Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SCG63-04 Room:104 Time:May 22 17:00-17:15

Clay mineral characteristics of the plate-boundary fault at the Japan Trench

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The 2011 Tohoku-oki earthquake (Mw9.0) rupture propagated along the plate-boundary megathrust and caused a huge tsunami. One anomalous aspect of this earthquake is that the seismic slip broke through the up-dip limit of the seismogenic zone, with slip propagating as far as the trench axis. In order to elucidate the physical mechanisms responsible for such unexpected behavior of the shallow fault, the IODP Ex 343 The Japan Trench Fast Drilling Project (JFAST) was carried out one year after the earthquake. It succeeded in recovery of material from within the plate boundary shear zone. Our data illustrate how mineralogical properties vary through a depth-section including the plate boundary fault rock, and we discuss the mechanical significance.

At the drilling site (C0019E) where the largest fault slip (>50m) occurred, a plate boundary shear zone was identified around 820 mbsf. X-ray diffraction (XRD) analysis of clay-fraction samples reveals that relative abundance of smectite is markedly higher at the fault (74-94 wt.%) than in the surrounding host rocks. Bulk-XRD results indicate the absolute smectite abundance in the fault rock reaches more than 70 wt.%, suggesting (by correlation with previous experimental studies of smectitic clays) the shear zone material had low intrinsic friction coefficient.

Because it has such a high smectite content, the shear zone is also expected to be influenced by physico-chemical interactions between smectite and interstitial water. In particular, the swelling behavior of smectite will affect the in-situ mechanical state of the fault. We estimated osmotic swelling forces the shear zone rock could cause by applying the Gouy-Chapman theory of diffuse double layer states under the restricted swelling strain condition. Based on measurements of exchangeable cation content, cation exchange capacity and BET surface area for some bulk rock samples (including 2 fault rocks), the theoretical estimate suggests osmotic repulsive forces of the order of ˜5MPa could act between the smectite particles within the fault. Thus, in addition to its contribution to a low friction coefficient, the swelling behavior of smectite might further reduce effective pressure (and therefore shear strength) of the plate-boundary fault, and help to promote localized slip on it.

Keywords: 2011 Tohoku-oki earthquake, JFAST, smectite