Supplementary Information for

Widespread submarine volcanic eruptions and tectonics revealed in the northwest Pacific Ocean

Juan Zhu[1], Lianxing Wen[2*]

[1]Laboratory of Seismology and Physics of Earth's Interior, School of Earth and Space Sciences, University of Science and Technology of China; Hefei, 230026, China.

[2]Department of Geosciences, State University of New York at Stony Brook; NY 11794, USA.

[*]Correspondence to: Lianxing.Wen@stonybrook.edu (L.W.)

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Supplementary Note 1 | Hydroacoustic data

We use continuous hydroacoustic data recorded from 1 January, 2010 to 13 December, 2022 by the H11 hydrophone array located near the Wake Island of the Northwest Pacific Ocean (Supplementary Fig. 1). The H11 hydrophone array is operated by the CTBTO and consists of two hydrophone subarrays (H11N and H11S) separated by about 135 km. Each subarray is equipped with three hydrophone stations situated in a triangle of a 2.0-km spacing (Supplementary Fig. 1). Hydrophones are moored in the SOFAR channel axis at water depths of 731 m (H11N1), 732 m (H11N2), 729 m (H11N3), 750 m (H11S1), 742 m (H11S2) and 726 m (H11S3) (Supplementary Fig. 1). Hydrophone sensors have a flat frequency response from 10 Hz to 100 Hz and a sampling rate of 250 Hz[1]. Data are band-pass filtered between 6 Hz and 60 Hz in accordance with the frequency character of the signals typically associated with submarine volcanic activity[2-5] while minimizing potential noise contamination in other frequencies from ocean microseism[6], marine mammal vocalization[7], and commercial shipping[8].

Supplementary Note 2 | Elimination of air-gun shot sources and other disturbed sources

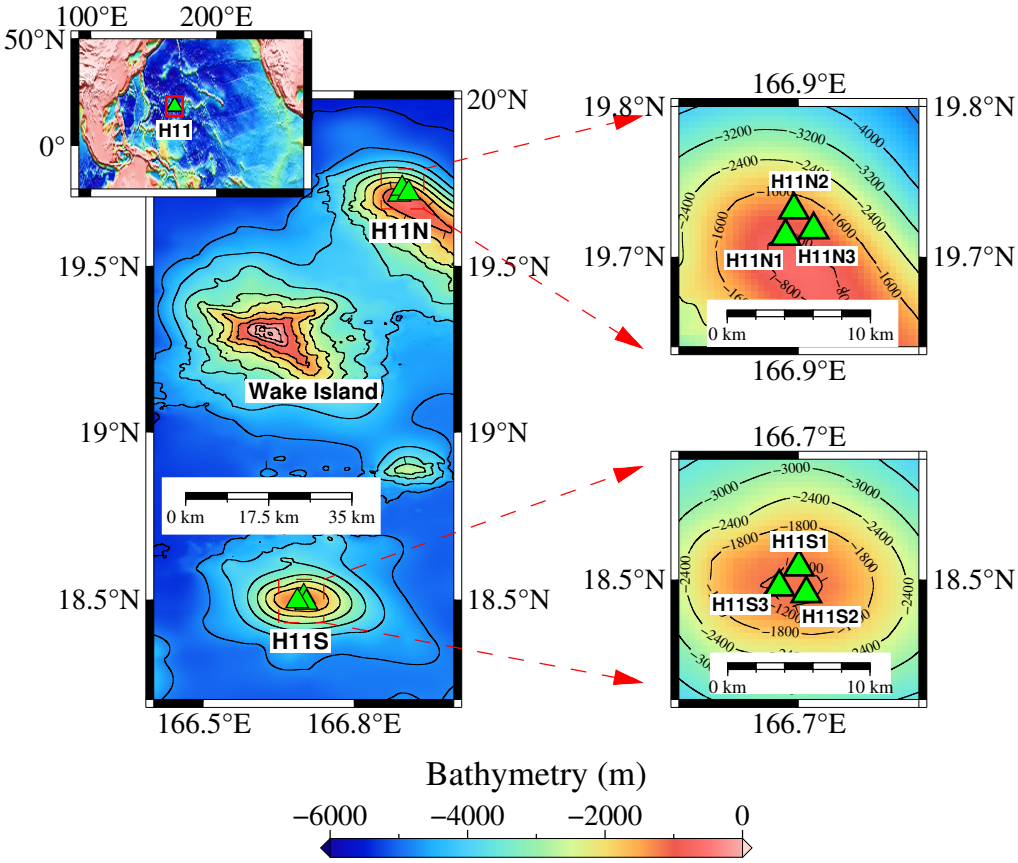
Air-gun shot sources are underwater anthropogenic explosive sources in the shallow water that could last for tens of hours with usually a fixed time interval between consecutive signals (Supplementary Fig. 4)[9,10]. They satisfy the discriminant criteria for an explosive submarine volcanic eruption, with a short and impulsive waveform, and inversed dispersion of frequency, and an irregular slow-decaying spectrum of the recorded signals (Supplementary Fig. 5). Typically, air-gun shot signals exhibit highly similar spectrum and waveforms (Supplementary Fig. 6). We remove the air-gun shot sources based on regularity of the time intervals and similarity of the waveforms between consecutive signals. In the first step, we identify air-gun

shot signals based on the equal time intervals between consecutive signals. If the two time-intervals range in 8-40 s and are equal or multiplicative between consecutive signals in each three subsequent signals, we identify the detected events as air-gun shots and remove them from the detection list. In the second step, we randomly select an identified air-gun shot event as a template and remove the events that have waveform cross-correlation coefficients larger than 0.6 with the template. The templates are selected within each 3-hour from those air-gun shots identified in the first step with a signal amplitude greater than 0.8 times the largest amplitude of all the identified events in the time period.

