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— V11B-01 —

Trapdoor faulting at Kita-Ioto Caldera, Japan: Quantification of magma overpressure beneath a submarine caldera

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Five-min. Summary is available on YouTube
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1. Introduction

A *volcanic earthquake* at Kita-Ioto caldera generated a *tsunami wave*. By using the tsunami data, we here attempt to estimate the ***magma overpressure*** that caused the volcanic tsunami.

Study target: Kata-Ioto caldera, south of Japan

- *Kita-Ioto caldera* has been known to be active, but recent volcanic activity is unknown.
- M_w 5.2–5.3 non-double-couple earthquakes, often called *vertical-CLVD earthquakes*, occurred every several years.

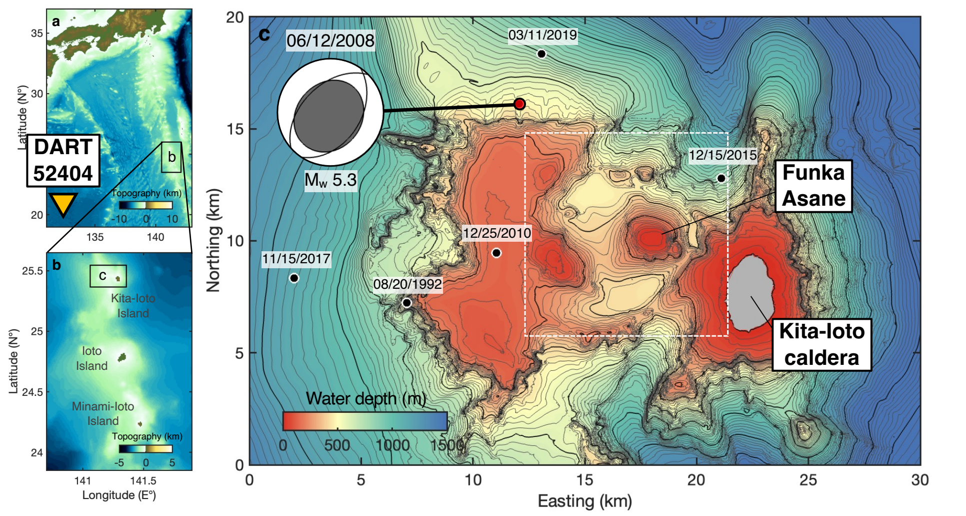

Fig. 1: A vertical-CLVD earthquake near Kita-Ioto caldera, a submarine caldera with a size of 12 km x 8 km near Kita-Ioto Island, in the Izu-Bonin arc. Each dot represents locations of repeating vertical-CLVD earthquakes. The 2008 event is plotted with its focal mechanism reported in the GCMT catalog.

Milli-meter tsunami due to the 2008 earthquake

- Following an M_w 5.3 event in 2008, a *tsunami signal* was recorded by an ocean-bottom-pressure gauge.

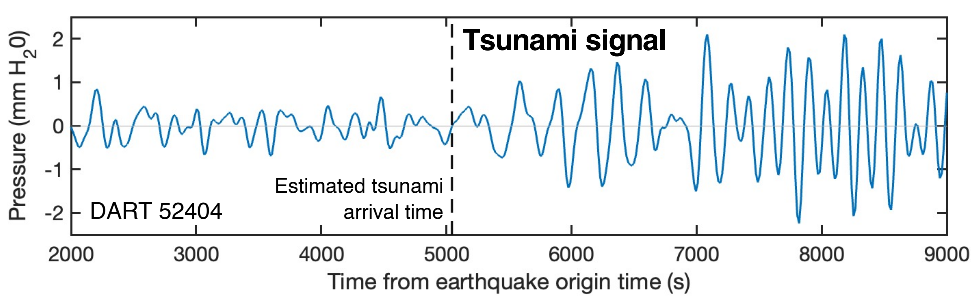

Fig. 2: Tsunami signal from the 2008 Kita-Ioto caldera earthquake, recorded by an ocean-bottom-pressure gauge of the DART 52404 station (orange triangle in **Figure 1a**).

