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The Continuing Problems of Ni in Garnet Thermometry: A SIMS Study of Ni in the Jagersfontein Peridotite Garnets

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Within the pressure and temperature regime of the upper mantle, the partitioning of Ni between olivine and chrome pyrope garnet is strongly temperature dependent. The use of Ni trace element concentrations in garnet as a geothermometer is potentially a very useful tool in assessing the thermal evolution of mantle derived chrome-pyrope garnets in peridotite xenoliths, mineral concentrates or 'pathfinders', and syngenetic inclusions in diamond. A significant advantage of Ni in garnet thermometry is that it is not susceptible to potentially inaccurate ferric iron estimations which do affect conventional garnet-olivine Fe-Mg exchange thermometry. To date, application of Ni thermometry has been based on analyses by proton microprobe. A new technique has been developed using the Cameca 4f ion microprobe in Edinburgh that allows routine high precision determination of the concentration of Ni in garnet by SIMS to within ±3.5 ppm. Within the garnet compositional range studied there was no matrix effect upon Ni, and the best Ni estimations were obtained at zero offset. The Ni in garnet thermometer has been calibrated empirically by comparison of Ni partitioning between garnet and olivine, with temperature estimates derived from conventional pyroxene thermometry and garnet-olivine Fe-Mg exchange thermometry (Griffin et al., 1989; Ryan et al., 1996). The Ni in garnet thermometer has also been calibrated experimentally (Canil, 1994; 1999). The results of these two methods have been shown to be significantly different at temperatures >1400ºC and <900ºC. This discrepancy was examined by applying both the empirical and experimental calibrations to a well-characterised suite of peridotite xenoliths from Jagersfontein, South Africa (Burgess and Harte, 1999 and references therein). Conventional pressure-temperature estimates for these peridotites were determined following the recommendations from the tests of thermometers and barometers carried out by Brey and Köhler (1990). Ni thermometry yields T_{Ni} estimates significantly different from conventional $T_{Fe\text{-}Mg}$ estimates (690 - 1370ºC), with the empirical calibrations yielding T_{Ni} between 874 and 1359 C, whilst the experimental calibrations produced a very restricted T_{Ni} range at 927 - 1237ºC. T_{Ni} was never found to be below 870ºC in any calibration.

The relationship between D_{Ni} (garnet-olivine) and temperature for the Jagersfontein xenoliths is shown in Figure 1. The experimental calibration line (C99) has a much steeper ln D_{Ni} (garnet-olivine) vs 1/T slope relative to the empirical calibration line (G89) of Griffin et al. (1989). Diamonds represent the conventional temperature estimates obtained from the Jagersfontein peridotites plotted against the measured ln D_{Ni}. A regression line through the data from Jagersfontein (diamonds) has a significantly shallower ln D_{Ni} (garnet-olivine) vs 1/T slope than either of the previous calibrations, and deviates most significantly from the Ni calibrations at lower temperatures. Canil (1999) suggests that the empirical calibration of the Ni thermometer would fit the experimental data better if all the original conventional temperature estimates used in empirical calibration were recalculated at one pressure. In the case of the Jagersfontein xenoliths such recalibration would only reduce even more the agreement between T_{Ni} and $T_{Fe\text{-}Mg}$.

In order to examine what implications the use of nickel thermometry may have for models of upper mantle thermal structure, T_{Ni} were used to derive pressure estimates using the major element phase compositions in the Al in opx barometer of Brey and Köhler (1990). This produced anomalously high pressure estimates for some low-T peridotites. Whilst this may infer lateral temperature gradients of up to 200ºC it is most likely an artefact of the disequilibrium between Ni-Mg exchange and Fe-Mg exchange. The alternative method of estimating pressure by extrapolation of T_{Ni} onto the 40 mW/m^2 southern African cratonic geotherm was examined and was found to transpose many peridotites from the graphite to the diamond stability field. This suggests that estimates of diamond grade made on the basis of Ni in garnet thermometry should be treated with some caution. Furthermore, neither the empirical nor experimental calibrations for Ni partitioning between garnet and olivine successfully account for the behaviour of Ni in the Jagersfontein peridotite xenoliths.

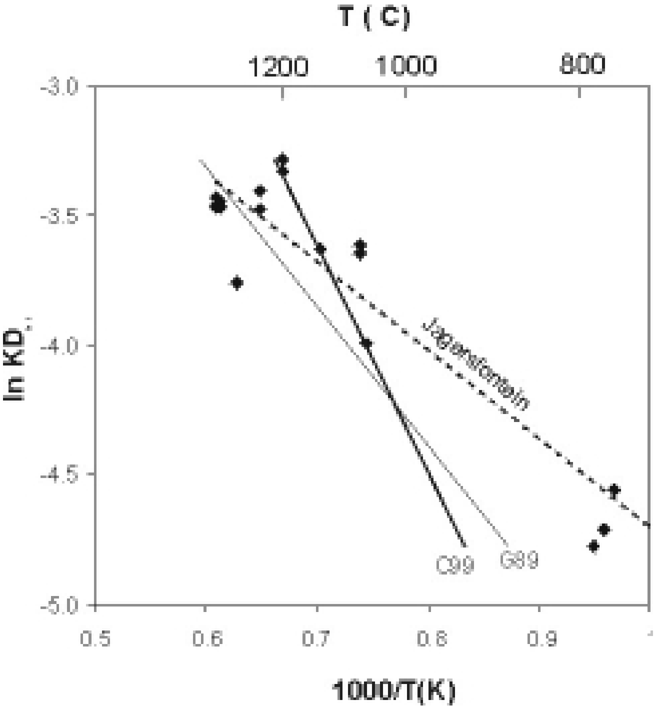

Figure 1. Ni partitioning as a function of temperature. C99 is the experimental calibration of Canil (1999). G89 is the empirical calibration of Griffin et al. (1989). Diamond symbols represent the conventional T estimates plotted against ln D_{Ni} measured for the Jagersfontein peridotites. Broken line is the best-fit line through the conventional temperature data obtained from the formulations of Brey & Köhler (1990) described in the text.

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