Cyclic growth conditions for Diavik diamonds? Insights from carbon isotopes

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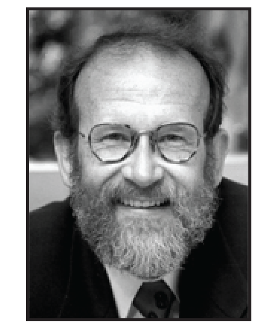
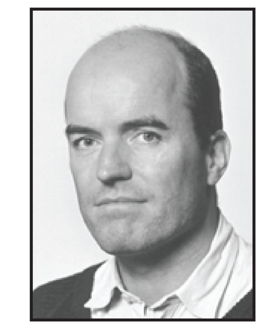




Introduction

The A154 South Pipe of Diavik Diamond Mine is known for producing exceptionally high quality stones. However, the existence of millions of sub-micron inclusions gives diamond a creamy white to opaque grey colour (Tomlinson, 2005). Such opaque diamond commonly occurs as "coats" surrounding clear diamond, while clear coats on opaque cores are rare. A secondary ion mass spectrometry (SIMS) study has been carried out in order to investigate $\delta^{13}C$ variations at scales of tens of microns in clear and opaque diamond.

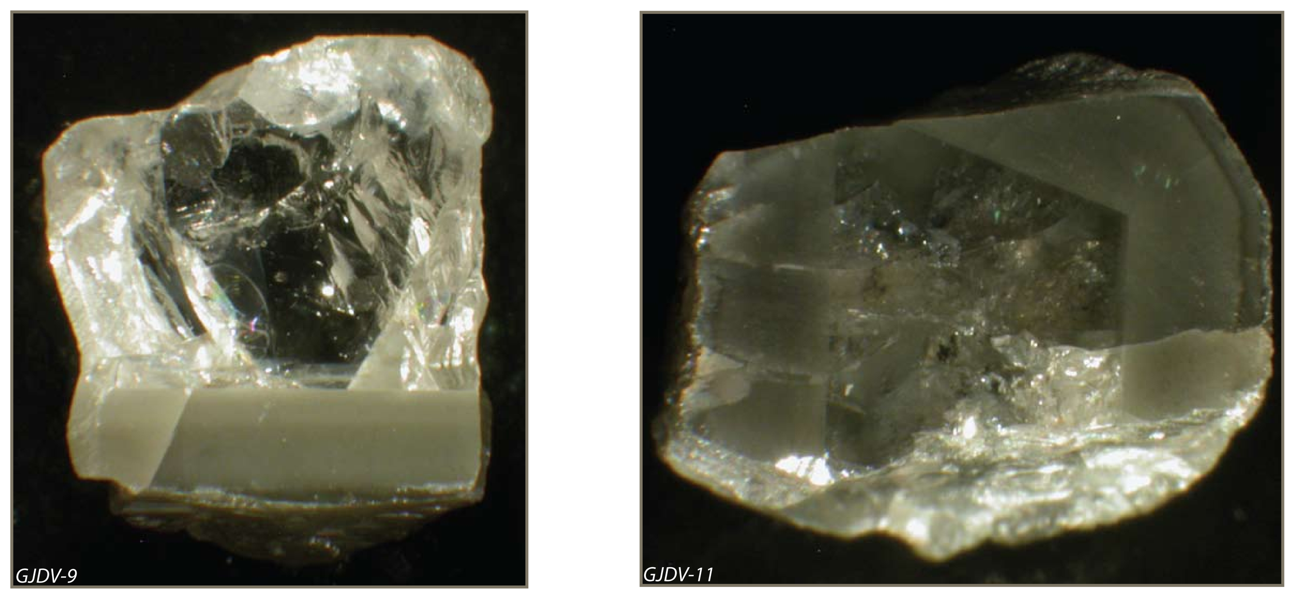
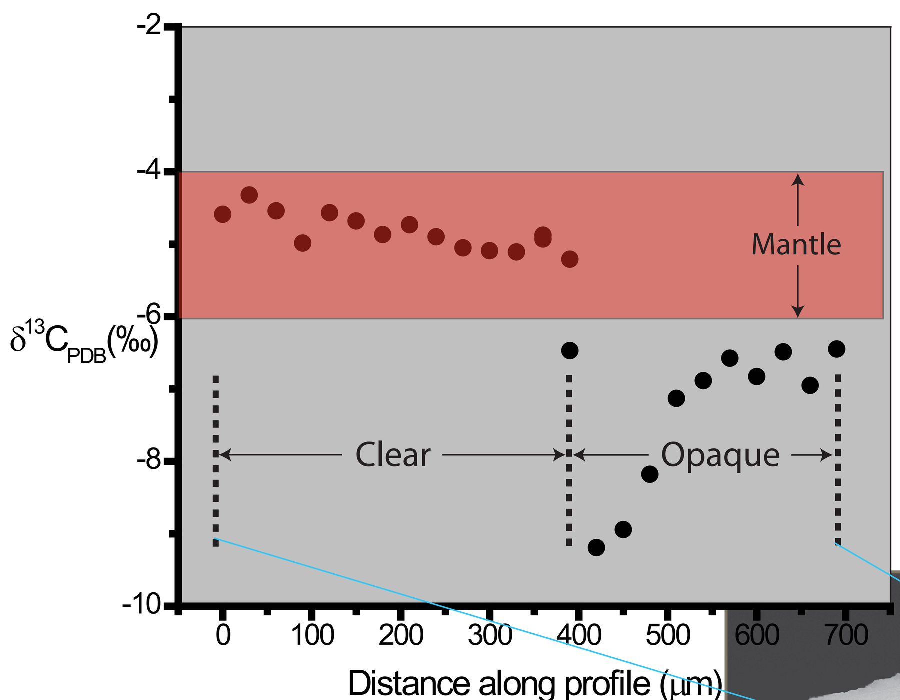