2. Methods: Mechanical model of trapdoor faulting

Hypothesizing the ***trapdoor faulting*** mechanism for the earthquake, we newly develop a ***mechanical model*** of trapdoor faulting to relate the ***magma overpressure*** as a driving force to the ***resultant tsunami***.

Hypothesis: "*Trapdoor faulting* (TF)"

- Recently found at Sumisu caldera.
  1) M_w~5 vertical-CVLD earthquakes
  2) Efficient tsunami generation
  3) Recurrence at a caldera

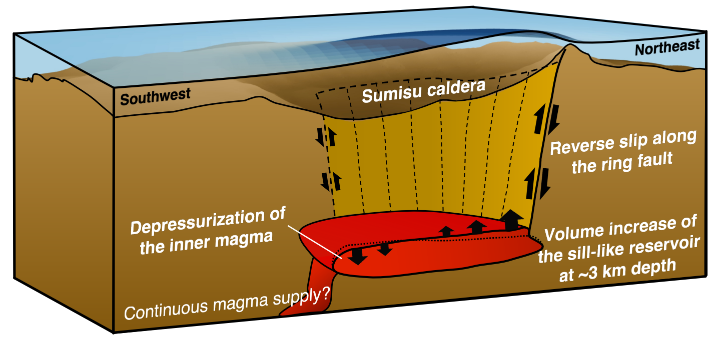

Fig. 3: Trapdoor faulting in Sumisu submarine caldera (Sandanbata et al., 2022).

Model setting

- Stress/dislocation interactions between (1) a ring fault (RF) and (2) a horizontal crack (HC) filled with magma are solved in a 3-D half-space elastic medium by the boundary element method (BEM).

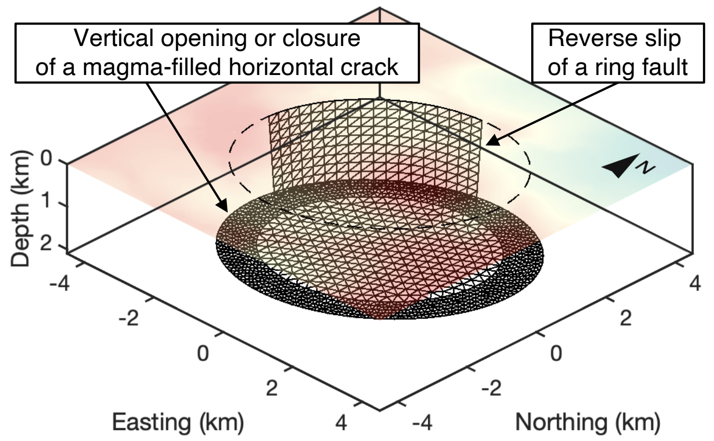

Fig. 4. Source structure of a mechanical model.

What equations to solve?

Assumptions:
I. TF is caused by magma overpressure (p_0)
II. TF occurs with (1) *reverse slip of RF*, $\underline{s}$, (2) *opening and closure of HC*, $\underline{\delta}$, and (3) *magma pressure change*, Δp.

Boundary conditions (BCs): Pre-assuming p_0, BEM determines RF/HC motions ($\underline{s}$, $\underline{\delta}$) and magma pressure change (Δp) during TF.

