12TH INTERNATIONAL KIMBERLITE CONFERENCE

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

12th International Kimberlite Conference Extended Abstract No. 12IKC-120, 2024

Kimberlite magmatism fed by broad upwelling above mobile basal mantle structures

Nicolas Flament[1], Omer Bodur[1], Anton Grabreck[1], Simon Williams[2], Andrew Merdith[3]
[1] *Environmental Futures, School of Earth, Atmospheric and Life Sciences, University of Wollongong, Australia,* nflament@uow.edu.au
[2] *Institute for Marine and Antarctic Studies, Hobart, Australia,* Simon.Williams@utas.edu.au
[3] *School of Physics, Chemistry and Earth Sciences, The University of Adelaide, Australia,* andrew.merdith@adelaide.edu.au

Experimental petrology studies suggest that kimberlite melts commonly form at ~300 km depth (Foley et al., 2019). Diamonds are transported to the surface from at least ~120 km depth (Pearson et al., 2014) and possibly more than 660 km depth in some instances (Walter et al., 2011), suggesting that the heat source for some diamond-bearing kimberlites might be advected from great depths. Indeed, possible geodynamic environments for the formation of kimberlite melts include the lower mantle and transition zone, subduction zones, the lithosphere-asthenosphere boundary and mantle upwelling into the upper asthenosphere (Giuliani & Pearson, 2019). Here we explore how deep mantle processes could transport heat to the source depth of kimberlite magmatism, keeping in mind that factors such as lithospheric structure (Begg et al., 2009), changes in plate velocities (Moore et al., 2008) or rifting (Gernon et al., 2023) are likely to localise partial melting at shallower depths.

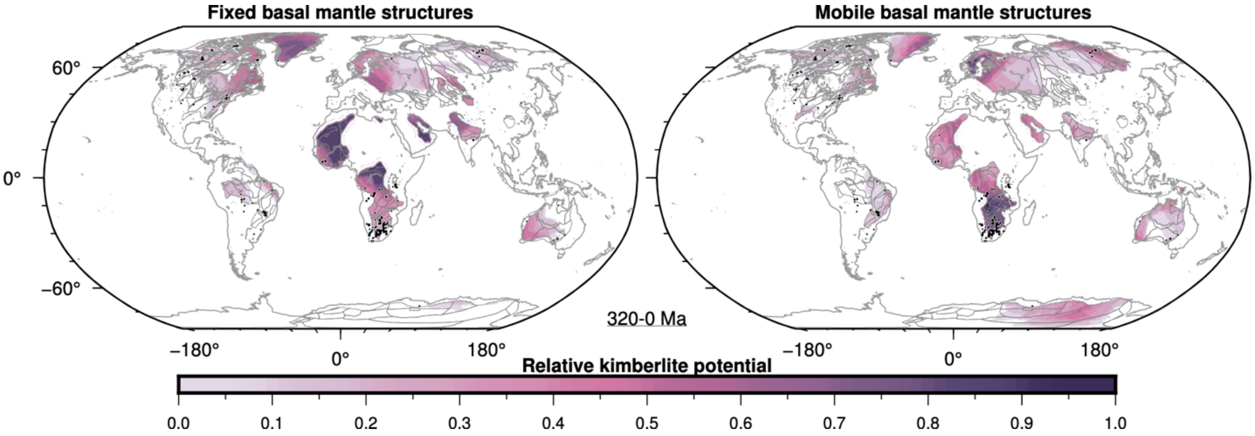

Figure 1: Predicted relative kimberlite potential. Global relative kimberlite potential maps for lithosphere thicker than 150 km from 320 Myr ago for fixed (left) and mobile (right) basal mantle structures. Kimberlites from Tappe et al. (2018) are shown as black disks.

A link between kimberlite eruptions and the present-day structure of the lowermost mantle was established by Torsvik et al. (2010), who argued that basal mantle structures are likely to be fixed over geological times because they are spatially correlated with the reconstructed locations of large igneous provinces (LIPs) and kimberlite eruptions from 320 Myr ago. Recent work showed that the strength of the spatial-statistical relationship between reconstructed LIPs and kimberlite eruption locations is similar for fixed LLSVPs imaged by seismic tomography and moving basal mantle structures predicted by forward models of past mantle flow (Flament et al., 2022). This relationship suggests that there may be no need for basal mantle structures to have been fixed over time, which is easier to reconcile with the dynamics of Earth's mantle predicted by current geodynamic models and inferred from seismologic observations that suggest that basal mantle structures are presently deforming (Lynner & Long, 2014).

