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“Foreshock migration preceded mainshock rupture of the 2016 Kumamoto earthquake: slow slip spread toward the mainshock fault”

Beginning in April 2016, a series of shallow moderate- to large-magnitude earthquakes and associated strong aftershocks struck the Kumamoto area of Kyushu, SW Japan. A Mw 7.0 mainshock occurred on 16 April 2016 (JST) close to the epicenter of a Mw 6.2 foreshock that had occurred ~28 hours earlier on 14 April. To deepen our understanding of stress interactions between the foreshock and subsequent mainshock ruptures, we investigated the spatio-temporal evolution of seismicity preceding the mainshock rupture, as well as geodetic deformation observed near the foreshock source area.

To more precisely characterize the evolution of the earthquake sequences, we applied a phase matching technique to continuous waveform data recorded at seismometers located in central Kyushu. Migrations of seismicity fronts along the directions of fault strike and dip are clearly seen, starting immediately after the Mw 6.2 foreshock. These migrations are interpreted to result from slow (aseismic) slip transient triggered by the foreshock, propagating towards the nucleation point of the subsequent Mw 7.0 mainshock rupture. The occurrence of aseismic slip is supported by transient surface displacements observed by high-rate GNSS data close to the foreshock area, following the Mw 6.2 foreshock rupture. When combined with static stress changes induced by the Mw 6.2 foreshock, it is likely that stress transfer from both aseismic and seismic slip modes during the foreshock sequence loaded stress onto the mainshock rupture faults, bringing them closer to failure.

References :
-Kato, A., J. Fukuda, S. Nakagawa and K. Obara, Foreshock migration preceding the 2016 Mw 7.0 Kumamoto earthquake, Japan, Geophys. Res. Lett., doi: 10.1002/2016GL070079, 2016.
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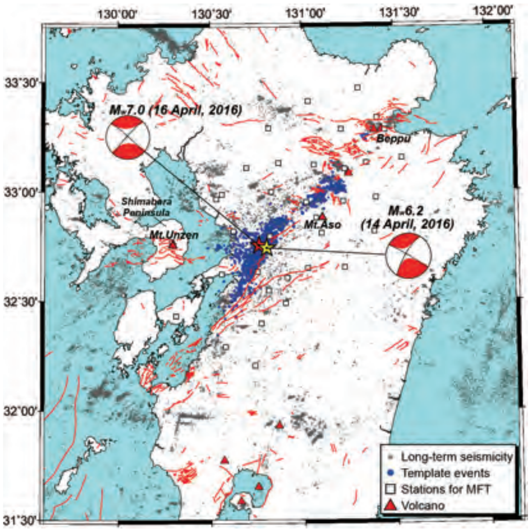

Fig.1 : Seismotectonic setting of central Kyushu, Japan. The foreshock and mainshock hypocenters of 14 and 16 April 2016 are respectively denoted by the yellow and red stars. Major active faults are denoted as red lines, and active volcanoes as red triangles. Permanent seismic stations used in the present study are shown by open squares. Events used for the analysis are shown by blue circles; long-term background seismicity is shown by gray dots.

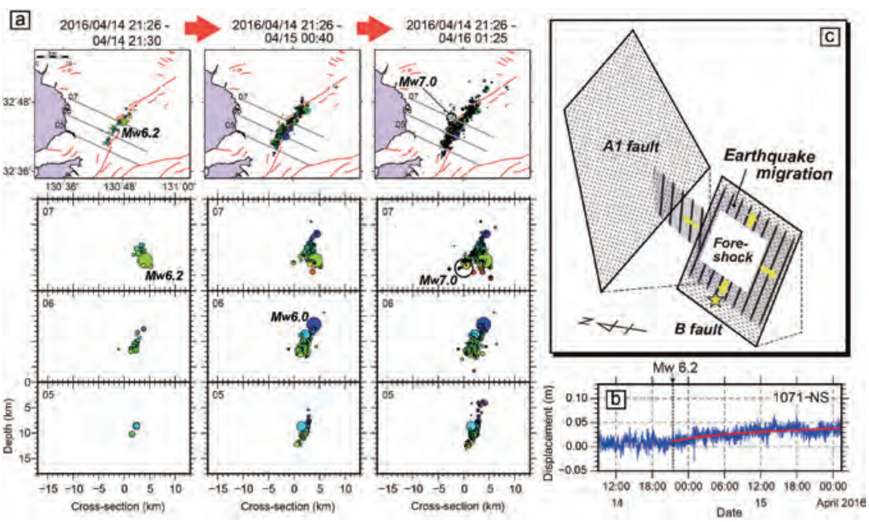

Fig.2 : a. Spatio-temporal evolution of seismicity during the period between the foreshock and mainshock ruptures. Plots of the cumulative distribution of epicentral locations over time, in map view and cross-section, are shown in the top and bottom panels, respectively. b. Time-series of surface displacement recorded at nearby GNSS station (north–south component). The foreshock origin time is denoted by the dashed line. c. Perspective view of foreshock slip and aseismic slip propagation on the mainshock rupture planes. The yellow star denotes the initiation point of the mainshock rupture.