BC I. On *RF*, *shear stress reduces to zero.*

$$\underbrace{\boldsymbol{\tau}(p_0)}_{\text{Shear stress before TF}} + \underbrace{\boldsymbol{P}\underline{\boldsymbol{s}} + \boldsymbol{Q}\underline{\boldsymbol{\delta}}}_{\text{Change of shear stress during TF}} = \underbrace{\underline{\boldsymbol{0}}}_{\text{Shear stress after TF}}$$

BC II. On *HC*, *normal stress = magma pressure.*

$$\underbrace{\boldsymbol{R}\underline{\boldsymbol{s}} + \boldsymbol{S}\underline{\boldsymbol{\delta}}}_{\text{Change of normal stress during TR}} = \underbrace{(\Delta p)\underline{\boldsymbol{I}}}_{\text{Change of magma pressure during TF}}$$

where $\Delta p = -\frac{1}{V_0\beta_m}\Delta V = -\frac{1}{V_0\beta_m}\sum_k A_k\delta_k$

P, Q, R, S: Interaction matrices that map dislocations of RF/HC into normal/shear stresses on RF/HC, computed by the triangular dislocation method (Nikkhoo & Walter, 2015).
ΔV: HC volume change during TF
V_0: Initial crack volume
β_m: Magma compressibility (here $V_0\beta_m$ = 1.50 m³/Pa)
A: Area of each HC mesh

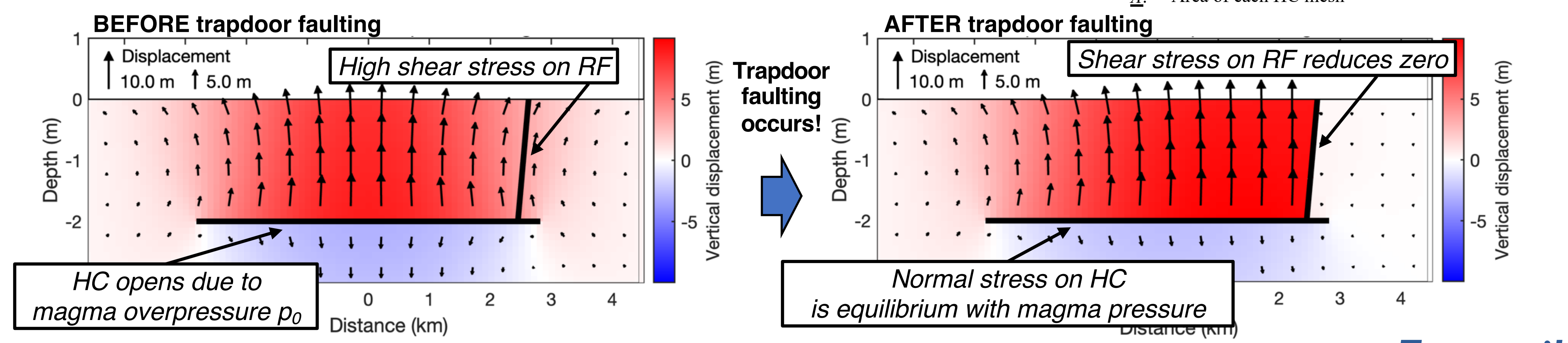

Fig. 5: SE–NW profile of displacement fields in the caldera (left) before and (right) after TF.

3. Results: Source model of the 2008 Kita-Ioto caldera earthquake

By comparing a mechanical-model-predicted tsunami waveform with the tsunami data, we determine the ***TF motions/size*** and the ***magma overpressure*** that caused the TF.

1) ***TF with RF slip of ~9 m*** *explains the tsunami data, as well as seismic data (not shown here).*
2) ***Magma overpressure of p_0~12 MPa*** *is required to cause the TF.*
3) ***Magma pressure drop is Δp_0~2 MPa****, only ~16 % of the overpressure before TF.*

