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4D analysis of interfering thrust-related anticlines in brittle analogue models

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Thrust-related anticlines are characteristic features of fold-and-thrust belts. Where different thrust-related anticlines interfere, the resulting structural style depends on e.g. orientation and time of activity. Examples of opposite verging and (partially) interfering thrust-related fold systems can be found in the Rioja through, Northern Spain, in the Assam Valley, northeastern India, and in the Magdalena Valley of the Colombian Andes. Two of the best examples of this kind of structures are situated at the outermost fronts of the Northern Apennines: the first in the Po Plain, where the Northern Apennines and the Southern Alps outermost thrust fronts are only a few kilometres apart; the second in the Adriatic Sea. This second case is particularly suitable for detailed examination because the two almost N-S trending opposite-verging thrust faults responsible for thrust-related anticlines are not parallel but get closer along strike.

We performed analogue models to reconstruct the complex structures and kinematics of opposite-verging thrust-related anticlines. In our rectangular model set-up, the inner edges of two horizontal base plates attached to the longitudinal vertical walls converge in one direction along strike but do not touch each other, simulating two converging velocity discontinuities (VDs). Inward displacement of the longitudinal walls results in shortening of the model. In a first model, both VDs are active at the same time, whereas in a second model, inward displacement of one VD occurs first and is stopped, and is followed by inward displacement of the second VD. As analogue material we used a 4-cm thick fine-grained quartz sand pack to simulate upper crustal brittle deformation.

The early stage of the first model sees the development of two opposite verging asymmetric thrust-related anticlines (asymmetric pop-ups) that converge along strike, with more displacement on the inner forethrusts than on the outer backthrusts. Due to this differential activity the zone of no interaction between two pop-ups show slight topography tilting of anticlines. In the intervening zone of interaction, a central, small pop-up is created by the crosscutting inner forethrusts. During the interaction fault dips remain constant at approximately 30 degrees. In later stages of deformation, new in-sequence forethrusts form in the non-interacting zone. Their along-strike propagation in the interacting zone uplifts the pre-existing pop-up and stops the displacement along the causative faults.

The second model simulates polyphase deformation. During the first phase only one thrust-related anticline is created. In the second phase, we deform the pre-existing thrust-related anticline by creating a second thrust-related anticline. In the early stage of this second phase, the inner forethrust of the pre-existing structure accommodates deformation and thus hinders the formation of a new in-sequence forethrust. As deformation continues, the pre-existing faults are crosscut and offset by the inner forethrust of the second thrust-related anticline.

Comparing our analogue model results with seismic reflection profiles of real cases shows good geometrical and structural similarities. This suggests that structural reconstructions and understanding of fault kinematics in such complex tectonic settings can benefit from a detailed analogue modelling approach.