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Thermal softening of continental crust, strain localization, and low-pressure, high-temperature metamorphism: Insights from the Mary Kathleen Zone, Mount Isa Inlier (Australia)

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A fundamental objective of studies in lithosphere geodynamics is to understand the relationships between tectonics as derived from the structural inventory of a region studied, and the pressure-temperature history as derived from the analysis of metamorphic rocks. Prograde metamorphism is commonly understood as the result of plate-tectonics-driven orogenic processes, and/or intrusions. Thermal modelling of crustal thickening predicts clockwise P-T paths with medium- to high-pressure metamorphic peaks; while heating and/or decompression with potential low-pressure metamorphic peaks is expected for crustal extension. Intrusions cause essentially isobaric heating into the low-P/high-T (LPHT) domain of P-T space, or possibly compressive heating in case of overplating. Accordingly, LPHT metamorphism should essentially be restricted to (and thus be indicative of) extensional tectonic settings, local or regional-scale thermal aureoles, or magmatic arcs [1].

This view is, however, challenged where field evidence is not compatible with any of these settings. A case in point is the Mary Kathleen Zone in central Mount Isa Inlier where LPHT metamorphism is recorded during the Isan orogeny, peaking at about 1580 Ma. The tectonic environment is one of crustal shortening, with metamorphic mineral growth documented for prograde and retrograde sections of an anticlockwise P-T path. Sequential prograde mineral growth accompanied progressive, bulk pure shear-dominated deformation, from minimal initial strain to a final state of at least 50% bulk shortening in this high-strain belt. Remarkably, there is no intrusive activity at the exposed mid-crustal level recorded anywhere in the Mount Isa Inlier for this period, nor is there evidence for crustal extension immediately predating the lateral compression.

Evidently, crustal thickening was not the ultimate cause of prograde metamorphism as initial growth of low-pressure minerals such as andalusite and cordierite occurred when the L-S fabrics were only weakly developed. The close correlation of crustal heating and the initiation of deformation indicates that a major heating event triggered regional-scale deformation by reducing crustal strength over much of the crustal profile. The strong deformational response suggests that the crust was already under considerable E-W-directed stress, but was mechanically too strong to yield in the "cold" state. The proposed mechanism invoked here can thus be described as a "thermally-induced lateral crustal collapse". The zone of maximum strain would thus be expected to follow, at least initially, the zone of maximum heating.

Geochronology and mineral assemblages of peak and retrograde stages indicate that heat input was indeed transient, meaning that the crustal geotherm had not been originally in the LPHT field. As post-orogenic reduction of crustal thickness was moderate, with the present erosion surface at a level of about 4-4.5 kbar metamorphic peak pressure, the maximum crustal thickness did never reach values that may be expected from the amount of lateral shortening observed. At the high geothermal gradient prevailing during orogeny, a deep crustal root would not have been gravitationally stable.

For the actual heat source, two possibilities are considered, mantle delamination correlating roughly with the position of the Mary Kathleen Zone, or massive intrusion of mafic magmas, which is supported by gravity surveys indicating high-density material below the Mary Kathleen Zone [2]. Quite possibly, mafic magmatism may have been directly linked to the delamination process.

References:

[1] Spear FS (1993) *Metamorphic Phase Equilibria and Pressure-Temperature-Time Paths*: Min Soc Am, 799p

[2] Blenkinsop TG et al (2008) Precambrian Res 163: 31-49