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Diamondiferous kimberlite from Garnet Lake, West Greenland I: genesis, geochemistry and emplacement

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Kimberlites, ultra-mafic lamprophyres (UML), carbonatites and related rocks occur abundantly in West and South-West Greenland (Larsen and Rex, 1992). These forms of magmatism, have occurred within the Archean craton from the Archean through to the Oligocene (reviews in Larsen and Rex, 1992 and Frei et al., 2008; Secher et al., 2008).

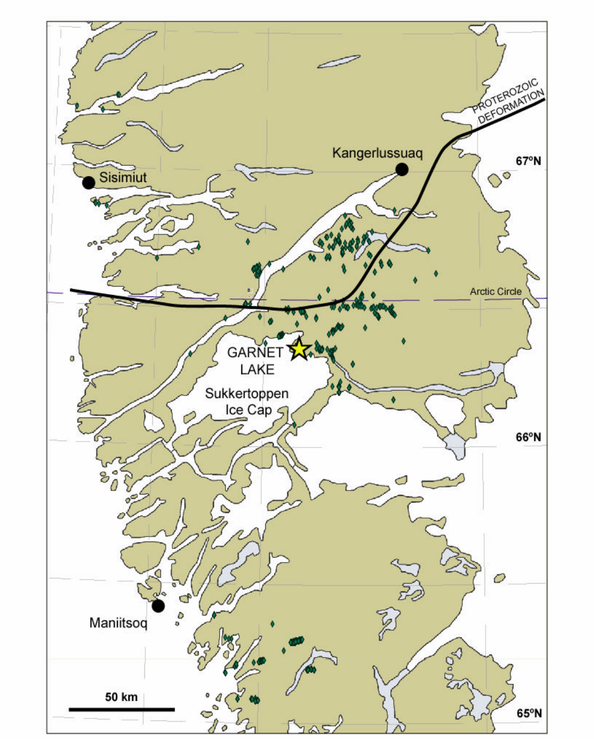

Fig. 1 Location of Garnet Lake in the context of West Greenland.

Yellow star :- Garnet Lake site; Green diamonds :- locations of in-situ kimberlitic rocks (refs. in Jensen et al., 2004); Solid black line :- boundary between undeformed Archaean (south) and rocks affected to the north by the 1.9–1.8 Ga (van Gool et al., 2002) Palaeoproterozoic Nagssugtoqidian Orogen.

Many of these intrusive bodies are of interest due to their diamond potential however the correct petrological classification of numerous diamond-bearing rocks from Greenland has proven to be controversial (e.g. Mitchell et al., 1999 and Nielsen and Sand, 2008). At Garnet Lake, Sarfartoq, West Greenland (Fig. 1) a series of stacked and anastamosing dykes of kimberlite-affinity contain an abundance of high quality diamonds. The so-called Garnet Lake 'main sheet' (m.s.) distinguishes itself particularly as containing higher concentrations of diamonds than other Greenlandic diamond sources, including nearby sub-parallel sheets (Hutchison, 2005). Mantle material from the Garnet Lake m.s., including diamond, is discussed in this volume in Hutchison and Frei (2008). Here we present data relating to the host kimberlite in terms of emplacement, mineralogy, petrology, and genesis.

Morphology and emplacement

The extent of exploration work conducted so far has identified a true thickness of up to 4.25 m and the body (Fig. 2) has been shown, to the limits of seismic reflection techniques available, to be largely continuous for over 2.2 km down its 24° north-easterly (True) dip. So far the sheet has been traced 1.4 km along its NW-SE strike (Hutchison, 2005) although given the presence of glacial cover, particularly to the north, it likely carries on past the extent proven. Drill core evidence and surface excavations demonstrate that the thickness of the body can be variable and whilst largely a single body occasionally bifurcates.

The Garnet Lake m.s. was emplaced in the late Neoproterozoic (568 Ma, Frei et al., 2008). However contact relationships, chilled margins within the main body, mineralogical and textural observations, described in the following, demonstrate that the Garnet Lake m.s. comprises of two related mineralogies.

Garnet Lake area intrusives often show clear evidence of emplacement controlled by crustal structural weaknesses such as shear zones and dykes. The Sarfartoq carbonatite complex, lying 21 km to the north-east of Garnet Lake occupies a major east-west structural feature. Revised age determinations demonstrate the carbonatite to be contemporaneous with kimberlitic magmatism in the area, including the Garnet Lake m.s. (Secher et al., 2008). Numerous kimberlitic sheets follow structures trending directly towards the carbonatite. Some of the structures these kimberlites occupy are pre-existing such as for the 'M' and 'N' kimberlitic dykes (Jensen et al., 2004), ~8 km north-west of Garnet Lake which can be traced for several kilometres along the strike of a considerably older Kangamiut dyke. However the stress on the crust during emplacement of such a large (8-12 km diameter) body as the Sarfartoq carbonatite would have been considerable and undoubtedly created it's own pattern of brittle deformation. With this in mind, it is notable that in addition to trending directly towards the carbonatite, other bodies (Larsen, L.M., GEUS, *pers. comm.* 2006), including the Garnet Lake m.s. strike orthogonally to, and dip towards the carbonatite. Such a morphology is reminiscent of a cone-structure and indeed the Sarfartoq carbonatite hosts a kimberlitic intrusion within it (Jensen et al., 2004). Diamonds mostly formed increasingly over the time running up to the emplacement of the carbonatite and kimberlitic sheets (Hutchison and Frei, 2008). Furthermore, the mineralogy of the Garnet Lake m.s. also shows a carbonatitic affinity as described below.

