Supplementary materials for

“Midcrustal moderate-size earthquake occurrence in paleovolcanic structures off Jeju Island, South Korea”

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**Introduction**

This supporting information provides additional materials and figures.

**Additional information**

The Korean Peninsula is located in the northeastern margin of the Eurasian plate (Fig. S1). The Korean Peninsula experienced temporal seismicity changes since the 2011 $M_W$ 9.0 Tohoku-Oki megathrust earthquake (Fig. S2). A series of moderate-size earthquake occurred after the the 2011 $M_W$ 9.0 Tohoku-Oki megathrust earthquake (Fig. S3). The 14 December 2021 $M_L$ 4.9 Jeju offshore earthquake occurred in an offshore region between the southern Korean Peninsula and southern Japanese islands (Fig. S1).

Seismic waveforms for the 14 December 2021 $M_L$ 4.9 Jeju offshore earthquake present $P$ and $S$ arrivals over the distances of 600 km (Fig. S4). A series of aftershocks follow the mainshock. The aftershocks are detected using a matched-filter analysis (Fig. S5). The focal depths of the mainshock and aftershocks are 8-19 km, mostly 12-16 km, suggesting midcrustal events (Fig. S6(a)). The magnitudes of most aftershocks are less than $M_L$ 2.0 (Fig. S6(b)). The seismicity density is high in the northwestern and western regions off Jeju island before the mainshock (Fig. S7). The mainshock and aftershocks occurred in a region of outskirt of southwestern high-seismicity region off Jeju island. The seismicity density distribution is consistent among events with different magnitudes.

We determine the magnitudes of aftershocks detected from a matched filter analysis. The magnitudes are determined using a magnitude-amplitude relationship (Fig. S8). We derive a linear relationship between magnitude and logarithmic amplitude ratio:

$$M_L = 3.2 + 0.74 \log(\gamma),$$  \hspace{1cm} (1)

where $M_L$ is a magnitude in local magnitude scale, and $\gamma$ is the amplitude ratio for
the reference waveform. The mainshock and aftershocks are relocated using a hypocentral inversion method (Fig. S9). The error ellipses for probability of 68 % suggest high accuracy. Also, the relocated locations by a double difference method (hypoDD) reasonably fit within the error ranges.

The mainshock produced strong ground motions around Jeju island and southwestern peninsula (Fig. S10). The contours of ground motions display N-E directional oval distribution, suggesting preferential amplification in NE. The ground motion distribution produces a similar form of dynamic stress changes (Fig. S11). Strong dynamic stress changes occur around the southwestern Jeju island which corresponds to the aftershock region. The observed large local ground motions are consistent with seismic amplification feature that is combined feature of crustal and shallow-medium amplifications (Fig. S12).
Figure S1. Tectonic structures around the Korean Peninsula. The coseismic displacements by the 11 March 2011 $M_W$ 9.0 Tohoku-Oki megathrust earthquake are presented.
**Figure S2.** Comparison of seismicity between before and after the 2011 $M_W$ 9.0 Tohoku-Oki earthquake. The spatial distribution of earthquakes is similar between before and after the megathrust earthquake.
Figure S3. (a) Major seismic events since 2000 on a seismicity density map. The major seismic events include earthquakes with magnitudes $\geq M_L 4.9$ and earthquake swarms. (b) Seismicity since 2000 in the Korean Peninsula. The major seismic events including earthquake swarms are indicated. Mid-to-lower crustal earthquakes and moderate-size earthquakes increased since the 2011 $M_W 9.0$ Tohoku-Oki earthquake (T).
Figure S4. Seismic waveform records for the 14 December 2021 $M_{L}$4.9 Jeju offshore earthquake: (a) radial, (b) tangential, and (c) vertical components. The theoretical $P$ and $S$ arrival times of the mainshock are marked. The seismic waveforms are filtered between 0.1 and 30 Hz.
Figure S5. Example of event detection using a matched filter analysis: (a) the 15 December 2021 $M_L1.0$ earthquake, (b) the 17 December 2021 $M_L1.2$ earthquake, (c) the 18 December 2021 $M_L1.3$ earthquake, and (d) the 26 December 2021 $M_L1.4$ earthquake. The seismic waveforms of detected events are compared with those of the reference event.
Figure S6. Distribution of (a) focal depths and (b) magnitudes of the mainshock and aftershocks. The earthquakes occurred in midcrust. The magnitudes of most aftershocks are less than $M_L 2.0$. 
Figure S7. (a) Seismicity density maps of events with magnitudes $\geq M_{L} 0$ (a) before, (b) after the mainshock, and (c) for the whole period. Those for events with magnitudes $\geq M_{L} 2.0$ (d) before, (e) after the mainshock, and (f) for the whole period. Those for events with magnitudes $\geq M_{L} 2.4$ (g) before, (h) after the mainshock, and (i) for the whole period. The normalized seismicity density (C) is presented. The mainshock and aftershock occurred in the southwestern offshore region.
Figure S8. Derivation of magnitude scaling relationship with respect to amplitude ratio. The local magnitude scaling function as a function of amplitude ratio is derived from observed data.
Figure S9. (a) Relocation of mainshock and aftershocks based on a hypocentral inversion method (VELHYPO). Error ellipses with probability of 68 % are presented. (b) Comparison of relocated event locations between two methods (VELHYPO, hypoDD). The differences are less than 2 km for most events.
Figure S10. Spatial distribution of (a) peak ground accelerations (PGAs) on bedrock in (a) EW, (b) NS, and (c) vertical components. Peak ground velocities (PGVs) on bedrocks in (d) EW, (e) NS, and (f) vertical components. The PGAs and PGVs present NE-directional oval distribution.
Figure S11. Spatial distribution of dynamic stress changes on bedrock in (a) EW, (b) NS, and (c) vertical components. The dynamic stress changes are high around the Jeju island and southwestern peninsula.
Figure S12. Spatial distribution of (a) seismic intensity anomalies and (b) shear-wave velocities up to a depth of 30 m ($V_{S30}$) in the Korean Peninsula. Strong seismic amplification is observed in the southwestern and southern peninsula. The seismic amplification is low in the central peninsula. The $V_{S30}$ is low along the coast, and is high in the eastern peninsula where the mountain belt develops.