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Department of
Earth Sciences

Master's Thesis

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Re-Os Isotope Constraints on the age of the Lithospheric Mantle beneath Western Greenland.



Sukkertoppen Ice Cap, South West Greenland

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15 MAY 2008

Submitted: September 2007

Supervisors: Prof Graham Pearson & Dr Sven Monrad Jensen



Abstract

Alkaline magmatic activity across Western Greenland (W.G.) provides a record of lithosphere evolution over the last 600 Ma. Ultra Mafic Lamprophyre (UML) magmatism in particular has erupted an exceptional inventory of mantle xenoliths allowing a detailed look at the lithospheric root beneath both the exposed craton and the re-worked Archean terrane (RAT) of the Kangerlussuaq region, SW Greenland. Samples from within the re-worked Archean terrane more commonly have diopside plus garnet, i.e. they are more lherzolitic whereas highly depleted harzburgites and dunitic lithologies are prevalent amongst xenoliths erupted through the undisturbed Archean craton.

W. Greenland peridotite xenoliths show a large range in bulk composition. The peridotites are MgO – rich (44-51 wt%), with most samples overlapping the range for cratonic peridotites and being generally more MgO-rich than non-cratonic or massif peridotites. In contrast SiO₂ contents are relatively low (36-43 wt%), being at the lower end of the range for both cratonic and non-cratonic/massif peridotites, indicating that the W.G. mantle has not experienced significant SiO₂ enrichment. The low SiO₂ of most residual, minimally metasomatised harzburgites indicate particularly orthopyroxene poor protoliths. This contributes to growing evidence that the Kaapvaal cratonic lithosphere is the exception rather than the rule in terms of craton lithosphere bulk compositions and evolution.

A selection of dunitic, harzburgitic and lherzolitic lithologies have been analysed for Re-Os isotopes and PGE abundances. Os ranges from 0.86 to 5.02 ppb, scattering around the typical average for cratonic residues. Re contents range from 0.009 to 0.290 ppb, and are all less than primitive mantle. However, in extended PGE patterns Re can be seen to be anomalously high in numerous samples and has obviously experienced secondary enrichment, possibly by UML infiltration. Pt and particularly Pd demonstrate their incompatible behaviour during high degrees of melting, with Pt as low as 0.035 and Pd depleted to 0.007 ppb, comparable to highly depleted residues from other cratons (Pearson *et al*, 2004). The effects of metasomatism are also seen on Pd in some samples but this element is less disturbed than Re and, for some samples, (Pd/Ir)_n correlates well with indices of melt depletion such as Al₂O₃ consistent with high degrees of melting. Some disturbance relates to metasomatic introduction of clinopyroxene in certain rocks.

Re-depletion ages for the most residual W.G. peridotites, corrected to the 600 My eruption age for the host UML, range from 1.8 to 3.0 Ga, with Archean depletion ages clearly evident in the lithosphere beneath the RAT of the Nagssugtoqidian. Archean (>2.5 Ga) ages are found in even the deepest derived (>200 km) samples indicating that the basal lithosphere is of this age.

The ages for W.G. peridotites together with pressure and temperature investigations by Sand (2007) indicate clearly that an Archean keel existed beneath the region that extended well into the diamond stability field at 600 Ma, both on the recognised craton and beneath the region of re-worked Archean crust suggesting that further exploration in this area can be targeted right across the region where UML's occur. The validity of these findings is emphasised by the recent new finds of macro-diamonds in the Kangerlussuaq region (Hudson Resources Website).

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CHAPTER 1
INTRODUCTION

Chapter 1:

Introduction

1.1 Overview

The development of the Archean lithospheric mantle is important for understanding when the continental crust began to stabilise in the young Earth. By 3.5 billion years ago (Ga) five significant areas of crust had formed in what is now known today as Archean cratons in North America, Siberia, Africa, Australia and Eastern Europe (Baltica) (Windley, 1977). The term craton is used for stable areas of crust and mantle which have not experienced any significant deformation for more than 500 million years (Ma). They are commonly found in the central areas of continents and are protected from deformations by their surrounding mobile zones. Evidence from diamond inclusions shows that these cratons were already thicker than 60km, even ~1Ga after the formation of the Earth (Boyd, 1985; Westerlund *et al.*, 2006). Almost all our knowledge of the formation of lithospheric mantle keels in the early Earth comes from fragments of mantle entrained in deeply-derived magmatic rocks, termed xenoliths. This study follows this line of investigation by using peridotite xenoliths sampled by alkaline rocks in W. Greenland to understand the timing of formation of the lithospheric mantle beneath this area of the North Atlantic Craton (NAC).

Lithospheric (solid crust & upper mantle) mantle xenoliths brought to the Earth's surface, through or around the edges of cratons, via magmatic activity can be geochemically and petrologically investigated to determine their composition, depth and age of formation. The significance of these investigations has implications for the mantle environment in which the xenoliths came from. Currently there is much debate focussed on whether modern day plate tectonics operated at 3.5 Ga and considerable uncertainty surrounding the melting environments in the Archean mantle, i.e., whether cratonic lithospheric mantle was generated in subduction zone settings or via plume activity (e.g., Davies, 1995; Griffin *et al.*, 2003; Leitch, 2004; Ernst, 2007; Simon *et al.*, 2007).

In this study over 160 lithospheric mantle xenoliths have been collected from c.600 Ma old alkaline dykes and sills (Larsen & Rønsbo, 1993; Mitchell *et al.*, 1999; Jensen *et al.*, 2003) which have intruded across a region of reworked Archean crust and undeformed Archean crust in S.W. Greenland. The xenoliths comprise lherzolitic, harzburgitic and dunitic lithologies and are thought to represent the lithospheric mantle root beneath this region of ancient crust.

The investigations to be carried out in this study involve using the platinum group elements (osmium, iridium, ruthenium, platinum, and palladium) and rhenium, together with the Re-Os isotope system. The Re-Os system has been shown to be singularly successful at dating mantle depletion events in peridotites (e.g., Meisel *et al.*, 2001; Pearson *et al.*, 1995a & b; Pearson *et al.*, 2004). The addition of PGEs to the analytical suite allows more stringent assessment of the effects of mantle metasomatism on the Re-Os system and so provides some indication of which samples are likely to be more disturbed than others (Pearson *et al.*, 2002; Pearson *et al.*, 2004). In addition, examination of inter-element PGE fractionations offer an insight into the variety of processes that may have affected cratonic lithosphere during and subsequent to its formation. Along with the PGE geochemistry, major elements have been analysed to further understand how their compositional variations reflect the possible melting environment and metasomatism. Using the PGEs and the major element compositions, comparisons can be made with other cratonic and circum-cratonic mantle xenolith suites, with an aim to characterise typical Archean cratonic mantle lithosphere and the processes that generate and modify it. Pressure and temperature investigations on the xenoliths from this area have also been carried out by GEUS (Geological Survey of Denmark & Greenland) in a separate Masters Research project by Sand (2007).

This study is currently a small part of a larger more comprehensive investigation into the lithospheric mantle beneath western Greenland, and the diamond potential of the area.

1.2 Aims

The aim of this project is to analyse a sub-set of mantle xenoliths for Re-Os isotopes and PGEs in order to provide the first age constraints for mantle lithosphere beneath the Kangalassaq area of S.W. Greenland. Of particular interest was the potential age difference of lithosphere beneath the Archean and reworked Archean crustal terranes. Whole rock major element data will also be used to characterise the major element composition of the xenoliths in comparison with other cratonic peridotites. Alkaline rocks containing diamonds have recently been found in both crustal terranes and there is considerable exploration interest in determining whether or not these diamonds originate from typical cratonic mantle (GEUS, 2004).

1.3 Geological background

The exposed Archean rocks of SW Greenland have similar stratigraphy and metamorphic grade to Archean rocks found in the Labrador Province of NE Canada, East Greenland and the Lewisian complex of NW Scotland, and are collectively termed as the North Atlantic Cratonic region (Windley, 1977). The opening of the North Atlantic in the Tertiary separated the craton into the several fragments revealed today (Fig. 1.1).

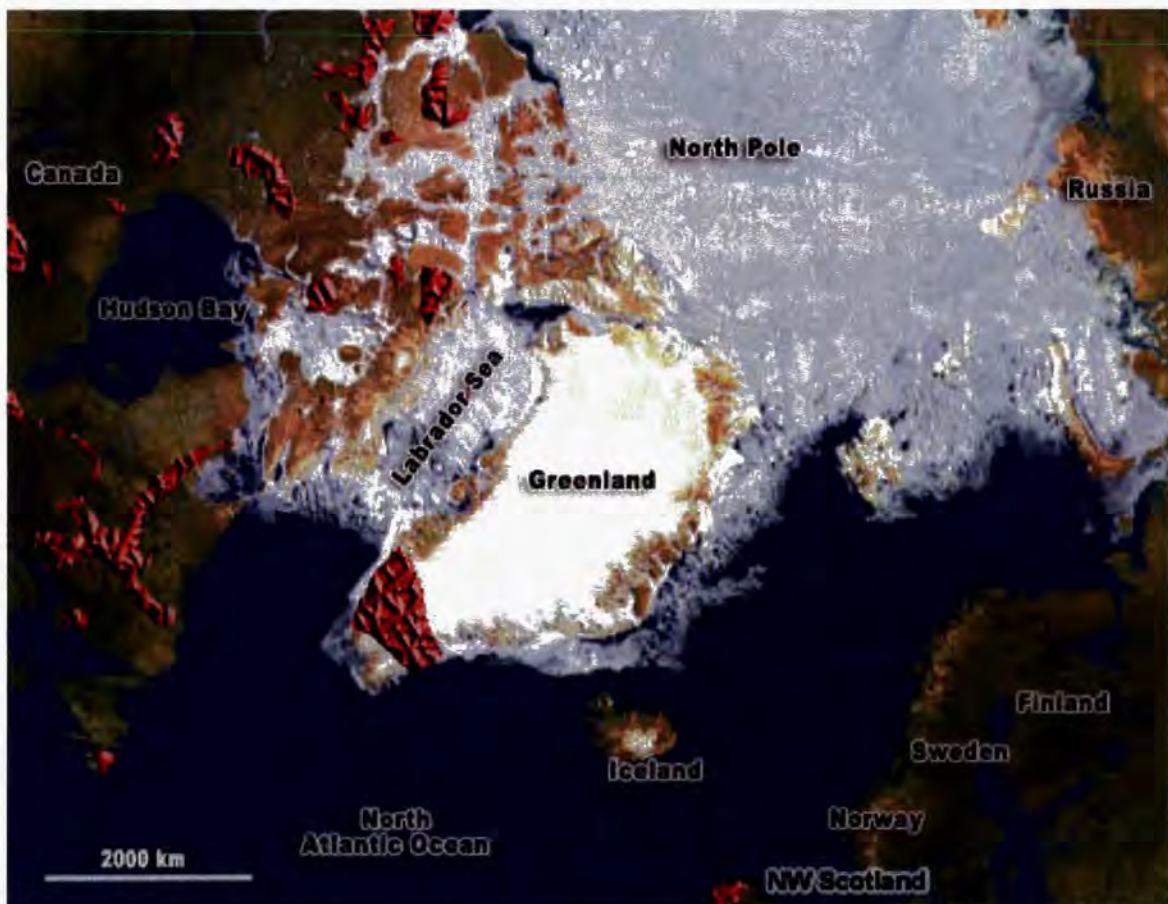


Fig. 1.1 Satellite image of Greenland and the surrounding countries. Red areas are the North Atlantic cratonic regions.

1.4 Regional geology

The North Atlantic Craton (NAC) in southern Greenland lies between two areas of reworked Archean mobile belts. To the North is the Nagssugtoqidian Mobile Belt, referred to here as the Reworked Archean Terrane (RAT: later discussed in more detail in section 1.6 Tectonic History), and to the South is the Ketilidian Mobile Belt (Bridgewater *et al.*, 1973) (Fig 1.2). This study is focussed on the north-western boundary of the NAC, where two generations of mafic dykes have intruded into the southern margin of the Nagssugtoqidian mobile belt and the northern margin of the Archean craton. The Kangâmiut Dyke Swarm emplaced doleritic dykes c.2040 Ma ago, trending NE-SW (Cadman *et al.*, 2001), and alkaline dykes emplaced c.600 Ma ago showing no specific orientation (Larsen & Rønsbo, 1993). Different levels of exposed deformation in the Kangâmiut dykes mark the boundary between the RAT and the Archean craton (Fig. 1.3). The c.600 Ma alkaline dykes do not show any deformation in either the RAT or the craton. This research concentrates on the xenoliths that have been entrained by the c.600 Ma alkaline dykes, between the Kangerlussuaq and the Safartoq area of S.W. Greenland (Fig. 1.4).



Fig. 1.2 Map of Greenland, showing the North Atlantic Craton between two Proterozoic mobile belts. The red oval indicates this research area. The Nagssugtoqidian is referred to here as the reworked Archean Terrane (RAT). To the North of the Nagssugtoqidian is the lesser known Disko Craton. (modified from Tappe *et al.*, 2004).

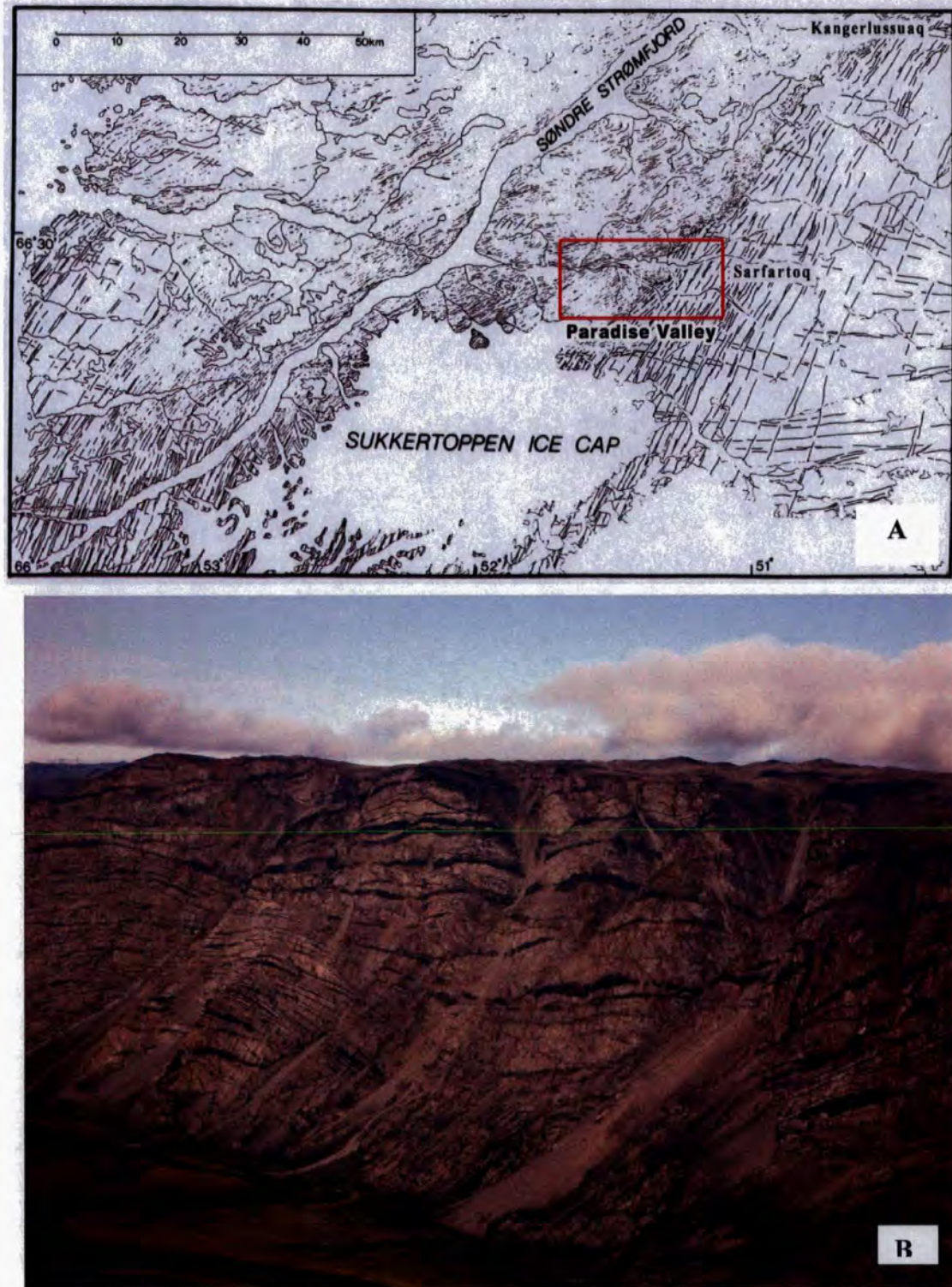


Fig. 1.3. A. The boundary between the Archean and the mobile belt can be seen very clearly by this drawing by Escher *et al.*, 1976. The Kangâmiut dykes are undeformed in the Archean NE of the Sukkertoppen Ice Cap, but NW of here the dykes are clearly disturbed. Red square shows where the photograph (**B**) was taken, looking down Paradise Valley, photo courtesy of Graham Pearson.

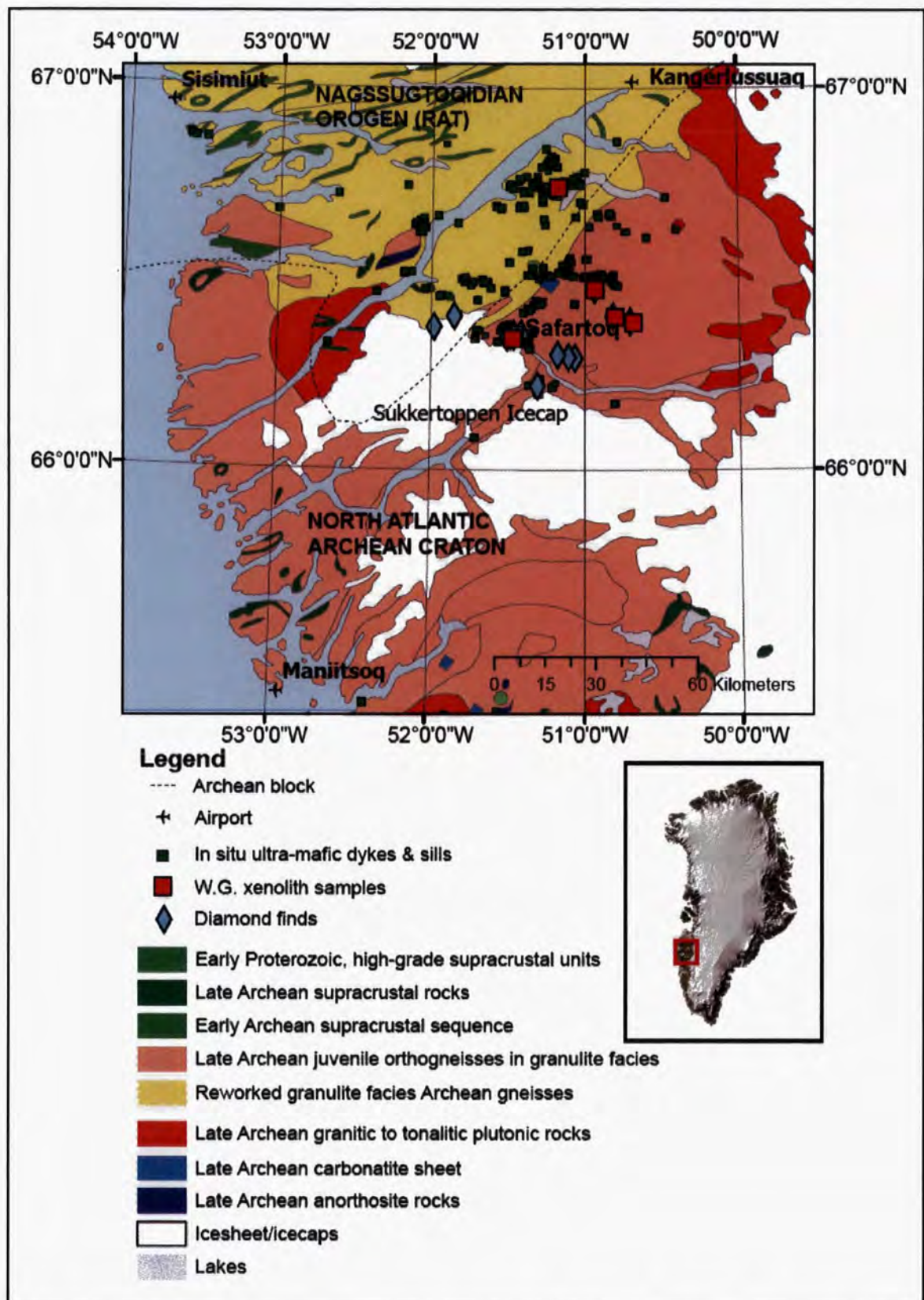


Fig. 1.4. Regional geology map of the research area. The dotted line indicates the aeromagnetic boundary between the RAT (Reworked granulite facies, Archean Gneisses) and the Archean craton. The red squares indicate where mantle derived peridotite xenoliths have been sampled for this study. The small green squares indicate where the alkaline dykes and sills have been reported. Blue diamonds denote reported diamond occurrences.

1.5 The geology at depth

One question that has arisen as a result of the recent diamond exploration activity, is whether the xenoliths in both crustal terranes have travelled through Archean lithospheric mantle or reworked Archean lithospheric mantle or even new Proterozoic lithospheric mantle? Previous work by the Geological Survey of Denmark (GEUS) and Hudson Resources Inc (2005) on this area have discovered micro-diamonds in some of the alkaline host rocks. There are several possibilities for the deep lithospheric structure beneath this area, illustrated in Fig. 1.5. Some possibilities involve diamonds being sampled in both terranes from typical cratonic mantle and other scenarios involve diamonds being sampled from mantle that is significantly younger than Archean, for instance, 2.0 Ga mantle produced during the Nagssugtoqidian orogeny.

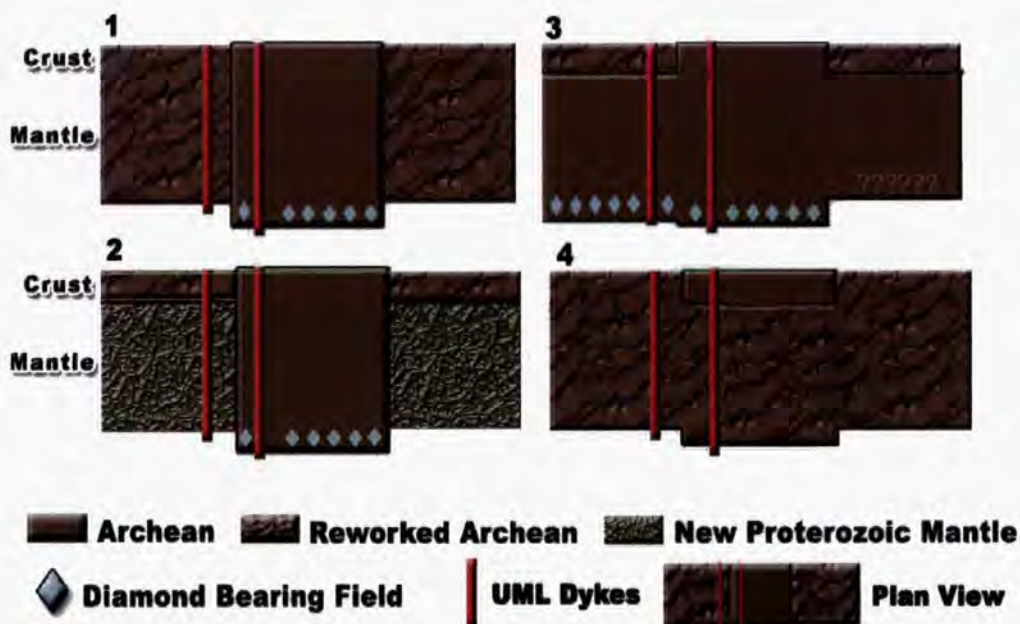


Fig. 1.5. In each of these four diagrams the crust on the surface appears the same, but the lithospheric mantle and diamond potential is different in each case.

1. The Archean and the reworked Archean in the crust continues into the mantle.
2. The reworked Archean mantle has been replaced by new Proterozoic mantle.
3. Only the Archean in the crust has been reworked.
4. Only the Archean in the crust has been preserved, entire mantle has been reworked.

1.5.1 Alkaline dyke classification

Currently there is significant debate concerning the classification of the alkaline dykes. Larsen & Rex (1992) have described these dykes as kimberlitic where as Mitchell *et al* (1999) uses mineralogical criteria to argue that most of the 600 Ma intrusions belong to the ultra-mafic lamprophyre (UML) clan of rocks. Most of the recent GEUS literature (e.g., Jensen *et al.*, 2003; Sand, 2007) use the term kimberlite for the dykes in this region and Neilsen (2006) makes a convincing case, based on detailed mineralogical criteria, for the name kimberlite being used for at least some of these rocks. It is not the purpose of this study to investigate this problem further and the term ultra-mafic lamprophyre (UML) will be used throughout to denote the host rocks. The use of this term does not endorse one classification over the other and resolution of this issue awaits a thorough petrological and mineral chemical investigation of many individual occurrences.

1.6 Tectonic History

This study area is situated on the north-western boundary of a large Archean craton, the North Atlantic Craton (NAC) in southern West Greenland (Fig.1.2). The Nagssugtoqidian to the North of the main craton exposure is a reworked Archean 'mobile belt'. The Kangâmiut Dykes mark the onset of a short term continental break-up event at c.2040 Ma ago. Thermal thinning in the Nagssugtoqidian resulted in the formation of a sedimentary basin at c.1950-1920 Ma, followed by convergence and consumption of the basin floor between c.1920-1870 Ma. This event produced a crustal thickening of the mobile belt and led to the Nagssugtoqidian Orogeny at c.1775 Ma (Cadman *et al.*, 2001). This syn-tectonic and thermal event aided the emplacement of the Kangâmiut dykes. A summary of the tectonic events which led to the Nagssugtoqidian orogeny and subsequent events are summarised in Table 1.

Table 1. A timeline of tectonic events which have effected the Safartoq area of S.W. Greenland.

Million Years ago	Event	Ref
~3870-2820	Amphibolite & Granulite metamorphic facies	McGregor <i>et al.</i> , 1986
~2800	TTG gneisses, Ilivertalik granite intrusion	Myers, 1984
~2750	North Atlantic Craton formation	Windley, 1977
~2040	Emplacement of the Kangamiut Dyke Swarm	Cadman <i>et al.</i> , 2001
~1950-1920	Formation of a sedimentary basin	van Gool <i>et al.</i> , 2002
~1920-1870	Convergence-consumption of the oceanic plate	Connelly <i>et al.</i> , 2000
~1860-1840	Suture & peak metamorphism, crustal thickening	Marker <i>et al.</i> , 1995
~1825	Large scale upright folding trending W-E	van Gool <i>et al.</i> , 2002
~1775	Nagsugtoqidian Orogeny	van Gool <i>et al.</i> , 2002
~600	Emplacement of the UML dykes & sills	Nielsen <i>et al.</i> , 2006
~70	Continental break up, opening of the Labrador Sea	van Gool <i>et al.</i> , 2002
~55	Opening of the North Atlantic	Saunders <i>et al.</i> , 1997

1.7 Field Observations

Fieldwork and rock sampling was carried out by the Geological Survey of Denmark and Greenland (GEUS) and the University of Durham in the summer of 2004. UML and xenolith samples were collected from Kangerlussuup Nunna (off-craton), Kissavissat Qooruate, Atanaligaarsiut and Safartoq (on-craton) (Fig. 1.6). The Kangerlussuaq region is referred to as the off-craton area and the Safartoq region is referred to as the on-craton area.



Fig. 1.6 Map of the study area showing the locations where xenoliths and host rock samples were collected from. The grey dashed line denotes the aeromagnetic craton boundary (van Gool, 2002).

1.7.1 Safartoq area – In the Archean block

The c600 Myr old UML dykes occur in the form of shallowly dipping (around 15° N) dykes and sills (Fig. 1.7). The dykes are emplaced into red/pink banded Archean gneisses the UML dykes are trending E-W and ENE-WSW. A large carbonatite complex is situated on the boundary between the RAT and the Archean craton, north of Safartoq, and named the Safartoq carbonatite complex. The UML dykes have earlier been interpreted as cone-sheets related to the carbonatite complex (Secher & Jensen, 2004).



