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Geochronologic and geochemical characterization of metasomatism in shear zones using apatite petrochronology

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Fluid-rock interactions involve mechanical and chemical processes that affect rheological properties, strain gradients and localization, permeability and material transport, and the mineralogy and strength of rocks in fault and shear zones. Apatite petrochronology is a powerful tool for constraining the timing of deformation and metasomatism and the geochemical nature of fluids, which are important aspects to understanding these geologic processes. We integrate microstructural, U-Pb, and trace and rare earth element (TREE) analysis of apatite from an exhumed extensional mylonitic shear zone, the Main Mylonitic Band (MMB), in the St. Barthélémy Massif, Northern Pyrenees, France. The North Pyrenean Zone represents a partially inverted, hyperextended rift margin that experienced crustal thinning, HT-LP metamorphism, and subcontinental mantle exhumation in the Early Cretaceous.

Apatite from the footwall gneisses show evidence of crystal plastic deformation characterized by low-angle boundaries (<5°) associated with dislocation creep and 120-100 Ma U-Pb dates that record ductile deformation. Apatite from (ultra)mylonitic portions of the shear zone show evidence of metasomatic alteration via coupled dissolution-reprecipitation. Single grain TREE and U-Pb maps show geochemically and geochronologically distinct domains of original and reacted apatite. Metasomatized apatite grains show low to no lattice misorientations. Some internal misorientations are likely from earlier crystal plastic deformation overprinted by dissolution-precipitation, suggesting apatite was deforming via dislocation creep and as rocks were exhumed, strain and fluids were progressively localized within the MMB. Apatite U-Pb analysis yields dates between 300-100 Ma, with youngest dates constraining the timing of metasomatism. The geochemical signatures enriched in light rare earth elements suggest that fluids were deep crustal and(or) mantle derived. Metasomatism in the shear zone was coeval with ductile deformation and exhumation of middle-lower crustal gneisses, subcontinental mantle exhumation, and significant metasomatism in the brittle hanging wall. The MMB likely acted as a conduit for deeply sourced fluids that affected the brittle-ductile transition, strain localization, and fluid pathways through the crust. Results collectively demonstrate that fluid-mediated reactions and crystal-plastic microstructures affect TREE and U-Pb systems, making apatite petrochronology a powerful tool for dating and characterizing the latest major deformation and fluid events, often not captured by higher temperature chronometers.