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Experimental constraints on rutile saturation during partial melting of metabasalt at the amphibolite to eclogite transition, with applications to TTG genesis

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Abstract

TiO_2 solubility in rutile-saturated felsic melts and coexisting minerals was determined at 1.5–3.5 GPa, 750–1250 °C, and 5–30 wt% H_2O. TiO_2 solubility in the melt primarily increases with temperature and melt basicity; it increases slightly with water content in the melt, and it decreases with pressure. A general TiO_2 solubility model was obtained and is expressed as: $\ln(TiO_2)_{melt} = \ln(TiO_2)_{rutile} + 1.701 - (9041/T) - 0.173P + 0.348FM + 0.016H_2O$, where TiO_2 and H_2O are in wt%, T is in Kelvin, P in GPa, and FM is the melt composition parameter given by $FM = (1/Si)\cdot[Na + K + 2(Ca + Fe + Mn + Mg)]/Al$, in which the chemical symbols represent cation fractions. TiO_2 solubility in amphibole, garnet, and clinopyroxene also increases with temperature and empirical equations describing this temperature dependence were derived. These data were used to assess the protolith TiO_2 content required for rutile saturation during partial melting of hydrous metabasalt at the amphibolite to eclogite transition. The results show that only 0.8–1.0 wt% TiO_2 is required for rutile saturation during low-degree (<20%) melting. Rutile is stable up to ~1150 °C with 1.6 wt% TiO_2 in the protolith and 30–40% melting for dehydration melting and up to ~1050 °C and 50–60% melting for fluid-present melting. The data also show that 0.7–0.8 wt% TiO_2 in the protolith is needed for rutile saturation during subsolidus dehydration. Therefore, nearly all basaltic protoliths in deep-crustal settings and subduction zones will be saturated with rutile during subsolidus dehydration and low-degree melting at hydrous conditions.

Archean tonalites-trondhjemites-granites (TTG) are widely accepted to be the products of low-degree melting of metabasalts at the amphibolite to eclogite transition, with rutile being present in the residue. Comparison of natural TTG compositions with our experimental rutile solubility data indicates that the dominant TTG magmas were produced at temperatures of 750–950 °C, which requires that the partial melting occurred at hydrous conditions. Models involving melting at the base of oceanic plateaus are inadequate to explain TTG genesis because the plateau root zones are likely dominated by anhydrous cumulates. A slab-melting model satisfies the requirement of a hydrous metabasalt, which during subduction would melt to produce voluminous TTG melts under high Archean geothermal gradients. The geothermal gradients responsible are estimated to be between 10 and 19 °C/km based on a pressure range of 1.5–2.5 GPa for the amphibolite to eclogite transition.

Keywords: Rutile, amphibolite to eclogite transition, partial melting, TTG, Archean subduction