

# The nature of Earth's deep and dynamic carbon cycle

---

Curious12

Geodynamics-Geochemistry-Resources

IAP2-20-191

## Overview

---

Tracing Earth's planet-wide carbon cycle is challenging, to say the least, because >90% of Earth carbon is stored within the inaccessible interior (mantle + core). However, there are windows into Earth's mysterious interior, and they're made of diamond (Fig.1). This project aims to address the origin of diamond-forming carbon in Earth's mantle within the context of deep volatile element cycles, through time. The deep carbon cycle can be investigated on billion-year timescales by studying the petrological and geochemical nature of mantle diamonds and their mineral/fluid inclusions and intergrowths. Diamonds form during metasomatic events in the mantle where the diamonds precipitate from high-density fluids. During growth, the crystal can trap silicate, sulphide, and fluid inclusions. As well as providing the only direct samples of metasomatic fluids from the mantle (Weiss et al., 2015), the trapped inclusions provide the deepest samples of Earth's otherwise inaccessible interior (Pearson et al., 2014). Decades of diamond geoscience has shown us that the carbon cycle is dynamic with evidence for the interaction of subducted volatiles with indigenous mantle carbon during complex tectonothermal events, such as the subduction of crustal material and/or plume-lithosphere interaction (Shirey et al., 2013). Diamond-formation appears to be episodic with events occurring across ranges of 2-3 billion years in the sub-continental lithospheric mantle (i.e. Timmerman et al. 2017). Furthermore, the components which make up the diamond-forming fluids can share distinct origins (Mikhail et al. 2019a). For example, Helium isotopes preserve the input of primary mantle material despite the carbon isotopes preserving strong evidence for subducted oceanic crust as the source of carbon (Fig.2).

### Supervisory Team

**Dr Sami Mikhail**  
University of St  
Andrews

**Prof Fin Stuart**  
University of  
Glasgow

### Collaborators

**Prof Gareth Davies**  
VU Amsterdam

**Prof D Graham  
Pearson**  
The University of  
Alberta

**Dr Feargus  
Abernethy**  
Open University

### Further Information

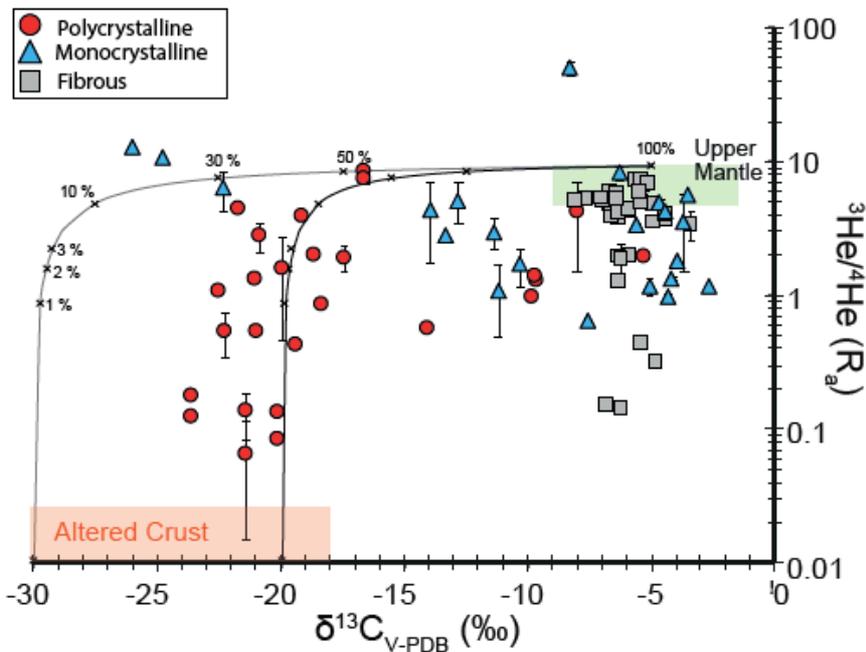
for informal enquiries,  
contact:

Dr Sami Mikhail

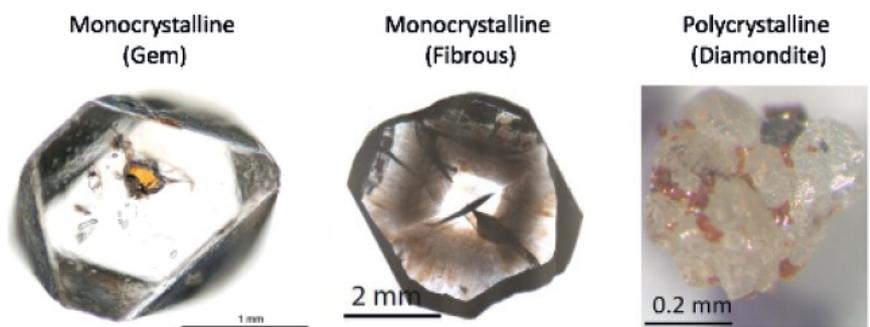
sm342@st-  
andrews.ac.uk

University of St  
Andrews

### Key Words



Diamond-formation;  
Isotope Geochemistry;  
Deep Volatile Cycles;  
Mantle Petrology;  
Plate Tectonics



### Image Captions

Figure 1. The Three main diamond types are recognised; monocrystalline (left), fibrous (middle) and polycrystalline (right). The monocrystalline diamond on the left contains an orange eclogitic garnet, the dark/brown colouration of the polished plate of the fibrous diamond in the middle indicates the presence of trapped silicates, oxides, and fluids, and the polycrystalline diamond (right) shows a mixture of diamond intergrown with orange eclogitic to websteritic garnets.

