Ultra high temperature crustal metamorphism.

Simon L. Harley
Geology & Geophysics, University of Edinburgh, West Mains Road, Edinburgh, Scotland EH9 3JW

The reality of ultra high temperature (UHT) regional metamorphism in which crustal rocks are subjected to temperatures of 950-1050 °C at moderate pressure (7-12 kbar) is now generally accepted by the metamorphic community. Several examples of terranes that have experienced UHT regional metamorphism are now recognised, including the Napier Complex of Antarctica, Sipiwesk Lake in Manitoba, the Eastern Ghats of India, In Ouzzal complex of Algeria, and the Aldan Shield of Siberia. Despite this, an undue reliance on cation partitioning geothermometers as the principal tools for temperature estimation in high-grade rocks has often led to the definition of erroneously low peak temperature conditions for these and other potentially UHT terranes. As a consequence, temperature remains the key parameter to constrain when dealing with UHT metamorphism. This work outlines two approaches to temperature estimation in UHT metamorphism and demonstrates how the pressure-temperature (P-T) histories of UHT terranes can be constrained through the judicious combination of reaction texture interpretations with improved petrogenetic grids developed from recent experiments.

The P-T conditions of UHT metamorphism are best constrained through the recognition of key mineral assemblages defined from experimental and theoretical petrogenetic grids, particularly applied to metapelites. The importance and utility of this approach is illustrated for contrasting examples from east Antarctica, India and South Africa. Garnet-sapphirine-quartz xenoliths in the Lace Kimberlite pipe, South Africa, imply peak P-T conditions of 10.5 kbar and 1000 °C, followed by near-isobaric cooling that produced garnet-cordierite and garnet-sillimanite coronas. In the Archaean Napier Complex, the best-preserved example of UHT regional metamorphism, the extreme metamorphic conditions are best defined from the occurrence of sapphirine + quartz, orthopyroxene + sillimanite, spinel + quartz and osumilite + garnet. High alumina contents in orthopyroxene (8-11 wt % Al_2O_3) coexisting with garnet yield high calculated temperatures (950-1000 °C) consistent with the assemblage constraints. New experimental data on the stability of osumilite-bearing UHT assemblages in chemical systems relevant to metapelites also allows the precise reconstruction of P-T histories in different parts of the Napier Complex (Carrington & Harley 1995). Post-peak near-isobaric cooling occurred at less than 8 kbar in the northern parts of the UHT region and at 9-10 kbar in areas further south, consistent with previous deductions from geobarometry.

Magnesian metapelites from the Rauer Group define a UHT near-isothermal decompression path, based on reaction textures in which pyropic garnet and orthopyroxene + sillimanite are replaced by lower-pressure equivalents such as sapphirine + orthopyroxene + cordierite and spinel + cordierite. Unusually, peak metamorphic conditions of 11-12 kbar and 1050 °C are in this instance indicated by both petrogenetic grids and geothermobarometry. Most notably, Fe-Mg partitioning between garnet porphyroblasts and included orthopyroxene (8-11 wt % Al_2O_3) records temperatures of over 1000 °C. The experimental petrogenetic grid of Carrington & Harley (1995), contoured for the X_{Mg} ratios of garnet, orthopyroxene, biotite and cordierite, demonstrates that melting to produce garnet (X_{Mg}>58) - orthopyroxene - sillimanite migmatites in this case proceeded at minimum P-T conditions of 8.6 kbar and 910 °C along a prograde heating path.

Further examples of UHT metamorphism followed by near-isothermal decompression constrained by reaction textures are provided by sapphirine granulites from Antarctica, Algeria, Sri Lanka and the Eastern Ghats. UHT metamorphism at mid-crustal or low-pressure conditions (4-6 kbar) is confirmed by assemblages involving osumilite in the case of Namaqualand. In general, low-pressure UHT metamorphism is difficult to establish on the basis of spinel-quartz assemblages because of significant uncertainties in the peak-T composition of spinels that may have subsequently exsolved and modified composition.

Mineral thermobarometry is inherently unreliable for UHT metamorphism because of post-peak diffusional exchange and closure effects that lead to both mismatch and feedback (Harley, 1989) between temperature and pressure estimates. This can, however, be used to advantage to estimate peak temperature through retrieval, or convergence, calculations. The main criteria for successful retrieval calculations are the availability of mineral compositional data on several samples with differing mineral modes and grainsizes and the presence of reference barometry with both low dP/dT and little dependence of P on the X_{Mg} of coexisting phases. Such barometry provides the benchmark for adjustment of other methods that have greater dP/dX_{Mg}.

Retrieval calculations have been performed on 26 garnet-orthopyroxene granulites from the UHT region of the Napier Complex. The extent of pressure underestimation (i.e. the closure pressure) obtained using an Fe-Mg sensitive Al-barometer (Harley, 1984) correlated well with the low apparent temperatures calculated using the garnet-orthopyroxene Fe-Mg exchange thermometer that range from 800 to 960 °C. Back-calculation of garnet or orthopyroxene XMg values following the approach of Fitzsimons & Harley (1994) yields an internally-consistent peak temperature estimate of 1000 ± 40 °C for the range of peak pressures (7-11 kbar) defined by independent barometry and petrogenetic grids. Similar retrieval procedures applied to other terranes with UHT mineral assemblages often result in peak temperature estimates in excess of 950 °C but yield peak temperatures of less than 870 °C for other granulite terranes that lack evidence for UHT metamorphism.

The precise tectonic settings necessary for the development of UHT metamorphism remain problematic. The extreme temperatures attained, however, suggest that convective thinning or detachment of the lithospheric thermal boundary layer during or after crustal thickening is a major factor in the formation of UHT metamorphic belts and hence the evolution of the deep continental crust.

References

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