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Characterization of Karst and Fault-Fracture Networks and their Impact on Thermal EOR in a Tight Carbonate Reservoir, Awali Field, Bahrain

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ABSTRACT

Extreme ranges in reservoir properties challenge the effectiveness of thermal enhanced oil recovery projects, but understanding these extremes unlocks development opportunities. For example, the Cretaceous Mishrif limestone in Bahrain was subject to faulting, fracturing, erosion and karsting. Locally named the “Rubble Formation”, dissolution-enhanced tectonic fractures and well-connected karst vugs and channels have permeabilities tens to hundreds of times that of the tight matrix. Core and well logs capture episodes of matrix dissolution, brecciation, soil infiltration, and compaction associated with karst cavity formation and collapse. Crevasses extend down more than ten feet and cavity collapse is observed deeper. Often the karst fabric exhibits elevated permeabilities, as demonstrated by distributed temperature surveys (DTS) in horizontal wells where injected steam enters the karst intervals while bypassing unaltered formation. Two fault systems slice through the Awali anticline. One set are NW-SE wrench faults with narrow damage zones. The second set are NNE-SSW conjugate normal faults that form a graben complex with abundant NE-SW fractures. Wellbore image logs and core show tectonic fractures with solution-enhanced apertures, indicating their presence during subaerial exposure and the likelihood they facilitated the deep vertical infiltration of leaching meteoric fluids. Intersecting karst, faults, and fractures dictate fluid flow. Primary wells with 10-20% matrix water saturation produce with 70-100% water cut. Production logging tools, DTS, and temperature logs run on horizontal wells show produced fluids and injected steam enter and exit the wellbores through these features. Formation brine and condensed steam support fluid contacts within the well-connected secondary porosity such that contacts rise during steam injection and fall during fluid production. The higher conductivity improves steam injectivity, however these features are not confined to the Rubble, so significant steam is lost out of zone instead of heating near-wellbore matrix oil. Wells producing from the underlying reservoir experience large increases in water production soon after Rubble steam injection commences. An integrated study was undertaken to delineate Rubble karst and fracture networks for guiding more effective steam placement and containment so to maximize heat transfer to the matrix oil. Methods, results, and recommendations will be shared in this paper.