Geothermal constraints from kimberlite-hosted garnet lherzolites from southern Greenland

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Introduction

Geothermobarometry calculations applied to kimberlite-hosted mantle xenoliths can provide information about mantle conditions at the time of kimberlite emplacement. Constraining the mantle geotherm is also useful for understanding the diamond potential of host magma. Considerable numbers of diamonds have been recovered from rocks within the Archean Craton in southern West Greenland (Jensen *et al.*, 2004; Hutchison, 2005; Hutchison *et al.*, *this volume*; Sand *et al.*, *this volume*, Fig. 1). However, kimberlites and related rocks are known from a wide area covering much of West and South-West Greenland (Larsen *et al.*, 1992; Andrews *et al.*, 1975, Emeleus *et al.*, 1975).

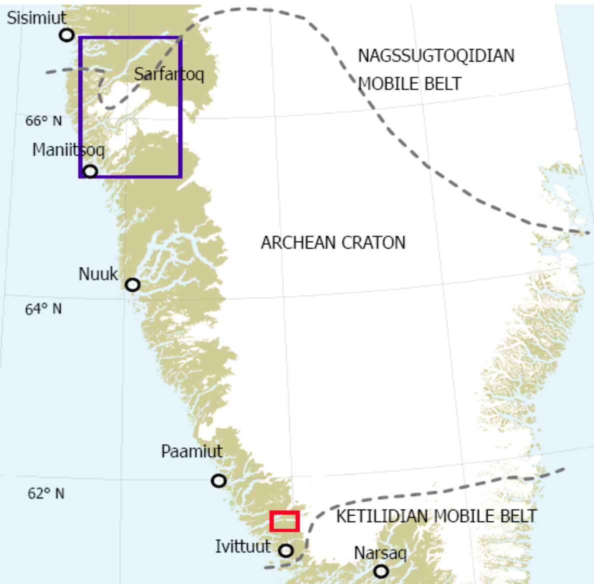

Figure 1 *The Archean North Atlantic Craton in southern West Greenland. The study area (Pyramidefjeld and Midternæs) is marked by red and lies on the border zone between the Ketilidian mobile belt and the Archean Craton. The area marked by blue is the study area of Sand et al. and Hutchison et al. (this volume) from where a considerable diamond potential has been revealed.*

Here we present a determination of the conditions of the mantle geotherm based on mantle xenoliths in kimberlitic rocks from South Greenland. Four-phase geothermobarometry was applied to garnet lherzolite xenoliths as a continuation of the work described in Hutchison *et al.* (2007). Samples studied comprise of xenoliths recovered in 2006 from kimberlitic rocks in two areas (Fig. 1), namely Pyramidefjeld and Midternæs (Andrews *et. al.*, 1975 and Emeleus *et al.*, 1975) and are supplemented by a single sample from Pyramidefjeld described by Andrews *et al.*, 1975. Eight micro-diamonds were recovered from samples with unknown weights from Pyramidefjeld and Midternæs by Renzy Mines Ltd., as a result of exploration during the 1970's (complete reports and references in Jensen *et al.*, 2004).

Methodology

Polished thin-sections were prepared from the garnet-bearing xenoliths and the mineral compositions were determined by electron microprobe analyses carried out primarily at the Department of Geography and Geology in Copenhagen, but also at the University of Cambridge. The operating conditions of the JEOL JXA-8200 in Copenhagen were 15 kV, 15nA and 5 µm beam, and the operating conditions of the Cameca SX100 in Cambridge were 15 kV, 10 nA and 1 µm beam.

The thermobarometry calculations are based on two different combinations of thermometers and barometers. The first one is the two-pyroxene thermometer (T_{BKN}) combined with the 'Al in orthopyroxene' barometer (P_{BKN}) both formulated by Brey *et al.* (1990). This combination has been widely used in literature and is often used as a reference system for other thermobarometers. The second combination is the Ca in orthopyroxene thermometer ($T_{Ca\text{-}in\text{-}opx}$) formulated by Brey *et al.* (1990) combined with the 'Al in orthopyroxene' barometer (P_{MC74}) by MacGregor (1974). This combination was concluded to be one of the most suitable thermobarometers applicable to garnet lherzolites from kimberlitic rocks from the North Atlantic Craton in southern West Greenland (Sand *et al.*, *this volume*).

