DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2010/30

Chemistry of mantle xenocrysts from aillikite dykes of the Tikiusaaq complex, southern West Greenland

A supplement to GEUS report 2007/64

Agnete Steenfelt & Karina Krarup Sand

(1 CD-Rom included)

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Contents

Abstract

Dykes of ultramafic lamprophyre associated with the Jurassic Tikiusaaq carbonatite complex are classified as aillikites, and they have similarities with diamondiferous Neoproterozoic aillikite dykes in the Sarfartoq and Maniitsoq regions. Since the publication of GEUS report 2007/64, data have been acquired from samples of the Tikiusaaq aillikites that are relevant to the diamond potential. These concern mineralogy, chemistry of groundmass minerals and mantle derived xenocrysts. Aillikitic magma is considered formed by melting in the deeper parts of the lithospheric mantle and the magma therefore has travelled through pressure-temperature regimes of the mantle, where diamonds are stable. The chemistry of the xenocrysts confirm that some of them are derived from within the diamond stable field of the lithospheric mantle.

Frontispiece

Big block of ultramafic lamprophyre (aillikite) close to the stream that follows a fracture assumed to host the dyke.

Introduction

The Jurassic Tikiusaaq carbonatite and associated ultramafic lamprophyre dykes were discovered in 2005 near the Inland Ice at latitude 64º N in southern West Greenland (Steenfelt *et al.* 2006, 2007). The complex belongs to a province of Jurassic carbonate-rich lamprophyre dykes and two carbonatite intrusions generated in response to incipient rifting of the Labrador Sea (Fig. 1; Larsen *et al*. 2009).

Exploration and mapping of the Tikiusaaq complex was conducted in 2006 to 2007 in a joint project between Geological Survey of Denmark and Greenland (GEUS) and Bureau of Minerals and Petroleum (BMP), Greenland. A comprehensive report published in 2007 contains documentation for the investigations undertaken during 2006 and first part of 2007, i.e. all field observations, field photos, field measurements, sample descriptions and results of chemical analyses of bulk rock samples together with a preliminary assessment of the mineral potential (Steenfelt *et al.* 2007).

The mineral potential of the carbonatite components concerns magmatic apatite accumulations and late stage vein type or impregnation type mineralisation with Nb, Ta, P, REE, Th, (U), while the potential of the ultramafic lamprophyres (aillikites) concerns diamond.

This report contains some results of studies conducted after the publication of the assessment report that are relevant to the evaluation of the diamond potential of the lamprophyre dykes. They comprise chemical analyses of so-called kimberlite indicator minerals recovered from samples of aillikite together with an interpretation of their origin. In addition, we draw attention to the publication by Tappe *et al.* (2009), which contain documentation and discussion of bulk chemistry, isotopic age dating, mineralogy and mineral chemistry of the dykes. The present report includes data for samples acquired in 2005, as these were not treated in GEUS report 2007/64.

The accompanying CD-ROM contains digital data for the aillikite samples, i.e. sample location and register of investigated samples, field photographs of aillikite occurrences, and photographs and chemical data for the 179 analysed xenocryst grains (Microsoft Excel format).

