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Incorporating Multiple Scenarios of Porosity Evolution into a Three-Dimensional Outcrop Reservoir Analog Model: A Case Study of the Upper Khuff Formation Oolite Carbonates, Central Saudi Arabia

Hassan A. Eltom[1], Abdaseed K. Kubur[2], Asaad M. Abdulraziq[2], Lameed O. Babalola[2], Mohammed H. Makkawi[2], and Osman M. Abdullatif[2]

[1]Kansas University
[2]King Fahd University of Petroleum and Minerals

Abstract

Oolitic grainstones can contain significant hydrocarbon reserves. Owing to differing sedimentary processes and diagenetic alteration, the porosity values of these deposits are highly variable. We identified intervals containing potential reservoir units in the Lower Triassic Khartam Member of the Upper Khuff Formation in central Saudi Arabia using an outcrop analog model incorporating multiple scenarios of porosity information. Six major surfaces were constructed using fourth-order sequence boundaries obtained from outcrop observations, which define the five zones in the model. In terms of depositional environments, these are defined as Zones 1 and 2 (foreshoal and shoal deposits), Zones 3 and 4 (shoal and backshoal deposits), and Zone 5 (tidal flat). Population of lithofacies in the 3D outcrop model was performed separately for each zone using a different geostatistical algorithm for each depositional environment. The resulting analog model adequately illustrates the continuity of beds and fairly represents the stratigraphic architecture observed in the outcrop. All of the mud-dominated and muddy-grainy facies in the studied outcrop were considered to be baffle flow units, whereas the grain-dominated lithofacies were regarded as reservoir flow units. The grain-dominated lithofacies were further grouped into oolitic-dominated, skeletal oolitic and dolomitic skeletal oolitic facies. The 3D volume of the reservoir units was subdivided into three broad stratigraphic intervals. The lower interval (Zones 1 and 2) was deposited within a rapid sea-level rise at the Permian–Triassic transition and mainly consists of ooid-dominated units. The middle interval (Zones 3 and 4), deposited within an interval of rapid sea-level fluctuation, was characterized by marine faunal recovery. The dominant porosity types within this zone are moldic, interparticle, and intraskeletal. The upper interval (Zone 5), deposited during a major sea-level regression, contains a significant amount of dolomite and is dominated by interparticle and intercrystalline porosity. Multiple scenarios of porosity enhancement and reduction were included within the constructed 3D outcrop model. The results demonstrate how inclusion of porosity evolution within a 3D outcrop reservoir analog model can provide multiple realistic and accurate visualizations of reservoir units. This methodology could be used to predict reservoir potential in analogous carbonate reservoirs.