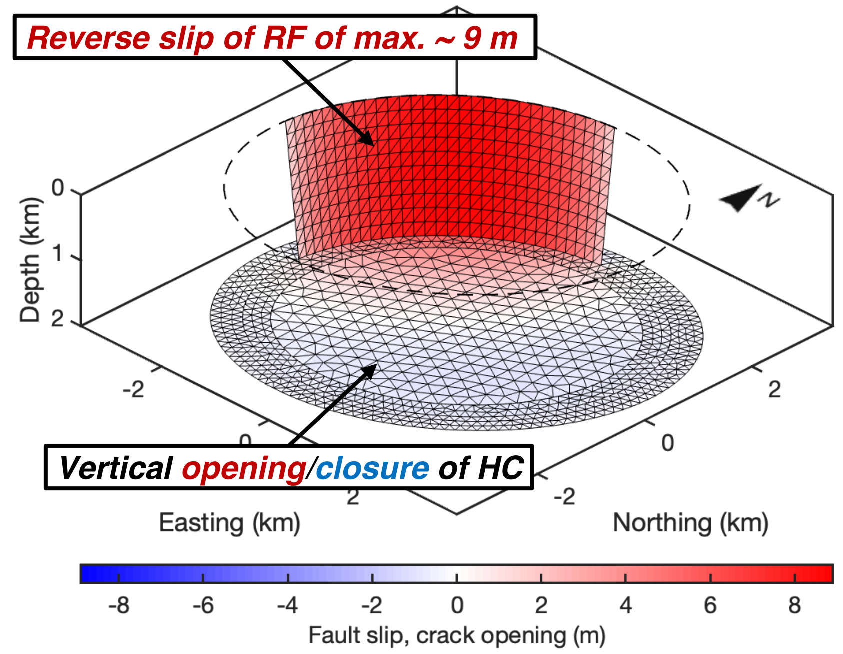

Fig. 6. Mechanical source model of the 2008 Kita-Ioto caldera earthquake constrained by the tsunami data.

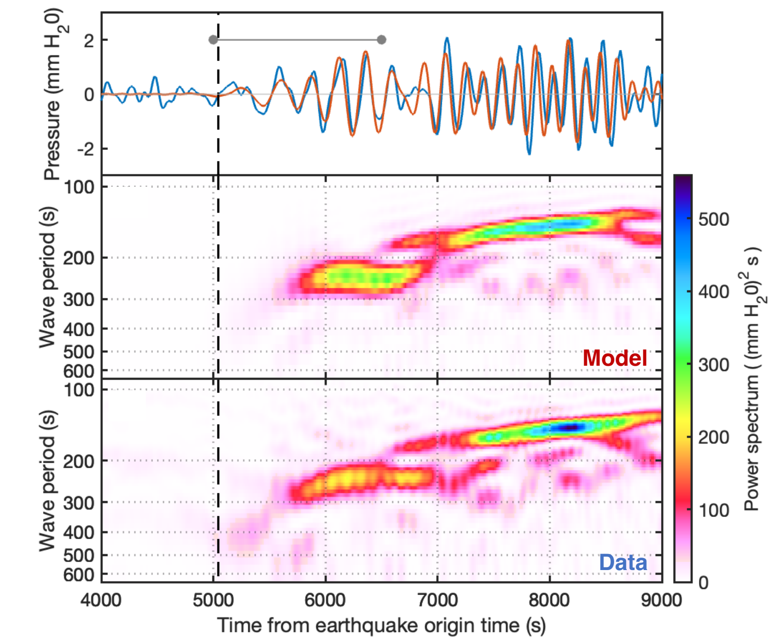

Fig. 7. Tsunami of the model and data: (top) waveforms, and (middle & bottom) spectrograms.

4. Discussion and Conclusions

- Our results suggest that the 2008 earthquake at Kita-Ioto caldera was caused by a trapdoor faulting under water.
- The estimated magma overpressure of >10 MPa shows that magma beneath the caldera was highly pressurized; this overpressure value is comparable to those estimated at Axial Seamount and Sierra Negra when the eruptions initiated (Cabaniss et al., 2020; Gregg et al., 2022).
- A trapdoor faulting reduces the magma overpressure by only 10–20%, suggesting that the potential for volcanic unrest remains high even after a trapdoor faulting.
- Although the estimated values vary depending on assumed source geometries, fault friction laws, and/or magma properties, trapdoor faulting data can be utilized to investigate the physical status of a submarine volcano.

Tsunami data **helps us to estimate remotely** ***the magma overpressure in a submarine caldera***