Numerical simulation of crustal deformation considering crustal fluids

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The crustal deformation in Japan shows nonuniform spatial pattern, which is controlled by the plate interaction and the heterogeneity of crustal material. For numerical simulations of long-term crustal deformation, it is important to clarify inelastic deformation considering the temperature structure and visco-elastic heterogeneity associated with crustal fluids (e.g., Shibazaki, 2013).
We conducted a numerical simulation adapted to the earthquake swarm area around Ibaraki and Fukushima Prefectures after the 2011 Tohoku earthquake. In the area, the crustal stress derived from seismic data shows crustal extension above 15 km depth and crustal compression below 15 km depth (Yoshida et al., 2015). Moreover, the crustal deformation during the late Quaternary is characterized by uplift (Suzuki, 1989). A geophysical anomaly with low seismic velocity (Zhao et al., 2015) and low resistivity (Umeda et al., 2015) was detected beneath the area of the earthquake swarm, which is strongly involved in the crustal fluids. To investigate the relation between crustal fluids and crustal deformation, we conducted 2D numerical simulation using FEM. In the analysis, an area filled with crustal fluids was assumed to be as a Maxwell visco-elastic body with viscosity of 1×10^{18} Pa.s. Also, seismic velocity was assumed to be 6% slower than that in the surrounding area and fluid content was 1%. As a boundary condition, a back-slip of 10 cm/yr due to the Pacific plate subduction was applied. As a result, for vertical displacement after 100 years, we can reproduce the local uplift around the area. We can also reproduce extensional stress field near the surface and compressive stress field just above the fluid filled area. These are concordant with observed GNSS velocities and stress field qualitatively.
In addition, we conducted 3D numerical simulation using FDM focusing on a shear zone at the southern part of Kyushu district, which is thought to be a young shear zone in a geological time scale. Here, we attempted to reproduce the zonal area with high shear strain rate ($1\text{-}2 \times 10^{-7}$/yr) along 32 degrees north latitude, which was derived from GNSS velocities (Wallace et al., 2009), and then, we investigated the formation of the shear zone, by considering the visco-elastic heterogeneous structure. Based on a model for stress accumulation of intraplate earthquakes (Iio et al., 2004), we assumed a Maxwell visco-elastic material with viscosity of 1×10^{18} Pa.s to fluid filled zone detected by magnetotelluric soundings (Umeda et al., 2014) under the aftershock area of the 1997 Kagoshima earthquake. We set 300 km in length, 200 km in width, and 30 km in depth as a study area, and divided the region into the upper crust (elastic material) and the lower crust (visco-elastic material) at the depth of 15 km. For boundary conditions, displacement rates of 3 cm/yr for the subduction of the Philippine Sea plate and 1 cm/yr for the back-arc spreading at the Okinawa Trough were set at the eastern and western sides of the model region. The elastic parameters were employed from subsurface structure model for deep sedimentary layers of Japan (Fujiwara et al., 2009). The viscosity derived by Kaufmann and Amelung (2000) was used. As a result, we succeed in the reproduction of a region with high shear strain rate of about $2\text{-}4 \times 10^{-7}$/yr, where the low viscosity zone under the aftershock region of the earthquake is leading to the surface. These results indicate that crustal fluids are closely related with crustal deformation.

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Keywords: numerical simulation, earthquake swarm, active shear zone at the southern part of Kyushu region, visco-elastic heterogeneous structure, low viscosity area

