

New clinopyroxene-liquid thermobarometers for mafic, evolved, and volatile-bearing lava compositions, with applications to lavas from Tibet and the Snake River Plain, Idaho

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ABSTRACT

Our ability to calculate the depths and temperatures at which magmas partially crystallize can prove crucial as petrologists test hypotheses of magma transport and evolution. Yet whereas numerous magma transport arguments involve hydrous and SiO₂-rich volcanic products, current clinopyroxene-liquid thermobarometers have been calibrated only from basaltic liquid compositions. To remedy this deficiency, new thermobarometers have been calibrated using new experiments that include hydrated (water-undersaturated) and SiO₂-rich liquids ranging to 71.3 wt% SiO₂. As with prior models, the new calibrations are based on jadeite crystallization and jadeite-diopside + hedenbergite exchange equilibria:

$$P(\text{kbar}) = -88.3 + 2.82 \times 10^{-3} T(\text{K}) \ln \left[\frac{[\text{Jd}^{\text{cpx}}]}{[\text{Na}^{\text{liq}} \text{Al}^{\text{liq}} (\text{Si}^{\text{liq}})^2]} \right] + 2.19 \times 10^{-2} T(\text{K}) - 25.1 \ln[\text{Ca}^{\text{liq}} \text{Si}^{\text{liq}}] \\ + 7.03[\text{Mg}^{\text{liq}}] + 12.4 \ln[\text{Ca}^{\text{liq}}]$$

$$\frac{10^4}{T(\text{K})} = 4.60 - 4.37 \times 10^{-1} \ln \left[\frac{[\text{Jd}^{\text{cpx}} \text{Ca}^{\text{liq}} \text{Fm}^{\text{liq}}]}{[\text{DiHd}^{\text{cpx}} \text{Na}^{\text{liq}} \text{Al}^{\text{liq}}]} \right] - 6.54 \times 10^{-1} \ln[\text{Mg}^{\text{liq}}] - 3.26 \times 10^{-1} \ln[\text{Na}^{\text{liq}}] \\ - 6.32 \times 10^{-3} [P(\text{kbar})] - 0.92 \ln[\text{Si}^{\text{liq}}] + 2.74 \times 10^{-1} \ln[\text{Jd}^{\text{cpx}}]$$

Here, T is in Kelvins and P is in kbar. Jd^{cpx} is the mole fraction of jadeite in clinopyroxene, where pyroxene cations are calculated on the basis of 6 O atoms, and Jd is the lesser of Na or $^{\text{VI}}\text{Al}$; remaining Al is used to form CaTs . DiHd^{cpx} is the mole fraction of diopside + hedenbergite in clinopyroxene, calculated as the fraction of Ca remaining after forming CaTs ($= ^{\text{VI}}\text{Al} - \text{Jd}$), $\text{CaTiAl}_2\text{O}_6$ [$= (^{\text{VI}}\text{Al} - \text{CaTs})/2$], and $\text{CaCr}_2\text{SiO}_6$ ($= \text{Cr}/2$). Terms such as Al^{liq} refer to the cation fraction of $\text{AlO}_{1.5}$ in the liquid, Fm^{liq} is the sum $\text{FeO}^{\text{liq}} + \text{MgO}^{\text{liq}}$, and Mg^{liq} is the cation fraction ratio $\text{MgO}^{\text{liq}}/(\text{MgO}^{\text{liq}} + \text{FeO}^{\text{liq}})$. Errors are similar to earlier models that utilize basalt compositions only. For the barometer, $R^2 = 0.97$ and the standard error of estimate (SEE) is 1.7 kbar for the regression data; for the thermometer $R^2 = 0.96$ and the SEE is 33 K. The models are applied to Neogene lavas from the Tibetan Plateau, and Neogene-Quaternary lavas from the eastern Snake River Plain (SRP), Idaho. Crystallization depths for Tibet cluster at the middle/lower crust boundary. Magma-crust density relationships suggest that the middle crust may act as a level of neutral buoyancy. In the SRP, however, magmas appear to bypass several possible density traps. We suggest that fracture properties, such as dike size and aspect ratio, control magma transport in the SRP.