Results and discussion

The results from thermobarometry calculations are plotted in Figures 2 and 3. In both figures, geophysically determined mantle geotherms are included as references, i.e. the steady-state mantle geotherm from McKenzie *et al.* (2005) and mantle geotherms (represented as surface heat-flow in mW/m^2) from Pollack *et al.* (1977). The diamond-graphite phase boundary is from Kennedy *et al.* (1976). The error bars represents 2σ accuracies and are based on the ability to reproduce experimental data (Brey *et al.*, 1990; MacGregor, 1974).

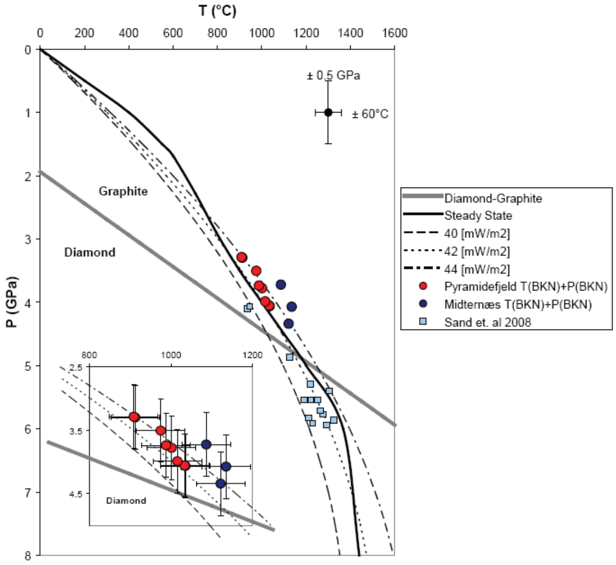

***Figure 2** Temperature-pressure diagram of the T_{BKN} and P_{BKN} thermobarometer combination. The diagram shows the positions of the calculated equilibrium conditions for the garnet lherzolites in this study and from the study conducted by Sand et al. (this volume).*

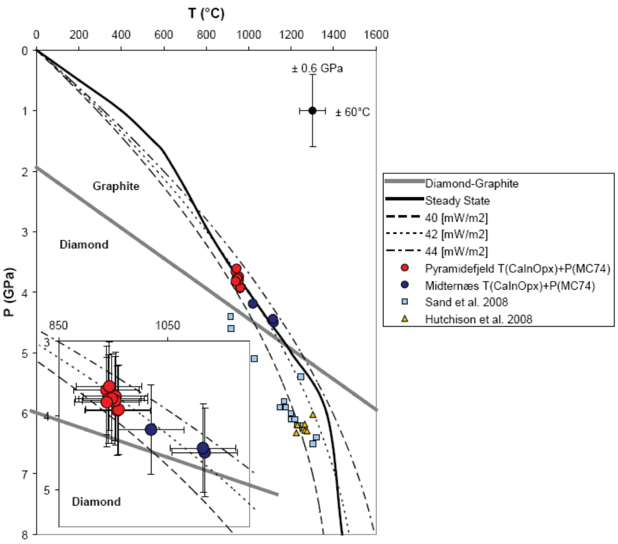

***Figure 3** Temperature-pressure diagram of the $T_{CaInOpx}$ and P_{MC74} thermobarometer combination for the garnet lherzolites in this study and the studies conducted by Sand et al. and Hutchison et al. (this volume).*

The results from the P_{MC74} + $T_{Ca\text{-}in\text{-}opx}$ combination (Fig. 3) appear to follow the steady state mantle geotherm by McKenzie *et al.* (2005), or the 42 mW/m^2 geotherm by Pollack *et al.* (1977). Whereas the results from the T_{BKN} + P_{BKN} (Fig. 2) are more scattered, but appear to follow a mantle geotherm closer to 44 mW/m^2 by Pollack *et al.* (1977). However, due to the margin of error of both the thermometers and barometers, it is not possible to isolate a conclusive geotherm. It is worth mentioning, that even though the T_{BKN} + P_{BKN} combination is the most commonly used, the $T_{Ca\text{-}in\text{-}opx}$ + P_{MC74} combination gives more or less the same results in this case.

