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Baddeleyite + W-bearing zirconolite + zircon-bearing veins as indicators for the polymetamorphic evolution of the eastern, lower Austroalpine nappes (Stubenberg Granite contact aureole, Styria, Eastern Alps, Austria)

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Contact metamorphism during emplacement of the Permian Stubenberg Granite has led to the formation of the assemblage forsterite + calcite + titanian clinohumite $\pm$ phlogopite $\pm$ chlorite in the adjacent marbles. During intrusion of the granite, veins, rich in Ti, Zr, REE and actinides (U + Th) formed. These veins show a distinct mineralogical zoning sequence with four zones. Going from the center of the vein to the margin, these zones include: (1) geikielite + baddeleyite + zirconolite + apatite + calcite + chlorite $\pm$ magnetite $\pm$ pyrrhotite assemblage, (2) calcite + chlorite, (3) forsterite + titanian clinohumite + chlorite + calcite $\pm$ phlogopite and (4) calcite $\pm$ forsterite. Baddeleyite is always replaced by zirconolite, possibly via the model reaction baddeleyite + 2 geikielite + 3 calcite + CO_2 = zirconolite + 2 dolomite. Zirconolites (Zirc I) show a strong internal oscillatory zoning and distinct overgrowths (Zirc II), which have a different chemical composition. The chemical variation between the cores (Zirc I) and the rims (Zirc II) can be explained by using the substitutions: Me^{5+} + Me^{2+} (Ti + Me^{3+} and REE + Me^{5+} + Me^{2+} (Ca + 2Ti. In contrast to zirconolites from metacarbonates associated with contact aureoles, these analyses show elevated Nb contents of up to 4.5 wt.% Nb_2O_5 and unusually high W contents of 1 – 2 wt.% WO_3. The Zr-mineral sequence baddeleyite – zirconolite – zircon implies an increasing a(SiO_2) and fCO_2 during the growth of these minerals. A strong Eo-Alpine metamorphic overprint

led locally to the formation of the assemblage chlorite + dolomite + calcite ± ilmenite ± zirconolite II ± geikielite + Fe-sulfides. Late zircon grew locally, presumably as the last Zr-mineral in the carbonates during the Permian contact metamorphism. Electron microprobe U-Th-Pb dating of zirconolites (Zirc I) yields weighted average ages of 263 ± 16 Ma and indicates that the HFSE- and REE-rich assemblages formed during Permian emplacement of the Stubenberg granite. As a result of the subsequent high-P Eo-Alpine metamorphic overprint (111 ± 15 Ma), zirconolite recrystallization occurred, leading to dissolution of zirconolite I and re-precipitation of the REE and Nb-rich overgrowths of zirconolite II.