Analog Modeling to Test Predictions of Strain and Morphology in Coulomb Wedges

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In the 1980's, Tony Dahlen was responsible for building much of the theoretical groundwork for the Coulomb 'bulldozer' wedge model, which has proved very useful in explaining many aspects of the thin-skinned tectonics of foreland fold-and-thrust belts and accretionary wedges. There is a long history of using analog models to test theoretical predictions for the growth of mountain belts, as well as to compare them with natural orogens. Such models match well the expectations of critical wedge theory, with wedge taper, thrust sequencing and structural styles that depend in predictable ways upon yield criteria in the wedge and along its base.

We have developed a technique that allows us to monitor the evolution of topography in a model orogen throughout its development and compare it with the distribution of quantitatively determined strain rate and bulk strain. Among the simplest predictions of critical Coulomb wedge theory is the assertion that cohesionless wedges should grow in a self-similar manner. This has been demonstrated many times for frictional analog models with normal convergence. With a simple series of experiments, we demonstrate that this is also true for critical frictional wedges in oblique convergence. In normal convergence, deformation begins with a symmetric pop-up structure, but (with fluctuations as individual thrust packets are accreted) the slopes of the pro- and retro-wedges rapidly evolve to distinct values, with the much steeper retro-wedge displaying a maximum (as opposed to minimum) critical taper. The same is true for models with small to moderate obliquities. At very high convergence obliquity θ, however, the distinction between pro- and retro-wedge breaks down. By an obliquity of $\theta=70°$, there is essentially no difference between the tapers of the two sides of the double model orogen, in which principal stresses have rotated and changed relative values toward a strike-slip domain. The transition from asymmetric to symmetric behavior as a function of obliquity is quite abrupt - despite accommodating substantial shear, the model orogen has a form like that for normal convergence at obliquities as high as $\theta=50°$ to 60°. Even at moderately high convergence obliquities, strain partitioning within the wedge allows the shortening direction at the deformation front to remain close to normal to the strike of the margin. With increasing convergence obliquity, the distribution of that shear becomes more concentrated toward the inner parts of the model orogen.

Thin-skinned wedges with very different convergence obliquities appear very similar structurally, both in the lab and in nature. In both cases, an analysis of strain indicators may be required in order to differentiate them unambiguously from normally-convergent wedges. Regardless of obliquity, purely frictional wedges never undergo extension, but they can be demonstrated even at low obliquity to become supercritical. This lack of extension for a frictional orogen is entirely consistent with theoretical work pioneered by Tony Dahlen, who showed that the predicted minimum tapers for extension and for stability under compression are quite distinct. For this reason, a frictional wedge that is stronger than its décollement will not begin to undergo gravitational spreading when slightly over-steepened or when dynamic (plate motion) support is removed – in sharp contrast to the behavior of a ductile wedge.