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Interactive comment on "Deformation of intrasalt competent layers in different modes of salt tectonics" *by* Mark G. Rowan et al.

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Thank you, Michael, for your generous and helpful comments. Below, we respond to the main issues you raise.

We agree that pure passive diapirs, without any precursor extension, contraction, or pillow formation, are relatively rare. They do exist, however, for example the Witchelina diapir in South Australia, where the very first (and subsequent) overburden strata onlapped the growing diapir (paper in review by E. Gannaway-Dalton). This situation is likely in settings with very shallow-water or nonmarine deposition, so that differential loading immediately above the salt creates exposed salt highs and thus truncating (diapiric) relationships between the salt and the flanking strata. In any case, we will state even more explicitly in the final version of the paper that we are examining end-member scenarios.

But let's address the diapirs in Northern Germany that you cite. You write that these diapirs, which probably have the best-mapped (and published) internal geometries in the world, are dominated by folds. We include an example in our Fig. 2c, which is actually the one you cite as Fig. 8.26 in Jackson and Hudec (2017). These folds are expressed by the different layers of the well-known Zechstein stratigraphy, which of course is dominated by halite, and include both map-view (curtain) folds and cross-sectional isoclinal folds (both with steep and curvilinear axial traces). The primary reasons for such folding are that (1) large areas of salt are typically moving in a convergent manner into the smaller area of a diapir, leading to constrictional strain, and (2) that folding is induced by differential flow and shear between the inner and outer parts of the rising diapir.

So yes, strong layers such as anhydrite, carbonates, and siliciclastics are carried and folded passively within the ductile halite (and bittern salts). However, the same maps and cross sections from Germany show that these strong layers are disrupted into boudins within these folds. In volume-constant strain, there cannot be just shortening, and at least one principal strain is lengthening. So we would respectfully disagree: boudins of strong layers are just as common in these diapirs as folds. Rather than considering two alternative styles (dissected stringers vs contractional folding), we argue that both features are part of the same deformation process. In our opinion, the impression that many passive diapirs are characterized by folding and contraction is created by a common focus on halite and other ductile layers. Our focus, however, is on the strong layers, and we would thus argue that the observations that you cite are actually compatible with our simple models. But we will do a better job in the revised version of making this distinction – between the large-scale halite-dominated folding and the brittle rupturing of strong layers – more clear.

As for the models by Chemia and Koyi, we argue that the material properties used in their numerical models are not appropriate and thus do not create ruptured boudins.

They use a Newtonian-viscous rheology for the salt, which is better modeled as a power-law fluid. More importantly, they applied a power-law (i.e., viscous) rheology to the anhydrite, stating that “the brittle rheology of anhydrite cannot be achieved in numerical models.” Thus, although the flow of the modeled anhydrite is appropriate for model folding, it does not allow the brittle rupture process that is well documented in anhydrite in nature (see Abe et al., 2013).

Finally, on the topic of drilling hazards, we agree that shear stresses between rock salt and competent layers can be significant. However, those calculated in Weijermars et al. (2014) are unrealistically high and to our knowledge cannot occur in the subsurface. Having said that, stresses in anhydrite stringers caused by salt flow or gravitational sinking are important but little studied. How there stresses affect possible open fractures in (overpressured) anhydrite is not well known but could well be important.

Again, thank you for your thoughtful comments. They will help us refine our message and minimize any possible confusion.

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Discussion paper