論文の内容の要旨

Spatiotemporal characteristics of slow earthquakes in subduction zones around Japan

（日本周辺の沈み込み帯における スロー地震の時空間特性の研究）

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Slow earthquakes, observed on plate boundaries in subduction zones or strike-slip faults, have longer and more various characteristic durations than regular earthquakes. Although there are many previous studies of slow earthquakes, the data and methods vary by area and there are few studies analyzing slow earthquakes around Japan comprehensively. Hence, comparison of slow earthquake activity in various regions and discussion of the factors which control the spatiotemporal variations in slow earthquake activity is difficult. To reveal the factors which affect slow earthquake activity based on physical models, simulations, or structural studies, I first detected very low frequency earthquakes (VLFEs), which is a type of slow earthquakes and observed in 0.02–0.05 Hz, as a representative of slow earthquakes around Japan in a uniform method and quantified the spatiotemporal variations in VLFEs on a regional scale. This is the first study which quantified spatiotemporal distribution of VLFE activity around Japanese islands by evaluating the moment-density release rate and the swarm ratio.

I detected VLFEs by the matched-filter technique by using synthetic waveforms as templates. I used continuous seismograms of F-net broadband seismometers. I calculated cross-correlation coefficients (CCs) between the synthetic template and F-net seismograms and detected events with the station- and component-averaged CCs exceeding the threshold set as nine times the median absolute deviation. After that, I estimated the seismic moment of each VLFE and evaluated the spatiotemporal variation in the moment-density release rate of VLFEs. As a result, the heterogeneity of spatial distribution of VLFEs is much stronger in the shallower part than in the deeper part. The moment-density release rate of shallow VLFEs off the Cape Muroto and off the Kii Peninsula is negatively correlated with interplate coupling derived from the distribution of the sip-deficit rate. This suggests that VLFEs tend to be less active near the strongly coupled zones. The negative correlation suggests that the interplate coupling is weak in Hyuga-nada, where the moment-density release rate of VLFEs is large. Furthermore, VLFEs tend to be active in low seismic velocity anomalies which can be caused by fluids. Thus, fluids can potentially promote VLFE activity.

Temporal variations in VLFE activities are categorized into three patterns: activation after a large earthquake, quiescence after a large earthquake, and repetition of swarm activities and quiescence. Inside a large coseismic slip area of the 2011 Tohoku earthquake (Mw 9.0), the VLFE activity was low thereafter, whereas, outside the area, VLFE activity increased after the 2011 Tohoku earthquake probably caused by their afterslip. VLFE activity is related to interplate coupling and afterslip of large earthquakes, thus VLFE activity can be an indicator of stress state on the plate boundary. To quantify the characteristics of repetition of swarm activities and quiescence of VLFE activity, I estimated swarm ratios of VLFEs and median intervals of two successive swarms. Swarm ratios of shallow VLFE activity are generally larger than those of deep VLFE activity. The intervals of swarms in shallow VLFEs are very various from 8 months to 4 years. Based on simulation or structural previous studies, the difference in intervals of shallow VLFE swarms may be related to the spatial variations in the effective normal stress on the plate boundary. The variation in VLFE activity is larger in the shallower part than in the deeper part both spatially and temporally.

The moment-density release rate of VLFEs in Hyuga-nada, off the Pacific coast of Kyushu Island, is especially larger than other slow earthquake regions. In addition, the relationship between VLFE activity and the subducted Kyushu-Palau Ridge can be discussed in Hyuga-nada. Therefore, I conducted a detailed analysis of slow earthquake activity in Hyuga-nada to reveal the factor which controls the spatial variation in slow earthquake activity on a local scale. I estimated the energy rates of tremors by using the seismograms of temporary ocean bottom seismometers in Hyuga-nada. I also evaluated the moment rates of VLFEs using F-net seismograms. Generally, energy rates of tremors and moment rates of VLFEs are larger outside the subducted Kyushu-Palau Ridge than inside the ridge, although there is an area with larger events in the updip part of the inside of the subducted ridge in 2015. Total moments of VLFEs are larger in the south of the subducted ridge, where interplate coupling is expected to be weaker inferred from the slip rate of repeating earthquakes. Although interplate coupling in Hyuga-nada is generally weaker than other slow earthquake regions, the correlation between interplate coupling and VLFE activity is also found on the local scale in Hyuga-nada.

Tremors and VLFEs start migrating in the south of the ridge with large energy rates and moment rates along the strike direction and decelerate after entering the area where the Kyushu-Palau Ridge is subducted. Based on a model by Newtonian rheology, the south and inside of the ridge are considered as strong and weak patch areas, respectively. There is a low velocity anomaly around the strong patch area. According to the physical and observation models, the low velocity anomaly can exist in the overriding plate. The dehydrated fluids can go into the overriding plate; 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 is stronger in the south of the subducted ridge. If a circular crack model is assumed, the stress drop of VLFEs is approximately four times larger in the south (strong patch) than inside (weak patch) the subducted ridge. The approximately four times difference in stress drop between strong and weak patches in Hyuga-nada is sufficient to cause the parabolic migration pattern, which is explained by the effect of Newtonian rheology in the ductile background. Although the interplate coupling inferred from repeating earthquake activity is stronger, the strength of the patches is inferred to be weaker inside the ridge than in the south of the ridge. Inside the subducted ridge, the portion of the accumulated stress released by regular interplate earthquakes adjacent to slow earthquakes may be large. On the other hand, most of the accumulated stress is released by slow earthquakes in the south of the ridge, where the interplate coupling is weaker and the strength of the slow earthquake patches is suggested to be stronger. This study revealed the spatial variation in sizes of tremors and VLFEs in Hyuga-nada. The heterogeneity of stress drop suggested by the difference in the magnitude of VLFEs can control the migration pattern of slow earthquakes based on a physical model. This study suggested the variation in the style of stress release on the plate boundary inside and in the south of the subducted ridge.