

P-T-D Histories and Reequilibration of Ti in Quartz: Using the TitaniQ Thermobarometer in Poly-Deformed Tectonic Terranes

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Constraining *P-T* conditions of deformation is essential in understanding lithospheric processes at all scales. The Ti-in-quartz ("TitaniQ") thermobarometer [1] has the potential to constrain either *T* or *P* if the other is known and if titania activity (a_{TiO_2}) can be estimated. The extensive petrologic and structural framework previously established for the Strafford Dome, coupled with abundant quartz in various microstructural settings, provides and excellent case study for investigating use of the method in poly-deformed terranes. Two nappe emplacements (*D*₁ and *D*₂) and a following doming event (*D*₃) resulted in three schistosity (*S*₁-*S*₃) that provide a framework to investigate whether [Ti] of quartz in different microstructural settings records *P-T* conditions of fabric formation. We conducted cathodoluminescence (CL) imaging to observe Ti-zoning in quartz grains and secondary ionization mass spectrometry to determine [Ti].

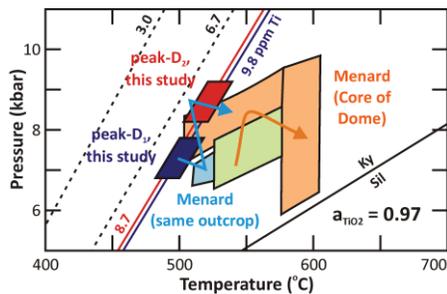


Figure 1: *P-T* paths calculated by TitaniQ from this study compared to proximal samples constrained in previous studies.

Results from these analyses coupled with previously established *P-T* paths [2] indicate that quartz preserves evidence for five recrystallization or reequilibration periods: 1) prograde (dark cores in CL, [Ti] = 2–3 ppm); 2) peak *D*₁ reequilibration (bright rims on quartz inclusions, [Ti] = 5.5 ppm); 3) dark rims on *D*₁ rims due a quartz-producing, kyanite-in reaction (sharp zonal sector contact); 4) peak *D*₂ in matrix quartz ([Ti] up to 9.8 ppm); and 5) retrograde reequilibration (darker rim in CL due to reduced *T* conditions). Rapid exhumation prevented extensive retrograde overprinting. This study has shown that TitaniQ coupled with microstructural analysis can provide insight into prograde conditions and reequilibration relative to deformation in poly-deformed terranes.

[1] Thomas *et al.* (2010) *Contrib Mineral Petrol* **160**, 743-759.

[2] Menard and Spear (1994) *J. Metamorphic Geol.* **12**, 811-826.

Equation of state for CaO-FeO-MgO-Al₂O₃-SiO₂ melts and evolution of a whole-mantle magma ocean

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Understanding the consequences for Earth evolution of formation and crystallization of a magma ocean – plausibly involving the entire silicate earth, e.g. after a moon-forming impact – requires detailed knowledge of the physics and thermochemistry of multi-component silicate liquids at all mantle pressures (*P*), near-liquidus temperatures (*T*), and a range of candidate bulk silicate Earth compositions. Also, a grasp of deep mantle partial melting (e.g. at the core-mantle boundary (CMB)) requires similar information for a wider range of liquids (with high volatile and incompatible concentrations) at near-solidus *T*.

There are sufficient constraints from shock wave data and first principles molecular dynamics to define the thermal equation of state (EOS) of end-members spanning the five oxides CaO-FeO-MgO-Al₂O₃-SiO₂. FeO-bearing compositions (Fe₂SiO₄ and CaFeSi₂O₆) have recently had their Hugoniot defined to CMB *P*; Fe₂SiO₄ results agree well with new simulations [1]. We still need to assume ideal mixing of volumes (except along MgO-SiO₂ [2]) to fill composition space, but two intermediate compositions that have been determined are consistent with this approximation. Hence, the data support construction of a liquid EOS able to describe density and compute isentropes for ultramafic to mafic liquids of varying composition.

The thermal EOS of each of five endmembers – CaMgSi₂O₆, CaAl₂Si₂O₈, MgSiO₃, Mg₂SiO₄, Fe₂SiO₄ – can be fit to one of several formalisms: (1) 4th order Birch-Murnaghan isentrope with Mie-Grüneisen (M-G) thermal pressure and constant heat capacity; (2) a linear shock wave EOS with M-G thermal offset; or (3) de Koker and Stixrude's fundamental relation [3]. Properties of other liquids are derived by assuming constant partial molar volume and heat capacity of the five endmembers at each *P* and *T*. Isentropes of intermediate compositions can be computed iteratively.

The liquidus curve for KLB-1 peridotite of [4] gives a critical isentrope with potential temperature 2800 K for onset of perovskite crystallization in the mid-lower mantle at ~80 GPa. But the steeper liquidus curve for model chondritic mantle by [5] gives a critical isentrope with potential temperature 2600 K for crystallization at the CMB. We find the neutrally buoyant liquids at the CMB as a function of Mg# and (Mg+Fe)/Si: at perovskite stoichiometry, liquid Mg# ≤ 0.55 is needed for liquid density to exceed that of MgSiO₃ perovskite, whereas at olivine stoichiometry only Mg# < ~0.9 is needed.

[1] Muñoz Ramo & Stixrude (submitted) *PRL*. [2] de Koker *et al.* (submitted) *Nature*. [3] de Koker & Stixrude (2009) *GJI* **178**, 162-179. [4] Fiquet *et al.* (2010) *Science* **329**, 1516-1518. [5] Andraut *et al.* (2011) *EPSL* **304**, 251-259.