Figure 1: Bisected and polished diamonds showing typical opaque coats surrounding clear cores.

Motivation

It is clear that different processes are responsible for the formation of clear and opaque diamond. While it is generally accepted that diamond forms by precipitation from a C-rich fluid (e.g. Stachel et al., 2006, Klein-BenDavid et al., 2007), the mechanisms governing the formation of opaque diamond are poorly understood.



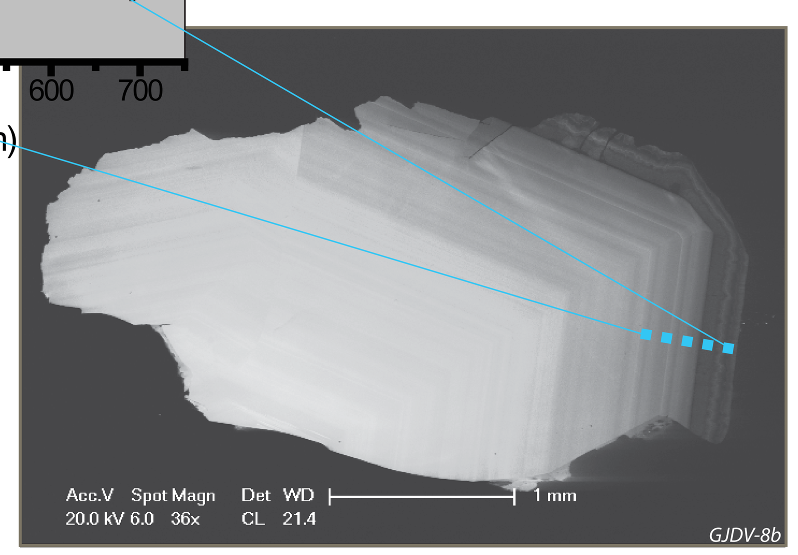


Figure 2: Cathodoluminescence image of sample GJDV-8b, with SIMS transect indicated by dashed blue line. Clear diamond is bright in CL; opaque diamond appears dark. The plot shows measured $\delta^{13}C$ values along the transect.

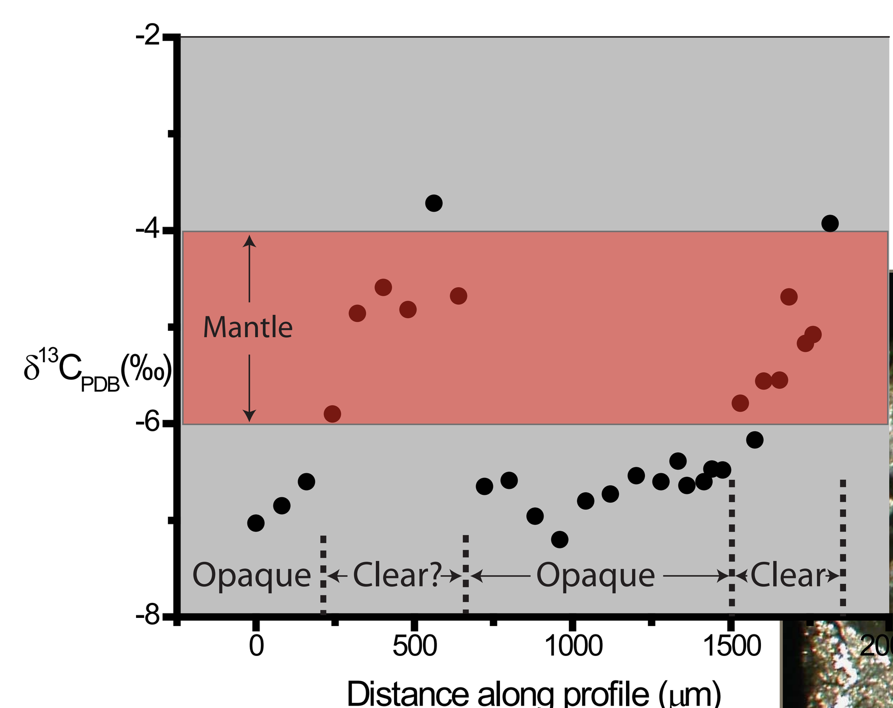
Carbon Isotopes

- ^{13}C and ^{12}C partition variably into different mineral and fluid phases
- Stable isotopes of carbon can serve as valuable geochemical tracers

Growth by Fluid Pulses

Core-coat boundaries are commonly marked by abrupt (<100 µm) decreases in $\delta^{13}C$ (Fig. 2), suggesting a similarly abrupt change in geochemical conditions during growth. Following this decrease, $\delta^{13}C$ values tend to increase gradually towards more "normal" mantle values.