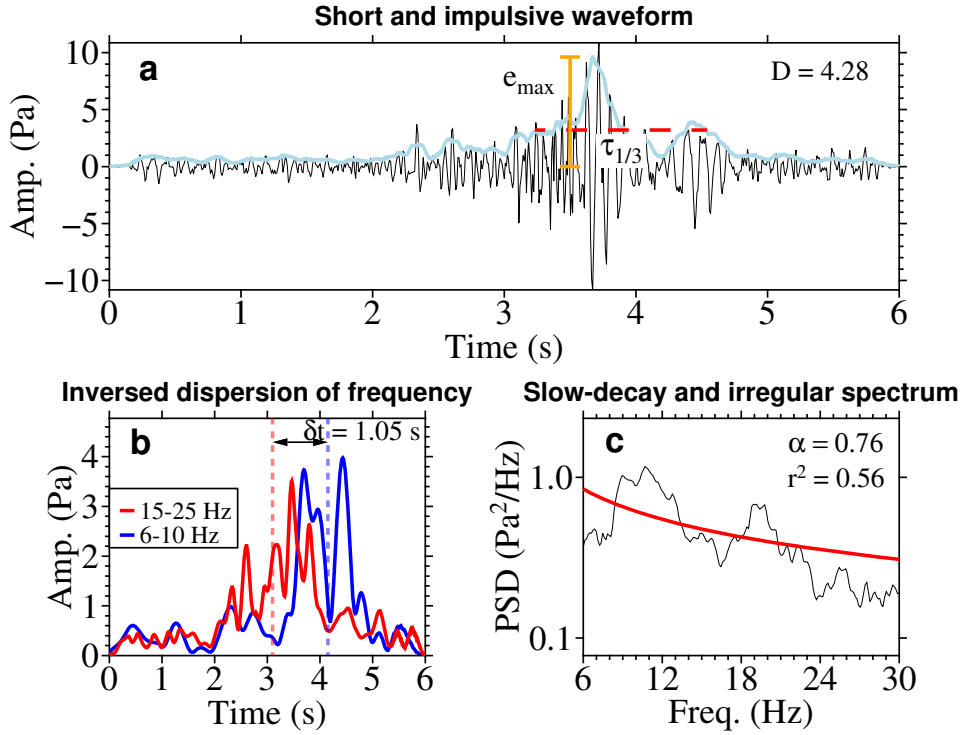
Supplementary Note 3 | Verification of explosive submarine volcanic eruption

There is no spatial or temporal overlap between the detected explosive submarine volcanic eruptions and the reported earthquakes in the catalogs from the U.S. Geological Survey (USGS) and the International Seismological Center (ISC) in the four regions of the Fukutoku-Okanoba, Kaitoku, Ahyi and South Sarigon seamounts. Many detected explosive submarine volcanic eruptions in those four regions can be independently confirmed by the observational eruption evidence of discolored surface ocean water, bathymetry changes, tsunamis, lava flows, pumice rafts and ash-steam plumes. We show an example for the detected Fukutoku-Okanoba submarine volcanoes (Supplementary Fig. 7). Two visible ash-steam plume eruptions and 67 discolorations of water on the sea surface were documented and time-stamped in the Fukutoku-Okanoba submarine volcano region, by vision aerial and satellite observations and pumice rafts conducted by the Japan Meteorological Agency (JMA) during 2010-2022[11-14]. Among the 471 explosive submarine volcanic eruptions detected in Fukutoku-Okanoba (Supplementary Fig. 8a), 300 events occurred within a week from the two observed plumes on 03 February, 2010 and August 15, 2021 and 45 observed events of discolored surface sea water

(Supplementary Fig. 8). The other 171 detected events occurred in the time windows of no collection of visual evidence (Supplementary Fig. 8). There are 22 observed events of discoloration of water with no associated explosive submarine volcanic eruptions detected. In those events, the discoloration of water occurred in small areas, likely caused by small eruptions that escape the detection by the hydroacoustic data. Similarly, more than 88% of the detected explosive submarine volcanic eruptions around Kaitoku, Ahyi and South Sarigon seamounts can also be verified by the observed discoloring events in both the occurring time and geographical location (Supplementary Figs. 9-11).