In addition to exploitation of existing weaknesses, the Garnet Lake m.s. has also imposed its effects on its host rocks. It is common to observe significant carbonate infiltration into a network of brittle fractures within the host gneiss up to 10 m from even the thinner, 1m pinches and this feature acts as an indicator of proximity to kimberlite during drilling.

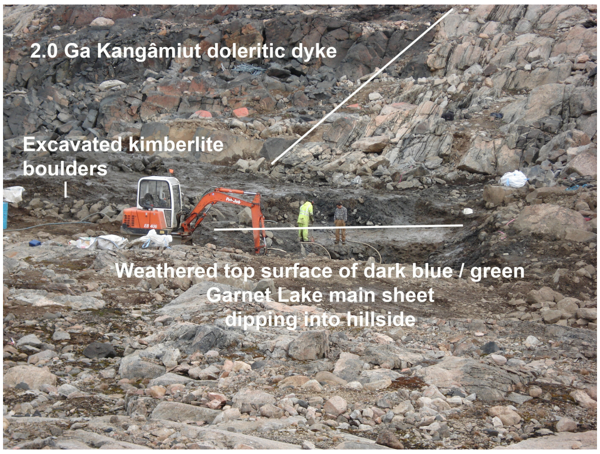

Fig. 2 The Garnet Lake main sheet.

Mineral Chemistry and Petrography

The kimberlite is hypabyssal and typically highly competent, fine grained (sub-mm) and dark green or blue. It has experienced little weathering except in areas where carbonate has been particularly abundant as a groundmass phase or in veins.

Kimberlite senso lato

The dominant rock is a carbonate-rich kimberlite *senso lato* and although a poorly constrained terminology, it may be termed a transitional-ultramafic lamprophyre (TransUML). It should be stressed that irrespective of the loose terminology, the rock is demonstrably diamondiferous. The texture is macrocrystal consisting 25% of mantle olivine (<3mm), pyrope and phlogopite macrocrysts. The groundmass mineralogy, which primarily determines rock classification, consists of 30% opaques (mostly Mg-ilmenite and spinel) and 20% phenocrystal phlogopite. The remaining groundmass is a mixture of primary olivine, calcite, dolomite and minor phases. The rock contains a relatively large amount of ilmenite, normally attributed to a true kimberlite although core compositions are at the lower Mg-end of the kimberlitic field (11-13 wt% MgO) and Mg-depleted rims (down to 7 wt% MgO) are certainly consistent with a TransUML. The presence of chromite again suggests a TransUML affinity although compositions again have a kimberlite affinity, in this case lying between the 'Type 1 magmatic trend' of Mitchell (1995) and the 'Type 2 orangeitic trend'. Phlogopites are deep brown and strikingly zoned with unusually high TiO_2 cores (>4 wt% TiO_2) and tetraferri-phlogopite rims and primary diopside is present in minor quantities; both features typical of orangeites or TransUML. Groundmass olivines lie in the compositional range of Mg# of 0.87-0.91. Finally baddeleyite and apatite occur as accessory minerals and the unusual carbonatitic Sr, Ba, Ca-carbonate mineral olekminskite appears along fracture surfaces in serpentinised olivine xenocrysts.

Kimberlite senso stricto

The second component of the Garnet Lake m.s. is a kimberlite *senso stricto.* It is aphanitic in texture with striking fresh pyrope garnets and disaggregated olivine being the principal mantle phases. Ilmenite and perovskite comprise some 40% of the groundmass mineralogy with grains typically up to 100 µm. Phlogopites (15%) are homogeneous and up to 1mm in diameter and olivine phenocrysts (occasionally serpentinised) contribute 15% of volume. The remaining crystallised phases are calcite, minor dolomite and apatite. Like the kimberlite *senso lato*, ilmenites have high Mg cores (11-14 wt% MgO) and Mg-depleted rims (6-7 wt% MgO). Perovskites are usually fresh but occasionally contain inclusions of baddeleyite, monazite and rutile. The high abundance of both ilmenite and perovskite is a typical characteristic of kimberlites *senso stricto*, as are phlogopite compositions. Phlogopites have only very thin rims which are enriched in BaO (up to 3 wt%) and their Al, Ti compositional variation lies on the kimberlitic trend.

Genesis

Nielsen and Sand (2008) argue that the carbonate-rich Majuagaa kimberlite, with the removal of olivine (based on Ni mass balance) and ilmenite, presents a bulk composition consistent with a melt of silicocarbonatite composition derived melt from very low degrees of partial melting of CO_2-lherzolite. A similar conclusion may be invoked for Garnet Lake. Furthermore, the presence and REE characteristics of lherzolite xenocrysts recovered from Garnet Lake heavy mineral separates also support an early event of mantle fertilisation likely contributing directly to the formation of diamond (Hutchison and Frei, 2008).

The presence of two petrological components at Garnet Lake may suggest two different mantle sources. However it is proposed from ilmenite compositional gradation in the kimberlite *senso stricto* that the original melt was a true kimberlite with subsequent evolution of a more transitional UML component. The evolution of rock type may be linked to diamond abundance in the Garnet Lake m.s. particularly if variability in the H_2O/CO_2 ratio is a controlling factor as favoured for similar rocks (Nielsen and Sand, 2008).

Summary and Conclusions

The Garnet Lake, diamondiferous main sheet has a temporal, geographic and chemical association with carbonate melt and the nearby Sarfartoq carbonatite complex. Multiple melt composition is evident within the sheet and it is proposed that Garnet Lake represents an evolving system from mantle fertilisation and diamond formation, initial kimberlite *senso stricto* melt generation evolving into a more transitional UML and associated with carbonatite.

Acknowledgements

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