A new garnet-orthopyroxene thermometer based on reversed Al₂O₃ solubility in FeO-Al₂O₃-SiO₂ orthopyroxene

L.Y. ARANOVICH¹,* AND R.G. BERMAN²

¹Department of the Geophysical Sciences, University of Chicago, Chicago, Illinois, 60637, U.S.A.
²Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, Canada K1A 0E8

ABSTRACT

Reversed phase-equilibrium data, collected over the P-T range 12–20 kbar at 850–1100 °C, define the solubility of Al₂O₃ in ferrosilite (Fs) in equilibrium with almandine garnet (Alm). The new data indicate significantly lower Al₂O₃ solubility in Opx in the Fe-bearing system compared with the Mg-system and extrapolate well to merge with the higher pressure bracket of Kawasaki and Matsui (1983). Orthopyroxene-garnet thermometry in crustal rocks, based on the equilibrium studied here (Alm = 3 Fs + Al₂O₃), is considerably more robust than previous calibrations based on the equivalent equilibrium in the Mg system. Results for several granulite terrains show that Al-Opx temperatures based on the new experimental data are generally higher than results based on Fe-Mg exchange thermometry, consistent with suggestions of previous workers. For many samples, the difference in apparent closure temperature between these equilibria (generally 50–130 °C) is within the combined uncertainty of their calibration (~75 °C) and is not as extreme as differences calculated on the basis of Harley’s (1984) unreversed experimental data (Bégirn and Pattison 1994). The lack of sensitivity of this new thermometer to late Fe-Mg exchange makes it a powerful tool for deciphering near-peak P-T conditions for high-grade rocks.

INTRODUCTION

The Al₂O₃ content in orthopyroxene coexisting with garnet in various rock types is recognized as a sensitive indicator of the pressure (P)-temperature (T) conditions at which rocks equilibrated. Initial experimental investigations focused on the simplest chemical system, MgO-Al₂O₃-SiO₂ (MAS), in order that P-T estimates could be derived for ultramafic, upper-mantle xenoliths (e.g., Boyd 1973). More recent interest in Opx-Gt thermobarometry stems from attempts to understand lower crustal processes by defining metamorphic conditions for granulate facies rocks. Of fundamental importance to these endeavors are inferences that the Al₂O₃ content of Opx in equilibrium with Gt (here referred to as Al-Opx thermobarometry) may be considerably more resistant to post-peak temperature reequilibration than Fe-Mg exchange thermometers (Aranovich and Podlesskii 1989; Anovitz 1991; Fitzsimons and Harley 1994; Pattison and Bégirn 1994; Bégirn and Pattison 1994). The interpretation that the Al-Opx thermometer may better record near-peak P-T conditions is based on observed compositional maps of Opx (Pattison and Bégirn 1994), with particular attention to comparative Al-Opx vs. Fe-Mg thermometry, the results of which are extremely sensitive to thermometer calibrations.

The amount of Al₂O₃ entering orthopyroxene in the MAS system was experimentally calibrated as a function of pressure and temperature by Perkins et al. (1981), Gasparik and Newton (1984), and Aranovich et al. (1983) for garnet-, spinel-, and cordierite-bearing assemblages, respectively. Most recent studies have attempted to calibrate the P, T, and compositional dependence of Al₂O₃ in Opx in the system FeO-MgO-Al₂O₃-SiO₂ (FMAS), which more closely represents orthopyroxene occurrences in crustal rocks (e.g., Kawasaki and Matsui 1983; Harley 1984; Aranovich and Kosyakova 1984, 1987; Lee and Ganguly 1988; Eckert and Bohlen 1992). All these studies have demonstrated the large effect of Fe on Al₂O₃ solubility in Opx: in garnet-bearing assemblages Al₂O₃ decreases with increasing bulk Fe/Mg ratio, while in cordierite-bearing assemblages Al₂O₃ increases with increasing Fe/Mg. Unfortunately, there is no consensus among these studies in quantifying this effect. The data of Harley (1984) seem to indicate a very sharp decrease in Al-solubility, while those of Aranovich and Kosyakova (1984; 1987) suggest a rather smooth one; the other studies fall between these extremes.

A major drawback of the FMAS studies mentioned above is that, with the exception of three experimental brackets of Lee and Ganguly (1988), equilibrium was not demonstrated by reversals of the Al₂O₃ content of Opx approached from under- and oversaturation. Lack of reversed phase-equilibrium data makes modeling of the thermodynamic properties of Al-bearing Opx highly uncertain and prevents robust calibration of thermometers involving aluminous Opx. We became aware of