Diagenesis Control on Reservoir Properties of a Permian–Triassic Carbonate Reservoir, North Oman

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Introduction

The subsurface Permian–Triassic Khuff carbonates in North Oman are sour reservoirs with variable amounts of H₂S and CO₂. A diagenetic study was part of an integrated multidisciplinary project aimed to understand the origin and distribution of H₂S, attributed either to bacterial or thermochemical sulphate reduction, and its relation to the hydrocarbon charge history for these reservoirs.

Methodology

The petrological study was based on the study of about 150 samples from 5 cored wells. The resulting paragenetic sequence was constrained from detailed transmitted, fluorescence and cathodoluminescence microscopy, together with stable isotope and fluid inclusions analyses.

Results

The study revealed that reservoir quality was significantly enhanced by early dissolution that created moldic and vuggy porosity, and pervasive dolomitization, which created intercrystalline porosity, both occurring in near-surface conditions. Different stages of calcite, dolomite and anhydrite cementation, formed in shallow to late burial diagenetic environments, played major roles in reservoir deterioration. Late (saddle) dolomite and late spar calcite cements occur in insignificant amounts, but could locally be important in reducing reservoir connectivity. Occurrence of different phases of solid bitumen, in conjunction with basin modeling, suggest at least two events of hydrocarbon charge: a first oil charge starting after early dolomitization and a later charge postdating late anhydrite cements.

Stable carbon, oxygen and strontium isotopes were bulk analysed on micrites and dolomicrites through the different depositional sequences in the main reservoirs, and microsampled on specific cement phases throughout the paragenetic sequence. In the upper, Early Triassic reservoir, data indicate more negative signatures of $\delta^{13}\text{C}$ versus $\delta^{18}\text{O}$ than in the lower, Late Permian reservoir. This could be interpreted as a result of changing secular trends. Oxygen isotopes in cements follow a typical burial trend with a shift towards more negative values, supporting a gradual increase in temperature and burial depth. Trends towards more negative values in carbon isotopes compared with Permian seawater compositions can be attributed to carbon sources from either meteoric water or from migrated hydrocarbons.

Fluid inclusion petrography and microthermometry results indicate high homogenization temperatures in dolomites, late calcites and anhydrites. The results further supports two hydrocarbon-charging events (or continuous charging), at two relatively high-temperature windows.

Conclusions

The Khuff subsurface reservoirs in North Oman underwent different diagenetic conditions from near- subsurface to deep burial. Reservoir properties were significantly enhanced by early dissolution and dolomitization. Calcite, dolomite and anhydrite cements deteriorated porosity. There is no compelling petrographic or isotopic evidence of mineral products

resulting from thermochemical sulphate reduction (TSR) (e.g. calcification of anhydrite). However, some high homogenization temperatures recorded from fluid inclusions keep open the possibility of incipient TSR-derived H₂S. Deep-seated faults could have acted as conduits of hydrothermal fluids infiltrating the grain-dominated layers of the Upper Khuff reservoir, as basin history does not support high burial depth/temperatures.

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Figure 1: Paragenetic sequence of the Khuff reservoirs in North Oman Field: process *versus* time/diagenetic environment. Note: Green-coloured events indicate porosity enhancement while the red ones are porosity destructive.