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A new garnet-orthopyroxene thermometer developed: method, results and applications

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The Fe-Mg exchange reaction between garnet and orthopyroxene is a robust geothermometer that has extensively been used to retrieve metamorphic temperatures from granulitic and peridotitic/pyroxenitic lithologies with important implications on the thermal state of the continental lithosphere. More than 800 experimental mineral pairs from both simple and complex systems were gleaned from the literature covering the P-T range 0.5-15 GPa / 800-1800°C. Grt was treated as a senary (Py, Alm, Grs, Sps, Kno and Uv), whereas Opx as a septenary (En, Fs, Di, Hd, FeTs, MgTs and MgCrTs) solid solution. For Opx, Al in the M1 site was calculated following Carswell (1991) and Fe/Mg equipartitioning between sites was assumed. A mixing on sites model was employed to calculate mole fractions of components for both minerals. With regard to the excess free energy of solution and activity coefficients the formalism of Mukhopadhyay et al. (1993) was adopted treating both minerals as symmetric regular solutions. Calibration was achieved in multiple steps; in each step ΔS was allowed to vary until the standard deviation of the differences between experimental and calculated temperature for all experiments was minimised. The experiment with the largest absolute relative deviation in temperature was then eliminated and the process was repeated. The new thermometer reproduces the experimental data to within 50°C and is independent of P-T-X variations within the bounds of the calibrant data set.

Application of our new calibration to metamorphosed crustal and mantle rocks that occur both as massifs and xenoliths in volcanics suggested the following results. Granulite terranes have recorded differences in temperature between peak and re-equilibration conditions in the range 100–340°C, primarily depending on the mechanism and rate of exhumation. Several provinces retain memory of discrete cooling pulses (e.g. Palni Hills, South Harris, Adirondacks, E. Antarctic Belt, Aldan Shield) whereas others are dominated by a single thermal event (Lisof Massif, SW Greenland, Eifel). UHT granulites appear to be more common than previously thought. There are a considerable number of localities in Europe that have recorded temperatures in excess of 950°C (South Harris, Schwarzwald, Pannonian Basin, Sudetes, Rogaland, Massif Central, Iberian Hercynian Belt), with the first four listed peaking over 1000°C. In settings such as South Harris, the model of Schmalholz & Podladchikov (2013) for heat generation within a crustal-scale shear zone is most appealing.

Mafic/ultramafic xenoliths from Deccan conform to geotherms with surface heat flow between 60 and 90 mW.m-2 signifying a reduction in lithospheric thickness of the order of 43 km. Similar xenoliths from the Tariat Depression testify to a 20 km thinning beneath Mongolia. Mantle xenoliths from Canadian and Russian kimberlites demonstrate the great diamond potential of the Lac des Gras, Jericho, Udachnaya and Mir pipes but the limited potential of the Somerset Isl. and Obnazhennaya pipes. UHP mantle peridotites from the Dabie-SuLu orogen are characterised by the coldest geotherm identified so far (33mW.m-2) implying a minimum removal of 110 km from the lithospheric keel underneath E. China.

References: Carswell, D. A., 1991. Min. Mag. 55, 19-31; Mukhopadhyay, B., et al., 1993. GCA 57, 277–283; Schmalholz, S. M., & Podladchikov, Y. Y., 2013. GRL 40, 1984–1988.