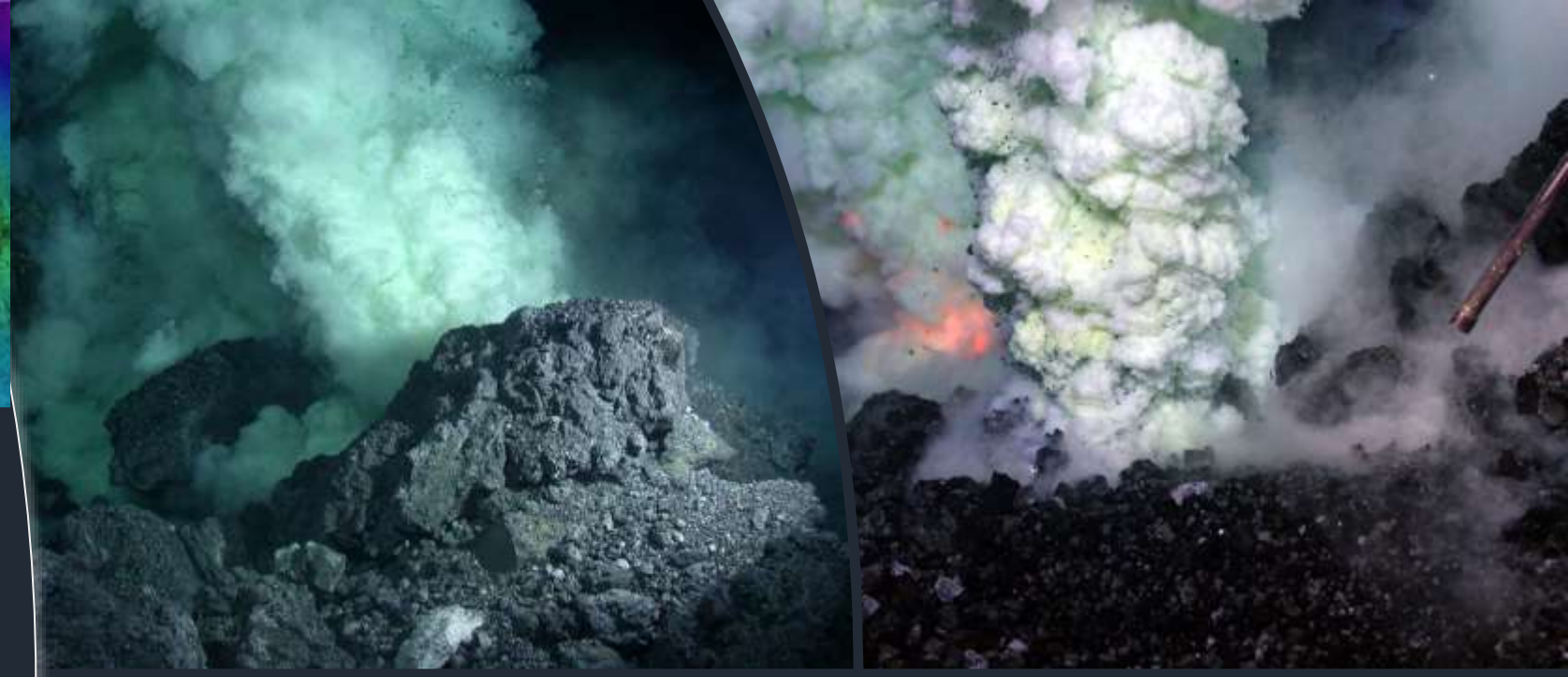


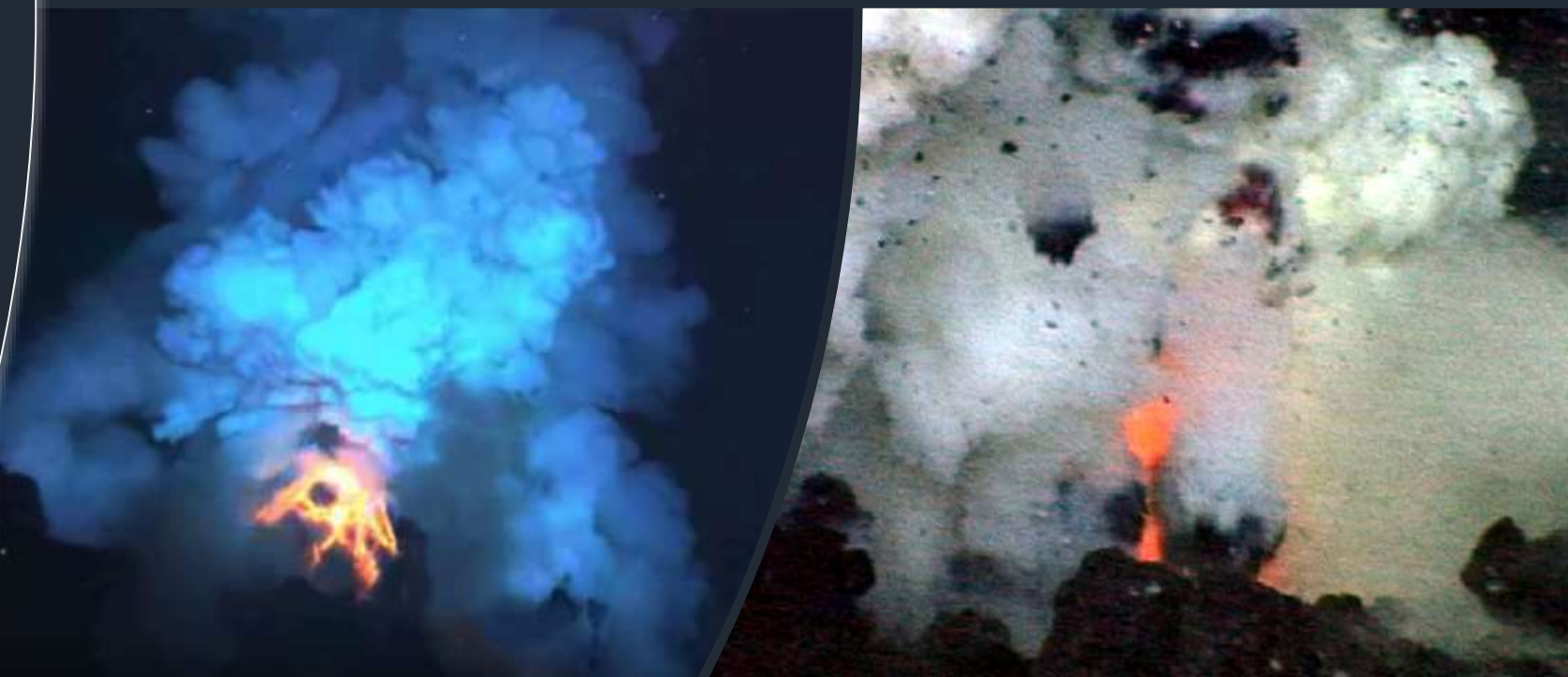
NW Rota 1, Marinas Islands



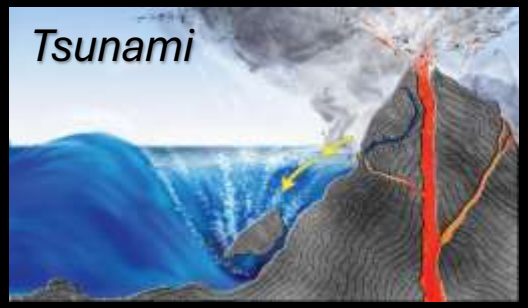
West Mata, Lau Basin

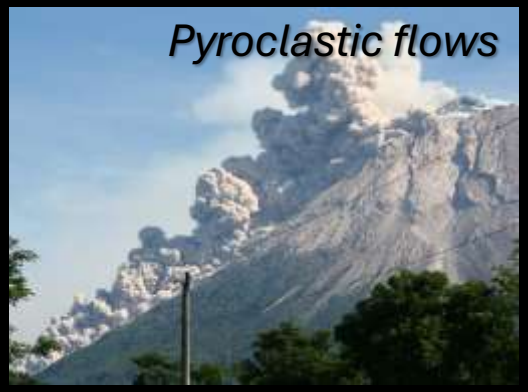
Observed eruptions



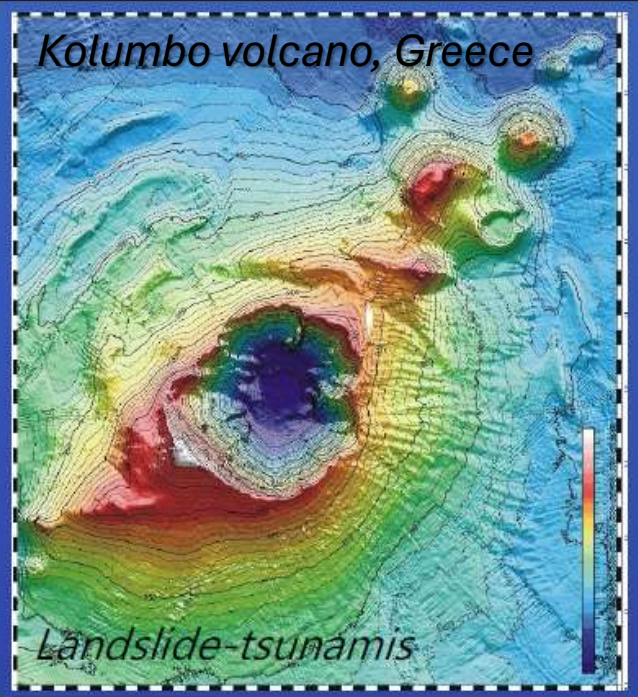


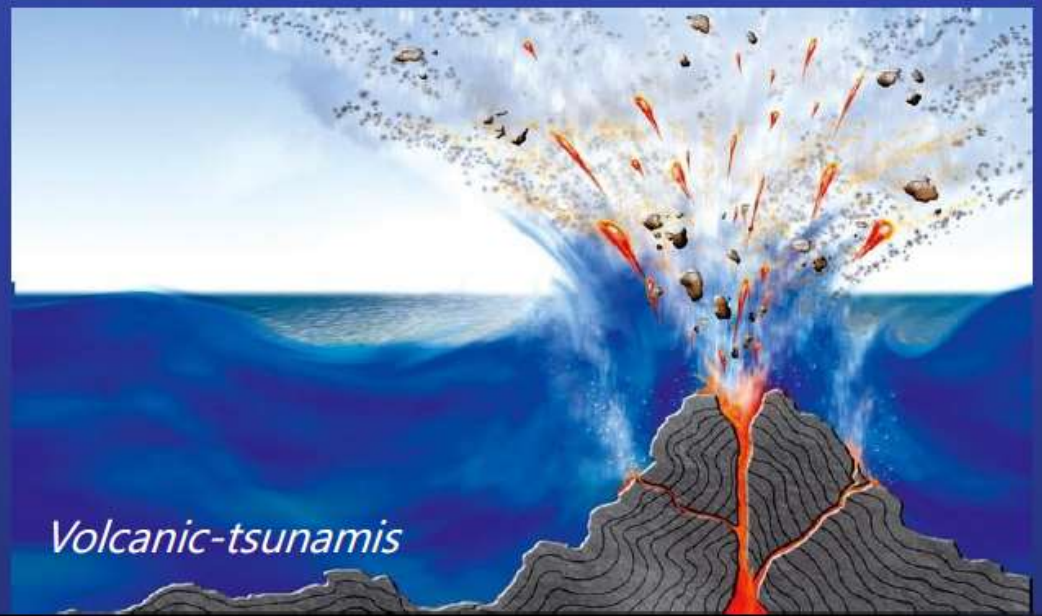
Hazards from volcanoes

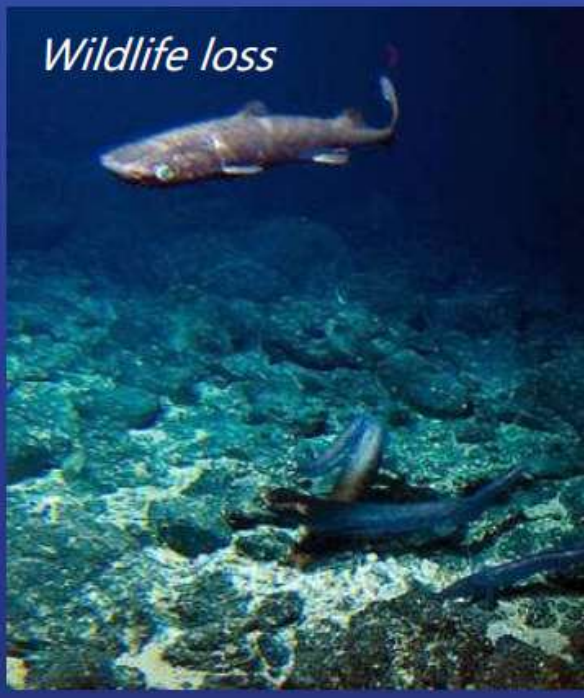




Submarine volcanic hazards







Pumice rafts

- Pumice can travel 1000s miles
- Blocking of shipping and harbours
- Danger to ship engines and water systems
- Can remain afloat for years

Okinawa, Japan, 2021

Pumice raft and HMS Cantebury, 2012

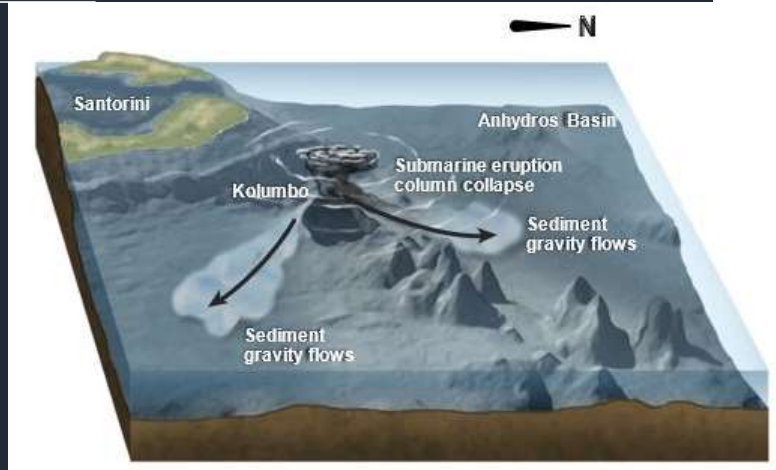
Pumice rafts

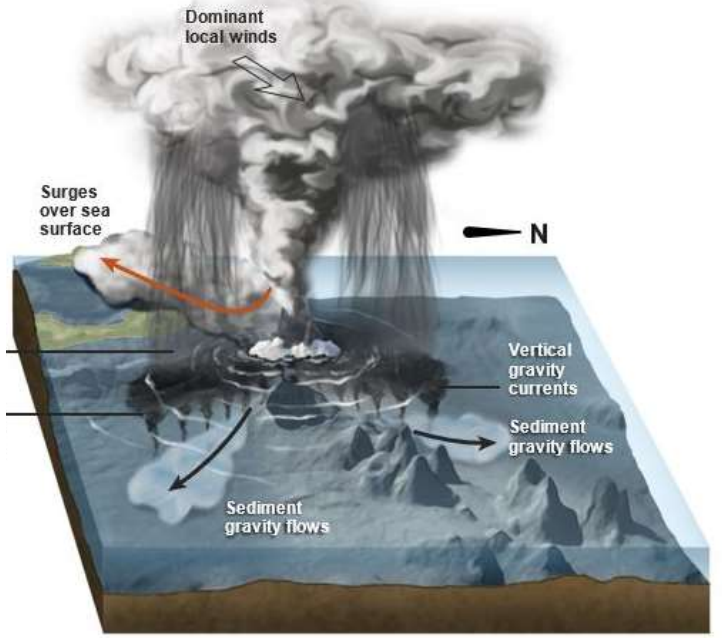
- Transport and harbouring marine life
- Transport of entire communities 1000's km
- Distributing micro- to macro-organisms
- Power of satellites to detect biosignatures
- Circumpolar navigation

