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Low-T mineral assemblages record the transition from early crustal softening to strain and fluid flow localization in the Bielsa massif (central Pyrenees) over 310 Ma

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This study uses low-T petro-chronology to establish a link between the rheological effects of low-T fluid-rock interactions and fluid flow. Newly-formed mineral assemblages during fluid-rock interactions are controls of fluid paths and deformation mechanisms during the evolution of orogens, where polyphased deformations are commonplace. In the cold and external domains of mountain belts, these interactions are therefore difficult to distinguish and characterize because they occur at low-T and low-P conditions. For this reason, in the central Pyrenees (Axial zone), the metamorphism associated to the Variscan deformation is hardly distinguishable from the Alpine one.

In this study*, we have characterized the different phases of low-grade metamorphism recorded in the Variscan granitic Bielsa massif, underthrusted below the Gavarnie unit during the Cenozoic orogenic evolution. In the studied area (Lake of Urdiceto), undeformed granite alternates with fractured and mylonitic rocks. In all samples, regardless the strain, the original magmatic mineral assemblage of biotite ± amphibole, plagioclase, K-feldspar, quartz and ilmenite is altered to a Fe-rich chlorite (chlorite1) ± white mica, ± prenhite. The titanium content of magmatic biotite and amphibole is incorporated in secondary Ti-bearing phases (rutile1 or titanite). The replacement reactions are pseudomorphic and fluid proceeds through microcraks. In 'discretely' deformed samples, flakes of chlorite and titanite are folded and cross-cut by fractures filled with Fe-poor chlorite (chlorite2), rutile2 ± monazite. In mylonites, rutile2 is the principal accessory mineral. Crystallization temperatures estimated with the multi-equilibrium approach for chlorite1 range between 300 and 350°C, while they range between 200 and 250°C for chlorite2. In-situ U/Pb LA-ICP-MS dating of rutile1, titanite and monazite yields ages of c. 310-280 Ma, while rutile2 and younger monazite domains show ages of c. 40-50 Ma. We conclude that the Bielsa granitic basement was softened and altered at low-T conditions at the late-Variscan, allowing a diffuse deformation. Low-T metamorphism and deformation was then localized during the Pyrenean phase as attested by the occurrence of the youngest rutile2 and monazite in the only mylonites. Furthermore, the occurrence of titanite over rutile is observed to be mainly dependent on the CO_2 activity of the fluid phase. Rutile occurs along mylonitic bands, where a localization of the fluid flow accompanying the Pyrenean metamorphism is speculated. The composition of secondary chlorite also varies from rutile-bearing to titanite-bearing samples. Hence, the spatial occurrence of accessory minerals and the chemical variations of chlorite2 allow the composition and circulation paths of the paleofluids to be mapped.

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