DIAMONDIFEROUS KIMBERLITES FROM THE GARNET LAKE AREA, WEST GREENLAND: EXPLORATION METHODOLOGIES AND PETROCHEMISTRY

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1. INTRODUCTION

Amongst the kimberlite-affinity rocks of West Greenland, of particular interest from the point of view of diamond prospectivity is the Garnet Lake locality lying approximately 2km to the North of the Sukkertoppen icecap, Sarfartoq, West Greenland (Fig. 1). Reported here are the results of diamond recovery of the largest diamond so far found in Greenland (1.90 x 1.70 x 1.42 mm) in addition to the largest calculated figures for metric carats of diamond per 100 tons (ct/100ton).

Diamond recovery data and geochemistry of mineral phases are presented, arising from samples of drill core and associated float recovered as part of the 2004 and 2005 exploration program of Hudson Resources, Inc. Comparison is made with mineralogy of diamond and non-diamond bearing rocks recovered from nearby localities principally within the same program with a view to clarifying indications of diamond prospectivity.

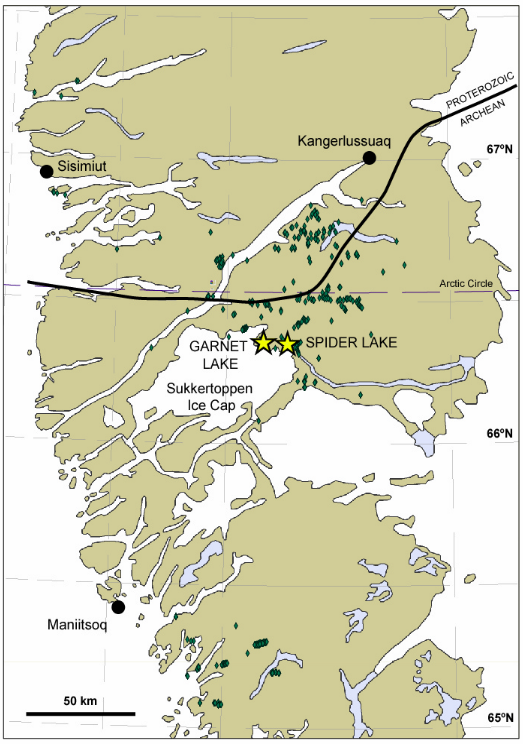

Figure 1. Map of locations of Garnet Lake and Spider Lake (yellow stars) with locations of in-situ kimberlite shown by green triangles after Jensen et al. (2004a)

The Garnet Lake site is centred around WGS84 UTM22N grid reference (469922, 7360319). Also discussed are results from the Spider Lake site (479467, 735374) and associated Spider Hollow (479087, 7358613) approx. 10 km to the east and the Silly Kimberlite site (470219, 7360929) approx. 700 m to the north-east of Garnet Lake.

2. GEOPHYSICAL EXPLORATION

The Garnet Lake site was discovered during 2004 ground reconnaissance following up on publicly available reports on indicator mineralogy (references in Jensen et al., 2004a) and an airborne DIGHEM resistivity / magnetic survey conducted at 100m line spacing for Hudson Resources Inc. by Fugro Airborne Surveys. The airborne magnetic survey in particular yielded a number of positive and negative semi-spherical and possible dipole anomalies which exhibited similarities with kimberlite pipes from elsewhere (e.g. Lockhart et al., 2004). Furthermore a number of strong linear basement features were seen to intersect each other within the Garnet Lake area.

