12 IKC 12TH INTERNATIONAL KIMBERLITE CONFERENCE
30 YEARS OF DIAMONDS IN CANADA
8–12 July 2024 • Yellowknife

12th International Kimberlite Conference Extended Abstract No. 12IKC-125, 2024

Eclogitic zircon geochronology and trace element geochemistry: an investigation of mantle metasomatism from the Cretaceous to the Archean beneath the Kaapvaal craton

Molly K. Paul[1] and Mark D. Schmitz[1]
[1]Boise State University, Boise, USA, mollypaul@u.boisestate.edu, markschmitz@boisestate.edu

Introduction & Petrologic Classification

Eclogite xenoliths entrained in kimberlites offer a rare perspective into metasomatism of the cratonic sub-continental lithospheric mantle (SCLM). To better understand the timing and geochemical consequences of SCLM metasomatism, we investigated zircon-bearing xenoliths from the Roberts Victor (lamproite, Group II kimberlite, orangeite) and Lovedale (Group I kimberlite, kimberlite *sensu stricto*) kimberlites, two type localities for Kaapvaal eclogitic xenoliths.

U-Pb zircon systematics in high-temperature mantle eclogites require unique interpretative frameworks, particularly because U-Pb discordance cannot be readily explained or remedied by common mechanisms employed in traditional U-Pb zircon geochronology. Zircon at mantle temperatures readily anneal radiation damage. While thermally activated diffusive Pb loss is possible, the absence of pervasive discordance or any correlation between discordance and grain size indicates this is not a feasible cause of Pb loss in our dataset. Dissolution and reprecipitation of zircon via melts or supercritical fluid infiltration is a viable mechanism of Pb loss and isotopic resetting. This mechanism also promotes high spatial variability at both the grain and sample scale and is physically plausible over long residence times in reactive mineralogy at high temperatures.

We use results from electron microscopy, laser ablation - inductively coupled plasma mass spectrometry (LA-ICPMS), and isotope dilution thermal ionization mass spectrometry of clinopyroxene, garnet, and zircon from a xenolith from each mine to make new inferences about the age and character of metasomatism in the SCLM of the Kaapvaal craton. Modal mineralogy and compositions of garnet and clinopyroxene in eclogites from these kimberlites show contrasting characteristics of initial composition and metasomatic alteration, both petrographically and geochemically. The Lovedale xenolith belongs to Group II (McCandless and Gurney 1989) and Type II (Macgregor and Carter 1970) eclogites and contains garnet, phlogopite, and clinopyroxene. Its garnets have Y-Zr compositions consistent with an undepleted protolith and relatively minor metasomatic alteration. The Roberts Victor xenolith is a unique, highly metasomatized, phlogopite-bearing eclogite. The composition of its garnets suggests formation from a partially depleted protolith that has experienced high-temperature metasomatism. It is a Type I (Macgregor and Carter 1970), Group I (McCandless and Gurney 1989), Type IB (Huang et al. 2012), or Type I (Gréau et al. 2011) mantle eclogite based on petrography, Na_2O in garnet, K_2O in clinopyroxene, FeO in garnet, and rare earth element (REE) patterns of major phases. The profound metasomatic character of the xenolith is evident from the major element oxide composition of its major phases and petrography, which includes abundant phlogopite, clinopyroxene exsolution, and coronae around garnet.

Lovedale: Geochemistry & U-Pb Zircon Geochronology

Zircon LA-ICPMS analyses yield $^{206}Pb/^{238}U$ dates from ~90 to 120 Ma with two types of rare earth element (REE) patterns apparent: those with flat heavy rare earth element (HREE) slopes that likely formed in equilibrium with garnet and those that lack relative depletion of HREE. Flat HREE slopes correlate to younger, rounded grains. In contrast, those that lack HREE depletion tend to have an older and more variable age distribution with subhedral grains. In trace element bivariate space, these two REE patterns concentrate into lamproitic versus carbonatitic fields. A few zircon grains in this sample previously dated by TIMS are as old as ~ 2.7 Ga, but this age component was not captured in the present study.

