# Diamond-forming fluids: elemental and radiogenic isotope studies of fibrous and non-fibrous diamonds from diamondiferous peridotite and eclogite xenoliths

D. Graham Pearson*
Durham University, Durham, United Kingdom
d.g.pearson@durham.ac.uk

O. Klein-BenDavid
Durham University, Durham, United Kingdom

F. Laiginhas
Durham University, Durham, United Kingdom

J.C.R. McNeill
Durham University, Durham, United Kingdom

J.J. Gurney

University of Cape Town, Cape Town, South Africa

G.M.Nowell
Durham University, Durham, United Kingdom

C.J. Ottley
Durham University, Durham, United Kingdom

## Summary

We present trace element and radiogenic isotope data for a suite (>40) of fibrous diamonds together with diamonds from an eclogite and 6 peridotite xenoliths to better understand the nature of the source of diamond-forming fluids. Large variations in Sr isotopes and trace element abundances are present between and within fibrous diamonds, supporting an origin via fluid mixing from at least 2 different sources. Diamonds from peridotite xenoliths show significantly variable elemental systematics, indicating the likelihood of different fluid sources within the P-type paragenesis.

## Introduction

The nature and complexity of fluid sources that control diamond growth in the Earth's mantle is essential to constrain if we are to fully understand the origin of the different types of diamonds that make up economic deposits. Fluid-rich diamonds of fibrous growth texture provide a wealth of information on the nature of diamond-forming fluids (Navon et al., 1988; Schrauder et al., 1996). The fluids are trapped as high density fluids during diamond growth. Fibrous diamonds and octahedral diamonds with a fibrous coat form a significant fraction of the diamond population in some kimberlite pipes, including those of the North West Territories (Gurney et al. 2004). Much less is known about the fluids that form smooth faced crystalline diamonds (see Gurney et al., in press for nomenclature) that are the most valuable gems.

## Samples and methods

We have developed a technique that allows the measurement of trace element and radiogenic isotope (Sr-Nd-Pb) systematics (Klein BenDavid et al., 2010) in fluid-rich diamonds. The method has also generated the first truly quantitative trace element abundance data for gem diamonds. These combined geochemical approaches, when coupled to more routine techniques, have the potential to provide powerful constraints on the origins of diamond-forming fluids. We have investigated >40 fibrous diamonds from the DRC, Botswana, Siberia, South Africa and Canada (Klein-Ben David et al., 2010 and in prep), together with a suite of diamondiferous peridotites and eclogites to examine the geochemical signature in diamond-forming fluids from both fluid-rich and fluid-poor diamonds and the effect of diamond-forming fluids on their host rocks.

## Results and discussion

The major element composition of diamond forming fluids varies along two arrays, between a silicic and a low Mg-carbonatitic end member, and between a saline and a high Mg-carbonatitic component (Klein BenDavid et al., 2009). Trace element systematics in the fibrous diamonds are characterised by a wide variety of elemental concentrations with variable fractionation of trace element ratios, including significant but variable depletions in high field strength elements. Nevertheless, despite the broad major element variability, the trace element patterns measured in diamonds containing all fluid types display only two major patterns (e.g., Weiss et al. 2009). Some diamonds show relatively flat Primitive Mantle-normalised incompatible element patterns and show no, or minor depletion in Sr and moderate depletion in Zr, Hf and Ti (i.e. "type I"). Other diamonds show a relative enrichment in Th, U, Ba, Pb and LREE concentrations and depletion in Rb, Nb, Sr, Zr, Hf and Ti relative to PM (i.e. "type II"). In some samples, Ba, Rb and Th abundances vary by over 3 orders of magnitude and may be a function of both fluid density and the possible fractionation of phases such as mica and apatite.

Radiogenic isotopes in fibrous diamonds are similarly variable, with Sr isotopes in particular displaying enormous variation ($^{87}Sr/^{86}Sr$ 0.7042 to 0.7123). Significantly, there is substantial Sr isotopic variation within single fibrous diamonds from Botswana (Klein BenDavid et al., 2010). This variation does not define any isochronous relationships but is inversely correlated with Sr concentrations, indicating a role for mixing of fluids from at least 2 sources, one with highly radiogenic Sr isotope composition ($^{87}Sr/^{86}Sr > 0.715$) and one with a Sr isotope composition more comparable to a depleted mantle source ($^{87}Sr/^{86}Sr \sim 0.703$). Some geographic variability is expressed in the range of Sr isotopes. The most radiogenic Sr isotope compositions are found in fibrous diamonds from DRC and Botswana. Those from the Canadian Diavik and Panda mines extend to moderately enriched Sr isotopic compositions, whereas the least radiogenic samples measured so far are from Udachnaya, Russia (Klein BenDavid et al., in prep). Only the most elementally enriched diamonds, that have the most radiogenic Sr, can be analysed for Nd and Pb isotopes. Nd is very unradiogenic, with $\varepsilon$Nd values <-30 in some samples indicating that the dominant component in this fluid endmember is derived from a source that experienced long-term LREE enrichment. Very elevated $^{207}Pb/^{204}Pb$ ratios for these fluids confirm the ancient nature of the dominant Pb-rich source, with a history of multiple U/Pb fractionation implied from the modest $^{206}Pb/^{204}Pb$ ratios.