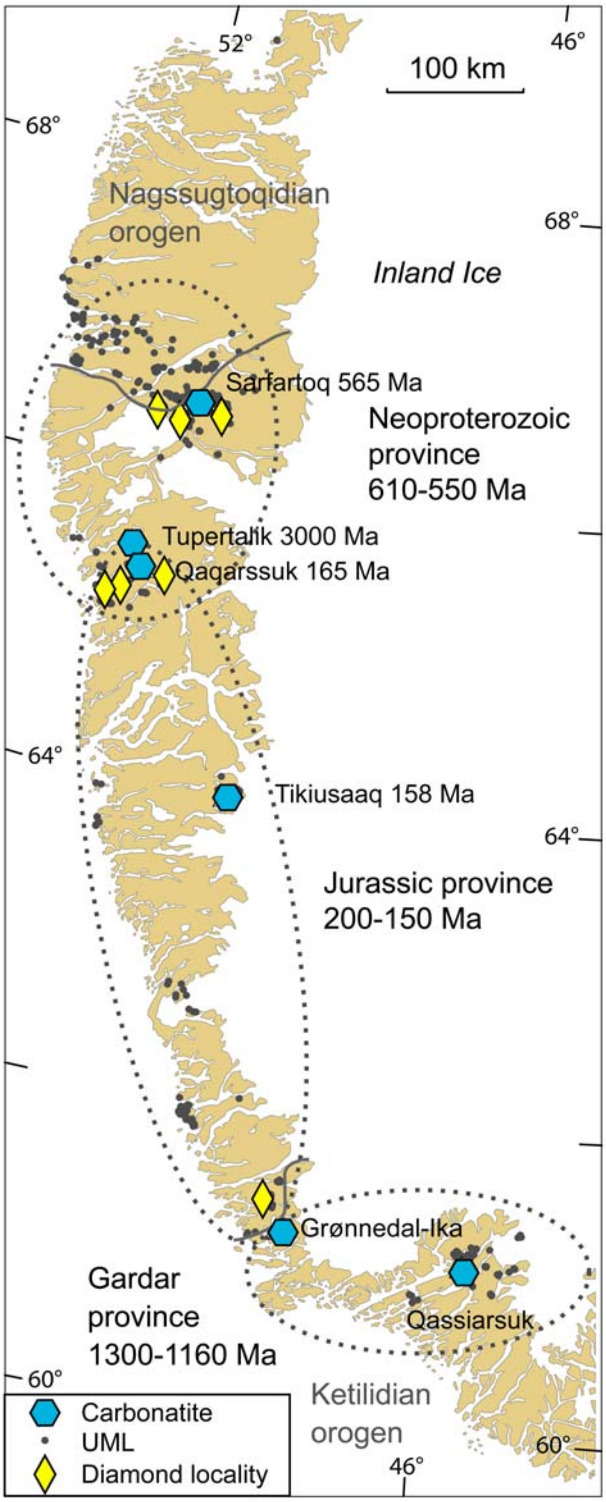


Figure 1. *Provinces of carbonatite-ultramafic lamprophyre(UML) magmatism in southern West Greenland*

Outline of Tikiusaaq carbonatite-aillikite complex

The Tikiusaaq complex is recognised in the field by intense fracturing, carbonate impregnation and rusty colouration of outcropping rock surfaces over an area of roughly 14 by 14 km around the lake Isortuarsuk (Figure 2). Within the impregnation zone, massive carbonatite sheets only outcrop in stream gullies transecting an east facing slope. It should be remarked that the shape of the impregnation zone has been slightly revised since GEUS report 2007/64 was published. Field observations together with aeromagnetic data suggest that parts of the massive carbonatite is hidden below glacial terraces towards the lake, and more carbonatite may even exist at depth beneath the northern and eastern part of the zone of carbonatite impregnation.

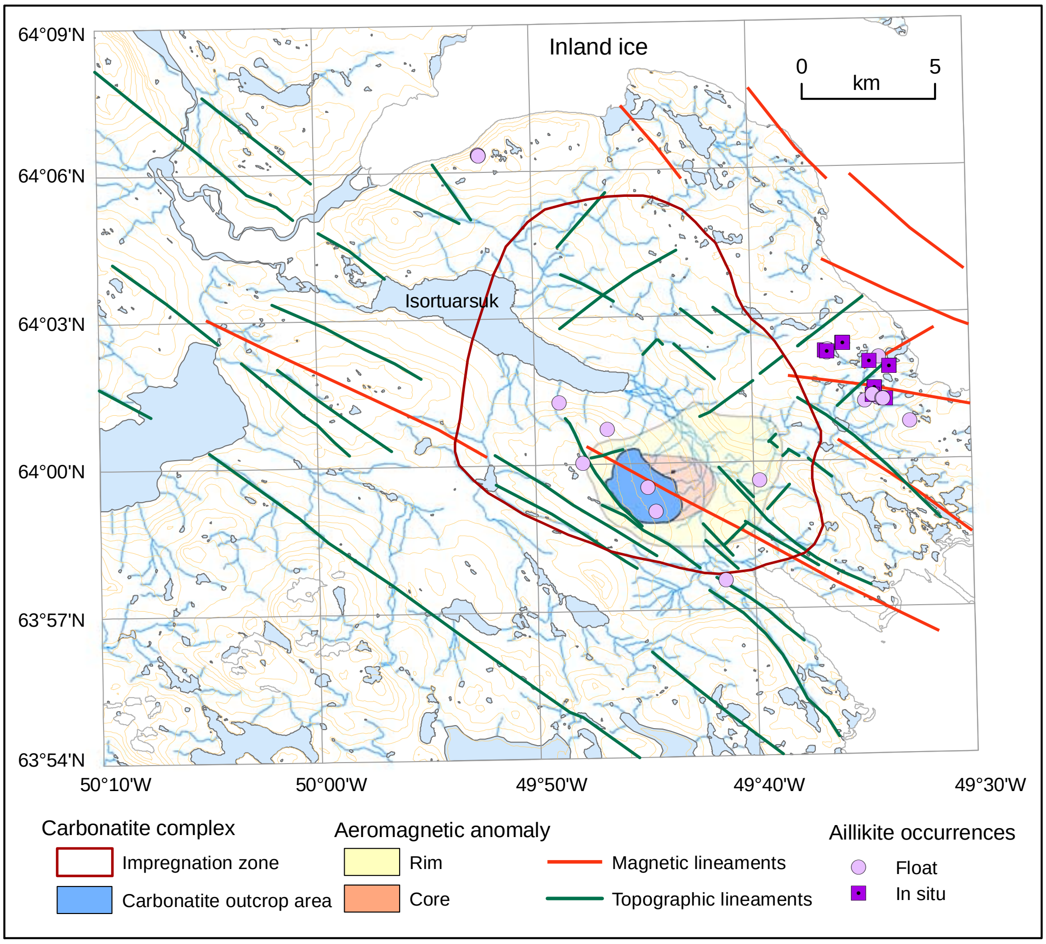


Figure 2. *Topographic map of the Tikiusaaq carbonatite complex showing main outcrops of carbonatite, the zone of fracturing and impregnation, and the size of the aeromagnetic anomaly that is interpreted to reflect non-outcropping magnetite rich carbonatite. Aillikite dykes are concentrated north-east of the carbonatite, but a cluster of aillikite boulders north of Isortuarsuk suggest the location of one or more dykes in that area as well. The carbonatite sheets are emplaced in the area with strong WNW shearing indicated by the topographical and magnetic lineaments; while the aillikite dykes are emplaced where cross-cutting brittle NE fractures are more prominent.*

The 2-to-50 m thick carbonatite sheets are the result of multiple intrusion comprising both calcitic and dolomitic units. Also late stage veining and hydrothermal alteration has affected the carbonatite. The slabs and large blocks of country rock intruded and engulfed by the carbonatite magma are variably to strongly fenitised (Steenfelt *et al.* 2007).

