Comparison of sandbox-style numerical extension experiments

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We directly compare results obtained with different numerical codes to results of analogue experiments from different laboratories with the aims to (1) test the code-independence of tectonic structures predicted by different numerical codes, (2) evaluate how closely various numerical solution methods can reproduce analogue model conditions, and (3) test the similarity of numerical and analogue models, in order to help establish robust features of tectonic models on the scale of the upper crust.

Our extension experiment was designed to reflect a setup often used in the study of upper-crustal processes with laboratory experimental models. It examines the influence of a weak, basal viscous layer on normal fault localisation and propagation in overlying brittle materials. Extension is achieved by moving one wall with an attached basal sheet outwards. Six numerical codes (using finite element or finite difference techniques) were used in our comparison: Abaqus/Standard, LAPEX-2D, I2ELVIS, Microfem, SloMo and Sopale.

Our results show that the overall evolution of all numerical codes is broadly similar. Shear zones initiate at the tip of the basal sheet, which acts as a velocity discontinuity. The asymmetric evolution of the models as the basal sheet is pulled out from underneath is similar for all numerical codes. In detail, differences exist in the number of shear zones that form and shear zone dip angles. We find that resolution of the calculation grid affects strain localisation and the number of shear zones that develop in strain-softening brittle material.

Comparison to equivalent analogue experiments show that the overall dynamic evolution of the numerical and analogue models is similar, in spite of the difficulty of achieving an exact representation of the analogue model conditions with a numerical model. We find that for this setup the degree of variability between individual numerical results is smaller than between individual analogue models. Differences among and between analogue and numerical results exist in predictions of number of shear zones that develop and their spacing and dip angle. Our results show that numerical models using different solution techniques can to first order successfully reproduce structures observed in analogue sandbox experiments.

Our results emphasize the importance of the following issues for numerical sandbox-type studies: (1) the ability to model large deformation structures; (2) the ability to represent boundary friction, velocity discontinuities and a free surface; (3) the representation of a composite (elasto)-visco-plastic rheology; (4) calculation with a relatively high resolution; (5) minimisation of numerical diffusion; (6) consensus on the procedure for quantification of modelling results. These are important for studies in which numerical and analogue models are used in combination, but reflect at the same time requirements for study of Earth tectonic processes.

As the initial setup and material properties of analogue models can be relatively well constrained, their results can form a useful test for numerical models. Numerical models may, therefore, benefit from future studies focussing on the differences between analogue and numerical modelling results. Our results indicate that future experiments should preferably (1) choose a simplified setup, which reduces the effects of boundary conditions and especially abrupt changes in boundary velocities, (2) prescribe resolution and time step size, (3) use material behaviour which is as similar as possible, and, (4) if possible, quantify results in an unambiguous manner.