Fig. 1.7 UML sill at Camp 2, on-craton in the Safartoq area

1.7.2 Kangerlussuaq area – In the Reworked Archean Terrane (RAT)

The RAT comprises of reworked Archean amphibolite facies gneisses (van Gool *et al.*, 2002). The c600 Ma UML dykes intruded into the RAT are undeformed, indicating that regional tectonic activity in this area had ceased by the time they were emplaced. Most UML dyke outcrops are weathered out, indicating a linear depression in the landscape (Fig. 1.8). The UML dykes are around ~1 to 1.5 m thick, and commonly occur as shallowly dipping sills, however, there are some vertical dykes present. With the action of freeze-thaw most sills/dykes are represented by large ultra-mafic boulder trails. These boulders can be traced E to W over a distance of 500 m.



Fig. 1.8 François Dyke, off-craton in the Kangerlussuaq area. Notice the weathered out feature.

1.8 Previous Diamond Investigations

Previous investigations by GEUS into the diamond potential of the Safartoq area in 1998, returned 474 micro-diamonds and 5 macro-diamonds for the UML dykes (Jensen *et al.*, 2004). The diamonds do not have recognisable crystal faces and are graphite coated (Boucher, 2000).

CHAPTER 2

WESTERN GREENLAND XENOLITH SAMPLES

Chapter 2:

W.G. Samples

2.1 Collection of Samples

Xenoliths and their ultra-mafic host rocks were collected from a traverse covering 300 km on and off the North Atlantic Craton in S.W. Greenland. The study area is indicated by the blue oval on Figure 2.1.

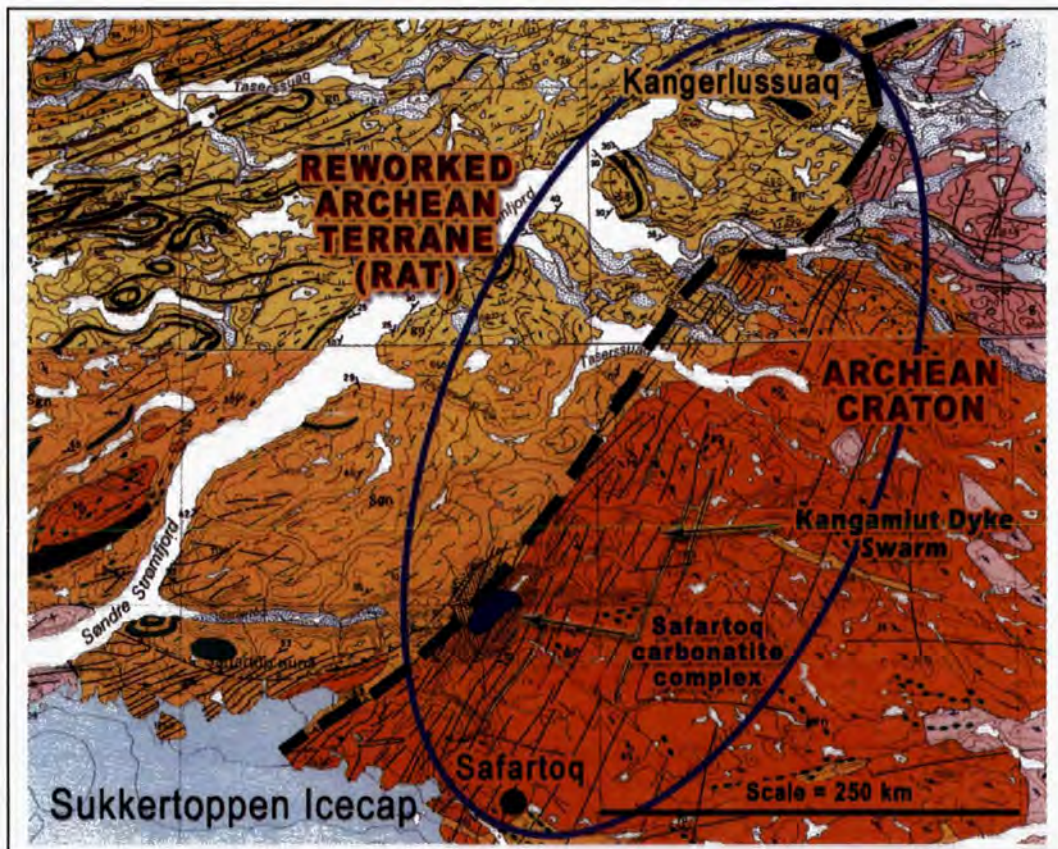


Fig. 2.1 Map of the study area in S.W. Greenland. Host rocks and xenoliths were collected on and off the craton between Kangerlussuaq and Safarteq. Black dashed line denotes the boundary between the Archean and the RAT (aeromagnetic boundary distinction, van Gool, 2002). Map adapted from section 2a & 3h from the GEUS online map database.

2.2 W.G. Peridotite Xenoliths

2.2.1 Size & distribution

The size of the peridotite xenoliths ranges from approximately 6 to 50cm. The samples which were used for analyses were all larger than 10 x 10cm. Each sample weighed over

500g. The distribution of the peridotite xenoliths were in some places very concentrated in the UML dykes, almost to the point where there were more xenoliths than matrix (Fig. 2.2 A & B). In other cases some peridotite xenoliths were very large and were found alone in the UML dyke (Fig. 2.2 F).

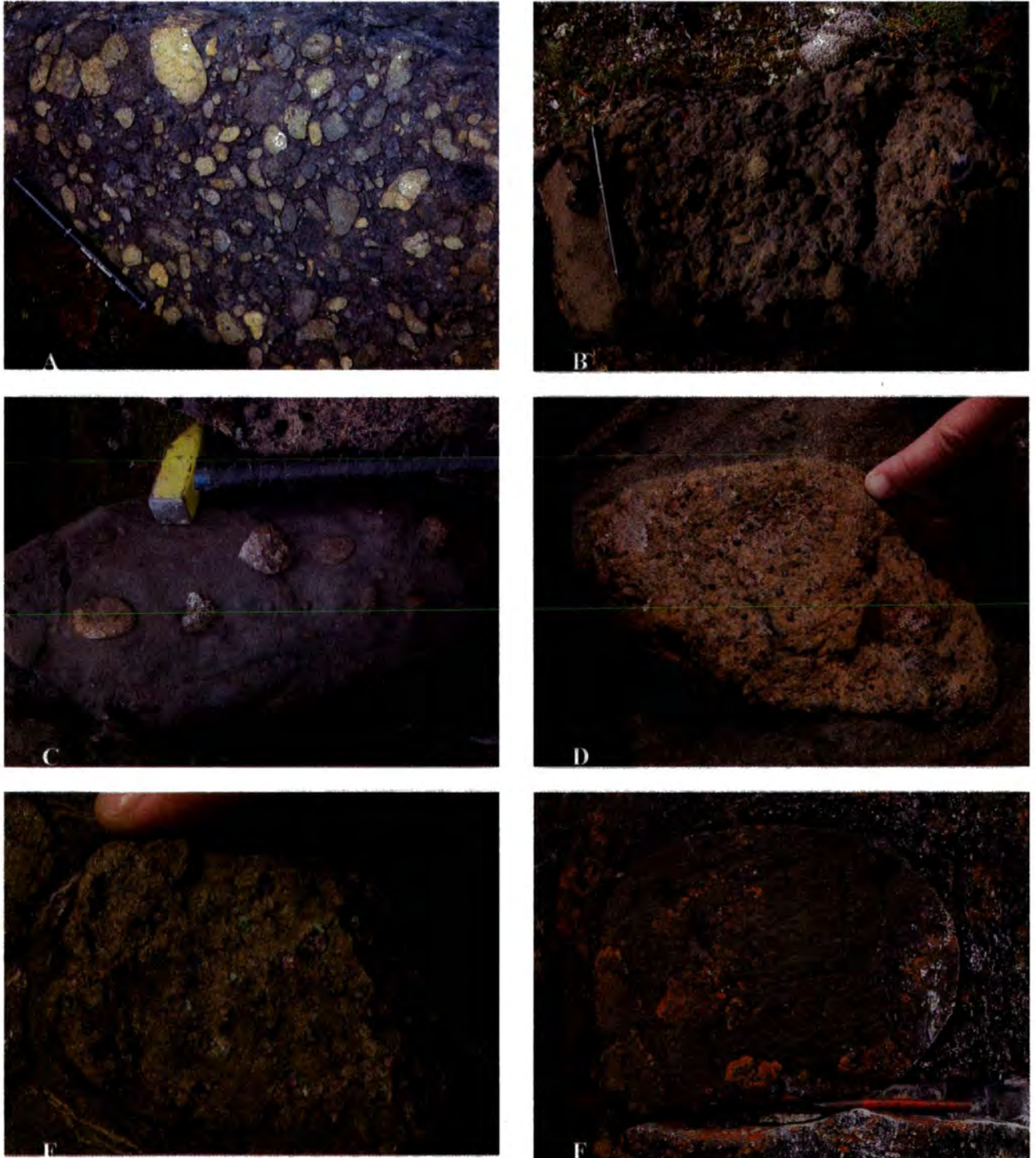


Figure 2.2 A. A high concentration of xenoliths in an UML boulder, on-craton. Pen is 14cm long. B. An UML boulder with a high concentration of small xenoliths, on-craton. C. A large UML boulder ~1m wide, with 7 large peridotite xenoliths standing proud of the surface of the boulder. D. A 14 x 9cm peridotite xenolith, standing proud of a UML boulder, small garnets are seen standing proud of the xenolith, off-craton. E. Garnets and clinopyroxenes are clearly seen in this 10 x 7 cm harzburgite xenolith, on-craton. F. A football sized peridotite xenolith in an UML dyke.

The UML dykes and sills are more susceptible to weathering and as a result, the xenoliths are quite often standing proud of the surface. The xenoliths are weathered on the outside with an orange rust colour on the surface. This is from the high concentration of olivines in the samples. In samples which are split exposing the fresh sample inside, the colour is usually dark grey to black. Some of the samples are fine grained and identifying minerals to the naked eye is not possible. Other samples like 474538 seen here in Figure 2.3, the crystals are much larger and this xenolith clearly contains ~5mm sized garnets. This sample is found in the Archean craton.



Fig. 2.3 Sample 474538 (on-craton) of the W.G. peridotite suite. This sample shows clearly the orange weathered surface and the grey-black fresh interior. Millimetre sized garnets are visible on the weathered and the freshly cut surface.

2.2.2 Off vs. On-craton xenoliths

Sample 474538 (Fig.2.3) was found on-craton. Figure 2.4 shows sample 474527 a xenolith found in the reworked Archean terrane. Both xenoliths have similar characteristics. Both have a fine grained grey-black matrix and ~1-5mm sized garnets. The garnets in the on-craton xenolith are less altered than the off-craton xenolith. Clinopyroxene is more common in the off-craton xenoliths.

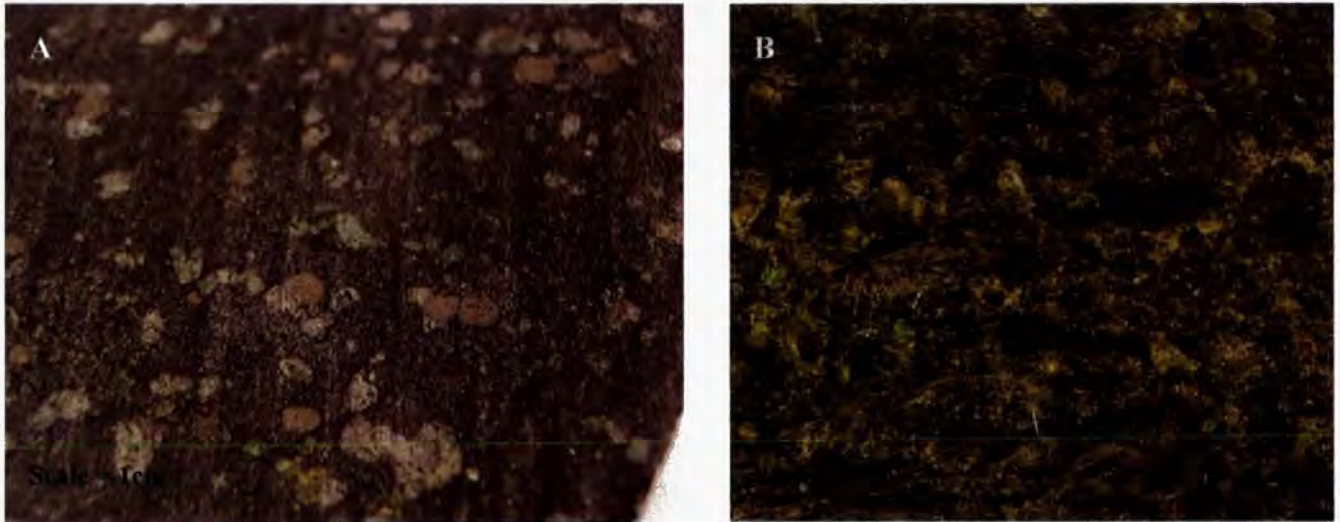


Fig 2.4 Shows sample 474527 (off-craton) **A.** shows the cut sample of the xenolith, where the minerals clinopyroxene and garnet are easy to see. **B.** Shows the weathered rusty olivines on the surface of this xenolith.



2.3 The UML host rock

The ultra-mafic lamprophyre rocks are fine grained, most are aphanitic and the mineralogy is too small to identify without a thin section. Where minerals are large enough to identify, the most common is olivine, followed by garnets and some ilmenites. Many of the samples of the host rock contain veins of carbonate infiltrating the rock. Some macrocrysts of olivine in the lamprophyre are highly serpentinized around the edges.

Fig. 2.5 A lamprophyre boulder containing xenoliths from W.G. (GEUS, 2004).

CHAPTER 3
ANALYTICAL METHODS

Chapter 3:

Geochemistry and Analytical Methods

3.1 Preparation of Xenoliths

All the weathered edges and serpentinisation on the xenoliths were removed with a diamond lap saw, exposing the block of peridotite in the centre. In order to remove any contamination from the saw blade, all the edges of the blocks were rubbed with corundum paper. The blocks were then placed in an ultrasonic bath, where small particles of dust would be dislodged and removed. The clean blocks were then split into smaller sized pieces using a splitter, and further crushed in a jaw crusher to 1-3mm sized grains. The grains were then transferred to an agate ball mill to produce a rock powder fine enough for digestion. A minimum of 500g of powder was stored for each sample.

3.2 Rock powder weighing and digestion

1 gram of the powdered sample was weighed in a clean environment and carefully transferred to a Carius tube or quartz Asher reaction vessel for digestion (described in more detail below). The advantage of this method of digestion means that all the PGEs (Os, Ir, Ru, Pt, Pd) plus Re can be retrieved from the same dissolution. Each sample was spiked with 5 μL of 'peridotite' spike solution enriched in ^{194}Pt , ^{191}Ir , ^{190}Os , ^{185}Re , ^{106}Pd & ^{99}Ru and used to recalculate concentrations during data analysis. The amount of spike is also weighed. This spike weight can then be factored into the calculation process of the data. The accepted dissolution for Re-Os isotope determination is a high temperature "inverse" aqua regia digestion (Shirey and Walker, 1995; Pearson & Woodland, 2000; Meisel *et al.*, 2001). Although this does not dissolve the rock powder completely Shirey and Walker (1995) and Pearson and Woodland (2000) have recorded good results from this method. The aqua regia consists of 2.5 mLs of chilled ultra-pure concentrated (conc.) hydrochloric acid (HCl) and 5 mLs of chilled and sparged (heated to 80°C and then air is bubbled through to remove any volatile Os), ultra-pure conc. nitric acid (HNO₃). The aqua regia was added to each Carius tube or reaction vessel, containing the sample powder and the weighed quantity of 'peridotite' spike.

3.2.1 Carius Tube digestion

The Carius tube method has proved to be a very effective means of digestion of Re-Os isotope determination (Shirey & Walker, 1995; Pearson & Woodland, 2000). However, there are some safety issues in using this technique. The aqua regia must be chilled to slow down the reaction of the acids and minimise the pressure build up in the tube before sealing. The Carius tubes are made from Pyrex/borosilicate glass, they have a long thin open neck to allow for the sample to be introduced via Teflon funnels and long enough for the tube to be sealed, and then reopened. The tubes containing the aqua regia are stood in a freezing mixture of dry ice and ethanol, to maintain the retarded reaction, and to reduce the possible loss of volatile Os and Ru tetroxides. The tubes must be sealed as soon as possible. The neck of the tubes are sealed using an oxygen and propane torch. Whilst the other tubes are being sealed, the sealed tubes are placed back into the dry ice mixture. It is important to subdue the reaction as much as possible in the tube, to minimise the risk of the tube exploding. When all the tubes are sealed they are left in a rack behind a safety shield to warm up to room temperature. Leaving the tubes to acclimatise allows for the detection of weaknesses in any of the tubes. Also allowing the tubes to acclimatise lessens the risk of the tubes exploding when temperatures begin to rise in the oven. The Carius tubes are then placed in stainless steel jackets to contain any potential Carius tube explosion, and transferred to a cold oven. The oven is slowly increased to 240°C, for 24 hours. The oven is completely cooled before removing the tubes. Again the tubes were stood in dry ice and ethanol to reduce the internal pressure before opening. After opening the tubes would be transferred to the fume cupboard for the following osmium extraction procedure (Section 3.3.1).

The Carius tube digestion method is very effective for Re-Os isotope determination, but there is an issue with Pt blanks, due to the 'high' Pt contents in the borosilicate glass that is used to make the Carius Tube (Fig. 3.1).



Fig. 3.1 Borosilicate Carius tubes.

3.2.2 Asher digestion

The high pressure Asher (Fig. 3.2) ((HPA-S) Anton Paar-Perkin-Elmer), digestion technique is described by Meisel *et al* (2001). This technique uses 90 mL quartz glass vessels with quartz glass lids (Fig 3.3). The advantage of using this digestion method is that the vessels can be cleaned and reused. However, because the technique is still in its infancy, it is uncertain if there are any problems with memory blanks. To avoid this



Fig. 3.2 The Anton Paar-Perkin-Elmer high pressure asher (HPA-S).

Fig. 3.3 7 x 90 mL quartz vessels with glass lids.

problem there are 3 sets of 7 vessels used for peridotite, basalt, and lunar sample digestions respectively. The cleaning procedure requires that the vessels are leached with aqua regia under high pressure and temperature in the HPA as well, as being cleaned manually. Another advantage of the HPA digestion is that the samples are subjected to both high pressures (130 bar) and high temperatures (300°C) for 5 hours. This method is more effective in dissolving the silicates and refractory phases such as high temperature sulphides and alloys, which are likely to occur in mantle peridotites (Luguet *et al.*, 2003 & 2007; Lorand *et al.*, 1999 & 2007). However, there is still some residue in the bottom of the vessels after digestion. The Pt blanks are low and appear to be much favorable than the Carius tube Pt blanks.

The volume concentration of reverse aqua regia to put into the Asher vessels with the sample and the spike is the same for the Carius tube method. The HCl and the HNO₃ are still chilled, but the HCl is put in the vessels just before they are sealed with Teflon tape. The sealed vessels are placed in the HPA overnight. The vessels are then removed the following morning from the Asher and taken to the fume cupboard for opening immediately and the osmium extraction procedure (**Section 3.3.1**).

3.3 Os Chemistry

3.3.1 Os Extraction

Each tube/vessel containing the aqua regia and digested sample was opened in a prepared fume cupboard. 7.5 mL of MilliQ H₂O (reverse osmosis purification of 18.2 MΩ cm of water in a MilliQ system), was gently added to each tube. Using a transfer pipette the MQ H₂O and reverse aqua regia supernatant was gently agitated and transferred to a clean 50 mL centrifuge tube. 1 mL of chilled carbon tetrachloride (CCl₄) was then added to the carius tube/asher vessel and shaken gently (great care must be taken when using the CCl₄, as this is toxic and carcinogenic, nitrile gloves, goggles and lab coat must be worn). The CCl₄ was then pipetted off the sample and added to the 50ml centrifuge tube which contained the aqua regia and MQ H₂O solution. Then an additional 2 mL of CCl₄ was added to the centrifuge tube and transferred to a shaker plate for 5 minutes (Fig. 3.4).



Fig. 3.4 Shows the 50 mL centrifuge tubes containing the aqua regia, MQ H₂O and the CCl₄, on the shaker.

After 5 minutes of shaking the centrifuge tube was removed from the shaker plate and the CCl₄ was pipetted off into a clean 20 mL Savillex Teflon beaker, containing 4 mL of chilled conc. ultra-pure hydrobromic acid (HBr). Then a further 2 mL of CCl₄ was added to the aqua regia and MQ H₂O solution and placed back on the shaker plate for 5 minutes. After 5 minutes the centrifuge tube was removed from the shaker plate and the CCl₄ was transferred to the 20 mL Teflon beakers containing the 4 mL HBr together with the previous 3 mL of CCl₄. This step was repeated once more, until there was 7 mL of CCl₄ and 4 mL of HBr in the 20 mL Teflon beakers.

3.3.2 The Os cut

The 20 mL Teflon beakers containing the hydrobromic acid and the carbon tetrachloride were then left to agitate on the shaker plate overnight.

3.3.3 Os Back Extraction

After the Os cut samples (CCl_4 & HBr) have been on the shaker plate overnight, the beakers were removed and the solution was allowed to settle. After a few minutes the HBr and the CCl_4 would separate and the HBr would be sitting on top of the CCl_4 . The HBr was then pipetted off the CCl_4 into clean 20 mL Teflon beakers, taking care not to incorporate any of the CCl_4 . The CCl_4 can be discarded and the HBr samples were then placed on the hotplate to dry down, ready for the micro-distillation procedure (Section 3.3.4).

3.3.4 Os Micro-distillation

40 μL of 12N sulphuric acid (H_2SO_4) was added to the dried HBr sample (the Os cut), in order to re-hydrate the sample and prepare it for chromic acid addition. Teflon tape was applied around the thread of a clean 7 mL Teflon "rocket" vial, to ensure a tight seal for the micro-distillation process. 20 μL of conc. HBr was pipetted into the apex of the rocket vial. The shape of the rocket vial allows the droplet to be retained here even when the vial is turned upside down. The lid of the rocket vial was placed facing upwards and 20 μL of the H_2SO_4 sample solution was pipetted into the centre of the lid. Then 20 μL of chromic acid (CrO_3) was carefully incorporated into the 12N H_2SO_4 droplet on the lid (Fig. 3.5). The chromic acid oxidises the Os to OsO_4 .



Fig 3.5 Shows the chromium oxide (Cr_2O_3) being added to the 12N sulphuric acid (H_2SO_4) droplet in the rocket vial lid. **Fig. 3.6** Shows the rocket vial upside down and sealed with the hydrobromic acid (HBr) droplet in the bottom of the cone, and the chromium oxide and sulphuric acid in the lid.

The rocket vial now containing the HBr was turned upside down and screwed carefully back on the lid (Fig. 3.6). Keeping the rocket vial upside down and very steady, aluminium foil was wrapped around the rocket vial with only the point of the conical base protruding out of the top. This encourages the volatile OsO_4 vapour to condense

where there is no foil, i.e. in and around the HBr droplet in the apex of the cone. The rocket vial is then placed upside down on the hotplate at 90°C for 2 hours (Fig. 3.7).



Fig. 3.7 Rocket vials on the hotplate, with aluminium foil wrapped around the base and the sides. The foil directs the heat up towards the cooler exposed tips of the cone.

After 2 hours the rocket vials were removed from the hotplate and the foil was carefully removed. Still with the vials upside down, the lid were removed and the vial was moved away from the lid. The vial base was then carefully turned the right way up, and placed back on the hotplate to dry down. The lids were then cleaned with MQ H₂O to be placed back on the vials when the sample was dry.

3.4 PGE Column Chemistry

3.4.1 The PGE cut

The remaining aqua regia and MQ H₂O solution (which now contains the highly siderophile elements minus the Os) in the 50 mL centrifuge tubes was transferred into clean 30 mL Teflon beakers and dried down on a hotplate. After the aqua regia had dried to a residue, 1 mL of SPA conc. HCl was added to the beaker, the cap was replaced, and the beaker was returned to the hotplate for 1 hour. After 1 hour the cap was removed and the sample was allowed to dry down to a residue again. After the sample had dried again, 10 mL of 0.5N HCl was added to the beaker, the cap was replaced, and the beaker was returned to the hotplate for one hour. The beakers were then taken off the hotplate and allowed to cool. At this point the samples were ready for their PGE column chemistry (**Section 3.4.2**).

3.4.2 PGE column Chemistry

The aqua regia and MQ H₂O from the extraction procedure were in the 30 mL Teflon beakers which had been dried down, and then re-hydrated with 10 mL of 0.5N UPA HCl and left to cool. They were now ready for the PGE column chemistry. 1cm³ of clean Bio-Rad AGI-X8 100-200# resin was pipetted into each column. The columns were then preconditioned with 6 mL of 6N SPA HCl, then 10 mL of MilliQ H₂O and then 5 mL of 0.5N UPA HCl (Fig 3.8). The 10 mL of sample in the beakers was then pipetted onto



Fig. 3.8 Photo taken in the clean lab, of the PGE column chemistry. The orange colour in the columns is the resin. Acid is dripping through the columns into the waste beakers below.

each column. Then 10 mL of 1N HCl/1N HF (hydrofluoric acid) was added to each column, this removes the hafnium, zirconium and yttrium (Hf, Zr, and Y oxides can interfere with several Pt, Ir and Pd isotopes) from the columns into waste beakers below. The leaching of the Hf, Zr and Y were initiated by Luguet & Pearson (unpublished) to reduce oxide interferences during analyses. Then 10 mL of 0.8N HNO₃ was added to each column, to convert it to nitrate. Then 12 mL of 13.5N HNO₃ was added to the columns and the Ir, Ru, Pt, & Re cut was collected in clean 20 mL Teflon beakers. The resin in the columns was then rinsed by adding 5 mL of MQ H₂O. 40 mL of 1N HCl/1N HF was then added to the columns in 10 mL batches and then 5 mL of MQ H₂O was added to the columns, to remove any remaining Zr and Y. 20 mL of 9N HCL was added to each column and the Pd cut was collected in separate clean 20 mL Teflon beakers. Both sets of beakers were placed on a hotplate at 90°C to dry down. Once the samples were dry, they each needed re-hydrating with 1 mL of 0.5N HCl and transferred to clean 2 mL centrifuge tubes, for analysis on the Thermo Finigan Element 2 HR-ICP-MS.

3.5 Triton Analysis of Os

3.5.1 Preparation of samples for Triton analysis

Platinum ribbon (0.02 x 0.001 inch, obtained from Electronic Space Products Inc.) was welded onto clean filament posts ready for osmium loading (Fig. 3.9 & Fig. 3.10). The



Fig. 3.9 Shows the Pt ribbon being welded onto the filament

Fig. 3.10 Shows the filaments with their welded Pt ribbons, ready for the Os loading procedure.

dried down osmium sample in the rocket vial was loaded onto the filament. The dried sample was re-hydrated with 0.5 μL of 9N HBr, this droplet was pipetted onto the centre of the platinum ribbon and dried with a heating lamp. 0.5 μL of mixed barium oxide $\text{Ba}(\text{OH})_2/\text{NaOH}$ activator was dried on top of the sample on the platinum ribbon. The filaments were then loaded onto a magazine which was inserted into the negative ion source of the Triton mass spectrometer (Fig. 3.11).

3.5.2 Triton Mass spectrometry

The mass spectrometer is used to measure the isotope ratio of the sample. The barium activator, in combination with a slow oxygen bleed into the source, produces a OsO_3^- ion beam. The ions are sent into a magnetized acceleration chamber where lighter ions are deflected more than the heavier ions onto a secondary electron multicollector.



Fig. 3.11 Thermo Finnigan. Triton Mass Spectrometer (N-TIMS). The image shows the -ve ion source, used for Os analyses only.

3.5.3 Triton analysis of osmium isotopes

The Os isotopes were analysed on the Triton operating in negative ion mode. All Os signals are measured by peak-hopping on the SEM. The raw Os data results are corrected for spike and blank concentrations. The rest of the PGE's and Re were analysed on the Element 2.

3.6 Element 2 analysis of PGE's and Re.

The sample is nebulized and delivered through a glass tube by an argon carrier gas. The sample is then exposed to radio frequency which converts the gas into a plasma. PGEs (Ir, Pt, Ru, Pd) and Re were analysed on a Thermo Finnigan Element 2 ICP-MS, following Dale *et al.*, (2007 in review).

3.7 Whole rock analysis

Major elements were obtained by X-ray fluorescence spectrometry (XRF); analyses were carried out by the Geological Survey of Denmark (GEUS).

