

A new global kimberlite geochemistry dataset: the benefits of open and complete data sharing

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Introduction

Despite over a century of investigation and the well-known role of kimberlites as remarkable geochemical probes of the Earth's interior, there is a distinct dearth of readily accessible databases of kimberlite geochemistry. In light of this, we have compiled a comprehensive, well-scrutinised database of whole-rock major and trace element results for global kimberlite occurrences, as well as available radiogenic and stable isotope compositions.

Database construction and dissemination

Our new database, published in Giuliani et al. (2024), builds on the major element compositions presented by Kjarsgaard et al. (2009, 2022), Tappe et al. (2017) and Dalton et al. (2019) including new localities, and we have also compiled available trace element compositions extracted from individual publications. It should be noted that the major element database is heavily skewed towards regions of abundant kimberlite magmatism and related diamond mining, including the Kaapvaal, Siberian and Slave cratons. This results in a “screened” (i.e. after removing data from overrepresented localities) major element database containing 1821 entries of rocks which we have classified as kimberlites, and 1624 entries for trace elements. Our database (https://doi.org/10.58024/AGUM_ToG2024) is hosted on ‘AusGeochem’ (Boone et al., 2022), an open, free, online geochemistry platform that allows users to inspect and plot the data within its spatiotemporal context as well as download data for their own purposes.

Results and Discussion

The database serves to highlight the variation in observed major element compositions (e.g., ~20–45 wt.% SiO₂; ~2–25 wt.% CaO), while also showing that global kimberlite compositions converge to a relatively narrow range (Fig. 2), with median compositions consistent with recent classifications of kimberlite rocks as rich in CO₂ (6.3 wt.%), silica-undersaturated (30.9 wt.% SiO₂), ultrabasic (27.3 wt.% MgO) and poor in alkalis (0.12 wt.% Na₂O; 0.78 wt.% K₂O) (e.g., Kjarsgaard et al., 2009; 2022; Pearson et al., 2019).

The database also allows the inspection of the impact of various magmatic processes, including contamination by lithospheric mantle and crustal material, on the bulk composition of kimberlites. It is clear that variations in abundance (i.e., accumulation or fractionation) of magmatic or xenocrystic minerals can account for a considerable proportion of the variability inherent to the global kimberlite dataset. For example, the distinct ‘limbs’ in the SiO₂ vs MgO kimberlite-rock distributions (Fig. 1a) can be reconciled by increasing contributions from olivine, while, unsurprisingly, accumulation of phlogopite (phenocrysts and/or macrocrysts) probably dictates the high-K limb of the distribution (Fig. 1c) and calcite appears to have a key role in the CaO and CO₂ budgets (Fig. 1c,d). Importantly, these charts also demonstrate that mineral phases can have diametrically opposing influences on bulk kimberlite compositions, such as olivine

and calcite, where the latter drives compositions to increased CaO and decreased SiO₂ and the former achieves the opposite (Fig. 1).

