Carbonate Clumped Isotope Thermometry as a Tool to Constrain Thermal Conditions in the Shallow Crust During Deformation and Diagenesis, Paradox Basin, Utah

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Take Home Message
• Clumped isotope thermometry constrains the thermal and chemical history of fluids in carbonate basins.
• Results indicate diagenetic calcite along the Moab Fault crystallized between 0-102˚C, in line with predictions from fluid inclusion1 and stable isotope1 studies.

Study Area: Paradox Basin
The Paradox Basin, one of the most well-studied regions in the country due to its hydrocarbon reserves at depth. An intraforeland flexural basin in SE Utah, it hosts 3 km of Pennsylvanian-Jurassic sediments that underwent burial, diagenesis, exhumation in the last 120 Myr. Along the 45-km Moab Fault in the northern Paradox Basin, diagenetic calcite occurs as veins, cement, and nodules in Jurassic sandstone. Previous work suggests that this calcite crystallized closely with Pennsylvanian-derived hydrocarbon migration between 60-125˚ as fluids migrated through the Basin from depth, along fault conduits created during Laramide deformation1.

Figure 1. A. Photo of the Moab Fault, at the entrance to Arches National Park. B. Overview map of the Paradox Basin, southeast Utah. Blue indicates the maximum extent of the Paradox Formation. Red area outlined in C., after Nuccio and Condon, 1996. C. Geologic map of the Courthouse Rock section of the Moab Fault. Calcite samples for this project were collected along fault segments 2, 3, 4, and 6. Modified from Eichhubl et al., 2009.

Results
Temperature and δ18Ocalcite of Diagenetic Calcite, Moab Fault, Utah

Figure 2. Oxygen isotopic composition versus crystallization temperature of diagenetic calcite precipitated as veins and cements at Courthouse Rock (Fig. 1C). Error estimates are not shown; error in δ 18O and δ 13C is less than 0.01‰, error in temperature is less than 3˚C.

Calcites precipitated above earth surface temperatures, at temperatures consistent with estimates from fluid inclusion and stable isotope thermometry

Clumped Isotopes Background
• Temperature-dependent bonding between 13C/12C
• Clumping vs. temperature relationship independent of time, pressure, and isotopic composition of coexisting fluids, which carbonates form.

Applicable between 0-300˚C

Figure 3. A. Carbonate crystal structure. B. Clumped isotope with a ‘clumped isotope outlined

Methods
1. Extract calcite from hand samples using a dremel drill and grind with a mortar and pestle.
2. Analyze CO2 on a modified dual-inlet gas spectrometer, Caltech Automated ‘clumped isotope’ prep line and gas source dual-inlet mass spectrometer, Caltech

Figure 4. Schematic of hydrocarbon migration and calcite precipitation along a normal fault. Calcite mineralization may occur as a result of microbial oxidation of hydrocarbons1,2.

Conclusions
• Diagenetic calcite crystallized along the Moab Fault between -0-100˚C
- Calcite precipitated during fault-parallel fluid migration (c.f. Eichhubl et al., 2009)
• Average fluid δ18O composition for calcite samples is -9.6‰ ± 2.7‰ SMOW
- Predominantly meteoric signal
- δ18Owater within the range from Eichhubl et al., 2009 (-11.4 to -7.2‰ SMOW)
- Calcites precipitated from one fluid source
- Deeply circulating meteoric waters

References

Next Steps
• Analyze diagenetic calcites along the entire length of the Moab Fault
- Identify different generations of mineralization within calcite veins using cathodoluminescence
- Analyze additional samples from Courthouse Rock
- ‘Micro’-analyze multiple generations of calcite within a vein using stable isotopes

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Methods
1. Extract calcite from hand samples using a dremel drill and grind with a mortar and pestle.
3. Measure the abundance of mass-47 CO2 ions in the sample over the stochastic distribution for the same bulk composition and determine calcite crystallization temperature

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