Fracture controlled fluid pathways in a limestone high-pressure cell (Natih Formation, Oman Mountains): Insights from Stable Isotopes

Max Arndt[1]*, Simon Virgo[1], Stephen F. Cox[2] & Janos L. Urai[1,3]
1) RWTH-Aachen University, Structural Geology, Tectonics and Geomechanics, Lochnerstraße 4-20, D-52056 Aachen, Germany; * m.arndt@ged.rwth-aachen.de
2) Research School of Earth Sciences, The Australian National University, Canberra, ACT 0200, Australia
3) German University of Technology, GUtech, Muscat, Sultanate of Oman

We measured $\delta^{13}C$ and $\delta^{18}O$ compositions of calcite veins and their immediate limestone host-rock from an intensely veined outcrop at the top of the middle Cretaceous Natih Formation in the Central Oman Mountains.
Detailed structural and microstructural analysis shows that there are two generations of veins in the outcrop, both at high angle to bedding. Stage 1 veins are localized within a stratigraphic thickness of a few meters; they form a vein mesh with variable orientations of individual segments and with crack-seal microstructures. Mutually crosscutting relationships occur between stage 1 veins of various orientations. Stage 2 comprises younger fault veins with normal displacement; on the basis of their strike extent these are inferred to cut deeper into the stratigraphy.
The $\delta^{18}O$ composition of the limestone host-rock ranges from 22.5‰ to 23.7‰ and the $\delta^{13}C$ composition ranges from 1.1‰ to 1.9‰. This range of compositions is lower than typical mid-Cretaceous marine limestones, but is consistent with regionally developed diagenetic alteration in parts of the Natih A member. The $\delta^{18}O$ compositions of vein calcite vary from 22.5‰ to 26.2‰, whereas $\delta^{13}C$ compositions range from -0.8‰ to 2.2 ‰. Two compositional trends are apparent for vein calcite data. In trend A there is a spread in $\delta^{13}C$ values from host rock compositions to values nearly 1.3‰ lower than the immediate host rock, whereas $\delta^{18}O$ remains nearly constant. In the second composition trend (B) vein calcites have $\delta^{18}O$ values up to 3.3‰ higher than the immediate host rock range, whereas the $\delta^{13}C$ compositions are similar to the host-rock values. The majority of the trend B samples are from the Stage 2 fault vein that cross-cuts Stage 1 extension veins. The variability in C/O isotopic compositions within veins, along with the presence of crack-seal textures indicates that vein formation occurred in an episodic flow regime.
We propose two stages in the evolution of the flow system associated with vein formation. In Stage 1, the formation of the complex and dense mesh of layer-bound crack-seal extension veins involved largely stratabound flow on scales at least of tens of meters, under lithostatic fluid pressures in a high-pressure cell. Stable isotope data of extension veins indicate that ^{18}O compositions of fluids are largely buffered by the composition of the immediate host rocks, whereas ^{13}C compositions are depleted relative to the immediate host rocks and may reflect reaction of low ^{13}C-CO_2 derived by fluid interaction with organic matter in the limestones. The formation of the fault veins during Stage 2 is associated with a change in the isotopic composition of fluids in the vein mesh. ^{13}C compositions of these veins are largely in equilibrium with the immediate host rocks, whereas ^{18}O compositions are enriched relative to the immediate host-rocks. These compositions indicate that the fault-controlled flow regime accessed fluids in equilibrium with limestones up to several tens of meters beneath the vein hosting beds.