Error sources in single-clinopyroxene thermobarometry and a mantle geotherm for the Novinka kimberlite, Yakutia

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ABSTRACT

A new suite of 173 clinopyroxene grains from heavy-mineral concentrates of the diamondiferous Novinka kimberlite (Upper Muna field, Yakutia) has been analyzed for major and minor elements with an electron microprobe to perform a thermobarometric study and model the thermal structure of the Archean Upper Muna lithospheric mantle. Scrupulous evaluation of propagation of analytical uncertainties on pressure estimates revealed that (1) the single-clinopyroxene geobarometer can be very sensitive to analytical uncertainties for particular clinopyroxene compositions, and that (2) most clinopyroxenes from Novinka have compositions that are sensitive to analytical uncertainties, notwithstanding their apparent compositional suitability for single-clinopyroxene thermobarometry based on previously proposed application limits. A test on various mantle clinopyroxenes containing different proportions of the sensitive elements Cr, Na, and Al allowed us to identify clinopyroxene compositions that produce unacceptably high propagated errors and to define appropriate analytical conditions (i.e., higher beam currents and longer counting times for specific elements) that allow precise P-T estimates to be obtained for sensitive compositions. Based on the results of our analytical test, and taking into account the intrinsic limitations of the single-clinopyroxene thermobarometer, we have designed a new protocol for optimum thermobarometry, which uses partly revised compositional filters. The new protocol permits precise computation of the conductive paleogeotherm at Novinka with the single-clinopyroxene thermobarometer of Nimis and Taylor (2000). Thermal modeling of the resulting P-T estimates indicates a ~34 mW/m² surface heat flow, a thermal lithosphere thickness of ~225 km, and an over 100 km thick “diamond window” beneath Novinka in the middle Paleozoic (344–361 Ma). We estimate that appropriate analytical conditions may extend the applicability of single-clinopyroxene thermobarometry to over 90% of clinopyroxene-bearing garnet peridotites and pyroxenites and to ~70% of chromian-diopside inclusions in diamonds. In all cases, application to clinopyroxenes with Cr/(Cr+Al)$_{tot}$/ < 0.1 is not recommended. We confirm the tendency of the single-clinopyroxene barometer to progressively underestimate pressure at $P > 4.5$ GPa.

Keywords: Geobarometry, chromian diopside, lithospheric mantle, palaeogeotherms

INTRODUCTION

Over the last few decades, thermobarometry of rocks and minerals derived from Earth’s mantle has represented a fundamental tool for the evaluation of the thermal state and structure of sub-craton and off-craton lithospheric sections (e.g., Boyd 1973, 1984; O’Reilly and Griffin 1985; Boyd et al. 1997; Kopylova et al. 1998; Griffin et al. 1999, 2002, 2004; Lazarov et al. 2009; Janney et al. 2010), as well as for the assessment of their diamond-bearing potential (e.g., Read et al. 2004; Read and Janse 2009; Cookenboo and Grütter 2010). Deep-seated mantle samples mostly occur as discrete xenoliths or xenocrysts in alkaline magmatic rocks, as isolated grains in sediments derived from their weathering and disruption, and as monomineralic or polymineralic inclusions in kimberlite- and lamproite-borne diamonds. Only the relatively rare discrete xenoliths and polymineralic inclusions in diamonds may be suitable for conventional, two-phase thermobarometry. Single-mineral thermometer–barometer pairs, such as those available for peridotitic garnet and clinopyroxene (Ryan et al. 1996; Nimis and Taylor 2000; Grütter et al. 2006), permit thermobarometric surveys to extend across copious data for mantle-derived xenocrysts. Although with some limitations concerning their reliability and applicability (e.g., Cookenboo and Grütter 2010), the single-mineral methods have enabled the vertical and horizontal mapping of the lithospheric mantle to an extent far beyond that achievable with xenoliths alone (e.g., Griffin et al. 1999, 2002, 2004; Malkovets et al. 2007; Ashchepkov et al. 2008; Grütter and Tuer 2009; Lehtonen et al. 2009; Nimis et al. 2009; Zozulya et al. 2009).

The single-clinopyroxene thermobarometer of Nimis and Taylor (2000) is one of the most used and most reliable single-