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Assessment of mantle geothermometers based on well-equilibrated natural samples

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Assessment of geothermometers for ultramafic mantle rocks can be made using independent constraints derived from either experimental or natural samples. Previous assessments using natural samples have generally been made by testing for consistency with petrological constraints (diamond–graphite and phlogopite stability fields), by measuring the scatter of P–T points around calculated geotherms, or by comparing T estimates with those derived from assumed "best" methods. This type of assessment requires strong assumptions on the degree of mineral equilibration and largely relies on the proper selection of the reference thermometer and barometer. A further major limitation of all previous evaluations based on experiments or real rocks has been the relatively small number of control data, which invariably covered a restricted range of P–T conditions and compositions compared with the large natural variability of ultramafic mantle rocks. To overcome these drawbacks, we have integrated previous experimental tests using data from experiments in highly sodic NCMAS systems (Bulatov et al. 2002). Our evaluation indicated the Taylor (1998; TA98) two-pyroxene and the Nimis and Taylor (2000; NT00) single-Cpx thermometers as the most robust reference thermometers for applications to natural compositions. Cross-validation of major-element geothermometers for garnet peridotites and pyroxenites was then carried out using published and some unpublished compositions of minerals for ca. 1800 Grt–Cpx–Opx(±Ol±Spl)-bearing mantle xenoliths from both cratonic (mostly kimberlites) and non-cratonic (mostly minette or alkali basalts) environments. The database was screened for mineral equilibrium by comparing T estimates obtained using independent pyroxene solvus and Fe–Mg exchange thermometers. About 750 xenoliths were selected, which showed strong, albeit non-linear, correlations between independent estimates, reflecting good equilibrium among pyroxenes and garnet down to T as low as 700°C. These well-equilibrated samples revealed systematic deviations (up to > 200°C) and/or excessively low precision against TA98 and NT00 for all of the most widely used thermometers. A slightly corrected version of the Brey and Köhler (1990) Ca-in-Opx thermometer and the new Opx–Grt thermometer by Nimis and Grütter (2009) are the only currently available methods that ensure consistency with TA98 and NT00 in applications to mantle ultramafic rocks in the range 700–1400°C. Observed discrepancies between the new Opx–Grt thermometer and TA98 for some localities may reflect (i) anomalous mantle redox conditions, or (ii) kinetic decoupling of slow Ca–Mg and fast Fe–Mg exchange equilibria. The latter can be induced by transient heating and is commonly, but not ubiquitously, observed in mantle xenoliths near the base of the lithosphere.

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