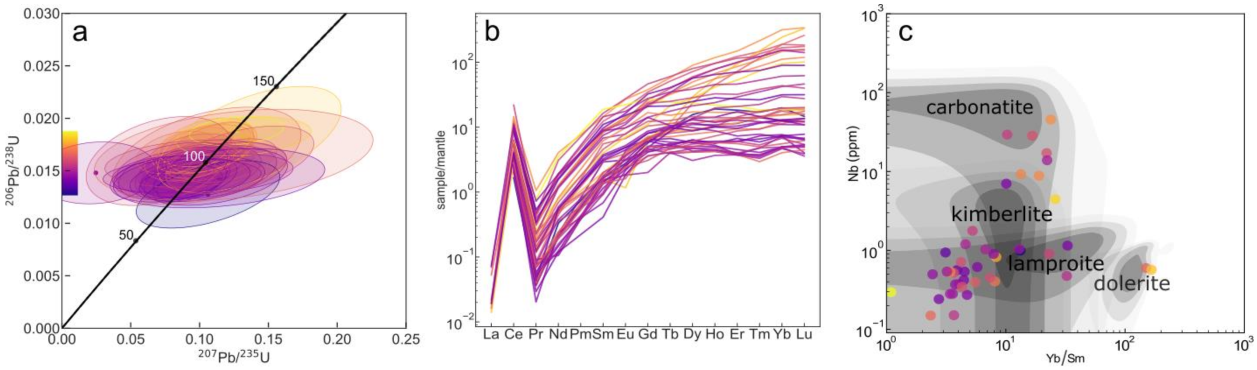

Figure 1: (a) Concordia diagram showing all Lovedale zircon LA-ICPMS analyses, color-coded by ^{206}Pb-^{238}U ratio. (b) Rare earth element plot normalized to pyrolite (McDonough and Sun 1995). (c) Trace element bivariate diagram with grey regions representing quintiles calculated using a kernel density estimate of data compiled by Itano and Sawada (2024) after Belousova et al. (2002).