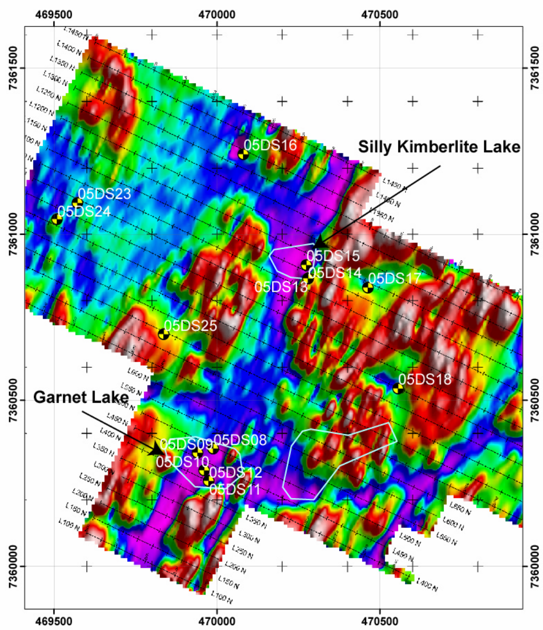

Figure 2. Ground based geophysical survey of the Garnet Lake area – total field. UTM coordinate system is based on WGS84 Zone 22N. Drill site locations are indicated by black/yellow circles. Note that lake shapes and locations are approximate and lie in reality ~100m W.

Further to the successful recovery of diamonds from the Garnet Lake site, reported below, a 50m line spacing ground-based magnetic survey was conducted around the

Garnet Lake and Silly Kimberlite sites in order to direct drilling operations during 2005. Results are presented as total field data in Fig. 2. Within the field of view, the most prolific kimberlite-bearing sites lie at the S.E. corners of Garnet Lake and the Silly Kimberlite Lake at the eastern extent of a strong N.E./S.W. trending magnetic low, interpreted as a basement feature. Furthermore, small linear features are seen to extend from these locations to the south and it is believed that in-situ kimberlite which was subsequently drilled at these sites may have been emplaced preferentially along intersections of basement weaknesses indicated by the geomagnetic trends. This observation is commonly made for kimberlite fields worldwide (e.g. Stubley, 2004). Amongst other intersections elsewhere, six drill holes on Garnet Lake, three at Silly Kimberlite and six at Spider Lake were successful in intersecting kimberlite bodies, all thought to be sills, with the principal intersection at Garnet Lake having a 3.9 m interpreted uninterrupted true thickness.

3. DIAMOND RECOVERY

Three samples of drill core and three larger samples of float taken from Garnet Lake were crushed and processed by caustic fusion for diamond separation at the SRC Geoanalytical Labs., Saskatoon, CA. Results are presented in Table 1. The more voluminous float samples were found to yield the largest diamonds with the three most significant being 1.90x1.70x1.42; 1.98x1.34x0.98 and 1.56x1.40x 1.16 mm. Figure 3 shows a slightly smaller colourless octahedral stone from float sample MHG9-7. Diamonds have been recovered in total from 36 samples from W. Greenland (references in Jensen et al., 2004a,b) with the largest previously reported being a single 1.62 x 1.53 0.22 mm stone from Pyramidefjeld (Geisler, 1974).

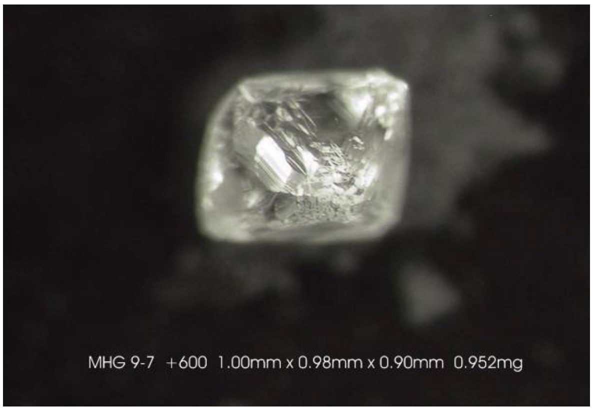

Figure 3. Photograph of diamond recovered from Garnet Lake float sample MHG9-7

Calculations of ct/100t are presented as a means of rough comparison between samples (Table 1). Due to the small sample size however, figures should not be considered to be suitable for comparison with those quoted for producing mines. It is notable however that core 05DS12-D yields recovery figures most comparable with float. This core was taken from shallow depth within a few metres of the float sampling site whereas the other drill cores were from 35-100m north. Values are much higher than those for diamondiferous samples previously recorded from Greenland with the exception of overlap with a 187 kg sample from east of Sukkertoppen (Bizzarro and Plouffe, 1999) which yielded 55 ct/100ton. Diamond recovery values for other sites from the same program reported herein were also comparably smaller. Aside from a number of diamond-absent samples, three micro-diamonds were recovered from 41.05kg Spider Lake core, two microdiamonds in 57.8 kg of float were recovered from the Silly Kimberlite and two in 64.45 kg from another nearby. Garnet Lake diamond recovery in comparison with other diamondiferous rocks from West Greenland, therefore suggests that this is a site from which a useful diamond prospectivity methodology may be constructed.

