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SPECIAL COLLECTION: RATES AND DEPTHS OF MAGMA ASCENT ON EARTH

A new clinopyroxene-liquid barometer, and implications for magma storage pressures under Icelandic rift zones

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Abstract

Pressure is one of the key variables that controls magmatic phase equilibria. However, estimating magma storage pressures from erupted products can be challenging. Various barometers have been developed over the past two decades that exploit the pressure-sensitive incorporation of jadeite (Jd) into clinopyroxene. These Jd-in-clinopyroxene barometers have been applied to rift zone magmas from Iceland, where published estimates of magma storage depths span the full thickness of the crust, and extend into the mantle. However, tests performed on commonly used clinopyroxene-liquid barometers with data from experiments on H_2O-poor tholeiites in the 1 atm to 10 kbar range reveal substantial pressure-dependent inaccuracies, with some models overestimating pressures of experimental products equilibrated at 1 atm by up to 3 kbar. The pressures of closed-capsule experiments in the 1–5 kbar range are also overestimated, and such errors cannot be attributed to Na loss, as is the case in open furnace experiments. The following barometer was calibrated from experimental data in the 1 atm to 20 kbar range to improve the accuracy of Jd-in-clinopyroxene barometry at pressures relevant to magma storage in the crust:

$$P(\text{kbar}) = -26.27 + 39.16\frac{T(\text{K})}{10^4}\ln\left[\frac{X_{\text{Jd}}^{\text{Cpx}}}{X_{\text{NaO}_{0.5}}^{\text{liq}} X_{\text{AlO}_{1.5}}^{\text{liq}}\left(X_{\text{SiO}_2}^{\text{liq}}\right)^2}\right] - 4.22\ln\left(X_{\text{DiHd}}^{\text{Cpx}}\right) + 78.43X_{\text{AlO}_{1.5}}^{\text{liq}} + 393.81\left(X_{\text{NaO}_{0.5}}^{\text{liq}} X_{\text{KO}_{0.5}}^{\text{liq}}\right)^2$$

This new barometer accurately reproduces its calibration data with a standard error of estimate (SEE) of ±1.4 kbar, and is suitable for use on hydrous and anhydrous samples that are ultramafic to intermediate in composition, but should be used with caution below 1100 °C and at oxygen fugacities greater than one log unit above the QFM buffer. Tests performed using with data from experiments on H_2O-poor tholeiites reveal that 1 atm runs were overestimated by less than the model precision (1.2 kbar); the new calibration is significantly more accurate than previous formulations. Many current estimates of magma storage pressures may therefore need to be reassessed. To this end, the new barometer was applied to numerous published clinopyroxene analyses from Icelandic rift zone tholeiites that were filtered to exclude compositions affected by poor analytical precision or collected from disequilibrium sector zones. Pressures and temperatures were then calculated using the new barometer in concert with Equation 33 from Putirka (2008). Putative equilibrium liquids were selected from a large database of Icelandic glass and whole-rock compositions using an iterative scheme because most clinopyroxene analyses were too primitive to be in equilibrium with their host glasses. High-Mg# clinopyroxenes from the highly primitive Borgarhraun eruption in north Iceland record a mean storage pressure in the lower crust (5.7 kbar). All other eruptions considered record mean pressures in the mid-crust, with primitive clinopyroxene populations recording slightly higher pressures (3.1–3.6 kbar) than evolved populations (2.6–2.8 kbar). Thus, while some magma processing takes place in the shallow crust immediately beneath Iceland's central volcanoes, magma evolution under the island's neovolcanic rift zones is dominated by mid-crustal processes.

Keywords: Thermobarometry, clinopyroxene-liquid equilibria, Iceland, magma plumbing