論文の内容の要旨

Tidal sensitivity of tectonic tremors and frictionally heterogeneous fault model

(深部低周波微動の潮汐応答性と摩擦不均質断層モデル)

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Several modes of shear slip on the fault have been recognized since modern research on earthquakes began in Meiji era. Regular earthquakes repeatedly brought devastating hazard to Japanese society for many times. Geodetic measurements revealed the ground deformation lasting for many years after large regular earthquakes, called afterslip. Tsunami sometimes hits the coast without large ground shaking, which is categorized as tsunami earthquake. Furthermore, recent dense seismic and geodetic observation networks revealed a new type of shear slip on the plate interface named slow earthquakes, which have a different scaling relation from regular earthquakes. Ground deformation lasts for several years accompanying tiny seismic signals both in high frequency and low frequency. The discovery of slow earthquake in 21st century forced us to realize that shear slip behavior on the plate interface is much more diverse than expected. Understanding its physical mechanism is important not only for the pure earthquake science, but also for the sake of exploring the possibility of probabilistic hazard forecasting. For this purpose, I have worked on data analysis of slow earthquakes during my PhD course. Many parameters characterizing slow earthquake activity have been quantified. Correlations between these parameters should provide constraints on the physical mechanism of shear-slip diversity. I have also conducted numerical simulation of seismic rupture as a first step to construct the unified seismic source model, which can explain diverse slip behavior.

Slow earthquake activity varies among subduction zones and even within an individual subduction zone. The spatial heterogeneity of tectonic tremor activities, which is a high-frequency seismic signal of slow earthquake, has been quantified in various ways mainly in Nankai and Cascadia subduction zones. In this thesis, three parameters are focused; duration, amplitude, and tidal sensitivity of tectonic tremors. As a result, it has been confirmed that tremor occurrence rate is exponentially sensitive to tidal stress in the entire slow earthquake zone as observed by previous studies, which implies that the plate interface is governed by the rate and state friction law. Furthermore, tidal sensitivity of tremors is higher for short-duration tremors. Increases of tidal sensitivity have been also observed after large-amplitude tremors occur. Correlations between these parameters can be qualitatively explained by a model, which is extended from models proposed by previous studies, in which the frictional heterogeneity on the plate interface is important.

Previous studies showed that the frictionally heterogeneous fault model have potential to explain both regular earthquakes and slow earthquakes. Therefore, slip behavior of the frictionally heterogeneous infinite linear fault governed by the rate and state friction law has been examined with numerical simulations to investigate how it changes with the frictional heterogeneity. Results show that slip behavior transits according to the spatial average of a-b value on the fault. When the spatially averaged a-b is positive, seismic slip is limited within a velocity-weakening zone on the fault. On the other hand, when the spatial average of a-b value is negative, the entire fault including velocity-strengthening zones slip seismically. At this transition where the spatial average of a-b is close to zero, slower deformation dominates during seismic events, which may correspond the slow earthquakes.

The seismicity of regular earthquakes, such as the maximum earthquake size or statistical parameter, has been compared among subduction zones in the field of comparative subductology. Quantifications of tremor activities made by the first half of this study enable this comparison of comparative subductology for slow earthquakes. As a result of comparisons, the constraint for the source model of slow earthquake has been obtained. The latter half of this thesis models the frictionally heterogeneous fault, which could qualitatively explain the observation of data analysis, revealing the slower deformation dominated by complex interactions between seismic slip and aseismic slip on the fault. Although there is still a long way to go, diverse slip behavior on the plate interface may be explained by the frictional heterogeneity on the fault, which should reflect tectonic environments. Construction of this model will provide us a new tool to search the relation between tectonic environment and earthquake genesis.