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Finite Amplitude Necking and Evolution of Pinch-and-Swell Structures in Power-Law Fluids

S.M. Schmalholz (1), D.W. Schmid (2) and R.C. Fletcher (3)

(1) Geological Institute, ETH Zurich, Switzerland (schmalholz@erdw.ethz.ch), (2) Physics of Geological Processes, University of Oslo, Norway, (3) Department of Geosciences, The Pennsylvania State University, U.S.A

Pinch-and-swell structures are often observed in layered rock sequences and are the result of a mechanical instability which is commonly termed necking. Thereby, a stiff layer, which may be embedded in a weaker material, is extended in a layer-parallel direction. Pinch-and-swell structures result from continuous necking in contrast to boudins, which are discretely segmented in cross section. Necking is not only a process acting on the small scale, but is also of major importance for understanding large-scale tectonic processes. It is well accepted that necking of the continental lithosphere is one of the principle mechanisms for sedimentary basin and continental margin formation. Necking was also shown to play a major role in the formation of the Basin and Range Province in the western United States, and the formation of the grooved terrain on Ganymede (a satellite of Jupiter) is most likely the result of a necking instability. In this study, finite amplitude necking and the evolution of pinch-and-swell structures is investigated with analytical and numerical methods. Necking instabilities can occur in elastoplastic solids and nonlinear power-law fluids, but this study focuses on power-law fluids only. A simple analytical solution for finite amplitude necking, which is based on the assumption that plane sections remain plane, is discussed and the analytical predictions are compared with numerical results of finite element simulations. This study further investigates the evolution of the layer thickness, the layer-parallel stress, the effective viscosity and the amplification rate of the layer perturbation during progressive formation of the pinch-and-swell structure. The impact of the power-law exponent on the evolution of these parameters is quantified. A main aim of this study is to derive an approximate analytical solution which describes the geometrical evolution of pinch-and-swell structures in power-law fluids up to high amplitudes.