CHAPTER 4

**DESCRIPTION OF
MAJOR ELEMENT GEOCHEMICAL
DATA**

Chapter 4:

Description of Major Element Geochemical Data

4.1 Introduction

Lithophile elements are Na, K, Si, Al, Ti, Mg and Ca, they are rock forming minerals of the crust and mantle. Siderophile elements are Fe, Co, Ni, Pt, Re and Os and have an affinity for iron and concentrate in the core. These elements can be further divided into their preference to be in the melt, and described as fusible elements or incompatible elements. Or they prefer to be in the residue left after melting and are described as refractory elements or compatible elements. Fusible elements which prefer to be in the melt are Na, K, Al, Ca, Si, and Ti, they often have low amounts in the mantle. Refractory elements such as Mg, Fe and Cr often have high amounts in the mantle, forming solid residues. Fluids are driven off oceanic slabs as they subduct into the mantle, and result in some elements being more mobile in fluids. Fluids that flux through the mantle can alter the composition of the residue. Na, K, Ca, and Fe, can often be transported in these fluids, their interaction with the solid residues in the mantle, is referred to as mantle metasomatism. The effect of mantle metasomatism can disturb their compositional signatures, especially when plotting their major element compositions.

4.2 Whole rock compositions

32 peridotite xenolith samples taken from the c600 Ma alkaline dykes in the Kangalussuaq and Safartog area of South West Greenland have been analysed for major element compositions. The incompatible elements CaO, Al₂O₃ and TiO₂ should show negative correlations with MgO. Figure 4.1 shows the incompatible elements plotted against MgO for Western Greenland (W.G.) peridotites, non-cratonic peridotites, Kaapvaal peridotites, East Greenland peridotites and a primitive mantle sample for comparison. Western Greenland on-craton samples are denoted by the red squares, the off craton samples are denoted by the black diamond in the centre of the red squares. There are also 3 samples which have their sample names indicated.

These have been highlighted specifically to track their behaviour and are discussed later in Chapter 6.

4.2.1 MgO vs. TiO₂, Al₂O₃ & CaO

W.G. peridotite xenolith samples have high contents of MgO between 41-51 wt.% as shown in Fig. 4.1, and showing similar contents to East Greenland (E.G.) which have 42-51 wt.% MgO. Cratonic Kaapvaal peridotite xenoliths have slightly lower MgO contents between 40-49 wt.%. The non-cratonic peridotite xenolith suite have a wide range in MgO contents between 32-48 wt.%. The off-craton peridotite xenoliths for W.G. (red squares with black diamonds) do not appear to be showing any similar characteristics in TiO₂/MgO or CaO/MgO, but they do appear to be slightly grouped in the Al₂O₃/MgO plot. Overall TiO₂, Al₂O₃, and CaO for W.G. samples do show negative correlations with MgO. However, sample 474566 has a very high content of TiO₂ (1.7 wt.%) and CaO (5.9 wt.%), and shows a very positive correlation to MgO. This sample also has the lowest concentration of MgO at 41.6 wt.%. Sample 488858 is also very high in TiO₂ (0.4 wt.%) with a given MgO, but has a very low ratio of CaO/MgO (0.3/44.8 wt.%). Generally the TiO₂ contents of the W.G. xenoliths (0.03-1.7 wt.%) is higher than those for other cratonic xenoliths, i.e. Kaapvaal and E.G. The Al₂O₃ contents of the W.G. xenoliths range from 0.06-1.8 wt.% and plot in a similar field to the other cratonic peridotite suites, but they do extend to a more depleted composition.

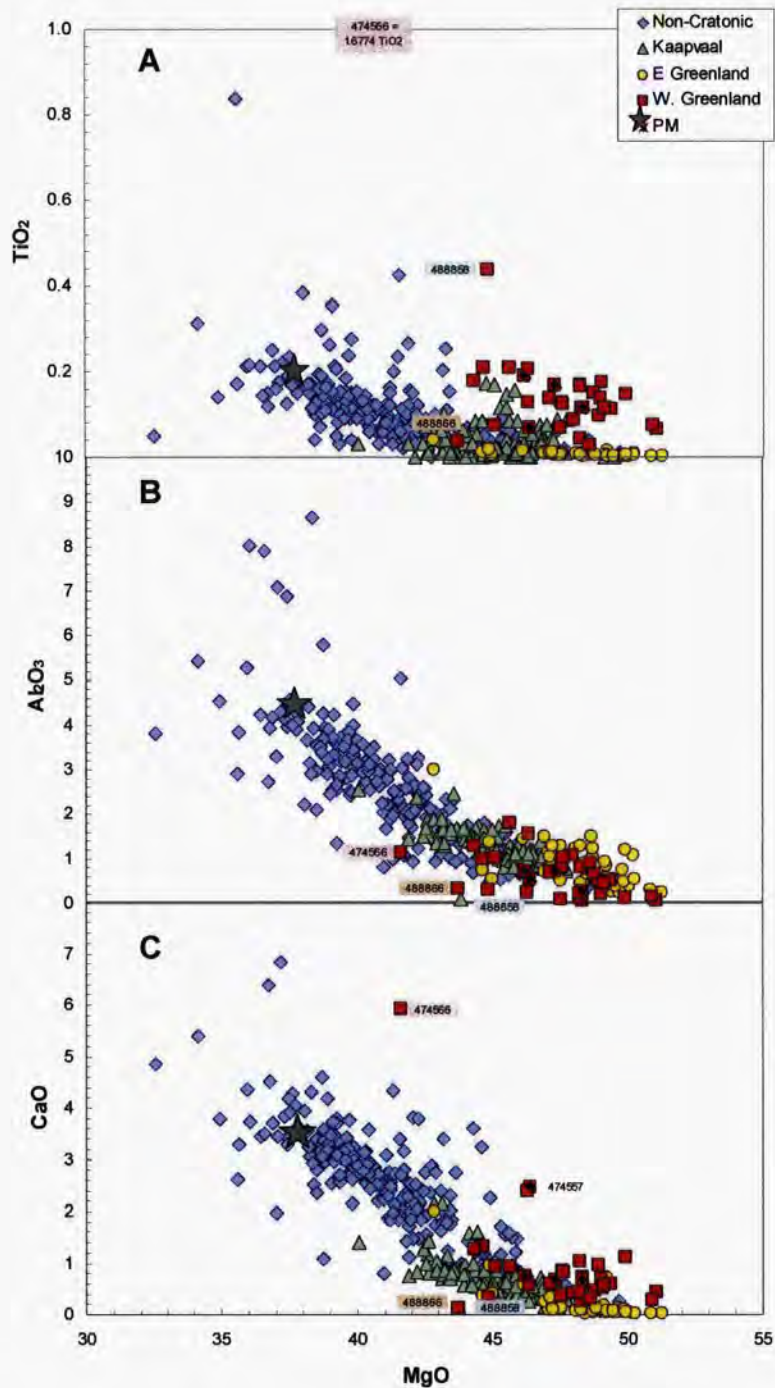


Figure 4.1. Whole rock MgO relations, **A.** MgO vs TiO₂. **B.** MgO vs Al₂O₃. **C** MgO vs CaO. **Red squares** =western Greenland on-craton peridotite xenolith suite (this study), **red squares with black diamonds** =western Greenland off-craton (this study). **Blue diamonds** = non-cratonic peridotite xenolith suite (Hungary (Embey-Isztin *et al.*, 1989), Romania (Vaselli *et al.*, 1995), Italy (Morton, 1987 & Dupuy *et al.*, 1987), British Isles (Hunter & Upton, 1987), Australia (Frey & Green, 1974; McDonough, unpublished; Yaxley *et al.*, 1991; Stoltz & Davies, 1988; Griffin *et al.*, 1987), Mexico (Luhr & Aranada-Gomez, 1997), Mongolia (Press *et al.*, 1986), China (Qi *et al.*, 1995; Song & Frey, 1999), Africa (Bedini *et al.*, 1997; Dautria & Girod, 1987; , Dupuy *et al.*, 1986)). **Green triangles** = cratonic peridotite xenolith suite, Kaapvaal, South Africa (Pearson *et al.*, 1995; Boyd *et al.*, 1993; Boyd *et al.*, 1999; Boyd & Mertzman, 1987). **Yellow circles** = cratonic peridotite xenolith suite, E. Greenland (Bernstein *et al.*, 1998). **Grey star** = Primitive mantle (McDonough & Sun, 1995). All oxides normalised to 100% water-free. Actual data is given for all in Appendix A, B, C, D, E & F.

4.3.2 SiO₂ vs. TiO₂, CaO and MgO

SiO₂ contents of the W.G. peridotite xenolith suite range from between 36-45 wt.%,

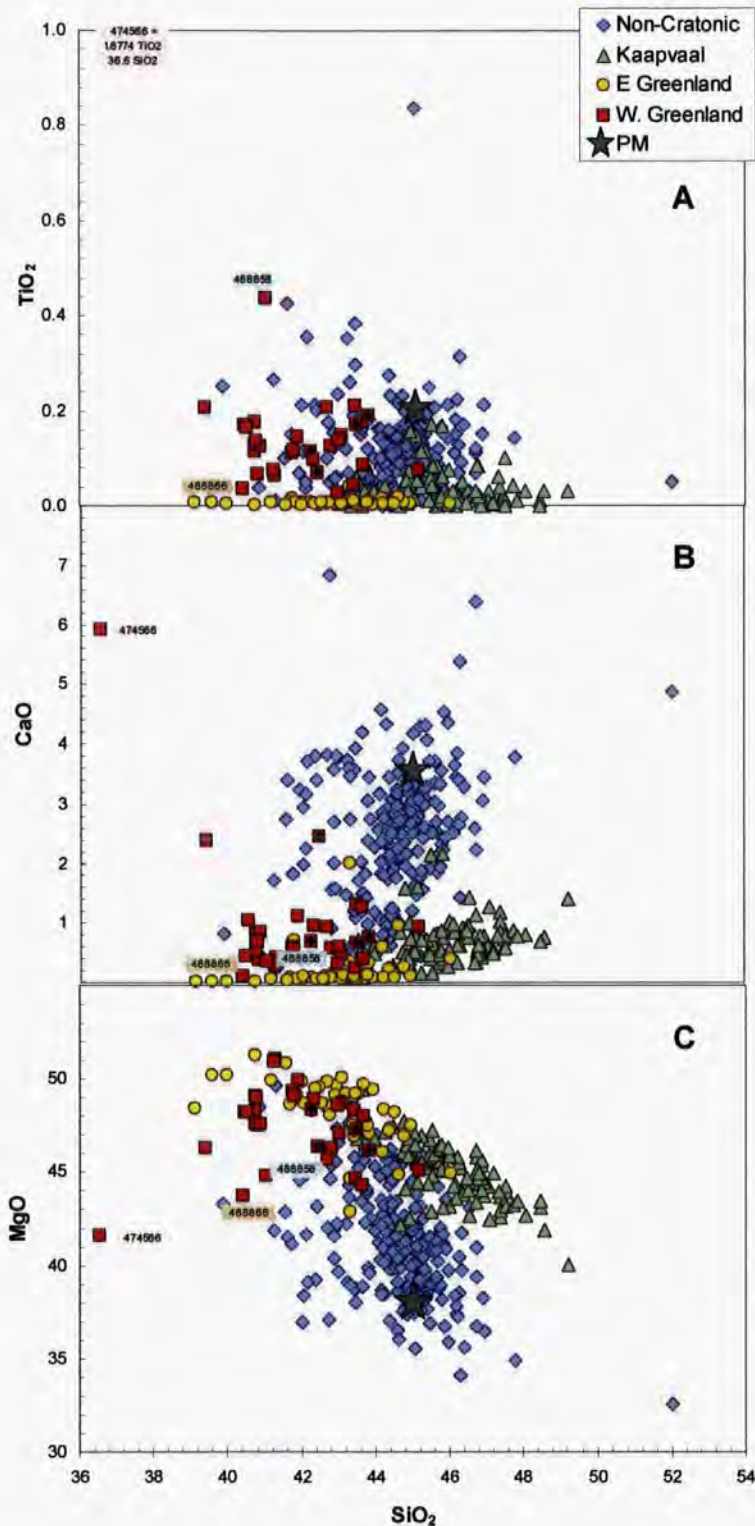


Fig. 4.2 Whole rock SiO₂ relations, A. TiO₂ vs SiO₂, B. CaO vs SiO₂, C. MgO vs SiO₂. For sources see Fig. 1.

with an average of 42 wt.% (Fig. 4.2). Figure 4.2 shows W.G. samples compared to other peridotite suites and the primitive mantle (sources are given in Figure 4.1 and Table 4.2) The E.G. suite show a similar range of SiO₂ between 39-46 wt.%, with an average of 43 wt.%. The non-cratonic data points show a wide range in SiO₂ from 39-52 wt.%, with an average of 45 wt.%. The Kaapvaal peridotite xenolith suite show a much higher average of SiO₂ at 46 wt.%, and range from 43-49 wt.%. An interesting point to make here is based on the average of SiO₂ in all the peridotite suites, and that the cratonic Kaapvaal suite has the highest average as seen in Table 4.1. Not expected for depleted cratonic peridotites.

There is no correlation observed with the off-craton samples for W.G.

Table. 4.1 SiO₂ contents of all the peridotite xenolith suites

Location	Range	Average
Kaapvaal	43-49 wt.%	46 wt.%
Non-cratonic	39-52 wt.%	45 wt.%
E.G.	39-46 wt.%	43 wt.%
W.G.	37-45 wt.%	42 wt.%

The W.G. peridotite sample 474566 has the lowest SiO₂ at 36 wt.%. Samples 488858 and 488866 have similar SiO₂ contents to the majority of the W.G. samples, and do not display any unusual anomalies.

Table 4.2 Data sources for major element compositions of peridotite xenolith suites.

Location	Authors	Year
<i>Non-cratonic</i>		
<u>Europe</u>		
Hungary, TVR	Embey-Isztin <i>et al</i>	1989
Romania, Perjani Mtns	Vaselli <i>et al</i>	1995
Italy	Morton	1987
Sardinia	Dupuy <i>et al</i>	1987
British Isles	Hunter & Upton	1987
<u>Rest of the world</u>		
USA	Menzies & Hawkesworth	1987
Various	Jagoutz <i>et al</i>	1979
S.E. Australia	Frey & Green	1974
S.E. Australia	McDonough	unpublished
S.E. Australia, Victoria	Yaxley <i>et al</i>	1991
E. Australia	Stolz & Davies	1988
Australia, Queensland	Griffin <i>et al</i>	1987
Mexico	Luhr & Aranada-Gomez	1997
Mongolia	Press <i>et al</i>	1986
S.E. China	Qi <i>et al</i>	1995
China, Hannuoba	Song & Frey	1989
East African Rift, Ethiopia	Bedini <i>et al</i>	1997
N. Africa	Dautria & Girod	1987
Algeria, Hoggar	Dupuy <i>et al</i>	1986
<i>Cratonic</i>		
S. Africa, Kaapvaal	Pearson <i>et al</i>	1995
S. Africa, Kaapvaal	Boyd <i>et al</i>	1993
S. Africa, Kaapvaal	Boyd <i>et al</i>	1999
S. Africa, Kaapvaal	Boyd & Mertzman	1987
Tanzania, Labait	Lee & Rudnick	1999
N. Tanzania, Olmani	Rudnick <i>et al</i>	1993
Tanzania,	Rudnick <i>et al</i>	1994
Siberia	Boyd <i>et al</i>	1997
Canada, Slave, Jericho K	Kopylova & Russell	2000
Canada, Somerset Island	Irvine <i>et al</i>	2003
Canada, Somerset Island	Schmidberger & Francis	1999
W. Australia	Jaques <i>et al</i>	1990
E. Greenland	Bernstein <i>et al</i>	1998
Beni Bousera, Morocco	Pearson <i>et al</i>	2004
Vitim,	Pearson <i>et al</i>	2004
Lesotho,	Pearson <i>et al</i>	2004
Namibia,	Pearson <i>et al</i>	2004

4.3.3 Al₂O₃ vs. CaO & SiO₂

Al₂O₃ is particularly useful in major element and PGE systematics as it is not effected by serpentinization or metasomatism. Therefore the Al₂O₃ content of the residual rock should be undisturbed, while other more mobile elements like Ca and Si may have been altered from their original composition. Figure 4.3 shows Al₂O₃ contents against the CaO and SiO₂ contents of various peridotite suites. The CaO for the W.G. xenoliths ranges from 0.2-5.9 wt.% with an average of 0.9 wt.%. The W.G peridotites have higher contents of CaO than E. Greenland. The E. Greenland peridotite suite ranges from 0.05-2.0 wt.% with an average of 0.2 wt.%. W.G. sample 474566 has a very elevated content of CaO, as seen in other plots. Samples 488890 and 474557 show elevated contents of CaO. Exploring the K, Ti, and P, will help to investigate the possibility of these samples being contaminated by the host magma (Fig 4.4).

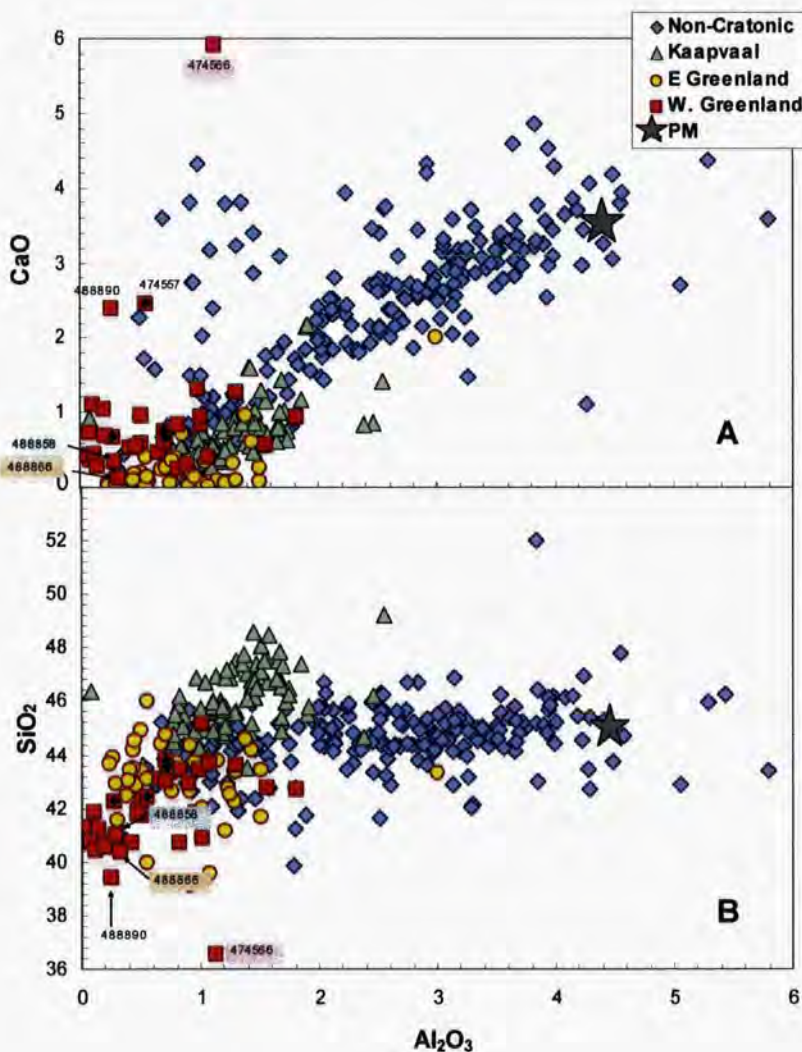


Fig. 4.3 Whole rock Al₂O₃ vs A. CaO and B. SiO₂ for W.G, E. Greenland, Kaapvaal and non-cratonic peridotite xenolith suites. Data sources given in Figure 1.1.

4.3.4 K₂O vs. P₂O₅ & TiO₂

Both the xenoliths and the host rock (UML) for the W.G. samples have been plotted on Figure 4.4, to investigate any host magma contamination. Most of the W.G. peridotite xenoliths are tightly compacted in the very low P₂O₅, K₂O and TiO₂. Sample 474566 plots at the edge of the UML field, suggesting that this peridotite sample has been significantly metasomatised by the host magma. Samples 488890 and 474557 also have slightly elevated TiO₂, P₂O₅ and K₂O. This may also indicate that these samples have experienced some host magma metasomatism.

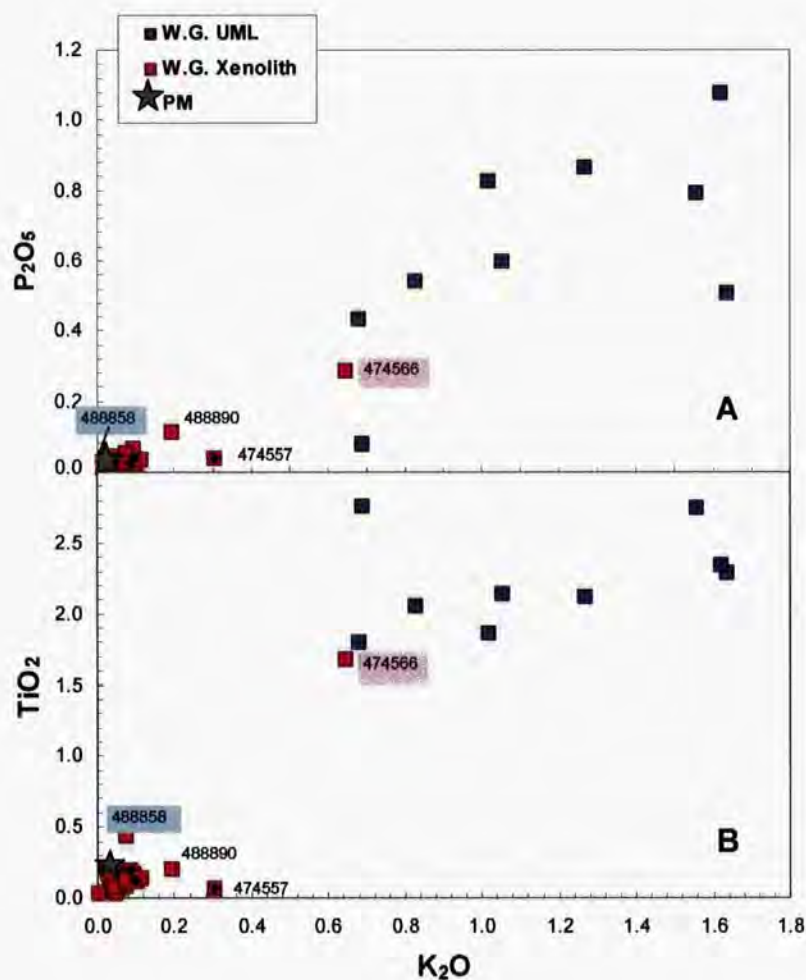


Fig. 4.4 Whole rock K₂O vs. **A.** P₂O₅ and **B.** TiO₂ for W.G. peridotite xenoliths (red squares) and W.G. UML (blue squares)

4.3.5 Al₂O₃ vs. V (ppm) and Cr (ppm)

V

Vanadium (V) is redox sensitive and its contents in peridotites vary with changes in oxygen fugacities (Canil, 2004). V against Al₂O₃ contents in garnet and spinel cratonic peridotites are generally very low (Fig. 4.5 inset), V is less than ~40 ppm (Canil, 2002). Abyssal and massif peridotite suites contain much higher contents of V ranging from ~50 to 100 ppm (Canil, 2002). The W.G. peridotite samples have scattered V contents, the lowest being ~13 ppm, to the highest at ~95 ppm. The majority of the samples are plotting within a range of approximately ~20 and ~60 ppm. Canil (2004) uses V contents to investigate late stage metasomatism on peridotite suites. If garnet has been added or subtracted it does not affect the V, but the addition or subtraction of clinopyroxene has effects on the V and Ti contents (Canil, 2004).

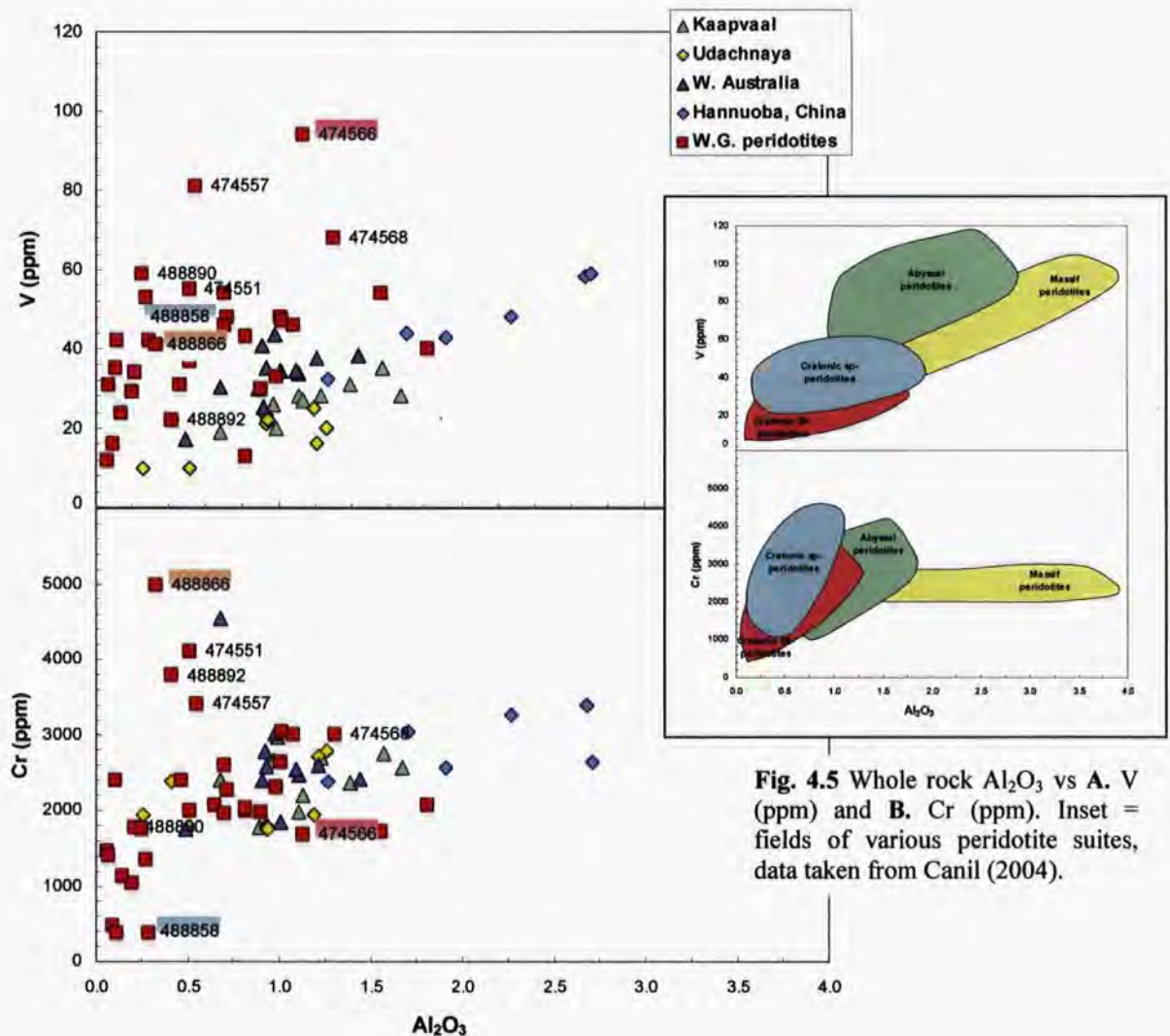


Fig. 4.5 Whole rock Al₂O₃ vs. A. V (ppm) and B. Cr (ppm). Inset = fields of various peridotite suites, data taken from Canil (2004).

Cr contents typically get more scattered with increasing depletion. Cr of massif peridotites is more confined to within 2000 to 3000 ppm (Canil, 2004). The scattering of the more depleted peridotites has been attributed to the 'nugget' effect of spinel. The spinels being mostly comprised of Cr would contribute considerably to the Cr contents.

The XRF results are essential to understanding the depleted nature of the W.G. peridotites and any subsequent metasomatism which has occurred. In the next chapter the W.G. peridotite xenoliths will be described in terms of their PGE and Re characteristics. PGE patterns normalised to whole rock chondrite will highlight any potential disturbances in I-PGE and P-PGE groups as well as documenting highly siderophile element behaviour in these rocks. Then the PGE systematics will be compared to major elements such as Al_2O_3 . Al_2O_3 is not easily disturbed during serpentinisation and metasomatism and will provide an anchor to observe Pt and Pd depletions and additions in residual rocks. Finally the ages of the xenoliths will be examined.

