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SPECIAL COLLECTION: RATES AND DEPTHS OF MAGMA ASCENT ON EARTH

Multiple-reaction geobarometry for olivine-bearing igneous rocks

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Abstract

Efforts to map the vertical distribution of mafic and ultramafic igneous rocks in the Earth's crust and uppermost mantle have long been hampered by the lack of precise geobarometers for the appropriate mineral assemblages. The average *P* (av*P*) method (Powell and Holland 1994) is a multiple-reaction approach that uses a least-squares minimization to average the pressures derived from individual mineral equilibria, taking into account both their uncertainties and correlations. We applied average *P* to a carefully selected database of published phase-equilibrium experiments in dry to H_2O-saturated, andesitic to basaltic and peridotitic systems at $P = 0.6–9.3$ kbar, $T = 940–1240$ °C, with log f_{O_2} from NNO-2.6 to NNO+3.6 log units (where NNO is nickel-nickel oxide buffer). We made minor modifications to the thermodynamic models of clinopyroxene, spinel, and olivine to improve the accuracy and precision of the results given by the av*P* method. Tests on the experimental database, using the modified thermodynamic models and spinel + clinopyroxene + olivine + plagioclase equilibria, showed that average *P* can reproduce the experimental *P*, within the calculated 1σ uncertainties (0.9–2.6 kbar; 1.6 kbar on average), for 67% of the database. No systematic deviations of the calculated pressure (*P*) with temperature (*T*) or mineral compositions are observed. Given the large compositional range of the experimental database, these results suggest that the method can be applied to any gabbroic, pyroxenitic, or peridotitic rocks that contain the appropriate phase assemblage clinopyroxene + olivine + plagioclase ± spinel. For assemblages equilibrated at $P < 5$ kbar, the calculated *P* shows a slight dependence on *T*, which therefore needs to be well constrained to keep the overall *P* uncertainties as low as possible. *T* can be estimated using either available independently calibrated geothermometers or a simple calculation routine suggested in this work. Application of average *P* to gabbroic xenoliths from Dominica, Lesser Antilles, and to gabbroic and peridotitic xenoliths from Wikieup, Arizona, demonstrates the ability of the method to produce precise *P* estimates for natural assemblages equilibrated at both mid- and lower crustal conditions, respectively. Depending on the errors on mineral composition, appropriateness of the *T* estimate, and attainment of equilibrium of the assemblage, *P* uncertainty for natural rocks is ≤1.0 kbar. Such a level of precision can help to discriminate between rival petrogenetic processes in subduction zone, intra-plate, and mid-oceanic ridge settings.

Keywords: Geobarometry, phase equilibria, mafic crust, gabbros, peridotites; Rates and Depths of Magma Ascent on Earth