Scaled laboratory experiments on sequential thrusting in a mechanically two-layered system and its implications in fold-and-thrust belts

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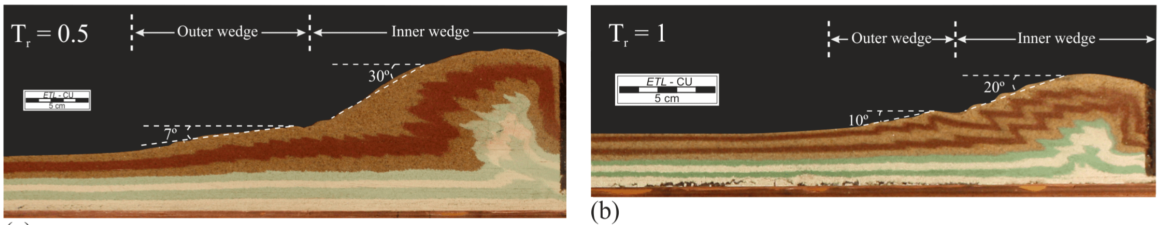
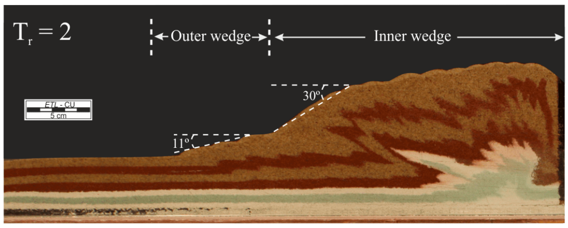
Thin-skinned tectonic models have been widely used to explain the process of sequential thrusting in convergent settings. These models generally treat the crustal horizon as a single mechanical layer on a weak basal detachment. However, many fold-and-thrust belts display multi-storied thrust sequences, characterizing a composite architecture of the thrust wedges. For example, the Himalayan wedge has produced a set of continental scale (first order) thrusts, namely Main Crystalline Thrust (MCT), Main Boundary Thrust (MBT) and Main Frontal Thrust (MFT), covering the entire strike length of the mountain belt. Taking a close-view to different sectors in this belt, one can find numerous closely spaced (higher order) thrusts in between any two first order thrusts.Despite dramatic progress in sandbox modelling over the last three decades, our understanding of such composite thrust-wedge mechanics is limited and demands a re-visit to the problem of sequential thrusting in mechanically layered systems. This study offers a new approach to sandbox experiments, designed with a two-layered sandpack simulating a mechanically weak Coulomb layer, resting coherently upon a stronger Coulomb layer. Experimental runs reproduce strikingly similar styles of the multi-storied frontal thrust sequences observed in natural fold-and- thrust belts. Our results show that the upper weak horizon undergoes sequential thrusting at a high spatial frequency, forming numerous, closely spaced thrusts, in contrast to widely spaced thrusts produced preferentially in the lower strong horizon. We investigated the development of such composite thrust styles by varying frictional strength (μ_b) at the basal detachment and thickness ratio (T_r) between the weak and strong layers. For any given values of T_r and μ_b, the two thrust sequences progress at different rates; the closely-spaced upper thrust sequence advances forelandward at a faster rate than the widely-spaced, lower thrust sequence. The stable elevation of a thrust wedge in a mechanically layered setup depends on the thickness ratio (T_r) between the weak and strong layers. The wedge can attain a stable hinterland elevation only when T_r 1 (Fig. 1). Basal friction (μ_b) has little effects on the thrust vergence in the upper weak layer and they always verge towards foreland, irrespective of *Tr* values. But, back-vergent thrusts develop in the lower strong layer when μ_b is low (˜ 0.36) (Fig. 2). In our experiments, closely spaced thrusts in the upper sequence (US) experience intense reactivation due to their interaction with widely spaced thrusts in the lower sequence (LS). This interaction eventually affects the wedge topography, leading to two distinct parts: *inner* and *outer* wedges, characterized by steep and gentle surface slopes, respectively.

Keywords: Mechanical layers, Multi-storied thrust sequences, Topographic slopes, Thrust wedge



(a) (b)



(c)

Figure 1. Development of inner and outer wedge in mechanically stratified models (μ_b= 0.36). Note that the lower strong layer remained completely undeformed below the outer wedge. Models show that the reactivation of earlier thrusts in the US separates the wedge into two segments: inner and outer wedge. Thickness ratios (T_r) between US and LS are 1:2 (a), 1:1 (b) and 2:1 (c); and the amount of shortening are 25 cm, 15cm and 28cm respectively. Note that the inner wedge has a flat topography near the hinterland buttress in (b) and (c), whereas (a) did not produce such a flat region in the inner wedge.

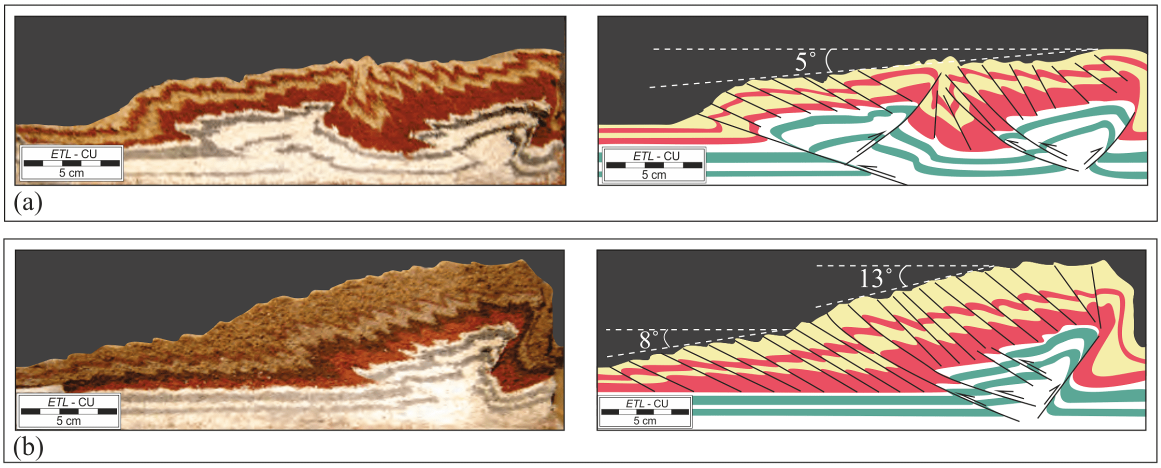


Figure 2. Multi-storied thrusting in sandbox models for varying basal friction (μ_b) and T_r=1. (a) μ_b= 0.36 and (b) μ_b= 0.46. Figures on the right side show corresponding sketches of the models. Note that the vergence of lower-order thrusts is sensitive to μb, where they form with both front and back vergence for low μ_b. In contrast, higher order thrusts in the upper sequence verge always in the frontal direction, irrespective of μ_b. The amount of finite shortening in (a) and (b) are 30 cm and 35 cm respectively. Note that the thrust ramp in the US has caused deformation localisation at their toes, resulting in their downward propagation into the lower strong layer.