CHAPTER 5

DESCRIPTION OF PGE AND Re GEOCHEMICAL DATA

Chapter 5:

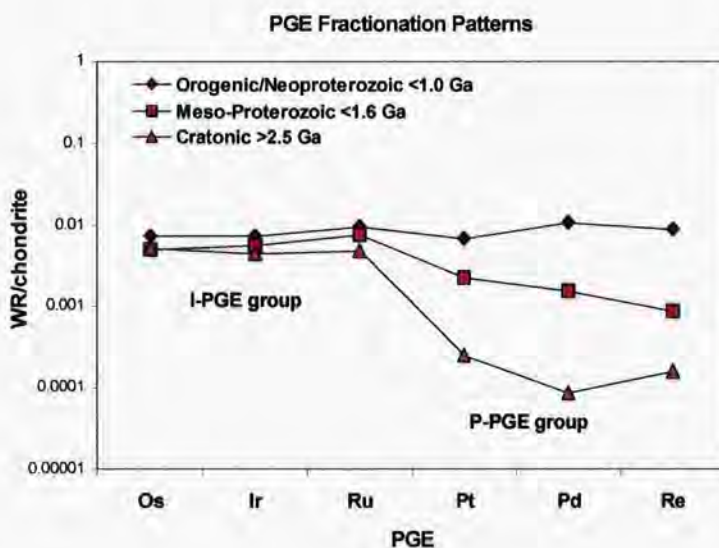
Platinum Group Element & Re Data Results

5.1 Introduction

The platinum group elements comprise osmium, iridium, ruthenium, rhodium, platinum, and palladium (for the purpose of this study, rhodium is not measured because it is mono isotopic and will not be discussed throughout the text). Rhenium is not classed as a platinum group element, but it displays a similar behaviour as it prefers to be in a metal rather than a silicate and is part of the Re-Os isotope decay system. Rhenium will be referred to along with the platinum group elements (PGEs).

I-PGE & P-PGE groups

Osmium, iridium, and ruthenium are classed as the iridium or I-PGE group, and display a compatible behaviour during melting (Pearson *et al.*, 2004). Platinum and palladium are classed as the platinum or P-PGE group and display incompatible behaviour, showing enrichment over I-PGEs in mantle melts. Therefore, I-PGE and P-PGE groups are commonly fractionated from each other (Fig. 5.1) (Pearson *et al.*,



2004). Rhenium is also an incompatible element and can be grouped along with the P-PGE group.

Fig 5.1 Typical PGE fractionation patterns for various peridotite suites. Data sources are for orogenic = sample GP13 Beni Bousera data set, Pearson *et al.*, 1993. Meso-Proterozoic = sample 40-21 Slave Jericho data set, Kopylova & Caro, 2004. Cratonic = sample 8-7 Slave Jericho data set, Kopylova & Caro, 2004.

$^{187}\text{Os}/^{188}\text{Os}$ Ratios Explained

During mantle melting Re is moderately incompatible and prefers to be in the melt. Os is compatible and remains in the residue. Consequently, compared to the mantle the crust is enriched in Re and relatively depleted in Os, this is shown by the highlighted reservoirs in Figure 5.2 (Carlson, 2005). The isotope ^{187}Re decays by β^- transmission to ^{187}Os . The decay constant for ^{187}Re is $\lambda^{187}\text{Re} = 1.666 \times 10^{-11} \text{ year}^{-1}$ this is based on a Re-Os isochron for group IIIA iron meteorites from Shen *et al* (1996); Smoliar *et al* (1996) (Fig. 5.3). Cratonic peridotites have experienced large degrees of partial melting, ~40% (Bernstein *et al.*, 2006). Hence Re is partitioned into the melt phase leaving the residue very depleted in Re. This removal of Re arrests the production of any more ^{187}Os , and so the measured Os isotope ratio provides an estimate for the age of the peridotites (Pearson *et al.*, 2002). This Re-Os age dating technique is described in more detail in **Section 5.8**.

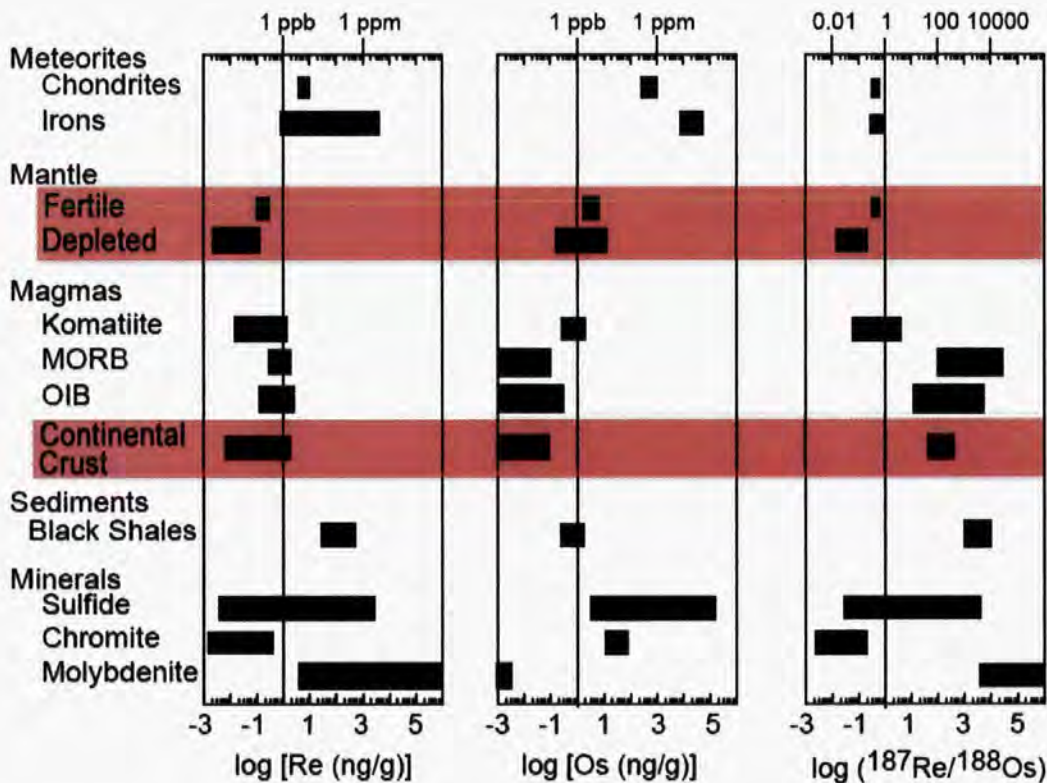


Fig. 5.2 Re and Os concentrations and $^{187}\text{Re}/^{188}\text{Os}$ from various rocks and minerals (Carlson, 2005), reservoirs of particular interest have been highlighted.

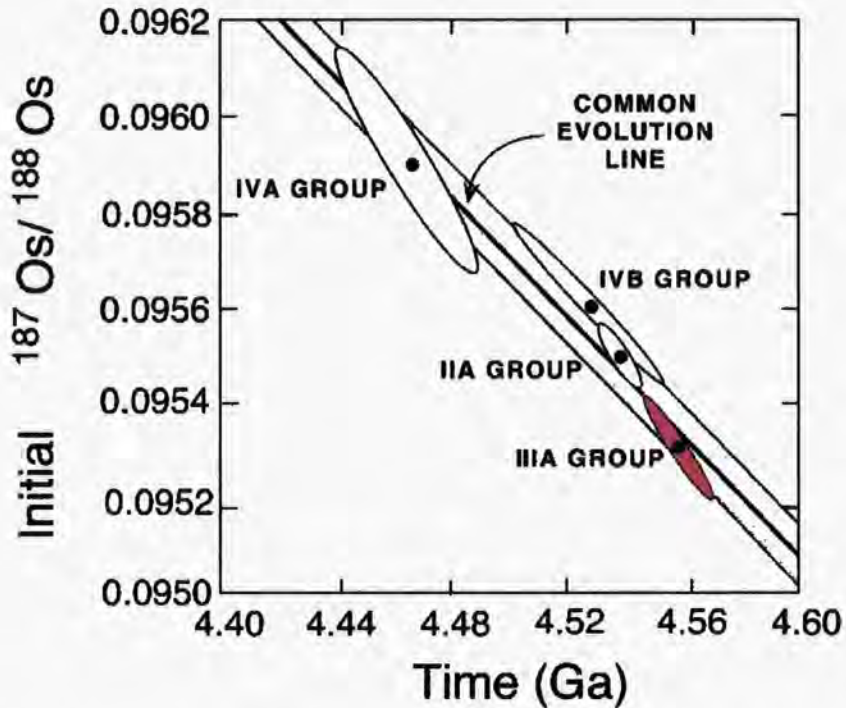


Fig. 5.3 Plot of initial $^{187}\text{Os}/^{188}\text{Os}$ ratios vs. age. The evolution line is the best fit for the group isochrons (Shirey & Walker, 1998). Slope of the regression for group IIIA, gives a decay constant for ^{187}Re of $1.666 \times 10^{-11} \text{ yr}^{-1}$.

The Os isotope characteristics of different mantle reservoirs are shown in Table 5.1. The most depleted sub continental lithospheric mantle has the lowest $^{187}\text{Os}/^{188}\text{Os}$ ratio, commonly described as unradiogenic.

Reservoir	$^{187}\text{Os}/^{188}\text{Os}$
Chondrite	0.127
PUM	0.129
EMII	0.136
EMI	0.152
SCLM	0.113
DMM	0.125
HIMU	0.150

Table 5.1 $^{187}\text{Os}/^{188}\text{Os}$ for various terrestrial reservoirs (Shirey & Walker, 1998). PUM (primitive upper mantle), EMII (enriched mantle II), EMI (enriched mantle I), SCLM (sub continental lithospheric mantle), DMM (depleted MORB mantle), HIMU (high μ).

5.2 W. Greenland PGE and Re concentrations

5.2.1 PGE concentrations

PGE concentration plots of Ir against each platinum group element should show good correlations with I-PGEs (Os, Ir & Ru), and negative correlations for P-PGEs (Pd & Pt) for highly depleted residual peridotites. Ir varies from <1 to 5.4 ppb with an average of 2.3 ppb (Fig. 5.4 & 5.5). Os varies from <1 to 5.0 ppb with an average of 2.2 ppb. Os and Ir are well correlated generally with $Os/Ir \sim 1$. The relationship of Os and Ir for W.G. and other typical peridotites can be seen more effectively in Figure 5.5. Ru concentrations are scattered, ranging from <1 to 33.4 ppb, with an average of 5.4 ppb. Ru is much less correlated with Ir than Os, with data scattering widely either side of $Ru/Ir = 1$. Pd concentrations vary from <0.01 to 4.6 ppb with an average of 0.7 ppb. Pd is not correlated with Ir. Pt concentrations vary from <0.1 to 38.7 ppb with an average of 2.8 ppb.

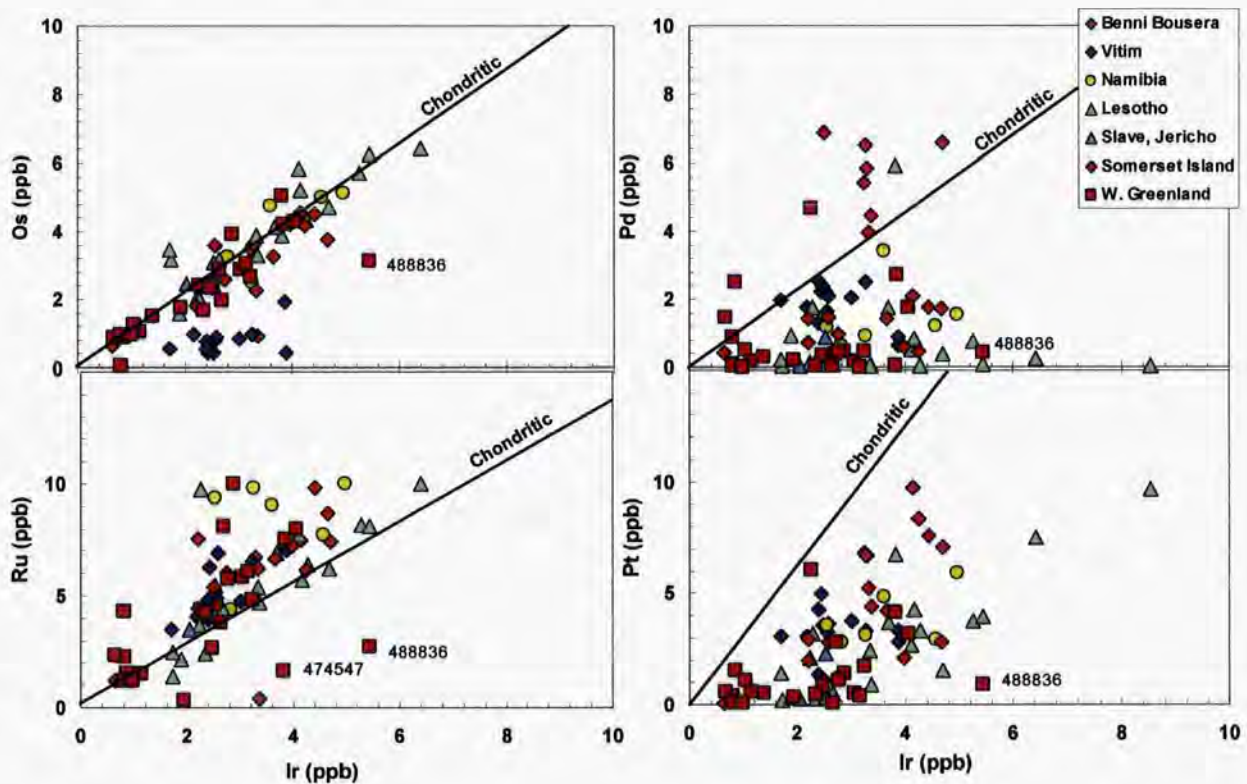


Fig. 5.4 Concentrations of Os, Ru, Pt and Pd with Ir (in ppb) for Beni Bousera, Vitim, Namibia, Lesotho (Pearson *et al.*, 2004), Slave Jericho (Kopylova & Russel, 2000), Somerset Island (Irvine *et al.*, 2003) and W. Greenland (this Study). Chondritic ratio after McDonough and Sun (1995).

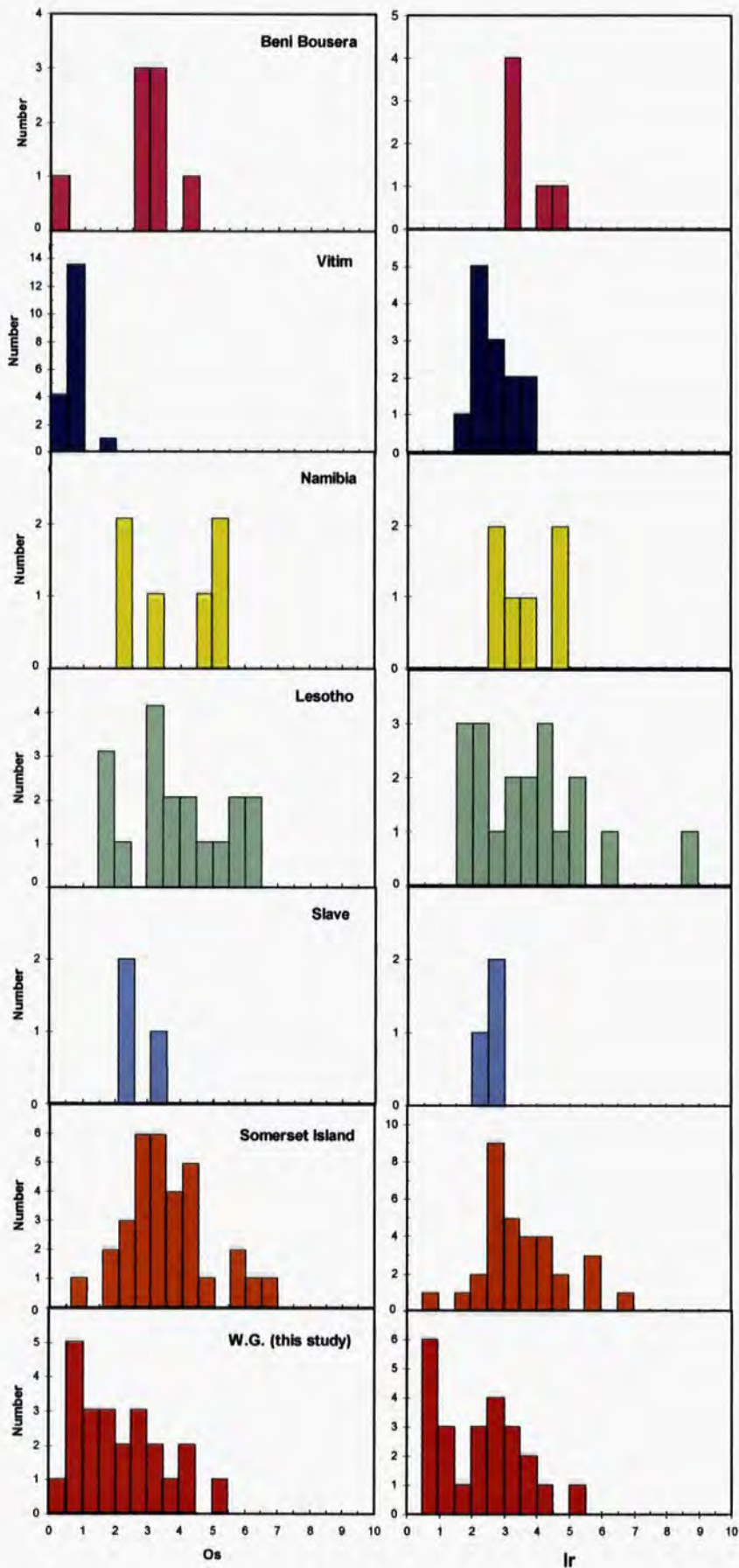


Fig. 5.5 Frequency distributions for Os ppb and Ir ppb for Beni Bousera, Vitim, Namibia, Lesotho, Slave, Somerset Island and W.G. peridotites suites. (For sources see Fig. 5.4).

5.2.2 Os and Re concentrations

Os concentrations for W.G. peridotites are widespread extending into the residue field, i.e. relatively high Os and low Re (Fig. 5.6). A relatively high proportion of samples have low Os, significantly less than primitive upper mantle (PUM), at low Re contents. Cratonic peridotites generally have higher Os contents when off-craton compared to spinel lherzolites which more commonly have lower Os contents at low Re, as typified by the Vitim suite (blue field Fig 5.6).

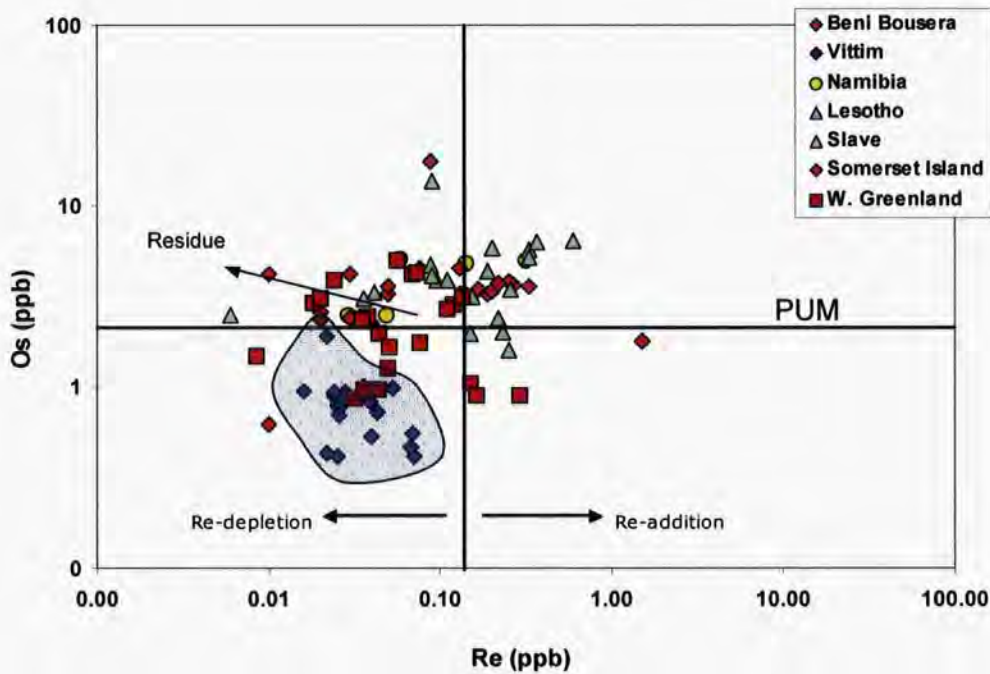


Fig. 5.6. Os ppb vs. Re ppb for Beni Bousera, Vitim, Namibia, Lesotho, Slave, Somerset Island and W.G. peridotites suites. Blue highlight is the Vitim suite. For data sources see Fig. 5.3.

5.3 W.G. PGE patterns – General characteristics

The W.G. peridotite xenolith samples have variably fractionated PGE patterns. Figure 5.7 shows all the W.G. samples together, normalised to chondrite. The most important distinctive feature to be observed in the W.G. peridotites is the presence in numerous samples that are very P-PGE depleted, similar to those observed in the Kaapvaal and Slave cratons (Pearson *et al.*, 2002 & 2004). These patterns are present in samples from both on and off craton localities. A wide variety of complex inter-element enrichments and depletions are super-imposed onto the general pattern of depletion. Before organizing the PGE patterns into distinguishing groups, we will examine how these PGE inter-element fractionations vary with indices of melt extraction such as Al_2O_3 .

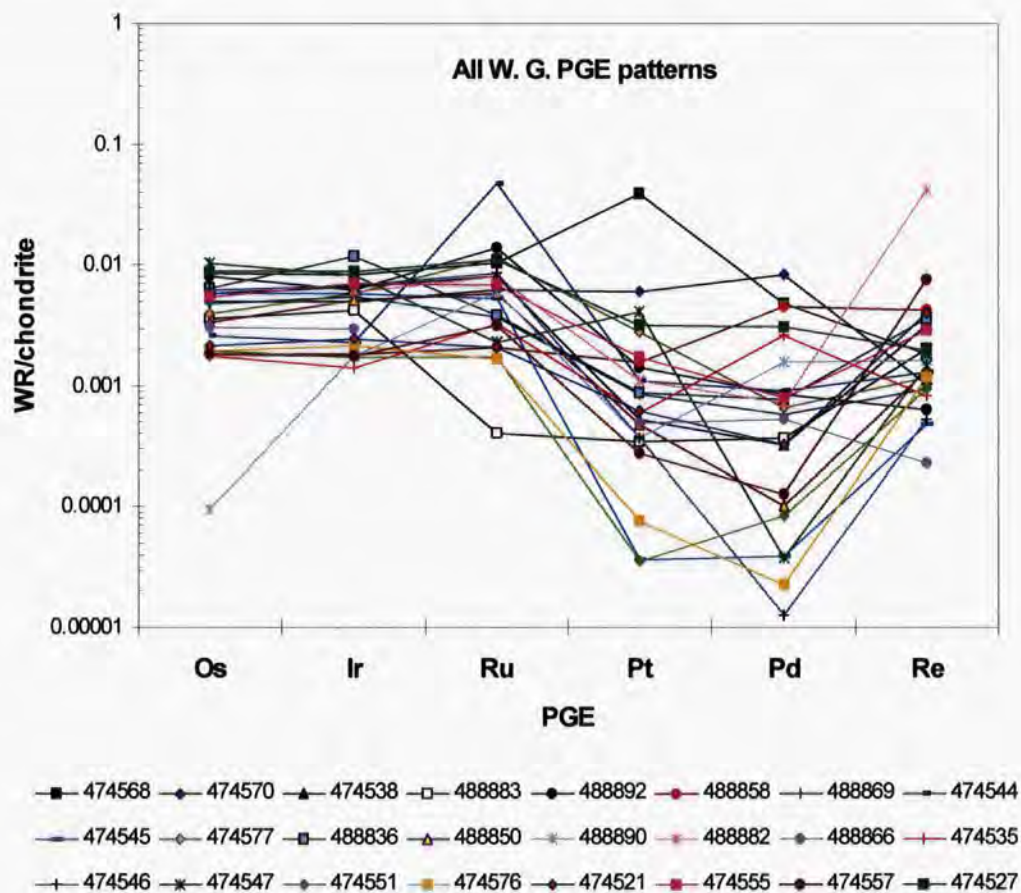


Fig.5.7 Chondrite normalised PGE patterns for the on-craton peridotite xenolith samples from West Greenland. Chondrite normalised values from McDonough & Sun (1995).

5.4 (Pd/Ir)*n* vs. Al₂O₃

In many W.G. peridotites samples, Pd is severely depleted relative to Ir. Very low contents of Pd are indicative of mantle residues e.g. Barnes, 1985; Pearson *et al.*, 2002. This level of depletion should be reflected in the major element systematics of the W.G. peridotites. Highly depleted mantle residues commonly have low Al₂O₃ contents and high MgO (Fig. 4.1). Looking at the relationship between (Pd/Ir)*n* against Al₂O₃ for the W.G. samples will help to further clarify their origin. In Figure 5.8 a & b the W.G. samples have been separated into 3 groups. Group characteristics are summarised in Table 5.2. Group 1 show low (Pd/Ir)*n* low Al₂O₃. A theoretical partial melting trend taken from Pearson *et al* (2002) has been plotted on Figure 5.8 b. This melting trend depicts a starting composition of 300 ppm of total sulphur. With each percentage of melting more residual sulphide is driven off, until it disappears at 25% melting. Group 1 peridotites show high degrees of partial melting. Group 2 show low Al₂O₃, but have higher (Pd/Ir)*n* than Group 1. Group 3 are not following the melting trend and have high (Pd/Ir)*n* and low Al₂O₃.

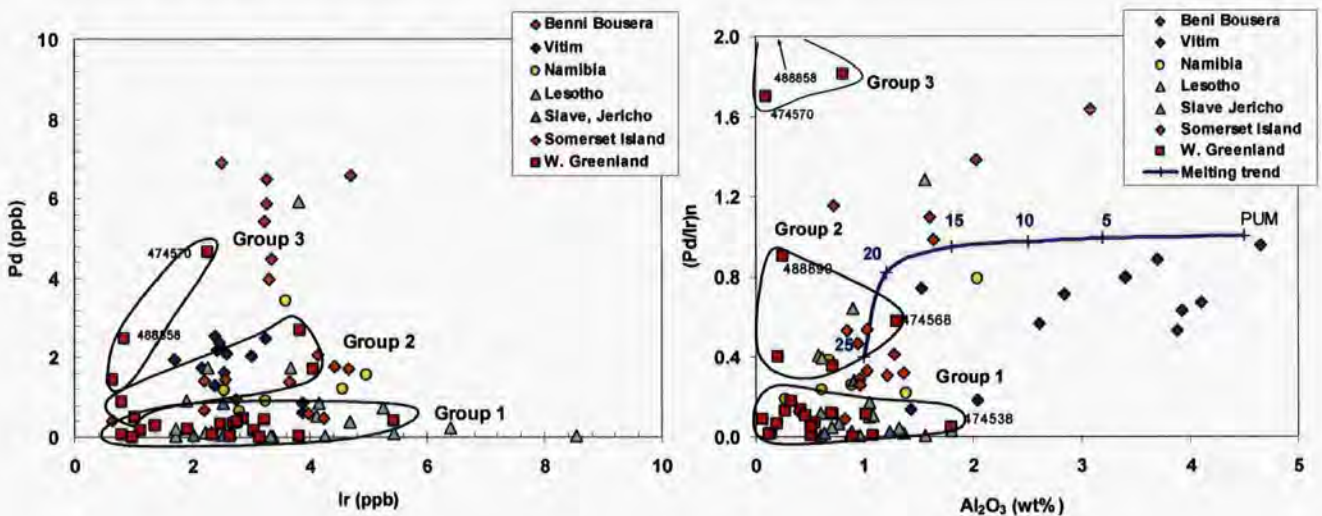


Fig. 5.8 a) Pd (ppb) vs. Ir (ppb). **b)** (Pd/Ir)*n* vs. Al₂O₃ for the Beni Bousera, Vitim, Namibia, Lesotho (Pearson *et al.*, 2004), Slave (Kopylova & Russel, 2000), Somerset Island (Irvine *et al.*, 2003) and West Greenland peridotite suite (this study).

