Spatial Variations in the Distribution of Carbonate Facies on the Late Jurassic Arabian Shelf: New Insights from Paleohydrodynamic Simulations and Implications for 3D Reservoir Architectures

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Abstract

This study presents a first attempt to model paleo-hydrodynamic conditions (currents and tides), temperature and salinity on the Late Jurassic Arabian shelf to better constrain the distribution of carbonate facies and resulting stratigraphic architecture both on a regional and reservoir scale. The simulation results were validated using well-constrained outcrop analogues and published well data.

The methodology is an amalgamation of data extracted from literature, hydrodynamic simulations and outcrop investigations. Paleobathymetry maps were generated for the Oxfordian/Kimmeridgian Hanifa Fm for an area covering the eastern boundary of the Arabian plate (3760 × 3360 km²). The initial ocean boundary conditions and atmospheric forcing were obtained from a published global model for the Late Jurassic. The KAUST supercomputer Shaheen II was used to simulate hydrodynamics using open-source simulator MIT general circulation model (MITgcm). Paleobathymetry scenarios were evaluated to capture scenarios for periods of relatively deep and shallow water depth and assess their impact on modelled current patterns.

The simulation results show a 3D-spatial distribution of currents, salinity and temperature on the shelf and reveal the presence of surface currents that not only control hydrodynamic energy but also strongly impact water quality on the shelf. For shallow water depth scenarios during early transgressive and late highstand system tracts currents slow down and a strong salinity contrast develops (~55 ppt landwards versus ~45 ppt seawards) leading to the inboard deposition of barren mudstone and oncoidal facies. In periods of deeper water conditions during late transgressive and early highstand system tracts, strong currents develop and prevent the development of a salinity contrast. The entire shelf displays a more constant near normal marine salinity of ~40 ppt and open marine strata dominated by stromatoporoid/coral build-ups and grainstone/packstones facies.

Detailed high-resolution studies of Hanifa Fm outcrops at Wadi Birk expose shallow water carbonate deposits containing the wide range of facies from barren to bioturbated mudstones to stromatoporoid/coral reef and oncoidal facies. Detailed datasets, including photogrammetry, behind the outcrop seismic and GPR reveal both restricted and
current shaped normal marine strata. Stromatoporoid/coral reefs in Wadi Birk indicate a preferential NW-SE orientation in line with currents predicted by the model.

Paleo-hydrodynamic models provide insights in understanding the distribution of facies and architecture of shallow water carbonates both regionally and on reservoir scales. On a flooded shelf of the size of Arabia during the Jurassic significant differences in water circulation pattern, current strength and direction must be expected impacting 3D sedimentary architecture locally. Paleo-hydrodynamic modelling is a powerful tool for predicting realistic subsurface reservoir architectures, fluid flow heterogeneity scenarios and optimized reservoir development plans.