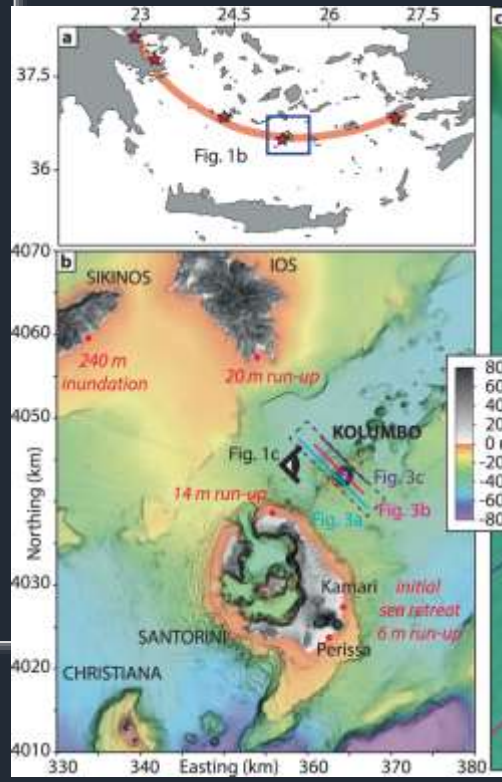
Historical eruptions

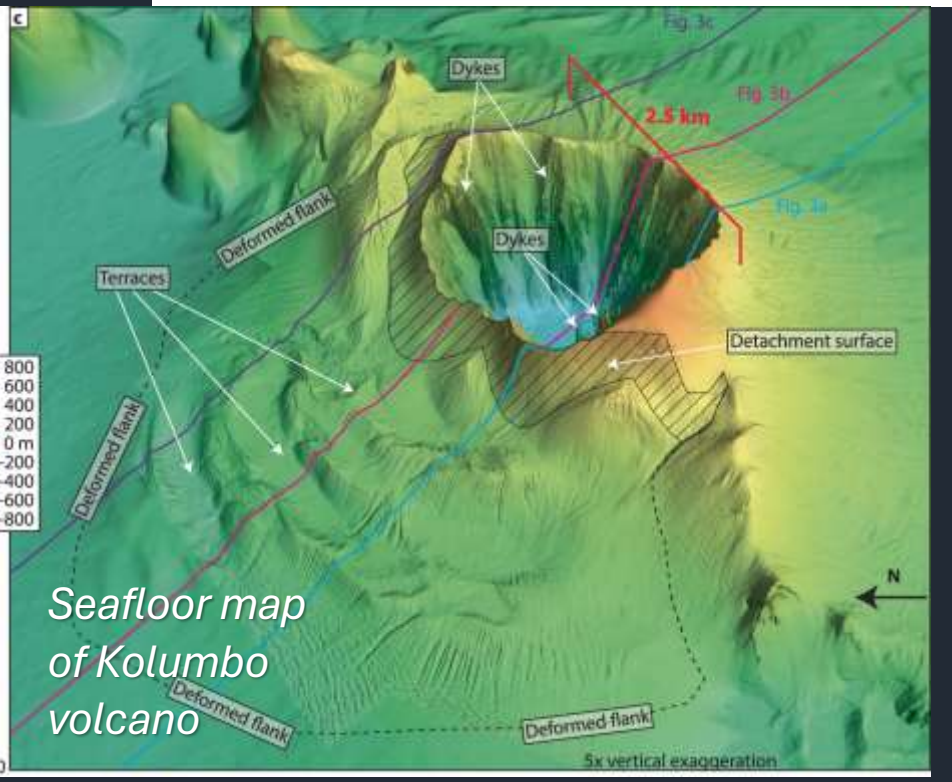
Kolumbo 1650

- 7km offshore Santorini
- Shallow submarine volcano
- Killed over 70 people from gas
- Tsunamis, pyroclastic flows, loss of livestock
- Risk to Santorini today





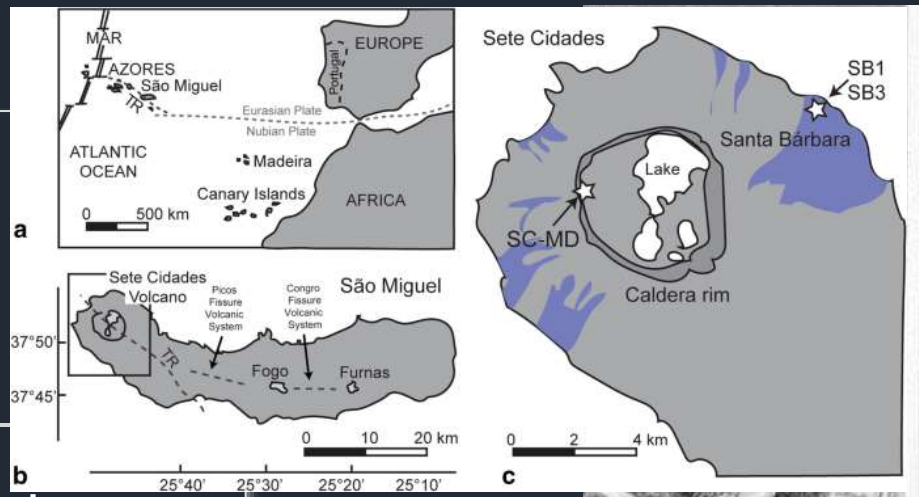


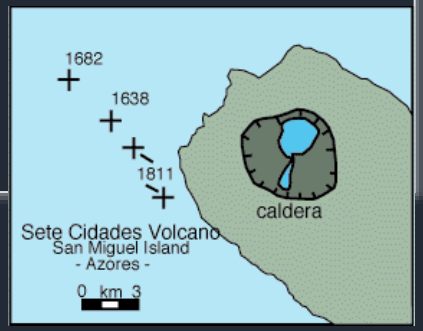


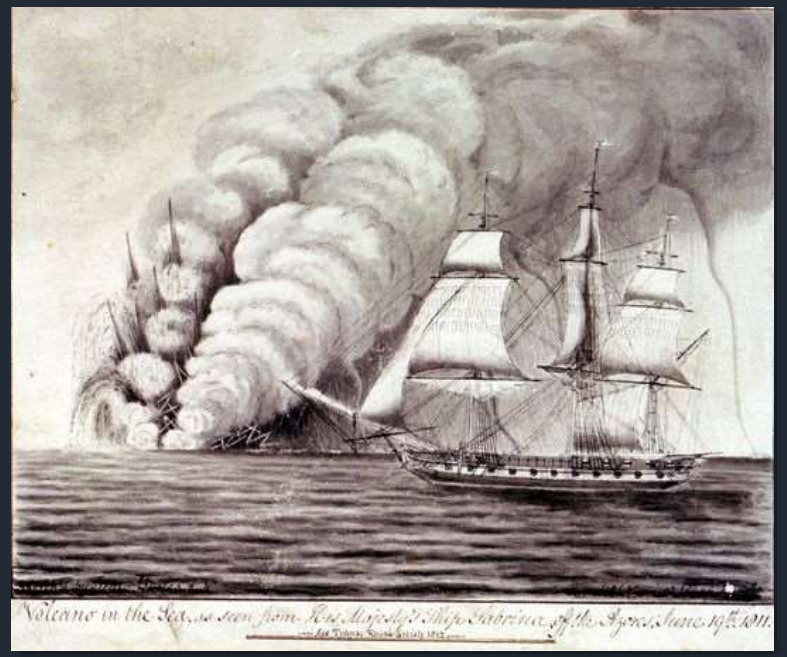
Seafloor map of Kolumbo volcano

Sabrina 1811

- 2km offshore Sao Miguel, Azores
- Sudden explosions out of the water
- Built an island - lasted just weeks then disappeared
- Captured in artwork





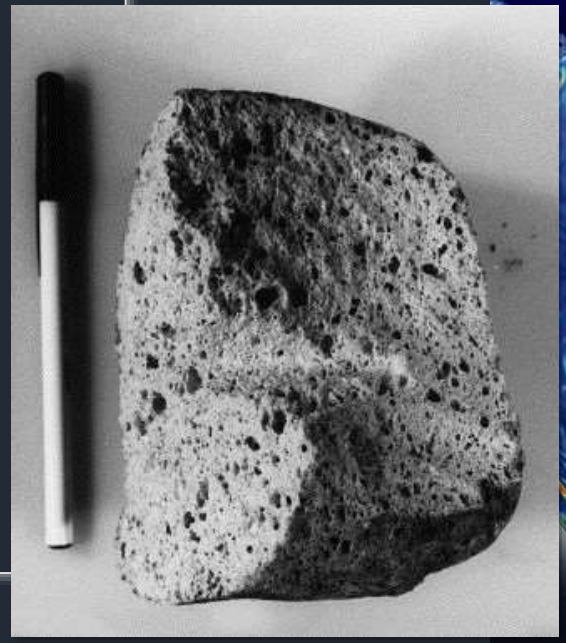


Artwork of the Sabrina vessel sailing offshore

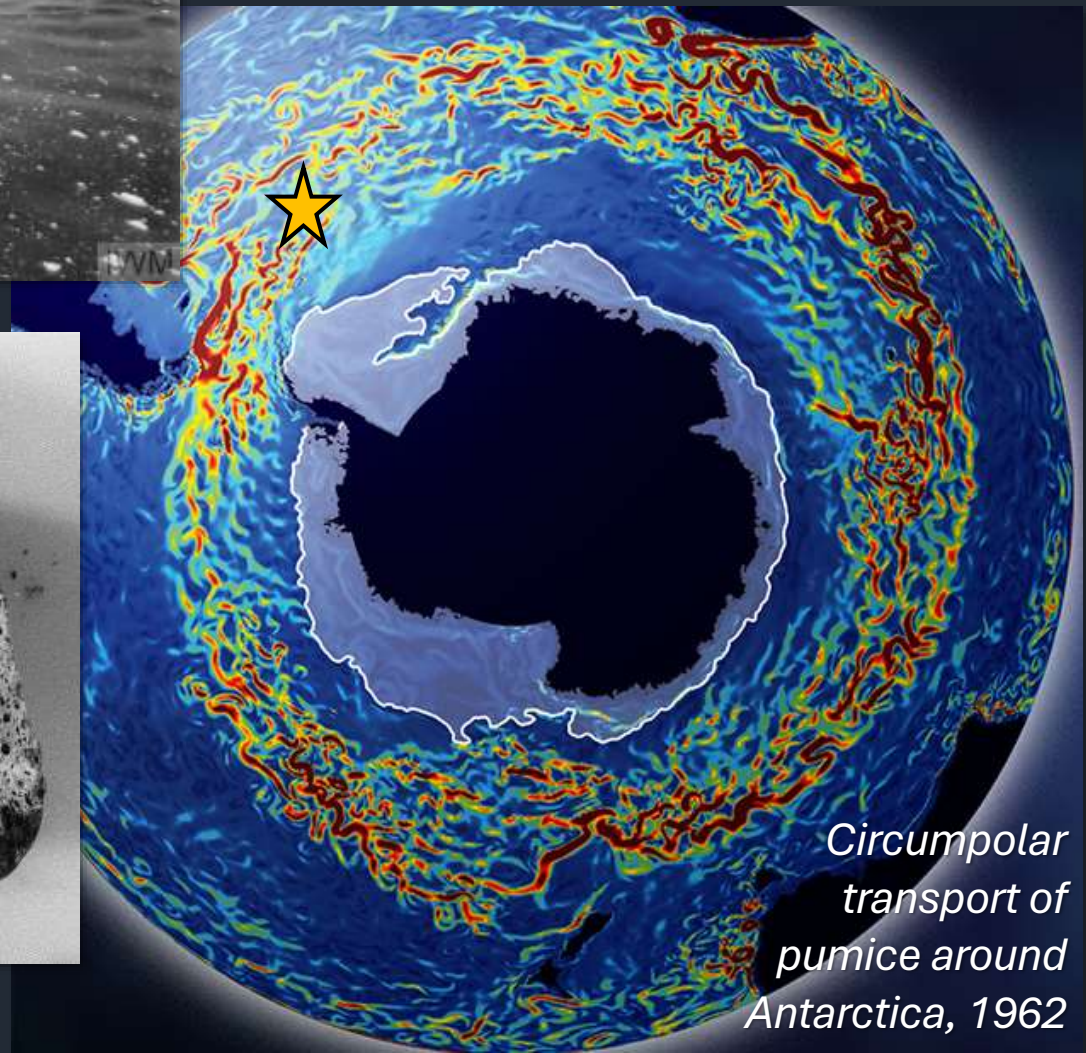
Protector Shoal, 1962

- Eruption in the South Sandwich Islands
- Produce a huge raft of pumice
- Circumnavigated Antarctica
- Only known about from HMS Protector intersect

HMS Protector amongst floating pumice, 1962



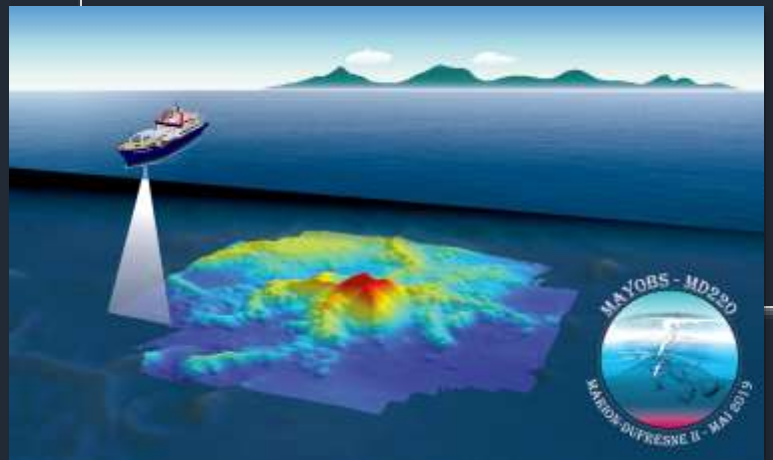
Pumice found in Chile, 1963



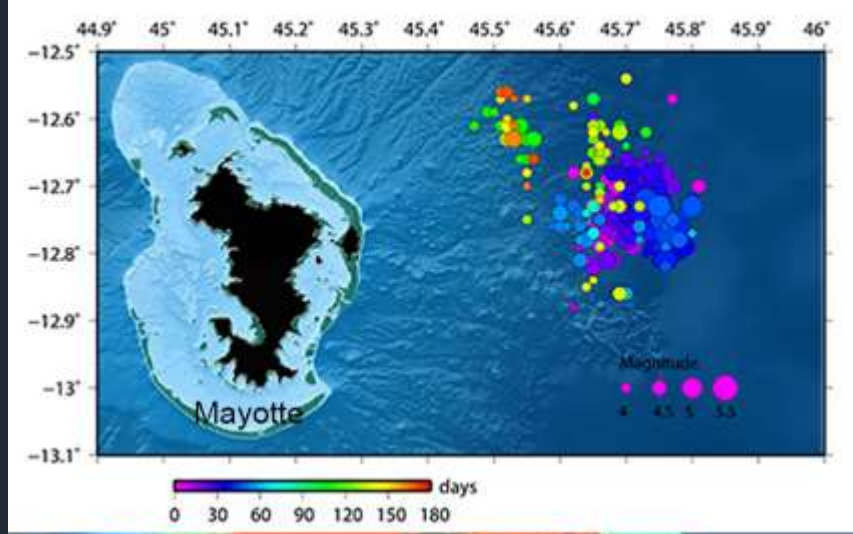
Circumpolar transport of pumice around Antarctica, 1962

Mayotte 2018

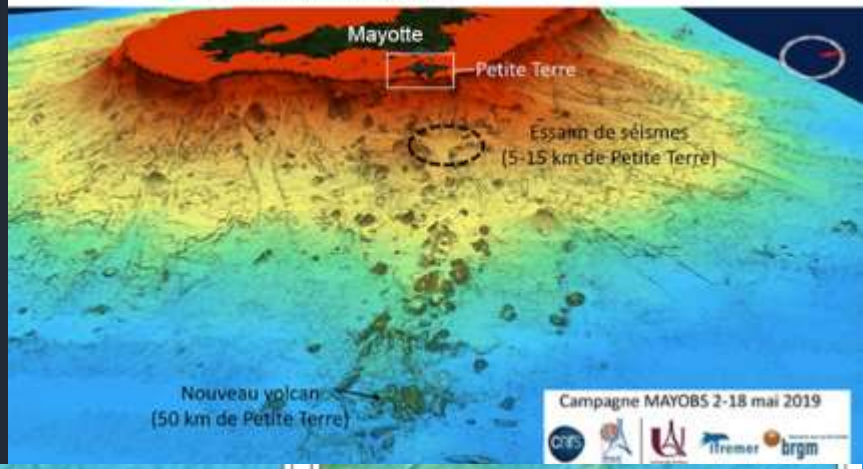
- Seismic Crisis on the French island of Mayotte
- Whole new underwater mountain 800m high!
- Site of many research expeditions now…

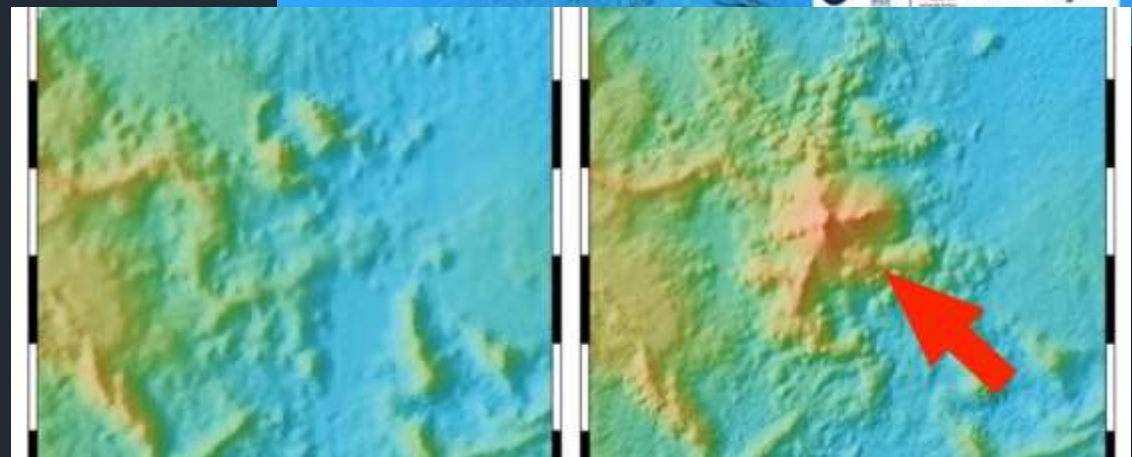


Offshore earthquakes up to M6 in size!