Aillikite dykes

In GEUS report 2007/64 most carbonate-rich dykes were noted as lamprophyres (*sensu lato*), but after closer examination of samples, the dykes have been divided into two groups, aillikites (*sensu stricto*) and carbonatite dykes (Tappe *et al.* 2009). It now appears that the carbonatite dykes occur largely within the impregnation zone, while in situ aillikite dykes and trains of aillikite boulders have been observed in two areas, to the east and north of the carbonate impregnation zone, respectively, where they occupy brittle fractures (Figure 2 and 3). A few small single boulders have been observed outside these areas, but they are considered ice-transported. The aillikite samples collected in 2005 were not included in the GEUS report 2007/64, but they are included here for completion.

Many of the observed dykes of aillikite are less than one metre wide and can only be followed over few metres or tens of metres; it is difficult to get a good impression of the composition and structure of these dykes. A few are considerably wider (Figure 4), one is up to 4 metres, and they exhibit flow banding and shearing along margins (see frontispiece). Angular blocks of aillikite are locally abundant on the surface and they are probably not transported very far (Figure 5 and 6). The most common rock type is dark grey, fresh-looking or with brownish weathering colour, and it is strongly magnetic. It consists of fine-grained (0.1 mm) groundmass of calcite with c. 15% magnetite and 3% brown mica (probably talc) with sparse (1%), small (1-2 mm), rounded magnetite and even sparser, similar-sized, fresh, rounded olivine xenocrysts, and phenocrysts of fresh olivine, magnetite and talc (Figure 5). Brown mica (phlogopite or talc) has been seen in some dykes and the amount of calcite and magnetite varies among dykes. Garnet xenocrysts are rare. Cm-sized xenoliths of country rock orthogneiss fragments are observed (Figure 6). The appearance of the aillikite is further illustrated by the field photographs stored on the CD-ROM.

The age and mineralogy of the aillikite dykes have been described in detail in Tappe *et al*. (2009). At the time of this reporting, 19 aillikite samples have been investigated more closely, see file ‘Tikiusaaq_aillikite_samp_register’ on CD-ROM. Their distribution is shown in Figure 3. With regard to mineralogy and chemistry, the rocks classify as monticellite aillikites following the revised IUGS scheme of Tappe *et al.* (2005). The aillikite dykes have microporphyritic textures (Figure 7); however, scant olivine, phlogopite, Ti-magnetite, and ilmenite macrocrysts up to 10 mm in size, as well as rare relatively small garnet peridotite xenoliths do occur. Olivine and phlogopite form microphenocrysts set in a matrix that is composed of primary calcite, monticellite (or clinopyroxene), phlogopite, Cr-spinel, Ti-magnetite, ilmenite, and perovskite (Figure 7). Primary Ti-rich garnets with elevated Zr contents have been identified in the groundmass of a few aillikite samples. These kimzeyitic garnets are diagnostic of carbonatite-UML associations and are not known from kimberlites.

