Multi-scale Assessment of the Middle Eastern Permian–Triassic Khuff Carbonate: Structural Evolution and its Impact on Reservoir Properties

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The Khuff Petroleum System Study is a multi-scale, multi-disciplinary analysis that integrates subsurface and outcrop, rock and fluid samples, and static and dynamic data in order to characterize the Permian–Triassic Khuff carbonate, one of the major petroleum reservoirs in the Middle East region. At regional scale, the Khuff carbonate shows a variety of depositional environments (with facies ranging from coastal plain anhydritic claystone, tidal flat/low-to-high energy lagoonal deposits to open-marine dolostones alternating with grainy limestones and high-energy shoal-dominated dolostone/thick grainy limestones) and thicknesses (from near zero at the pinch-out of siliciclastic facies in Central Saudi Arabia, to more than 400 m (1,300 ft) in Ghawar Field in northern Saudi Arabia, expanding to 800 m (2,600 ft) in the North field, Qatar and to nearly 1,000 m (3,300 ft) in the eastern United Arab Emirates.

Local seismic data calibrated to regional well correlations indicate that Khuff thickness, lithology and facies distributions are strongly controlled by the inherited structural relief and also by the reactivation of the basement structural fabric related to Permian–Triassic tectonic events. Therefore according to the tectonic setting, the study area could be subdivided in four mega-structural provinces: (1) the Arabian Peninsula, (2) Oman, (3) the Zagros region, and the (4) the salt provinces.

In the Arabian Peninsula, Pre-Khuff basement-related anisotropies are interpreted to have formed as early as Late Neoproterozoic to Ediacarian time and to follow four main trends: (1) N-S (Nabitah), (2) NW-SE to WNW-ESE (Najd), (3) NNW-SSE to NW-SE (Mesopotamian).

At the regional-scale the Lower Khuff thickness shows a step-wise increase from fault block to fault block towards the northeast. This trend is consistent with an extensional/transensional reactivation of the NW-SE to WNW-ESE pre-existing basement anisotropies. During the Middle to Late Permian, the break-up of the Cimmerian terranes was associated with an azimuth of extension oriented around NNE-SSW implying the Lower Khuff to represent a syn-rift sequence. During the Early–Middle Triassic, the Cimmerian blocks made a relatively rapid separation from the Arabian margin, opening the Neo-Tethys behind. Its evolving active spreading centre exerted a ridge-push progressively stabilizing the passive margins of the opening oceanic basin. Accordingly, the stress field was re-oriented with a NE-trending maximum horizontal stress direction allowing reactivation of the N-S and the NNW-/NW-trending basement fabrics. The resulting pattern of fault-interferences is interpreted to be responsible for the irregular thickness distribution observed in the Upper Khuff Member.

Within the salt mega-structural province, the producing fields and discoveries in the Southern Gulf Salt Basin show a surprising variability in depth, thickness, bulk lithology, average porosity, reservoir fluids and productivity. At regional scale, the variability in reservoir properties identified in this study is interpreted to be controlled by different tectonic structuration and activity such as fault reactivations, by salt diapir-specific growth history coupled with large-scale burial alteration, deep burial *in-situ* modification of hydrocarbons in-place and displacement of hydrocarbons by late non-hydrocarbon charge. Therefore, understanding the interaction between regional tectonic events, basement lineaments and

sedimentation is a crucial and critical step in order to map paleogeography, thickness distributions, facies patterns and play fairways across the entire Arabian Plate.