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Enhanced mantle cooling and global mantle perturbations linked to the onset of modern plate tectonics

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Earth's tectonic regime has undergone a series of transitions over geological time. A key question is how the long-term evolution of tectonic regimes, especially the establishment of modern plate tectonics in the late Neoproterozoic, reshaped surface-mantle interactions.

Here we compile global geochemical data of intracontinental basalts, using their alkalinity index to constrain the pressure-temperature conditions of magma generation. Together with previous estimates of mantle potential temperature, we reconstruct its evolution over the past billion years. The results show that during Earth's "middle age", mantle potential temperature remained nearly constant; yet following the onset of modern plate tectonics and the Snowball Earth events, it dropped rapidly by ~50 °C during the Cryogenian and Ediacaran. This suggests that global-scale subduction under the modern plate tectonic regime accelerated mantle cooling.

Further analysis of isotopic and geochemical data from global intracontinental basalts reveals that basalts with enriched mantle signatures only began to appear after ~300 Ma. This change is consistent with compositional variations and eruption frequencies of kimberlites and other silica-undersaturated mantle-derived magmas, reflecting the substantial influence of subducted material on the convecting mantle's chemical composition. The paleogeographic locations of intracontinental basalts and kimberlites with enriched geochemical characteristics do not show a clear correlation with their proximity to subduction zones. Given that the time required for the sinking and (re)incorporation of slabs into the sources of mantle-derived magmas is at least 250−300 Myr, the eruption of enriched intracontinental basalts and kimberlites after ~300 Ma may be a delayed consequence of the late Neoproterozoic onset of modern plate tectonics. During Pangea assembly (via Gondwana, ca. 630−320 Ma), the modern plate tectonic regime, with its increased oceanic lithosphere subduction flux and widespread continental crust subduction, fundamentally altered mantle composition and drove the global-scale evolution of chemical heterogeneity in the convecting mantle.