Geophysical Research Abstracts
Vol. 12, EGU2010-10267, 2010
EGU General Assembly 2010

Metamorphic re-equilibration of highly chromian garnet-rich xenoliths from South African kimberlites

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A history of decompression and metasomatism is preserved in a suite of highly chromian, garnet-rich peridotitic xenoliths with peridotitic affinities from the Newlands and Bobbejaan kimberlites, South Africa. A high proportion of the garnets and chromites in these rocks plot in the diamond facies fields on Cr2O3-CaO and Cr2O3-MgO wt. % plots; Cr-rich compositions are found extensively in the lherzolite field as well as in the harzburgitic field. Compositions at clinopyroxene-garnet boundaries for the final stages of mineral equilibration indicate conditions corresponding to cool, continental, geotherms with pressures of 35-55 kb and temperatures of 850-1250°C. Petrographic evidence suggests that the earliest known mineralogies were those of olivine-bearing garnet-rich rocks with granuloblastic textures. These were modified by a decompression event driving the reaction garnet + olivine = spinel (chromite) + pyroxene(s), the evidence for which is preserved in garnets showing crystalligraphically orientated inclusions of spinel and pyroxenes. In addition, most of the garnets have strongly developed major element zonation patterns which are of three principal types: (1) external re-equilibration between garnet and matrix; (2) internal re-equilibration between garnet and its chromite and pyroxene inclusions; (3) metasomatically induced zoning between garnet core and a metasomatic rim. Formation of these zonations appears to have overlapped in time. (1) and (2) show a major decrease in Cr/Al and modification of Ca/Mg, whilst (3) primarily involves an increase in Ca/Mg and Ti towards the garnet rim. The compositional trajectories associated with zonations (1) and (2) in Ca-Cr plots, may be closely modelled by means of sliding, garnet-spinel transition reactions whose slopes vary with bulk Ca composition; at intermediate Ca compositions the trajectories closely match the slope of the lherzolite line or harzburgite/lherzolite boundary. The decreasing Cr/Al of the garnet in these zonations supplements the evidence for decompression given by the petrographic features. Estimation of the overall changes in garnet composition shown by the petrographic reaction features and the zonation features indicates a decompression event of at least 10 kbar, and this is supported by thermodynamic modelling (Klemme et al., 2009, Lithos). A decompression of this magnitude points to the occurrence of a major tectonic event which would have affected crust as well as mantle. This may have been associated with orogenic events in the South African crust at 2.9 to 2.7 Ga, and may have involved lithospheric inversion. If so, it implies that the zonation features have been held in a state of preservation for that length of time. Such preservation of features and reaction history would only be expected in exceptionally Cr-rich xenoliths, which could have formed exceptionally Cr-rich garnets at depth.