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At Riedel shears do seismic ruptures nucleate?: Suggestions from stick-slip experiments

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Motivation

Seismic nucleation process prior to main shocks was found first by Iio (1992, 1995) and Ellsworth and Beroza (1995). Moreover, it is well-known that the seismic moment of main shocks is proportional to the size of nuclei to the power of 3 (Ellsworth and Beroza, 1995; Ohnaka, 2000). Since seismic nucleation is an inevitable precedent process, hence it is important not only for the earthquake physics but also for the central issue where and how seismic nuclei are formed in fault zone. From frictional experiments, Ohnaka and Shen (1999) found that the size of seismic nuclei corresponds to characteristic wave length of the topography of precut surface at which fractal is broken down. On the other hand, natural faults zones are associated inevitably with gouge layers whose thickness is proportional to total fault slip, and it is very likely that seismic nuclei are form in gouge layers. Therefore, Ohnaka and Shen's experimental results which were obtained for bare rock surfaces cannot be extrapolated directly to the nature. Among the various structures inside gouge layers, Riedel shears are most universal structures both in natural and experimental fault zones. Moreover, it has been known that Riedel shears are developed prior to unstable slip events. The critical size of seismic nuclei is the only one characteristic size of earthquake phenomena. On the other hand, Riedel shear is the only one characteristic structure inside fault zones. Therefore, it is very likely that they are intimately related.

Experimental Method

Using a tri-axial apparatus, we conducted stick-slip experiments for simulated fault gouge layers with a high resolution for both time and space. Quartz powder was sandwiched between the precut surfaces of cylindrical granite samples: the diameter of 20mm, the length of 40mm, precut surface inclined 45 degrees and mirror finished. Five or seven strain gauges were pasted directly on the side surface of a granite sample. Two were served for the measurement of axial stress and fault slip, and others were for detecting the arrival times of elastic wave radiated by stick-slips. The strain gauges were pasted apart 3-5mm from a precut surface at 5mm intervals. The granite samples with a simulated gouge layer (0.5 mm thick) were encapsulated in Teflon jackets. All signals were amplified through signal conditioners, and were acquired synchronously and continuously in PC by NI-DAQ6110+LabView at 2.0-2.5 MHz. This data acquisition rate enabled to distinguish the difference in arrival time of elastic waves if the distance between strain gauges is larger than 2.5mm.

The simulated gouge layers were compacted during one hour under the confining pressure of 180 MPa and differential stress of 250 MPa. Thereafter, axial load was increased. After only first one stick-slip event occurred, axial loading was stopped. Thin sections were prepared from the experimented samples, and the microstructures inside the simulated gouge layers were observed by SEM.

Results and Conclusions

Based on the difference in arrival times of elastic waves and the directivity effects, the epicenters could be determined, but the correspondent Riedel shear was not specified, because plural Riedel shears were developed in a gouge layer. Here it is noteworthy that comminuted thin layers were developed discontinuously along the boundaries between the gouge layer and precut surfaces, namely Y-shears. The epicentral locus that was determined by strain gauges is nearly correlated with the location where a prominent Y-shear extends from a Riedel shear. It has been known that Riedel shears are developed prior to unstable slip events (Bartlett et al., 1981; Gu and Wong, 1994). Moreover, the bending point from Riedel shear to Y-shear is a geometrical barrier (Aochi et al., 2002). Therefore, seismic nucleation is likely the process in which anyone of Riedel shears get over this barrier.