Kimberlilitic olivine research directions, implications, and tracking mantle cargo

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Why has research on kimberlitic olivine become so popular?

- BSE images of olivine from the Lando dike, Tongo-Tonguma, Sierra Leone

Viljoen et al. (2022 – Lithos)
Terminology based on zoning

Giuliani (2018 – Lithos)
Complexity of zoning

Howarth and Taylor (2016 – Lithos)

BSE image

XPL image
Complexity of zoning

Howarth and Taylor (2016 – Lithos)

Rim zone

BSE image

XPL image

400 μm
Compositional zoning of olivine

Mitchell et al. (2019 – Elements)
Electron probe microanalyser

• High resolution but cannot accurately analyse full suite of trace elements

Howarth and Gross (2019 – GCA)
Laser ablation ICP-MS

Laser

EPMA

75 µm spot size

Bussweiler et al. (2015 – Lithos)
Recent research directions

1. Al-in-olivine thermometry used to understand SCLM sampling depths

2. Correlations between core and rim compositions indicate kimberlite melt influenced by SCLM assimilation

3. Complex rim zoning used to constrain kimberlite petrogenesis from source to surface

4. Melt/fluid inclusions can be used to understand kimberlite melt compositions and evolution
Global olivine core-rim correlation

- Olivine core-rim correlations indicate kimberlite melt is influenced by the mantle material sampled

Giuliani et al. (2020 – Science Advances)
Tips on use of the Al-in-olivine thermometer

\[ T[\, ^\circ C] = \frac{11245 + 46.0 \times P[kbar]}{13.68 - \ln(Al[ppm])} - 273 \]

Bussweiler et al. (2017 - Lithos)
**Al-in-olivine thermometry**

- Performs well compared to two pyroxene thermometer of Brey and Köhler (1990)
- Slight overestimation of T relative to single cpx thermometer of Nimis and Taylor (2000)

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Bussweiler et al. (2017 - Lithos)
Data filtering

Step 1:
Olivine xenocryst filtering

- Mg# > 90
- Ni > 2350 ppm
- Ca < 715 ppm
- Mn < 1160 ppm

Step 2:
Al-V discrimination diagram

- Al-in-olivine thermometry only applicable to gt-peridotite
Al-in-olivine thermometry

- Al-in-olivine thermometry can be used to calculate equilibration P-T-depth
- Team diamond - https://cms.eas.ualberta.ca/team-diamond/downloads/

Bussweiler et al. (2017 - Lithos)
Practical application of the Al-in-olivine thermometer – Koidu kimberlites

Andrea Giuliani, Yannick Bussweiler, Merrily Tau, Sinelethu Hashibi, Phil Janney, and Tom Nowicki
Mantle sampling – Koidu example

Howarth et al. (in revision – Min. deposita)
Mantle sampling – Koidu example

DZA dike

Howarth et al. (in revision – Min. deposita)
Mantle sampling – Koidu example

- EPMA data for kimberlite phases
- DZA dike has notable break in Mg# ~90

Howarth et al. (in revision – Min. deposita)
Megacryst filtering:

- LA-ICP-MS trace element data
- Al-Zn-Mn discriminate megacrysts
Mantle sampling – Koidu example

Spinel peridotite filtering

- Al-V discriminate spinel peridotites

Howarth et al. (in revision – Min. deposita)
Mantle sampling – Koidu example

DZB dike/Pipe 1

Temperature (°C)

Frequency

600 1000 1400

0 4 8

Olivine data – Howarth et al. (in review)

Cpx from Koidu ltd. using single cpx thermometer of Nimis and Taylor (2000)

Diamond stability and geotherm from Smit et al. (2016; Precambrian research)

DZA dike

Temperature (°C)

Frequency

600 1000 1400

0 12 24

Olivine - DZA dike

Howarth et al. (in revision – Min. deposita)
Mantle sampling – Koidu example

Olivine data – Howarth et al. (in review)
Diamond inclusion data – Lai et al. (in review)
Diamondiferous eclogite data from Hills and Haggerty (1989; Contributions) and Lai et al. (in review) using Krogh (1988)
Cpx from Koidu ltd. using single cpx thermometer of Nimis and Taylor (2000)
Diamond stability and geotherm from Smit et al. (2016; Precambrian research)
Mantle sampling – Koidu example

