How homogeneous boundary conditions lead to heterogeneous strain in analogue simple shear models

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Analogue modeling of geological structures in simple shear investigating, for example, the rotation and interaction of rigid or weak inclusions in a matrix, single layer folding, or fold interference patterns, commonly employs a linear simple shear or general shear rig. While the boundaries of such deformation rigs theoretically prescribe a homogeneous isochoric (plane strain) flow, the internal deformation pattern of the analogue material (paraffin wax or silicone putties) may strongly deviate from the intended homogeneous strain conditions. For example, in simple shear experiments (x-y-coordinate system, simple shear in x-direction) the following observations can be made: (1) Close to model boundaries initially parallel to the y-direction a prominent deflection of passive marker lines develops during the experiment, indicating less shear strain than imposed on the boundary. (2) Close to model boundaries initially parallel to the x-direction a prominent deflection of passive marker lines develops during the experiment, indicating more shear strain than imposed on the boundary. (3) The central part of the model rotates with the opposite sense of rotation compared to the imposed vorticity.

We employ two-dimensional numerical finite element models to investigate the observed deviation from a homogeneous simple shear flow field in simple shear rig experiments. A Newtonian rheology is used to represent the analogue material. We tested different boundary conditions (at boundaries initially parallel to the x- and y-direction, respectively) that do not represent perfect simple shear boundary conditions, but could possibly be present in analogue experiments. The numerical results show that neither traction-free slip nor free surface boundary conditions at the four walls, nor any combination of these boundary conditions produces the deformation pattern observed in analogue experiments. Therefore, we conclude that the imposed boundary conditions at the walls of the analogue rigs (initially parallel to the x- and y-direction, respectively) are not the reason for the observed heterogeneous strain field.

In analogue experiments, the analogue material commonly lies on top of a weak viscous material (e.g. vaseline) or is sandwiched between two layers of such a material. These layers are also deformed during an experiment and represent boundary conditions in the third dimension (i.e the z-direction). In the two-dimensional numerical simulation, a velocity-dependent traction force that acts on the analogue material represents this viscous shear boundary condition. The numerical simple shear experiments including this traction force precisely reproduce the heterogeneous strain observed in analogue experiments. Therefore, we conclude that boundary effects in the third dimension of simple shear rigs (i.e. weak viscous layers) are the primary reason for the observed heterogeneous strain field. As the viscous stresses arising from deforming the weak boundary layers are velocity dependent, the deviation from a homogeneous strain pattern in the analogue material depends on the applied shear strain rate. We thus recommend to run analogue models in shear boxes at preferably low strain rates.