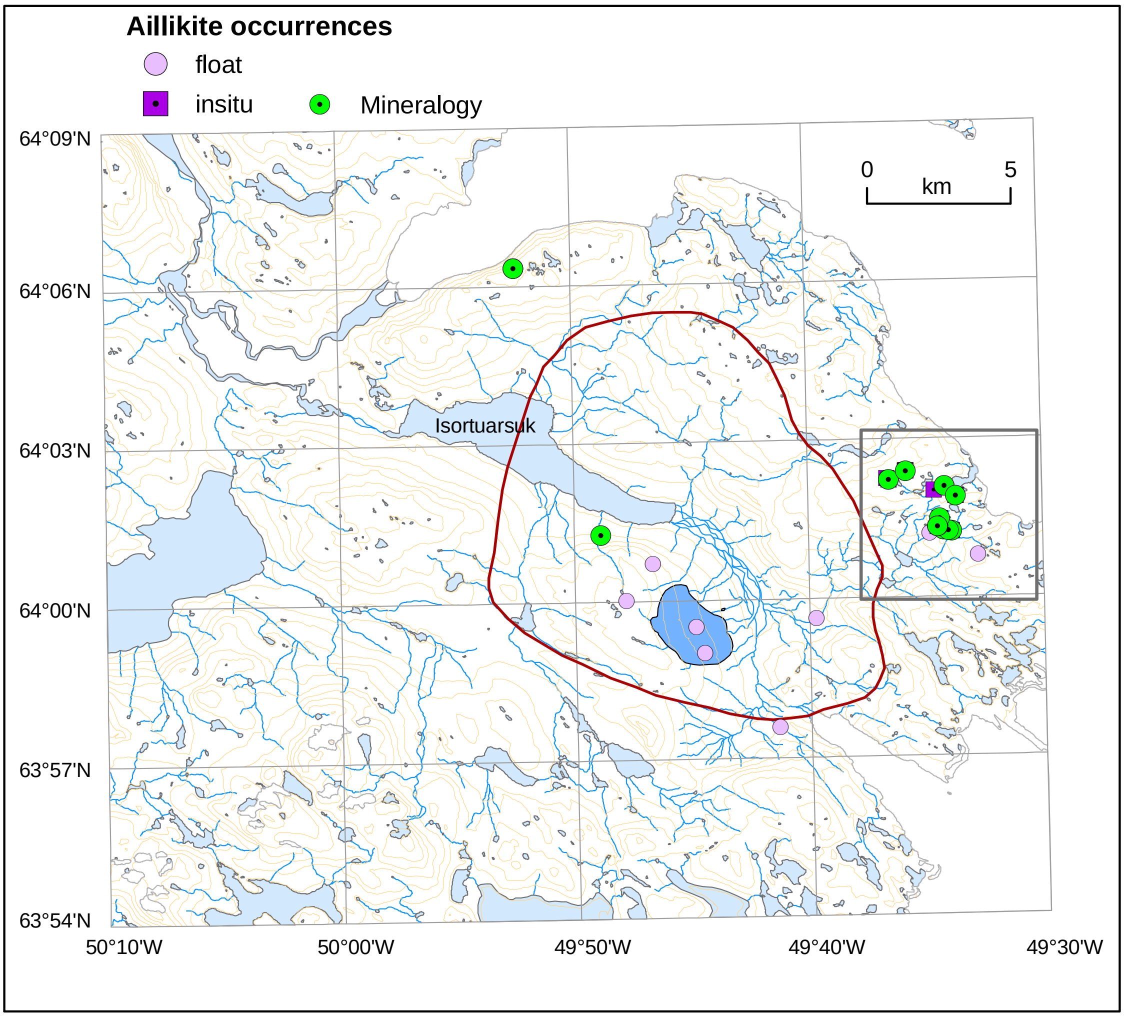


Figure 3. *Distribution of aillikite occurrences also showing position of samples that have been studied mineralogically by Tappe* et al. *(2009). A list of sample coordinates is stored on the accompanying CD-ROM. The frame shows the location of Figure 8.*

The aillikites at Tikiusaaq are mineralogically and chemically similar to the diamondiferous Neoproterozoic aillikite dykes and sills of the Sarfartoq and Maniitsoq provinces further north in southern West Greenland (Jensen & Secher 2004, Steenfelt *et al.* 2009a,b, Secher *et al*. 2009, Nielsen *et al.* 2009, Sand *et al.* 2009) and in Labrador (Tappe *et al.* 2009).

Figure 4. *Aillikite dyke outcropping in stream upstream from the boulder field where sample 459144 was collected. Hammer shows contact to orthogneiss at right.*

Figure 5. *Angular float of aillikite close to hidden dyke. The rock is the same as in sample 459144, see location on Figure 8.*

Figure 6. *Angular boulder of aillikite with white fragments of orthogneiss at the boulder field north of Isortuarsuk, see location in Figure 3.*

