30 YEARS OF DIAMONDS IN CANADA
8–12 July 2024 • Yellowknife

12th International Kimberlite Conference Extended Abstract No. 12IKC-038, 2024

Tracing the relative roles of lithospheric and sublithospheric mantle in kimberlite source regions using highly siderophile elements and Re-Os isotope systematics

Yong Xu[1], D. Graham Pearson[1], Bruce Kjarsgaard[2], Sarah Woodland[1], Jingao Liu[3]

[1] University of Alberta, Edmonton, Alberta, Canada, yong22@ualberta.ca, gdpearso@ualberta.ca, swoodlan@ualberta.ca

[2] Geological Survey of Canada, Ottawa, Canada, bruce.kjarsgaard@NRCan_RNCan.gc.ca

[3] China University of Geosciences, Beijing, China, jingao@cugb.edu.cn

Introduction

Kimberlites - ultrabasic, Si-undersaturated, low-Al, and low-Na volcanic rocks enriched in volatiles (CO_2 and H_2O) and incompatible trace elements - have been the subject of considerable debate regarding their source regions (Pearson et al., 2019). However, the multitude of processes experienced by these rocks limits our ability to accurately resolve their source region inputs. Distinct from the incompatible lithophile element-based isotopes (e.g., Sr-Nd-Hf), the highly siderophile characteristics of the Re-Os isotope system are less sensitive to most forms of crustal contamination, but more sensitive to lithospheric mantle interaction. Hence, Re-Os isotopes provide very complementary information to the lithophile element-based isotope systems. Compared to basalts, few kimberlites have been analyzed for Re-Os, with published data focusing on older intrusions where alteration can affect Re abundances, and thus initial ratio estimates. Here we present new data for fresh kimberlites from the Slave Craton, NWT, Canada, focusing on specific intrusions (e.g., Grizzly, Leslie, Aaron, Mark and Jericho), plus other global kimberlites (Greenland and Southern Africa) with predominantly young emplacement ages, to better constrain initial $^{187}Os/^{188}Os$ ratios. Our newly acquired data, combined with the previously reported Re-Os isotope data for archetypal kimberlites, will be further compared with the datasets of similar deep-seated mantle-derived rocks including carbonate-olivine-lamproites (CROLs; "Group II kimberlites") and oceanic-island-basalts (OIBs). Finally, we couple our new Re-Os isotope data with new highly siderophile element (HSE, here including Re and five PGEs (Os, Ir, Ru, Pt, Pd)) data to help to quantify mixing scenarios between kimberlite melts and different mantle or crust components (e.g., lithospheric mantle peridotites, recycled components, metasomatic sulfides, and crustal rocks, etc.), with the aim of providing a clearer picture of the relative roles of these components and evaluating recent proposals for the location of the kimberlite source.

Results and Discussion

Kimberlites (n=68) show widely varying Os concentrations (0.1-3.5 ppb) and $^{187}Os/^{188}Os$ ratios (with initial γOs values – where $γOs_i$, represents the percentage deviation of initial sample $^{187}Os/^{188}Os$ relative to chondritic reservoir - ranging from -15 to +55) (**Figure 1**). The majority of kimberlites have unradiogenic Os isotopic compositions (-15 to <0) similar to refractory, depleted cratonic mantle residues (Pearson et al., 2021). In contrast to these high-Os kimberlites that are strongly affected by ancient lithospheric mantle, some low-Os (<1 ppb) kimberlites with more radiogenic ^{187}Os signals broadly overlap with OIBs (e.g., Day, 2013). There is also a broad negative correlation between Os concentration and $γOs_i$ for most samples, which can be simulated, to some extent, by binary mixing scenarios between ancient cratonic peridotite and our putative primary kimberlite melt with an OIB-like Re-Os elemental and isotopic composition (e.g.,

γOs_i=~+10). Accordingly, the high-Os and low-γOs_i kimberlite magmas may require >50% contribution from the cratonic mantle root. Beyond that, the few samples with very low Os concentrations are apparently susceptible to contamination by high Re/Os continental crust during kimberlite magma ascent. The radiogenic γOs_i (+30-+60) of these kimberlites is also consistent with the modelling result.