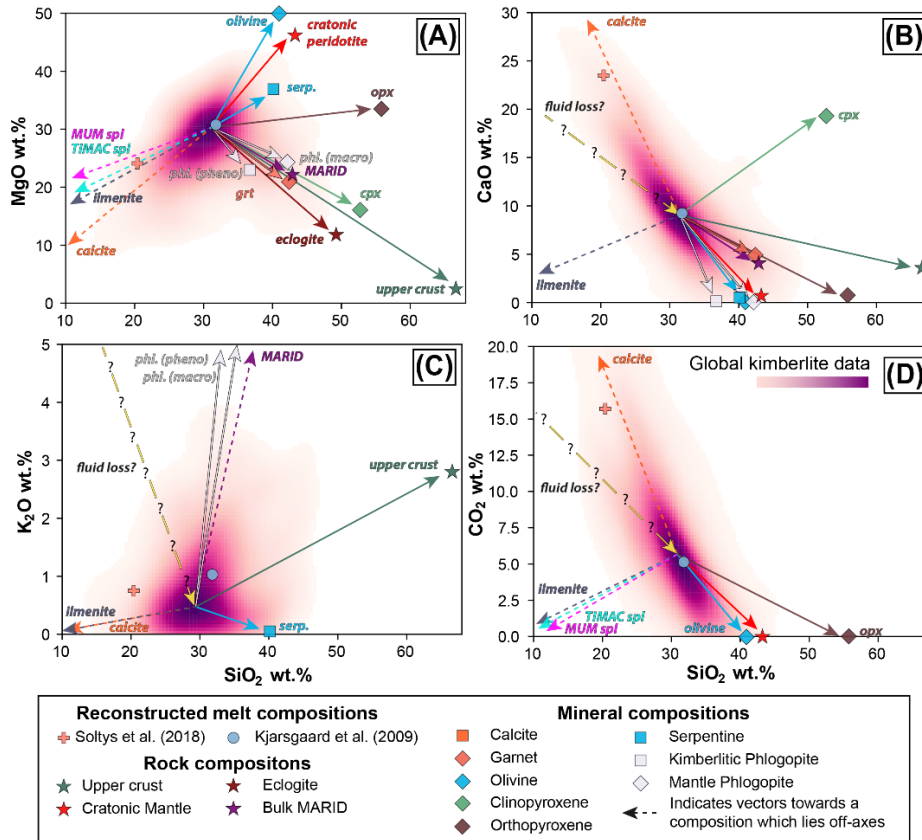


Figure 1. Major oxide co-variation charts for the global kimberlite database (Giuliani et al., 2024) using a gaussian kernel density estimation to highlight the most ‘typical’ compositions (using pyrolite; Williams, 2020): SiO₂ vs a) MgO; b) CaO; c) K₂O; d) CO₂. Also plotted are vectors to hypothesised sources of compositional variation in kimberlites due to contribution of mantle xenoliths/xenocrysts, crustal material, magmatic minerals and fluid loss.

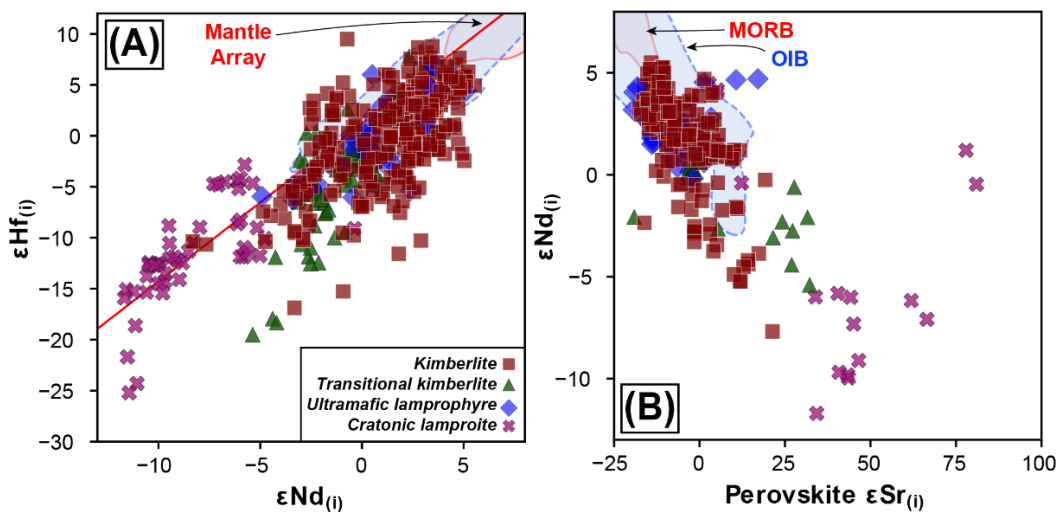


Figure 2. Sr-Nd-Hf isotope covariation plots of archetypal kimberlites, transitional kimberlites, ultramafic lamprophyres and cratonic lamproites worldwide plotted from the compiled database (Giuliani et al., 2024). a) ϵNd_i vs ϵHf_i ; b) ϵNd_i vs perovskite ϵSr_i ; Fields of mid-ocean ridge basalts (MORBs) and ocean island basalts (OIBs) are shown for comparison.

Regarding Sr-Nd-Hf isotopic compositions, our global compilation (Fig. 2) is consistent with previous observations which note a similarity between kimberlites and the composition of ocean island basalts (e.g., Smith, 1983) and more recently, ultramafic lamprophyres (e.g., Pearson et al., 2019), suggesting a genesis from broadly similar sources in the convecting mantle. However, this data also reveals a common peak (Fig. 3) in $\Delta\epsilon_{\text{Hf}_i}$ at -2 to -3 for kimberlites, both archetypal and transitional, and ultramafic lamprophyres through time after the anomalous and oversampled Lac de Gras and southern African kimberlites are excluded. Importantly, $\Delta\epsilon_{\text{Hf}_i}$ show no correlation with indices of crustal contamination. Instead, it is possible that these marginally negative $\Delta\epsilon_{\text{Hf}_i}$ values reflect widespread cycling of subducted oceanic crust and homogenisation of this component in the kimberlite sources. However, we also observe a temporal pattern, with changes in the overall distribution of Hf (and Sr) isotopes in archetypal kimberlites before and after 250 Ma which is at odds with a similar extent of oceanic crust cycling in the source of these magmas with time. Additional data from systems sensitive to crustal recycling, will therefore be required to understand the origin of this peculiar geochemical feature of kimberlites and ultramafic lamprophyres.

