Numerical models of salt dome formation by downbuilding: the role of sedimentation rate, viscosity contrast and other parameters

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1 Introduction

While the formation of salt domes as process of up-building has been studied extensively as an application of the classical Rayleigh-Taylor Instability (e.g. Ramberg, 1967), fully consistent fluid dynamical models of down-building salt diapirs (i.e. syndepositional diapirism) are rare (e.g. van Keken et al. 1993; Chemia et al, 2007). Here we systematically study the effect of the sedimentation rate v_s, the viscosity contrast *m* between salt and overburden, the wavelength λ, and the initial amplitude δ of the perturbation on the success or failure of downbuilding and the geometrical shape of salt diapirs

2 Governing equations and model set up

The conservation equations of mass, momentum and composition are solved for a three component system, consisting of an initiallaly flat salt layer with a viscosity ratio m times softer than the sediments, a denser sediment layer and a zero density much softer “sticky air” layer. The 2D Finite Difference code FDCON based on a stream function formulation is used in combination with a marker approach based on a predictor-corrector Runge-Kutta 4th order scheme.

Initially no sediments are present. To initiate down-building, sedimentation is modelled by successively elevating the initially perturbed level of the sediment layer by a prescribed sedimentation rate and transforming all “sticky air” particles below this level into sediments. Due to the small initial perturbation differential sediment loading drives the salt towards the centre of the future diapir. If the top of this diapir rises faster than the sedimentation level until the complete initial salt layer is drained down-building is defined to be successful. If sedimentation is too fast, the salt layer may only reach the pillow stage, then it is buried completely by the stiff sediment layer. This case defines failed down-building

3 Model results

Variation of the four model parameters have a strong effect on the resulting diapir shape. Small *m* and v_{sed} result in flat and broad domes, higher values leads to narrower and higher domes. Small δ -values result in narrow stems and wide diapir heads, larger values lead to domes with subvertical side walls. The boundary between successful and failed down-building can be constrained within the 4-dimensional parameter space: Failing of down-buildiung occurs at high *m* or v_{sed} and at small δ. Variation of λ shows that down-building is most successful within a λ-range around $2\pi\ h_{salt}$ of about 1 order of magnitude width.

4 Discussion and conclusion

If v_{sed} is scaled as

$$v'_{sed} = v_{sed} \frac{\eta_{salt}}{h_{salt}^{\ 2} \Delta\rho g} \qquad (1)$$

with η as viscosity, h as thickness, $\Delta\rho$ as density difference and g as gravitational acceleration, then a simple channel flow model predicts that the critical sedimentation velocity separating successful from failed down-building is given by

$$v'_{sedcrit} = C_1 \frac{1}{2} \delta_0' \rho_0' \frac{k'^2}{k'^2 + C_2} \qquad (2)$$

where the lengths are scaled by h_{salt} and the density is scaled by $\Delta\rho$. This model is confirmed to first order by the numerical experiments, which allows to determine the constant C_1 and C_2 as 0.026 and 0.09, respectively. However, non-linear effects due to laterally varying sediment amounts are observed and lead to moderate deviations from the simple relation (2).

We conclude that our numerical experiments and the resulting relation (2) allow to predict whether a salt layer will evolve into a salt dome by down-buildung during sedimentation, and, in reverse, may be used to constrain past sedimentation rates.

References

Ramberg, H. (1967): Gravity, Deformation, and the Earth's Crust: In Theory, Experiments and Geological Application, Acad. Press, London and New York N.Y., 214 pp.

Chemia, Z., H. Koyi, and H. Schmeling (2007): Numerical modeling of rise and fall of a dense layer in salt diapers. Geophys. J. Int., 172, 798-816.

van Keken, P. E., C.J. Spiers, A.P. van den Berg, and E.J. Muyzert (1993): The effective viscosity of rocksalt: implementation of steady state creep laws in numerical models of salt diapirism, Tectonophysics, 225, 457-476.