CONSTRUCTION OF A LONG-BASELINE LASER STRAINMETER: BEYOND THE LIMIT OF CONVENTIONAL OBSERVATIONS

In seismology and geodesy, ground motions are measured using various methods, such as seismometers and global navigation satellite systems (GNSS). Using strainmeter is another method to observe ground strain changes by measuring distance between two points with a reference of length. Laser interferometers are sometimes used as strainmeters to ensure the accurate reference of length with a frequency stabilized laser and the high resolution of distance measurement using laser interferometry. We have constructed a 1500-m laser strainmeter, the longest geophysical laser strainmeter to our knowledge, at an underground site in Kamioka, Gifu Prefecture, Japan. The km-scale baseline is expected to average out local disturbances that have been noise sources of 10-m to 100-m-scale laser strainmeters and thus improve accuracy of strain measurement.

Fig.1 shows the location and a picture of the laser strainmeter. The site is a part of underground facilities of the Institute for Cosmic Ray Research (ICRR), University of Tokyo, and the baseline is in parallel with one arm of the KAGRA gravitational-wave telescope. Fig.2 (a) shows the optical layout of the laser strainmeter, which has 1500m separation between the mirrors. A sample interference fringe is shown in Fig. 2 (b).

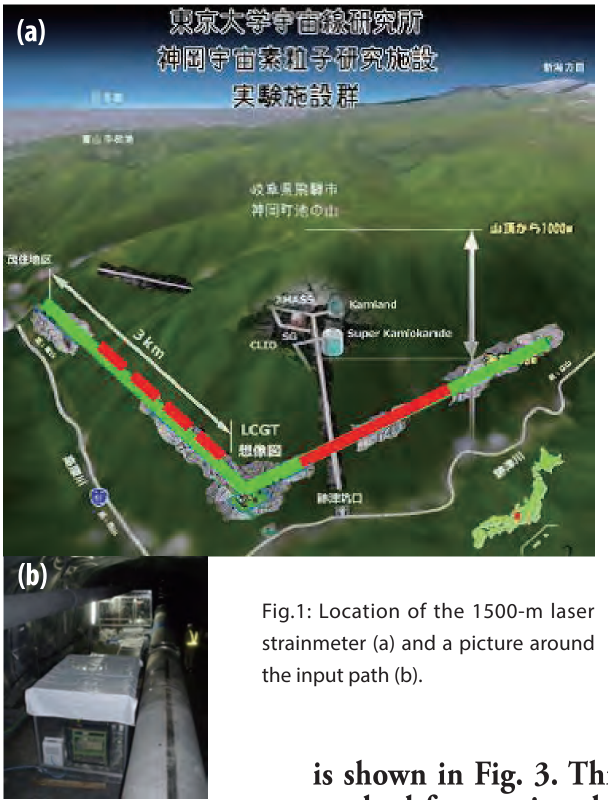

Fig.1: Location of the 1500-m laser strainmeter (a) and a picture around the input path (b).

Operation of the laser strainmeter started in August 2016. As of August 2017 we have confirmed the reduction of the background noise to a sub pico-strain level in the millihertz region, 13% reduction of tidal amplitude by topographic effect. Further the coseismic strain steps associated with earthquakes are in agreement with the fault mechanism. An example of strain waveforms of an earthquake with earth tides is shown in Fig. 3. This strainmeter provides a new method for precise observation of ground motions on seismic, geodetic and intermediate timescales.

References:
-A. Araya, et al., Design and operation of a 1500-m laser strainmeter installed at an underground site in Kamioka, Japan, Earth, Planets and Space 69:77, 2017.
-K. Somiya, Detector configuration of KAGRA -the Japanese cryogenic gravitational-wave detector, Class. Quantum. Grav. 29: 124007, 2012.

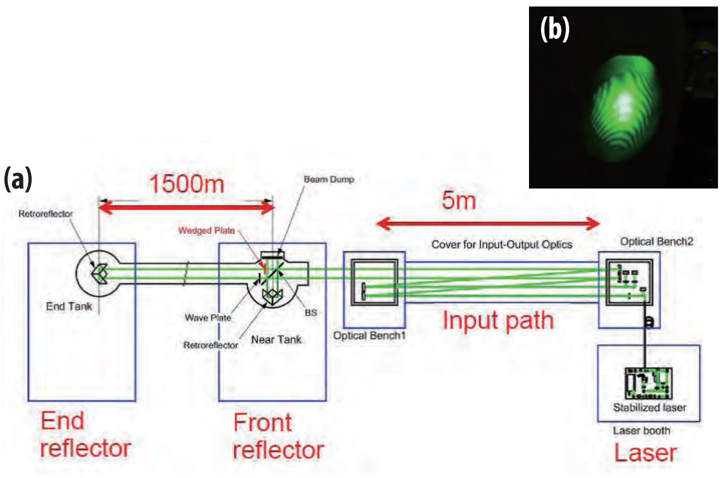

Fig.2: Optical layout of the strainmeter (a) and the interferometer fringe (b).

