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The occurrence and chemistry of Ti-oxide phases and their timing of crystallization along the P2 fault, Athabasca Basin, Saskatchewan, Canada

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Titanium oxide minerals are examined in hydrothermally altered rocks along the P2 fault, the main structure hosting the McArthur River deposit. Two TiO_2 polymorphs occur with contrasting mineral assemblages: i) rutile with oxy-dravite, graphite, pyrite, zircon and quartz in basement metapelite, and ii) anatase with hematite (± dolomite, kaolin, illite and aluminum phosphate sulfate minerals) in basement rocks and overlying sandstone. Rutile contains variably high Nb_2O_5 (up to 3.86 wt.%), Ta_2O_5 (up to 0.42 wt%), Cr_2O_3 (up to 0.48 wt.%), Fe_2O_3 (up to 1.48 wt.%), ZrO_2 (up to 0.49 wt.%), WO_3 (up to 2.54 wt.%), and V_2O_3 (up to 2.12 wt.%), suggesting low water/rock ratios during crystallization. The coupled substitution mechanisms $M^{3+} + M^{5+} \rightarrow 2Ti^{4+}$ and $2M^{3+} + M^{6+} \rightarrow 3Ti^{4+}$ partially explain the incorporation of non-tetravalent cations in rutile. However, high abundances of trivalent cations relative to pentavalent and hexavalent cations, coupled with weak Raman shifts near 3100 cm^{-1}, indicate protonation of oxygen in rutile crystal structure through the exchange $M^{3+} + OH^- \rightarrow Ti^{4+} + O^{2-}$. The Zr-in-rutile geothermometer yields temperatures between 740 and 890 °C, reflecting granulite facies regional metamorphic conditions of the 1.8 Ga Trans Hudson Orogeny. However, the U-Pb ages of rutile are young, ranging from 1726 to 1771 Ma. The rutile ages represent either i) slow cooling to 400-500 °C, or ii) a thermal event, possibly related to the ~1.75 Ga anorogenic Neultin Suite. With the exception of variably high Fe_2O_3 (up to 1.96 wt.%), anatase contains low elemental impurities reflecting crystallization at low temperature. High Fe^{3+} is likely accommodated by substitution with OH^-. Anatase gives a relatively young age of 1569 ± 31 Ma in the basement far below the unconformity, indicating the onset of oxidizing basinal hydrothermal activity in the basement rocks along the P2 fault.