Roberts Victor: Geochemistry & U-Pb Zircon Geochronology

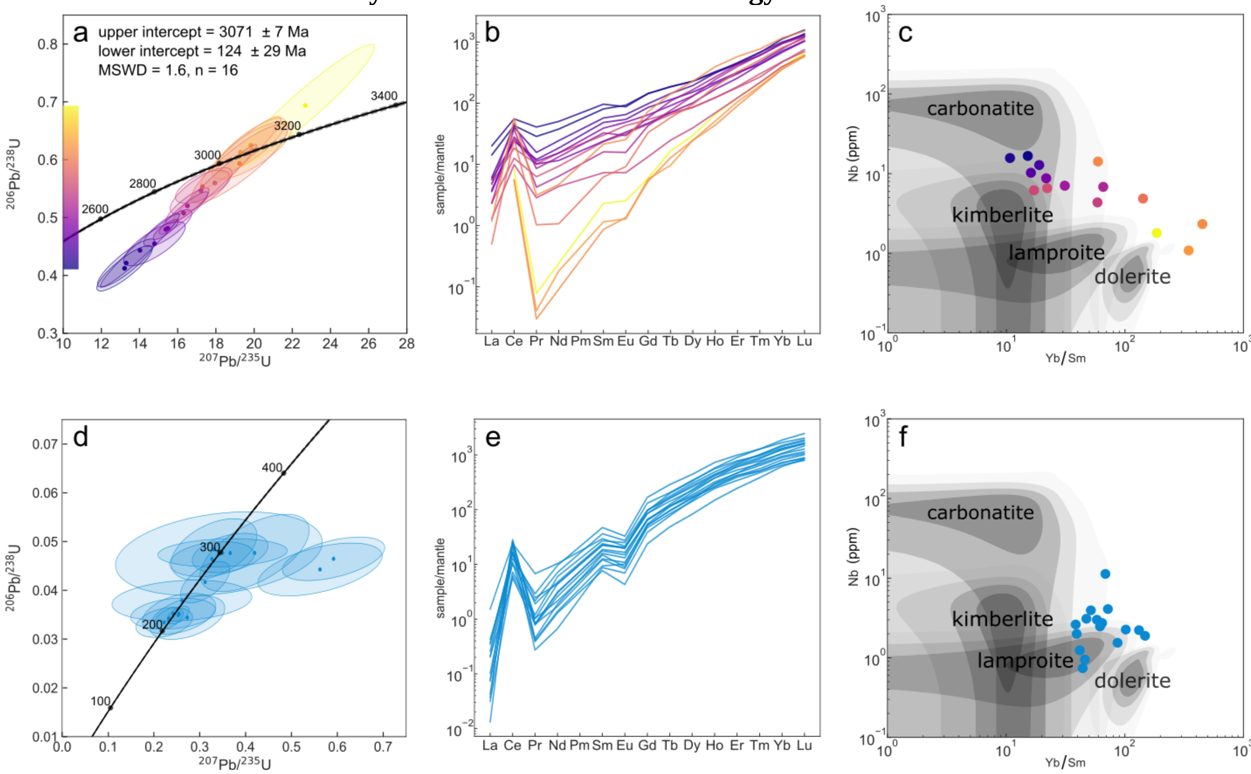

Figure 2: (a) Concordia diagram showing a subset of Archean Roberts Victor zircon LA-ICPMS analyses, color-coded by ^{206}Pb-^{238}U ratio, which form a discordia array toward the eruption of the Roberts Victor lamproite. The same analyses are plotted in a rare earth element plot normalized to pyrolite (McDonough and Sun 1995) (b) and placed in a broader petrologic context using a trace element bivariate diagram (c). (d) A concordia diagram of young zircon LA-ICPMS analyses. These same analyses are plotted in a rare earth element plot normalized to pyrolite (McDonough and Sun 1995) (e) and a bivariate diagram (f). Grey regions in the bivariate diagrams (c, f) are quintiles calculated using a kernel density estimate of data compiled by Itano and Sawada (2024) after Belousova et al. (2002).

Zircon grains from the Roberts Victor eclogite range in age from Triassic to Archean; here, we focus on the oldest and youngest dominant subgroups of this complex age distribution. A group of variably discordant Mesoarchean (~3.07 Ga) zircon crystals have a shallow Eu anomaly, steep HREE, and lower Nb and Ti concentrations. These compositions fan toward shallower REE slopes and higher trace element concentrations with increasing discordance. Archean ages with concordant $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$ dates demonstrate that zircons are not pervasively reset by thermally activated diffusive Pb loss. Instead, the discordia array covariance with trace element geochemistry (Fig. 2a) suggests apparent Pb loss due to partial dissolution and reprecipitation during late-stage metasomatism by a carbonatitic melt. The lower intercept of this discordia is consistent with Cretaceous metasomatism. This relationship between discordance and trace element geochemistry can also be observed in other discordia arrays in the dataset, as well as coarsely at a single-grain scale. The youngest zircon growth in this eclogite is recorded by concordant to slightly discordant Permian to Triassic crystal ages. Young zircon growth (Fig. 2c) can be linked to lamproitic melt compositions (Fig. 2 e,f) and clearly predates volcanism.

Conclusions

Metasomatic zircon in eclogites record a prolonged and diverse geochemical history. Zircon from within the same sample bear witness to different metasomatic events, supporting the notion that metasomatism can act over small spatial scales via melt and fluid infiltration. Lovedale Cretaceous zircon appear to have crystallized from metasomes involved in lamproite and carbonatite formation. Similarly, a Roberts Victor ~3.07 Ga doleritic zircon population experienced partial dissolution-reprecipitation due to a Cretaceous, carbonatitic metasome. Triassic Roberts Victor zircon record a distinct, lamproitic metasome. Simple models of thermally activated diffusion cannot explain temporal variations in zircon geochemistry. Rather than diffusive resetting, zircon in eclogites preserve a multi-episodic and diverse geochronological and geochemical expression of metasomatic dissolution-reprecipitation reactions through time. We continue to explore how discrete tectonic and orogenic events have unique metasomatic imprints in the mantle through this zircon lens.

References

Belousova E, Griffin W, O'Reilly SY, Fisher N (2002) Igneous zircon: trace element composition as an indicator of source rock type. Contrib Mineral Petr 143:602–622. https://doi.org/10.1007/s00410-002-0364-7

Gréau Y, Huang J-X, Griffin WL, et al (2011) Type I eclogites from Roberts Victor kimberlites: Products of extensive mantle metasomatism. Geochim Cosmochim Ac 75:6927–6954. https://doi.org/10.1016/j.gca.2011.08.035

Huang J-X, Gréau Y, Griffin WL, et al (2012) Multi-stage origin of Roberts Victor eclogites: Progressive metasomatism and its isotopic effects. Lithos 142:161–181. https://doi.org/10.1016/j.lithos.2012.03.002

Itano K, Sawada H (2024) Revisiting the Geochemical Classification of Zircon Source Rocks Using a Machine Learning Approach. Math Geosci 1–22. https://doi.org/10.1007/s11004-023-10128-z

Macgregor ID, Carter JL (1970) The chemistry of clinopyroxenes and garnets of eclogite and peridotite xenoliths from the Roberts Victor mine, South Africa. Phys Earth Planet Inter 3:391–397. https://doi.org/10.1016/0031-9201(70)90081-6

McCandless TE, Gurney JJ (1989) Sodium in garnet and potassium in clinopyroxene: criteria for classifying mantle eclogites. Geological Society of Australia Special Publication 14:827–832

McDonough WF, Sun S -s. (1995) The composition of the Earth. Chem Geol 120:223–253. https://doi.org/10.1016/0009-2541(94)00140-4