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A new approach for unveiling fluid isotopic signature from polymineralic gouges

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In fault zones, circulating and mineralizing fluids may vary in temperature and composition, leading to the precipitation of different authigenic minerals (e.g., carbonates, clay minerals). In carbonate-hosted faults, stable and clumped isotopes analyses, microthermometry of fluid inclusions, and U-Pb dating of carbonate mineralizations are applied to determine temperature, composition, origin of fluids and time of faulting. The mineral-water fractionation factor (α) represents to the difference in isotopic composition between a mineral and the water with which it interacts, and it quantifies how isotopes are exchanged between a mineral and water as function of temperature. In carbonate-hosted faults, the mineral-water fractionation factor (α) refers to a single mineral phase (e.g., calcite) occurring in the mineralization. In clay-rich fault zones, gouges are composed of polymineralic assemblage made up of neoformed and inherited minerals from the host-rock. Here, the application of the mineral-water fractionation factor is more challenging, as each mineral contributes to the rock isotopic signature. Most papers on clay-rich gouges refer to nearly monomineralic samples where the prevalent mineral has a content >90%, leading to a very low number of data, and limiting the application of isotope studies on clay-rich fault rocks. We developed a new approach to calculate the water-signature directly from polymineralic samples, combining H, O isotopes and X-ray diffraction of clay-rich gouges on dated grain size fractions (from <0.1 to 10 μm). We investigated two regional-scale extensional faults on Lemnos Island (Greece), the Kornos-Aghios Ioannis fault and the Partenomythos fault, affected by Si-rich hydrothermal alteration. Our findings show that authigenic clay minerals are not in isotopic equilibrium with the host-rock, indicating that meteoric-waters infiltrated during faulting and mixed with hydrothermal fluid since Miocene time. Then, combining mineralogical, geochronological, and geochemical data, we reconstructed the compositional development of fluids through time with a fluid evolutionary model, as a function of the polymineralic fractionation, fluid-rock interaction processes, and temperature variation. This approach represents an important step forward for a deeper understanding of fluid isotopic evolution in clay-rich fault zones and constitutes a valuable tool for identifying fluid mixing in the shallow crust.