Volcanic tsunami earthquakes repeating at submarine calderas (1): Physical mechanism

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1. Introduction

Anomalous volcanic earthquakes repeatedly occurred about once every decade at submarine calderas near Torishima Island in Japan (Torishima earthquakes) [e.g. *Fukao et al.*, 2018, Sci. Adv.] and near Curtis Island in New Zealand [*Sandanbata et al.*, 2019, JpGU]. Despite their moderate seismic magnitudes M_w 5-6, the earthquakes generated disproportionately large tsunamis. Their moment tensors were dominated by non-double-couple (NDC) components. Considering their volcanic origin and efficient tsunami excitation, they are called as *volcanic tsunami earthquakes*. The mechanism of these events remains unresolved. Here, we present an overview of this project to determine the physical mechanism and characteristic features of these events. The details of kinematic source modeling will be presented by *Sandanbata et al.* in "Tsunami and tsunami forecast (H-DS08)" session.

2. Physical mechanism inferred from kinematic source model

From the analyses of tsunamis and long-period seismic waves, we successfully constructed a kinematic source model of the 2015 Torishima earthquake (Fig.a). This model can explain quantitatively both tsunami and long-period seismic waves. The model consists of *thrust slip on inwardly down-dipping ring faults extending partially along the rim* and *asymmetric opening and closing of a sub-caldera horizontal fault* (Fig.b). In this model, thrust slip on a partial ring fault is caused by highly-pressurized magma inside a sill-like chamber below the caldera floor. This mechanism is similar to the *trapdoor faulting* observed geodetically at Sierra Negra caldera, Galápagos [e.g. *Jónsson*, 2009, Tectonophysics].

3. Characteristic properties of long-period seismic excitations

We next examine their long-period seismic excitations from this source. It is generally known from seismic excitation theory that the moment tensor components, M_{rt} and M_{rp}, and the volumetric change of a sill-like chamber at a shallow depth do not significantly contribute to seismic excitation [e.g. *Kanamori & Given*, 1981, PEPI]. In addition, the ring-fault slip partially eliminates its long-period seismic radiation due to cancellation of excitations from double-couple (DC) components from different portions of the ring fault [*Ekström*, 1994, EPSL]. These properties not only explain the NDC-type moment tensors of these events but also play an important role in the tsunami earthquake natures. The curved fault geometry focusing deformation just over the caldera also amplifies tsunamis.

We demonstrate that the observable moment tensor components (other than M_{rt} and M_{rp}) reflect source geometries, arc length and orientation of the ring faults. The similarities of the observable source parameters of most of the recurrent volcanic tsunami earthquakes suggest that the trapdoor faulting repeated at an identical ring-fault geometry every decade. This implies that magma recharges into a shallow sub-caldera chamber, which leads to ring-fault ruptures repeating at least for the decades.

4. Conclusions

We propose a physical mechanism of volcanic tsunami earthquakes by constructing their kinematic source models. A similar mechanism is also suggested for the 2017 Curtis earthquake, although we do not refer to the details here. Our model provides new and first evidences of trapdoor faulting at submarine calderas. We also demonstrate that we can study remote active submarine volcanoes using far-field observations of tsunamis and long-period seismic waves from M_w 5-6 earthquakes.

Keywords: volcanic earthquake, caldera volcanism, tsunami, long-period seismic wave, recurrent earthquakes

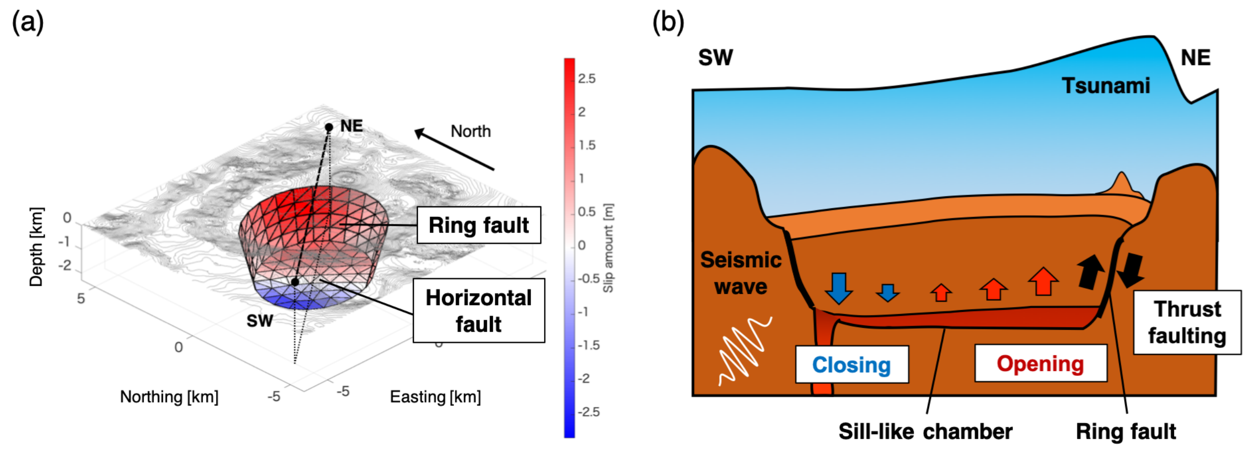

Fig. (a) Kinematic source model of the 2015 Torishima earthquake. Red color represent amount of thrust slips on the ring fault and opening of the horizontal fault. (b) Physical mechanism of volcanic tsunami earthquakes inferred from the kinematic source model.

