Modern single-grain thermobarometry techniques applied to mantle xenocrysts from the Safartoq area, Greenland

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Introduction

The search for kimberlite-hosted diamonds in Greenland expanded rapidly in the mid-1990's, due largely to the activities of Canadian-funded exploration companies seeking opportunities beyond the confines of the Slave craton. According to some estimates, a total of some \$40-million was spent in the years 1994 to 2002 on diamond exploration in an area covering 60,000 km^2. The kimberlitic indicator mineral (KIM) data generated by this effort has been captured by the Geological Survey of Denmark and Greenland (GEUS) with the help of reports supplied by the Bureau of Minerals and Petroleum (BMP) of Greenland, and made available digitally to interested parties at a cost of about \$300 (see Jensen et al., 2004). In this work we focus on applying modern single-grain thermobarometry techniques to the available microprobe data for ~13,400 clinopyroxene (cpx) and ~6,750 garnet (gar) grains that represent ~ 1,600 samples collected within a 1,000 km^2 area located mostly to the south of Sondre Strom Fjord near Kangerlussuaq. Hudson Resources currently holds mineral exploration licenses over the area of interest.

Single-cpx thermobarometry

Compositional screening shows that some 95% of the 13,400 analysed cpx grains are derived from non-KIM sources (i.e. crustal sources), but single-cpx thermobarometry techniques (Nimis and Taylor, 2000) were applied to 436 mantle-derived cpx grains. Some 45% of these failed established compositional and mineral-formula criteria that delimit valid P-T data (e.g. Nimis, 1998); the single-cpx P-T values calculated for the remaining 243 grains are shown in Figure 1. The P-T values constrain a cold geotherm at the time of kimberlite emplacement, circa 530 to 600 Ma ago. The geotherm is well defined over the whole mantle temperature range and enters the diamond stability field at T > 900°C, as for the Slave craton (see Fig. 1). Kimberlites at Safartoq and in the Slave craton entrained mantle material to depths of 60 kbar, but mantle sampling at Safartoq occurred at P < 36 kbar and T < 750°C, shallower within the graphite stability field than for kimberlites of the Slave craton (Fig. 1). Differential entrainment of mantle with respect to graphite-diamond may therefore cause significant variability in diamond potential at Safartoq. We utilize Cr-pyrope thermobarometry to address this issue.

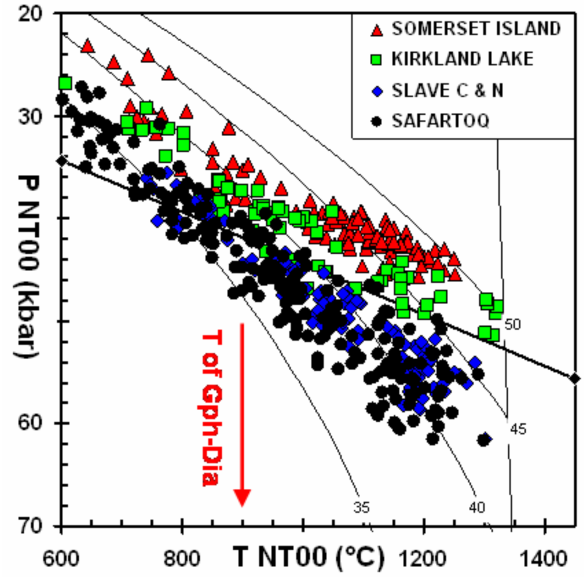

Fig. 1 Single-cpx P-T results for Safartoq. Data from Jensen et al. (2004).

