Isotope analysis of vein-hosted fluid inclusions: A case study on fracture-controlled fluid flow in the Albanian foreland fold-and-thrust belt

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Vein-hosted fluid inclusions may represent remnants of subsurface paleo-fluids and therefore provide a valuable record of fracture-controlled fluid flow. Isotope data (\(\delta^2\)H and \(\delta^{18}\)O) of fluid inclusions are particularly useful for studying the provenance and type of paleo-fluids circulating in the subsurface. Although isotopic analysis of sub-microliter amounts of fluid inclusion water is not straightforward, major steps forward have been made over the past decade through the development of continuous-flow set-ups. These techniques make use of mechanical crushing at a relatively low-temperature (110°C) and allow for on-line analysis of both \(\delta^2\)H and \(\delta^{18}\)O ratios of bulk fluid inclusion water. However, continuous-flow techniques have mostly been used in speleothem research, and have not yet found a widespread application on vein systems for hydrogeological reconstructions.

We used isotope data of fluid inclusions hosted in calcite vein cements to reconstruct regional fluid migration pathways in the Albanian foreland fold-and-thrust system. Tectonic forces during thrust emplacement typically instigate distinct phases of fracturing accompanied by complex fluid flow patterns. The studied calcite veins developed in a sequence of naturally fractured Cretaceous to Eocene carbonate rocks as a result of several fracturing events from the early stages of burial onward. Fluid inclusion isotope data of the veins reveal that fluids circulating in the carbonates were derived from an underlying reservoir, which consisted of a mixture of meteoric water and evolved marine fluids, probably derived from deep-seated evaporites. The meteoric fluids infiltrated in the hinterland before being driven outward into the foreland basin. The fluid inclusion isotope data furthermore show that meteoric water becomes increasingly dominant in the system through time as migration pathways shortened and marine formation fluids were progressively flushed out.

The diagenetic stability of fluid inclusions is of key interest in the study of their isotope ratios. Recrystallization, secondary fluid infiltration and isotope exchange processes could potentially drive alterations of fluid inclusion isotope signatures after entrapment. In this case, however,
isotope signatures of fluid inclusions seem to have remained largely unaltered, despite the Cretaceous to Tertiary age of the vein system. Oxygen isotope exchange processes between the fluid inclusion water and host mineral could have been inhibited at the relatively low temperatures of vein formation (i.e. <80°C). Although more research into the diagenetic stability of fluid inclusion isotope ratios is required, the fluid inclusion isotope record has potential as a powerful tool for fluid provenancing in subsurface fluid flow systems.