Supplementary Fig. 1 | H11 hydrophone array used to study explosive submarine volcanoes. Northern and southern subarrays (green triangles) are labeled as H11N and H11S respectively. Regions of red dashed box are enlarged and shown in the right panels with individual hydrophone stations labeled. Left-top inset shows the region (red box) in a broader region of the Pacific Ocean. Background color and black contours show bathymetry[15].



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104 **Supplementary Fig. 2 | Same as Extended Data Fig. 2, except for hydrophone station**

105 **H11S2.**

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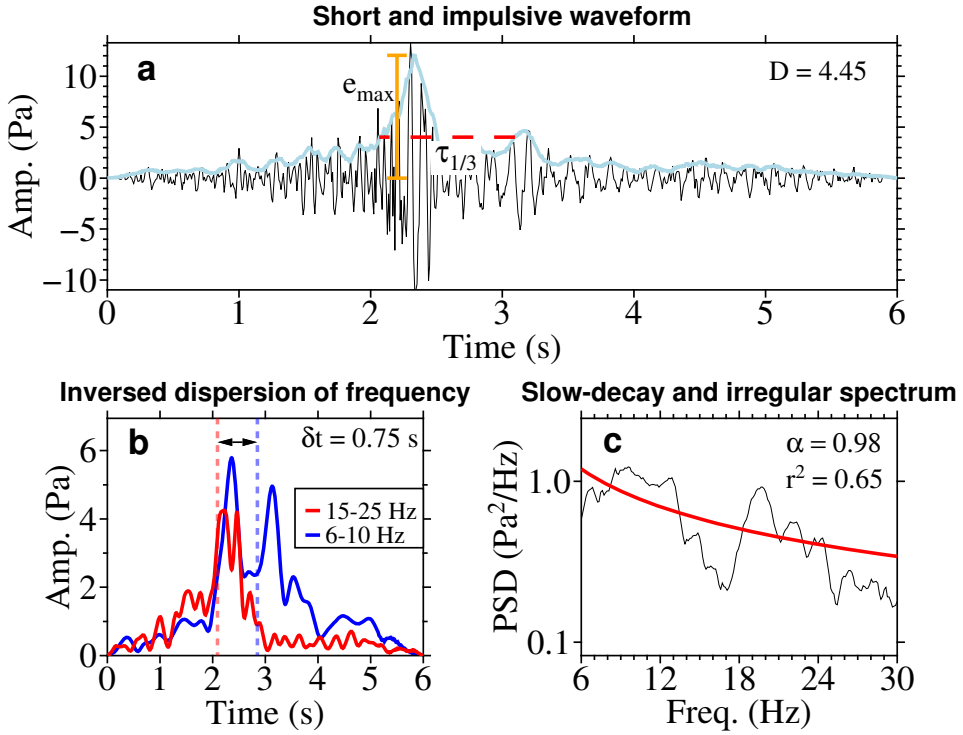

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108 **Supplementary Fig. 3 | Same as Extended Data Fig. 2, except for hydrophone station**

109 **H11S3.**

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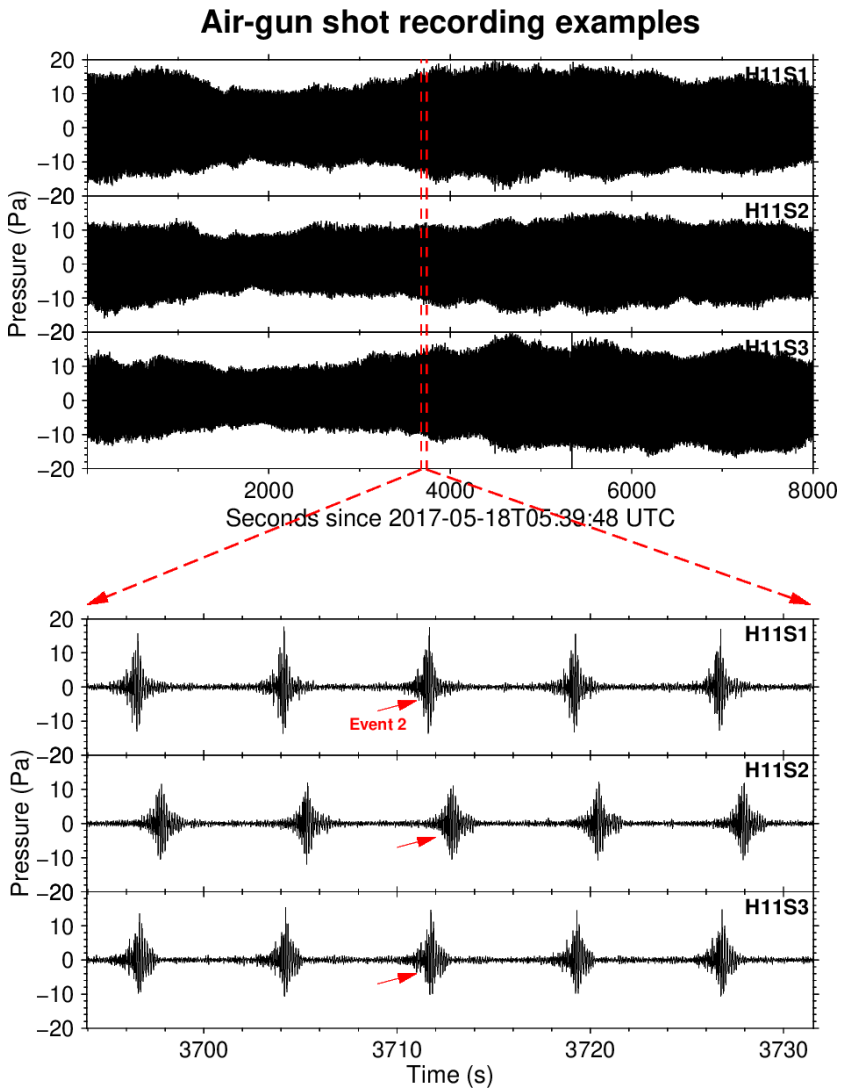