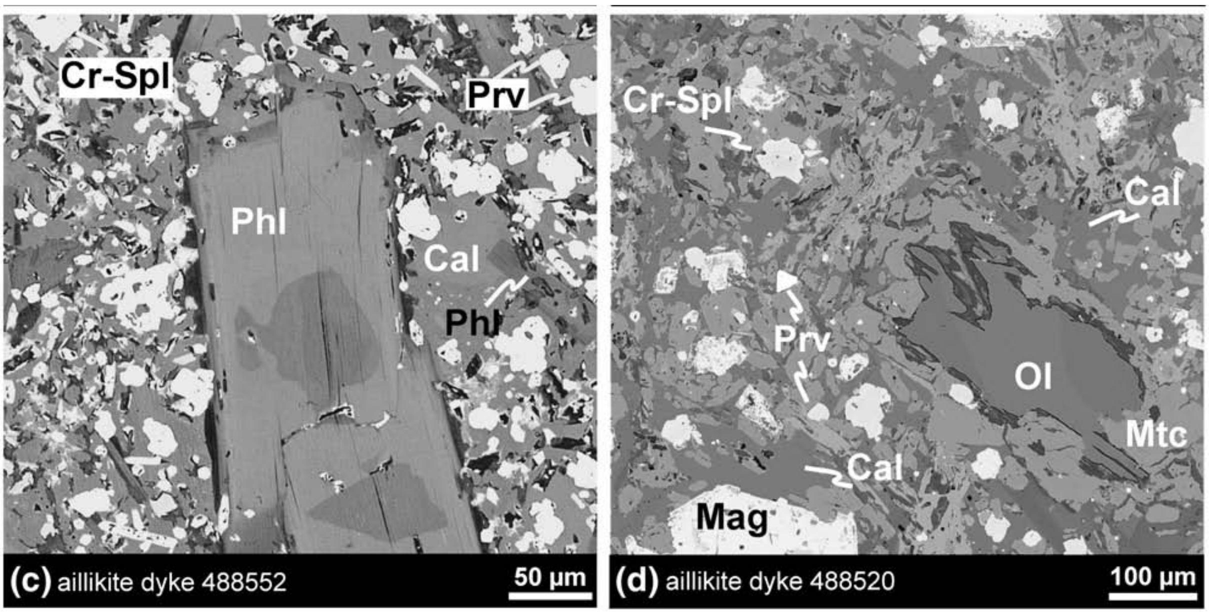


Figure 7. *Microphotographs of aillikite samples. From Tappe* et al. *(2009).*

Kimberlite indicator mineral test

The investigations undertaken in 2006-2007 comprised a test for the so-called kimberlite indicator minerals. Three samples of aillikite dykes and one of carbonatite dyke were submitted to Overburden Drilling Management Ltd. (ODM), Ontario, Canada for crushing, mineral separation and picking of kimberlite indicator minerals from three grain size fractions of heavy (d>3.2g/cm^3), non-ferromagnetic mineral separates. No indicator minerals were recovered from the carbonatite dyke. The location of the samples is shown in Figure 6, and picking results for the aillikite samples as reported by ODM are shown in Table 1.

At GEUS, grains were selected from the mineral fractions returned by ODM, and they were mounted and polished for probing. Photographs of the mounted grains are included in the CD-ROM.

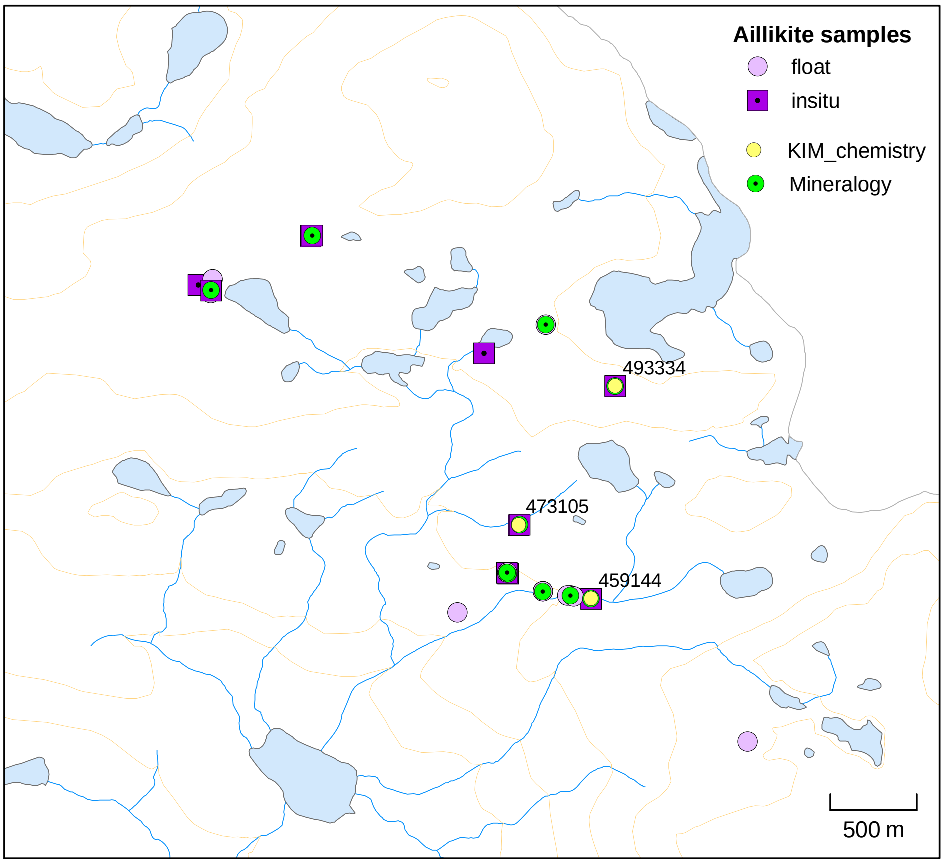


Figure 8. *Close-up of area with sample sites for aillikite dykes and boulders, see Figure 3 for location. Samples used for mineralogical studies (see Tappe* et al. *2009) are marked in green, while samples submitted for recovery and analysis of kimberlite indicator minerals (KIM) are shown in yellow with their GEUS sample number.*

	1.0-2.0 mm						0.5-1.0 mm						0.25-0.5 mm					
Sample ID	GP	GO	DC	IM	CR	FO	GP	GO	DC	IM	CR	FO	GP	GO	DC	IM	CR	FO
473105	0	0	0	0	0	50 (150)	0	0	0	20 (50)	0	50 (70,000)	3	1	0	50 (2,000)	0	50 (2,000,000)
459118	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
459144	0	0	0	0	0	50 (2000)	0	0	0	0	0	50 (20,000)	0	0	8	5	1	50 (250,000)
493334	0	0	0	13	0	50 (1000)	0	0	0	50 (125)	0	50 (20,000)	4	0	3	50 (3500)	0	50 (250,000)

Table 1. *Number of identified indicator minerals obtained after processing at Overburden Drilling Management Ltd., Ontario, Canada. Numbers in brackets are estimated total number of grains in the picked sample. GP: garnet purple, GO: garnet orange, DC: chrome diopside (clinopyroxene), IM: ilmenite, CR: chromite, FO: olivine. Sample weights: 473105: 20 kg, 459144: 2.3 kg, 493334: 2.1 kg.*