Table 5.2 Summary of the W.G. groups and their (Pd/Ir)*n* vs. Al₂O₃ contents

Group	(Pd/Ir) <i>n</i> Vs. Al ₂ O ₃	Description
Group 1	≤0.2	High degree of partial melting
Group 2	0.3-0.9	Either less melting or Pd addition
Group 3	≥1.0	Enriched or fertile composition

The PGE fractionation patterns for W.G. samples can now be placed into the three groups as seen earlier in the $(Pd/Ir)_n$ vs. Al_2O_3 plots. This will allow us to investigate the group's relative fractionation of I-PGE from P-PGE plus Re and their depletion of Pd relative to Pt.

5.5 W.G. PGE patterns – Group Characteristics

5.5.1 Group 1 PGE Fractionation Pattern

Considerable variations exist in the degree of fractionation of the P-PGEs from the I-PGEs (Fig. 5.9). All samples show a marked depletion of Pd, consistent with Figure 5.8b. Pd concentrations for Group 1 samples 474546 and 474576 are almost 3 orders of magnitude less than their I-PGEs. Pt is also depleted relative to I-PGEs but less so than Pd. Almost all samples apart from 488892 and 488866 show evidence of Re addition. Sample 488882 shows a greater enrichment of Re than the rest of the group. Minor fractionations are seen within the I-PGE group. The most obvious of these is with Ru. Sample 488883 is depleted by one order of magnitude compared with those typical of Group 1.

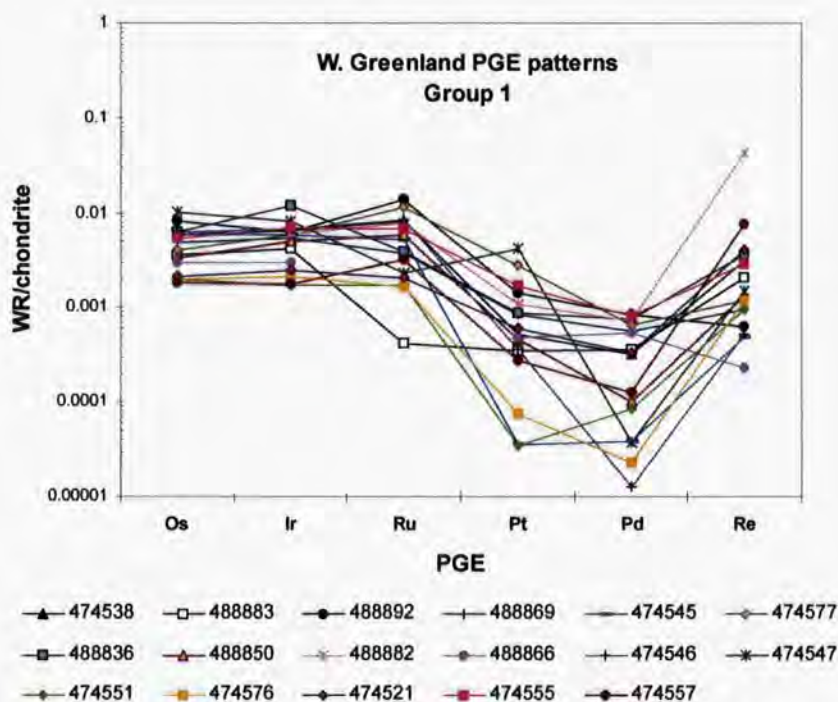


Fig. 5.9 Chondrite normalised PGE patterns for Group 1 W.G. peridotites from West Greenland. Chondrite normalised values from McDonough & Sun (1995).

5.5.2 Group 2 PGE Fractionation Pattern

Pd and Re abundances are sub-chondritic to chondritic (Fig. 5.10), being depleted by less than one magnitude than I-PGEs. Pd contents for Group 2 peridotites are greater than the Pd contents in Group 1. Pt contents and hence $(Pt/Ir)_n$ for Group 2 are very fractionated compared to the Pd. The P-PGE group is fractionated from the I-PGE group, but there are also fractionations within the groups themselves. Samples 474544 and 488890 have high Ru contents. Sample 488890 also has an anomalously low Os content. Sample 474568 has the highest content of Pt out of the entire W.G. peridotite suite. This Pt anomaly is discussed in more detail in **Section 5.6**.

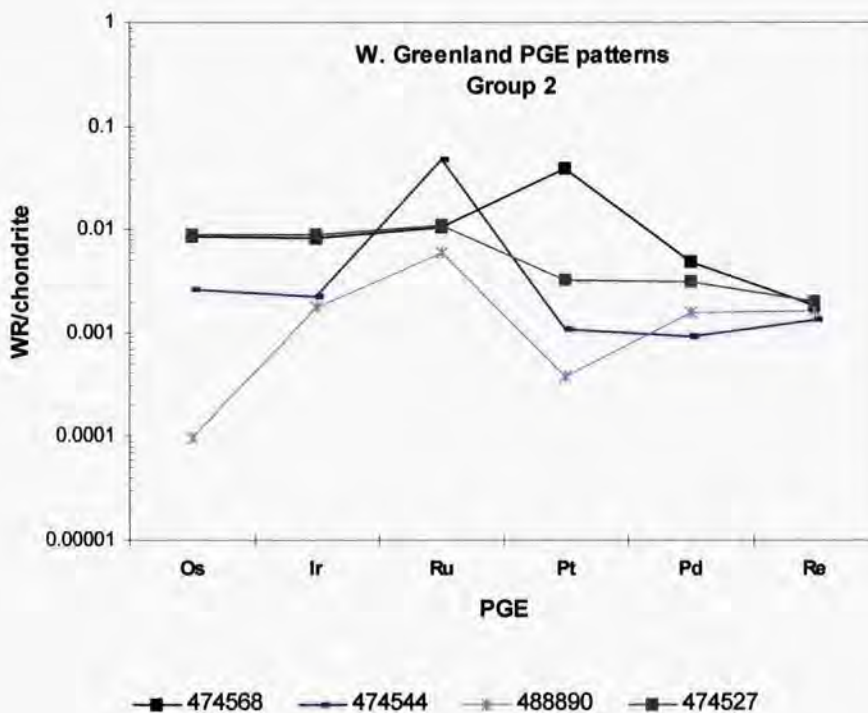


Fig. 5.10 Chondrite normalised PGE patterns for Group 2 W.G. peridotites from West Greenland. Chondrite normalised values from McDonough & Sun (1995).

5.5.3 Group 3 PGE Fractionation Pattern

The PGE fractionation patterns for Group 3 peridotites are shown in Figure 5.11. The most striking observation is that the fractionation pattern is much flatter than those of either Group 1 or 2. Also there is a greater enrichment in Pd relative to Pt within the group and hence Pd/Pt in Group 3 is greater than Pd/Pt in Group 2. Re-depletions are seen in samples 474570 and 474535, while 488858 shows a Re-addition. A positive Ru anomaly is seen in sample 474535.

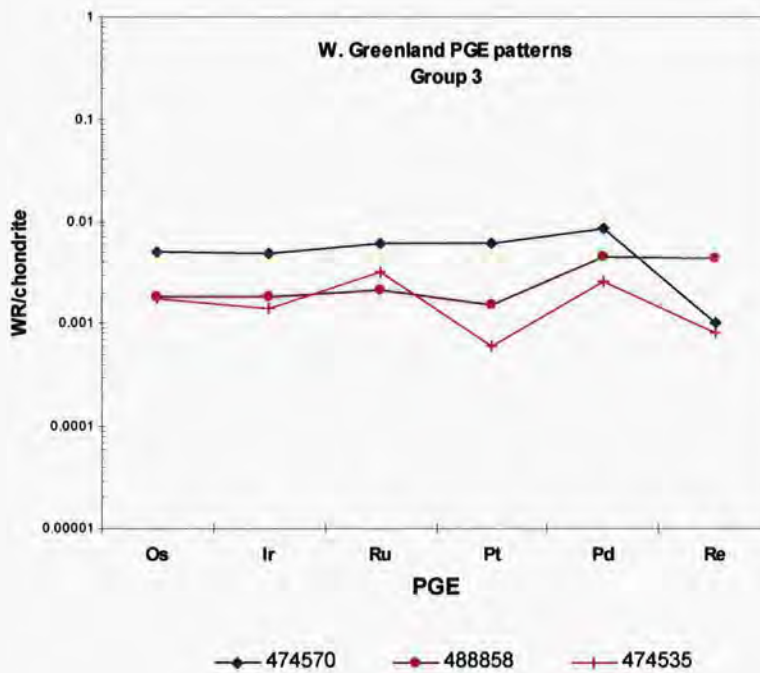


Fig. 5.11 Chondrite normalised PGE patterns for Group 3 W.G. peridotites from West Greenland. Chondrite normalised values from McDonough & Sun (1995).

5.5.4 Grouping characteristics

Table 5.3 summarises the varying characteristics of the different peridotite samples and groups.

Sample No.	Cratonic pattern	Ru Addition	Ru Depletion	Pt Addition	Pd Addition	Re Depletion
Group 1						
474557						
488850						
474576						
488883						
474551						
474538						
474521						
474545						
488892						
474546						
488836						
474547						
488869						
488866						
474555						
488882						
474577						
Group 2						
474568						
474544						
474527						
488890						
Group 3						
488858						
474570						
474535						

Table 5.1. Summarises the characteristics seen in the PGE fractionation patterns in Group 1, 2 and 3 for the W.G. peridotites.

5.6 Positive Pt anomaly in sample 474568

Sample 474568 of the W.G. peridotite suite falls into Group 2 in terms of its PGE characteristics. It shows an enrichment of Pt in the PGE fractionation pattern (Fig. 5.10). Figure 5.12 a), b) and c) shows the sample 474568 in photomicrographs. Figure 5.12 a), shows a group of intergranular sulphides (Pers. Com. Jean-Pierre Lorand). Figures b) and c) show a sulphide inclusion in an olivine (Pers. Com. Jean-Pierre Lorand). Positive Pt anomalies in a peridotite are not easily resolved by addition of Pt from secondary metasomatism alone; Pt fractionations are much more complicated than this and are discussed in more detail in the interpretation (Chapter 6). For now it is important to recognise that there are intergranular sulphides in this sample.

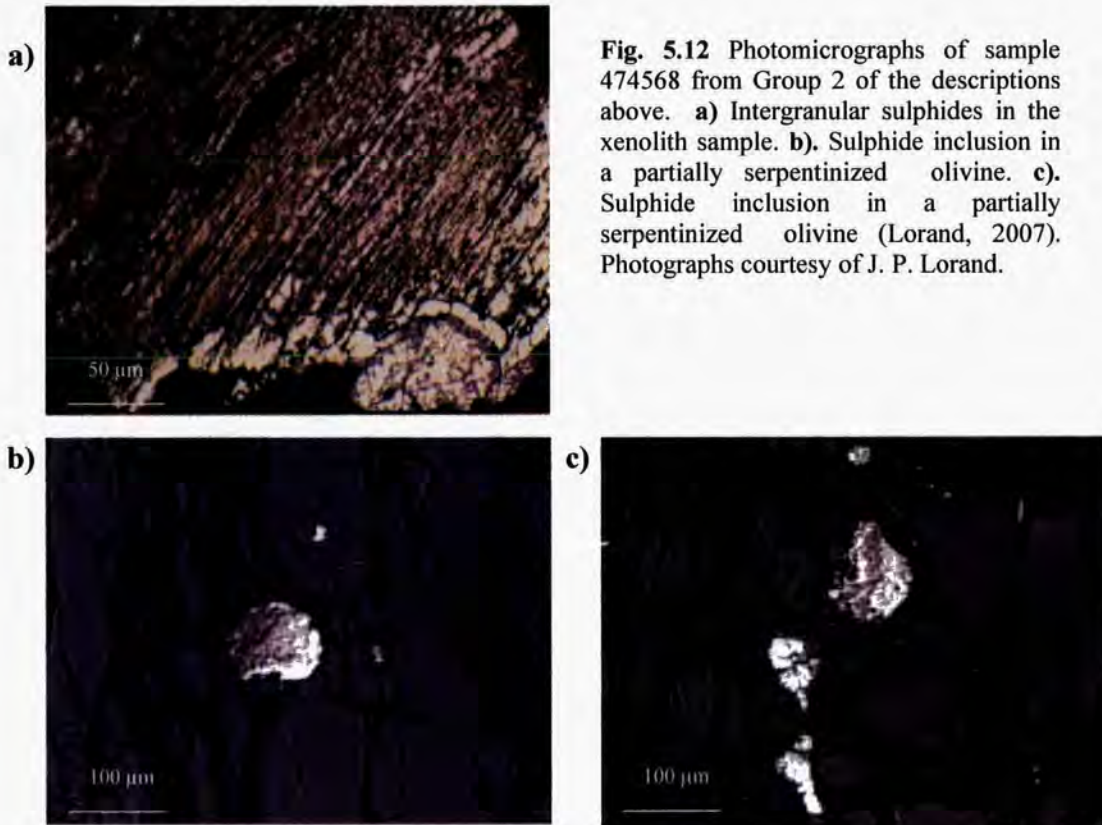


Fig. 5.12 Photomicrographs of sample 474568 from Group 2 of the descriptions above. **a)** Intergranular sulphides in the xenolith sample. **b).** Sulphide inclusion in a partially serpentinized olivine. **c).** Sulphide inclusion in a partially serpentinized olivine (Lorand, 2007). Photographs courtesy of J. P. Lorand.

5.7 Os Isotope characteristics of W.G. peridotites

Gamma Os is used as a percentage deviation in the Os isotope composition of a given rock, from that of the bulk silicate Earth's $^{187}\text{Os}/^{188}\text{Os}$ value of 0. Increasing negative γOs (unradiogenic $^{187}\text{Os}/^{188}\text{Os}$) is typical of ancient depleted peridotites (Fig. 5.13). Typical cratonic peridotite γOs ranges from -6 to -18, and typical non-cratonic γOs ranges from 4 to -6 (Pearson *et al.*, 2004). W.G. samples show a very large range in γOs ranging from -17 to 0 γOs (Fig. 5.14).

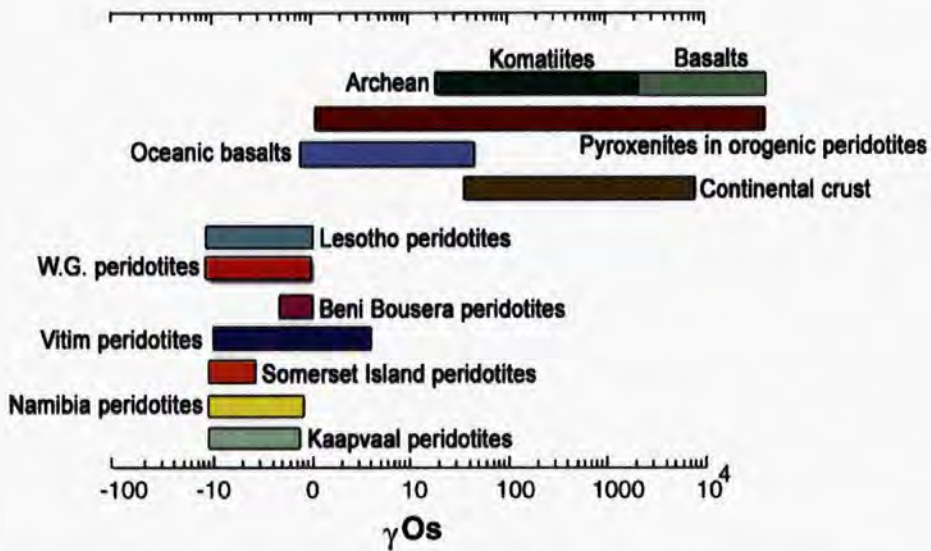


Fig. 5.13 Variations in Os isotope given as γOs in various rock types (adapted from Pearson, 1999).

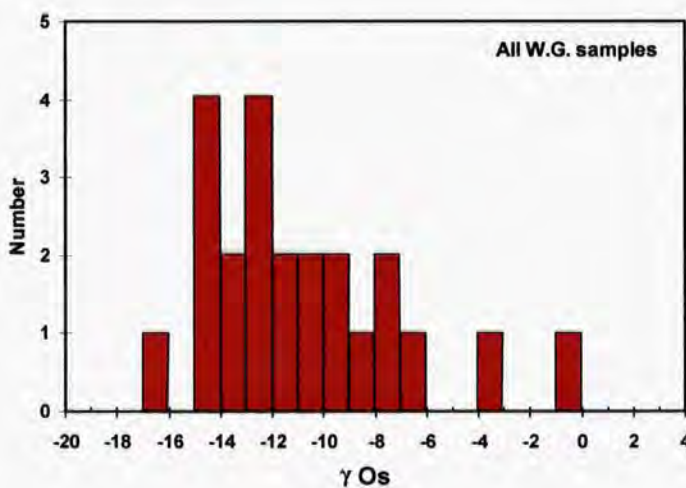


Fig. 5.14 Frequency distribution of initial γOs values calculated at 600myr for the W.G. peridotite suite. γOs values for peridotite xenoliths are calculated at the time of their eruption.

5.8 Age determination

5.8.1 Model ages

Mantle derived xenoliths are very often deformed and altered due to their geological history and their subsequent journey to the Earth's surface. Most of the xenoliths original isotopic signature can be overprinted and disturbed during these events. Osmium isotopic signatures are relatively resilient to disturbance, due to the compatible behaviour of Os. Re is more incompatible than Os and prefers the melt phase. In theory, when the peridotite formed, all the Re would be depleted during large degrees of melt extraction, meaning that Os isotopic evolution is effectively arrested. Any Re now present in the xenolith is likely to have been added after the melting event and mostly from the host magma that brought the xenolith to the surface. This is indicated by the almost ubiquitous elevation of Re in extended PGE patterns. For this reason, Re-depletion ages, that assume zero Re/Os (T_{RD}), are more reliable than the Re-Os model ages (T_{MA}). However, in ancient Re-rich host magmas Os isotopic evolution is no longer arrested. ^{187}Re is decaying to ^{187}Os . $T_{RD\text{ erup.}}$ takes into account any ^{187}Os production since the eruption, and provides a more reliable estimation than T_{RD} (Fig. 5.15).

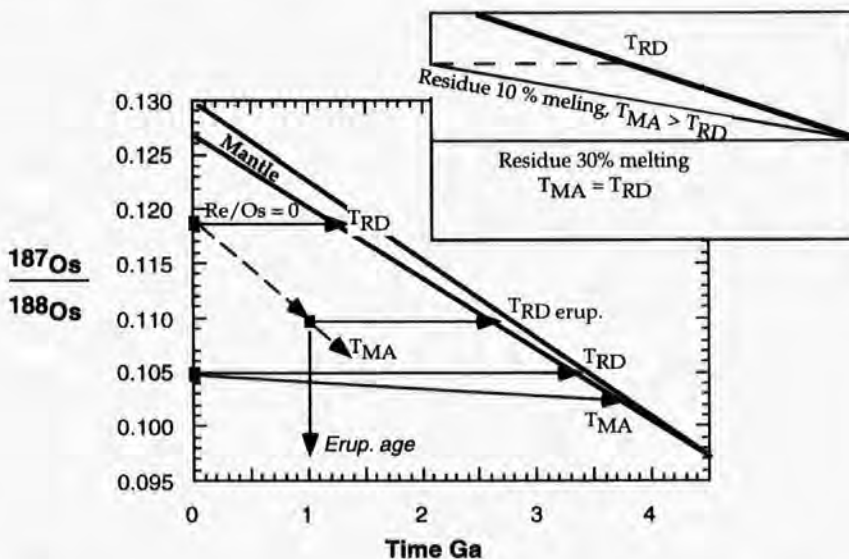


Fig. 5.15 Os isotope evolution diagram showing the T_{RD} , T_{MA} and $T_{RD\text{ erup.}}$ model age systematics (Pearson, 1999; Pearson *et al.*, 2002). Insert shows hypothetical effects of various degrees of melt extraction on the Os isotope evolution of a residual peridotite.

The equations for T_{RD} and T_{MA} calculations are: -

$$T_{RD} = \frac{1}{\lambda} \ln \left\{ \left[\left(\frac{{}^{187}\text{Os}}{{}^{188}\text{Os}}_{\text{Bulk Earth}(t)} - \frac{{}^{187}\text{Os}}{{}^{188}\text{Os}}_{\text{Sample}(t)} \right) / \frac{{}^{187}\text{Re}}{{}^{188}\text{Os}}_{\text{Bulk Earth}(t)} \right] + 1 \right\}$$

$$T_{MA} = \frac{1}{\lambda} \ln \left\{ \left[\left(\frac{{}^{187}\text{Os}}{{}^{188}\text{Os}}_{\text{Bulk Earth}(t)} - \frac{{}^{187}\text{Os}}{{}^{188}\text{Os}}_{\text{sample}(t)} \right) / \frac{{}^{187}\text{Re}}{{}^{188}\text{Os}}_{\text{Bulk Earth}(t)} - \frac{{}^{187}\text{Re}}{{}^{188}\text{Os}}_{\text{sample}(t)} \right] + 1 \right\}$$

The Bulk Earth reservoir is taken as chondrite and 't' is the time of eruption.

5.8.2 W.G. Ages

Re-depletion (T_{RD}), Re-Os (T_{MA}) and $T_{RD \text{ erup}}$ model ages for W.G. peridotites are presented in Figure 5.16. T_{RD} ages (plot A) range from 0.5 - 3.3 Ga, with 7 samples out of the 24 having a T_{RD} age of 3.0 Ga. T_{MA} ages (plot C) range from 0.7 - 6.0 Ga, this must be considered an over estimate seeing as the age of the Earth is estimated at being 4.6 billion years old (Patterson, 1956; Allègre *et al.*, 1995). Therefore the T_{MA} ages are not reliable. The $T_{RD \text{ erup}}$ model ages for the W.G. peridotite samples take into account any production of ${}^{187}\text{Os}$ since the time of the UML eruption.

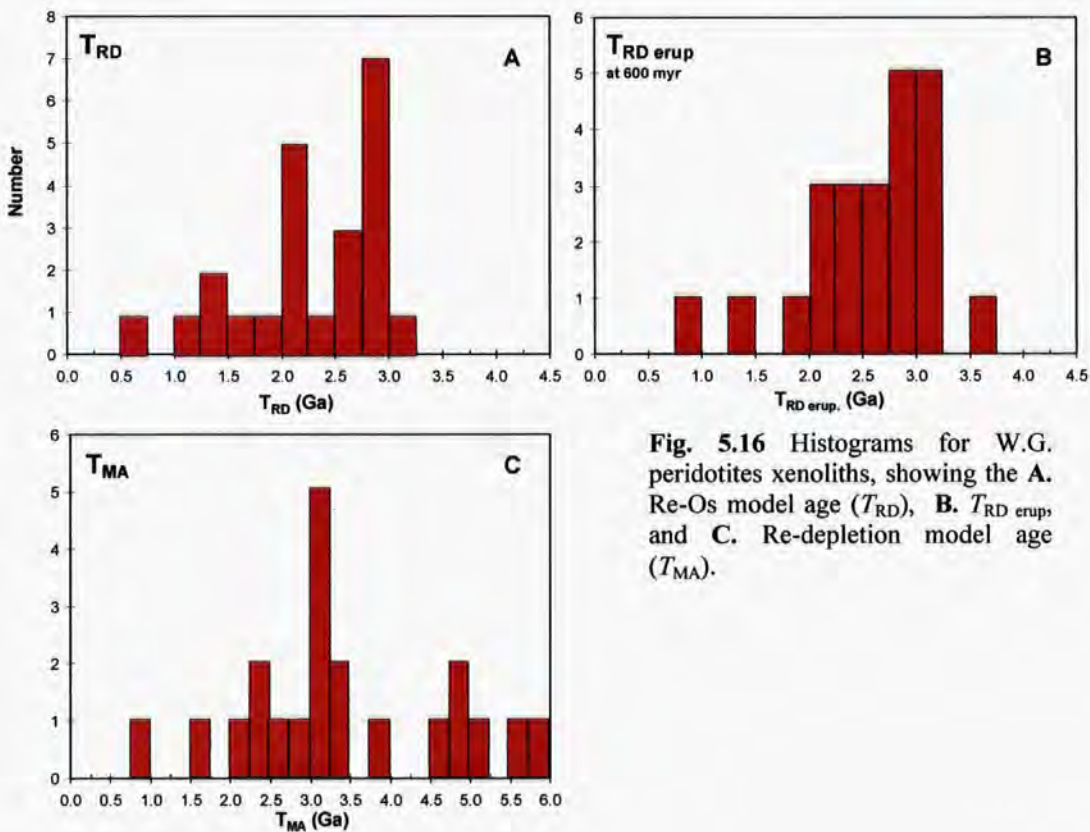


Fig. 5.16 Histograms for W.G. peridotites xenoliths, showing the **A.** Re-Os model age (T_{RD}), **B.** $T_{RD \text{ erup}}$, and **C.** Re-depletion model age (T_{MA}).

The W.G. peridotite samples were brought to the surface by ~600 Myr old UML dykes (Larsen & Rex, 1992). Since the UML eruption, substantial radiogenic Os may have accumulated from the decay of ^{187}Re to ^{187}Os . For this reason, the isotopic compositions are corrected for the in-growth of ^{187}Os giving the $T_{\text{RD erup.}}$ age. $T_{\text{RD erup.}}$ age is a more reliable age for the W.G. peridotite samples, as seen by Figure 5.16 B.

T_{RD} , $T_{\text{RD erup.}}$ and T_{MA} ages for the W.G. peridotites are shown in Table 5.4. It has already been established that Group 1 of the W.G. peridotites (discussed earlier) are the best representative group for indicating the most depleted peridotites, with the highest degrees of melting and the least alteration. Therefore Group 1 $T_{\text{RD erup.}}$ ages should have the most reliable ages.

Table 5.4 Model ages for the W.G. peridotite xenoliths

Sample No.	T_{RD}	$T_{\text{RD erup.}}$	T_{MA}	Craton
<i>Group 1 – High degrees of partial melting</i>				
474557	1.5	3.6	-0.6	off
488850	3.0	3.2	4.6	on
474576	2.9	3.2	5.9	on
488883	2.8	3.1	5.5	on
474551	2.9	3.1	4.8	on
474538	2.8	3.1	5.2	on
474521	2.0	3.0	3.3	off
474545	2.9	2.9	3.1	on
488892	2.8	2.9	3.0	on
474546	2.8	2.8	3.0	on
488836	2.5	2.8	4.9	on
474547	2.6	2.7	3.0	on
488869	2.6	2.7	3.1	on
488866	2.1	2.2	2.3	on
474555	1.8	2.1	3.3	off
488882	2.1	2.1	2.1	on
474577	1.7	1.9	2.3	on
<i>Group 2 – Less melting or Pd addition</i>				
474568	2.5	2.6	3.0	on
474544	2.2	2.5	3.9	on
474527	2.2	2.3	2.7	off
488890	No ^{187}Re data			on
<i>Group 3 – Primitive or enriched</i>				
488858	1.2	2.4	-1.1	on
474570	1.3	1.4	1.5	on
474535	0.6	0.8	0.9	on

The $T_{RD \text{ erup}}$ ages and Groups for the western Greenland samples are presented in Figure 5.17. This Figure shows that the majority of the Group 1 W.G. peridotites have ~ 3.0 Ga $T_{RD \text{ erup}}$ ages.

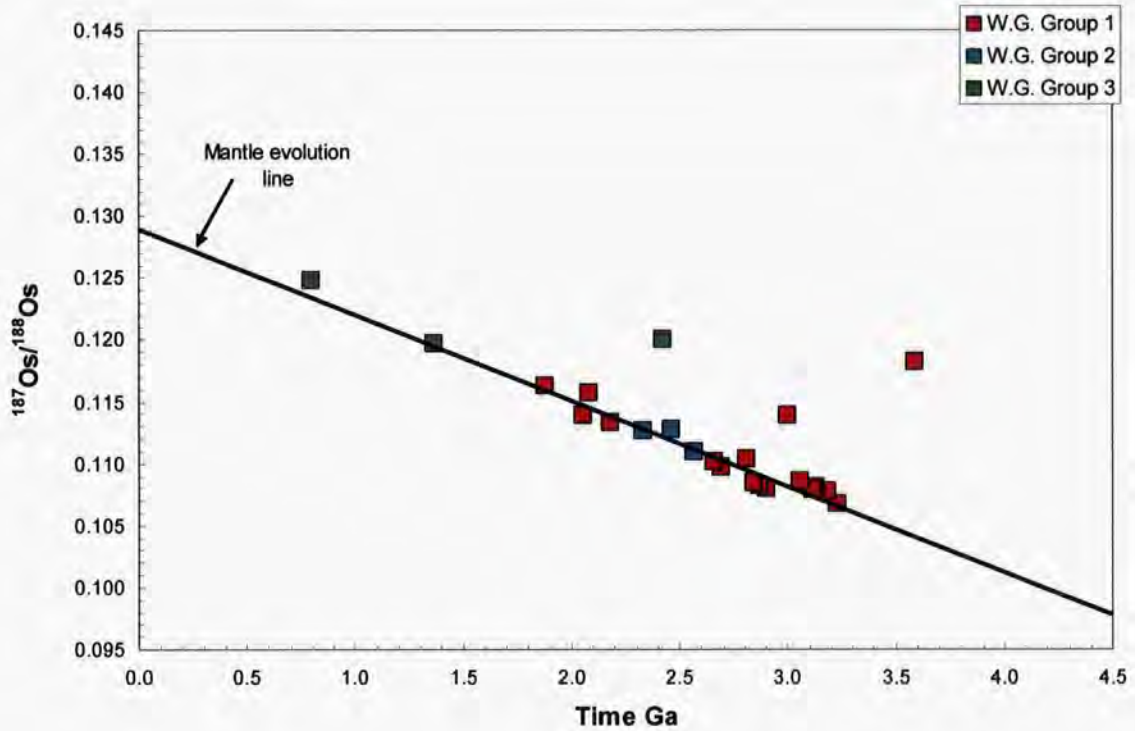


Fig. 5.17 Os isotopic evolution diagram showing the $T_{RD \text{ erup}}$ age and Groups for the W. Greenland peridotites. Mantle evolution line taken from Pearson *et al.*, (2002). Line also indicated by group IIIA on Fig. 5.3.