The data from both combinations suggest that the mantle lithosphere geotherms underneath Midternæs and Pyramidefjeld are the same over the period of time that the sampling has occurred. The Midternæs samples appear to represent slightly greater temperatures and pressures, and hence come from a deeper region than the Pyramidefjeld samples.

Compared to the samples studied by Sand *et al.*, and Hutchison *et al.* (*this volume*), the garnet lherzolites investigated here were clearly sourced at a shallower depth. Furthermore, the geotherm for Midternæs and Pyramidefjeld appears to be slightly hotter compared to the geotherms from further north within the Archean Craton.

A comparison of the calculated temperatures and pressures are plotted in Figures 4 and 5. As seen from Figure 4, the T_{BKN} generally yields higher temperatures compared with the $T_{Ca\text{-}in\text{-}opx}$, but the agreement is still good within the reported 2σ error of 60 °C for both thermometers. As seen from Figure 5, there is a slight tendency for the P_{MC74} to yield higher pressures compared with the $P_{Ca\text{-}in\text{-}opx}$, but again the agreement is good within the reported 2σ error of 0.6/0.5 GPa for the two barometers.

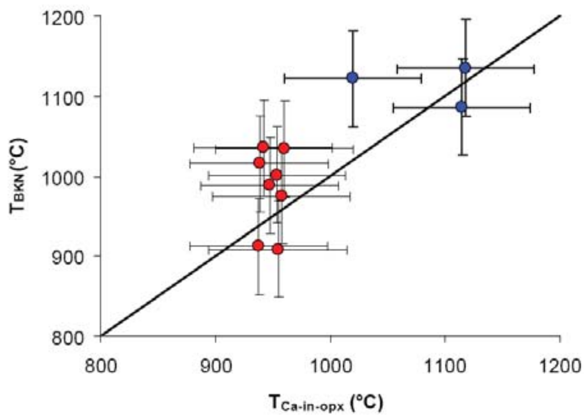

***Figure 4** Comparison of $T_{Ca\text{-}in\text{-}opx}$ and T_{BKN}. The black line represents ideal (linear) correlation. Red dots represent garnet lherzolites from Pyramidefjeld and blue from Midternæs.*

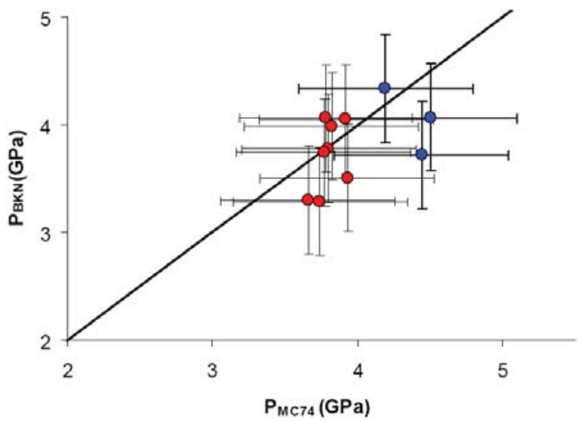

***Figure 5** Comparison of P_{MC74} and P_{BKN}. The black line represents ideal (linear) correlation. Red dots represent garnet lherzolites from Pyramidefjeld and blue from Midternæs.*

Irrespective of what methodology is used for calculating P and T, all samples have been shown to have come from depths just outside the stability field of diamond. The presence of diamonds within similar rocks from the same areas (Jensen *et al.*, 2004), clearly demonstrate that some components of the Pyramidefjeld and Midternæs kimberlitic rocks had a deeper source.

Summary and Conclusions

The mantle geotherm constructed on the basis of garnet lherzolites from kimberlites from South Greenland appears to be slightly hotter compared to geotherms constructed from further north within the Archean Craton. Furthermore, the South Greenland garnet lherzolites studied have a shallower source, just outside the stability field of diamond in contrast to the deeper sourced northern xenoliths. Although deeper material in the form of diamonds is known from the South Greenland localities, these observations likely reflect a difference in lithosphere thickness between the areas studied by Sand *et al.* (*this volume*), Hutchison *et al.* (*this volume*) and the areas studied in the South. It should be noted that given the different ages of samples however, Jurassic in the South and very late Proterozoic in the North (Frei *et al.*, *this volume*), this topography may not have been contemporaneous.

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