

Toward understanding generation mechanism of crustal earthquakes based on accumulation/release of elastic strain energy

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Although the physical process of interplate earthquakes has been modeled from the viewpoint of accumulation and release of shear stress on plate boundaries, it is difficult to apply the framework directly to cycles of crustal (inland) earthquakes. It is necessary to assume a fault plane to obtain shear stress in a stress field, but the faults in the crust are not a continuous and unique plane of weakness like plate boundaries. Furthermore, there are many unknown faults covered by sedimentary layers.

The shear strain energy is a scalar quantity appropriate for evaluating the potential of earthquake occurrence in the case that the fault plane cannot be specified. The scalar quantity corresponds to the average value of the shear stress acting on randomly distributed cracks in the crust (Saito et al., 2018). In other words, an increase and decrease in the shear strain energy correspond to the accumulation and release of crustal stress, respectively. In addition, since the work done for shear faulting is related to the release of elastic strain energy in the surrounding region (Aki & Richards, 1980; Matsu'ura et al., 2019), the strain energy can be thought of as an essential physical quantity for earthquake generation. Evaluating the accumulate and release of the shear strain energy in the crust, therefore, would help to understand the generation mechanism of crustal earthquakes.

To evaluate the shear strain energy changes, we must have not only stress changes but also background stress fields. However, it is difficult to know the absolute value of the background stress. Under the assumption that the absolute level of the background stress is much greater than the stress changes, Saito et al. (2018) derived an expression of shear strain energy changes normalized by the differential stress of the background stress using the spatial pattern of background stress orientation and the stress changes. Then, they calculated the normalized shear strain energy changes in the inland seismogenic layer caused by interplate coupling along the Nankai Trough, and found the correlation between the shear strain energy changes and seismicity in the southwestern Japan.

In order to apply this framework to tectonic zones in the crust, Noda et al. (2018 AGU) developed a method to evaluate the shear strain energy changes using elastic/inelastic strain analysis method (Noda & Matsu'ura, 2010). Firstly, we inverted the 3-D moment tensor density distribution in the crust as the source of crustal deformation from GNSS displacement data. The 3-D elastic/inelastic strain distribution in the crust was obtained from the estimated moment tensor density distribution. The stress changes were calculated by multiplying the elastic strain distribution by assumed elastic constants. Secondly, given a background stress field, the 3-D shear strain energy changes in the crust was evaluated from the calculated stress changes.

This method was applied to coseismic and preseismic GNSS data associated with the 2016 Kumamoto earthquake. For the background stress, we used the 3-D tectonic stress field estimated by CMT data inversion (Terakawa & Matsu'ura, 2010). The coseismic shear strain energy changes were estimated from the coseismic GNSS displacement data and showed its correlation with the spatial pattern of aftershock activity. Next, we evaluated preseismic changes in shear strain energy from GNSS displacement rate data (2005~2011), and found an increase (accumulation) in a part of the Futagawa fault, which is one of the main faults coseismically slipped during the earthquake, and a large decrease (release) in the

northeastern end of the fault, where the coseismic slip terminated. The shear strain energy change was caused by a large inelastic deformation (brittle fracture/plastic deformation) in the shallow crust along the Aso-Kuju volcanoes.

Keywords: elastic strain energy, crustal earthquake, elastic/inelastic strain, background stress field, 2016 Kumamoto earthquake