Continuous formation processes of the shallow plate boundary fault in the Japan Trench reproduced by analog modeling experiments

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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. These large slips on shallow decollement 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. At the 2011 earthquake, the slip of the plate boundary fault reached to the trench, and the seafloor of the outermost part of the landward trench slope horizontally moved approximately 50 m toward the trench, and uplifted approximately 7 to 10 m (Fujiwara et al., 2011, Science). The large fault rupture and propagation might be due to the essentially weak fault material and dynamic weakening, suggested by high-velocity frictional experiment on fault zone material (Ujiie et al., 2013, Nature Geoscience) and borehole temperature measurement (Fulton et al., 2013, Nature Geoscience) during the IODP JFAST study.
Our previous study (Koge et al., 2014, EPS) applied the theory of critically tapered Coulomb wedge 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 (e.g. 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 structural geological principals and techniques or can be forward modeled through analog modeling.
Therefore, in order to understand the formation history of the shallow plate boundary faults which was related to the 2011 earthquake, 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. Stage 1: The front of the wedge stacks when the wedge enters the graven. Stage 2: The wedge starts to grow (uplift) by forming a branch fault. Stage 3: A new frontal thrust is formed, and the activity of the branch fault is stopped. Stage 4: The frontal thrust continues the activity with that a decollement is torn and eventually step down to half-graven as a new thrust.
For future work, by comparing these experimental results with the seismic structure, it would lead to an understanding of the fault formation and development processes at the toe of the trench landward slope.

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