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Numerical models of diapiric structures - analysis of the finite strain distribution

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In gravity driven tectonic structures finite strain is a key parameter to understand the evolution of the underlying dynamic processes. In the study conducted here, the strain was analyzed numerically for two different diapiric models, the model of a classical Rayleigh-Taylor instability [1], which is mainly important for magmatic diapirs, and the down-building model [2], which is especially important for salt diapirs where the rise is driven by differential sediment loading.

The equations of conservation of mass, momentum, and composition are solved by a 2D finite difference code (FDCON) based on a stream function formulation in combination with a marker approach based on a predictor-corrector Runge-Kutta 4th order scheme. The finite deformation was determined using the algorithm of McKenzie [3] calculated centered in time and in space, where the information of the deformation matrix is advected with the markers in the model.

Two series of different viscosity contrasts $m = \frac{\eta_{buoyant}}{\eta_{top}}$ and different thicknesses were calculated for each $h_{buoyant}$ of a Rayleigh-Taylor like instability with both no slip and free slip boundary conditions at the top and bottom. In the case of the down-building models we present two model series with different viscosity regimes: one with a stiff subsiding sediment layer, with the result of high deformation within the salt and negligible deformation in the ambient sediments and another with relatively weak sediments, in which the deformation is partitioned between the salt and the sediments. In addition to the local analysis of the strains in each layer, the strain partitioning is considered on the entire volume of the two layers. Therefore the maximum shear strain [4] is integrated in each layer and forms the ratio Sr between the integrated values of the upper and lower layer. This ratio provides information on how the strain is distributed between the two layers.

For the RTI models the maximum values of the finite deformation inside the layers are decreasing and increasing for a higher or lower viscosity, respectively. In the overburden layer above the head, however, there is a region with stronger strains which are always greater than the strain within the head. This is favored by the constraints of the model so that the upper layer is continuously stretched while the rising source layer is destrained as it approaches the top of the model. In principle the free slip models show a similar behavior of finite strains, but the strains due to the boundary conditions at the top and bottom of the model disappear and also the thinner layers get more stretched than the thicker ones. It is found in the strain partitioning that the strain in the softer layer is always larger. However, interestingly the ratio is significantly smaller than the viscosity contrast. Thus, analyses of strain partitioning in natural scenarios may only give limited information about viscosity contrasts. There are similar deformation patterns in both down-building model series besides a larger deformation along the margins of the diapir. Moreover they show an interesting effect. Due to the subsidence of sediment basins on the side of the evolving diapir head we find an enhanced internal circulation within the diapir. This amplification leads to several overturns during an early phase of ascent.

References

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