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フロンティアセミナー

講演者　：　氏家　恒太郎　准教授

所　属　：　筑波大学

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担当教員：　伊藤　喜宏　助教

内線#/ E-mail:yito@aob.gp.tohoku.ac.jp

Earthquake rupture propagation through shallow subduction zone: Insights from high-velocity frictional properties and microstructures of clay-rich fault gouges

講義内容：

Conventional thinking is that water-saturated, clay-rich sediments in shallow subduction zones are too weak to support large shear stress and tend to show velocity-strengthening behavior, so earthquake instability should not nucleate or easily propagate through the shallow portion of the subduction interface.　On the other hand, some earthquake ruptures propagate through the shallow portion of the subduction interface and the splay fault branched from the subduction thrust, causing devastating tsunamis associated with large seafloor displacement (e.g., the 2011 Mw9.0 Tohoku-Oki Earthquake). Recently, Integrated Ocean Drilling Program (IODP) Expedition 316 drilled into the shallow portion of the megasplay fault zone and the plate boundary décollement zone in the Nankai accretionary margin off Kumano, where great earthquakes such as the 1944 Tonankai earthquake (Mw8.1) occurred repeatedly. Both fault zones exhibit the slip localization along the ~2-10 mm-thick clay-rich fault gouges in which the increased vitrinite reflectance and illitization are detected, possibly representing the generation of frictional heat during subduction earthquakes. Previous friction experiments on the clay-rich materials in the Nankai subduction zone showed velocity-strengthening behavior at low slip rates of less than 100 μm/s. We conducted high-velocity (1.3 m/s) friction experiments on clay-rich sediments taken from the immediately below the fault gouges under dry (room humidity) and wet (water-saturated) conditions and examined the resulting microstructures. All experiments show slip weakening associated with fluid pressurization and frictional heating. Compared to the dry tests, however, the wet tests are marked by smaller critical slip weakening distance and fracture energy. The steady-state shear stress in the wet tests is almost independent of normal stress, suggesting a fluid-like behavior of the fault gouge during high-velocity shearing. The resulting microstructure after the wet tests is characterized by the development of the reverse grain size segregation in the fault gouge. The reverse grain size segregation only occurs at high slip rates of ≥0.62 m/s, which is attributed to the Brazil-nut effect resulting from the difference in dispersive pressure in the granular-fluid shear flow at high shear rates. Interestingly, the same microstructure was reported from the earthquake slip zone (clay-rich fault gouge) in the northern part of the Chelungpu thrust fault where large slip with low-frequency seismic energy release occurred during the 1999 Chi-Chi, Taiwan earthquake (Mw7.6). Our results highlight the importance of investigating the response to shallow subduction material when subjected to a large rupture initiation. Earthquake rupture can propagate through the water-saturated, clay-rich fault gouge in the shallow subduction zone without much resistance, once slip is sufficiently rapid. This could foster tsunamigenesis during subduction earthquake and potentially leaves the microstructure resulting from the flow sorting during gouge fluidization at high slip rates. The shallow earthquake rupture may be controlled by high-velocity weakening and can possibly occur in the velocity-strengthening material in fault zones.

主　催　：　東北大学　グローバルCOEプログラム
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拠点リーダー　大谷　栄治

連絡先:　宮城県仙台市青葉区荒巻字青葉
東北大学大学院理学研究科　地学棟 404 号
GCOE地球惑星科学事務室　苫米地　由布
TEL/FAX 022(795)6668