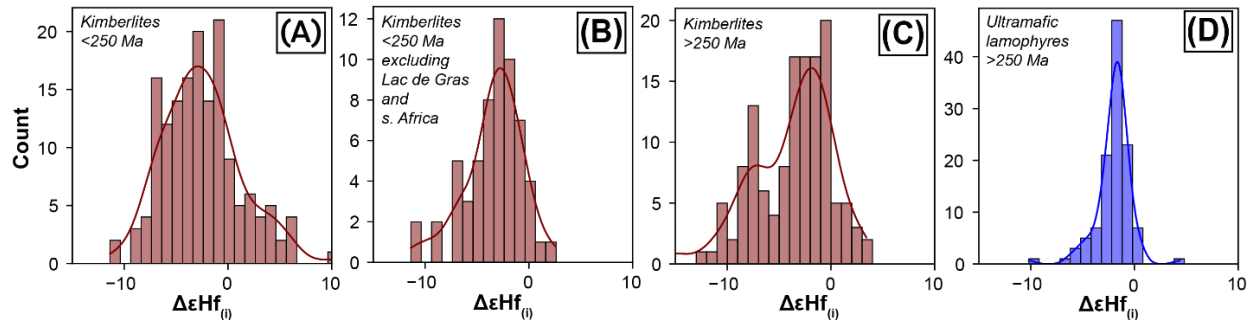


Figure 3. Kernel density distribution of $\Delta\epsilon_{\text{Hf}_i}$ values for archetypal kimberlites, and ultramafic lamprophyres younger and older than 250 Ma. $\Delta\epsilon_{\text{Hf}_i}$ values represent deviations from the Nd-Hf mantle array.

Outlook

The above represents just a small snapshot of the data collated as part of this work (Giuliani et al., 2024), which importantly, emphasises the data ‘gaps’, ongoing sources of controversy, and open questions concerning the genesis of kimberlites. For example, kimberlite sources within the convecting mantle seem to be robustly constrained (Fig. 2), yet the exact nature of these sources is not. Future global-scale investigations, with an expanding toolkit incorporating novel geochemical tools, and integration of geochemistry, geochronology, petrology and geodynamics will help solve some of these outstanding questions.

References

- Boone SC, Dalton H, Prent A, Kohlmann F, Theile M, Gréau Y, Florin G, Noble W, Hodgekiss S-A, Ware B, Phillips D, Kohn B, O’Reilly S, Gleadow A, McInnes B, Rawling T (2022) AusGeochem: An Open Platform for Geochemical Data Preservation, Dissemination and Synthesis. 46(2):245-259
- Dalton H, Giuliani A, O’Brien H, Phillips D, Hergt J, Maas R (2019) Petrogenesis of a Hybrid Cluster of Evolved Kimberlites and Ultramafic Lamprophyres in the Kuusamo Area, Finland. *Journal of Petrology* 60(10):2025-2050
- Giuliani A, Dalton H, Pearson DG (2024) Kimberlites: the deepest geochemical probes of Earth. In: Chauvel C (ed) *The Treatise on Geochemistry*, 3rd edition. Elsevier
- Kjarsgaard BA, de Wit M, Heaman LM, Pearson DG, Stiefenhofer J, Janusczyk N, Shirey SB (2022) A Review of the Geology of Global Diamond Mines and Deposits. *Reviews in Mineralogy and Geochemistry* 88(1) Reviews in Mineralogy and Geochemistry
- Kjarsgaard BA, Pearson DG, Tappe S, Nowell GM, Dowall DP (2009) Geochemistry of hypabyssal kimberlites from Lac de Gras, Canada: Comparisons to a global database and applications to the parent magma problem. *Lithos* 112:236-248
- Pearson DG, Woodhead J, Janney PE (2019) Kimberlites as Geochemical Probes of Earth’s Mantle. *Elements* 15(6):387-392
- Tappe S, Brand NB, Stracke A, van Acken D, Liu C-Z, Strauss H, Wu F-Y, Luguét A, Mitchell RH (2017) Plates or plumes in the origin of kimberlites: U/Pb perovskite and Sr-Nd-Hf-Os-C-O isotope constraints from the Superior craton (Canada). *Chemical Geology* 455:57-83
- Williams MJ, Schoneveld L, Mao Y, Klump J, Gosses J, Dalton H, Bath A, Barnes S (2020) pyrolite: Python for geochemistry. *The Journal of Open Source Software* 5(50)