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112 **Supplementary Fig. 4 | Waveform characteristics of air-gun shot signals.** (Top) 8000-s
113 pressure recordings of air-gun shot signals at hydrophones H11S1, H11S2 and H11S3.
114 (Bottom) Enlarged pressure recordings in the time window between the red dashed lines in the
115 top panel. Red arrows in the bottom panel indicate an air-gun shot signal that is used to show
116 its possession of similar seismic discriminants for the detection of an explosive submarine
117 volcanic eruption in Supplementary Fig. 5.

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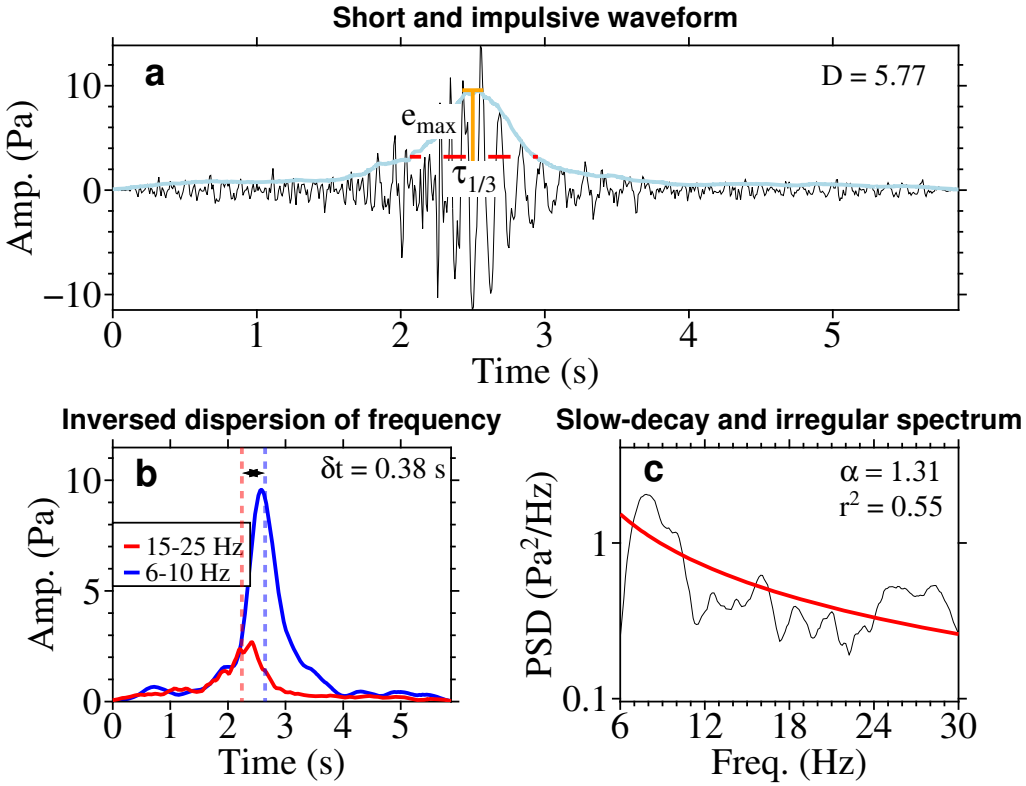

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120 **Supplementary Fig. 5 | Same as Extended Data Fig. 2, except for an example air-gun shot**

121 **indicated in Supplementary Fig. 4.** Note the similarities of seismic discriminants between