Cr-pyrope thermobarometry

The Safartoq data set of Jensen et al (2004) contains 6,753 garnet analyses derived from ~1,600 samples, of which 624 analyses (9%) represent non-KIM varieties. A conventional Cr_2O_3 vs CaO diagram for the KIM garnets is shown in Figure 2. G9 garnets are dominant and some high-Cr_2O_3 G10 garnets confirm the observation made from cpx barometry that the mantle section extends to 60 kbar depth (based on the P38 Cr/Ca-garnet barometer of Grütter et al., 2006). Low-Cr G10 garnets are very well represented and their compositions extend to rare low CaO values, normally associated with extremely depleted, dunite-harzburgite protoliths with excellent inferred diamond potential. However, a low proportion of the Safartoq G10 garnets cross the graphite-diamond constraint (GDC) to higher Cr_2O_3 content, and this is cause for concern from an exploration perspective:- given the presence of significant graphite-facies cpx, the high-potential G10 garnets may be derived from shallower than the GDC, i.e. from inside the graphite stability field. The GDC is shown in Fig. 2 by a solid red line at $Cr_2O_3 = 0.94CaO + 5$ (after Grütter et al., 2006).

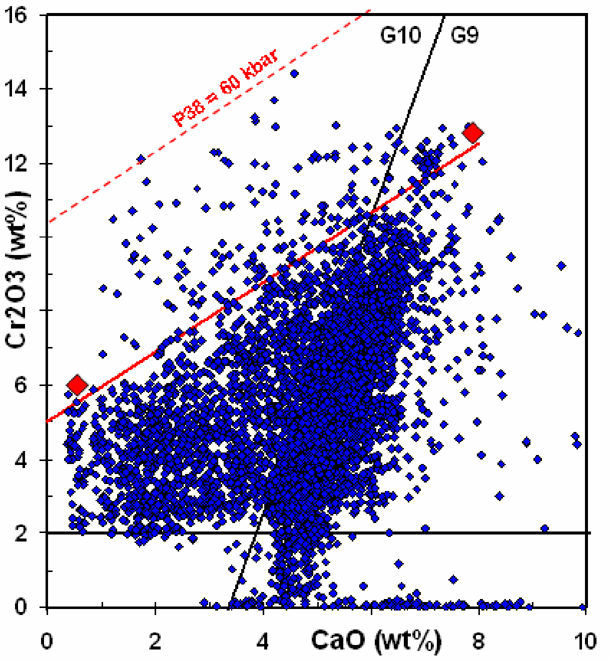

Fig. 2 Cr_2O_3-CaO compositions of KIM garnets from Safartoq till samples. Data from Jensen et al. (2004).

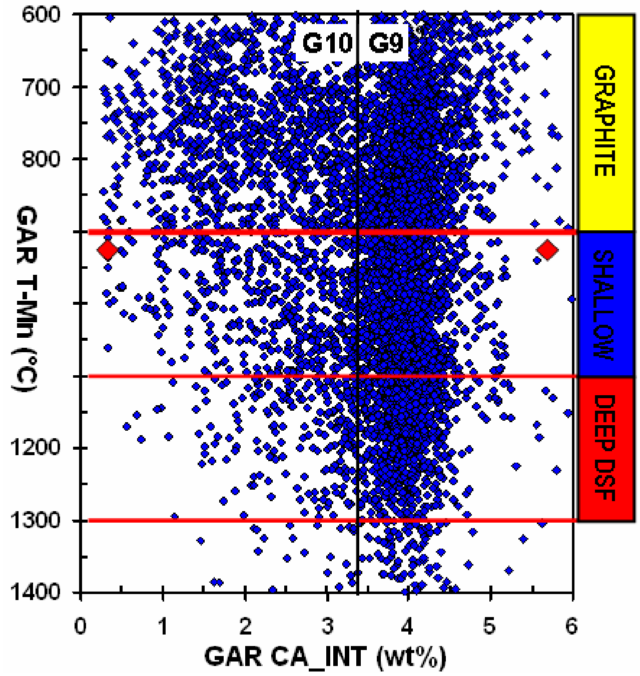

Fig. 3 Distribution of Safartoq Cr-pyrope compositions with temperature (= depth). Mantle tenure classes are designated by yellow, blue and red color-coding.

