What Drives and Sustains High Geothermal Gradients in the Earth's Crust?

Chris Clark[1] and Dave Healy[2]

[1]*The Institute for Geoscience Research (TIGeR), Department of Applied Geology, Curtin University of Technology, GPO Box U1987, Perth WA 6845, Australia*

[2]*Department of Geology and Petroleum Geology, University of Aberdeen, Aberdeen AB24 3UE, United Kingdom*

How the Earth's deep crust can reach and sustain extreme temperatures (> 900 °C) in high geothermal gradient environments remains an unanswered question and most models of continental geothermal gradients fail to predict this type of metamorphism. Extreme thermal conditions in the crust have also been considered as anomalous for many decades despite the wealth of mineralogical evidence indicating otherwise. The nature of the heat source causing deep crustal high geothermal gradient metamorphism is crucial to understanding UHT metamorphism as an earth process. Currently, there are two main competing hypotheses for the heat source needed to generate high geothermal gradient conditions in the deep crust at a regional scale, essentially thin lithosphere (extension) vs high abundance of HPEs:

Model 1: Regional deep-crustal high-geothermal gradient metamorphism in excess of ~30 °C/km may occur in continental back-arc basins and pre-date the closure and thickening of these basins, which are regions of thinned continental lithosphere, characterised by high heat flow from the mantle. In this model, the extreme metamorphic temperatures are due to high mantle heat flow into the back-arc region that thermally prime the system prior to orogenesis, and the geotherm is enhanced during orogenesis by thickening of the hot crustal column.

Model 2: Numerical models suggest that the deep crust can be heated to UHT conditions during metamorphism by radioactive decay of anomalously high concentrations of HPE. In this case, high temperatures are the result of heat generated within the thickened crust during orogenesis.

The most likely tectonic environment for inversion of a back-arc basin in Model 1 is that of accretion-collision at a magmatic arc, which is consistent with the observation that UHT metamorphism is generated during periods of continental assembly. In contrast, Model 2 requires a thick pile of sedimentary rock with high concentrations of HPE that is subsequently thickened during orogenesis. The observed link with continental assembly suggests one likely setting for this model is a passive margin basin derived by erosion of a source with high HPE concentrations and inverted during continental collision.

Here we present the results of numerical models for each of these scenarios and reference them against petrological and geochronological data from two UHT exposures in the Southern Granulite Terrane of India.