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Paleofluid flow and basement-cored folding: Combined geochemical and microstructural studies at Sheep Mountain Anticline (Wyoming, USA)

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Paleofluid flow during basement-cored folding are investigated and reconstructed in a Laramide asymmetrical fold related to a blind thrust: the Sheep Mountain Anticline, Wyoming, USA. By combining isotope data (Oxygen, Carbone, and Strontium), observations under cathodoluminescence and fluid inclusion microthermometric study with a previous well-defined microstructural data set, we here determine the origin, the pathway and the interactions between fluids, host rocks and fracture pattern at the reservoir scale. Furthermore, we discuss the structural implications of these results on the structural evolution of the fold/thrust system. Isotope study was performed on pre-folding and fold-related calcite veins and their sedimentary host rocks.

The comparison of oxygen isotope data with fluid inclusion microthermometry data reveals that most of the fluids filling the fold-related fracture sets precipitate from an upward flow of Paleogene meteoric fluid heated at depth. We can also split these precipitations into a first group of veins cemented by calcite from fluids poorly equilibrated with their host rocks (corresponding to syn-folding fracture set), and a second group of veins cemented by calcite from fluids more equilibrated with their host-rocks (corresponding to LPS-related fracture sets). Moreover, the high temperature of fluid precipitation indicated by fluid inclusion microthermometry (Th>110°C) suggests a correlation between the veins with the most depleted δ18O values and the high temperature of fluid flow.

A projection of δ18O values in map-view at the fold-scale highlights a localized zone of fluids which have precipitated with depleted δ18O values (δ18O$\leq$-19‰ , striking parallel to the actual hinge of the fold, but shifted toward the backlimb. This zone of hot fluids entails the occurrence of an efficient vertical conduit in the cover, mainly composed by impermeable shales, and could imply the propagation of the basement fault into the sedimentary cover. Even if the minimal temperature reached by the fluids suggest that fluids likely flew beneath the basement-cover interface, the 87Sr/86Sr ratios show mainly poorly radiogenic fluids, which implies a complex fluid migration at the basin scale discussed in this study.

The integration of all data sets supports a reservoir-scale fluid flow scenario involving the basement fault as an efficient vertical conduit in the basement and the syn-folding fracture set as the main efficient lateral and vertical conduits within the cover, especially above the fold tip. The localization of the zone of fast migration of heated fluids in map-view and in cross-section constrains the location of the tip of the basement thrust and its geometry at depth, which leads to a new balanced cross-section of the fold. The shift of this zone from the actual hinge toward the backlimb suggests the existence of a proto-hinge and its possible localization/migration during fold growth. This study illustrates the potential of combining microstructural and geochemical analyses of paleofluid flow in diffuse fracture sets to constrain foreland deformation, especially basement-involved shortening and therefore the structure and kinematics of Laramide-type thick-skinned orogenic forelands.