Geophysical Research Abstracts
Vol. 17, EGU2015-7309, 2015
EGU General Assembly 2015
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Fluids in the damage zone: Insights from clumped isotope thermometry of fault-hosted carbonate cements

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Carbonate cements in fault zone rocks contain both chemical and physical information about the interaction and coevolution of their source fluids with surrounding fault rock. In this work, we present an analysis of textural relationships and isotopic compositions of carbonate cements in sandstone, within a well-characterized upper-crustal fault intersection zone, "Courthouse Junction" along the Moab Fault in southeast Utah, USA. Structures exposed at the outcrop record several phases of overprinting brittle deformation, including cataclastic deformation bands, fracturing and faulting. Carbonate diagenesis is thought to be a later stage, possibly facilitated by an increase in fault parallel permeability. Calcite is hosted within joints and concretions associated with both deformation-band faults and fracture-based faults. We have used cathodoluminescence, oxygen and carbon isotopes, and clumped isotope paleothermometry to differentiate two populations of calcite cement in the fault intersection zone: cool (<35˚C) cements with dull luminescence and warm (up to 90˚C) cements with red to bright orange luminesce. Warmer cements are depleted in ^{13}C relative to the cool cements. The difference in luminescence suggests that the two populations of carbonate have distinct trace element compositions. Oxygen isotopic composition of the source fluid is not correlated with temperature, and ranges from -14 and to -4 ‰ (VSMOW). These values overlap with local modern meteoric waters, but are generally more enriched in ^{18}O, suggesting the presence of non-meteoric source fluids during carbonate precipitation. A map of the spatial distribution and structural setting of the cements reveals that the cool cements are restricted to the damage zone closest to the major faults and are associated with deformation bands. The warmer cements are ubiquitous throughout the outcrop and are principally hosted by joints. Considering the differences between the structural setting and chemical composition of the two cement populations, we consider two competing hypotheses for the origin and timing of cementation at Courthouse Junction: 1) The two cements represent two fluid sources present simultaneously, with warm cements reflecting ambient conditions and the cool cements transmitted along the high-permeability damage zone. 2) The two cements are derived from a single hydrocarbon-rich source fluid that underwent a thermally-mediated change in decomposition mechanism, resulting in the observed change in ^{13}C values. These hypotheses can be evaluated using CL-based observations of the relative age relationships among cements and their relationships to the brittle deformation that produced their heterogeneous distributions.