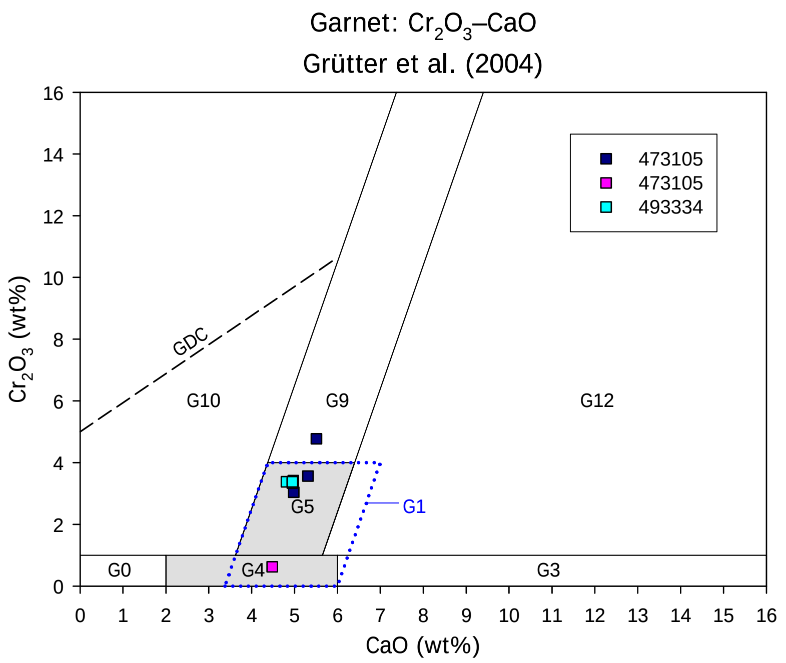
The mounted grains were analysed by JEOL 733 electron microprobe at Institute of Geography and Geology, University of Copenhagen, Geocenter Danmark. Chemical data for the grains have been plotted in discrimination diagrams used to estimate the pressure-temperature regimes within the mantle from where the grains were hosted, i.e. where they equilibrated.

Results

The chemical data presented in file 'TikiusaaqMicroprobe_data', stored on the CD-ROM, comprise 179 mean grain analyses in total, hereof 8 garnets, 1 chromite, 5 clinopyroxenes, and 165 ilmenites. Unfortunately, the minerals most important for estimating temperature and pressure, garnet and clinopyroxene, are scarce, while ilmenite grains are abundant.

Garnet

In the CaO versus Cr_2O_3 diagram (Grütter *et al.* 2004; Figure 8), one analysed purple garnet grain is lherzolitic (G9), three purple grains plot in the overlapping G5 and G1 field. The TiO_2 concentration of the latter grains suggests they are Cr-poor megacrysts, i.e. G1 class. The one orange grain classifies as G4. This confirms a lithospheric mantle origin of the grains, but the depth is inconclusive from this diagram.

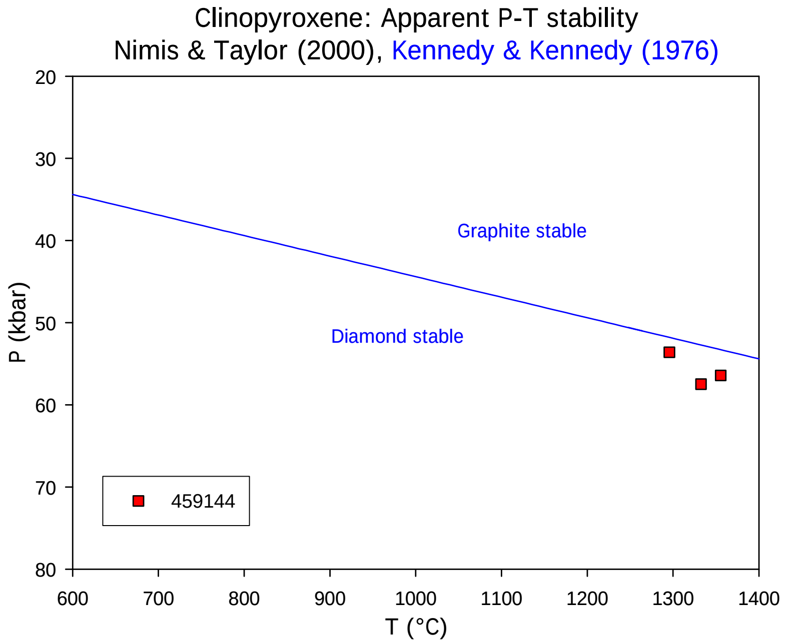


Label	*Explanation*
G12	Wehrlitic
G11	High-Ti peridotitic
G10D	Harzburgitic (diamond-facies)
G10	Harzburgitic
G9	Lherzolitic
G5D	Pyroxenitic, websteritic and eclogitic (diamond facies) - with higher Fe than moderate- to low-Cr G9 garnets
G5	Pyroxenitic, websteritic and eclogitic - with higher Fe than moderate- to low-Cr G9 garnets
G4D	Pyroxenitic, websteritic and eclogitic (diamond facies) - with Cr lower than G9 garnets and overlapping with low-Ca eclogitic garnets
G4	Pyroxenitic, websteritic and eclogitic - with Cr lower than G9 garnets and overlapping with low-Ca eclogitic garnets
G3D	Eclogitic (diamond facies)
G3	Eclogitic
G1	Low-Cr megacrysts
G0	Unclassified
GDC	Graphite-diamond constraint

Figure 9. *Chemical data for garnet grains from two aillikite samples plotted in a diagram used to estimate the origin of xenocrystic garnet.*

Clinopyroxene

There are only a few grains, but the diagrams show that the chemistry of most grains are comparable to those found in kimberlites, and they appear to have equilibrated at depths in the lithospheric mantle, where diamond is stable.



