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The role of intra-salt heterogeneity on the internal and external geometry of salt bodies – a numerical modelling approach with applications for geo-storage

Leonardo Pichel, Ritske Huismans, Thomas Theunissen, Sabine Delahaye, Alexandre Pichat, Jean-Paul Callot, and Naim Celini
University of Bergen, Earth Sciences, Bergen, Norway (leonardompgeologia@gmail.com)

Thick salt deposits occur in a wide range of sedimentary basins and orogens. They are associated with large and geometrically complex structures due to the inherent ability of salt to flow as a viscous fluid. Salt basins form major hydrocarbon provinces and are increasingly targeted for CO_2/H_2 storage and geothermal energy due to the unique physical properties of salt, its low viscosity, high thermal conductivity and impermeability. Despite considerable advances in understanding salt basins and salt tectonics, there is still a significant knowledge gap on the internal geometry of salt structures. We apply a novel, very-high resolution (20x50m)2D numerical modelling approach to simulate salt diapirism and minibasin formation for heterogenous, layered salt sequences. We test the effects of varying i) viscosity, ii) density, iii) thickness, and iv) stratigraphic arrangement of intra-salt layers on the kinematics, and the internal and external geometries of deformed salt bodies by using scaled material properties to simulate: i) weak pure halite, ii) less-weak impure halite, ii) strong and dense anhydrite-rich layers, and iv) very-weak K-Mg salts.

Our results show that salt sequences including an alternation of weak and less-weak layers with different viscosity and density produce major intra-salt strain partition and complexity characterized by highly convoluted folding, horizontal and vertical shearing, and preferential flow of the weaker, less-dense salt (pure halite) into the core of diapirs. The less-weak layers can eventually flow into the diapir crest but are generally disrupted by flow of the underlying weak layers and positioned towards the diapirs' flanks where they become overturned. The most complex and convolute intra-salt geometries occur around the diapirs' flanks when there is an abrupt internal shift of minibasin depocentres. Recumbent intra-salt folds are also common and associated with the development of secondary minibasins by diapir-fall. For models that include strong anhydrite-rich layers, there is a general decrease in the magnitude and complexity of diapirism, with these layers being passively folded by flow of the underlying weak salt and displaying only moderate to negligible flow onto diapirs and vertical stretching. These stronger layers become trapped underneath the base of diapirs and their associated minibasins where they typically form short-wavelength folds. For models that include very-weak and light K-Mg salt layers, there is an increase in rate of diapirism with rapid vertical shearing and stretching of the weak layers along the diapir's flanks and sub-horizontal flow and recumbent folds along their crests.

Varying the position of both very-weak and strong layers generates very contrasting internal and external diapir geometries. These results can aid in the characterization of the internal structures of deformed, diapiric salt bodies, which is critical for the use of salt structures in the context of energy transition. They provide important insights that can help the design of salt caverns for H_2/CH_4 storage by identifying areas with broadly homogenous halite-rich salt, 2) avoiding drilling through sheared and highly-stressed and strained intra-salt heterogeneities, and 3) constraining minibasin architecture and evolution, improving the understanding of the distribution and geometry of CO_2 reservoirs.