Figure 2. Carbon-helium isotope systematics of diamonds from Southern Africa. AOC = altered oceanic crust; CUM = convecting upper mantle; SCLM = sub-continental lithospheric mantle. Modified from Mikhail et al., 2019a.

## Methodology

This programme of research builds on very recently published work and aims to examine several suits of diamonds and their inclusions to illuminate the nature of Earth's deep He-C-N cycles (Mikhail et al., 2019a,b). This student will apply major and trace element geochemistry alongside stable and radiogenic isotopic tracers ( $^{13}\text{C}/^{12}\text{C}$ ,  $^{15}\text{N}/^{14}\text{N}$ ,  $^3\text{He}/^4\text{He}$ ,  $^{143}\text{Nd}/^{144}\text{Nd}$ ) to establish the origin of and temporal development of diamond-forming media in Earth's mantle. The samples in this study represent all three mantle diamond types; monocrystalline, fibrous and polycrystalline. The PhD will use different samples to answer different questions. The chapter breakdown is envisaged as described below:

1. Using Orapa (Botswana) as a case study, the major and trace element geochemistry of fluids and silicates alongside stable and radiogenic isotope data

from the diamonds and their fluid inclusions ( $^{13}\text{C}/^{12}\text{C}$ ,  $^{15}\text{N}/^{14}\text{N}$ ,  $^3\text{He}/^4\text{He}$ ) will be used to explain the similarities and differences for the source(s) of carbon for the three main diamond types (see methods in Mikhail et al., 2014; 2019a,b).

2. Fluid-rich fibrous diamonds and near gem-quality diamonds from the Congo, Canada (Ekati, Diavik, Snap Lake, Victor), and South Africa (Finsch, Newlands) will be used to constrain the degree of helium isotope homogeneity in the sub-continental lithospheric mantle as a function of mantle lithology (e.g. eclogitic vs peridotitic; see methods in Mikhail et al., 2019a).

3. Garnets extracted from southern African diamondites will be used to date silicate and fluid-rich polycrystalline diamond-formation (using  $^{143}\text{Nd}/^{144}\text{Nd}$ ) into the wider context of diamond-formation. E.g. relating diamondite-formation to known tectono-thermal events such as craton stabilisation, craton break-up, and plume-lithosphere interaction (see methods Timmerman et al. 2017)

4. Collectively, these thesis chapters/papers will allow the student to chart, describe, and model the evolution of helium, carbon, and nitrogen isotope systems in the sub-continental lithospheric mantle.

## Project Timeline

---

### Year 1

Year 1: Sample collection (Alberta). Initial training in isotope ratio mass spectrometry, SEM, LA-ICP-MS & FTIR. Sample characterisation and filtering using optical spectroscopy, SEM, and FTIR.

### Year 2

Year 2: Helium isotope analysis of selected samples (SUERC) followed by C-N isotope analysis (Open Univ.). Present results at national meeting (Volcanic and Magmatic Studies Group 2023, London, UK).

### Year 3

Year 3: Further Helium isotope analysis of selected samples (SUERC) followed by C-N isotope analysis (Open Univ.), where required. Dating (Nd-isotope analysis) of selected and characterised garnets (VU Amsterdam). Present results at international meeting (Goldschmidt 2023).

### Year 3.5

Year 3.5: Write, submit, and defend Ph.D. thesis.

## Training & Skills

---

This IAPETUS2 DTP project will provide training in petrology, stable isotope geochemistry, and geochemical modelling. The focus on petrological characterization of minerals, advanced analytical isotope ratio geochemistry, and the formation of an economically profitable resource (diamond) will provide the student a skill-set to competitively acquire postdoctoral research positions, or to transition from an academic to industrial/economic career upon completion of their Ph.D. degree.

Examples of analytical skills include FTIR spectroscopy, scanning electron microscopy, laser-ablation ICP-MS, coding with Python (St Andrews), TIMS (VU Amsterdam), gas-sourced isotope ratio mass spectrometry (SUERC, Open University). Training will be provided on a continual basis throughout the PhD.

Skills development will be monitored and delivered by the supervisory team, inclusive of the non-IAPETUS2 supervisors during the visits to external laboratories at VU Amsterdam, The Netherlands (Prof Gareth Davies), the University of Alberta, Canada (Prof D Graham Pearson), and The Open University, UK (Dr Feargus Abernethy).

## References & further reading

- Mikhail et al. 2014. Constraining the internal variability of carbon and nitrogen isotopes in diamonds. *Chemical Geology*
- Mikhail et al. 2019a. Helium reveals what C-N cannot, a mantle component in <sup>13</sup>C-depleted diamond-forming fluids. *Geochemical Perspectives Letters*
- Mikhail et al. 2019b. Diamondites: Evidence for a distinct tectono-thermal diamond-forming event beneath the Kaapvaal craton. *Contributions to Mineralogy and Petrology*
- Pearson et al. 2014. Hydrous mantle transition zone indicated by ringwoodite included within diamond. *Nature*
- Shirey et al. 2013. Diamonds and the geology of mantle carbon. *Reviews in Mineralogy and Geochemistry*
- Timmerman et al. 2017. Dated eclogitic diamond growth zones reveal variable recycling of crustal carbon through time. *Earth and Planetary Science Letters*
- Weiss et al. 2015. Highly saline fluids from a subducting slab as the source for fluid-rich diamonds. *Nature*

## Further Information

For more information contact Dr. Sami Mikhail ([sm342@st-andrews.ac.uk](mailto:sm342@st-andrews.ac.uk))