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Connecting the Deep Earth and the Atmosphere

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The connections between the Earth's interior and its surface are manifold, and defined by processes of material transfer: from the deep Earth to lithosphere, through the crust and into the interconnected systems of the atmosphere-hydrosphere-biosphere, and back again. One of the most spectacular surface expressions of such a process, with origins extending into the deep mantle, is the emplacement of large igneous provinces (LIPs), which have led to rapid climate changes and mass extinctions, but also to moments of transformation with respect to Earth's evolving paleogeography. But equally critical are those process which involve material fluxes going the other way—as best exemplified by subduction, a key driving force behind plate tectonics, but also a key driver for long-term climate evolution through arc volcanism and degassing of CO_2.

Most hotspots, kimberlites, LIPs are sourced by plumes that rise from the margins of two large low shear-wave velocity provinces in the lowermost mantle. These thermochemical provinces have likely been quasi-stable for hundreds of millions, perhaps billions of years, and plume heads rise through the mantle in about 30 Myr or less. LIPs provide a direct link between the deep Earth and the atmosphere but environmental consequences depend on both their volumes and the composition of the crustal rocks they are emplaced through. LIP activity can alter the plate tectonic setting by creating and modifying plate boundaries and hence changing the paleogeography and its long-term forcing on climate. Extensive blankets of LIP-lava on the Earth's surface can also enhance silicate weathering and potentially lead to CO_2 drawdown (cooling), but we find no clear relationship between LIPs and post-emplacement variation in atmospheric CO_2 proxies on very long (>10 Myrs) time-scales. Hotspot and kimberlite volcanoes generally have relatively small climate effects compared with that of LIPs (because of volumetric and flux differences), but the eruption of large kimberlite clusters, notably in the Cretaceous, could be capable of delivering enough CO_2 to the atmosphere to trigger sudden global warming events.

Subduction is a key driving force behind plate tectonics but also a key driver for the long-term climate evolution through arc volcanism and degassing of CO_2. Subduction fluxes derived from full-plate models provide a powerful way of estimating plate tectonic CO_2 degassing (sourcing). These correlate well with zircon age frequency distributions and zircon age peaks clearly correspond to intervals of high subduction flux associated with greenhouse conditions. Lows in zircon age frequency are more variable with links to both icehouse and greenhouse conditions, and only the

Permo-Carboniferous (~330-275 Ma) icehouse is clearly related to the zircon and subduction flux record. A key challenge is to develop reliable full-plate models before the Devonian in order to consider the subduction flux during the end-Ordovician Hirnantian (~445 Ma) glaciations, but we also expect refinements in subduction fluxes for Mesozoic-Cenozoic times as more advanced ocean-basin models with intra-oceanic subduction are being developed and implemented in full-plate models.