122 Supplementary Fig. 5 and Extended Data Fig. 2.

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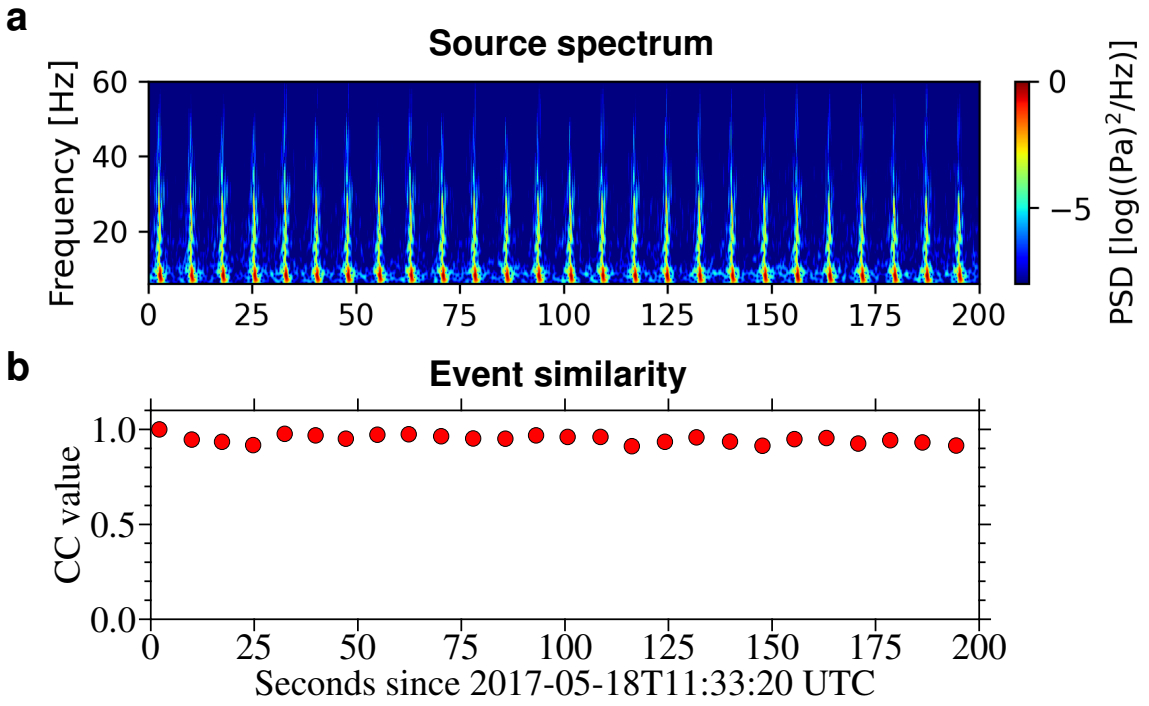
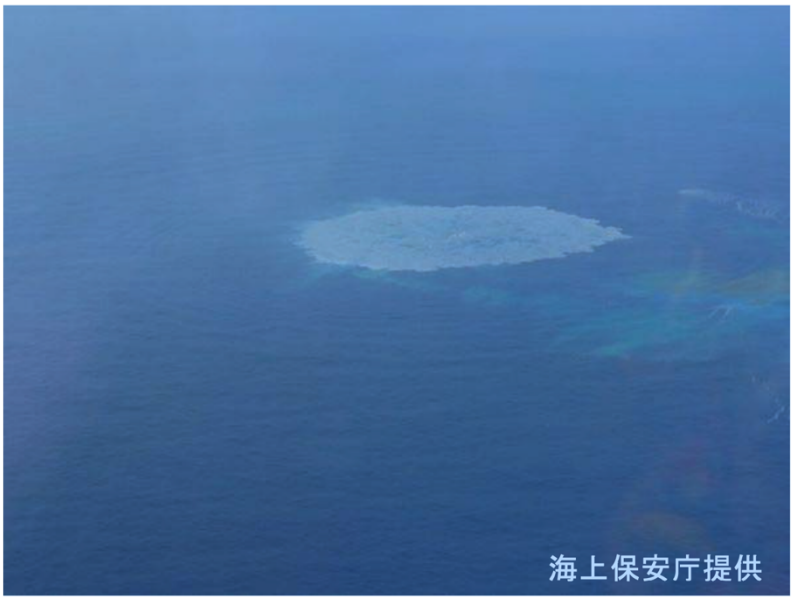
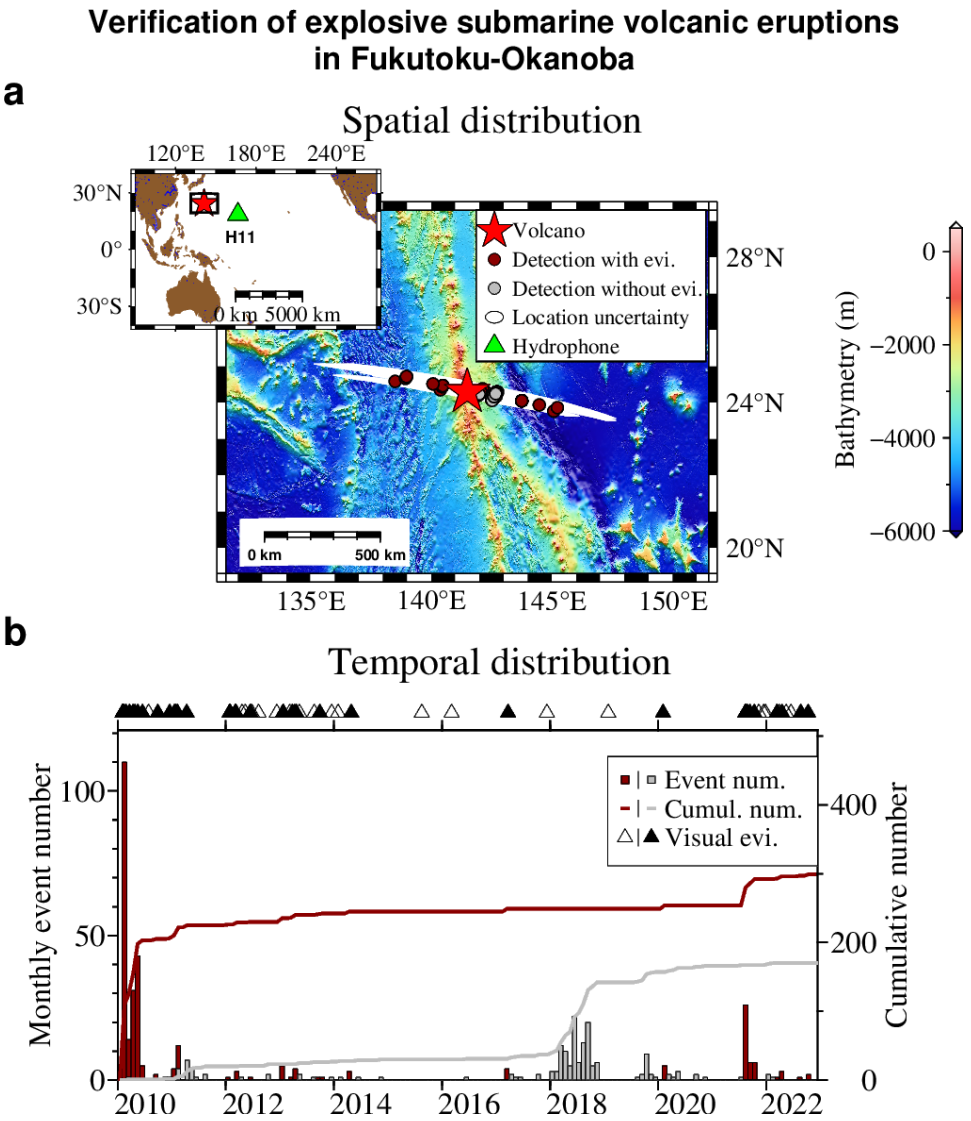