Olivine data – Howarth et al. (in review)
Diamond inclusion data – Lai et al. (in review)
Diamond stability and geotherm from Smit et al. (2016; Precambrian research)

Howarth et al. (in revision – Min. deposita)
Mantle sampling – Koidu example

Howarth et al. (in revision – Min. deposita)
Summary/future directions

1. We need a trace element in olivine dataset for mantle xenoliths and diamond inclusions
   • e.g., Korolev et al. (2018); Meyer (2021; PhD); Lai (2022; PhD)

2. Olivine xenocryst and mantle xenolith data from single locations
   • e.g., Greene et al. (2023)

3. Olivine xenocryst data from more kimberlites where traditional indicator mineral data is available
   • e.g., Tau et al. (2024; IKC)
Questions

Do you want to ask an anonymous question?

Text it to +1 778 883 7422

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Terminology based on zoning

Abersteiner et al. (2022 – J.Pet)
Complexity of olivine zoning

Macrocryst and true phenocryst

Oxide inclusions in olivine:
- Chromite
- Ilmenite
- MUM

Benfontein sill

Howarth and Gross (2019 – GCA)
Complexity of zoning

Benfontein kimberlite, Kimberley
Complexity of olivine zoning

Benfontein kimberlite, Kimberley
Phosphorus zoning

Howarth and Gross (2019 – GCA)
Global olivine core compositions

Giuliani (2018 – *Lithos*)
Global olivine rim compositions

Howarth and Giuliani (2020 – Lithos)
Global olivine rim compositions

Casetta et al. (2023 - EPSL)
Olivine evolution stages - Benfontein

- Olivine fractional crystallisation
- Low phosphorous with decreasing Ni and increasing Ca, Mn etc.
- Inclusion of chromite

- Partial equilibration with Cr-enriched kimberlite host melt prior to rapid ascent to surface
- Low phosphorous but increasing Cr and other trace elements

- Incorporation of low phosphorous olivine xenocryst core as polygonal to angular grains

- Emplacement as macrocrystic hybrid magma in sill complex below lithological barrier and late-stage oxidation to form rind
- Inclusion of magntite-rich spinel

- Magma-mixing with new pulse containing T2 rim evolutionary trend

- Temporary stalling at lithological barriers in crust followed by rapid decrease in pressure related to breaking the barrier and formation of P-rich T1 rim zone through solute trapping
- Inclusion of ilmenite

Howarth and Gross (2019 – GCA)
Global olivine core-rim correlation

Howarth et al. (2022 – J.Petrology)
Cratonic lamproite olivine core-rim correlation

Finsch olivine lamproite, South Africa

Howarth and Nembambula (2021 – Lithos)

Sarkar et al. (2023 – GEOLOGY)
Mantle sampling – Koidu example

(a) 
Cr$_2$O$_3$ (wt.%) vs Ca#

Pipe 1
Pipe 2
Cr-poor megacrysts

(b) 
Depth (km) vs Ca#

Cr-poor megacrysts
Diamondiferous lamproites - India

Shaikh et al. (2019 – Lithos)
Jericho kimberlite example

Greene et al. (2023 – Lithos)
Jericho kimberlite example

Veglio et al. (2022 – Lithos)
Jericho kimberlite example

Veglio et al. (2022 – Lithos)
Koffiefontein kimberlite

Meyer (2021 – PhD, University of Alberta)
Cullinan diamond inclusions

Korolev et al. (2018 – Lithos)
Fig. 14. Diagram illustrating a possible mechanism for the formation of megacrysts, macrocrysts and dunitic nodules in kimberlites. Reaction between protokimberlite fluid and mantle peridotite extracts pyroxene and garnet from zone closest to conduit leaving dunite with rare ilmenite crystals. Farther from the conduit, interaction between fluid and peridotite facilitates the growth of large crystals of olivine, pyroxene and garnet. The Mg# is higher than in mantle peridotite close to the conduit and lower far from the conduit.

Arndt et al. (2022 – J.Pet.)