Secular cooling of Earth's mantle: geochemical evidence and geodynamic implications

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The potential temperature of Earth's mantle is one of the key variables that influences the style of tectonics, the rates of mantle-derived magmatism, and ultimately the habitability of our planet on long (Gyr) timescales. While secular mantle cooling is often assumed on the basis of hot accretion and higher radiogenic heat production in the early Earth, much remains unknown about the rate and magnitude of mantle cooling over the past 4 Gyr.

A recent accumulation of geochemical evidence consistently suggests only limited (~100-175 C) cooling from the early Archean to the present[1-4]. While such limited cooling may be consistent with the crustal and mantle rheologies that could support plate tectonics throughout the Archean, limited mantle cooling is difficult to reconcile with current estimates of Earth's radiogenic heat production: slower mantle cooling requires a greater contribution of radiogenic heat production (higher Urey ratio) in order to explain Earth's present day heat flow. Convection models that impose a negative feedback to limit plate rates at high mantle temperature (e.g. [5]) may help to reconcile high observed heat flow with low Urey ratio by delaying mantle heat loss. However, the sum of observed geochemical constraints suggest a declining rate of mantle cooling. Consequently, while evidence for limited mantle cooling is increasingly clear, reconciling the existing geochemical and geophysical constraints may require either (1) anomalously high modern heat flow, (2) very high core heat flux, or (3) significant errors in either current parametrized convection models or geochemical temperature constraints. Resolving this problem is critical to our understanding of Earth's past tectonics and habitability.

References

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