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Dynamic experiments investigating non-critical orogenic wedges

Susanne Buiter and Nicolas Molnar
RWTH Aachen University, Tectonics and Geodynamics, Faculty of Georesources and Materials Engineering, Aachen, Germany (susanne.buiter@tag.rwth-aachen.de)

A series of influential papers in the 1980's showed how the long-term evolution of fold-and-thrust belts and accretionary wedges (here collectively termed orogenic wedges) can quantitatively be described as striving towards a mechanical equilibrium defined by their internal and basal material strengths (Dahlen 1984, Dahlen et al. 1984, Davis et al. 1983). Unstable orogenic wedges will deform to adjust their basal and surface slopes to a critical taper angle, defined by a wedge that is at the verge of failure everywhere. Critical taper theory has been confirmed by analogue and numerical experiments and found numerous successful applications in field studies.

The success of critical taper theory forms a framework that allows investigating non-critical behaviour of orogenic wedges. Previous numerical and analogue studies pointed out that: (1) Only portions of orogenic wedges may be at failure at any given time, separating critically stressed from non-critical segments (Lohrmann et al. 2003, Simpson 2011). As these wedges still observe a critical taper, this may indicate that it is the critically stressed segments that define the overall wedge shape. (2) Numerical experiments often attain a critical taper at lower shortening percentages than analogue experiments. We speculate that this may be related to larger amounts of strain softening generally used in numerical setups and/or the number of shear zones that forms at equivalent shortening (which is controlled by numerical resolution and analogue material properties). This non-criticality is thus likely only a transient state.

We here ask the question whether structural inheritance from earlier compressional or extensional deformation phases may lead to longer-term non-critical wedge behaviour by favouring out-of-sequence thrusting or shear zone propagation into the foreland. To address this question, we combine a review of previous dynamic wedge experiments with new analogue experiments that investigate the influence of inherited shear zones and variations in material properties on wedge evolution. We shorten quartz sand layers overlying a weak basal microbeads layer with a non-deformable backstop. The backstop has two independently moving parts, allowing to alternate thin- and thick-skinned deformation. We find that the reactivation of basement shear zones formed in earlier deformation phases is short-lived and does not affect thrusting to a degree that would distinguish these wedges from those without inheritance. We extend these experiments by including variations in internal material properties and weaker shear zones, remaining however in the domain of brittle orogenic wedges.

Non-critical wedge behaviour may only be a transient state, but could occur frequently owing to variations in material properties or structural inheritance, which are to be expected in regions of inter-plate shortening of former rift regions. Our contribution hopes to highlight the potential for future modelling studies of orogenic wedges to examine how non-critical wedge behaviour could play into the evolution of fold-and-thrust belts and accretionary wedges.