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Analogue modelling of inversion tectonics: investigating the role of multiple extensional basins in foreland fold-and-thrust belts

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When orogeny reactivates extensional structures or uplifts pre-existing depocenters in the foreland (inversion), the overall nature, dimension, and geometry of these rheological heterogeneities represent one of the main controlling factors in the spatio-temporal evolution of foreland fold-and-thrust belts. Relationships between inversion structures in the foreland and far-field stresses caused by orogenic fronts have long been identified (e.g., Ziegler, 1989, Geol. Soc. Spec. Publ. 44). However, conditions that facilitate or hinder basin inversion in these settings remain unclear, mainly due to the intrinsic complexity of analysing multiple overprinted geological events.

We use novel laboratory experiments of basin inversion to investigate how compressional stresses are transferred across a heterogeneous crust. More specifically, we determine how the presence of multiple extensional basins in the foreland controls the location, occurrence, and sequencing of foreland thrusts. Quantitative analysis of our experiments allows us to define conceptual models for comparison and application to natural examples where geological interpretation remains partially conjectural due to their intrinsic complexity, such as the permo-carboniferous troughs beneath the Swiss Molasse basin or the inverted Broad Fourteens Basin in the North Sea.

Our experiments are built in a modelling apparatus with a mobile backstop, using quartz sand to model brittle crustal materials and glass microbeads to simulate a weaker basal detachment layer. Velocity discontinuities at the base are created by attaching multiple thin basal sheets to the mobile wall during extensional phases (pulling). The location of each extensional basin is defined by the lengths of the basal sheets. During extension, the resulting graben-like structures are progressively filled with microbeads to create a sedimentary infill that is less competent than the surrounding rock. The basal sheets are completely detached from the mobile wall before the initiation of the shortening phase (pushing). Topography, surface and lateral deformation is quantified employing a high-resolution particle imaging velocimetry (PIV) system.

We present results of shortening multiple extensional basins at fixed distances from the orogenic front. Detailed analysis shows that extensional basin faults are not reactivated during shortening, but instead inversion is characterised by an initial squeezing of the basin fill and subsequent formation of either frontal or back thrusts that localise along the microbead-sand interface, leading to the overall uplift of the basins. This mechanism occurs independent of the distance of the basin to the orogenic front. However, when several grabens are present, the extent of shortening that each extensional structure localises differs greatly between experiments, showing variability according to the number of basins and their distance to the orogenic front.

When compared to reference models with a homogeneous crust, our results show that the presence of multiple extensional basins in the foreland exerts a first-order control on the evolution of propagating fold-and-thrust belts. Thrust location and sequencing evolve differently, with frontal thrusts developing along pre-existing basins boundaries at early stages, and subsequent stages of back thrust formation characterising wedge thickening at the hinterland of the extensional basins.