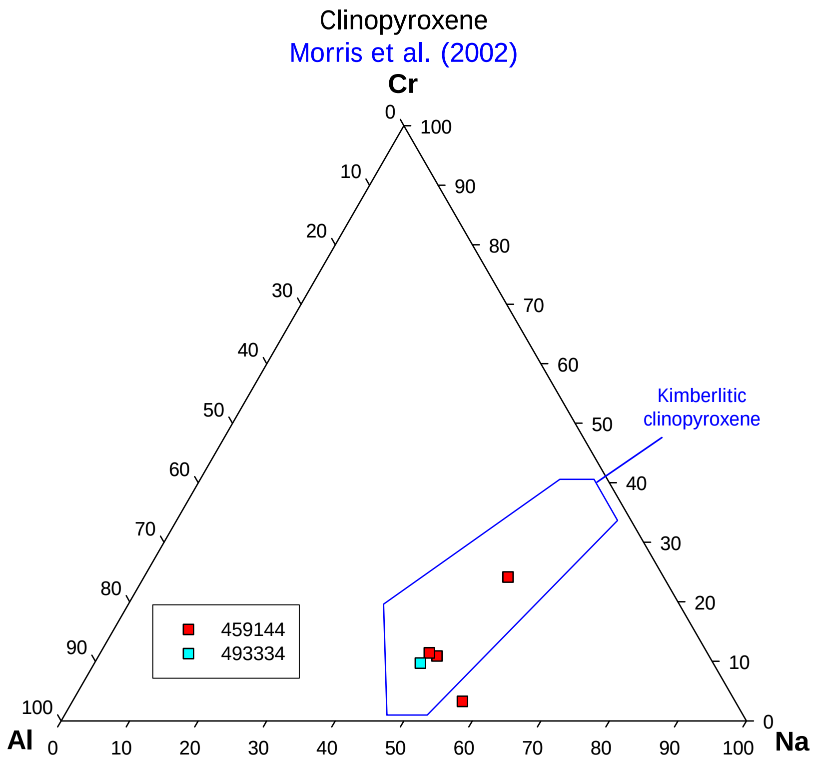
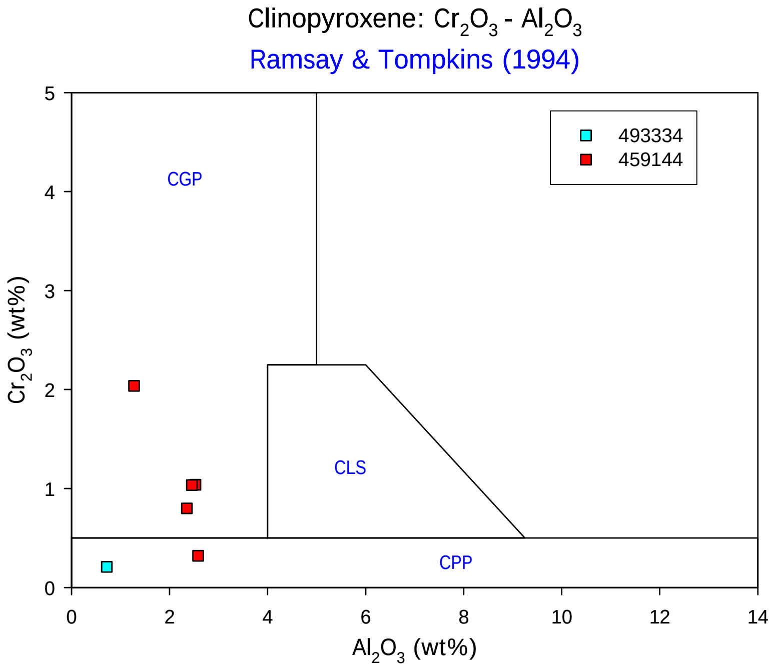


Figure 10. *See explanation next page*



Label	*Explanation*
CGP	Clinopyroxene from garnet peridotite
CLS	Clinopyroxene from spinel lherzolite and 'off-craton' garnet peridotite
CPP	Eclogitic, megacrystic and cognate clinopyroxene

Figure 10 (continued). *Chemical data for xenocrystic clinopyroxene grains from two aillikite samples plotted in three diagrams used to estimate their origin.*

Ilmenite

Ilmenite is abundant in the aillikite and a great many grains were recovered in the KIM processing. The scatter in chemistry is considerable and a number may actually be groundmass grains, as they are chemically similar to the groundmass grains studied by Tappe et al. (2009). Few, however, are enriched in Mg and Cr which indicates higher pressure.