Supplementary Fig. 6 | Source characteristics of air-gun shot signals. (**a**) Source spectrum and (**b**) waveform similarity of example air-gun shot signals taken from 11:33:20 to 11:36:40 UTC, on May 18, 2017. Red dots in **b** represent the cross-correlation values for each signal with the first signal in the time window. Note the similarities of source spectrum and waveforms between air-gun shots.



Supplementary Fig. 7 | Discolored water spreading in a lotus pattern at 04:51 UTC on February 4, 2010 observed by a local flyover photo near the sea surface of the Fukutoku-Okanoba. The source is issued by the Japan Meteorological Agency (JMA).



Supplementary Fig. 8 | Detection and verification of explosive submarine volcanic eruptions of Fukutoku-Okanoba in the northwest Pacific Ocean. a, Locations of the detected explosive submarine volcanic eruptions around Fukutoku-Okanoba (red star), with those of red dots verified by the observed ocean surface coloring and those of gray dots without verifiable ocean surface observation. White ellipses represent errors of the determined locations of the events. The background color marks bathymetry. The left-top inset shows the region (black box) in a broader region with the H11 hydrophone array (green triangle). **b**, Numbers of the detected explosive submarine volcanic eruptions from 2010 to 2022, with the monthly numbers represented by bars (the left vertical axis for scale), and the cumulative numbers represented by curves (the right vertical axis for scale). The bars and curves are color-