In chapters 4 and 5 the W. Greenland peridotite xenoliths have been described in terms of their major element contents and their PGE systematics respectively. In the next chapter the major elements and the PGE systematics of the W. Greenland peridotite suite will be investigated further. They will be interpreted and compared with other peridotite suites from around the world.

CHAPTER 6

SYNTHESIS

Chapter 6:

Synthesis

6.1 Major element constraints on peridotite genesis in W. Greenland

6.1.1 Whole Rock analyses

The W.G. peridotite xenoliths show a large range in major element composition. For Mg/Si vs Al/Si (Fig. 6.1) most W.G. samples overlap the range for cratonic peridotites. W.G. & E.G. peridotite suites display very similar bulk Earth compositions. The WG samples extend to much lower Al/Si and generally higher

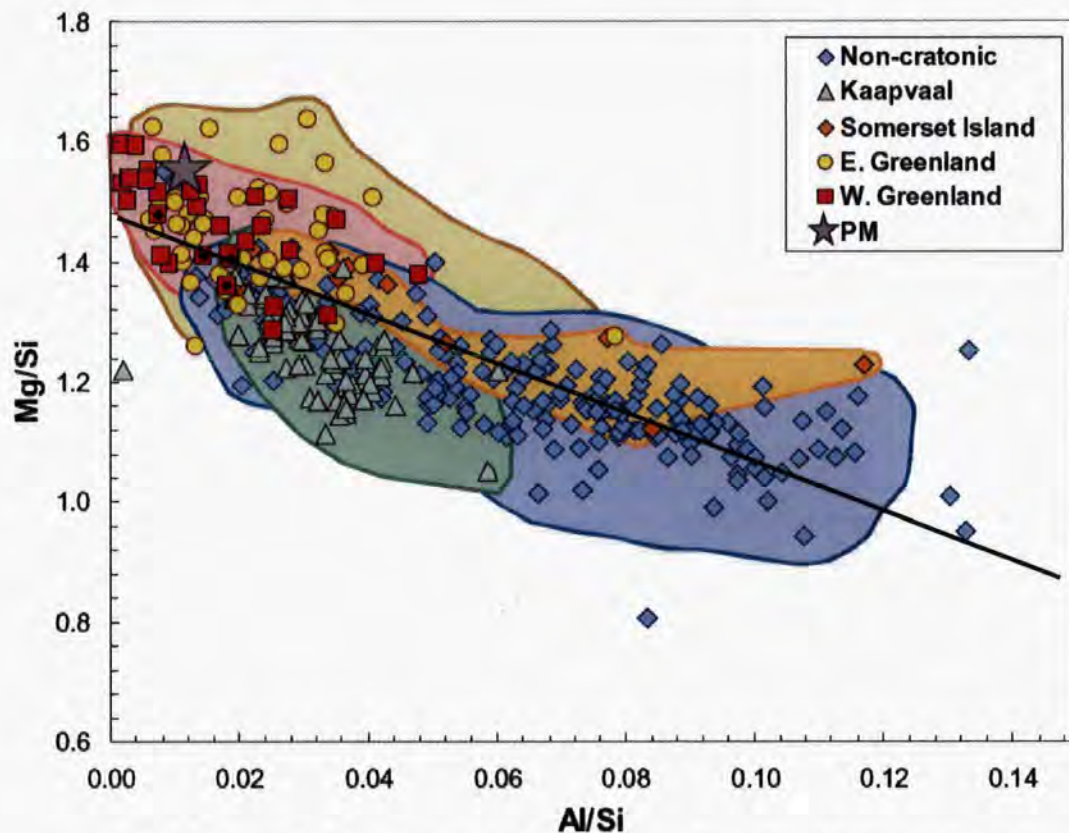


Fig. 6.1 Plot of bulk Earth composition. Mg/Si vs Al/Si of peridotite xenolith suites. Yellow field = E. Greenland (Bernstein et al, 1998), red field = W. Greenland (this study), blue field = Non-cratonic (various authors Appendix E & F), orange field = Somerset Island (Irvine et al, 2003), and green field = Kaapvaal (Boyd et al, 1993; Pearson et al, 1995). PM = primitive mantle (McDonough & Sun, 1995).

Mg/Si values than other cratonic samples except those from other locations on the N. Atlantic craton, specifically from Greenland. Such high Mg and low Al are

consistent with an origin as residues from high degrees of partial melting (e.g., Boyd, 1989; Pearson, 2003). These characteristics in particular the high Mg and low Al are similar to those of typical cratonic peridotite compositions and give the first indication that the W.G. mantle may be of cratonic origin (Boyd, 1989; Pearson *et al.*, 2003).

6.1.2 Typical cratonic mantle

The Kaapvaal and Siberian peridotite suites have much higher contents of SiO_2 than W.G., E.G., Somerset Island and Tanzanian peridotites. Walter (1998) used a plot of MgO/SiO_2 vs SiO_2 (Fig. 6.2) to illustrate the differences between silica-rich low-T and silica-poor high T cratonic peridotites from the Kaapvaal craton. The olivine and

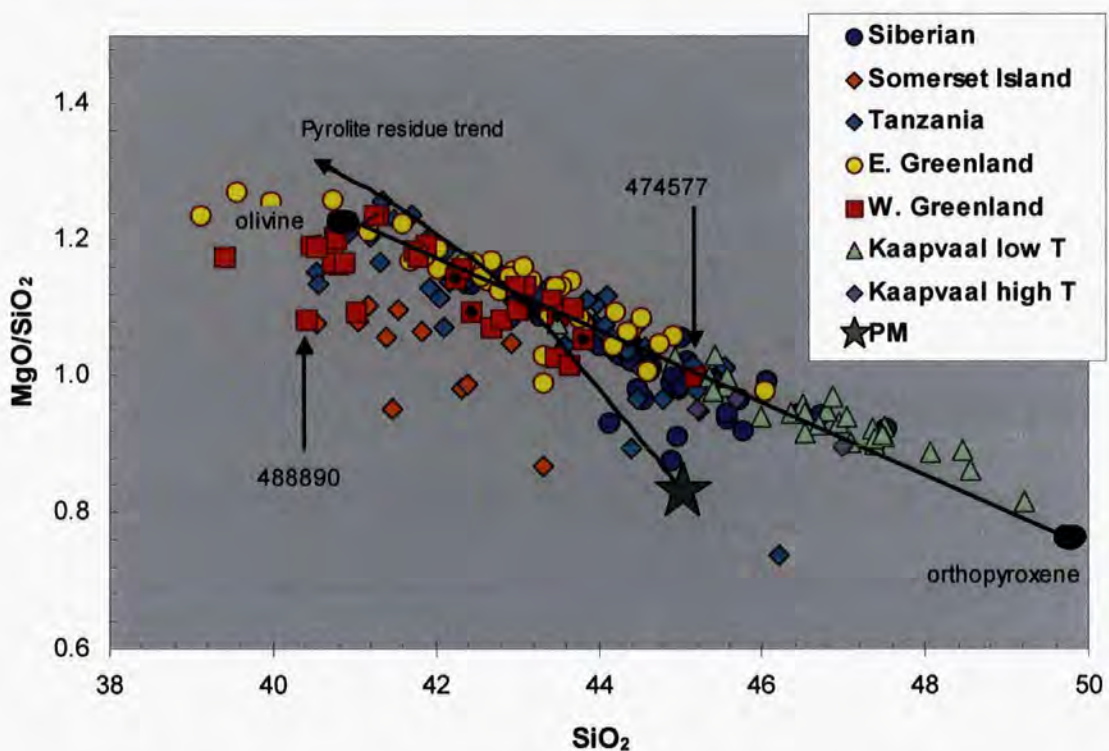


Fig. 6.2 MgO/SiO_2 vs SiO_2 for cratonic peridotites. Straight black line is the olivine – orthopyroxene mixing trend. Curved black line is the pyrolite residue trend. Grey star is the primitive mantle. Sources see Fig 4.1.

orthopyroxene line in Figure 6.2 is a mixing trend between these two mineral end members. Low temperature Kaapvaal peridotites plot along the olivine – orthopyroxene mixing trend. This suggests that low temperature Kaapvaal peridotites with high SiO_2 were strongly affected by orthopyroxene addition. Peridotites from W. Greenland (and the N. Atlantic craton in general) plot to the silica-poor side of the opx-olivine mixing line, confirming the opx-poor characteristics observed in the field

and petrographically. Sample 474577 of the W.G. peridotite suite is separate from the rest of the W.G. field having very elevated SiO_2 and low MgO/SiO_2 , lying close to the olivine-orthopyroxene mixing line, and so may be indicative of orthopyroxene addition. Sample 488890 is also separate from the rest of the field; this sample has very low SiO_2 and high MgO/SiO_2 .

It has become increasingly apparent that the high levels of SiO_2 in the Kaapvaal and the Siberian peridotite suites are not typical of all Archean cratonic mantle (Bernstien *et al.*, 1998; Bernstein *et al.*, 2006). It has been suggested that the elevated amounts of SiO_2 are a result of orthopyroxene addition (Kelemen *et al.*, 1992; Kelemen *et al.*, 1998; Simon *et al.*, 2007). Simon *et al.* (2007) suggest that this orthopyroxene addition took place in a Archean subduction zone environment. In contrast, the SiO_2 poor character of the W. Greenland peridotites and peridotites of the NAC in general indicates a lithospheric mantle with considerably less opx (Bernstein *et al.*, 2006). The olivine-rich NAC peridotites also have high olivine Mg numbers, typical of those from the Kaapvaal craton and this has been taken by Bernstein *et al.* (2006) to indicate that the NAC and Kaapvaal peridotites experienced very similar degrees of melt extraction but in the case of the Kaapvaal craton later opx enrichment took place. In this way the compositions of the NAC peridotites might be a better estimate of the pre- metasomatic bulk composition of cratonic lithospheric mantle (Bernstein *et al.*, 2006). The olivine-rich, orthopyroxene poor peridotites reported in this thesis concur with this picture of the NAC lithospheric mantle and strongly support the views of Bernstein.

One anomaly in the NAC mantle is sample 474577 that has very low Mg/Si (Fig. 6.2) and hence may have experienced some SiO_2 enrichment, possibly from orthopyroxene addition. This sample is atypical of the NAC as a whole.

The SiO_2 poor nature of NAC samples is in keeping with that expected experimentally, for residues derived from melting pressures between 2 and 5 GPa (Walter, 2003; Canil, 2004). It seems likely that these compositions may be the typical residual mantle composition for cratons before substantial melt- and fluid-related modification takes place, such as the complex scenario suggested by Simon *et al.* (2007) for the Kaapvaal craton peridotites.

6.1.3 The degree of partial melting in W.G. peridotites

The Ca- and Al-poor nature of W.G. peridotites plus their high olivine magnesium numbers (Mg#) clearly indicate an origin as residues from large fractions of partial melting, probably close to or above 40 % melt extraction (Fig. 6.3 A) (Bernstein *et al.*, 2006). The olivine Mg# is a useful measure for observing the degree of partial

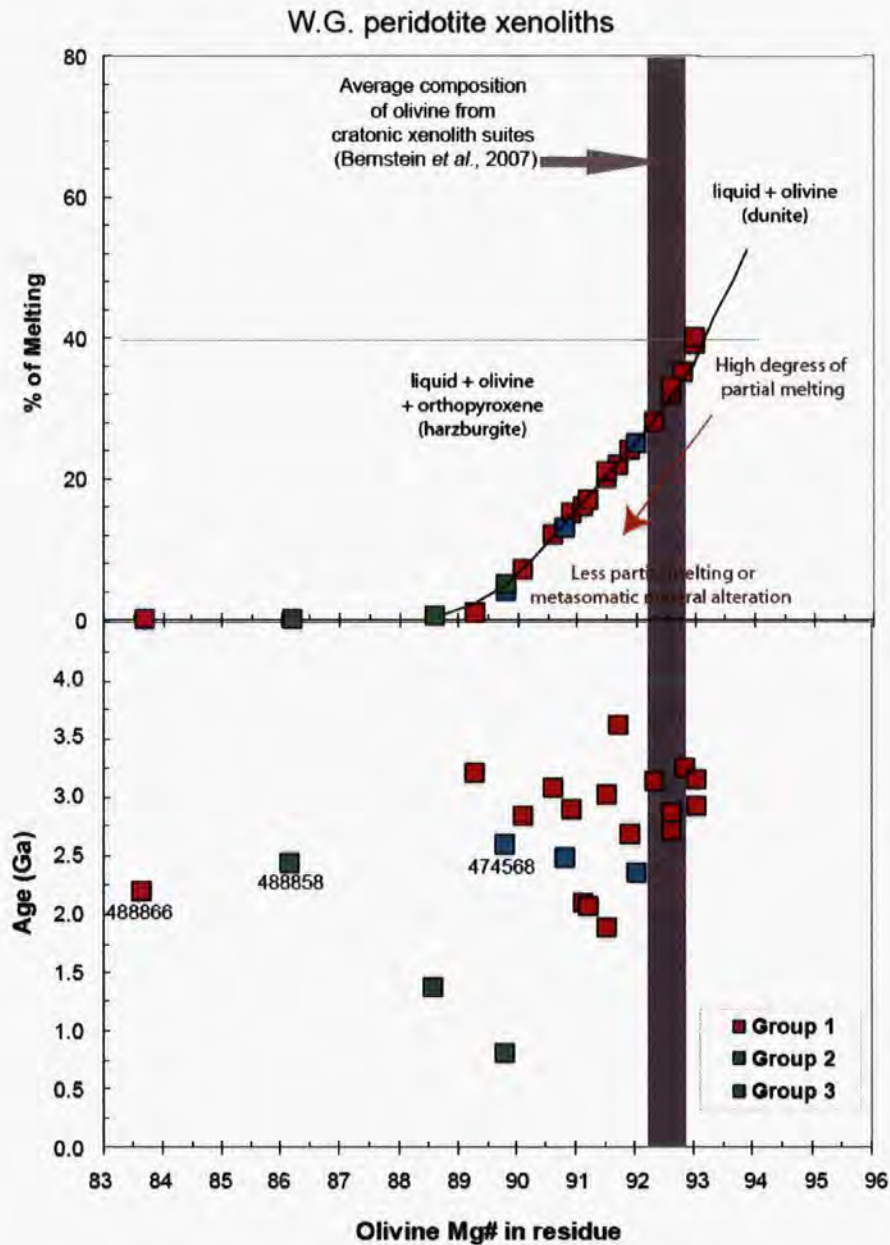


Fig. 6.3 A. Percentage of melting against olivine Mg number (Mg#) in a peridotite residue for the W.G. peridotites. Groups 1, 2 and 3, refer to the groupings made in Chapter 5 based on their PGE fractionation patterns. The black curve is taken from Bernstein *et al.* (2007). **B.** Age (Ga) against olivine Mg number (#) for the W.G. peridotite suite.

melting which has occurred. High Mg# indicates a high degree of primary melt extraction. However, secondary processes such as metasomatism or serpentinization can modify the olivine Mg# of the residue (Pearson *et al.*, 2004).

Because P-PGEs are fractionated from I-PGEs during partial melting, $(Pd/Ir)_n$ can be used to evaluate the degree of partial melting. All the W.G. samples are characterised by very low Al_2O_3 which is indicative of residues from high degrees of partial melting. The very low $(Pd/Ir)_n$ values of the W.G. Group 1 peridotites are also consistent with residues for very large degree of melt extraction, and indicate in excess of 25% melt extraction (Fig. 6.4). These large fractions of melt extraction characterise all the W.G. peridotites, even Group 3, samples whose Pd contents suggest lower degrees of melting have very low Al_2O_3 indicating that they too have experienced large degrees of partial melting, and have later been re-enriched in metasomatic Pd, giving higher $(Pd/Ir)_n$ ratios.

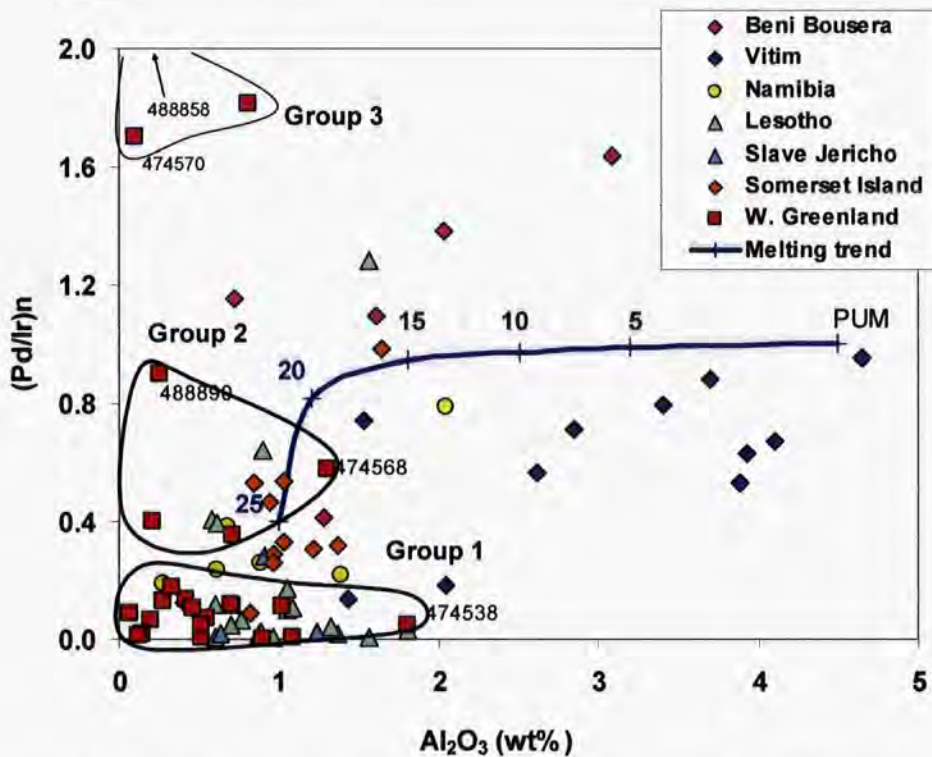


Fig. 6.4 $(Pd/Ir)_n$ vs. Al_2O_3 . W.G. peridotites are separated into 3 groups. Group 1 are residues from high degrees of partial melting. Group 2 have either experienced less partial melting than Group 1, or have been enriched in Pd. Group 3 have also either experienced less partial melting than Group 1 and 2, or have also experienced some enrichment of Pd. Melting trend taken from Pearson *et al* (2002).

6.1.4 Fe and Ti metasomatism

A large proportion of the W.G. peridotites have elevated FeO* contents relative to most other peridotites of the primitive mantle (Fig. 6.5 A). The W.G. peridotites plot much higher than E. Greenland, Kaapvaal and even non-cratonic peridotite suites. Similarly the W.G. samples also have higher contents of TiO₂ than the other peridotite suites (Fig. 6.5 B). Late stage metasomatism associated with UML magmatism may be responsible for the elevated contents of Fe and Ti (Boyd et al, 1993). Figure 6.5 C & D, shows the W.G. samples separated into their groups as described in Chapter 5, which were, Group 1 is highly depleted; Group 2 has P-PGE enrichments, and Group 3 has more P-PGE enrichment than Group 1 and 2. From Figure 6.5 C it is clear that Group 3 has experienced FeO* addition. Since highly depleted peridotites are characterised by low FeO* contents (Simon, 2004), it could be argued that the Fe has been introduced metasomatically to the W.G. peridotites. In Figure 6.5 D sample number 488858 is the only one with high TiO₂ from Group 3. The FeO* and TiO₂ anomalies may possibly be some mixture between ilmenite and melt addition.

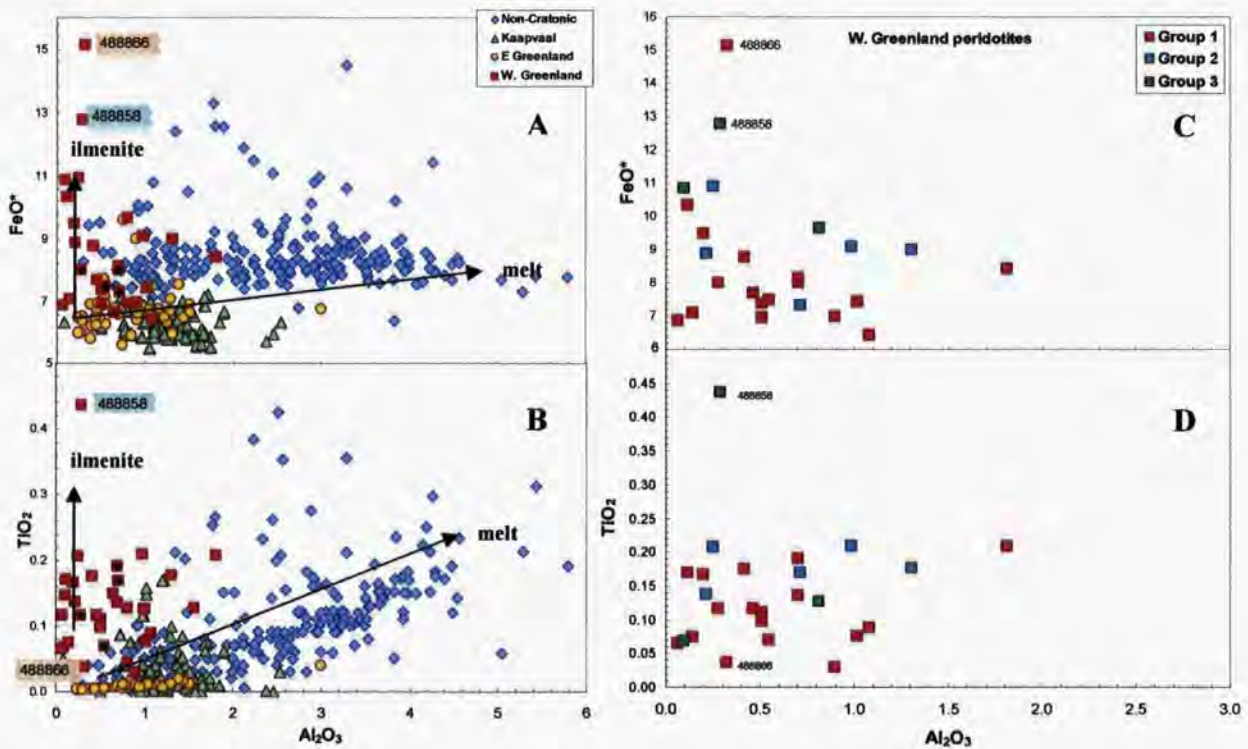


Fig. 6.5 Plots of FeO* and TiO₂ against Al₂O₃. A & B. are for various peridotite suites including W.G. C & D are for the W.G. peridotites and they are separated into the groups defined in Chapter 5. Group 1 highly depleted, Group 2 less depleted, and Group 3 is enriched or fertile.

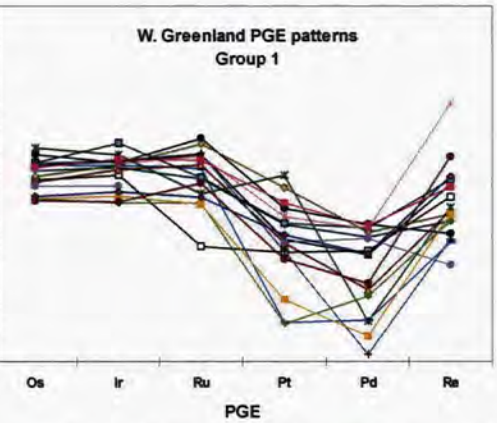
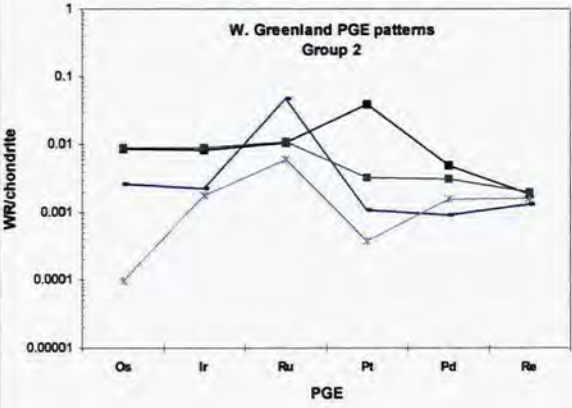
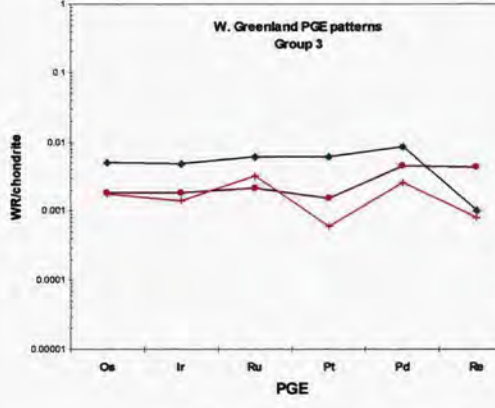
6.2 PGE systematics of the W.G. cratonic lithospheric mantle

After the initial formation of a residual peridotite any subsequent disturbance from melts or fluids will be reflected in the PGE patterns and the PGE-major-element systematics (Pearson *et al.*, 2004). The PGE and Re contents of the W.G. peridotite xenoliths were described in Chapter 5. The 24 samples of the peridotite suite were divided into 3 groups of similar characteristics which are summarised in Table 6.1.

Group 1 comprises 17 of the 24 samples and show typical highly P-PGE depleted patterns (Fig. 6.6) that are characteristic of cratonic peridotites. This is due to the fact that they are residues from large fractions of melting (>40%) (Bernstein *et al.*, 2006; Boyd, 1989; Pearson *et al.*, 2004). The cratonic extended PGE pattern of the W.G. peridotites shows some Re enrichment, closely resembling the N. Lesotho peridotites analysed by Irvine (2002) and Pearson *et al.*, (2004). Re enrichment is probably due to small amounts of host dyke infiltration.

Group 2 and 3 peridotites show elevated contents of the P-PGEs compared to Group 1. This feature could be due to lower levels of melt depletion compared with the peridotites from Group 1, i.e. they are more fertile. Alternatively, Pt, Pd and Re have been added to the residual peridotites via metasomatism. From the investigation of the Mg-number and the $(Pd/Ir)_n$ vs. Al_2O_3 on all the W.G. peridotites (Fig. 6.3 & 6.4), it is clear that the peridotites were all once residues from $\geq 40\%$ partial melting of a fertile mantle (Bernstein *et al.*, 2006). The lack of correlation between Mg# and Pd/Ir suggest that any elevated contents of Pt, Pd and Re are more likely to arise from metasomatic addition of fluids or melts. However, Guo *et al* (1999) notes that small amounts of Pt and Pd derived from immiscible sulphide melts, can get trapped in the residual mantle during partial melting, if this were the case for the W.G. peridotites for Group 2 and 3, then further investigations on the sulphides are needed to evaluate whether such trapped sulphides could account for the P-PGE enrichment. The additions of Pd and Re for Group 2 and 3 can be explained by metasomatic addition via sulphides, possibly during the formation of the ~2.0 Ga Kangâmiut dyke swarm and or from the host dyke during ascent through the crust. Unfortunately there was no scope for an in-depth investigation into the Pt and Pd anomalies found in this suite of peridotites. An investigation was conducted into sample No. 474568 in Group 2.