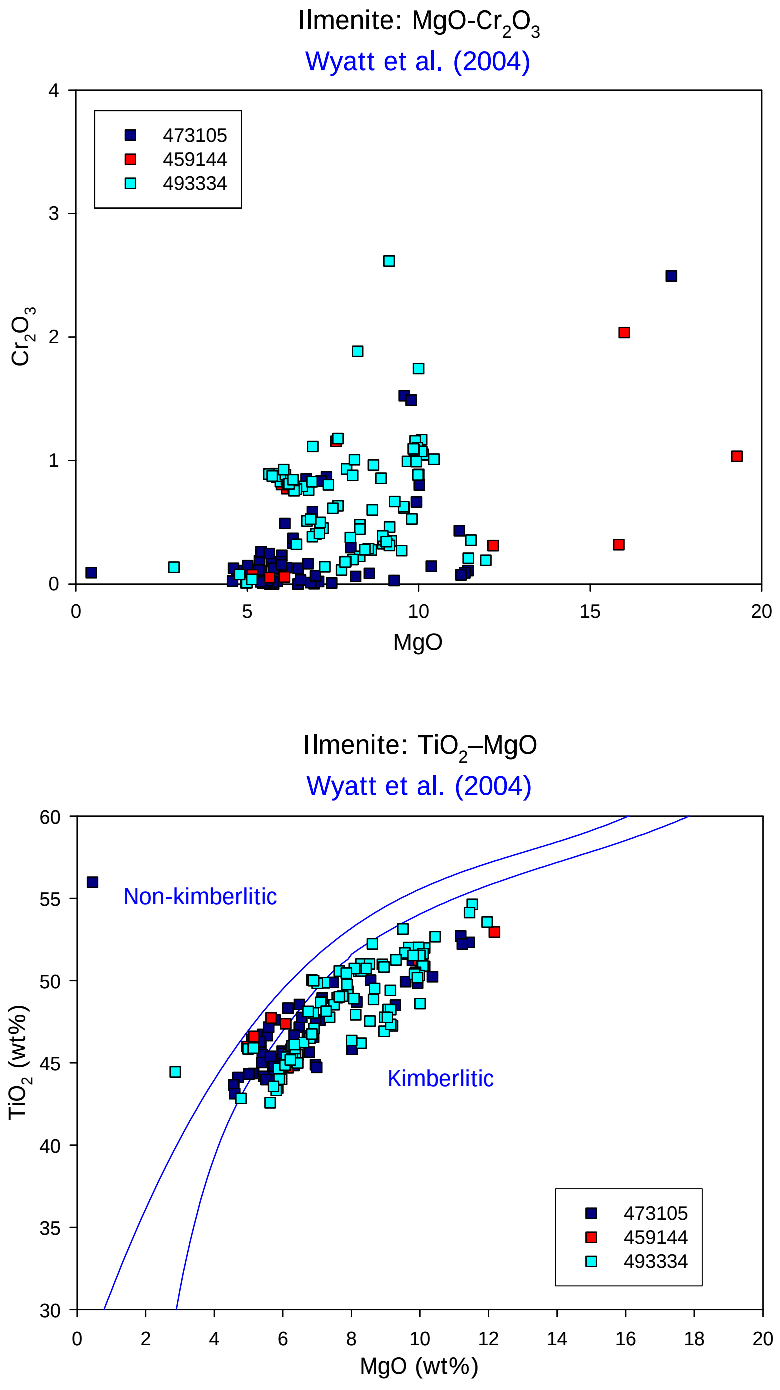


Figure 11. *Chemical data for ilmenite grains from three samples of aillikite plotted in diagrams used to estimate their origin.*

Concluding remarks

The lack of deep mantle xenoliths and the small number of indicator minerals recovered, confirming the visual observation that such minerals are rare in the exposed parts of the dykes, are unfavourable factors with regard to the diamond potential. However, the chemistry of several of the grains demonstrates that they have equilibrated at high pressure, and the character of the aillikite magma confirms that it was generated at depths below the diamond-graphite transition. One microdiamond found in an aillikite sample by NunaMinerals A/S (Secher 2010) constitutes another confirmation of the capacity of the aillikite magmas to carry deep lithospheric mantle material to the surface. A few dykes are comparable in size with diamondiferous Neoproterozoic dykes in the Maniitsoq district (see Steenfelt et al. 2009b and references therein). Therefore, if substantial amounts of mantle material can be located in hidden (or hidden parts of) wide dykes in the area, the aillikite occurrences may have an economic potential.

Abundant kimberlite-like boulders up to one metre across occur at the nearby locality, Nunatak 1390. The boulders have a groundmass that looks like a pyroclastic rock with abundant mantle xenoliths and were immediately regarded as diamond favourable. However, a diamond test turned out negative, and mineral studies concluded that the xenolithic material is derived from zones within the graphite stability field (Sand *et al.* 2007). The magmatism is likely to be coeval to that at Tikiusaaq (Sebastian Tappe pers. comm. 2008), and although no source for the boulders have been located, the occurrence testifies to more widespread deep-seated volcanic activity in this part of southern West Greenland.

The Jurassic aillikites in the Pyramidefjeld-Midternæs area in South Greenland contain microdiamonds (see references in Jensen *et al.* 2004), despite that pressure-temperature estimates for xenolithic minerals pointed to equilibration just above the diamond stability field (Nielsen *et al.* 2008). This underlines again the ability of aillikite magmatism to sample diamondiferous parts of the lithospheric mantle.

Acknowledgement

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