New volcano formed over 6 months, and still growing…



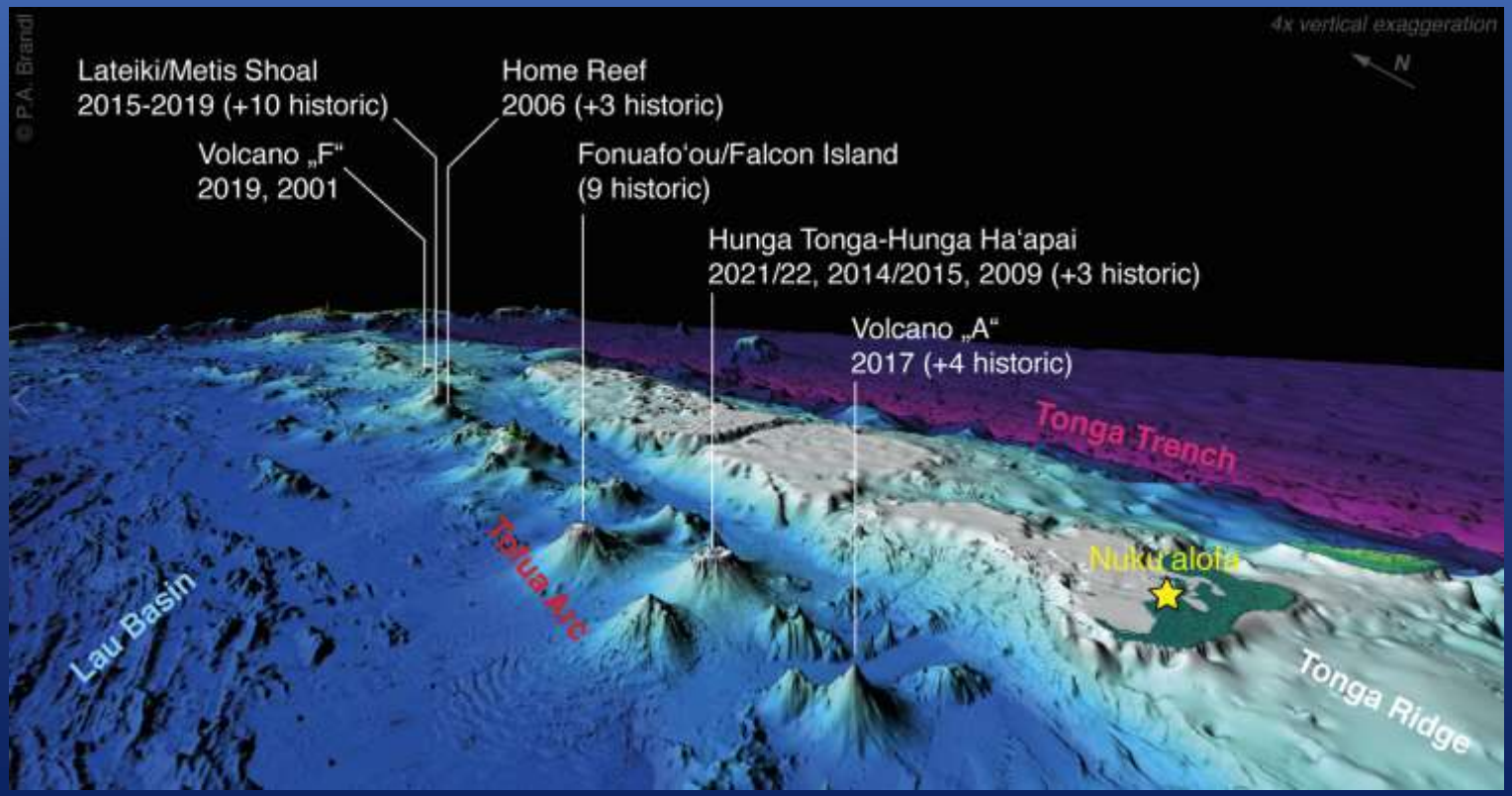


Hunga Tonga – Hunga Ha'apai, eruption (Hunga Volcano, Tonga) 2022

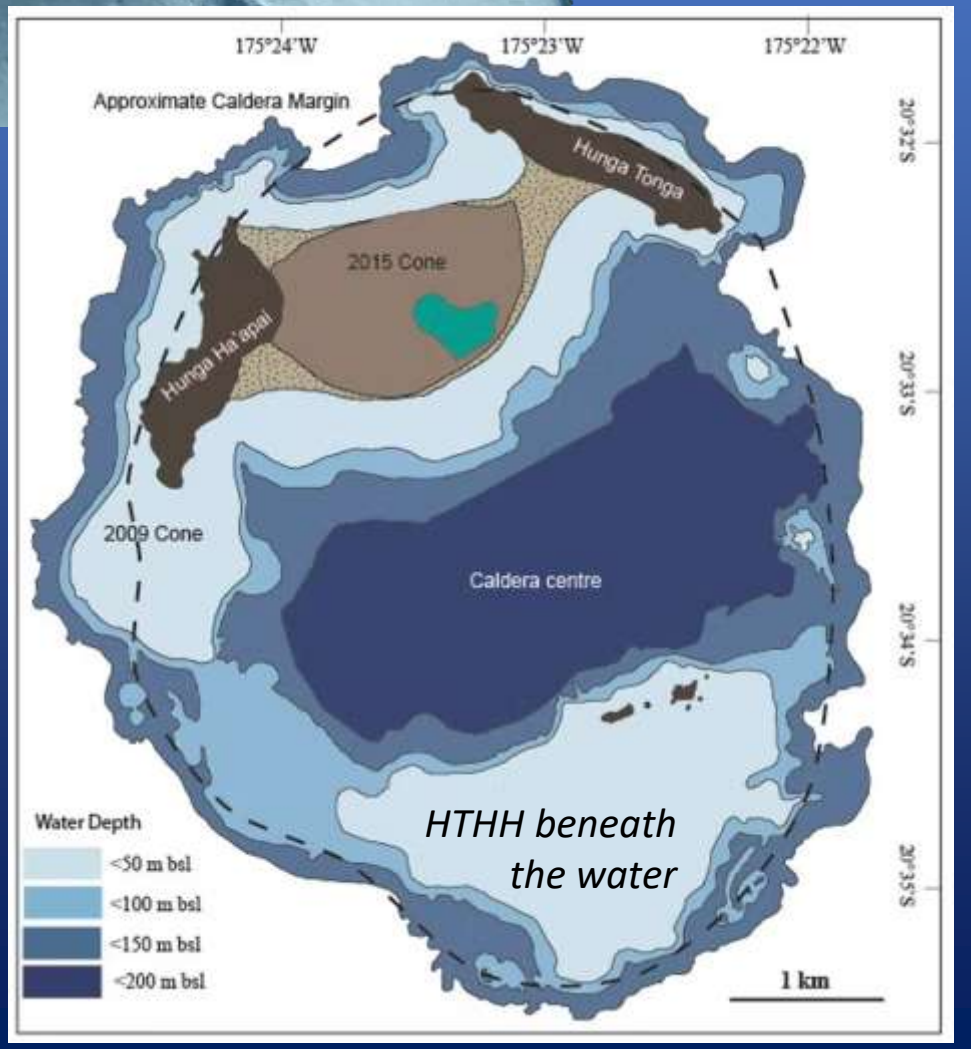
Changing our perspectives on ocean-emergent volcanism

022-01-15 05:00:00 UTC

- Observed eruptions in 2009, 2014/15, Dec 2021 and early January 2022
- Historic eruptions going back several ka
- Islands built up and eroded over time
- Two small islands of a larger shallow marine caldera
- Part of the larger, active Tofua Arc in Kingdom of Tonga



Active submarine volcanoes along the Tofua Arc, Tonga



Previous eruptions:

- Mixture of ash and white steam jets, low altitude ash clouds
- Explosive magma-water interactions
- Relatively small, unsteady, short-lived explosions
- Larger more-explosive “uncharacteristic” event on January 14th 2022

2015 eruption activity

2014 eruption activity

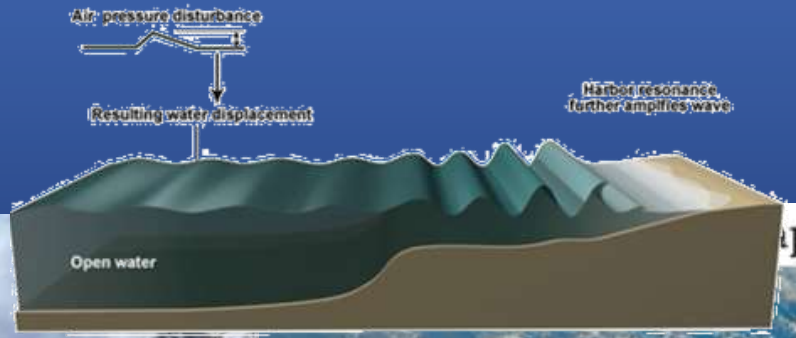
January 14th 2022 explosion (NOT the main event)

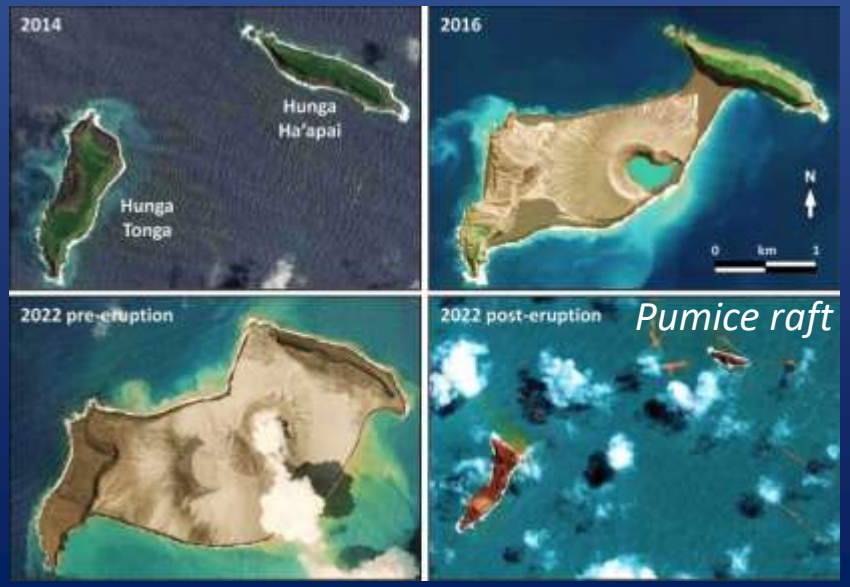
Then January 15th, suddenly the **highest volcanic plume** ever witnessed and **loudest sound recorded** since 1883…

Observations of eruption:

- Sudden volcanic plume up to 55km high (over 30 miles) into the mesosphere!
- Huge cloud extending over the SW Pacific
- Series of tsunami events across the entire Pacific and a “meteotsunami” in the Gulf of Mexico
- Main shockwave of the primary explosion circulated the Earth five times (detectable).
- Sound heard in Alaska over 9000km away