- Abrupt decrease may be due to influx of low $\delta^{13}C$ fluid
- High carbon activity in the new fluid would cause rapid growth of diamond on existing "seed" crystals
- New fluid gradually equilibrates with surroundings, causing the observed gradational return to higher $\delta^{13}C$ values



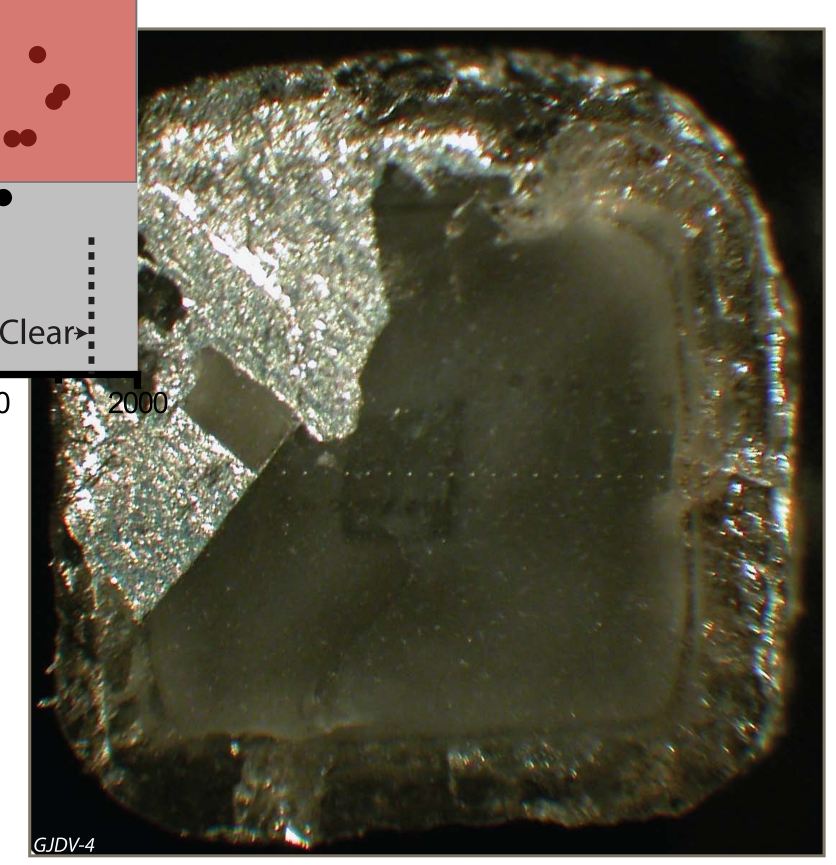


Figure 3: Reflected light photomicrograph of sample GJDV-4; SIMS pits from $\delta^{13}C$ measurement appear as light coloured spots transecting the sample. Note that clear diamond occurs as a coat surrounding opaque diamond; isotopic similarity of inner core and outer coat suggests that the inner core is composed of clear diamond.

Diffusional relaxation of $\delta^{13}C$ homogeneity

Not all core-coat boundaries show abrupt changes in $\delta^{13}C$, suggesting that diffusion of carbon may have obscured an initially sharp contact. In order to investigate the magnitude of this effect, diffusion of ^{13}C was modelled using a numerical solution to the continuity equation:

$$\frac{\partial C}{\partial t} = \kappa \frac{\partial^2 C}{\partial x^2}$$

where the proportionality constant κ is the self-diffusion coefficient of carbon and has been determined as a function of temperature by Koga et al. (2003)

After 1 Ga at 1400K, an initially very abrupt (0.1 µm) change from -5 to -9‰ will be gradational over a length of 1-3µm, while 1 Ma at 2000K will cause the same initial contrast to grade over 100µm. A 3‰ change over ~400µm similar to that shown in Figure 3 would take approximately 4.5Ga at 1750K, or 17Ma at 2000K.

Conclusions

- Injection of C-supersaturated, low $\delta^{13}C$ fluid is consistent with measured profiles
- Abundant inclusions are also explained by rapid growth due to diamond precipitation from a C-supersaturated fluid
- Diffusion at normal lithospheric mantle temperatures cannot account for the gradational changes in $\delta^{13}C$ across clear-opaque boundaries

Acknowledgements

We thank Diavik Diamond Mines for access to diamonds. We are grateful to John Craven and the University of Edinburgh Ion Microprobe Facility (EIMF) staff for their help with ion probe analyses. The National Environment Research Council is thanked for access to the EIMF. The Northwest Territories Geoscience Office is thanked for financial support.

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