147 coded with the dots in **a**. Symbols above the panel indicate the observed visual eruption events,
148 with filled and blank tringles representing visual eruption events with and without associated
149 detections of submarine volcanic eruption within a week of the event.
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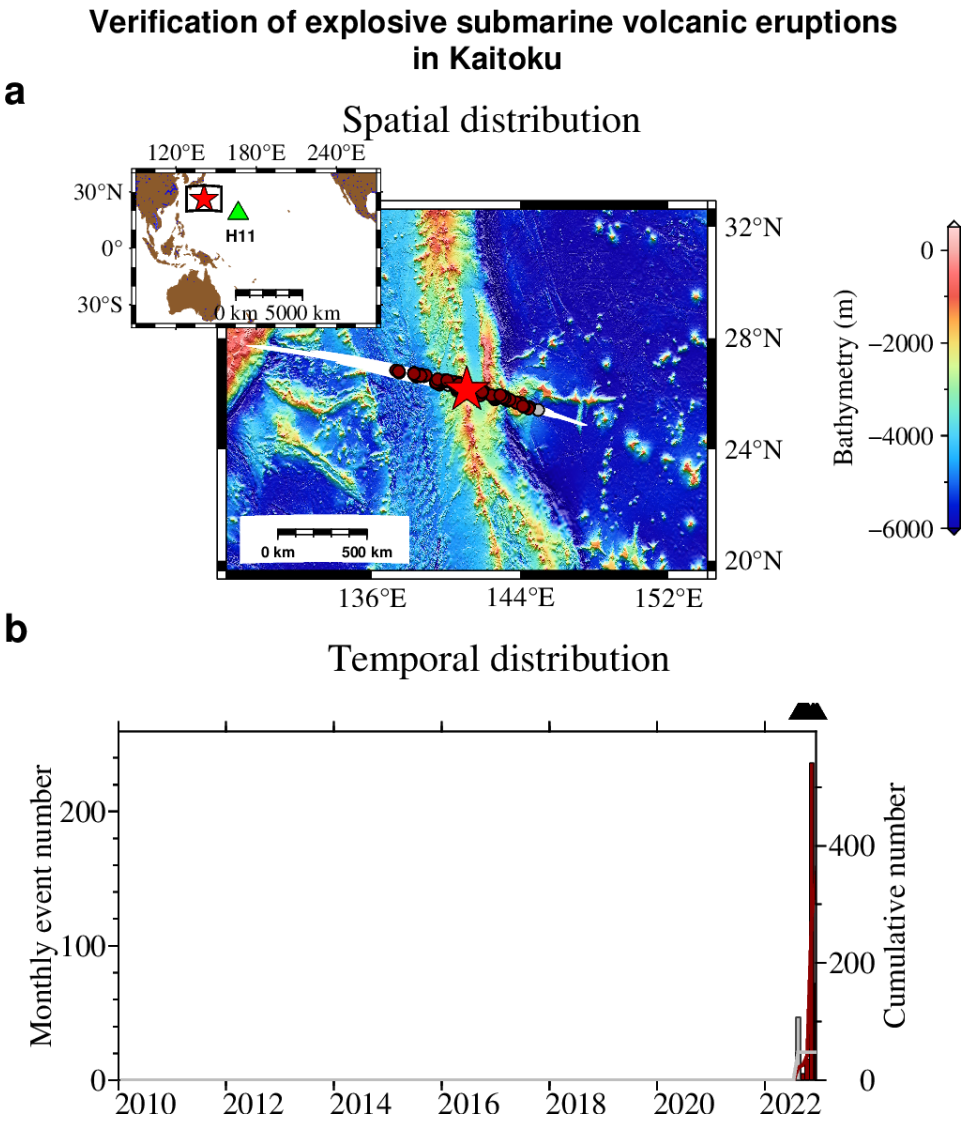
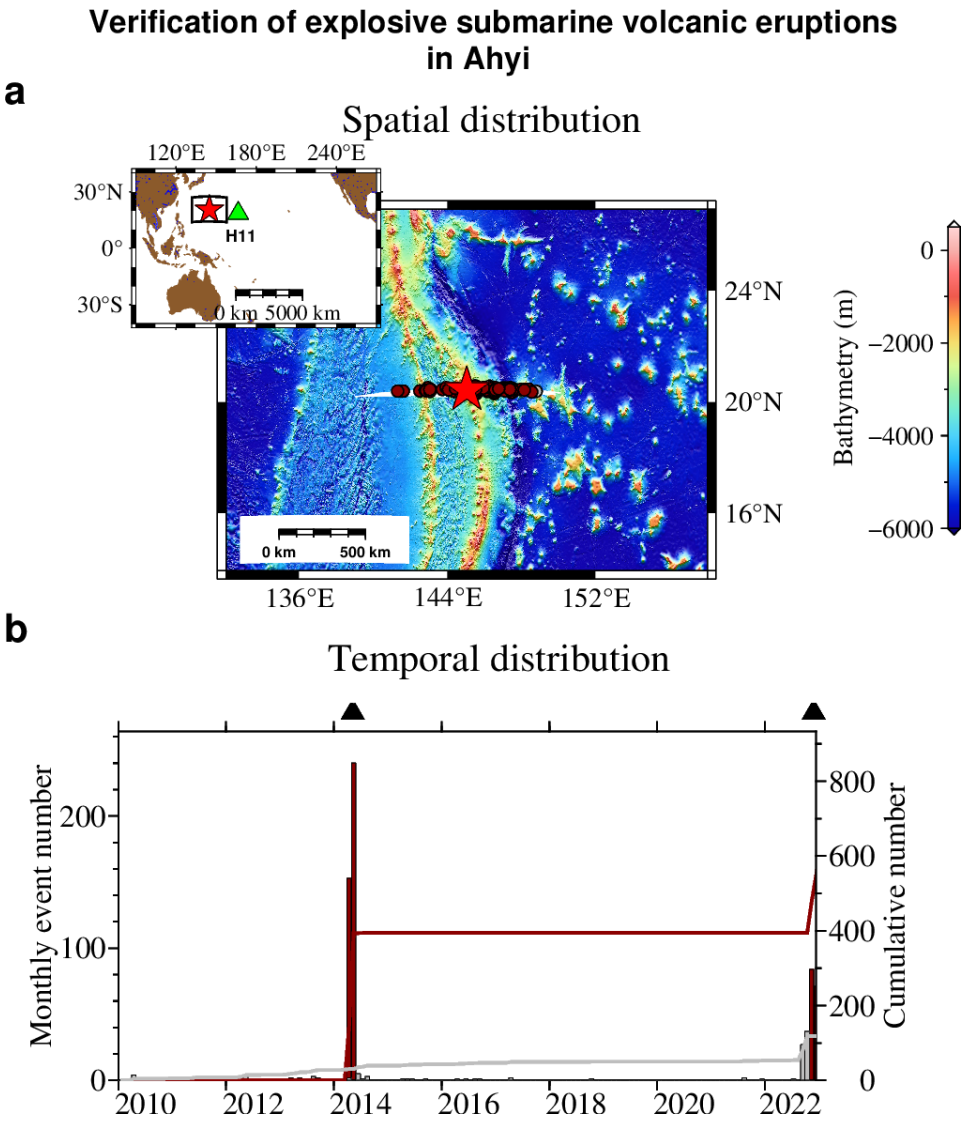