Table 6.1 W.G. peridotite groups.

Group 1	Group 2	Group 3
<i>Depleted/residual plus Re addition</i>	<i>Less depleted than Gp1 or Pt, Pd and Re addition</i>	<i>Metasomatised/ Pt, Pd and Re addition</i>
Low Al ₂ O ₃ Low (Pd/Ir) _n	Low Al ₂ O ₃ Med-Low (Pd/Ir) _n	Low Al ₂ O ₃ High (Pd/Ir) _n
High degrees of partial melting	Less partial melting or Pt & Pd addition	Enriched by later melt
I-PGE>P-PGE	I-PGE>P-PGE (apart from Pt in sample 474568)	I-PGE = P-PGE
Age range is 1.75-3.75 Ga	Age range is 2.25-2.75 Ga	Age range is 0.75-2.50 Ga
 <p style="text-align: center;">W. Greenland PGE patterns Group 1</p>	 <p style="text-align: center;">W. Greenland PGE patterns Group 2</p>	 <p style="text-align: center;">W. Greenland PGE patterns Group 3</p>
<p> 474538 488883 488892 488889 474545 474577 488836 488850 488882 488886 474546 474547 474551 474576 474521 474555 474557 </p>	<p> 474568 474544 488890 474527 </p>	<p> 474570 488858 474535 </p>

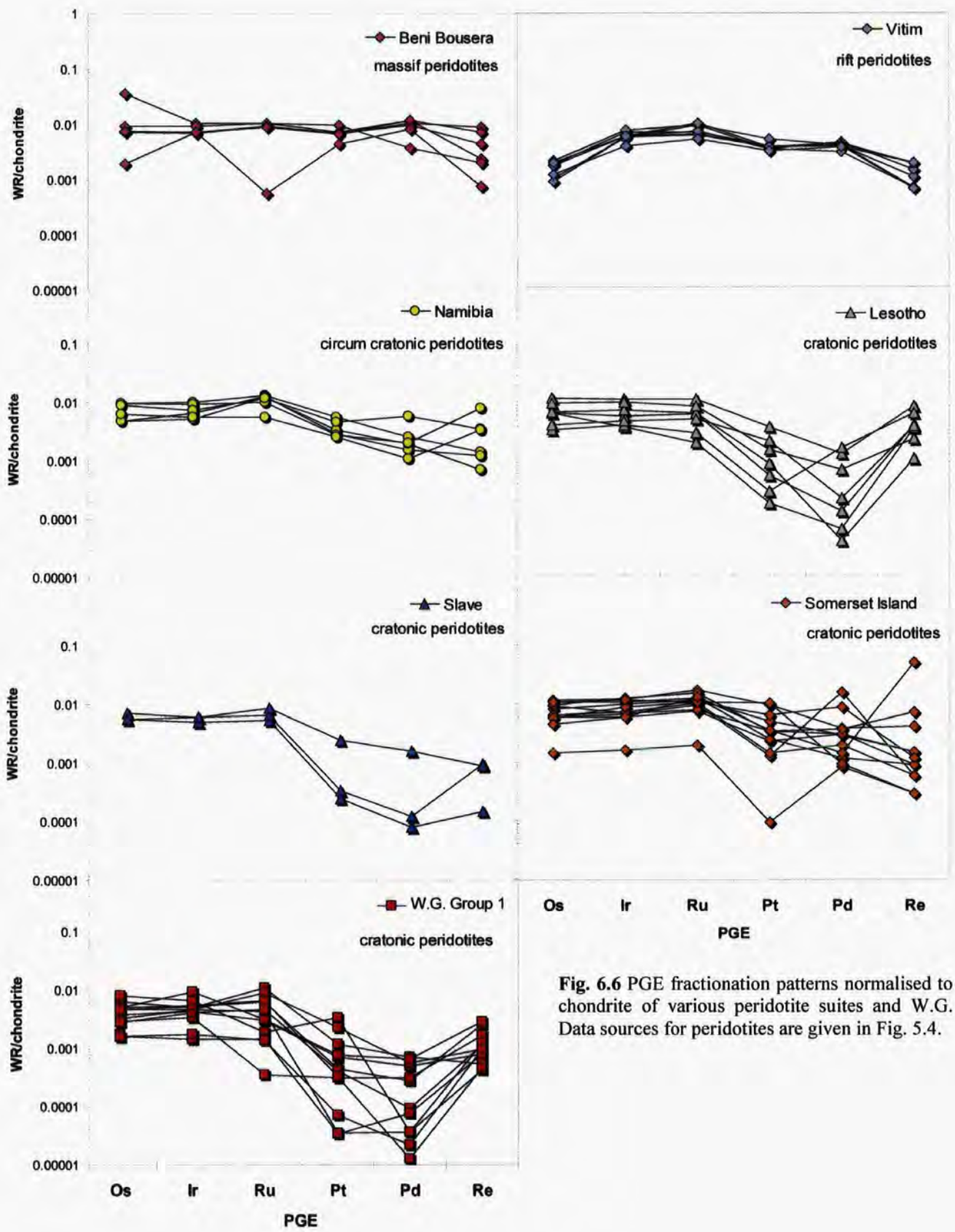


Fig. 6.6 PGE fractionation patterns normalised to chondrite of various peridotite suites and W.G. Data sources for peridotites are given in Fig. 5.4.

6.3 Investigation of a positive Pt anomaly in sample 474568

Low melting temperature sulphides are incorporated into the melt phase during high degrees of partial melting. Os, Ir and Ru are compatible refractory sulphides + alloys and can stabilise in the residue, but Pd and Re act moderately incompatible and are incorporated into the melt phase (Bockrath *et al.*, 2004). The behaviour of Pt is much more complicated than Pd and Re. Pt can be incompatible and enter the melt phase during partial melting, but as a Pt-Ir alloy it can be chemically inert and behave as a highly refractory compatible element becoming trapped in the residue (Luguet *et al.*, 2004).

Under conditions where monosulphide solid solution (Mss) is melting Pd it is more incompatible than Pt, and usually begins to enter the melt phase first and Pd therefore shows higher levels of depletion than Pt (Fig. 5.9) (Luguet *et al.*, 2004). The characteristic depletion of Pt and Pd in PGE fractionation patterns is an expected feature of residual peridotites. The relative depletions observed in harzburgites and depleted lherzolites require $D^{\text{solid/liquid}} \text{Re} < D^{\text{solid/liquid}} \text{Pd} < D^{\text{solid/liquid}} \text{Pt} < 1$ for peridotite-melt partition coefficients (Pearson *et al.*, 2004; Becker *et al.*, 2006).

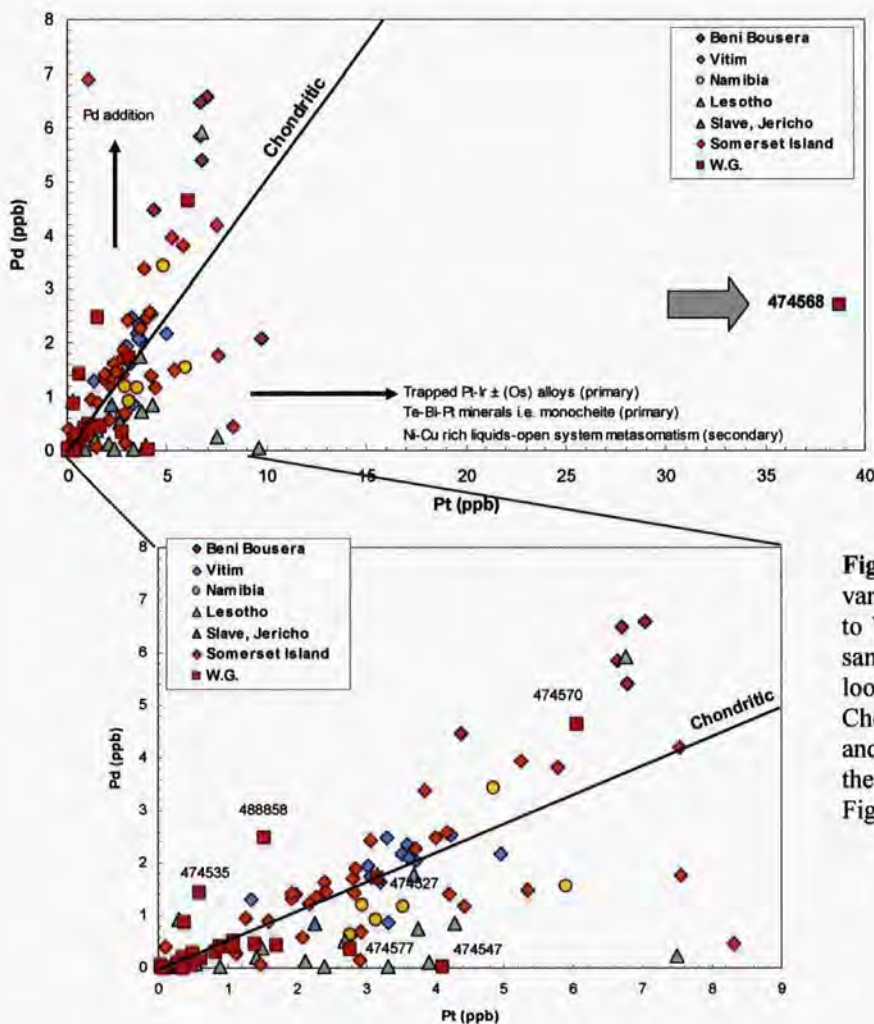


Fig. 6.7 Pd (ppb) vs. Pt (ppb) for various peridotite suites compared to W.G. Grey arrow is indicating sample 474568. Inset is a closer look at the low Pd vs. Pt area. Chondritic ratio after McDonough and Sun (1995). Data sources for the various peridotites are given in Fig. 5.4.

Pd is well correlated with Pt for the majority of the W.G. peridotite suite (Fig. 6.7) and other peridotite suites worldwide. Both Pt and Pd levels are generally low in all these residual peridotites. However, sample 474568 is extremely enriched in Pt, well above any normal metasomatic disturbances. This requires some explanation. In some residual peridotites Pt and Pd can be significantly disturbed, (see numerous discussions on this subject by Lugué *et al.*, 2006 & 2007; Ohnenstetter, 1992; Lorand *et al.*, 2007; Becker *et al.*, 2006).

Refractory Pt-Ir alloys can get trapped in residual peridotites after high degrees of partial melting due to the desulfidation of base metal sulphides (BMS) in the fertile mantle (Lugué *et al.*, 2007; Lorand *et al.*, 2007). This may account for the positive Pt anomaly in 474568. Pt-Ir alloys are chemically inert and can be highly refractory during this primary melting process (Lugué *et al.*, 2007; Lorand *et al.*, 2007). Alternatively, Ohnenstetter (1999) has suggested that positive Pt anomalies in mantle peridotites can be due to a mineralizing process involving fluid transport and precipitation of platinum group minerals (PGM) in fractures, associated with open system metasomatism in late stage fluids.

Photomicrographs of sample 474568 (Fig. 5.12) in Chapter 5, show a group of intergranular sulphides, probably not formed during primary melting and melt trapping processes. It is likely that these sulphides are of metasomatic origin i.e. high temperature processes, because of their inclusion in silicate phases (Pers. Com. J.P. Lorand). Photomicrographs 2 and 3 show a sulphide inclusion in a partially serpentinized olivine. The inclusion was formally composed of Mss and pentlandite. Mss phases are only stable at high temperatures. When the temperature begins to drop, the Mss begins to decompose to pentlandite, Pt-alloys and or other sulphide phases (Lugué *et al.*, 2004). The Mss in photomicrographs 2 and 3 of sample 474568 have now been replaced by microporous pentlandite by reacting with the low temperature serpentinization fluids (pers. com. J-P Lorand; Lorand and Grégoire, 2006). The presence of this secondary pentlandite can not contribute to positive Pt anomalies in PGE fractionation patterns (Lugué *et al.*, 2004), it is formed by replacement, as Pentlandite has negative Pt anomalies. However, sample 474568 has the highest Pt anomaly of all the W.G. peridotite samples by ~1 order of magnitude above the I-PGE group. This suggests that the presence of pentlandite in this sample

is not dominating the PGE budget of the rock. Other means of creating a positive Pt anomaly must be considered for this sample.

A Pt-Ir alloy deposited by decomposition of Mss or deposited from a percolating melt will create a positive Pt anomaly (Luguet *et al.*, 2007). Another possibility for generating anomalously high Pt contents could be via a Pt 'nugget effect' during sampling and digestion. The powdered sample may have a small grain of Pt-alloy incorporated into the digestion process. In order to eliminate the 'nugget effect' from this sample, it would be necessary to repeat another digestion of this sample and probably using a larger sample size. Unfortunately this was not possible due to the time constraints of this study. The presence of some Pt-Ir alloy phases seems the most likely explanation for this unusual Pt enrichment and a further SEM/TEM study to search for such phases seems warranted.

6.4 Timing of the stabilisation of the craton in S.W. Greenland

The residual signature and high degree of partial melting observed in the Group 1 peridotites for W.G., offer the best opportunities for constraining the true ages and therefore the stabilisation of the W.G. lithospheric mantle, because melt depletion may have frozen in unradiogenic Os isotope signatures.

Archean Re-depletion ages of ~3.0 Ga dominate the Group 1 peridotites for W.G. (Fig. 6.8). There is no obvious distinction between the Re-Os ages of xenoliths found on or off the craton (Fig. 6.9 & Fig. 6.10). This suggests that the Archean lithospheric mantle beneath the craton also extends beneath the reworked Archean terrane (RAT). However, a Re enrichment is seen in all W.G. samples, suggesting some Re addition from the host magma. This Re enrichment places some doubt on the true Re-Os model ages for W.G. peridotites, and makes it likely that they are minimum ages.

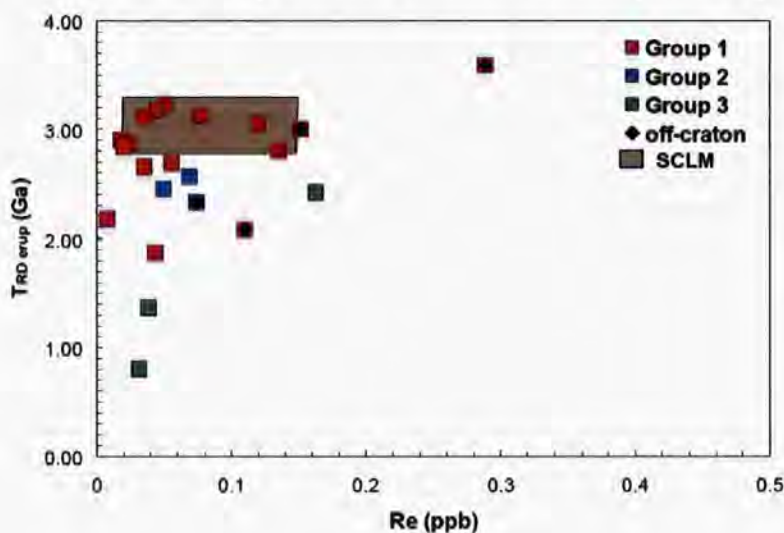


Fig. 6.8 $T_{RD\ erup}$ (Ga) model age vs. Re (ppb). Sub continental lithospheric mantle (SCLM) taken from Shirey & Walker, 1998). One data point has anomalously high Re (ppb) and the oldest age.

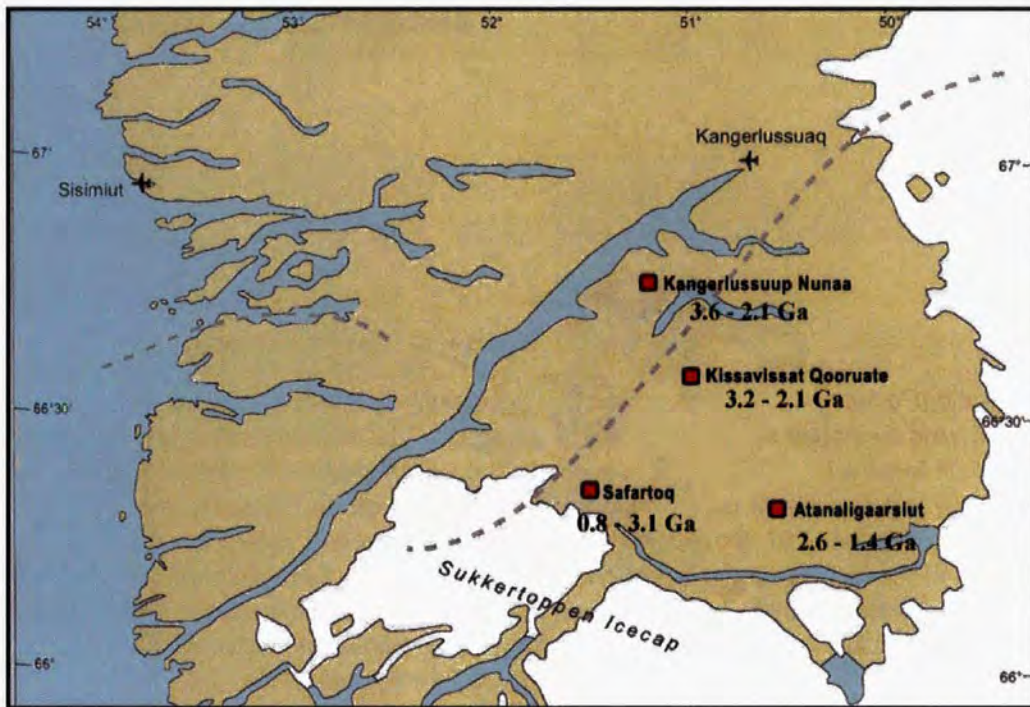


Fig. 6.9 Age ranges (Ga) for the W.G. peridotite xenoliths collected at the four localities

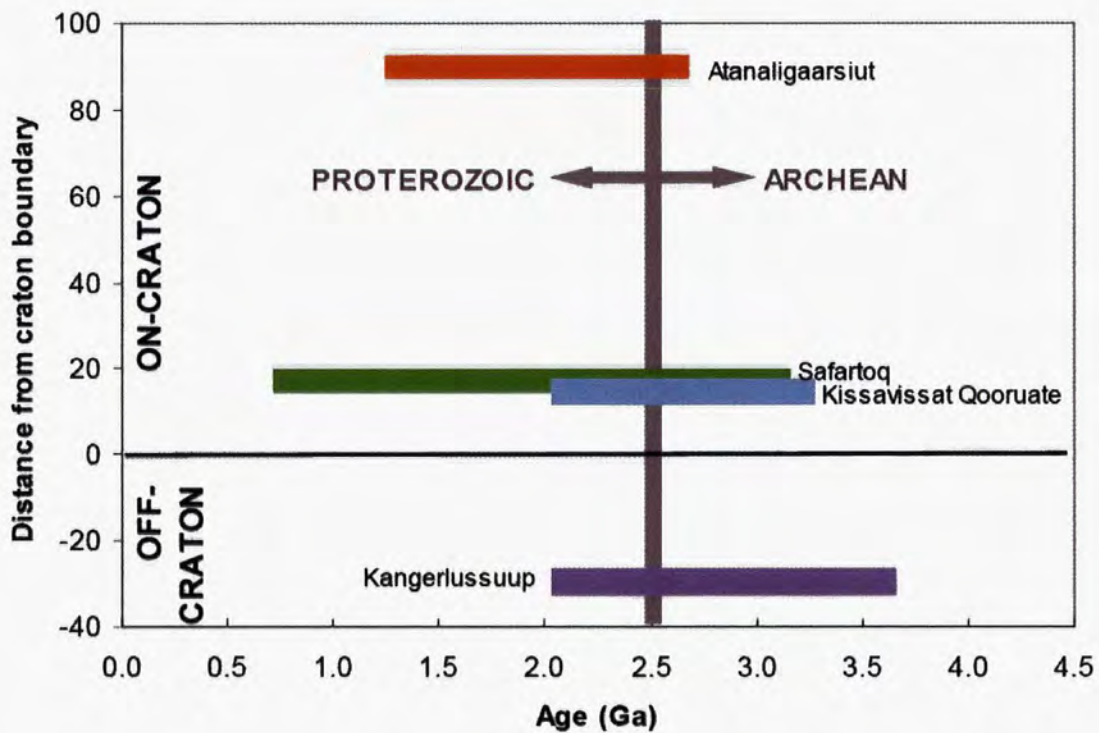


Fig. 6.10 Age ranges for the W.G. peridotite samples plotted against distance in km from the craton boundary. The grey line represents 2.5 Ga crust, older represents Archean crust and younger represents Proterozoic crust.

6.5 Diamond Potential in W.G.

Recent field studies by GEUS in W.G. have returned 111 micro- and 9 macro-diamonds from Garnet Lake in the Safartog area in 2004, and 124 micro- and 4 macro-diamonds from Safartog - Maniitsoq (south) in 2003 (Secher & Jensen, 2004).

Many reconnaissance investigations have taken place in the Safartog area; these are ground geophysics, mapping, helicopter borne geophysics, regional till and stream sediment research (Secher & Jensen, 2004). In constraining the diamond potential of this region it is important to determine lithospheric ages for both on and off the craton, as UML dykes occur in both these areas. This study is the first investigation into the age and timing of the stabilisation of the Archean lithospheric mantle beneath western Greenland. Specifically what lies beneath the re-worked Archean terrane? Is it all re-worked Archean, or new Proterozoic mantle, or undisturbed Archean lithosphere? The possible variations are illustrated in the 4 scenarios of Figure 6.11. In each scenario the plan view is the same, i.e. a central block of Archean crust surrounded by re-worked crust, but the cross section through the crust and mantle and the diamond potential is different. From the Re-Os age dating carried out by this research, Archean ~ 3.0 Ga mantle extends beneath the re-worked Archean terrane, indicating that scenario 3 from Figure 6.11 is representative of the lithospheric mantle beneath W.G.

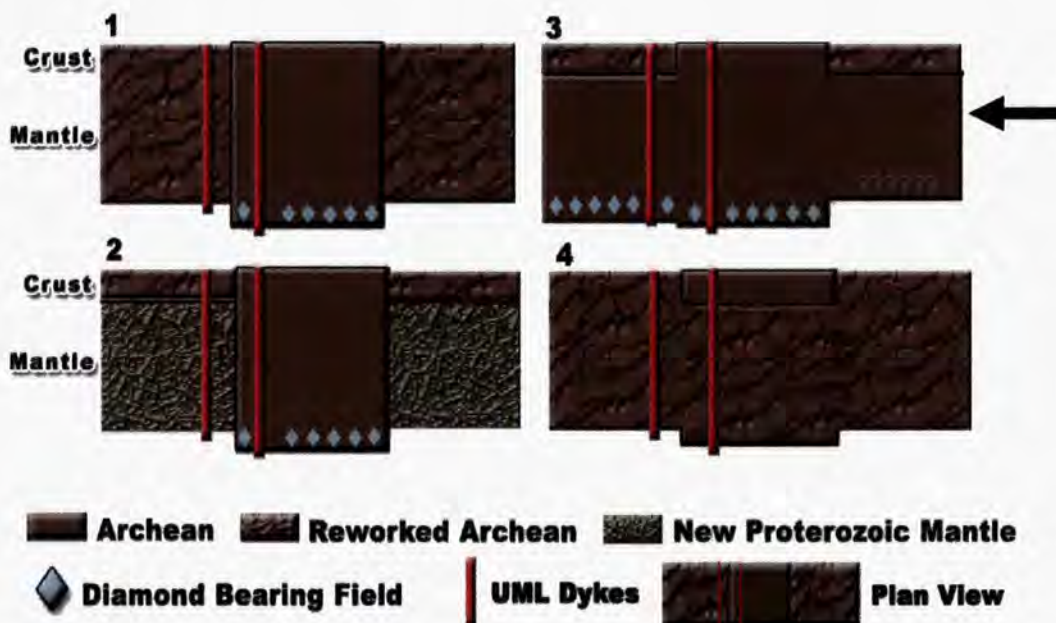


Fig. 6.11. In each of these four diagrams the crust on the surface appears the same, but the lithospheric mantle and diamond potential is different in each case. The scenario that appears to represent the lithospheric mantle beneath W.G. is No. 3. This would suggest the there is diamond potential in this area, both on and immediately at the edge of the 'craton' as defined by the area of re-worked Archean crust.

A better understanding of the depth of the Archean lithospheric mantle beneath W.G. is important in evaluating whether the UML dykes have come from the diamond stability field (>150 km) or not. Pressure and temperature work on peridotites xenoliths carried out by Sand (2007) has indicated that the depth of the lithosphere beneath W.G. extends to a depth of 220 km (Fig. 6.12 A).

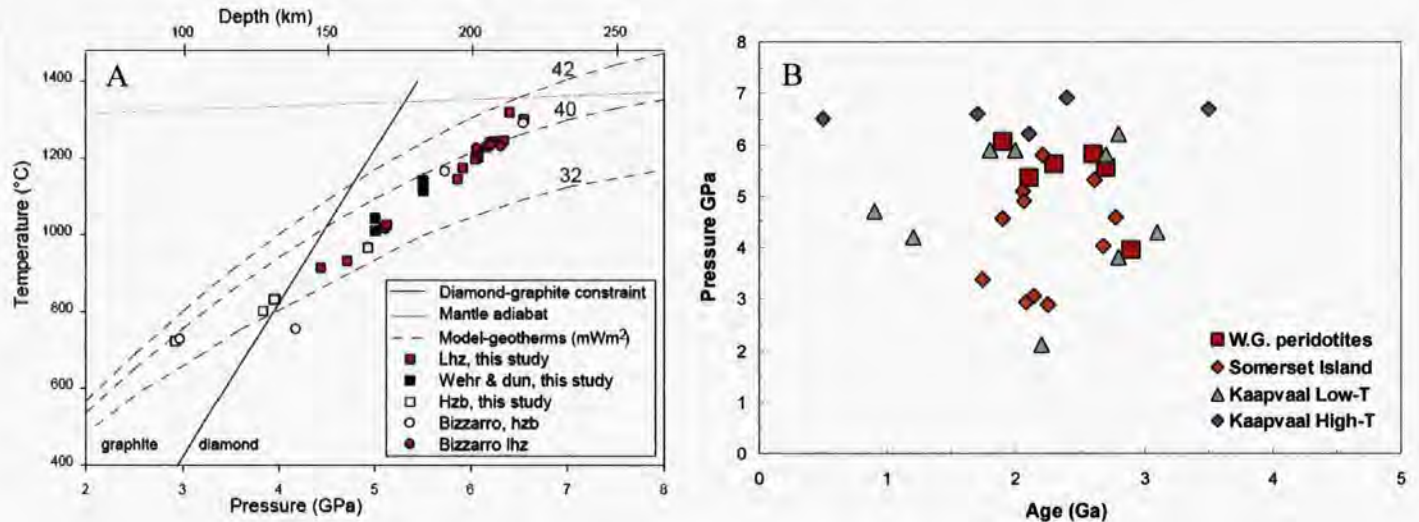


Fig. 6.12 A. Pressure and depth vs. temperature for W.G. samples taken from Sand (2007). B. Pressure (GPa) vs. Re-depletion ages (Ga) for W. G. peridotites and various other peridotite suites. (Data sources are Somerset Island = Irvine *et al.*, 2003, Kaapvaal low-T & high-T = Pearson *et al.*, 1995a) (W.G. pressure data was provided by Sand (2007)). There are only limited samples where pressure data is available for their corresponding ages.

A limited number of peridotites on which pressure and temperature determinations have been made have been analysed for Re-Os isotopes to determine their age (Fig 6.12 B). These samples show a range of pressures between 4 and 6 GPa. Sand (2007) suggests samples which are between 5.7 and 6.5 GPa have come from a depth range between 190 and 220 km. Although there is a range of ages in the samples determined for pressure and temperature, probably because these are clinopyroxene bearing lherzolites that have undergone metasomatism, Archean (>2.5 Gyr) Re-depletion ages are evident in both the shallowest and deepest samples. This indicates the presence of Archean mantle right into the diamond stability field in this region. The large proportion of samples in the depth range of 150-220km (Sand, 2007) suggests that a significant proportion of the xenoliths are being sampled from mantle in the diamond stability field. So from a diamond potential perspective, relating to the age of the Archean mantle beneath both areas, there is potential for diamond exploration.

CHAPTER 7
CONCLUSION

Chapter 7:

Conclusions

600 My old ultra-mafic lamproite (UML) dykes in the region between Kangerlussuaq and Safartoq of S.W. Greenland have erupted a remarkable collection of mantle xenoliths. This suite of peridotite xenoliths is particularly useful for Re-Os analysis because they are found in dykes that have intruded within the edge of an Archean craton, and the surrounding reworked Archean terrane. The aim of this research was to constrain the age of the lithospheric mantle beneath both these terranes, and to explore whether the Archean lithospheric mantle extends beneath the reworked Archean terrane. This study is a small part of a more extensive ongoing investigation by the Geological Survey of Denmark (GEUS) into the likely diamond potential of the area.

