Halokinetic modulation of sedimentary systems: an integrated approach

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Complicated structural-stratigraphic traps at the salt-sediment interface have historically hosted large hydrocarbon discoveries. Understanding sediment-routing around active salt bodies, is now vital for carbon capture and storage projects due to salt being a ‘near-perfect’ seal. Despite advances in subsurface visualisation, the salt-sediment interface remains difficult to image due to steep-bedding, bed-thickness changes and lithological contrasts. Outcropping examples provide depositional facies understanding, but are limited, largely due to the dissolution of associated halites. Studied analogues represent specific sedimentation rates and salt rise rates, which are difficult to accurately constrain and decipher.

Discrete Element Modelling (DEM) provides an efficient and inexpensive tool to analyse how depositional architectures around salt structures vary with sedimentation rate. Model input parameters are taken from the Bakio diapir, Basque Cantabrian Basin and the Pierce diapirs, eastern Central Graben and their adjacent, halokinetically influenced stratigraphic successions.

Six experiments were run, lasting for a total of 4.6 Myr. After a 2.2 Myr calibration period sediment was added to the model over three 800,000 year stages: 1) 2.2-3 Myr, 2) 3-3.8 Myr 3) 3.8-4.6 Myr. Sedimentation rate was varied to study the effects of sedimentation on mini-basin individualisation and extent of halokinetic modulation. The six experiments represent: no sedimentation, slow, intermediate and fast sediment input, increasing sedimentation and decreasing sedimentation. Outputs are validated by comparison to subsurface and outcropping examples globally.

Results show that:

1) Diapir growth is increased with some sedimentation, compared to no sedimentation, in agreement with models of passive diapirism by sediment loading, however growth is inhibited by increasing sedimentation rate.

2) Salt withdrawal mini-basins of 4-5 diapir-widths are formed and are controlled by the width of the diapir; outside of this, the overburden is undeformed.
3) Strata, at least initially, onlap and thin towards the topographic high created by the diapir.
4) Slow aggradation results in rotation of onlaps and sedimentation being restricted to mini-basins, making individualisation more probable, while sedimentation on the diapir roof eventually occurs in all other experiments.

5) Under high sedimentation rates, halokinetic influences on stratigraphy are ‘buried’ quicker, which could make the upper part of the syn-kinematic sequence difficult to decipher from the post-kinematic sequence.

The increasing sedimentation scenario simulates progradation, and is integrated with findings from the halokinetically-influenced successions around the Bakio (N.Spain) and Pierce (UK North Sea) diapirs. At Bakio, stratigraphy deposited above the diapir was removed by Pyrenean inversion. Incorporating outcrop-based sedimentary facies analysis with numerical modelling indicates that deposits experience facies changes towards stratigraphic pinch outs, mass failures could be common closest to diapirs and allows for the development of ‘zones’ of variably severe halokinetic influence. Combining Pierce core data and model results highlights a trade-off between reservoir quality and stratigraphic trap integrity that may aid development of hydrocarbon fields and carbon capture and storage sites in salt-bearing sedimentary basins.

Our innovative, iterative, integrated approach is capable of improving understanding of the variables influencing sediment-routing and stratigraphic trap configuration around extensional-passive diapirs, and can be applied to a multitude of depositional settings.