To investigate further the compositions of fluids that may have formed smooth crystalline diamond, and to better understand the effects of these fluids on their mantle wall rocks, we applied the above techniques to the analysis of a suite of diamonds plus co-existing host silicates from several diamondiferous xenoliths (6 harzburgites, 1 eclogite) from the Finsch and Newlands kimberlites. All diamonds are non-fibrous yet some display enrichments in trace element abundances that are equivalent to fluid-rich fibrous diamonds. Only a few diamonds from the xenoliths show very low trace element abundances equivalent to those found by McNeill et al. (2009), although the visible impurity levels present in the xenoliths-derived diamonds appear higher. An eclogitic diamond shows similar trace element systematics to some of the harzburgitic diamonds. However, there are large differences within the harzburgitic diamonds from different xenoliths. Those from Finsch diamondiferous harzburgite F866 show significant enrichments in Ba, Sr and Pb relative to other elements compared to other harzburgitic diamonds. Nd isotope data on the host silicates is variable and dominantly unradiogenic, indicative of long-term enrichment typically associated with the source of some diamond-forming fluids. We will present Sr isotope data on silicates and diamonds from the same xenolith to further constrain the sources of the fluids that form smooth crystalline diamonds.

We interpret the varied trace element and radiogenic isotope signatures in the fibrous diamonds that we have studied as a product of mixing between a carbonate-rich melt originating from the convecting mantle that induced fluid-release from mica-rich metasomatic wall rocks. Mica-breakdown releases hydrous fluid while leaving residual low-Al mica (Klein BenDavid et al., 2010). Support for this model comes from the observation of low-Al mica trapped as micro-inclusions within fibrous diamonds.

## Acknowledgements

We thank Oded Navon and De Beers for generous supply of samples together with funding from the Diamond Trading Company and De Beers.

## References

J.J. Gurney, P.R. Hildebrand, J.A. Carlson, Y. Fedortchouk & D.R. Dyck (2004) The morphological characteristics of diamonds from the Ekati property, Northwest Territories, Canada. Lithos, 77, 21-38.

J.J. Gurney, H.H. Helmstaedt, S.H. Richardson & S.B. Shirey (in press). Diamonds through time. SEG special publication.

O. Klein-BenDavid, D.G. Pearson, G.M. Nowell, C.J. Ottley, J.C.R. McNeill and P. Cartigny (2010). Mixed fluid sources involved in diamond growth constrained by constrained by Sr–Nd–Pb–C–N isotopes and trace elements. Earth and Planetary Science Letters. 289, 123–133.

O. Klein-BenDavid, A. Logvinova, M. Schrauder, Z. Spetius, Y. Weiss, E. Hauri, F.V. Kaminsky, F.V. Sobolev, N.V. Navon, O. (2009). High-Mg carbonatitic microinclusions in some Yakutian Diamonds — a new type of diamond-forming fluid. Lithos, 112, 648–659.

J.C.R. McNeill, D.G. Pearson, O. Klein-BenDavid, G.M. Nowell, C.J. Ottley & I. Chinn (2009). Quantitative trace element analysis of gem quality diamonds. Journal of Physics: Condensed Matter. 21, 364207, 13 pp.

O. Navon, I.D. Hutcheon, G.R. Rossman, & G.J. Wasserburg, G.J. (1988). Mantle-derived fluids in diamond micro-inclusions. Nature 335, 784–789.

M. Schrauder, C. Koeberl, and O. Navon, 1996, Trace element analyses of fluid-bearing diamonds from Jwaneng, Botswana: Geochimica et Cosmochimica Acta, v. 60, no. 23, p. 4711-4724.

Y. Weiss, R. Kessel, W.L. Griffin, I. Kiflawi, O. Klein-BenDavid, D.R. Bell, J.W. Harris, O. Navon, 2009. A new model for the evolution of diamond forming fluids: Lithos, 112S, 660-674.