We used the strong spatial-statistical relationship between kimberlites and basal mantle structures, and the preferential association of diamond-bearing kimberlites with thick lithosphere to create global maps of relative kimberlite potential (Grabreck et al., 2022). This was done by reconstructing the location of lithosphere presently thicker than 150 km, determining its intersection with either fixed or mobile basal mantle structures, and averaging the results over the last 320 Myr. The results are in general agreement with the locations of kimberlite eruptions in the database of Tappe et al. (2018) both for fixed and moving basal mantle structures (Fig. 1).

The strong spatial-statistical relationship between kimberlites and basal mantle structures is somewhat unexpected because LIPs that are the product of deep mantle plumes are not systematically associated with kimberlites (Ernst & Jowitt, 2013). It is therefore unlikely that kimberlites are produced by narrow mantle plumes. Recent work suggests that broad mantle upwelling could instead link kimberlite eruptions to the deep Earth (Bodur & Flament, 2023). This work mapped the evolution of broad mantle upwelling in forward reconstructions of past mantle flow (Fig. 2). It showed that broad mantle upwelling primarily occurs above moving basal mantle structures (Fig. 2b-c), and that there is a strong spatial-statistical relationship between the kimberlite eruptions in the database of Tappe et al. (2018) and the predicted broad mantle upwelling. The models show that deep Earth material is transported to the source region of kimberlite melt, which is consistent with the geochemical signature of some kimberlites (Giuliani et al., 2021). The areas covered by broad mantle upwelling (Fig. 2a) is much larger than the areas over which kimberlite eruptions occur, and we suggest that broad mantle upwelling could be the process that transports heat from the deep Earth to the source depth of kimberlite melts, where shallower geodynamic processes localise kimberlite eruptions.

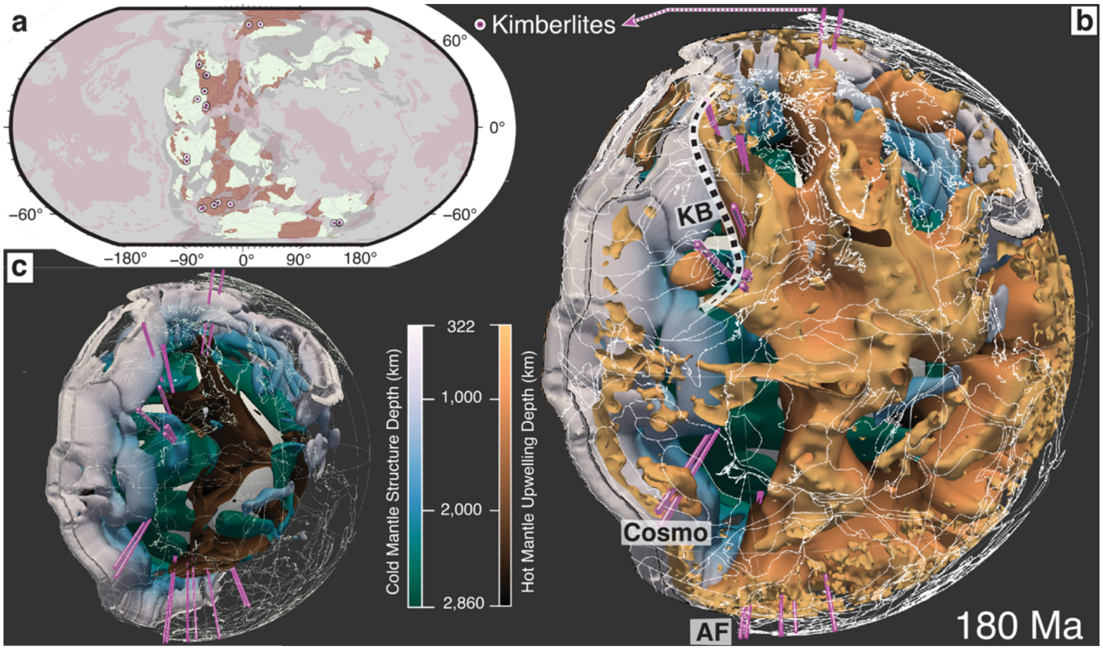

Figure 2: Link between broad mantle upwellings and kimberlites. a, Map of broad mantle upwellings (brown in continental blocks and dim red in oceans and continents), reconstructed continental blocks (green polygons), reconstructed continents (grey polygons), and reconstructed kimberlites (symbols) at 180 Ma. **b,** 3-D view of cold mantle structures coloured by depth in the African hemisphere, broad mantle upwellings deeper than 322 km coloured by depth, and reconstructed kimberlites shown as magenta columns extending up from the core-mantle boundary. The black dashed line shows the kimberlite belt (KB) in Canada and North America. AF and Cosmo designate kimberlites in Africa and Brazil, respectively. **c,** Similar to **b** but for shown for broad mantle upwellings deeper than 2,000 km depth.

