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Paleofluid evolution in fault damage zones and complex vein networks (Jebel Qusaybah, North Oman)

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Fault- and fold-related fracture systems strongly control fluid flow and diagenesis of carbonates. Using an integrated structural-diagenetic approach, this study aims to reconstruct the fluid circulation history, including hydrocarbons, in fault systems that cross-cut the Natih Formation in Jebel Qusaybah as a part of the North Oman foreland basin.

The Natih Formation (Late Albian - Early Turonian) and its time equivalent carbonates are reservoirs in giant oil fields in Middle East. The exposure of Natih Formation carbonates in Jebel Qusaybah provides the opportunity to study the evolution of fluids circulating in the fault and fracture systems in a major reservoir analogue. This jebel consists of a 8.5 km long, E-W-trending anticline affected by widespread NE-SW and NW-SE strike slip and N-S extensional fault zones. Circulation of multiple fluids along these fault zones is recorded by several stages of calcite and localized dolomite cementation in fault cores and damage zone fracture networks. Based on cross-cutting relationships, petrography and geochemical analysis, the calcite cemented fracture-fills and veins can be divided into five main generations related to major deformational events associated with progressive faulting, folding and exhumation. The first calcite phase was likely associated with pre-fold to early N-S compression (-10.3‰ $< \delta^{18}$O V-PDB<-6‰ and +1.6‰ $< \delta^{13}$C <+3.5‰). The four other calcite generations are associated with syn-faulting events, which can be subdivided into two main stages including: 1) strike slip faulting, with Fe-rich calcites containing hydrocarbon fluid inclusions and displaying a wide range of ^{18}O values and more clustered δ^{13}C compositions (-11.2‰ $< \delta^{18}$O V-PDB<-1.15‰ and +0.25‰ $< \delta^{13}$C<+3‰). The wide range of δ^{18}O may relate to different thermal regimes during the structural development of the Qusaybah anticline, or to the involvement of fluids of different origins. 2) N-S extensional faulting (fold-related), with Fe-intermediate to Fe-poor calcites, containing solid bitumen inclusions and less depleted δ^{18}O values and high δ^{13}C values (-3‰ $<^{18}$O V-PDB<+1.5‰ and +3.5‰ $< \delta^{13}$C< +8‰). Whether the high δ^{13}C signature of vein and fault fills is the result of bacterial methanogenesis or CO_2 degassing is under investigation. The presence of monophase aqueous fluid inclusions in these calcites suggests precipitation temperatures below 50°C. Relatively high ^{87}Sr/^{86}Sr in all generations of Fe-rich calcites (0.7080-0.7082) suggests the inflow of fluids that had interacted with siliciclastics and/or basement rocks.

This study highlights the importance of structurally controlled diagenesis in the porosity development and fluid conduits created by faults and fractures, especially if the latter occur in potential hydrocarbon reservoirs.