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The nucleation of “fast” and “slow” stick slip instabilities in sheared granular aggregates

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Seismological observations in the past few decades have revealed a diversity of slip behaviors of faults, involving interactions and transition between slow to fast slip phenomena. Field studies show that exhumed fault zones comprise mixtures of materials with variable frictional strength and stability. Emergent models of slip diversity emphasize the role of heterogeneities of fault zone properties and the potential interactions between seismic and aseismic deformation. Here, we develop analog laboratory experiments to study the mechanics of heterogeneous faults with the goal to identify factors controlling their slip stability and rupture style.

We report on results from room temperature sliding experiments using a rotary shear apparatus. We simulated gouge heterogeneity by using materials with different frictional strength and stability. At room temperature conditions, dry glass beads typically stick slip, whereas dry granular calcite exhibits stable sliding. The peak strength of glass beads aggregates is typically lower than that of granular calcite aggregates. Our samples consisted of a layer of glass beads sandwiched between two layers of granular calcite. The initial particle size was between 100 and 200 μm for both materials and the initial thickness of each layer was about 1.5 mm. We tested our layered aggregates under 1 to 7 MPa normal stress and at sliding velocities between 1 and 100 μm/s. Within that range of conditions, high normal stress and slow sliding velocities promoted fast, regular stick slip. For normal stress values of less than about 4 MPa, the recurrence time and stress drop of stick slips became irregular, particularly at sliding rates above 20 μm/s. As the accumulated shear displacement increased, slip events became slower and the magnitudes of their stress drop, compaction and slip distance decreased. We recorded acoustic emissions (AEs) associated with each slip event (fast and slow) and estimated their source azimuth. AE activity was distributed in several clusters, some of which remained stationary, whereas others appeared to migrate with increasing shear displacement. We performed post-mortem microstructural analysis (tabletop SEM) of select AE nucleation sites and found significant mixing of glass beads with the calcite layer abutting the rotating piston ring. No mixing was observed between the glass beads and the calcite layer on the opposite side, nor any features that would indicate strain localization along the interface of the calcite and the adjacent stationary piston.

These results show that the frictional behavior of our aggregates changed from fast to slow slip as the amount of glass beads mixed with granular calcite increased. Migrating AE clusters imply that nucleation occurred within the mixed calcite-glass beads layer, where most of the shear strain appears to have been accommodated, whereas stationary clusters probably originated within the adjacent, more slowly deforming layer of glass beads. This suggests that AEs belonging to migrating clusters were perhaps triggered by stress changes due to the gradual mixing of the two sample constituents. This process may explain migrating seismicity in natural fault zones.