Despite the limited dataset, the CROLs (n=15) genarally share common characteristics with kimberlites, for example, their large range of Os concentrations (0.5-3.5 ppb) and γOs_i values (-10 to +10). These magmatic rocks are also distributied along mixing trends between the OIB field and cratonic mantle residues (**Figure 1**), suggesting an important role of continental lithosphere in their fomation or subsequent evolution. Nevertheless, it is worth noting that there is a scarcity of low-Os, highly radiogenic ^{187}Os samples in CROLs, indicating some source lithological and petrogenetic differences to kimberlite melts.

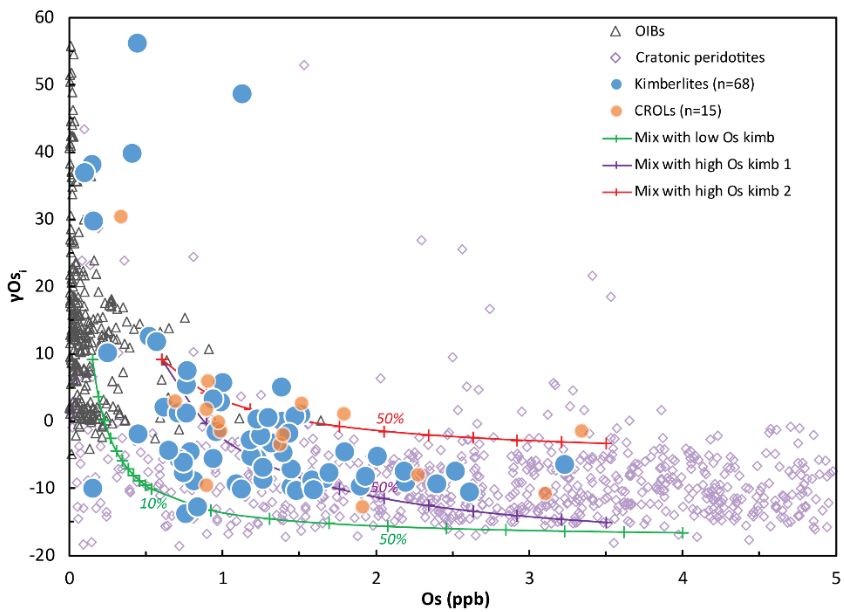

Figure1 Initial γOs values (γOs_i) versus Os concentrations for the kimberlites and CROLs.

Most kimberlites (Canada: Leslie, Grizzly, Aaron, Mark; Russia: Internationalaya; and Greenland: Maniitsoq) display nearly flat PUM-normalized HSE patterns, except for AAR-2 that has an abnormal W-shaped pattern, and some having moderately to remarkably elevated Re abundances (**Figure 2**a). This is in good agreement with previously published HSE data (also using the isotope dilution method) for the kimberlites from the Superior, Karelia, and Kaapvaal cratons (e.g., Maier et al., 2017; Tappe et al., 2017). Like the unradiogenic initial Os isotopes, the unfractionated PUM-like (chondritic) relative HSE abundances presented by the majority of global kimberlites likely indicate significant involvement of cratonic mantle root in kimberlite magmas. However, a simple mixing model between the OIBs and cratonic peridotites cannot adequately explain the observed low-HSE patterns. We thus consider the potential assimilation of continental crust, which can effectively dilute the absolute HSE abundances. This would inevitably lead to the elevation of Re/Os and accumulation of radiogenic ^{187}Os, which is also consistent with the actual kimberlite HSE curves.