A thermometric technique has to be used to locate Cr-pyrope grains relative to graphite-diamond in a mantle section. We have applied an updated version of the Mn-in-garnet thermometer (T-Mn, Grütter et al, 1999) in combination with the garnet CA_INT projection (Grütter et al., 2004) to construct a simplified garnet-based mantle section for Safartoq (Figure 3). G9 garnets (at CA_INT 3.4 to 5.4) occur throughout the whole mantle section, from 600°C to slightly over 1300°C, the same temperature range as observed using cpx thermometry (cf. Fig. 1). Roughly half of all high-temperature garnets (T > 1200°C) have TiO_2 > 0.6 wt% (not illustrated), consistent with Fe-Ti metasomatism deep within the diamond stability field (DSF).

G10 garnets (with CA_INT < 3.4) from Safartoq also occur throughout the whole mantle section. Their average CaO content increases with depth, specifically within the DSF at T > 900°C. Although a relatively high proportion of all the KIM garnets from Safartoq are G10 varieties (32%), Fig. 3 illustrates that the majority (60%) are derived from within the graphite stability field, at T < 900°C. A further 28% of G10's are shallow diamond-facies grains (900 to 1100°C) and 12% are derived from deep within the diamond stability field (deep DSF, 1100 to 1300°C). The Mn-thermometry highlights that 20% of all KIM garnets in surficial samples from the Safartoq area are "deep DSF" grains, and only 1 in 5 of these is a G10 (Fig. 3). Differential sampling of the Safartoq mantle by a kimberlite magma would result in some unusual associations between G10 garnet and diamond: shallow mantle sampling would produce barren kimberlites carrying significant quantities of low-Cr G10 garnets, while diamondiferous kimberlites with deep mantle tenure would carry few G10 garnets, though with Cr_2O_3 content higher than the GDC (Fig. 2).

Mapping deep mantle tenure

Categorization of KIM garnets by T-Mn class permits representation of mantle tenure at the scale of individual surficial sample results (Fig. 4). The garnet T-Mn populations in most samples show graphite-facies > shallow DSF >> deep DSF tenure (yellow > blue >> red in Fig. 4). Kimberlite float collected from these areas has consistently produced barren or low-interest microdiamond results[1] and show similar mantle tenure – deep DSF grains are typically absent. Several discrete sources with dominantly deep mantle tenure (red ≥ blue >> yellow) are evident in Fig. 4, and micro-diamond results for kimberlite float collected from these select few localities typically endorse pursuit of the source[2]. Follow-up work at Garnet Lake isolated a high-interest 2.5 m thick kimberlite sheet with 3.0 km strike extent that currently is subject to advanced-stage bulk sampling and on-site recovery of commercial diamonds (see www.hudsonresources.ca for details). Additional follow-up exploration is in progress at Itisooq and other localities highlighted by deep mantle tenure (Fig. 4).

The mapping results for stream sediment samples collected within glacial valleys show well-mixed, homogenized mantle tenure (as expected, Fig. 4). These results poorly reflect the diamond-associated deep mantle tenure that occurs in-situ within basal till and related felsenmeer at the higher elevation of Garnet Lake, located only 8 km away. This observation emphasizes the point that garnet compositions such as shown in Figures 2 and 3 should not be construed as representing a true mantle section:- the incidence of KIM garnet compositions in an exploration-level data

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[1] see http://www.hudsonresources.ca/files/srcreport.pdf