Table 1. Weights and numbers of diamonds recovered from Garnet Lake float and drill core.

Sample	Sample wt.	#	Diamond wt.	ct/100t
05DS08-D	14.4	6	0.269	9.3
05DS10-D	14.15	6	0.098	3.5
05DS12-D	10.95	15	0.662	30.2
MHG9-5	29.65	71	6.654	112.2
MHG9-7	21.2	28	4.269	100.7
MHG9-13	57.05	52	9.696	85.0
TOTALS	**147.4**	**178**	**21.648**	**73.4**

Samples prefixed by 05DS are drill core samples; samples prefixed by MHG are float samples; Sample weight in kg; diamond weight in mg; # :- number of diamonds. Note that ct/100t values are not statistically robust due to the small sample sizes involved.

3. MINERALOGY

Compositions of kimberlite and xenolith phases have been measured using standard EPMA techniques (Univ. Copenhagen JEOL 733) from samples of heavy mineral separates recovered from crushed float and core and from polished thin sections taken from both float and core. Mineral separation was conducted at the SRC Geoanalytical Labs., Saskatoon, CA.

3.1 Olivine

Olivines have been analysed in abundance from both mineral separates and groundmass and xenolith-hosted grains from thin sections. Strong trends in Ni at constant Fo content are apparent for Garnet Lake samples particularly at Fo content of 0.86, 0.90 and 0.92. Although there is a dominance of analyses within the proposed diamond field of Fo > 0.90 and Ni > 2250 ppm atomic (Jago, 2004), no strong differences are observed between olivines from nearby less diamondiferous localities.

3.2 Ilmenite

Ilmenites from Garnet Lake samples are almost exclusively picro-ilmenites although with variable Cr_2O_3-content up to 6.78 wt%. The occurrence of ilmenites with MnO greater than 1 wt% is highly variable with some samples having no such grains and one thin section having only Mn-rich ilmenites. Variability in Mg, Cr and Mn is not strikingly different between Garnet Lake and other samples in this study with perhaps the exception of Silly Kimberlite samples which are typically more Cr_2O_3-rich (up to 16.5 wt%) and yield no Mn-rich examples.

3.3 Garnet

Following the classification scheme of Grütter et al. (2004), Garnet Lake samples are rich in harzburgitic G10D and particularly eclogitic G3D and G4D diamonds in comparison with other samples. G10D and G3D-G4D garnets comprise 10% and 11% respectively in comparison with for example Spider Lake with 11% (the most comparable G10D occurrence) and no eclogitic garnets. Garnet Lake garnet compositions in terms of a Cr_2O_3/CaO discriminatory diagram (Fig. 4) demonstrate the proliferation of G10D and eclogitic garnets in core and float mineral separates. Thin sections of float and core show a similar spread of data and also include a single G12 wehrlitic garnet.

The Na_2O content of Garnet Lake garnets is unusually high (averaging 0.19 up to 0.518 wt% and up to 0.28 wt% for G4D garnets in an eclogitic garnet-bearing xenolith from Garnet Lake drill core). The only Greenlandic samples otherwise reported with the range of Na approaching this trend is the Majuagaa kimberlite, Maniitsoq (Nielsen and Jensen, 2005), however their highest Na_2O content is reported as 0.18 wt%.

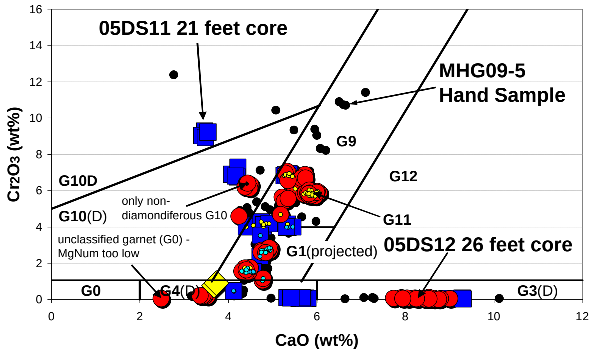

Figure 4. Compositional variation of garnets from Garnet Lake samples expressed as Cr_2O_3 versus CaO (wt%). Yellow diamonds :- 05DS07-162 foot thin section G4D eclogitic garnets.

