Spatial variations in shallow slow earthquake activity associated with a subducted ridge in Hyuga-nada, southwest Japan

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Slow earthquakes, such as tremors and very low frequency earthquakes (VLFEs), have longer characteristic durations than regular earthquakes and occur mainly around the seismogenic zones on the plate boundary. Hyuga-nada, off the Kyushu Island, is the most active slow earthquake region around Japan (e.g., Baba et al., 2020). The tectonic regime in Hyuga-nada is characteristic; historical earthquakes with Mw >8 have not been reported and the Kyushu-Palau Ridge is subducted. In Hyuga-nada, shallow tremors and VLFEs were observed in previous studies (Yamashita et al., 2015; 2021; Asano et al., 2015) and their activity can be associated with the subducted ridge. In this study, we quantitatively investigated the spatial distribution of slow earthquake activity in Hyuga-nada and discussed the tectonic environment characterizing slow earthquakes.

For the tremor analysis, we applied a band-pass filter of 2–8 Hz to ocean bottom seismometer records in 2013 and 2015, calculated the root-mean-square envelope, and estimated energy rates of tremors detected by Yamashita et al. (2015; 2021). We also estimated seismic moments and source durations of VLFEs in 2010 detected by Asano et al. (2015) and those which correspond to tremors in 2013 and 2015 by comparing synthetic and observed NIED F-net waveforms in a frequency range of 0.02–0.05 Hz.

The characteristics of spatial variation in tremor energy rate and VLFE moment are similar. We focused on the episodes in 2010 and 2013 when tremors and VLFEs migrated on a large scale along the strike direction from 30.3ºN to 31.7ºN at a depth of ˜10 km. According to tremor energy rate, VLFE moment, and their migration speed, slow earthquake activity in the along-strike migration can be classified in areas of the south (30.3ºN–31.0ºN) and inside (30.3ºN–31.0ºN) of the subducted ridge. The average VLFE moment is 2.4×10^{15} Nm and 5.6×10^{14} Nm in the south and inside of the subducted ridge, respectively. The migration started at ˜80 km/day and decelerated to ˜30 km/day in the north of 31.0ºN after entering the area with the subducted ridge in 2013.

The difference in average VLFE moment and migration speed between inside and south of the ridge can be explained by the models of Ando et al. (2012) and Kano et al. (2018). Assuming the same patch size, the stress drop of VLFEs is expected to be larger in the south of the ridge than that inside the ridge based on a circular crack model. Based on Ando et al. (2012), inside and south of the ridge are considered as weak and strong patch areas, respectively. There is a low velocity anomaly suggested by Nishizawa et al. (2009) around the plate boundary in the south of the ridge. We interpret that this low velocity anomaly corresponding to the strong patch area indicates fluid in the overriding plate migrated from the plate boundary (c.f. Kano et al., 2018); therefore, the pore pressure on the plate boundary can be lower. Thus, the effective normal stress on the plate boundary can be higher and the strength of the patches can be stronger in the south of the ridge than inside the ridge. By the existence of low velocity anomaly and variations in migration speed and event size, the heterogeneity of effective normal stress associated with the location of the ridge on the plate boundary is suggested in Hyuga-nada.

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