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A combined microstructural and geochronological approach to reconstruct the structural and fluid history of a terrane-bounding deformation zone

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Crustal-scale deformation zones play a key role in accommodating deformation in the Earth's crust and providing pathways for fluids, magmatism and ore mineralization. Reconstructing the evolution of these complex deformation corridors presents a significant challenge as evidence of earlier fluid and deformation events is often obscured by later overprinting events. Here we combine detailed petrographic and microstructural analysis with *in situ* geochronology of key phases to characterize and date distinct deformation and fluid events in long-lived deformation zones. We present petrography, EBSD data, and geochronological results from the Llewellyn-Tally Ho deformation corridor, a major terrane-bounding deformation zone in the northern Canadian Cordillera that records ductile fabrics in Late Triassic gabbro, Jurassic and Cretaceous magmatism, and late brittle faulting and associated mineralization. Within the ductile high-strain zone of the deformation corridor, dated minerals are characterized based on genetic textures, microstructures and distinct isotopic and geochemical signatures. Titanite aligned with ductile fabrics record synkinematic dynamic (re)crystallization at ca. 211 Ma, while magnetite-mantling titanite preserve evidence of at least two fluid events at ca 185 and 115 Ma. Prismatic apatite inclusions in augite phenocrysts record post-crystallization cooling at ca. 212 Ma, whereas apatite in the deformed matrix preserve microstructures and geochemistry consistent with partial recrystallization of pre-existing apatite at ca. 115 Ma. Outside of the ductile high-strain zone, narrow (<1 m) brittle-ductile high-strain zones associated with the brittle fault zone are defined by networks of fine-grained white mica that yield Rb-Sr dates of ca. 75 Ma, reflecting dynamic neocrystallization. Fault-related carbonate yield U-Pb dates of ca. 47–44 Ma. These new data indicate that the main stage of ductile deformation began shortly after emplacement of the Late Triassic gabbro. At least two post-kinematic fluid events at 185 Ma and 115 Ma broadly coincide with local magmatism. The development of discrete brittle-ductile deformation fabrics at ca. 75 Ma within mid- and Late Cretaceous plutons is followed by a final, Eocene brittle deformation and fluid event, recorded by the fault-related carbonate. This study demonstrates the effectiveness of a multidisciplinary approach in characterizing distinct deformation and magmatic-hydrothermal events influencing long-lived, complex deformation systems.