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Influence of surface processes, strain softening and mechanical heterogeneities on orogenic wedge growth

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The convergence of two tectonic plates at a subduction zone may lead to the development of an orogenic wedge (fold-and-thrust belt or accretionary wedge) due to off-scraping of material from the downgoing plate and deformation of the overriding plate. The geometry and state of stress of an orogenic wedge at the verge of failure can successfully be predicted by the analytical critical taper theory. Stable wedges grow self-similarly as fresh material is accreted. Surface processes or competency contrasts may perturb the stable geometry; consequently the wedge adjusts by internal deformation in order to attain a stable taper angle. The analytical theory is less suitable for the study of internal wedge deformation and more insight may be obtained by tectonic modelling techniques.

We use a two-dimensional finite element code to investigate the kinematics and the internal deformation of orogenic wedges growing by frontal accretion. The rigid-plastic materials in our models represent upper crustal rocks. A 5 km thick sediment layer, underlain by a weak basal detachment, is pushed at a constant velocity towards a strong backstop. We systematically study the effects of 1) diffusive erosion and sedimentation, 2) frictional strain softening, and 3) sensitivity to dimension and spacing of mechanical heterogeneities.

Our results show 1) the development of in-sequence forward thrusts, 2) a taper angle within the stable range, and 3) internal deformation focused on individual thrusts. Erosion causes thrust propagation to slow down and deformation to focus near the backstop, while the taper angle is not affected. Frictional strain softening as well as weak material heterogeneities facilitate thrust formation by focusing of deformation.

Weak heterogeneities within the sediment layer influence propagation, spacing as well as orientation of shear zones. In later stages of convergence, older, more internal shear zones may be reactivated, and may thus disrupt the in-sequence forward thrust propagation.

Our experiments compare to natural analogs. For example, a similar in-sequence thrusting can be observed in the Rocky Mountain Foreland Belt where thrusting propagates towards the craton during formation of the orogenic wedge by frontal accretion. Alternatively, back-stepping of thrusting during overall in-sequence thrusting happened at certain instances in the Alps.

First experiments at lithospheric scale including the effects isostatic compensation confirm some of these conclusions. In particular we observe in-sequence growth of orogenic wedges.