Volcanic tsunami earthquakes repeating at submarine calderas (2): Kinematic source modeling of the 2015 Torishima earthquake

*Osamu Sandanbata[1], Shingo Watada[1], Kenji Satake[1], Hiroo Kanamori[2], Luis Rivera[3], Zhongwen Zhan[2]

1. Earthquake Research Institute, the University of Tokyo, 2. California Institute of Technology, 3. Université de Strasbourg, CNRS, IPGS UMR 7516, F-67000 Strasbourg

1. Introduction

Almost every decade, v*olcanic tsunami earthquakes* occurred at a submarine volcano named Smith Caldera near Torishima Island in Japan (Torishima earthquakes). These earthquakes generated disproportionately large tsunamis for their seismic magnitudes (M_w 5-6) [e.g. *Fukao et al.*, 2018, Sci. Adv.]. In order to determine their physical mechanism, we constructed a kinematic source model based on analyses of tsunamis and long-period seismic waves. Here, we present the detail of kinematic source modeling of the 2015 Torishima earthquake. The overview of the project, including the physical mechanism, characteristic seismic properties, causes of tsunami earthquake nature and similarities of recurrent earthquakes, will be presented by *Sandanbata et al.* in "Active Volcanism (S-VC45)" session.

2. Hypothetical fault systems inferred from initial sea-surface displacement

We started the kinematic source modeling of the 2015 Torishima earthquake by estimating the initial sea-surface displacement around Smith Caldera by the tsunami waveform inversion. We used tsunami waveforms recorded at ocean-bottom pressure gauges deployed in the southern oceanic region of Japan, such as a temporary array [*Fukao et al.*, 2018], DONET, the Deep Sea Floor Observatory off Muroto Cape, and the DART system. We found (1) a large uplift concentrated just over the caldera floor, and (2) clear peripheral subsidence at least along the northern side of the rim structure.

Based on the results, we hypothesized a sub-caldera fault system composed of ring and horizontal faults (Fig.a). In the following sections, we examine whether the hypothetical fault system explains both tsunami and long-period seismic records. We also investigate the detailed fault geometries employing multiple fault models with variable fault parameters (i.e. depth of the horizontal fault, dip angle and length of the ring fault).

3. Inversion of tsunami waveforms for slip distributions of sub-caldera ring and horizontal faults

We determined slip distributions on the sub-caldera ring and horizontal faults from the tsunami records by applying a new efficient technique for computing tsunami Green's functions from subfault slips. In most cases, inverted slip distributions consist of *thrust slip on an inward-dipping ring fault* and *asymmetric opening and closing of a horizontal fault* (Fig.a).

The slip distributions on the multiple fault models accurately reproduce the tsunami records (Fig.b), indicating that these are plausible models for explaining tsunami excitation of the Torishima earthquake. However, if the ring fault extends to a horizontal fault lying at a depth of about 4 km below the caldera floor, slip direction of the ring fault becomes opposite between the upper and lower half portions, which we consider unrealistic. Hence, we believe that the horizontal fault lies at a shallower depth of approximately 2 km.

4. Forward modeling of long-period seismic waves from slip distributions

Finally, we investigated the plausibility of the slip models by comparing long-period seismic records at the F-net and GSN stations with their synthetic waveforms. Among the slip models, one with a ring fault with a 75° dip angle extending along an approximately three-quarter portion of the rim structure can best reproduce the observed long-period seismic waves (Fig.c). The waveforms of horizontal components and overall amplitude are sensitive to dip angle and length of the ring fault, respectively. This helps us to constrain the detailed fault parameters well.

5. Conclusion

We concluded that the slip model thus obtained can explain quantitatively both tsunami and long-period seismic records, and is a good kinematic source model of the 2015 Torishima volcanic tsunami earthquake. The source model consists of *thrust slip on inwardly down-dipping ring fault extending partially along the rim* and *asymmetric opening and closing of a sub-caldera horizontal fault* is attributed to the *trapdoor faulting* at the active submarine caldera.

Keywords: volcanic earthquake, tsunami, long-period seismic wave, tsunami waveform inversion, tsunami earthquake

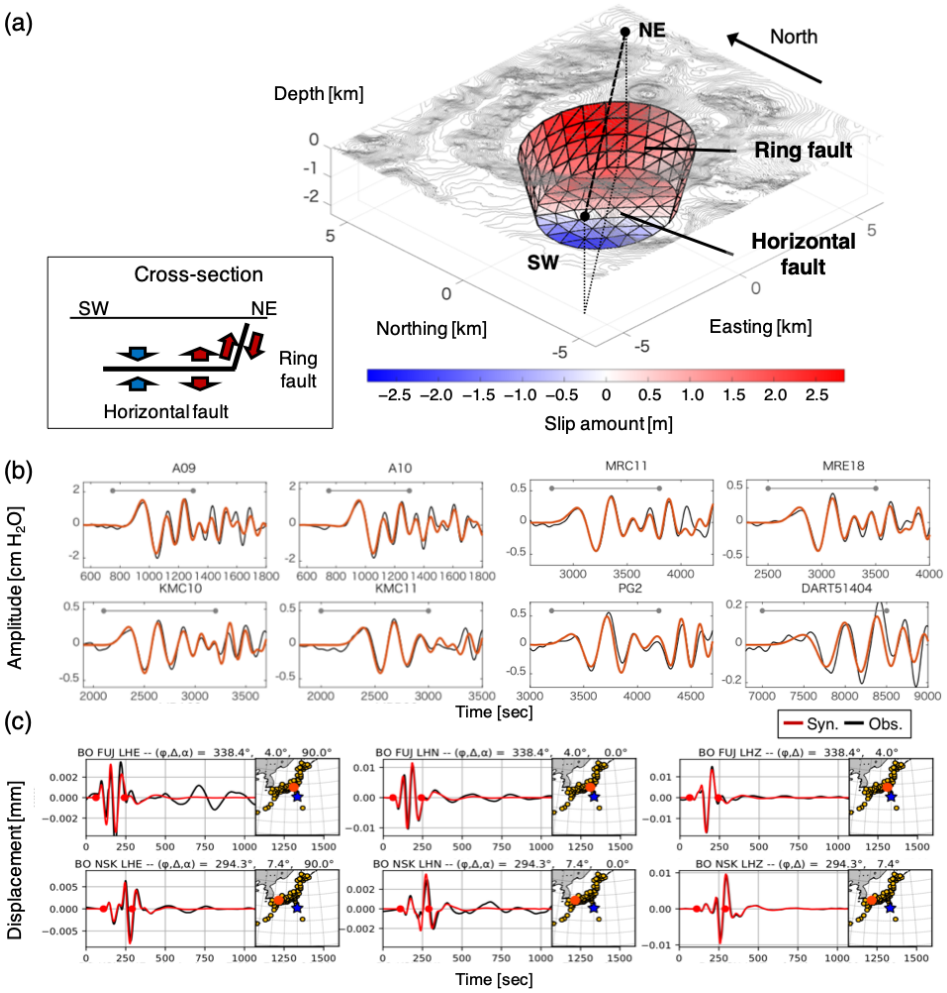

Fig. (a) Kinematic source model of the 2015 Torishima earthquake. Red color represents amount of thrust slips on the ring fault and opening of the horizontal fault. (b) Tsunami waveforms. (c) Long-period seismic waveforms.

