Granulites and the Nature of Crust-Mantle Interactions

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The importance of granulites in the Earth System has long been recognised by David Green. His seminal study, with Ringwood, of the gabbro-eclogite transition was followed by benchmark work on cordierite- and sapphirine-bearing assemblages with Hensen, Ellis and others, and the application of these and other experimental studies to the remarkable granulites of the Napier Complex and elsewhere. These contributions still underpin quantification the P-T conditions and P-T paths of granulites, complemented by more recent methods such as internally consistent datasets.

This quantitative understanding of granulites is central to the issues of the transfer of heat in the crust-mantle system and the nature of the coupling between lithosphere and underlying asthenosphere during orogenesis. Granulites worldwide indicate regional-scale deep (7-12 kb) crustal metamorphism at temperatures generally higher than 800°C, and in the ultrahigh temperature (UHT) granulites as extreme as 1150°C. Such extreme deep crustal temperatures have been attained in several places and at several different times in Earth history – with Cambrian UHT terrains being as ‘common’ as Archaean ones. Moreover, analysis of granulite P-T-time records demonstrates that some remained deeply buried and cooled slowly ($dT/dt = 1\text{-}4$°C/Myr) subsequent to their thermal peak whereas others were short-lived and exhumed to shallow crustal levels within 10-20 Myr (or less!) of their peak. Models for the generation of granulites, and for the character of crust-mantle interactions during these events, must be able to account for this variety in P-T-time paths.

Focusing on granulites formed in collisional orogens, it is clear that self-heating of thickened crust and lithosphere cannot account for the high to extreme temperatures attained: the heat must be derived from sub-lithospheric mantle. Conceptually, there are two ways in which this can occur. In the first, the crustal rocks are taken to great depths (> 20-30 kb) and then brought into contact with asthenosphere – a deep, cold to hot scenario terminated by decompression prior to or concomitant with cooling. In the second, the hot asthenosphere is raised relative to its usual depth, and brought into contact with existing ‘warm’ deep crust that can flow laterally in response to loading – a shallower, warm to hot scenario terminated by cooling with minimal decompression. Hybrid scenarios can produce intermediate P-T paths; the critical constraints remain the amount of thickening, the timing and timescale of heat input relative to any thickening, and the lateral boundary conditions. These principles and contraints apply to ‘channel flow’ models. Modified versions of these may be applicable to granulite formation, but, as explained here, require further assessment.