Olivine and matrix picking experiments on kimberlites reveal that the olivines (a mixture of xenocrystic and phenocrystic olivine, typically dominated by the former) have PPGE-depleted HSE patterns that are similar to highly depleted cratonic mantle residues, in striking contrast to their whole rock counterparts that have higher PPGEs (**Figure 2**b). This HSE discrepancy clearly indicates that in addition to involvement of IPGE-rich lithospheric mantle, there is also an asthenosphere-derived PPGE-rich melt phase controlling the formation of kimberlite magmas, and could balance the influence of subsequent lithosphere addition.

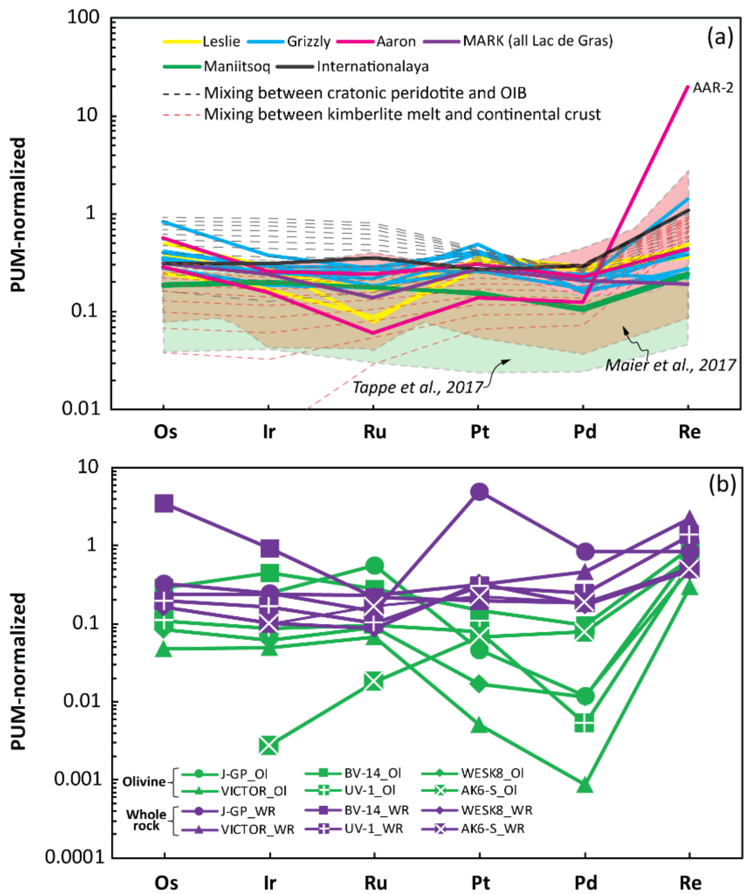

Figure 2 The PUM-normalized HSE patterns for the global kimberlites (a), and the HSE pattern comparison between the kimberlite whole rocks and olivines (b). The mixing models are made in an increment of 10%.

Conclusion and Remark

1) Both whole-rock Re-Os isotope and HSE evidences suggest that most kimberlites and CROLs are strongly affected by ancient refractory lithospheric mantle, necessitating olivine and matrix picking experiments to better resolve the impact of the asthenospheric source;
2) The higher PPGE abundances and unfractionated patterns of whole rocks relative to olivine are strong indicators of the influence of the asthenospheric source for global kimeberlites.

References

Day JMD (2013). Hotspot volcanism and highly siderophile elements. Chemical Geology 341: 50–74.

Maier WD, O'Brie H, Peltonen P, Barnes SJ (2017). Platinum-group element contents of Karelian kimberlites: Implications for the PGE budget of the sub-continental lithospheric mantle. Geochimica et Cosmochimica Acta 216: 358–371

Pearson DG, Scott JM, Liu J, Schaeffer A, Wang LH, van Hunen J, Szilas K, Chacko T, Kelemen PB (2021). Deep continental roots and cratons. Nature 596(7871): 199–210

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 CZ, Strauss H, Wu FY, Luguet 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