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

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Large earthquakes and tsunamis have repeatedly occurred along the Japan Trench. In the 2011 Tohoku-Oki earthquake (Mw 9.0), the fault rupture extended to the shallow portion of the Japan Trench (e.g. Fujiwara et al., 2011, Sun et al., 2017). These large slips resulted in the huge tsunami that devastated much of the east coast of Japan. Therefore, it is key to understand the history of fault formation near the trench for the disaster prevention.

Our previous study (Koge et al., 2014) applied the theory of critically tapered Coulomb wedge theory (e.g. Davis et al., 1983) to 12 transects of Japan Trench before the 2011 earthquake, in order to obtain along-trench variations of frictional properties (especially, effective frictional coefficient of the plate boundary megathrust). The results show that the area of high effective frictional coefficient has characteristic topographies (seamount or well-developed horst-and-graben structure) on subducting plate, and effective frictional coefficient closely correlates with the near-trench slip distribution during the 2011 earthquake. However, it has not been sufficiently considered how the topography affects the processes of wedge formation and internal deformation. This is because the seismic profiles represent snapshots at certain times. The kinematic history should be reconstructed using principals and techniques of structural geology or can be forward modeled through analog modeling.

Therefore, in order to understand the formation history of the shallow plate boundary faults, we conducted analog model experiments reproducing that the half-graben structure subducts the frontal wedge. In the experiments, deformation of the sand layer was photographed at intervals of 5 seconds, and then these snapshots were analyzed with digital image correlation (DIC) to show the temporal transition of the fault activity inside the wedge. Our experiments show that the fault activity changes at the following four stages when the frontal part of the wedge reaches half-graben structure.

For the condition in which the half-graben basement without a trench fill, we observed sequential deformations characteristically divided into four stages.

At stage 1, the decollement reached the half-graben with long distance. At stage 2, the horizontal progress speed of frontal part of the wedge started becoming slow, and the part of the frontal wedge started vertical lift up. Since the undeformed area started to be compressed between the front (the stacked tip part) and the back (the deformation of the backstop interface), the pop-up type deformation was started. The pop-up deformation have fore and back thrusts, and fore thrust can be called branch fault, due to the motif. At stage 3, the branch fault stopped its activity, and decollement repeated the connection and disconnection. For convenience, we call this phenomenon “Dancing”. Stage 4, a new decollement is developed from the landward edge of the half-graven toward the sediment-basement boundary and a new frontal thrust is initiated.