Effect of a half-graben structure on formation of a shallow plate boundary fault in subduction zone with analog modelling

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Recently, the study of the shallowest part of plate boundary faults has become the frontier of fault rupture process research. Until the 2011 Tohoku-oki earthquake, the shallow part had generally been regarded as an aseismic stable zone (e.g. Scholz 1998). However, during the 2011 earthquake, the fault rupture extended to the shallowest portion (Fujiwara et al., 2011, Kodaira et al., 2012). The associated displacement of the frontal accretionary prism was up to ~60 m and triggered a massive tsunami. In the research, many studies just after the 2011 earthquake focused on the area in which large shallow slip occurred near the trench.

In our previous study we applied the critically tapered Coulomb wedge theory (e.g. Davis et al., 1983; Dahlen. 1984) to twelve seismic reflection profiles across the toe of the frontal wedge in the Japan Trench (Koge et al., 2014, EPS). The results showed high friction at the hypocenter, the south-end, and the north-end of the slip distribution. We interpreted these variations of effective friction as caused by the subduction of seamounts or well-developed horst-graben structures. Therefore, the surface geometry of the incoming plate contributes to the effective friction of the shallow plate boundary fault. Such prior researches, however, were based on present snapshots. It is difficult to identify how the fault was created and which fault actually moved.

Most previous studies focused on the effects of convex basement geometry such as as seamounts (e.g., Dominguez et al., 1998; Mochizuki et al., 2008; Morgan et al., 2017). However, there are only a few studies on the control of concave basement geometry on the effective friction. To better understand the plate boundary fault formation process in an accretionary prism that develops on top of half-graben basement structures, we conducted an analog sandbox experiment. We photographed the experiments every 5 seconds and analyzed the images using digital image correlation (DIC) to show the temporal transition of the fault activity inside the wedge.

Fault activity in the experiment can be summarized in four stages. At stage 1, the forethrust was formed with long fault interval at the half-graben. At stage 2, the horizontal progress speed of the frontal part of the wedge slowed down, and the frontal wedge started to lift up to form a pop-up structure. At stage 3, the most frontal part of the decollement becomes a network of anastomosing fault. At stage 4, a secondary decollement steps down from the landward edge of the half-graben toward the sediment-basement boundary and a new frontal thrust is initiated.

This experience gives new insight into the finite thickness of natural decollement, the formation of multiple decollements and the segmentation of accretionary prisms. Furthermore it points out that decollement can propagate sub-horizontally even within homogeneous sediments.

キーワード：アナログモデル実験、日本海溝、東北地方太平洋沖地震
Keywords: analog modeling, Japan Trench, The 2011 Tohoku-Oki earthquake

