Development of slip partitioning within wet kaolin and dry sand oblique-convergence experiments

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Abstract

Slip partitioning systems can accommodate oblique convergence with different slip rake in two or more faults and are well documented; however, the evolution of slip partitioned crustal systems is underresearched. Carefully scaled physical experiments in crustal analogs inform our understanding of fault evolution because we cannot control the loading and directly observe the ensuing deformation. Using experiments in both dry sand and wet kaolin clay, we explore how slip partitioning evolves under different convergence angles. Previous experiments on dry sand experiments documented that convergence angle and fault strength control slip partitioning. In contrast to dry sand, the non-zero cohesion of wet kaolin produces long-lived fault structures that easily reactivate. Scaled experiments using both dry sand and wet kaolin with identical boundary conditions provide insights into the role of material properties in slip partitioning. We use notation movement of rigid blocks overlaid by a layer of dry sand or wet kaolin clay to approximate crustal deformation due to oblique subduction zone convergence. Digital image correlation combined with stereovision techniques provides evidence of horizontal strain and uplift that constrains fault geometry and slip vectors along the faults. Additionally, force gauges record the evolution of fault-normal forces throughout slip partitioning, such as stress drops associated with fault growth. Within the dry sand, an oblique-slip forethrust-backthrust pair forms first followed by a late stage through-going strike-slip fault. In contrast, at shallow convergence angles within the clay, the strike-slip fault forms first and a backthrust never develops. As convergence accumulates, the clay, a forethrust forms dipping toward the underlying subductivity. The lack of cohesion in dry sand may prevent the concentration of model tectonics that leads to the early vertical-strike-slip fault growth observed in the clay. The cohesion of the clay, which is similar to crustal rock strength, may facilitate the maintenance of slip partitioned fault systems.

Slip Partitioning in the Crust

Slip partitioning can occur at multiple scales within the crust and ranges from local convergence within restraining bends (e.g., the Transverse Ranges of the southern San Andreas Fault system) to thousands of kilometers across subduction zones such as the Great Sumatran Fault (right) or oceanic transform links in Japan (e.g., Bussenius et al., 2015; Jones & Rosenstock, 1992; Fitch, 1972).

At the subduction zone scale, slip partitioning occurs along two parallel thrusts with a characteristic geometry: a dipping oblique slip fault along the trench and a continental vertical strike-slip fault (Fitch, 1972).

Due to their crustal scale, these faults are capable of producing some of the largest magnitude earthquakes in recorded history including the devastating Sumatran-Andaman earthquake of 2004 and the more recent 2011 Tohoku Oki earthquake in Japan.

Above, a three-dimensional schematic of the Sumatra subduction zone depicts the oblique-thrust fault along the Sunda trench where the Australian and Indian plates subduct beneath the Sunda plate. May-view shows the parallel trending strike-slip fault bounding Sumatra. Modified from Nature 437, 736-77 (5 June 2003).

**Experimental Design**

Three plastic blocks with a height of 30 cm contains a 2.5 cm overlying layer of dry sand (125 µm) or wet kaolin. The blocks are positioned on two planes: one fixed and the other moving along the x- and y-axes by two stepper motors.

A calibrated stereo camera system mounted above the model captures high-resolution images of the region of interest (ROI). A force sensor embedded in the city, or attached to the drive plates for sand models, records the variation in fault normal stresses throughout the experiment.

**Length Scaling**

Dry Sand: 1 cm = 5 km crust width 1 cm = 1 km

We measured the city’s shear strength by fail cycle method and adjust to 99.115 bars by varying the water content (90%/weight).

Wet Kaolin clay deforms as a bi-voceous Burger’s material exhibiting rate and state behavior at failure.

**Summary of fault timing reveals how convergence angle, normal material, and the presence of a pre-existing weakness (pre-cutting a vertical fault) affect the development and maintenance of slip partitioning.** The wet kaolin experiments form a strike-slip fault (red arrows) early before the oblique-thrust fault (blue arrows). In contrast, the dry sand experiments form an oblique-slip forethrust fault (F) backthrust (B) pair before a through-going strike-slip fault facilitates slip partitioning. Only the pre-cut clay 15 deg forms strike slip partitioning, the other 15 expiments only form a single strike slip fault. The onset of slip partitioning in the clay is later for lower convergence angles (opposite for sand) and earlier in pre-cut clay experiments than uncut.

**Discussion/Conclusions**

1. Dry sand: an oblique-slip forethrust-backthrust pair forms first followed by a late stage through-going strike-slip fault

2. Wet Kaolin clay: the strike-slip fault forms first and a backthrust never develops, a forethrust forms dipping toward the underlying subductivity

3. The lack of cohesion in dry sand may prevent the concentration of model tectonics that lead to the early vertical-strike-slip fault growth observed in the clay.

4. The cohesion of the clay, which is similar to crustal rock strength, may facilitate the maintenance of slip partitioned fault systems.

5. Pre-existing crustal weaknesses, such as back-arc volcanism along a subduction zone, play an important role in the timing of slip partitioning.

6. Due to the high obliquity of the tested convergence angles, these experiments however, likely more appropriately model small scale transtensional systems such as the West Spitsbergen fold-and-thrust belt or Transverse Ranges of the San Andreas Fault system rather than larger scale subduction zones.

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