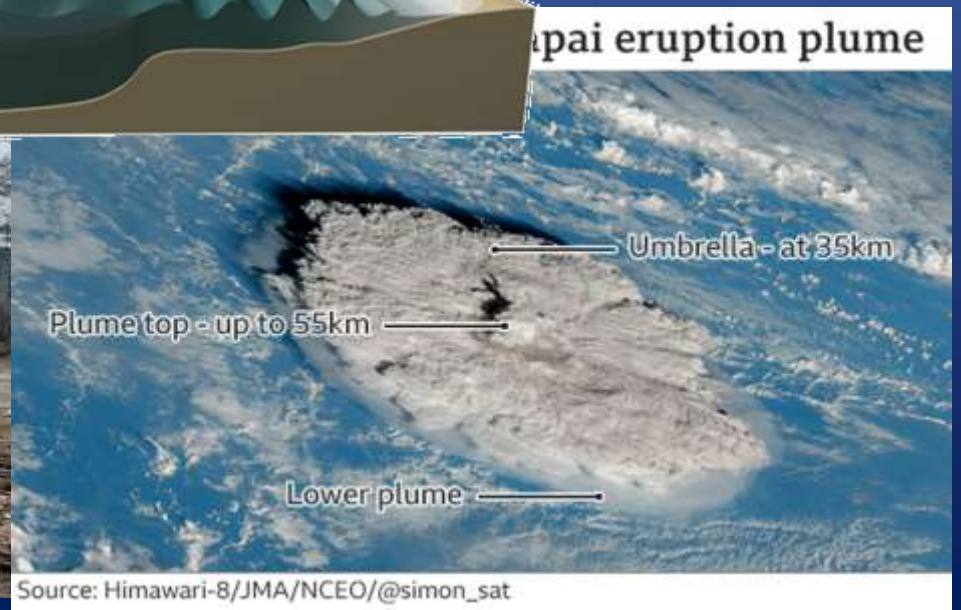
Himawari/GOES8 satellite





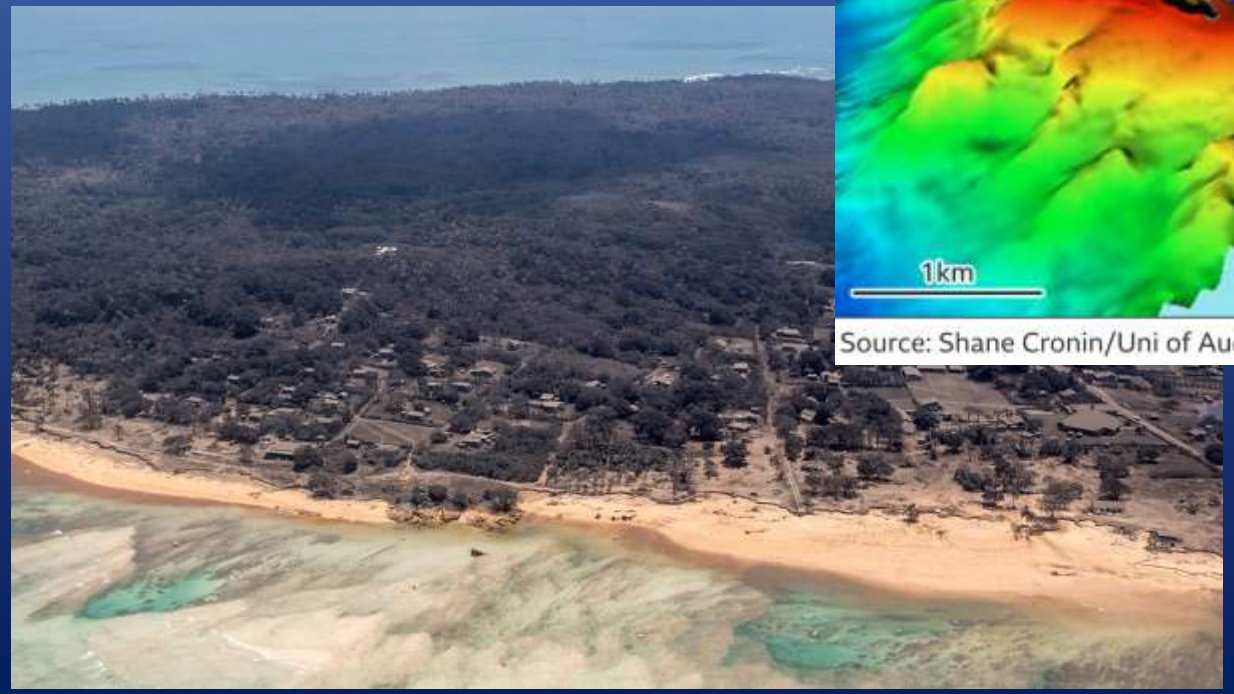
Pumice raft

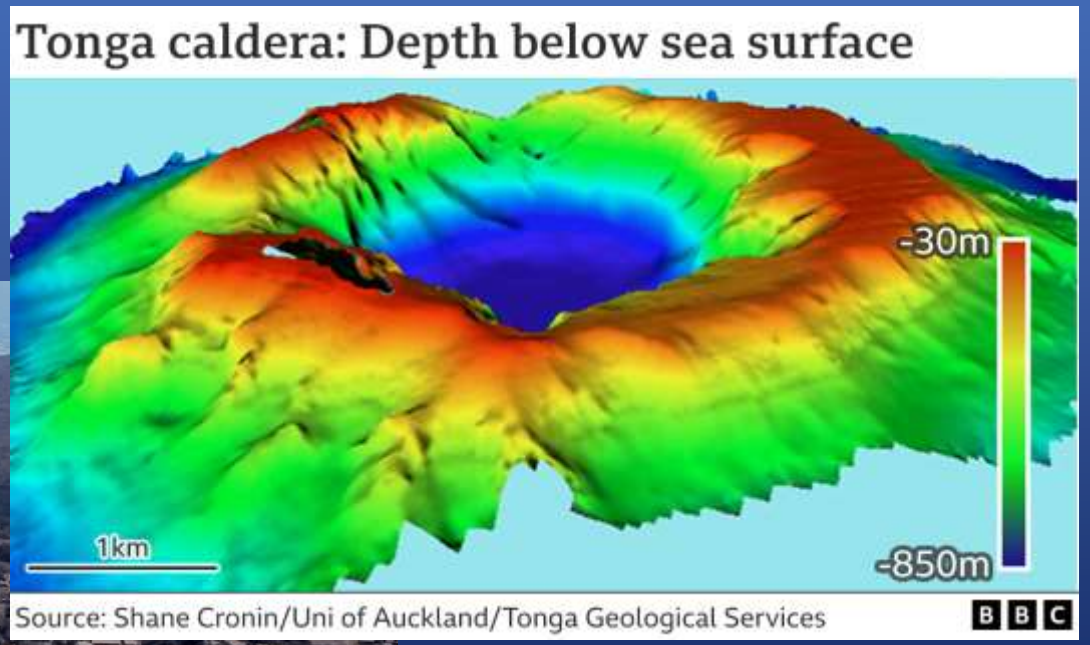
Tsunami damage + ash fall afterwards



Impacts of eruption

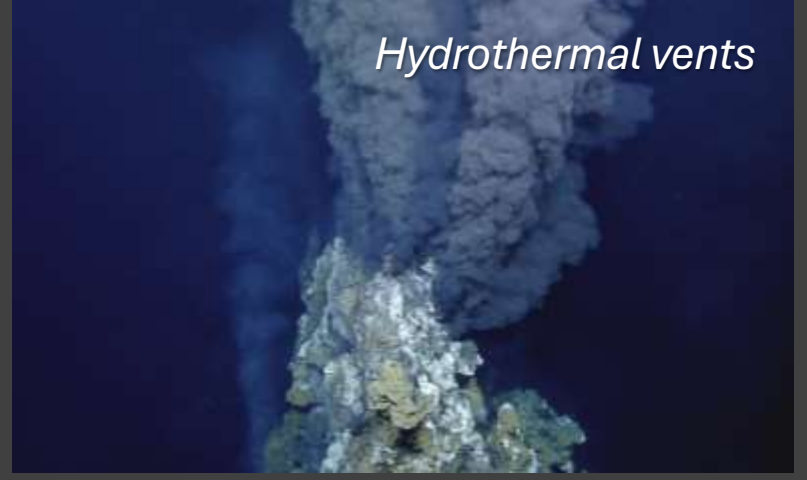
- Tsunamis and ashfall devastated all islands of Tonga.
- <10 deaths recorded across world. 2 on capsized ships in Peru
- Destruction of the two islands
- Huge volume lost from caldera. Now 700m deeper in crater!





Hunga underwater bathymetry

Benefits of volcanic eruptions?



Geotourism and economy

Fertile lands and soil

Atoll and reef development

Looser regulations on land lease

Nutrients and heat for hydrothermal systems

Landforms for unique habitats

Substrates for growth (ash, lava)

New land, resetting of environments

Art, culture, media, history

Geothermal energy and resources

Porphyry copper and mining ops.

Cultural influence

Influence of culture e.g. Hawaiian mo'olelo

Blossoming of life after eruptions fuels song, stories, narrative

A draw to earth science when we incorporate beauty in nature

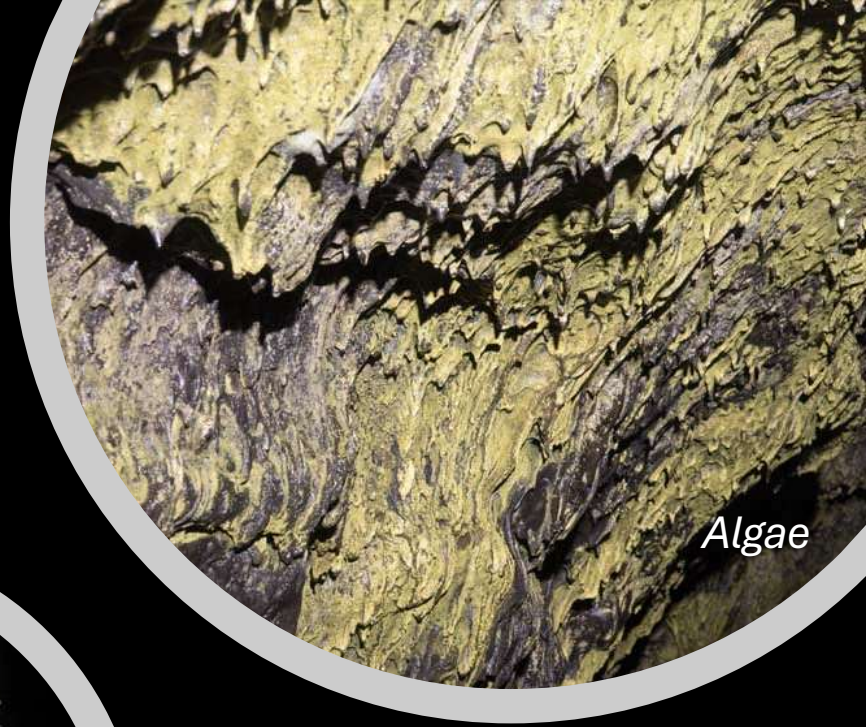
Metrosideros polymorpha, the ʻōhiʻa lehua

Hiʻiaka and Hopoe

Pele

First recovery of life

Volcanoes are an extreme environment

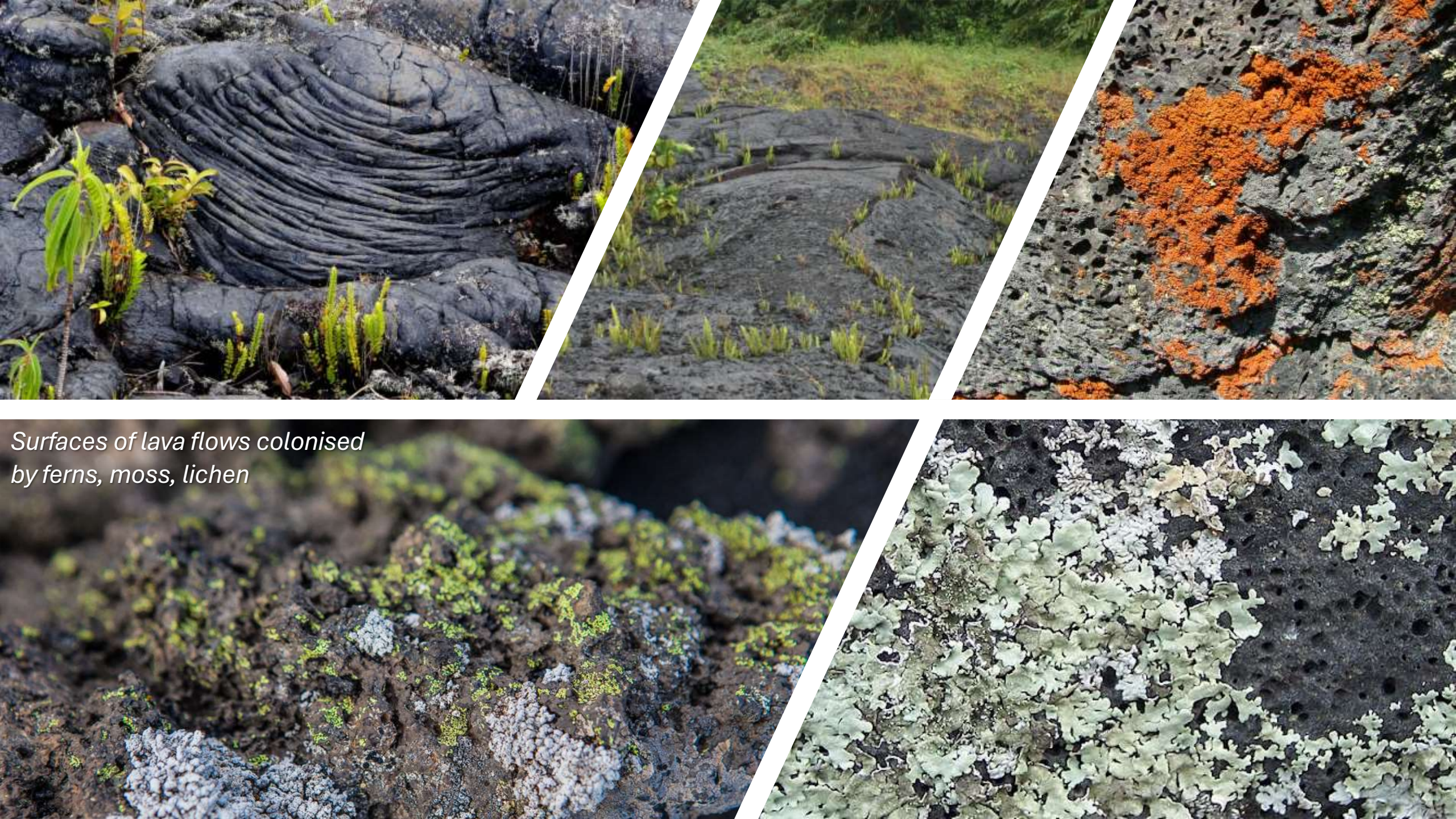


Algae

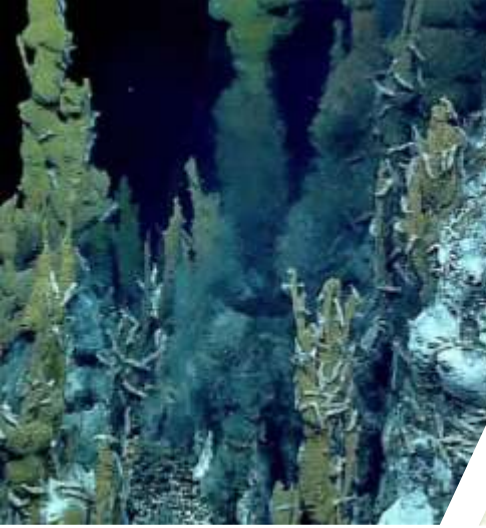
But life can recover quickly:

- First saplings, dew, spores, pollen, root structures, first flowers
- Lava flows and lava tubes used as exoplanet studies
- Bacteria, algal mats, lichen, moss, insects

Kaumana lava caves, Hawai'i



Surfaces of lava flows colonised by ferns, moss, lichen

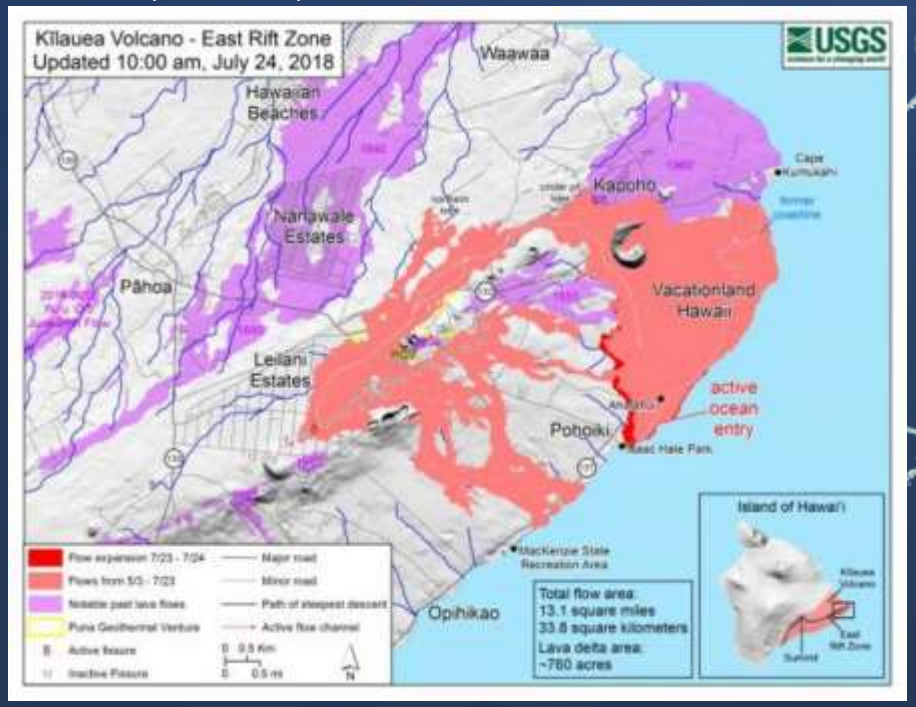


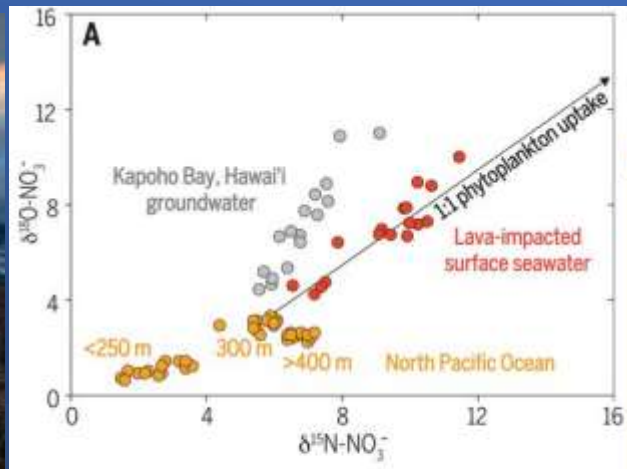

Deep volcanism and vents

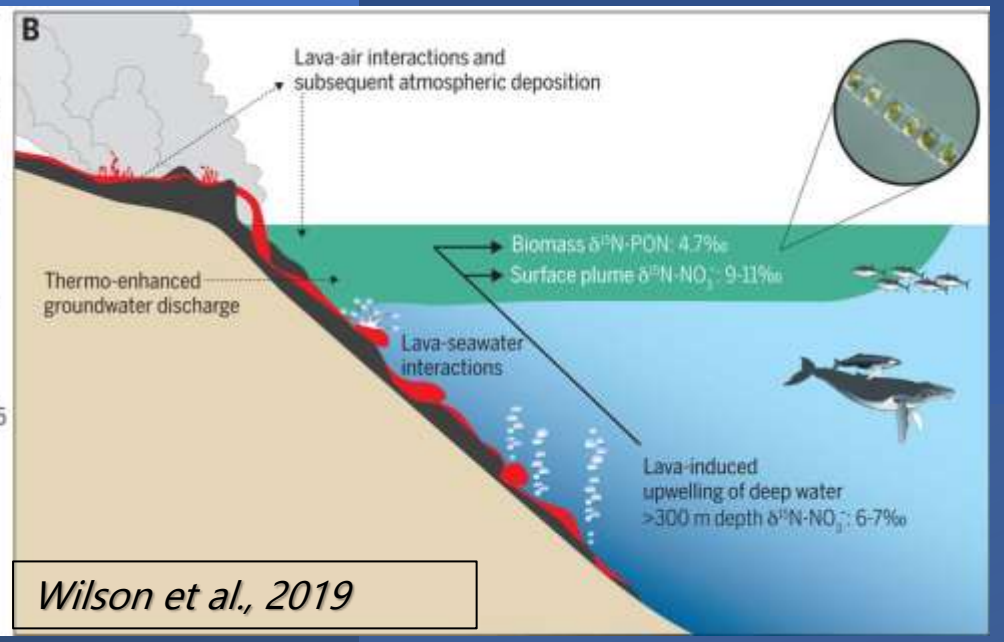
- Stranger and stranger as we discover more systems
- Heat, chemosynthesis, nutrient-metal rich
- Deep lava making good substrate for deep water reefs