Acknowledgements

This work was supported by Australian Research Council Linkage grant LP170100863 (industry partner: De Beers). This research was supported by the Australian Government's National Collaborative Research Infrastructure Strategy (NCRIS), with access to computational resources provided by the National Computational Infrastructure (NCI) through the National Computational Merit Allocation Scheme and through the University of Wollongong (UOW).

References

Begg, G., Griffin, W., Natapov, L., O'Reilly, S. Y., Grand, S., O'Neill, C., Hronsky, J., Djomani, Y. P., Swain, C., & Deen, T. (2009). The lithospheric architecture of Africa: Seismic tomography, mantle petrology, and tectonic evolution. *Geosphere, 5*(1), 23-50.

Bodur, Ö. F., & Flament, N. (2023). Kimberlite magmatism fed by upwelling above mobile basal mantle structures. *Nature Geoscience, 16*(6), 534-540.

Ernst, R. E., & Jowitt, S. M. (2013). Large igneous provinces (LIPs) and metallogeny.

Flament, N., Bodur, Ö. F., Williams, S. E., & Merdith, A. S. (2022). Assembly of the basal mantle structure beneath Africa. *Nature, 603*(7903), 846-851.

Foley, S. F., Yaxley, G. M., & Kjarsgaard, B. A. (2019). Kimberlites from source to surface: insights from experiments. *Elements: An International Magazine of Mineralogy, Geochemistry, and Petrology, 15*(6), 393-398.

Gernon, T. M., Jones, S. M., Brune, S., Hincks, T. K., Palmer, M. R., Schumacher, J. C., Primiceri, R. M., Field, M., Griffin, W. L., & O'Reilly, S. Y. (2023). Rift-induced disruption of cratonic keels drives kimberlite volcanism. *Nature, 620*(7973), 344-350.

Giuliani, A., Jackson, M. G., Fitzpayne, A., & Dalton, H. (2021). Remnants of early Earth differentiation in the deepest mantle-derived lavas. *Proceedings of the National Academy of Sciences, 118*(1), e2015211118.

Giuliani, A., & Pearson, D. G. (2019). Kimberlites: from deep earth to diamond mines. *Elements: An International Magazine of Mineralogy, Geochemistry, and Petrology, 15*(6), 377-380.

Grabreck, A., Flament, N., & Bodur, Ö. F. (2022). Mapping global kimberlite potential from reconstructions of mantle flow over the past billion years. *Plos one, 17*(6), e0268066.

Lynner, C., & Long, M. D. (2014). Lowermost mantle anisotropy and deformation along the boundary of the African LLSVP. *Geophysical Research Letters, 41*(10), 3447-3454.

Moore, A., Blenkinsop, T., & Cotterill, F. (2008). Controls on post-Gondwana alkaline volcanism in Southern Africa. *Earth and Planetary Science Letters, 268*(1-2), 151-164.

Pearson, D., Brenker, F., Nestola, F., McNeill, J., Nasdala, L., Hutchison, M., Matveev, S., Mather, K., Silversmit, G., & Schmitz, S. (2014). Hydrous mantle transition zone indicated by ringwoodite included within diamond. *Nature, 507*(7491), 221-224.

Tappe, S., Smart, K., Torsvik, T., Massuyeau, M., & de Wit, M. (2018). Geodynamics of kimberlites on a cooling Earth: Clues to plate tectonic evolution and deep volatile cycles. *Earth and Planetary Science Letters, 484*, 1-14.

Torsvik, T. H., Burke, K., Steinberger, B., Webb, S. J., & Ashwal, L. D. (2010). Diamonds sampled by plumes from the core–mantle boundary. *Nature, 466*(7304), 352-355.

Walter, M., Kohn, S., Araujo, D., Bulanova, G., Smith, C., Gaillou, E., Wang, J., Steele, A., & Shirey, S. (2011). Deep mantle cycling of oceanic crust: evidence from diamonds and their mineral inclusions. *Science, 334*(6052), 54-57.