3.4 Spinel

A variety of spinel compositions have been recovered from Garnet Lake, involving ülvospinel, magnetite and magnesioferrite components to varying degrees. Notably however few chromites have been recovered, unlike at Spider Lake and Spider Hollow where chromites are common. Compositions of chromites from Garnet Lake and other localities from this study are presented as a projection onto the reduced spinel prism (Fig. 5). Individual grains are grouped separately according to sample with different legend sizes corresponding to different samples. Where trends in composition are apparent these are annotated on the diagram. There is a significant spread in the data, partly due to the involvement of magnetite and Mg-rich spinel however it is apparent that examples of both T1 and T2 trends of Mitchell (1995) plus a mixed trend for Garnet Lake sample T1 occur (similar to that described in Mitchell et al., 1999). Mitchell (1995) describes the T1 trend as being kimberlitic and the T2 trend as being orangeitic.

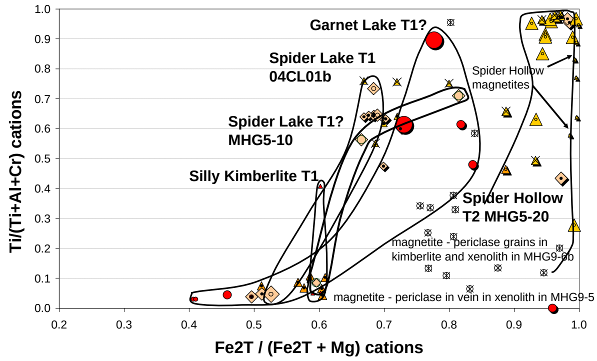

Figure 5. Compositional variation of spinels projected onto the front face of the reduced spinel prism: expressed as Ti/(Ti+Al+Cr) cations versus total Fe calculated as Fe^{2+} (Fe2T)/(Fe2T+Mg) cations. Red circles are Garnet Lake samples, red triangles are from the Silly Kimberlite, yellow diamonds are from Spider Hollow and flesh-coloured triangles are from Spider Lake samples.

3.5 Mica

Individual samples from Garnet Lake, as from the other localities studied show a range in mica compositions. Of particular use for classification are the variations in Al, Ti and Fe. Mica compositions in terms of Al and Ti wt% oxide are presented in Figure 6. Individual grains are typically significantly homogeneous with the exception of rims of tetra-ferriphlogopite. The Garnet Lake samples distinguish themselves in being particularly Ti-rich (also compared to Greenlandic micas published elsewhere, e.g. Nielsen and Jensen, 2005). Their trend towards tetra-ferriphlogopite can be considered to be orangeitic (Mitchell, 1995). It is notable that Spider Lake and Spider Hollow compositions have a similarity with those from the Majuagaa calcite-kimberlite despite Spider Hollow in particular having otherwise an orangeitic character (e.g. in terms of spinel composition).

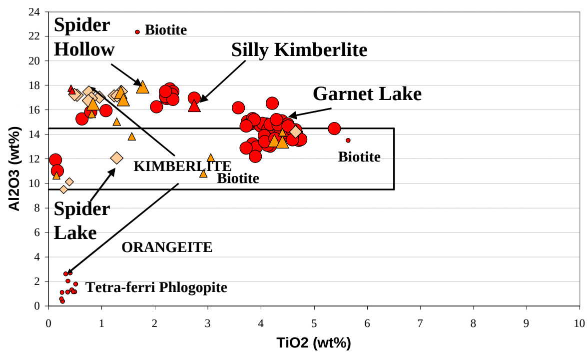

Figure 6. Compositional variation of phlogopites from Garnet Lake and Spider Lake samples expressed as Cr_2O_3 versus CaO (wt%). Tetra-ferriphlogopite rims on micas from three Garnet Lake float samples are shown as small red circles.

4. GEOTHERMOBAROMETRY

Calculations of equilibration pressure and temperature of a Garnet Lake sample was undertaken using data from phases in a garnet lherzholite xenolith taken from float sample MHG9-6 (Figure 7). A four phase assemblage calculation is considered preferable to calculations based on fewer phases and the commonly used technique of using mineral compositions from mineral separates. The latter method allows no confidence of mineral equilibration and can result in misleading conclusions.

