Mechanics of salt systems: state of the field in numerical methods, Part II

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This is the second part of a thematic collection on studies that employ numerical methods to understand the mechanics of salt systems. Part I of the thematic collection (Nikolinakou et al. 2019) focused on studies of micro- and macro-structural salt behaviour as well as the mechanical interaction between salt and basin sediments. This second part explores the application of numerical models to understand the evolution of salt mini-basin arrays and rifted continental margins, as well as a static geometrical approach of a salt basin case studies offshore West Africa.

The first paper (Fernandez et al.) presents results from forward models of salt mini-basin arrays. Salt minibasins are 10–30 km zones of local sediment subsidence (Heaton et al. 1995; Montoya 2006) that form by expulsion of an underlying salt layer. In contrast to traditional numerical models, which typically analyse an isolated mini basin (e.g. Hudac et al. 2009; Goteti et al. 2012), Fernandez et al. use the systems approach (e.g. Agar & Geiger 2015 and references therein) to analyse salt mini basins. Such an approach has significantly improved our understanding of the role of interactions between individual features on the evolution of the larger arrays (refer to Faulds & Varga 1998; Walsh et al. 2002; Ando et al. 2004 for examples on fault arrays, and to Schmid et al. 2008; Fernandez & Kaus 2014 for examples on 3D fold trains). Fernandez et al.’s study addresses a gap in our understanding of the kinematic interaction between minibasins in an array and the effects on the evolution of an individual minibasin. The authors develop 2D plane-strain models of salt minibasins in a neutral tectonic setting (i.e. no tectonic contraction or extension) using the finite element code MVEP2 (Thielmann & Kaus 2012), a Lagrangian formulation that supports large strains and elastic-visco-plastic rheology for salt. The authors demonstrate that kinematic interactions between adjacent minibasins can have a significant impact on the timing of subsidence and the stratigraphic geometries of minibasins. Even in a neutral tectonic setting, where regional salt flow is minimal or absent, minibasins can develop asymmetric stratigraphic geometries due to the kinematic interactions between adjacent minibasins and/or the translation of minibasins in a closely spaced array. In this context, the onset of stratigraphic tilting and asymmetry in a minibasin may not be necessarily indicative of the approach of welding of the underlying salt (e.g. Rowan & Weimer 1998). The modelling results suggest that interpretations of the timing of subsidence, sinking and welding of minibasins in an array should take into account the kinematic interaction between minibasins.

The second paper (Allen et al.) presents results from evolutionary thermo-mechanical models of rifting in wide, weak continental margins, attendant sedimentary basins and salt tectonics. Studies of sedimentary basin formation and regional salt tectonics at rifted margins have gained significant attention because of the occurrence of commercial quantities of hydrocarbons in rifted margins such as the Gulf of Mexico, S. Atlantic and N. Atlantic margin, offshore Canada (Hudec & Jackson 2007; Mohriak et al. 2012). Nonetheless, few numerical models have focused on analysing the interdependence among rifting, sediment accommodation and salt tectonics in an internally consistent manner. Salt tectonics in rifted margins, is a product of complex interaction between factors such as salt mobility, evolution of the margin tilt due to subsidence and sediment loading (density, strength and volume of sediments) (Albertz et al. 2010; Brun & Fort 2011, 2012; Rowan et al. 2012; Goteti et al. 2013), and the timing of salt deposition relative to that of rifting (Rowan 2014). Geomechanical forward modelling is a useful technique to assess the interdependence among these factors and their impact on the evolution of rifted margins. Allen et al., assess the impact of sedimentation style on the localization of crustal deformation and feedback between synrift salt deposition and subsequent halokinesis due to the syn- and post-salt sedimentation. They employ the finite-element software SOPALE Nested (Beaumont et al. 2009), which uses an arbitrary Lagrangian-Eulerian formulation (ALE) (Fullsack 1995) to solve equations of incompressible (Stokes) viscous flow. Their model includes domains with two different scales: a 600-km-deep upper-mantle model, termed the large-scale (LS) model, which provides the thermo-mechanical framework for modelling rifting and a nested, high-resolution small-scale model (SS), which simulates upper lithospheric extension, crustal scale faulting, sedimentary basin formation and salt tectonics. The ALE formulation (Fullsack 1995; Allen & Beaumont 2016) supports large strains associated with flow in the mantle, crustal deformation and salt tectonics. The models demonstrate that the type (aggradation v. progradation) and spatial extent of synrift sedimentation plays a strong role in the localization of deformation in the crust and style of rifting in the margin. The timing of salt deposition in the rifting process affects the distribution and continuity of salt basins due to changes in accommodation across the margin. The authors compare the model results with basin development in the central and northeastern regions of the Scotian margin. They suggest that the enhanced proximal graben development in the northeastern region may have occurred because of significant progradational post-salt synrift sedimentation, in contrast to the central region, which experienced less post-salt sedimentation.
The last paper (Hooghvorst et al.) presents a comparative study between 2D (plane-strain) and 3D static geomechanical models of the Tarafay basin, offshore West Africa, to assess the performance of these models for exploration risking and well planning. Geomechanical modelling over the past two decades has shown that salt bodies can cause anomalies in the in-situ stress of surrounding sediments (Fredrich et al. 2003; Willson & Fredrich 2005; Sanz & Dasari 2010; van-der-Zee et al. 2011; Schutjens et al. 2012; Nikolainakou et al. 2014). Pre-drill assessments made for the stress regime based on tectonic settings (e.g. normal, strike-slip or reverse faulting) may not be valid near salt structures (Dusseault et al. 2004; Willson & Fredrich 2005). Analytical models have been developed to estimate the stress regime near salt diapirs (e.g. Heidari et al. 2017). Although these models can provide rapid first-order estimates for the stress regime near salt bodies, the amplitude and spatial extent of stress perturbations that these models predict may not be representative of actual ones because the geometry of the salt body and the behaviour of materials in these models are represented simplistically. 2D and 3D finite element modelling allows for a much more realistic representation of the geometries and of the material behaviours and can thus be a robust technique to assess the spatial and temporal variation of stresses near complex salt structures (Fredrich & Fossum 2002). Hooghvorst et al. find that stress perturbations near a salt diapir in their case study depend primarily on the geometry of the salt diapir and the contrast in the material properties of salt and surrounding sediments. They also find that the plane-strain 2D model predicts larger stress perturbations that extend over a greater region above the crest of the salt diapir than the 3D model. Hence, they conclude that although 2D models can provide reasonable pre-drill stress estimates near salt walls or elongated diapirs, 3D modelling is more appropriate for more complex diapir geometries.

References