[2] see map http://www.hudsonresources.ca/files/2005_Locations.pdf

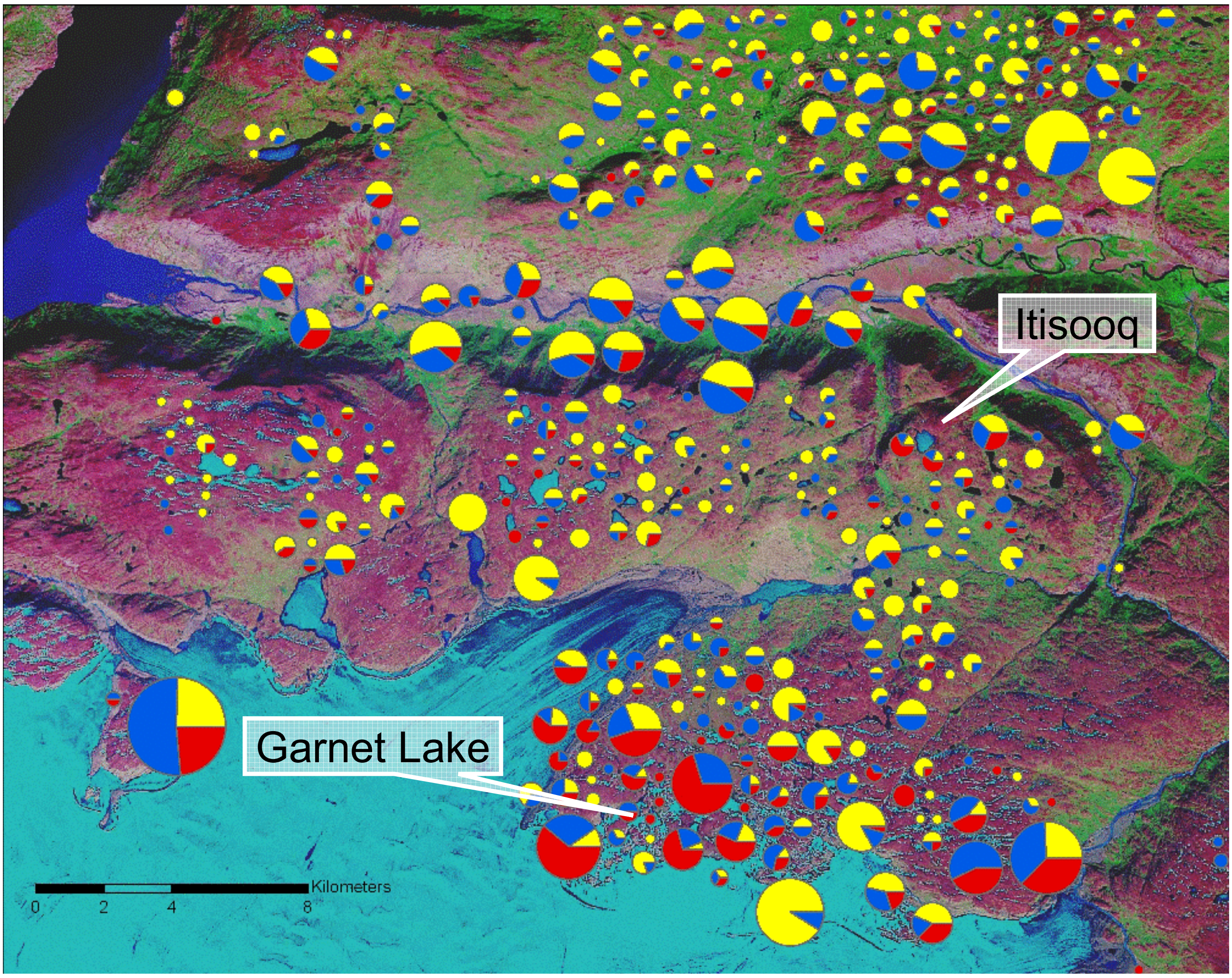

Fig 4. Mantle tenure classes (pie-chart colors) and KIM garnet abundance (pie chart sizes) in surficial samples from the Safartoq area. KIM compositions and sample locations are from Jensen et al (2004).

set depends on the extent of mixing in the secondary environment, the colour representation and quantity of concentrate garnets analysed, the distribution of harzburgitic or lherzolitic bulk compositions at depth within the lithosphere, and the vagaries of how such mantle rock types are entrained by, and disaggregate within, kimberlite magmas.

Conclusions

Application of modern single-grain thermobarometry and related techniques to public-domain, exploration-level KIM cpx and gar compositions from Safartoq reveals (at 530 – 600 Ma):

- a cold cratonic geotherm.
- a depleted lithosphere extending to 60 kbar depth.
- deep mantle Fe-Ti metasomatism.
- an abundance of graphite-facies G10 garnets.
- differential depth entrainment of mantle by kimberlite magmas, expressed here as "mantle tenure".
- a clear correspondence of encouraging microdiamond results and potentially commercial macrodiamond results with deep mantle tenure.

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