Two calculations were carried out using the Al in Opx barometer of Brey and Köhler (1990) and the following thermometers:
1. Ellis and Green (1979) Fe-Mg exchange in garnet-cpx
2. Brey and Köhler (1990) Na in Opx-Cpx
3. Brey and Köhler (1990) Cpx-Opx solvus

The first calculation used averaged analyses of touching grains considered most likely to be in chemical equilibrium. The second calculation used averaged analyses for grains of opx, cpx, olivine and garnet taken from within the unaltered centre of the xenolith.

Equilibrium conditions are calculated to lie within the range P=61.4 to 66.7 kbar and T=1352°C to 1327°C. Comparison with the fields of Greenland till samples calculated after data in Jensen et al. (2004a) which cuts off at ~1270°C, indicates that the depth of origin of the xenolith from the diamond-bearing Garnet Lake locality is greater than generally observed previously. Admittedly equilibration within till sample grains, as described previously, may not be assured. Data from Garnet Lake is also consistent with a similar cold geotherm, as in for example the Kaapvaal craton (references in Nixon, 1987).

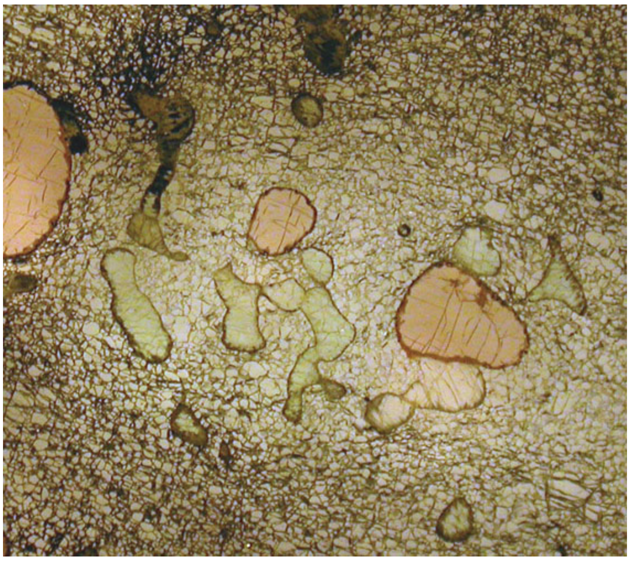

Figure 7. Transmitted light photomicrograph of garnet lherzolite xenolith sample tsMHG06b. Field of view is approximately 2 cm. Green macrocrysts are cpx, colourless are opx, orange are garnet. Finer grains are almost exclusively olivine.

5. DISCUSSION AND CONCLUSIONS

Similarities between diamond recovery and mineral compositions between Garnet Lake core and float, in comparison with data from nearby samples (e.g. Fig. 4) strongly suggests that the Garnet Lake float can be considered to be close to in-situ. It is reasonable therefore to accommodate data from float into discussion of the significance of mineralogy of Garnet Lake samples in general.

Table 2. Orangeite and Kimberlite Affinities of Najaat samples – Garnet Lake core and associated float

	h11	h12	t7C	t7F	h9-5	t9-2	t9-3	t9-5	t9-6a	t9-6b
Olivine *Macrocrysts*	?p	?p	-	-	?p	-	-	-	-	-
Phenocrysts	**O**	**O**	?c	?c	**?c**	**O**	**O**	**O**	?-	**K**
Mica *Groundmass*	?p	?p	**O**	**K**	**K**	-	-	**O**	**O**	**O**
Macrocrysts	?p	?p	?p	?p	**?p**	**O**	**O**	**O**	**O**	**O**
Spinel	?p	?p	-	-	-	-	-	**K** (ülv, T1?)	**K** (ülv, T1?)	-
Perovskite	?p	?p	**O**	**K**	?p	<<	<<	<<	<<	<<
Apatite	?p	?p	- ?c	**K** ?c	-	-	-	-	-	-
Carbonate	?p	?p	**O***	**K**	-	?c	?c	?c	?c	?c
K-richterite	<<	<<	<<	<<	<<	<<	<<	<<	**O?**	<<
Mn-ilmenite	**K**	**K**	**K**	**K**	**K**	-	**O**	**K**	**O**	-
REEphosphates	?p	?p	<<	**O**	?p	<<	<<	<<	<<	<<
Barite	?p	?p	**K**	**K**	?p	<<	<<	<<	<<	<<
Ni sulphide	?p	?p	**K**	<<	?p	<<	<<	<<	<<	**K**
lowCr,Ti macro.	**K**(G1)	**K**(G1)	?p	?p	**K**(G1)	<<	<<	<<	**K**(G1)	**K**(G1)
K or O affinity	**K**	**K**	**O**	**K**	**K**	**O**	**O**	**O/K**	**O/K**	**K**