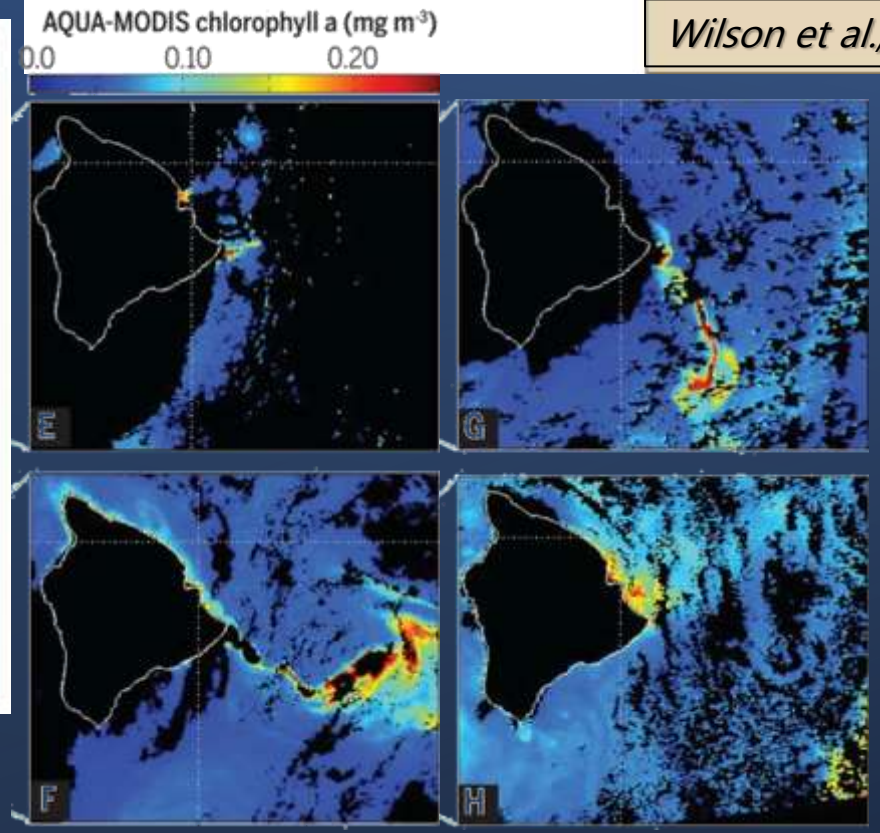
Kīlauea, Hawai'i, 2018





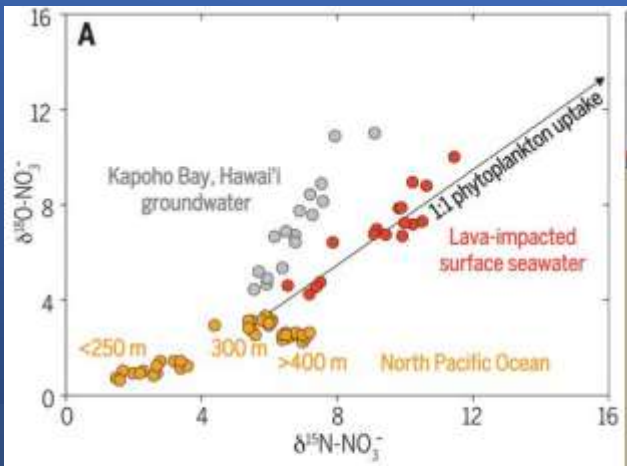


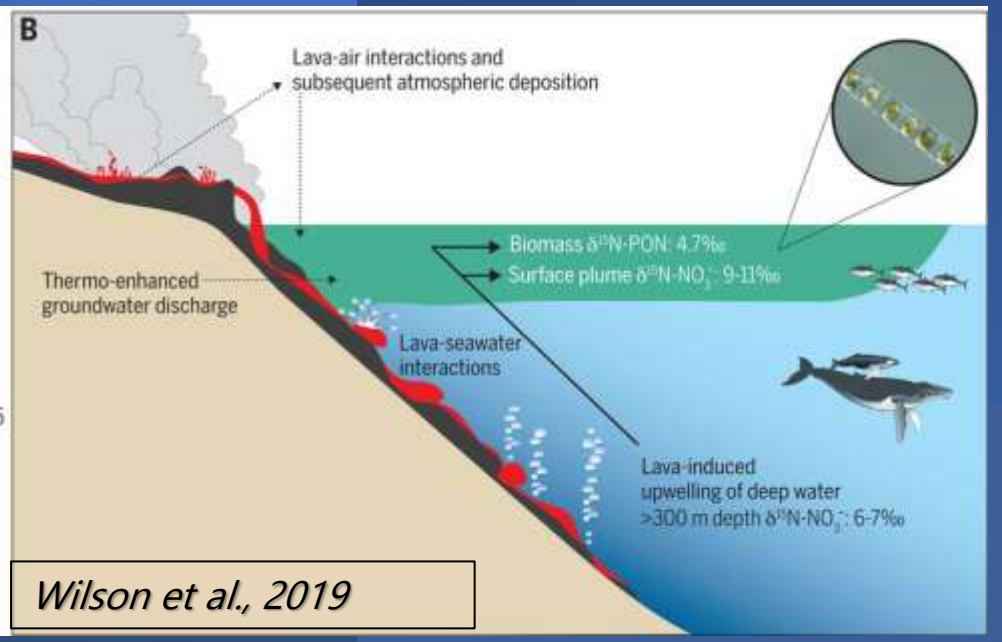
Wilson et al., 2019



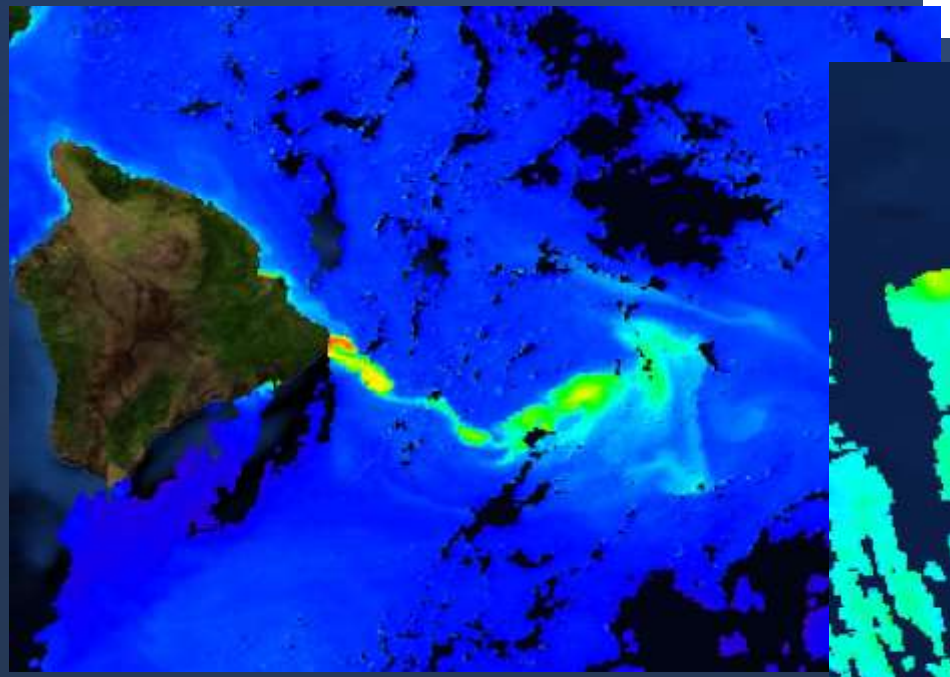
- Lava deltas entering the water triggering blooms of phytoplankton
- High chlorophyll conc.
- Lavas induce upwelling of cold nutrient water to surface

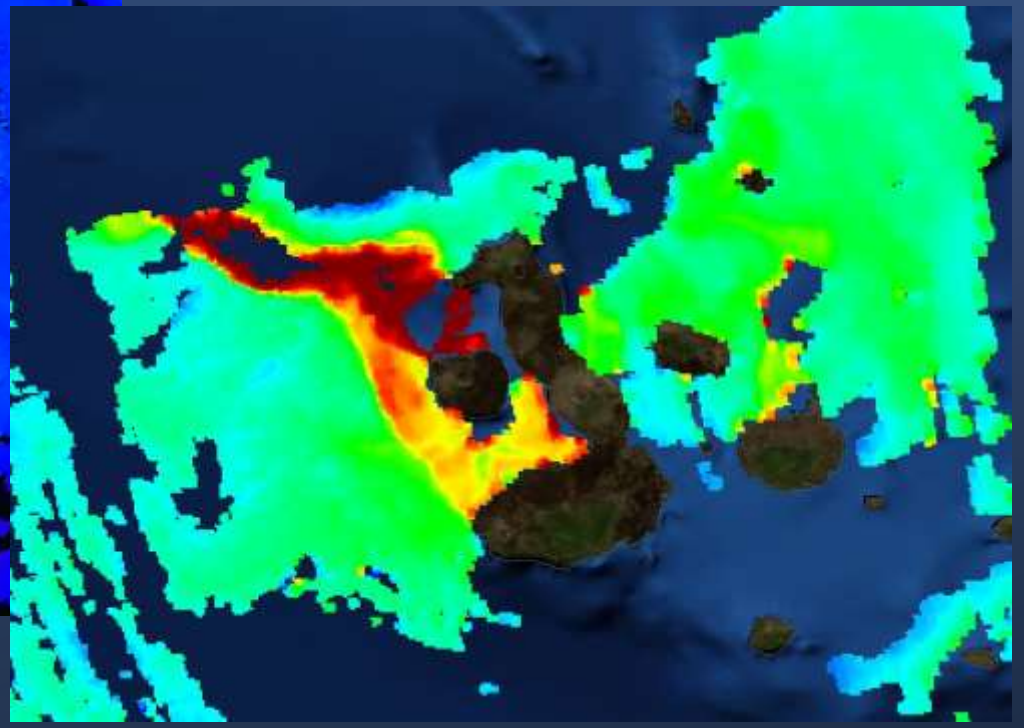
Kīlauea, Hawai'i, 2018





Wilson et al., 2019





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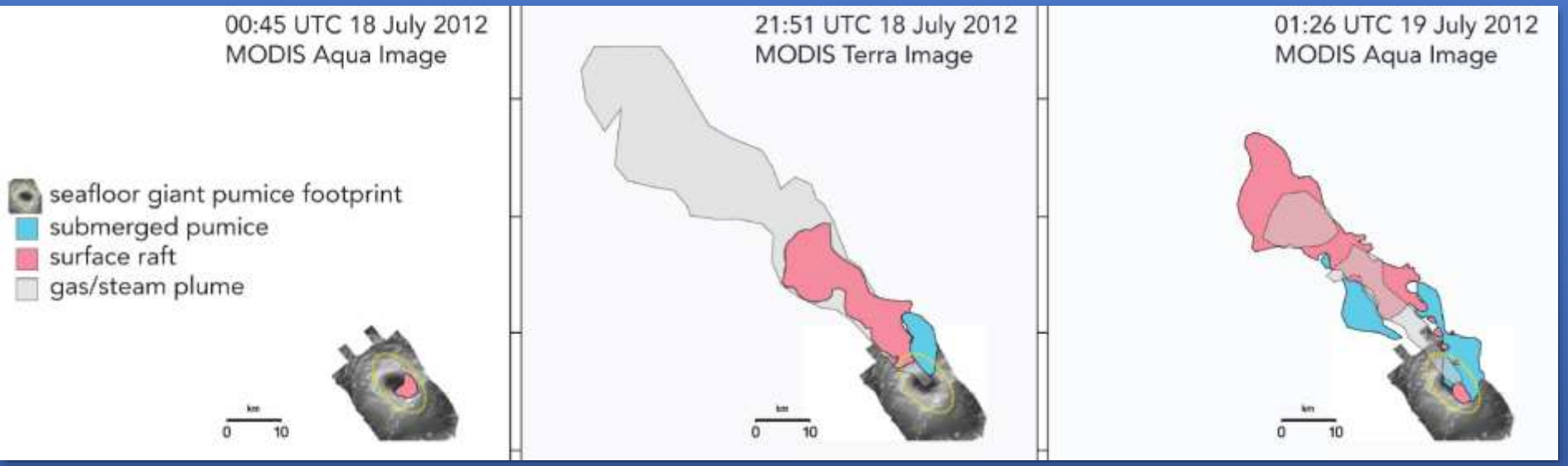
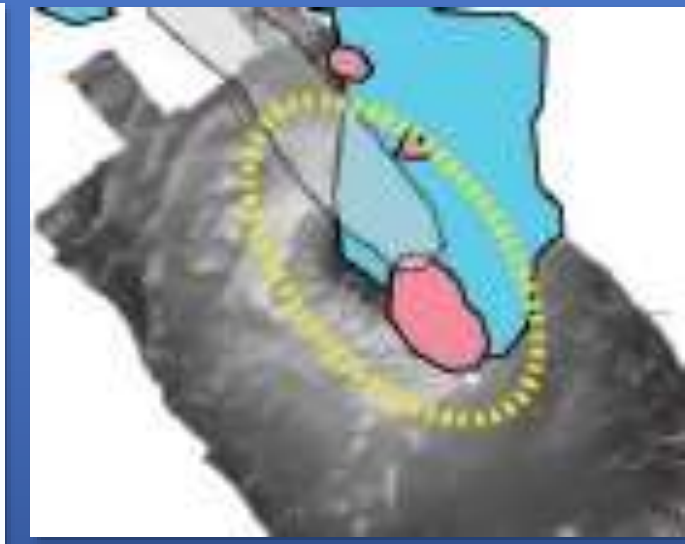
Using satellites to monitor submarine volcanic hazards





Carey et al., 2018

Brandl et al., 2019

Jutzeler et al., 2014

Remote sensing of pumice rafts – The 2012 Havre eruption

A world of new underwater technology

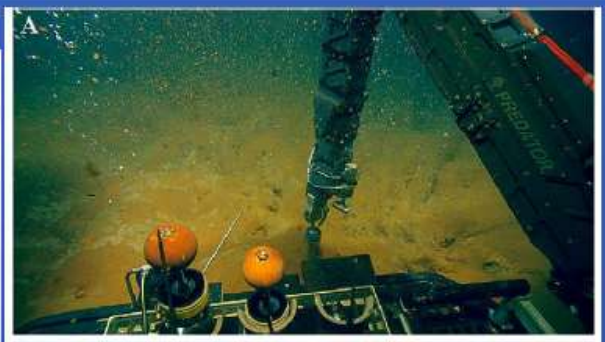
Submersibles: HOVs – Human Occupied Vehicles

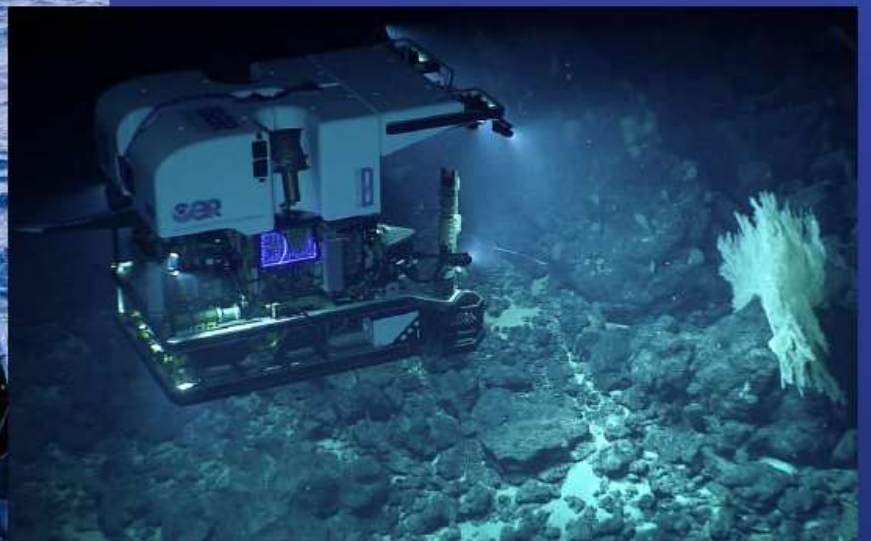
HOV Alvin (modern)

