American Mineralogist, Volume 92, pages 491–502, 2007

The barometer tremolite + tschermakite + 2 albite = 2 pargasite + 8 quartz: Constraints from experimental data at unit silica activity, with application to garnet-free natural assemblages

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ABSTRACT

Garnet is notably absent in mafic to felsic lithologies, in low-*P* metamorphic terranes, and in Mg-rich bulk compositions in high-*P* regionally metamorphosed terranes. In the absence of garnet, existing mineral barometers cannot be applied for estimating metamorphic pressure. A new garnet-free, hornblende-plagioclase barometer has been formulated based on the reaction tremolite + tschermakite + 2 albite = 2 pargasite + 8 quartz. The intra- and cross-site mixing parameters for hornblende were retrieved exclusively from experimental data in the *P-T* window 1–15 kbar and 650–950 °C, after screening the available data for the presence of quartz. A linear least-squares fit to the coexisting hornblende and plagioclase composition in the experiments yields the following barometric expressions:

$$P_1(\text{kbar}) = [-9.326 + 0.01462\text{T (K)} + \text{R}T\ln K_{\text{ideal}} - 98.698X^{\text{A}}_{\text{Na}} - 33.213X^{\text{A}}_{\text{K}} - 20.338X^{\text{M4}}_{\text{Na}} - 39.101X^{\text{M13}}_{\text{Fe}^{2+}} + 100.392X^{\text{M2}}_{\text{Al}} + 131.03X^{\text{M2}}_{\text{Fe}^{2+}} + 82.479X^{\text{M2}}_{\text{Fe}^{3+}} - 118.653X^{\text{T1}}_{\text{Al}} - 2\text{R}T\ln\gamma_{\text{Ab}}]/(-\Delta V)$$

and

$$P_2(\text{kbar}) = [-1.869 + 0.0076\text{T (K)} + \text{R}T\ln K_{\text{ideal}} - 102.692X^{\text{A}}_{\text{Na}} - 35.251X^{\text{A}}_{\text{K}} - 15.969X^{\text{M4}}_{\text{Na}} - 40.499X^{\text{M13}}_{\text{Fe}^{2+}} + 93.069X^{\text{M2}}_{\text{Al}} + 130.750X^{\text{M2}}_{\text{Fe}^{2+}} + 74.226X^{\text{M2}}_{\text{Fe}^{3+}} - 104.402X^{\text{T1}}_{\text{Al}} - 2\text{R}T\ln\gamma_{\text{Ab}}]/(-\Delta V)$$

where

$$K_{\text{ideal}} = \left[\frac{16(X^{A}_{\text{Na}})(X^{\text{T1}}_{\text{Al}})}{(X^{A}_{\square})(X^{\text{T1}}_{\text{Si}})(X_{\text{Ab}})}\right]^2.$$

X^{j}_{i} denotes the mole fraction of cation i in site j of amphibole, X_{Ab} and γ_{Ab} are the mole fraction and activity coefficient of albite in plagioclase, respectively, and ΔV is the volume change for the reaction. In the expression for P_2, the first two terms in the numerator on the right-hand side corresponding to $\Delta H°$ and $\Delta S°$, respectively, were adopted from an internally consistent thermodynamic database. In the expression for P_1, the first term on the right-hand side of the numerator, $\Delta\hat{H}$ (–9.326 kJ) = $\Delta H° + a_9$, where a_9 is a mixing parameter, and the second term $\Delta S° = 0.01462$ kJ/K, were retrieved by a linear least-squares fit to the experimental data. The formulations reproduced experimental *P* values within 2 kbar for 83% of the experimental runs. The cumulative precision (1σ) of pressure estimated using the formulations varied between 800 and 2000 bars for errors propagated due to uncertainties in *P-T*, volume, and thermometric estimate, and inaccuracies in estimated composition of phases. In natural assemblages spanning a pressure range of 2.5 to 12.5 kbar, the quartz–hornblende–plagioclase barometers yielded pressure within 2 kbar of the *P*-value recommended by the authors, and is consistent with the stable Al_2SiO_5 polymorph in associated metapelites.

Keywords: Thermobarometry, hornblende, plagioclase, quartz, thermodynamics, mixing parameters of hornblende, experimental petrology, mafic rocks, silica-saturated, metamorphic petrology