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Lithospheric architecture controls on the global occurrence of intraplate alkaline magmas

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Intraplate alkaline silicate rocks and associated carbonatites play an important role in global carbon cycles. Studies have shown that some of these magmas (carbonatites and kimberlites) are emplaced within and along the margins of global cratons (e.g., [1]), indicating a significant role of thick lithospheric mantle in their petrogenesis. To further quantify the relationship between lithospheric architecture and the generation of young (<200 Ma) intraplate alkaline magmas, we examined the relationship between their compositions, global locations, and shear wave velocities (Vs) at lithospheric depths, obtained from recent seismic tomography. Using thermodynamic inversions of seismic data, we used Vs to estimate lithospheric thickness. Our results show a systematic increase in lithospheric thickness from basanites, which occur in regions of relatively thin lithosphere, to melilitites, nephelinites, and ultramafic lamprophyres in intermediate lithosphere, to lamproites and kimberlites that are emplaced atop thick cratonic lithosphere. This trend is corroborated by increasing median Dy/Yb and La/Sm ratios from basanites to kimberlites, indicating greater depths and lesser extents of melting, respectively, as the lithosphere thickens. Median K_2O/Na_2O ratios also increase progressively from basanites to kimberlites, signaling a transition from sodic to potassic magmas with increasing lithospheric thickness. This transition mirrors the destabilization of calcic amphibole as the lithospheric contribution to the melt deepens, giving way to phlogopite and K-richterite as the primary hydrous phases in >100-km-thick lithosphere. Importantly, we find that our lithospheric thickness estimates for primitive mafic CO_2-bearing magmas (ultramafic lamprophyres, melilitites and nephelinites) correspond well with those of carbonatites. Because these thicknesses correspond to much lower pressures than those required for primary carbonatite petrogenesis in the convecting mantle (>6 GPa; [2]), we propose that most carbonatites are products of either liquid immiscibility or crystal fractionation from ultramafic lamprophyric, melilititic and nephelinitic parental magmas. In summary, based on our multidisciplinary findings, we conclude that the global occurrence of alkaline magmas and associated carbonatites is primarily determined by the thickness of the subcontinental lithospheric mantle and is consistent with the composition-temperature-pressure relationships determined from experiments.

[1] Gibson, McKenzie & Lebedev (2024), *Geology* 52, 667–671.

[2] Dasgupta & Hirschmann (2006), *Nature* 440, 659–662.