Original HOV Alvin

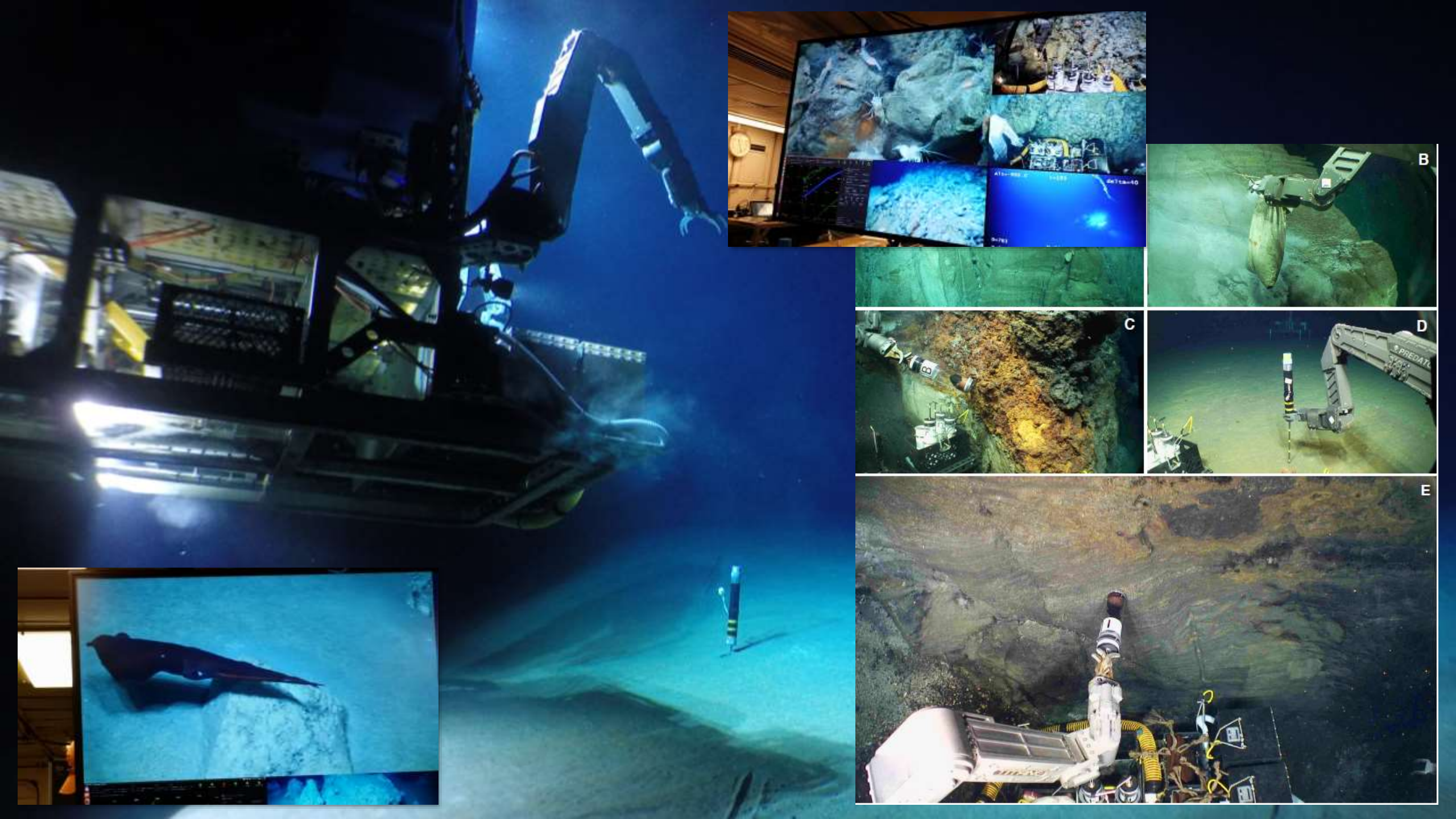
HOV Shinkai

Submersibles: ROVs – Remotely Operated Vehicles





Submersibles: ROVs – Remotely Operated Vehicles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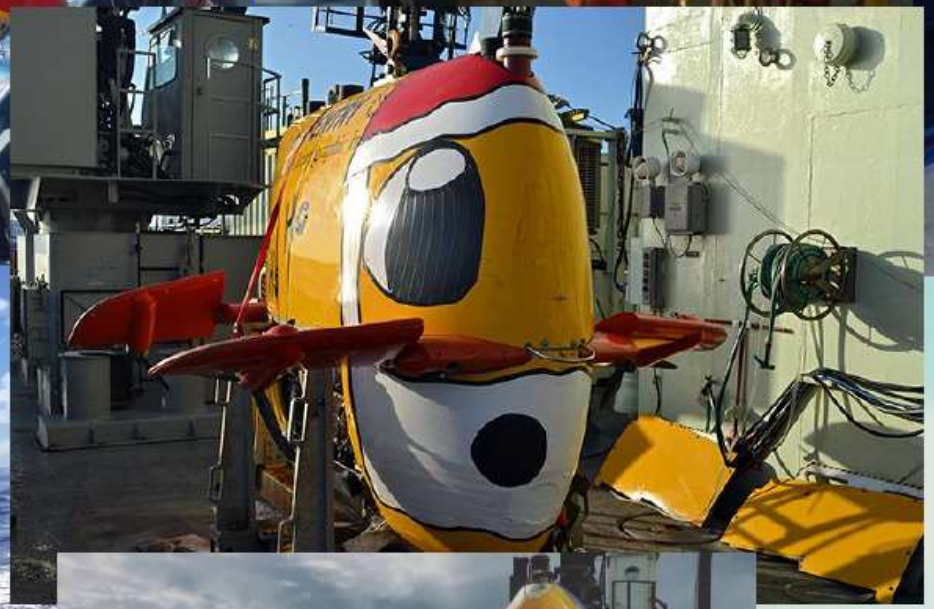
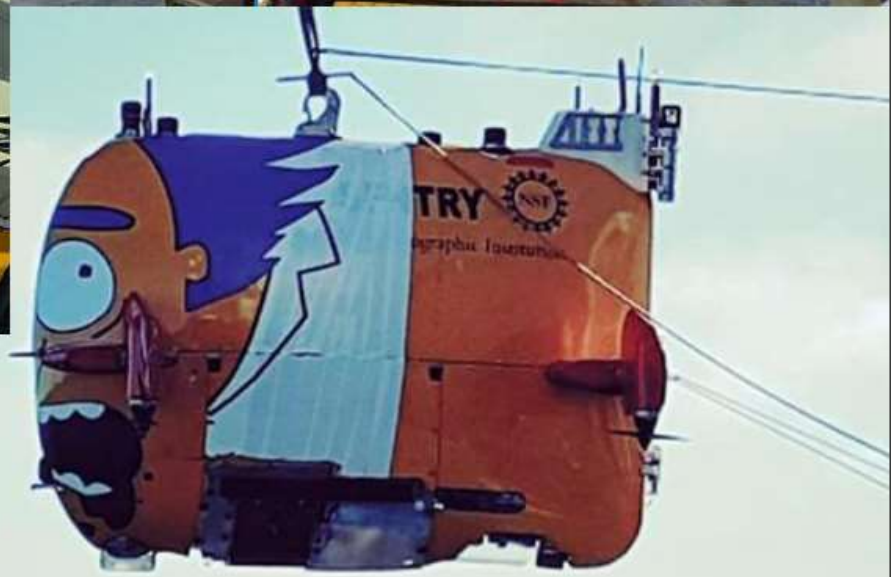
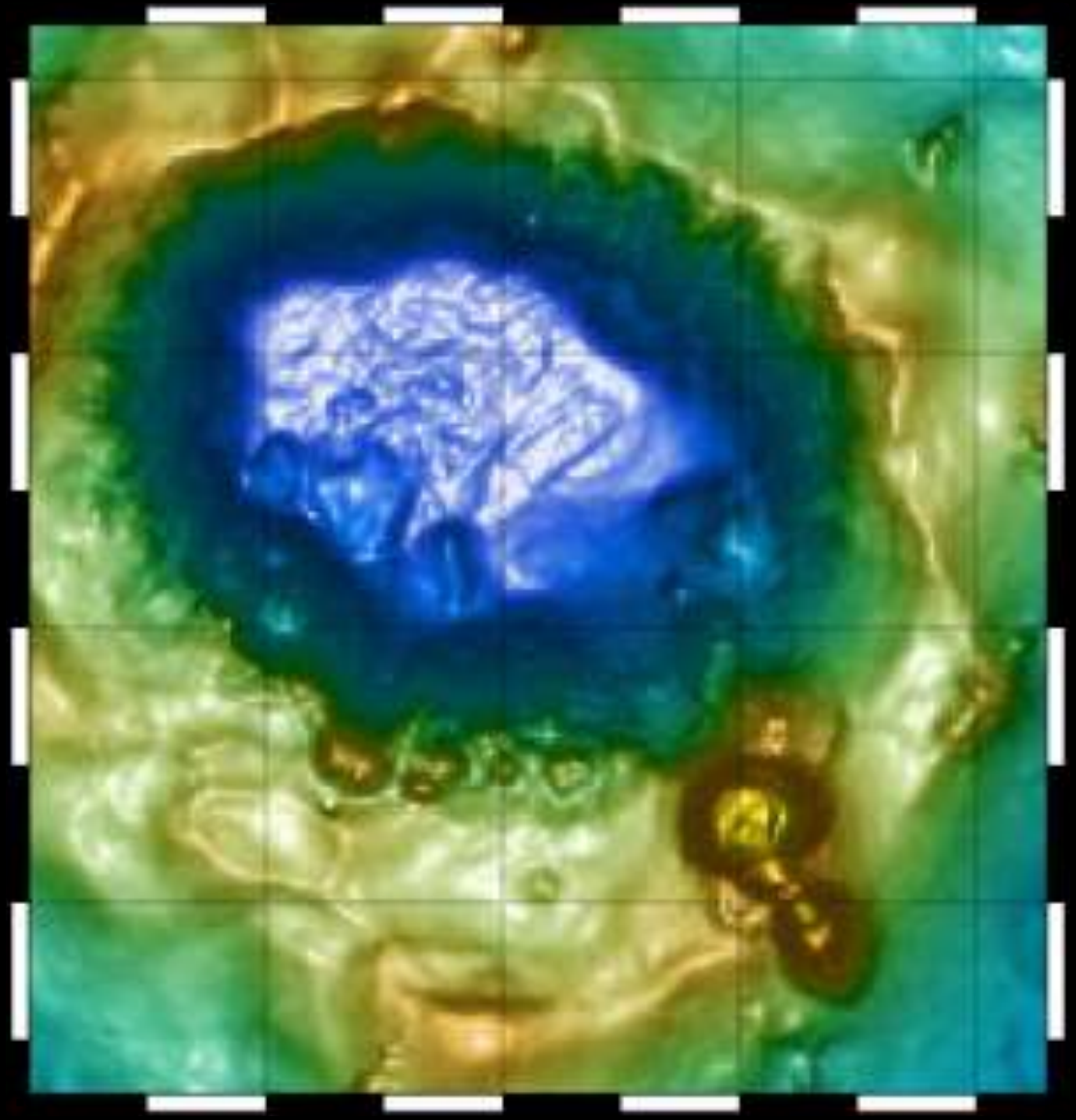
Submersibles: AUVs – Autonomous Underwater Vehicles