h11 and h12 :- heavy mineral separates from cores 05DS11-21 and 05DS12-26 respectively; t7F :- thin section 05DS07-155b (apahanitic); t7C :- thin sections 05DS07-155-a and –c (macrocrystal); h9-5 :- heavy mineral separate from MHG9-5; t9-2. t9-3. t9-5, t9-6a and t9-6b :- thin sections MHG9-2, MHG9-3, MHG9-5, MHG9-6a and MHG9-6b respectively. Orangeite and Kimberlite characteristics after Mitchell (1995); K :- kimberlite; O :- Orangeite; ülv :- ülvospinel; macro: :- macrocrysts; * :- contains olekminskite; ?c :- composition unknown; ?p :- proportion unknown; << not abundant, however absence can't be stated with confidence; - :- phase present but observed characteristics do not allow from distinction between rock types; T1 and T2 :- spinel magmatic trends T1 and T2 respectively.

Garnet Lake samples distinguish themselves from neighbouring diamond-poor kimberlitic rocks by the following characteristics:

- implied high diamond grade;
- commonly visible garnet megacrysts in the matrix;
- dominance of diamond-stable peridotitic garnets;
- abundance of diamond-stable Na-eclogitic garnets;
- deep solution to geothermobarometry calculations

The closest analogy reported elsewhere may be the Majuagaa calcite-kimberlite (Nielsen and Jensen, 2005). Diamond content of 125 microdiamonds in 1060 kg (Jensen et al., 2004b) are higher than most tested Greenlandic kimberlites but are still significantly lower than Garnet Lake samples. Majuagaa does contain significant eclogitic garnets and concentrations of Na in garnet overlap the lower end of the Garnet Lake range.

In terms of classification, there has been some significant debate as to how to describe the Greenlandic kimberlitic rocks (e.g. Mitchell et al., 1999 and Nielsen and Jensen, 2005). Table 2 summarises the mineral compositional data described above in association with additional observations in the context of Mitchell's (1995) orangeite/kimberlite classification scheme. It is apparent that the mineralogical and geochemical characteristics of most of the samples studied would lead to a classification of either kimberlite or orangeite depending on which is considered to be the most important criteria. Garnet Lake samples often contain low Cr, Ti-macrocrysts, occasional Ni-sulphide and Mn-ilmenites are rare. These are all characteristics of kimberlite. On the other hand tetra-ferriphlogopite rims on phlogopite are seen in many samples, olekminskite (Sr,Ba,Ca carbonate) is reported and olivine phenocrysts are typically Fo-rich. These are all characteristics of orangeite. Such conflicting characteristics are not confined to mineral separates but are also seen in thin section. Similar mixed characteristics are seen in Spider Lake, Spider Hollow and Silly Kimberlite samples. Indeed a single core section from Garnet Lake (05DS07-262) consists of a coarse grained rock with strong orangeitic affinity abutting a fine grained perovskite-rich rock of strong kimberlitic affinity.

As the orangeite classification relies heavily on southern African samples, it is perhaps not surprising that the terminology has questionable direct application to Greenlandic rocks. However the natural question which arises is whether or not Garnet Lake, and other kimberlitic rocks from Greenland represent a mixing of true primary orangeite with kimberlite in the source region, or whether some genetic spectrum of kimberlite-orangeite primary magma is possible. Significantly more work is required to fully address this issue. It is at least safe to say at this stage however, that notwithstanding uncertainty on classification, Garnet Lake samples demonstrate that Greenlandic kimberlitic rocks can be substantially diamond-bearing.

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