



Secular and cyclic variation of the heat budget of crustal metamorphism: geodynamic implications

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Metamorphism of crustal rocks is due to heat generated by radioactive decay and viscous dissipation, and the heat flux from the mantle. Radiogenic heat production has declined by $>75\%$ since the Hadean and mantle potential temperature (T_P) has declined by $\sim 200\text{--}300^\circ\text{C}$ since 3.0 Ga. However, the ΔT_P at the start of mantle convection after crystallization of the last magma ocean is poorly constrained—either initial cooling changed to warming as heat production overwhelmed heat loss or the mantle evolved at close-to-constant temperature until $c. 3.0$ Ga. The thermal history of the crust is less well known, although in principle it is preserved in the record of metamorphism. At present, different plate tectonic settings exhibit contrasts in heat flow that are registered as differing metamorphic facies series in distinct crustal terranes. However, how far back in time these relationships are reliable is unclear, the thermal effects of the formation and breakup of supercontinents are poorly characterized and the geodynamic regime operating in the Archean is controversial.

To evaluate variation of the heat budget of crustal metamorphism through time we have compiled T , P and apparent thermal gradient (T/P), and age of metamorphism for 456 localities from the Cenozoic to the Eoarchean, but before the Neoproterozoic reliable data are sparse. Based on T/P , metamorphic rocks are classified into three groups: high dT/dP ($>775^\circ\text{C/GPa}$), intermediate dT/dP ($775\text{--}375^\circ\text{C/GPa}$) and low dT/dP ($<375^\circ\text{C/GPa}$). Plots of T and T/P against age show that since $c. 3.0$ Ga cyclic variations in the heat budget of crustal metamorphism have been superimposed on secular cooling.

A first cycle is marked by the widespread occurrence of two contrasting types of metamorphism—high dT/dP and intermediate dT/dP —in the rock record synchronous with the amalgamation of dispersed blocks of lithosphere into protocontinents during the Mesoarchean–Neoproterozoic. Paired metamorphism due to different heat budgets at convergent margins is characteristic of plate tectonics. During the Paleoproterozoic, the fragmentation of protocontinents into cratons and their subsequent accretion into the supercontinent Columbia represents a transition from the first to a second cycle. Around 2.3 Ga, T and T/P of high dT/dP metamorphism increased leading to a thermal maximum in the mid-Mesoproterozoic, reflecting insulation of the mantle beneath the quasi-integral lithosphere of Columbia. Cycle II extended through the geographical reorganization of Columbia into Rodinia, but during the Tonian a steep decline in the T and T/P of high dT/dP metamorphism to their lowest values coeval with the breakup of Rodinia marked a transition to Cycle III. The start of this cycle was synchronous with the appearance of low dT/dP metamorphism in the rock record, registering a change to deeper, colder subduction. During the Cryogenian, T and T/P of high dT/dP metamorphism again increased to a thermal high in the Ediacaran–Silurian, reflecting insulation of the mantle beneath Gondwana during the Pan-African thermal event before it sutured with Laurussia to form the short-lived supercontinent Pangea. Cyclic variations in the metamorphic heat budget reflect changes in geodynamics and supercontinent formation, longevity and breakup.