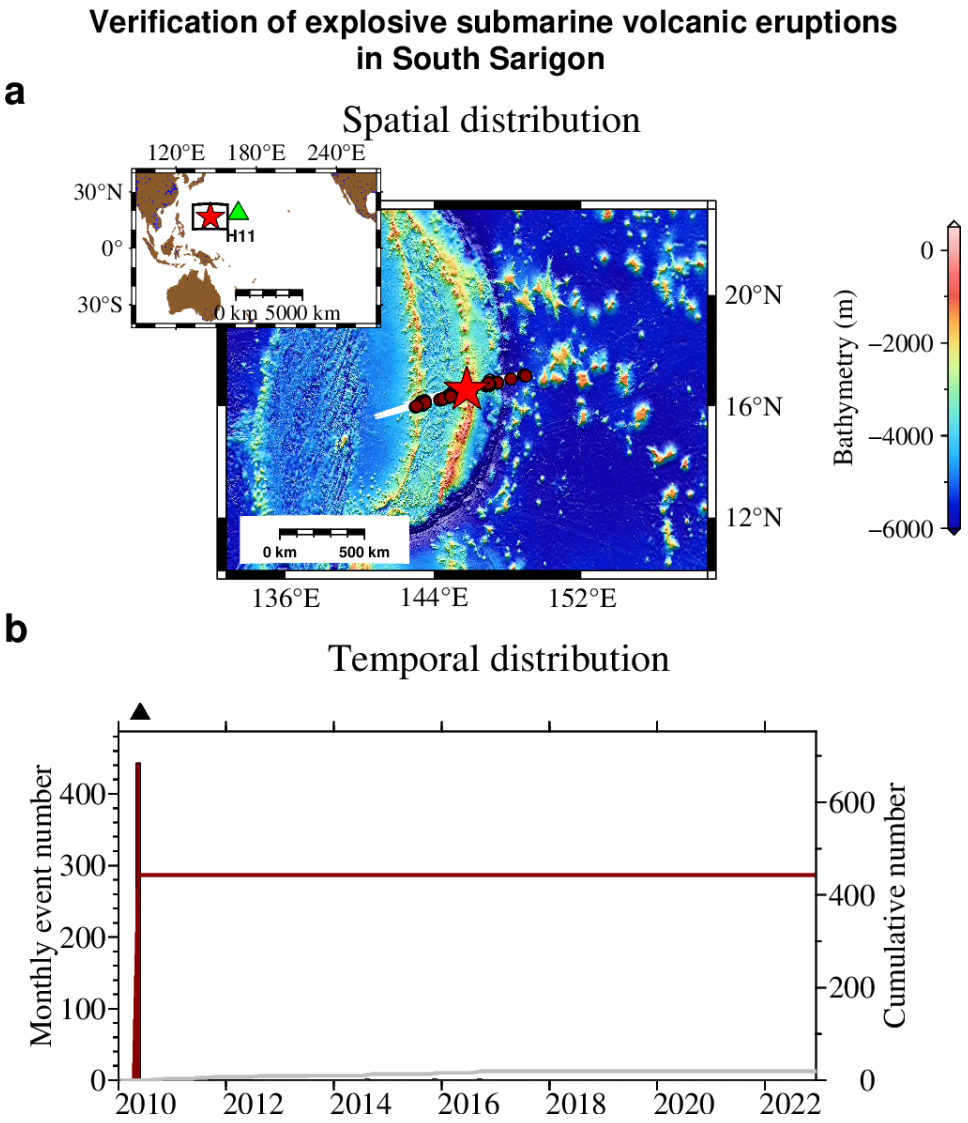


Supplementary Fig. 9 | Same as Supplementary Fig. 8, except for explosive submarine volcanic eruptions in Kaitoku.



Supplementary Fig. 10 | Same as Supplementary Fig. 8, except for explosive submarine volcanic eruptions in Ahyi.



Supplementary Fig. 11 | Same as Supplementary Fig. 8, except for explosive submarine volcanic eruptions in South Sarigon.

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