Foreshock activities controlled by slip rate on a 4-meter-long laboratory fault

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We report foreshock activities associated with evolving local slow slip events preceding the main rupture on a laboratory fault. To investigate the preparation process of laboratory earthquake with enough spatial resolution, we used a large-scale friction apparatus newly developed and installed at National Research Institute for Earth Science and Disaster Resilience (NIED) as shown in Figure 1. We used two rectangular metagabbro blocks as experimental specimens, whose nominal contacting area was 4.0 m long and 0.1 m wide. Height of each specimen was 0.2 m. Normal load was applied by eight flat jacks on the top surface of the upper specimen, and the associated pressures were kept at around 6 MPa during the experiments. After applying normal load, we applied shear load to the side surface of the lower specimen by manually pumping up a hydraulic jack, which was fixed at the western end of the apparatus. To monitor local phenomena on the fault, we installed 16 AE sensors, 40 triaxial rosette strain gauges, and 10 eddy current displacement sensors along the fault. We conducted experiments with relatively high shear loading rate (67-185 kPa/s) and low shear loading rate (2-7 kPa/s). In each experiment, displacement data showed that both the eastern and western edges of the fault kept slipping during the shear loading, though the slip rate was very low (< ~20 μm/s). It is consistent with FEM calculation that fault should start to slip at both edges in this configuration. This steady slip was significant during the experiments with low loading rate, in both quantity and area. However, such steady slip did not immediately trigger seismic events. Most of seismic events occurred just before the main rupture, and therefore should better be termed foreshocks. To understand what controls the occurrence of foreshocks, we first investigated the amount of stable slow slip accumulated after the previous main rupture. We found that foreshocks were not activated at around both fault edges even after the accumulated slip attained around 10 μm there (Figure 2a). On the other hand, foreshocks occurred around the central locked area with only a small amount of slip. We next compared the spatiotemporal distribution of foreshocks with that of slip rate. Displacement and strain data indicated that precursory slow slip began at the central locked area and then propagated outward over the fault area preceding the main rupture. We found that this slow slip had caused high slip rate (several hundreds of μm/s), which coincided with the occurrence of foreshocks (Figure 2b). These observations suggest that the key factor controlling the occurrence of foreshocks in this experiment is not the amount of accumulated slip but that of slip rate. The mechanism may be associated with the unstable fault slip triggered by fast loading in the laboratory (McLaskey and Yamashita, 2017, JGR; Xu et al., 2018, Tectonophysics), and the seismicity episodically activated in nature such as emergence of repeating earthquakes due to increased loading rate by afterslip of the 2011 *M*9.0 Tohoku-oki earthquake (Hatakeyama et al., 2017, JGR).

Keywords: Rock friction experiment, Slow slip, Foreshock, Slip rate

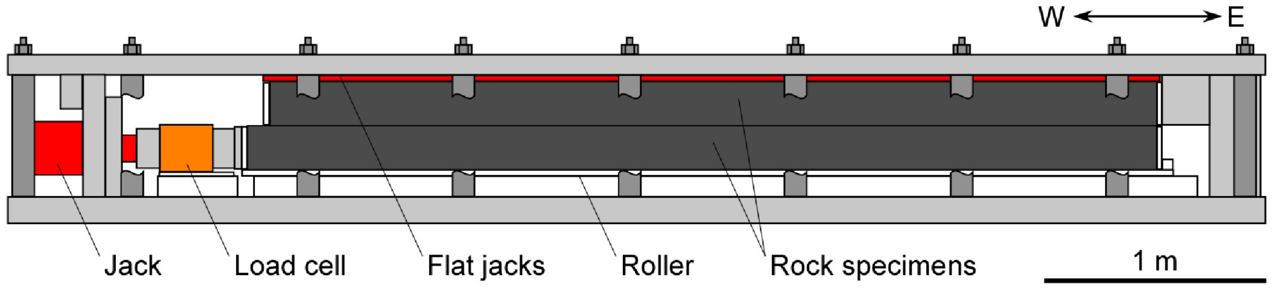

Figure 1

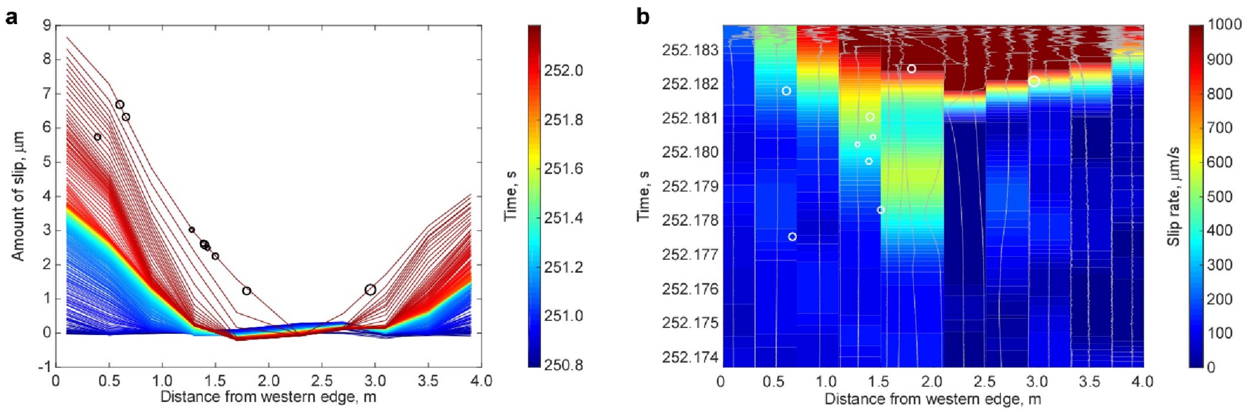

Figure 2