Submersibles: AUVs – Autonomous Underwater Vehicles





Ship vs. AUV bathymetry

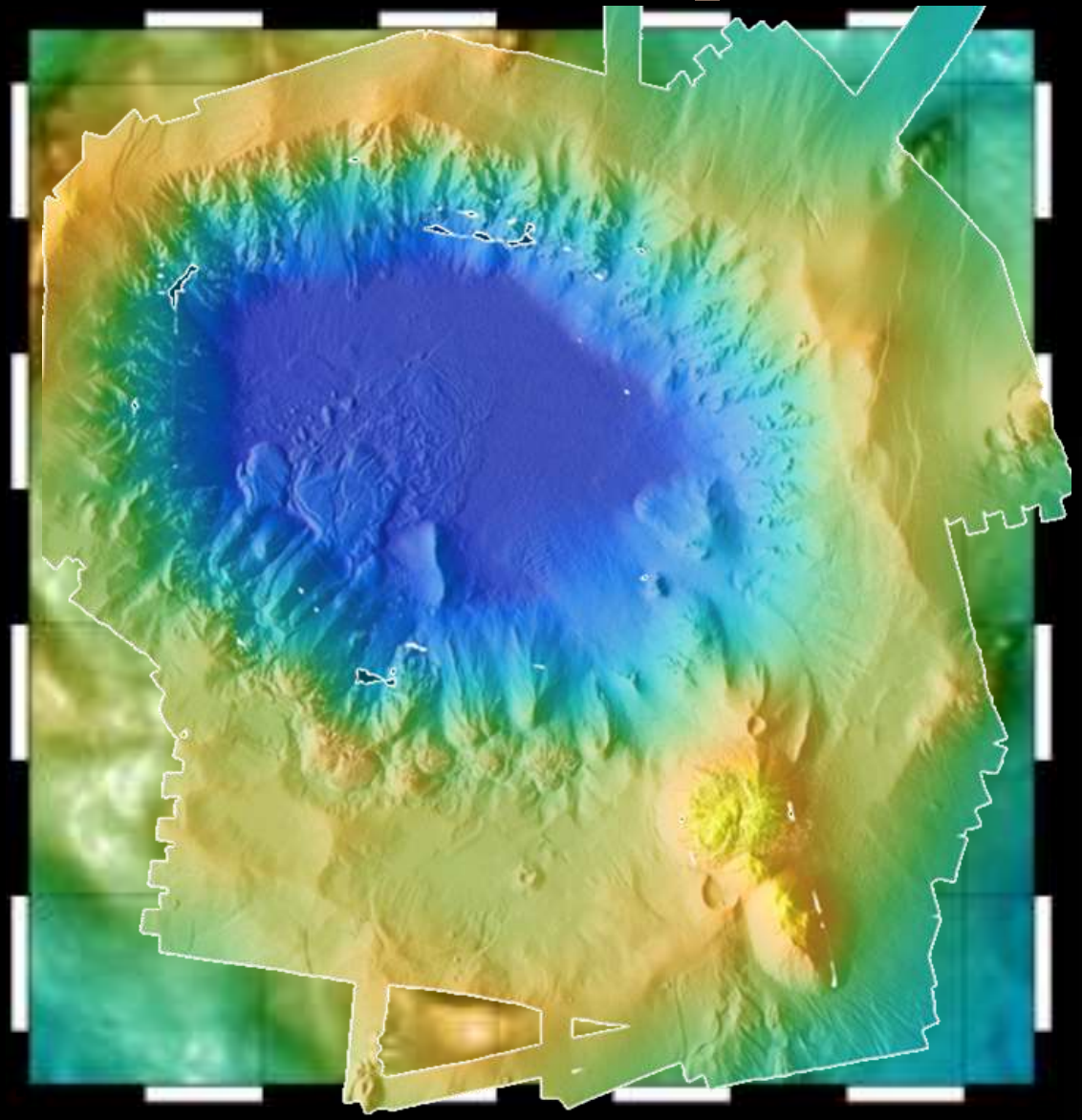


Using ***AUV Sentry*** able to collect 1m resolution bathymetry

Carey et al., 2018

Resolving unresolvable features using Sentry

Ship vs. AUV bathymetry



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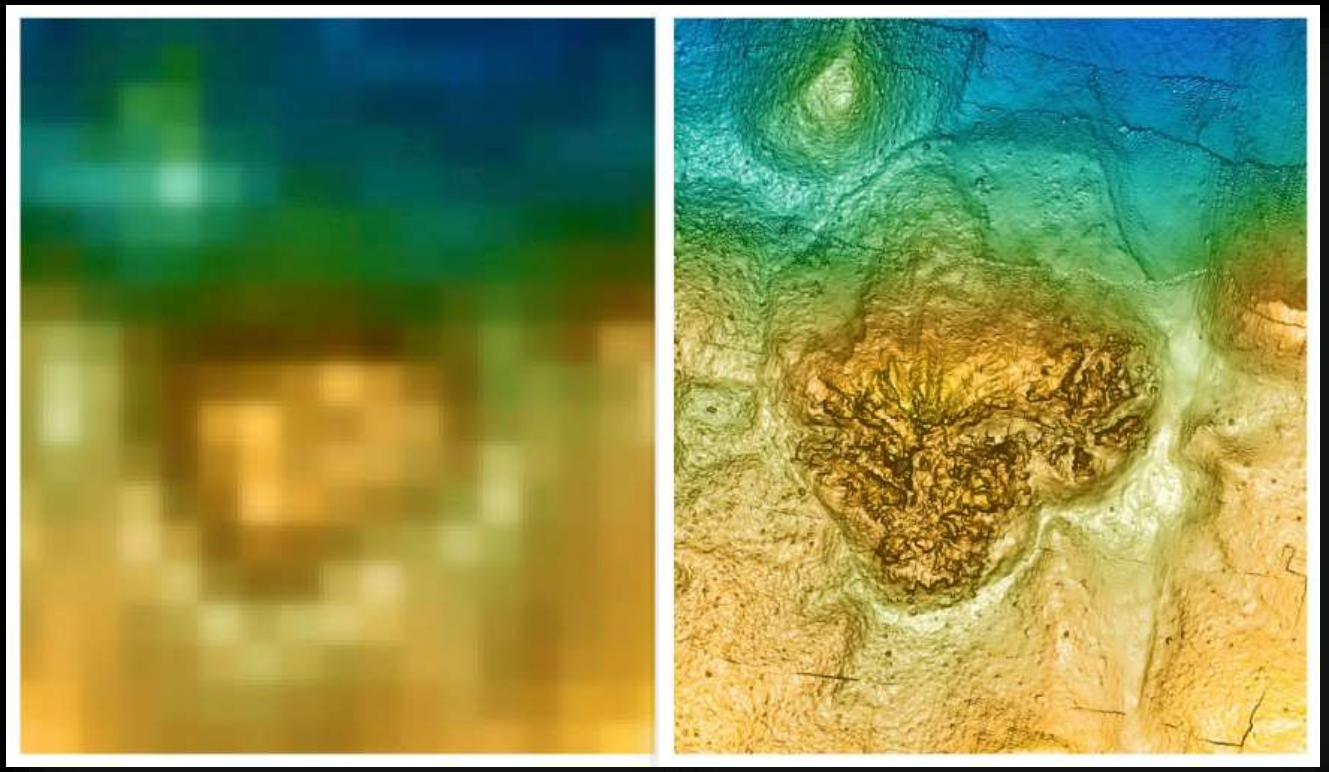
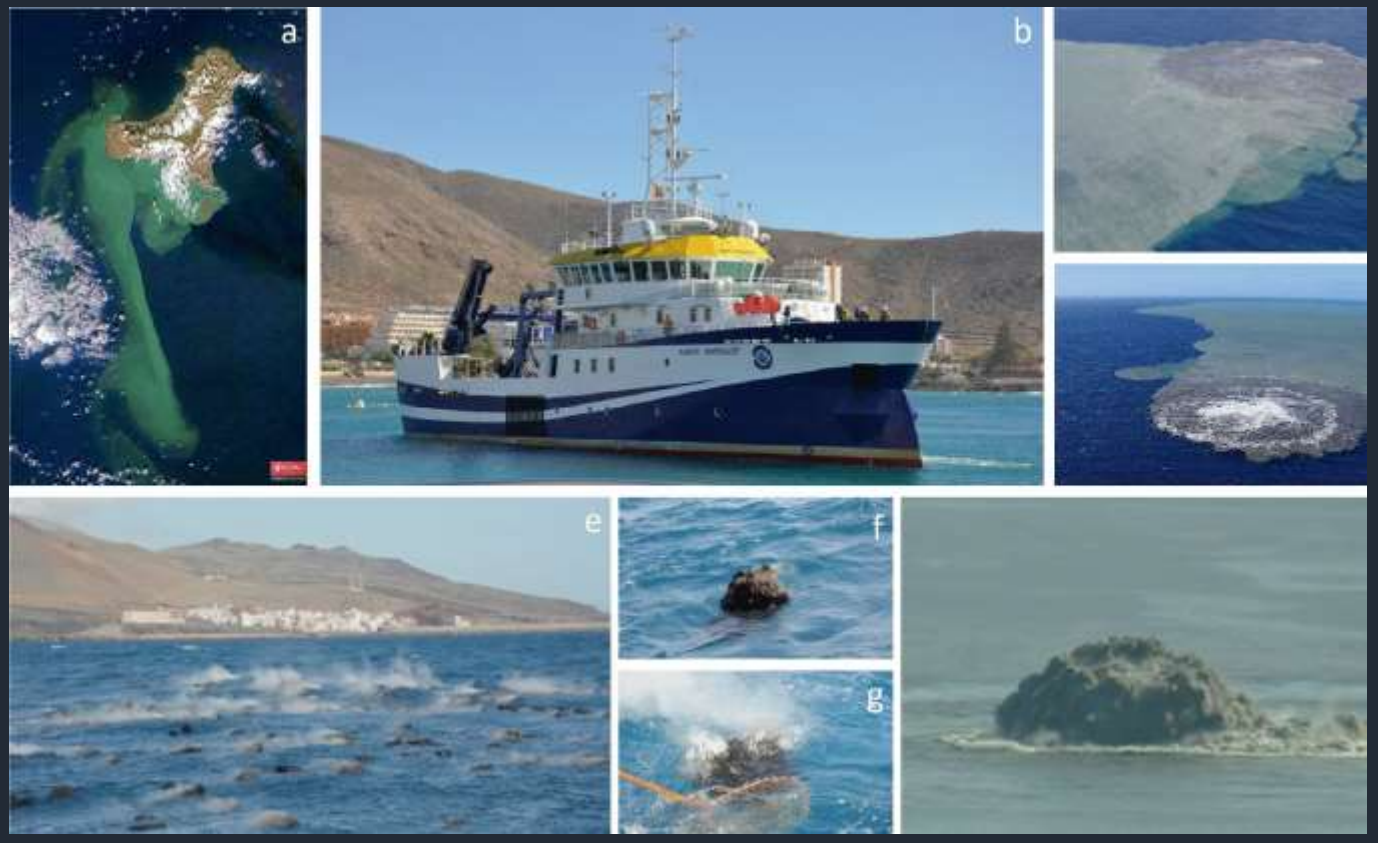


Underwater observatories

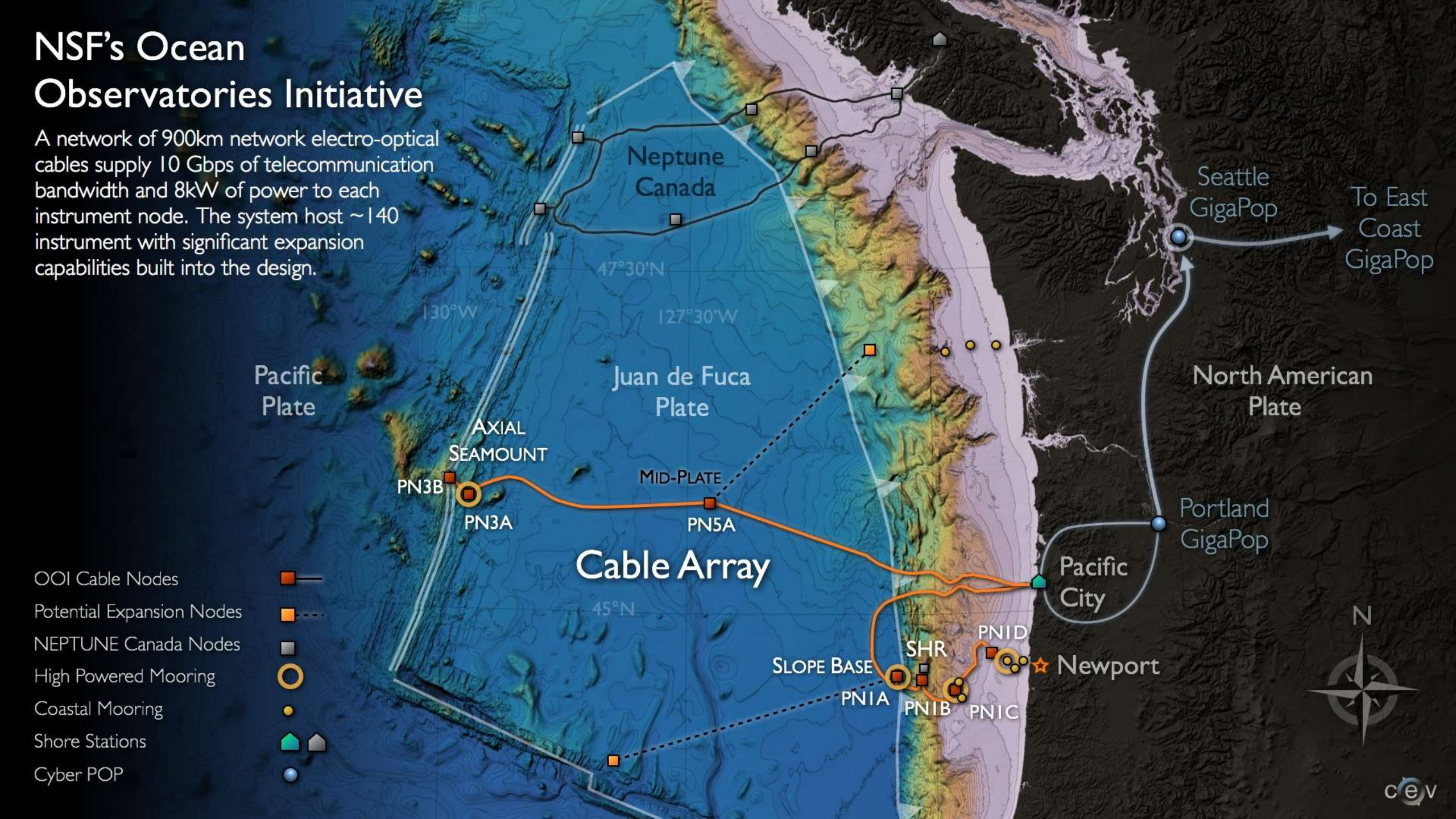
El Hierro, Tagoro submarine volcano

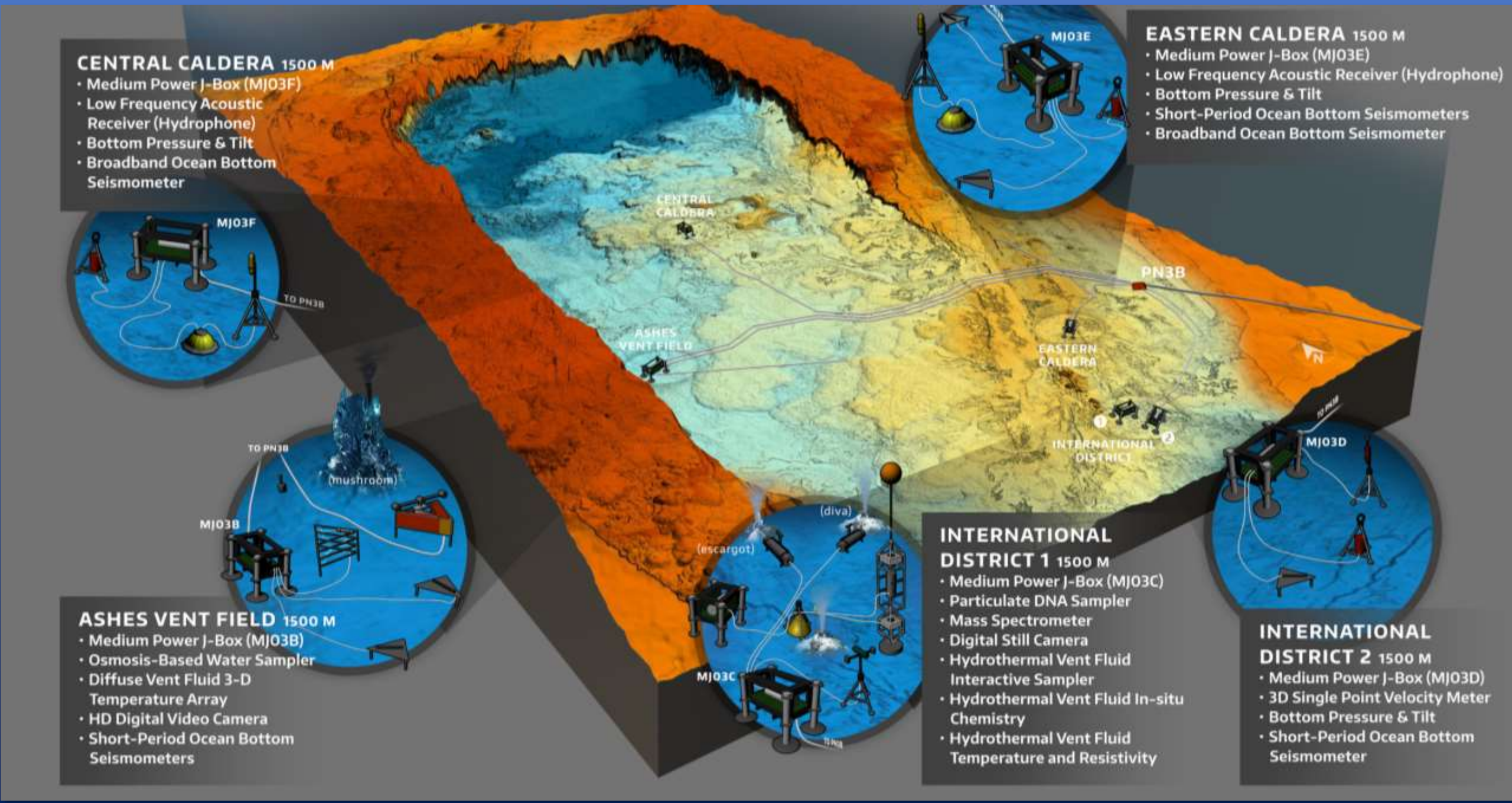
- Erupted in 2011-12 off the coast of El Hierro
- Shallow submarine volcano
- Monitoring for over 12 years the development of life over this timescale
- Not the only submarine volcano heavily monitored for life

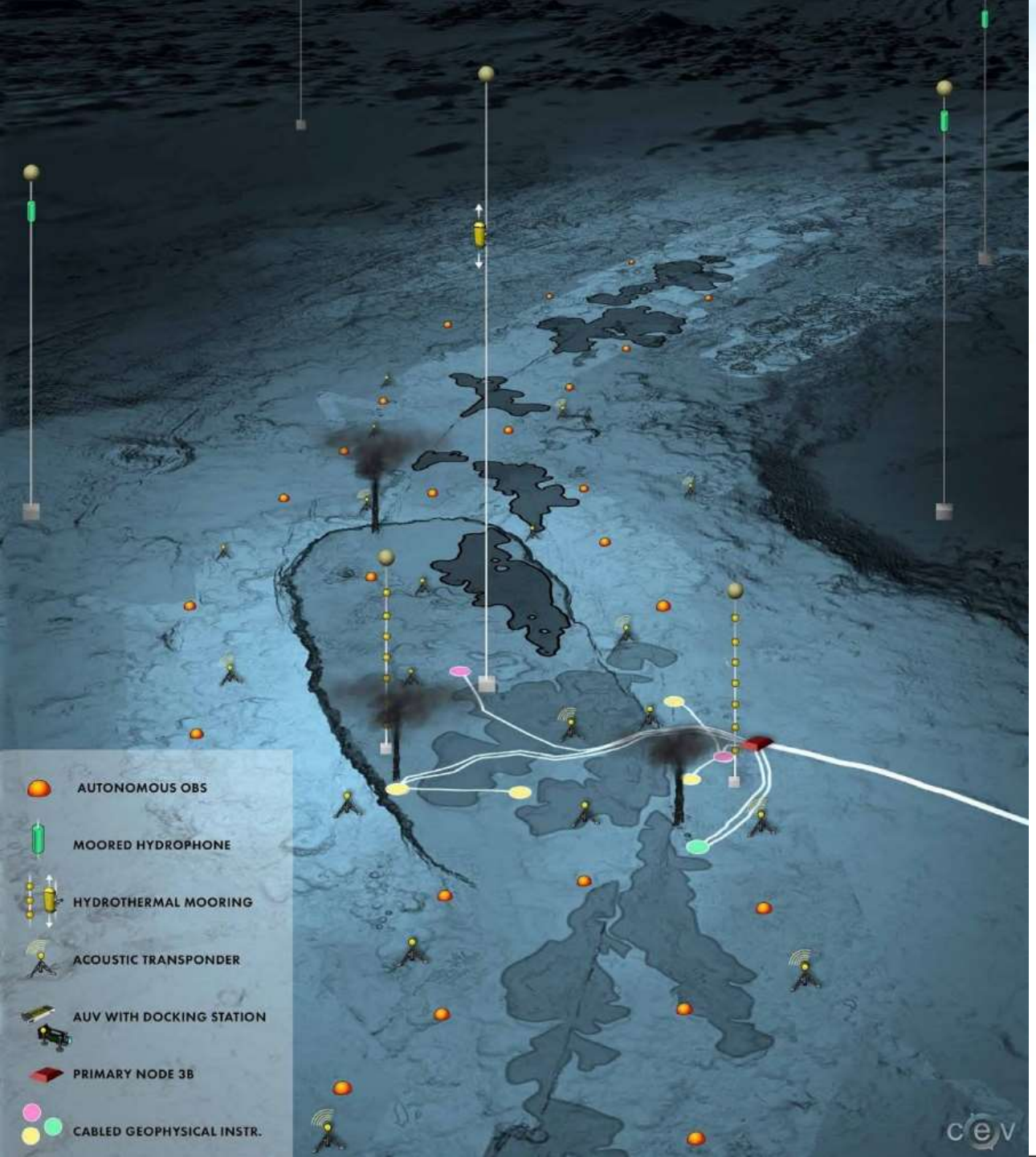


NSF's Ocean Observatories Initiative

A network of 900km network electro-optical cables supply 10 Gbps of telecommunication bandwidth and 8kW of power to each instrument node. The system host ~140 instrument with significant expansion capabilities built into the design.