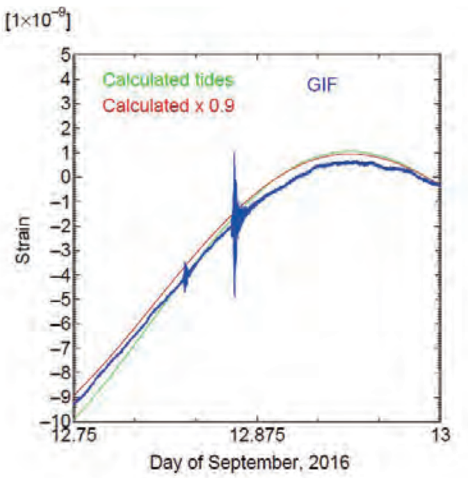

Fig.3: Strain waveforms of earth tides (calculation with (red) or without (green) topographic correction) and seismic waves (blue) associated with two earthquakes in South Korea occurred at 10:44:33 (UTC, M4.9) and 11:32:54 (UTC, M5.4) on September 12, 2016.

Volcanic eruption in Nishinoshima island

A new volcanic islet had been growing up with lava effusion and Strombolian activities at Nishinosima, Izu-Bonin arc, since November 2013. Before this eruption, Nishinoshima was a small island of the area of 0.29 km^2 and elevation of 25 m, but it had a huge edifice rising of 3000 m from the seafloor. By March 2016, area and elevation reached 2.7 km^2 and 140 m, respectively (GSI). The evolution of Nishinoshima had been monitored based on airborne observations and satellite images [see Fig.1]. The eruption activities have been continuously monitored using Ocean Bottom Seismometers (OBS). The number of eruptions gradually declined and finally ceased by the end of November 2015. After the volcanic activity falling to a low level, we conducted a research survey of volcanology and bionomy at Nishinoshima from 16th to 25th of October, 2016. The investigation team conducted a geological survey, installed seismic station, and surved nidification of seabirds. Further, the pre-installed OBSs were recovered and new OBSs and Ocean Bottom Electromagnetometers (OBEM) were installed around Nishinoshima. A monitoring system of remote volcanic island using WaveGlider was operated around Nishinoshima on a trial basis. An analysis of whole rock chemical composition of the lava and the fallout rocks of 2013-2015 eruption reveals that all samples are composed of andesite with SiO_2 content of 59.5-59.9wt%. This value lies in between the SiO_2 contents of an undated older eruption and the content of 1973-1974 eruption. After one and a half year quiescence, a new eruptive phase started in April, 2017. On April 20, Japan Coast Guard confirmed the new eruption by airplane observation. Our on-land seismic sensor detected precursory signals as early as April 17. The seismometer also recorded characteristic waveforms during the very early stage of the new eruption phase, before the data transmission was terminated on April 21.

Based on recent satellite observation, the surface thermal temperature of Nishinoshima had been gradually descending since beginning of July 2017, and reached to ambient level by the early part of August. The lava flow also had stopped by August 24.

We will continue with our study on the growing process of volcanic islet together with geological and geophysical knowledges based on further analyses of volcanic products and those of OBS and OBEM data.

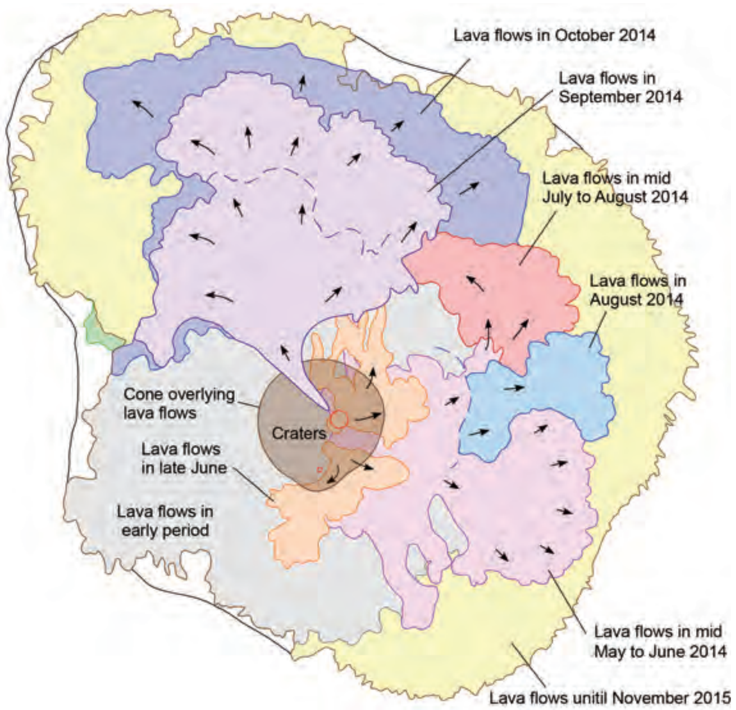

Fig.1:Evolution of Nishinoshima based on airborne observations and satellite images.

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