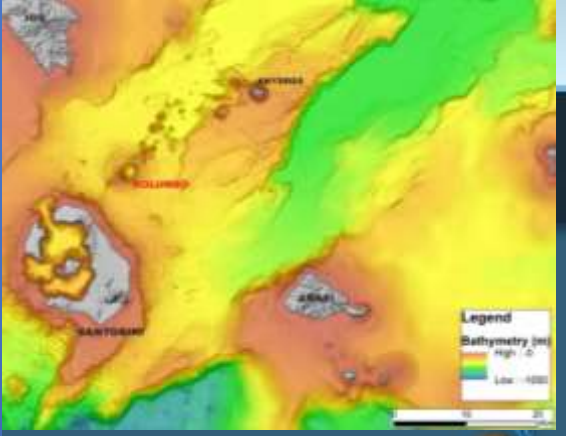

CENTRAL CALDERA 1500 M
• Medium Power J-Box (MJ03F)
• Low Frequency Acoustic Receiver (Hydrophone)
• Bottom Pressure & Tilt
• Broadband Ocean Bottom Seismometer
MJ03F
TO PN3B
EASTERN CALDERA 1500 M
• Medium Power J-Box (MJ03E)
• Low Frequency Acoustic Receiver (Hydrophone)
• Bottom Pressure & Tilt
• Short-Period Ocean Bottom Seismometers
• Broadband Ocean Bottom Seismometer
MJ03E
CENTRAL CALDERA
PN3B
ASHES VENT FIELD
EASTERN CALDERA
INTERNATIONAL DISTRICT
TO PN3B
(mushroom)
MJ03B
ASHES VENT FIELD 1500 M
• Medium Power J-Box (MJ03B)
• Osmosis-Based Water Sampler
• Diffuse Vent Fluid 3-D Temperature Array
• HD Digital Video Camera
• Short-Period Ocean Bottom Seismometers
(diva)
(escargot)
MJ03C
INTERNATIONAL DISTRICT 1 1500 M
• Medium Power J-Box (MJ03C)
• Particulate DNA Sampler
• Mass Spectrometer
• Digital Still Camera
• Hydrothermal Vent Fluid Interactive Sampler
• Hydrothermal Vent Fluid In-situ Chemistry
• Hydrothermal Vent Fluid Temperature and Resistivity
MJ03D
INTERNATIONAL DISTRICT 2 1500 M
• Medium Power J-Box (MJ03D)
• 3D Single Point Velocity Meter
• Bottom Pressure & Tilt
• Short-Period Ocean Bottom Seismometer



Live Video from Axial Seamount: August 2020

Every 3-hours from 250 miles off the Oregon coast, and 1 mile underwater, HD video streams in live over the Internet through the OOI's Cabled Array in situ camera system. Live video streams of an actively venting hydrothermal chimney occur during the hours of **2:00, 5:00, 8:00, and 11:00 EDT & PDT** day and night, for a duration of 14 minutes.

In addition, as of November 2016, the camera now records for **24 hours non-stop on the 10th and 20t of every month**, and **72 hours non-stop from the 1st to 3rd of every month**, to examine animal behavior, diurnal/tidal cycles, and longer-duration changes in hydrothermal flow.



SANTORY

Winched Profiler

Sub-surface Float & Instrument Packages

MOORING

Autonomous Underwater Vehicle

Profiler

Current Meter

Acoustic Modem

Hydrophone

Pressure Sensor

Broadband Seismometer

Medium Power Junction Box

HPIES

ADCP

Low Voltage Node

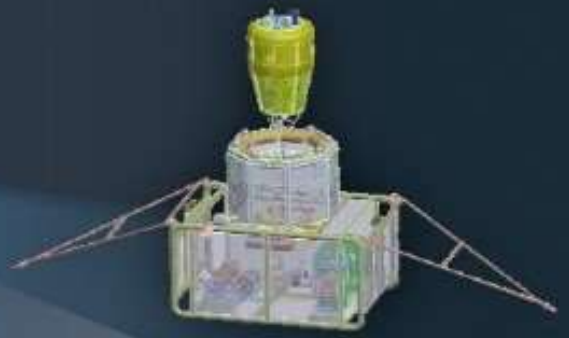
Hydrophone

Dissolved Oxygen

CTD

Fluorometer

PRIMARY NODE



Winch Instrument Package

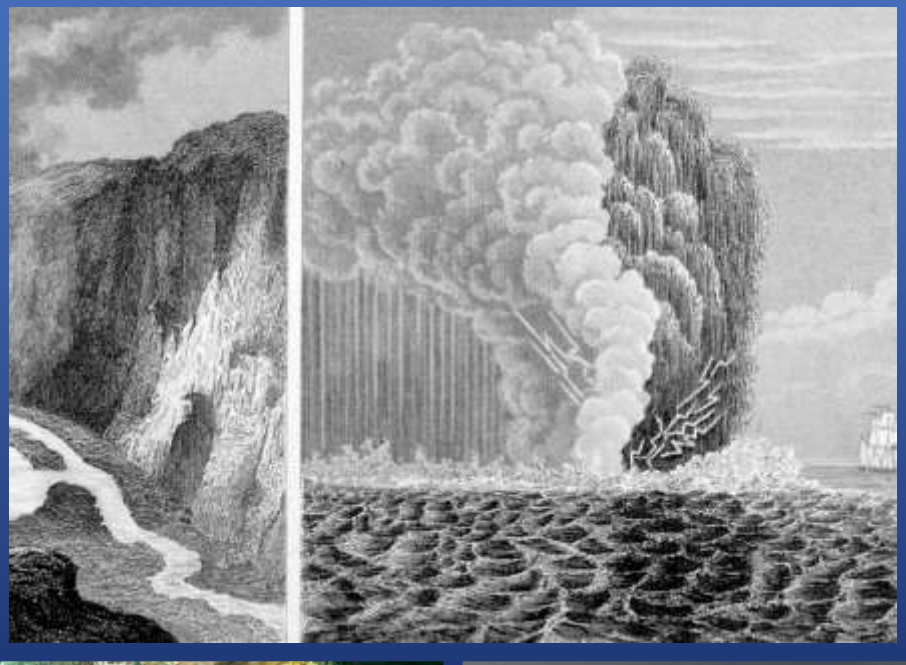
Winch Instrument Package

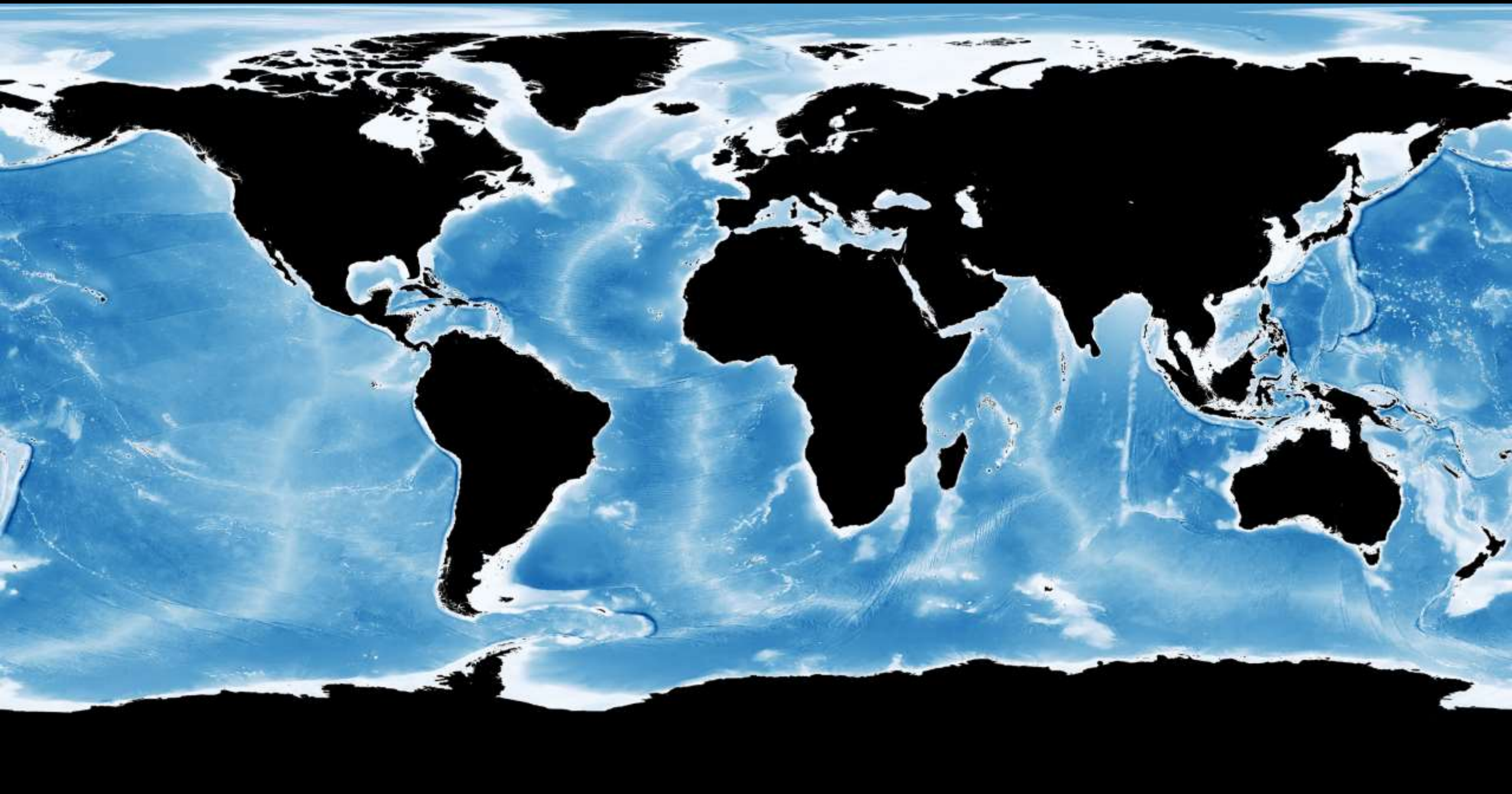
- Current Meter-T
- CTD Dissolved O2
- Fluorometer OB
- Nitrate
- pH
- Optical Attenuation
- Spectral Irradiance
- PAR
- PCO2
- Digital Still Camera
- Fluorometer - 3W

Float Instrument Package

- Broadband Hydrophone
- CTD-Dissolved O2
- Fluorometer OB
- pH
- VADCP
- Digital Still Camera
- Acoustic Modem
- ADCP-150kHz

The future of underwater volcanoes





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Underwater Volcanoes

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Volcanologist / Marine geologist

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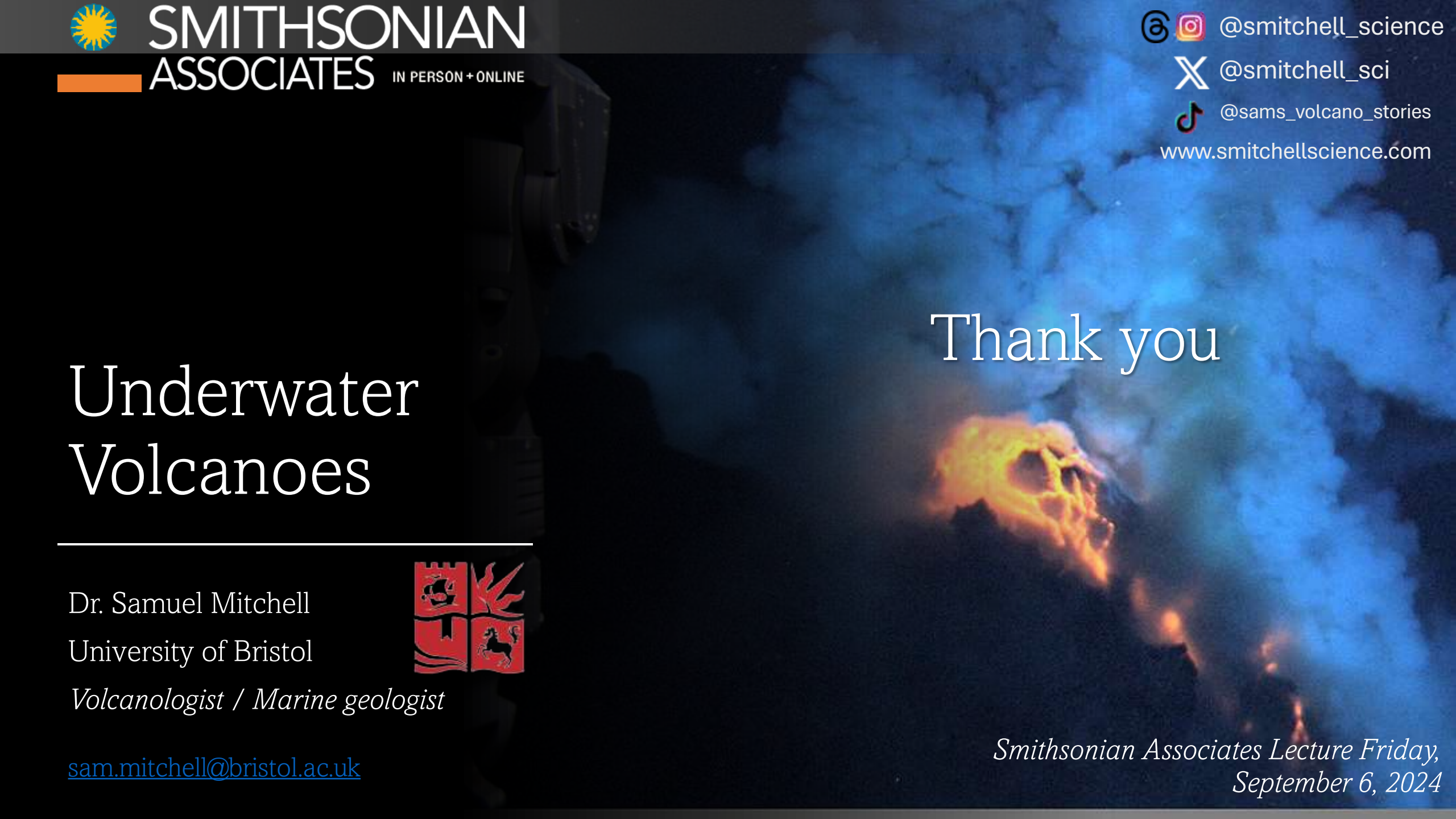

Thank you

Smithsonian Associates Lecture Friday, September 6, 2024