After careful investigation the W.G. peridotites were separated into 3 distinct groups based on their major element and PGE and Re contents. Group 1 are depleted residues from high degrees of partial melting probably up to ~40%. They have major element and PGE inter-element fractionation patterns characteristic of Archean mantle. These are, very low Al_2O_3 contents and Mg# of olivine ranging up to >93, plus PGE patterns that are significantly depleted in both Pt and Pd. The samples have minimum Re-Os ages ranging from 1.8 to 3.0 Ga. Thermobarometry investigations by Sand (2007) have revealed equilibration pressures for some of these samples of between 5-7 GPa, with a maximum depth of 220 km at 600 Ma (Sand, 2007). The xenoliths have therefore come from the diamond stability field. There is no distinct difference in the geochemical signatures of the xenoliths found on or off the craton. Re-depletion ages >2.5 Gyr for samples both on and off the craton edge indicate that old Archean lithospheric mantle extends beneath both the re-worked Archean terrane and the Archean craton. Groups 2 and 3 of the W.G. peridotites show more complicated disturbances in their geochemistry. Group 2 show positive anomalies in Ru, Pt, Pd and Re, Group 3 have relatively flat, unfractionated patterns. The additions of Pd and Re for Group 2 and 3 can be explained by metasomatic addition via sulphides, possibly during the formation of the ~2.0 Ga Kangâmiut dyke swarm and or from the host dyke during ascent through the crust. However, large positive Pt anomalies can

be more complicated to resolve. The most likely explanation for a large Pt anomaly found in one sample is the formation of anomalous amounts of refractory Pt-rich alloy phases in this sample.

The W.G. peridotite xenoliths that were placed into Group 1 most closely retain evidence of the original partial melting process and subsequent stabilisation of the W.G. mantle lithosphere. Therefore, the oldest Re-Os age data for Group 1 should be the most reliable age for the stabilisation of the lithospheric mantle beneath W.G. which is ~ 3.0 Ga.

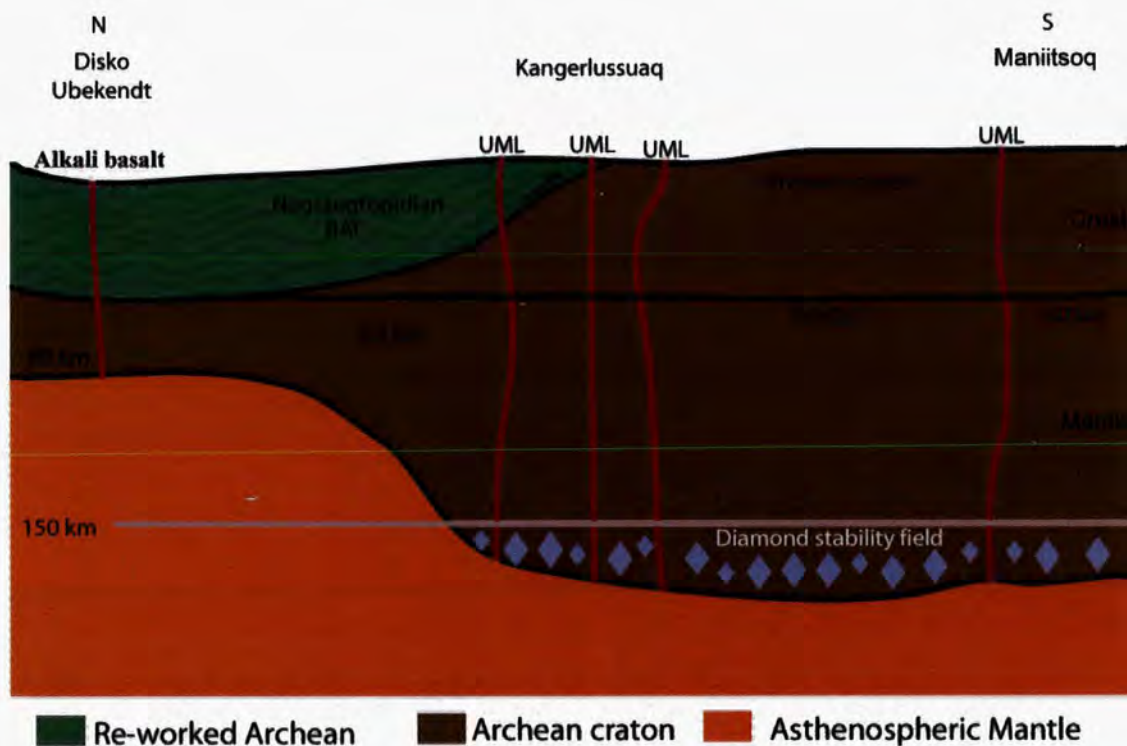


Fig. 7.1 Illustrates the Archean craton extending below the Nagssugtoqidian reworked Archean terrane. Disko alkali basalt from Bernstein *et al.*, 2006

7.2 Diamond potential

Thermobarometry work by Sand (2007) has shown that numerous peridotite samples from the Kangerlussuaq and Safartoq areas of W.G. have come from the diamond stability field plus shallower parts of the W.G. lithosphere. This plus the Archean ages found in this study therefore provide 2 main requirements for diamond potential one is very deep lithosphere and the second is Archean age. Work already carried out

by GEUS on some of the ultra-mafic dykes in this region have already returned micro and macro-diamonds (Fig. 7.2).

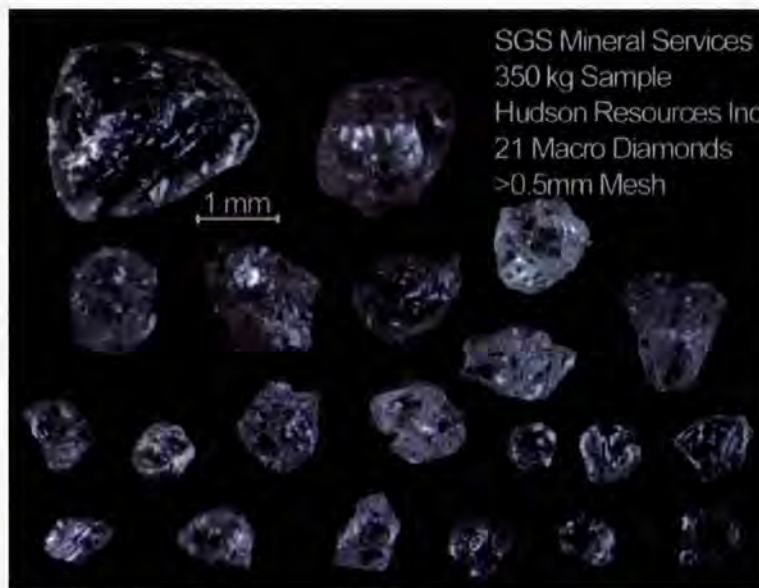


Fig. 7.2 Diamonds already discovered by Hudson Resources in SW Greenland. (HR website)

Further work is needed on the indicator minerals within the xenoliths to further constrain their relation to the diamond potential, and also on the mineralogy of the host dyke to understand its composition. There is still an ongoing debate as to whether the ultra-mafic dykes that brought these xenoliths to the surface in W.G. are kimberlitic or ultramafic lamprophyre. UML dykes are becoming increasingly more significant to the diamond exploration industry for hosting diamonds (Tappe *et al.*, 2004).

7.3 Future work

More peridotite xenoliths need to be collected and analysed from the off-craton area in W.G. In this study only 4 samples were analysed from UML dykes in the reworked Archean terrane. Although the major element and Re-Os data for these 4 samples is informative, it may not give a true representation of the area as a whole.

Analysing the trace element characteristics for the W.G. peridotite xenoliths would help to more firmly establish the depth of melting

Investigations into the FeO* content of the W.G. peridotite samples would resolve the large positive anomalies seen in the major element compositions.

A mineralogical investigation on the host dyke is needed to classify its composition. Is it a lamprophyre or a kimberlite?

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Appendices

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Appendix A

**Western Greenland
Rock Samples**

Appendix A (I)

Western Greenland peridotite xenolith sample descriptions

GEUS No.	Field number	Sample description	Grid Reference	Comments	Date
474521	L4a	Large lherzolite xenolith in float	N66° 44' 38.2/W51° 09' 65.6.	Hyperbyssal kimberlite with xenolith and ilmenite. a) harz xeno. b) lherz xeno. N66o 44' 52.8/51o 09' 89.0 = "sill" xenoliths.	19/07/2004
474527	L6a	very large (>10 kg) garnet/lherz xen, "sheared" high T? from Naroii dyke of Diamet	N66° 44' 45.1/W51° 10' 59.0	none	19/07/2004
474535	P1	2 fragments of very large (25 kg) garnet lz xenolith	N66° 21' 10.7/W51° 27' 47.6	none	13/07/2004
474536	P2	spinel/chromite lherz large 30 15 x 10 cm	N66° 21' 10.7/W51° 27' 47.6	none	14/07/2004
474538	P4	fist-sized garnet lherzolite	N66° 21' 10.7/W51° 27' 47.6	none	15/07/2004
474544	P10	fist sized garnet-harz/lherz abundant garnet	N66° 21' 10.7/W51° 27' 47.6	none	16/07/2004
474545	P11	large 15 x 10 cm garnet harz	N66° 21' 10.7/W51° 27' 47.6	none	17/07/2004
474546	P12	garnet harz fist sized	N66° 21' 10.7/W51° 27' 47.6	none	18/07/2004
474547	P13	garnet harz fist sized	N66° 21' 10.7/W51° 27' 47.6	none	19/07/2004
474551	P17	garnet, lz, scarce garnet	N66° 21' 10.7/W51° 27' 47.6	none	20/07/2004
474555	L1a	large garnet lherz- 3 fragments	?	none	20/07/2004
474557	L1c	fist sized peridotite xenolith	?	none	21/07/2004
474566	P-dyke	none	?	none	23/07/2004
474568	Hardy 1	Xenolith	N66° 23' 17.9/W50° 42' 52.1	none	15/07/2004
474570	Anna	none	?	none	15/07/2004
474573	P18	none	N66° 21' 10.7/W51° 27' 47.6	none	17/07/2004
474574	P19	none	N66° 21' 10.7/W51° 27' 47.6	none	18/07/2004
474575	P20	none	N66° 21' 10.7/W51° 27' 47.6	none	19/07/2004
474576	P21	none	N66° 21' 10.7/W51° 27' 47.6	none	20/07/2004
474577	P-dyke 3	Xenolith	?	none	15/07/2004
488836		10 x 5 + 8 x 3 cm sp. Lz. In same block. Poss same sample	N66° 28' 29/W 50° 56' 49		14/07/2004
488850		3 fragments large coarse lherz	N66° 28' 29/W 50° 56' 49	Ilmenite bearing kimberlite (26) the rest are xenoliths. Some with garnet. Strong serpentinisation in most nodules have lead to black colour - very difficult to see garnet or cpx. 2 samples with chromite and garnet to take back to Durham.	14/07/2004
488858		2 altered lherz in hand specimen	N66° 28' 29/W 50° 56' 49		14/07/2004
488866		dunite loose block in granite - poss refer to carbonatite cumulate??			14/07/2004
488869		5 fragments altered lherz diff samples	N66° 28' 33.5/W50° 56' 57.5		16/07/2004
488882		single 10 x 10 x 8 cm lherz xenolith	N66° 28' 33.5/W50° 56' 57.5	Lower portion of main Francois dyke. Sunny and cool. 1/2 km from camp on lake edge. Good exposures of xenoliths bearing float in broad shallow gully at small mossy lake behind prominent granite "Kopje" ~0.5 km below base of main gully. Good garnet bearing (purple) +1 chromite, dunite Lherzolite lots of ilmenite locally in kimberlite. Several locations ~5-10 m apart in small gully leading from lake (minor stream to NE).	16/07/2004
488883		7 fragments of single large lherz xenoliths	N66° 28' 33.5/W50° 56' 57.5		16/07/2004
488888		9 x 6 chromite/lherz xenolith	N66° 28' 33.5/W50° 56' 57.5	Superb blocks packed with ~70 - 90% peridotite xenoliths (N66o 28' 31/W50o 56' 57.7) Tracing of main Francois dyke indicates continuity from upper main gully to within 50m of lake shore and then probably extends across lake - evidenced via loose blocks walking towards outcrop in gully to N. Host is altered granite.	16/07/2004
488890		4 lherz/dunite xenoliths	N66° 28' 33.5/W50° 56' 57.5		16/07/2004
488892		large chromite lherz xenolith	N66° 28' 33.5/W50° 56' 57.5		16/07/2004

Appendix B

**Western Greenland
Major Elements**

Appendix B (I) W.G.

Anhydrous Major element oxides Western Greenland peridotite xenolith suite (This Study)

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	K ₂ O	P ₂ O ₅	Total	LOI
474521	0.0810	48.3453	0.2778	42.2496	0.6830	0.1158	0.1088	7.9986	0.0995	0.0405	100.00	1.16
474527	0.1151	47.3349	0.7160	43.4986	0.6636	0.1696	0.1078	7.3190	0.0471	0.0283	100.00	1.05
474535	0.0346	47.5576	0.8146	40.7457	0.8469	0.1281	0.1281	9.6567	0.0542	0.0335	100.00	1.15
474536	0.0457	49.9355	0.1051	41.8936	1.1118	0.1463	0.0983	6.5781	0.0411	0.0446	100.00	1.14
474538	0.0915	45.6446	1.8103	42.7003	0.9337	0.2083	0.1327	8.4225	0.0469	0.0092	100.00	1.14
474544	0.0474	49.0026	0.2122	40.7831	0.6994	0.1375	0.1197	8.8855	0.0759	0.0367	100.00	1.19
474545	0.0812	47.9866	1.0801	43.6884	0.4130	0.0882	0.1056	6.4409	0.0754	0.0406	100.00	1.16
474546	0.0352	48.6110	0.9000	42.9755	0.3059	0.0293	0.0996	6.9687	0.0492	0.0258	100.00	1.17
474547	0.0707	48.9456	0.5088	42.3244	0.9551	0.0978	0.0848	6.9528	0.0318	0.0283	100.00	1.18
474551	0.0556	49.3954	0.5116	41.7436	0.5995	0.1112	0.1057	7.3807	0.0634	0.0334	100.00	1.11
474555	0.1207	46.1628	0.7058	43.8150	0.7661	0.1910	0.1153	8.0135	0.0856	0.0241	100.00	1.10
474557	0.1231	46.3816	0.5460	42.4546	2.4613	0.0694	0.1197	7.4987	0.3065	0.0392	100.00	1.12
474566	0.0807	48.2757	0.8159	43.4366	0.2478	0.0438	0.0991	6.9485	0.0426	0.0092	100.00	1.15
474566	0.0977	41.6183	1.1317	36.5567	5.9125	1.6774	0.1892	11.8850	0.6470	0.2845	100.00	1.22
474568	0.1770	44.6618	0.9836	43.4747	1.3122	0.2091	0.0852	9.0743	0.0221	0.0000	100.00	1.11
474568	0.1127	44.3436	1.3034	43.6406	1.2753	0.1769	0.0856	9.0079	0.0315	0.0225	100.00	1.13
474570	0.0813	47.5095	0.0945	40.8202	0.3730	0.0681	0.1260	10.8693	0.0559	0.0020	100.00	1.02
474573	0.0580	47.6211	1.0079	40.8827	0.8385	0.1264	0.1345	9.2520	0.0510	0.0278	100.00	1.16
474574	0.0578	48.7545	0.6524	43.1054	0.4765	0.1492	0.0948	6.6422	0.0312	0.0359	100.00	1.16
474575	0.0917	46.3292	1.5607	42.8054	0.5699	0.1273	0.1101	8.3208	0.0527	0.0321	100.00	1.15
474576	0.0679	48.2362	0.1154	40.4598	0.4481	0.1697	0.1075	10.3319	0.0272	0.0362	100.00	1.13
474577	0.0793	45.0835	1.0156	45.1786	0.9420	0.0759	0.1200	7.4235	0.0510	0.0306	100.00	1.13
488836	0.0233	48.2509	0.1989	40.5321	1.0469	0.1663	0.1466	9.4769	0.0942	0.0640	100.00	1.16
488850	0.0345	50.9367	0.1413	41.2561	0.2919	0.0747	0.0988	7.0775	0.0448	0.0437	100.00	1.15
488858	0.0346	44.8310	0.2887	41.0381	0.3477	0.4366	0.1120	12.7865	0.0751	0.0497	100.00	1.15
488866	0.0109	43.7464	0.3256	40.4144	0.1172	0.0369	0.2030	15.1315	0.0033	0.0109	100.00	1.09
488869	0.0447	49.1236	0.4619	41.7936	0.5592	0.1163	0.1107	7.6915	0.0738	0.0246	100.00	1.12
488882	0.0454	47.1079	0.7027	43.0130	0.6040	0.1362	0.1090	8.1318	0.1147	0.0352	100.00	1.14
488883	0.0708	51.0607	0.0602	41.2955	0.4321	0.0649	0.1003	6.8683	0.0449	0.0024	100.00	1.18
488888	0.1035	48.3260	0.0725	40.7455	0.7396	0.1162	0.1472	9.6298	0.1012	0.0184	100.00	1.15
488890	0.0235	46.3023	0.2527	39.4212	2.3909	0.2069	0.1728	10.9253	0.1939	0.1105	100.00	1.18
488892	0.1145	49.0545	0.4158	40.7532	0.5304	0.1753	0.1168	8.7719	0.0607	0.0069	100.00	1.15
PM	0.3600	37.8000	4.4500	45.0000	3.5500	0.2000	0.1350	8.0500	0.0290	0.0210	99.60	

FeO* : Total Fe given as FeO*. Corrected for LOI. Analyses were performed by X.R.F. at Geological Survey of Denmark (GEUS). Oxides in wt%.

PM: Primitive Mantle (McDonough and Sun, 1995).

Appendix B (II) W.Greenland

Major element oxide ratios Western Greenland peridotite xenolith suite (This Study)

SAMPLE	MgO/SiO ₂	Al/Si	Ca/Al	Mg/Si	Ca/Si	Mg#
474521	1.144278	0.007444	3.319737	1.476424	0.024712	91.5
474527	1.088194	0.018634	1.251688	1.404062	0.023324	92.0
474535	1.167181	0.022632	1.403959	1.505976	0.031775	89.8
474536	1.191959	0.002841	14.281964	1.537946	0.040571	93.1
474538	1.068952	0.047994	0.696541	1.379233	0.033430	90.6
474544	1.201540	0.005890	4.451044	1.550308	0.026216	90.8
474545	1.098383	0.027987	0.516373	1.417208	0.014452	93.0
474546	1.131132	0.023708	0.458926	1.459463	0.010880	92.6
474547	1.156440	0.013609	2.535129	1.492117	0.034500	92.6
474551	1.183305	0.013875	1.582318	1.526780	0.021954	92.3
474555	1.053585	0.018236	1.465910	1.359406	0.026732	91.1
474557	1.092497	0.014559	6.087876	1.409614	0.088631	91.7
474566	1.111406	0.021265	0.410080	1.434011	0.008721	92.5
474566	1.138458	0.035047	7.055010	1.468916	0.247256	86.2
474568	1.027307	0.025613	1.801548	1.325501	0.046142	89.8
474568	1.016108	0.033812	1.321223	1.311051	0.044674	89.8
474570	1.163874	0.002622	5.329004	1.501708	0.013971	88.6
474573	1.164823	0.027909	1.123522	1.502933	0.031356	90.2
474574	1.131054	0.017133	0.986464	1.459362	0.016901	92.9
474575	1.082322	0.041275	0.493130	1.396485	0.020354	90.8
474576	1.192202	0.003230	5.242735	1.538260	0.016932	89.3
474577	0.997895	0.025449	1.252546	1.287551	0.031877	91.5
488836	1.190438	0.005555	7.107376	1.535983	0.039485	90.1
488850	1.234645	0.003879	2.788634	1.593023	0.010816	92.8
488858	1.092426	0.007965	1.625883	1.409522	0.012951	86.2
488866	1.082445	0.009121	0.486145	1.396643	0.004434	83.7
488869	1.175386	0.012512	1.634869	1.516562	0.020455	91.9
488882	1.095202	0.018496	1.160604	1.413103	0.021466	91.2
488883	1.236471	0.001651	9.691117	1.595378	0.015995	93.0
488888	1.186043	0.002013	13.782669	1.530312	0.027751	89.9
488890	1.174553	0.007258	12.775426	1.515488	0.092719	88.3
488892	1.203699	0.011551	1.722413	1.553094	0.019895	90.9

Analyses were performed by X.R.F. at Geological Survey of Denmark (GEUS). Oxides in wt%.

Appendix B (III) W. Greenland

Trace elements Western Greenland peridotite xenolith suite (This Study)

Sample	Ba	Rb	Nb	La	Ce	Sr	Zr	Y	V	Cr	Ni	Cu	Zn	Mo	Sn
474521	38	0	7	18	0	97	0	0	53	1360	2286	9	49	0	0
474527	8	0	0	29	0	68	0	0	48	2269	2318	19	53	0	0
474535	97	0	0	51	0	73	0	0	43	2029	2556	13	56	0	0
474536	52	0	1	24	0	85	0	0	35	2403	2534	6	41	0	0
474538	0	0	0	47	0	84	0	0	40	2073	2211	12	48	0	0
474544	72	0	9	0	0	89	0	0	34	1786	2444	12	34	0	0
474545	55	0	0	0	0	62	0	0	46	3018	2145	3	38	0	0
474546	61	0	7	0	0	60	0	0	30	1980	2438	7	26	0	0
474547	49	0	0	0	0	124	0	0	37	1993	2427	6	38	0	0
474551	74	0	2	0	0	84	0	0	55	4118	2537	11	47	0	0
474555	84	0	9	0	0	82	0	0	54	1970	2425	12	37	0	0
474557	42	8	6	0	0	117	5	0	81	3420	2306	14	37	0	0
474566	0	0	0	79	0	69	0	0	13	2003	2361	19	37	0	0
474566	359	9	88	84	100	456	66	0	94	1693	1515	36	74	0	0
474568	0	0	0	90	0	67	0	0	33	2321	2233	16	40	0	0
474568	23	0	0	0	0	72	0	0	68	3018	2225	9	44	0	0
474570	0	0	0	108	0	98	0	0	16	485	2765	12	76	0	0
474573	0	0	0	2	0	61	0	0	48	2641	2460	13	55	0	0
474574	14	0	0	27	0	56	0	0	39	2071	2196	7	38	0	0
474575	19	0	2	40	0	68	0	0	54	1731	2147	18	55	0	0
474576	30	0	5	19	0	93	0	0	42	393	2302	7	70	0	0
474577	7	0	5	5	0	75	0	0	47	3053	2150	11	28	0	0
488836	112	0	14	0	0	134	0	0	29	1048	2445	14	37	0	0
488850	23	0	6	0	0	72	0	0	24	1136	2494	9	26	0	0
488858	24	2	13	58	0	79	0	0	42	394	1851	38	61	0	0
488866	8	3	12	7	0	68	4	0	41	4995	2059	6	119	0	0
488869	32	0	5	0	0	71	0	0	31	2402	2519	11	34	0	0
488882	134	0	7	0	0	76	0	0	46	2602	2267	15	35	0	0
488883	0	0	0	64	0	80	0	0	12	1472	2505	7	36	0	0
488888	40	0	0	79	0	105	0	0	31	1412	2206	9	58	0	0
488890	177	8	20	26	0	236	20	0	59	1758	2005	21	58	0	0
488892	0	0	0	69	0	87	0	0	22	3800	2539	9	48	0	0

Analyses were performed by X.R.F. at Geological Survey of Denmark (GEUS). Elements in pp

Appendix B (IV) UML

Major element anhydrous oxides Western Greenland UML suite (Holgate, 2005).

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	K ₂ O	P ₂ O ₅	Total
474514	0.128	29.084	3.017	33.789	15.113	2.646	0.234	13.506	1.898	0.585	100.000
474515	0.141	28.207	3.146	33.649	13.970	3.225	0.260	14.646	1.830	0.926	100.000
474516	0.083	26.754	2.960	32.384	18.042	2.773	0.271	13.532	1.926	1.275	100.000
474517	0.072	42.217	1.409	36.125	3.198	3.321	0.200	12.532	0.834	0.092	100.000
474560	0.060	38.795	1.028	34.019	9.509	2.160	0.239	12.849	0.819	0.520	100.000
483838	0.113	39.498	1.690	32.784	10.897	2.851	0.195	10.909	0.719	0.343	100.000
483840	0.071	38.975	1.943	35.067	8.474	3.114	0.219	11.390	0.427	0.320	100.000
483842	0.132	39.878	1.880	30.304	11.995	3.145	0.219	11.471	0.586	0.390	100.000
483843	0.094	38.908	3.203	28.784	8.737	4.917	0.268	14.262	0.629	0.200	100.000
483844	0.158	40.085	1.835	32.332	10.303	2.757	0.200	10.909	1.049	0.371	100.000
483845	0.070	44.066	0.669	35.398	5.699	2.555	0.172	10.934	0.120	0.317	100.000
483847	0.103	46.639	0.966	33.635	4.789	2.279	0.190	11.094	0.250	0.055	100.000
483848	0.224	40.966	1.363	28.879	13.830	2.385	0.220	10.938	0.113	1.081	100.000
483849	0.076	40.014	2.197	30.128	8.736	4.027	0.269	13.431	0.682	0.440	100.000
483850	0.120	39.072	1.656	30.043	14.059	2.801	0.213	11.108	0.604	0.324	100.000
483857	0.140	41.824	1.719	31.164	8.823	3.275	0.229	12.265	0.116	0.445	100.000
483860	0.118	41.426	1.356	31.627	8.740	2.779	0.211	12.237	0.599	0.907	100.000
483861	0.071	39.952	1.284	31.617	13.462	2.229	0.185	10.465	0.205	0.530	100.000
483862	0.197	34.709	1.734	21.927	23.328	4.854	0.244	12.481	0.062	0.465	100.000
483863	0.079	43.567	1.525	32.701	6.219	3.580	0.212	11.922	0.112	0.083	100.000
483864	0.103	38.433	1.869	29.715	7.898	7.265	0.227	13.519	0.570	0.401	100.000
488810	0.084	36.986	1.559	32.093	12.342	2.471	0.226	12.597	0.994	0.648	100.000
488822	0.099	31.832	2.411	30.888	17.376	2.620	0.213	11.917	1.573	1.071	100.000
488823	0.097	36.230	1.847	32.532	11.801	2.583	0.241	12.667	1.277	0.724	100.000
488825	0.074	33.130	1.858	31.834	16.549	2.295	0.194	11.781	1.263	1.021	100.000

FeO* : Total Fe given as FeO*. Corrected for LOI. Analyses were performed by X.R.F. at Geological Survey of Denmark (GEUS). Oxides in wt%.

Appendix B (V) UML

Trace elements Western Greenland UML suite (Holgate, 2005)

Sample	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Mo	Sn	Ba	La	Ce
474514	214	1527	878	134	111	82	1062	28	198	109	0	0	805	77	119
474515	221	1687	752	123	107	79	833	38	412	124	0	0	712	149	134
474516	237	1358	706	120	103	91	1076	43	408	131	0	0	712	175	156
474517	102	1488	1431	72	77	23	267	0	53	130	0	0	527	94	89
474560	166	2345	1289	48	94	27	910	0	75	115	0	0	548	116	109
483838	160	1591	1399	110	72	0	695	0	95	155	0	0	1042	270	100
483840	144	1531	1381	122	69	0	477	0	104	170	0	0	1090	157	106
483842	166	1721	1235	99	71	0	1065	0	143	179	0	0	1927	246	107
483843	217	2232	1166	234	89	14	722	11	272	278	0	0	1984	312	305
483844	128	1402	1255	105	65	23	923	0	95	177	0	0	1709	222	91
483845	119	1528	1699	52	47	0	621	0	56	128	0	0	817	174	31
483847	111	1431	1564	83	56	0	572	0	104	117	0	0	842	133	56
483848	125	1485	1232	82	67	0	1620	0	138	232	0	0	2506	286	268
483849	163	1816	1132	103	63	9	1459	0	153	220	0	0	1447	236	138
483850	149	1399	1209	90	69	1	915	0	130	112	0	0	1239	169	77
483857	158	1485	1262	103	75	0	989	0	168	208	0	0	1591	238	217
483860	132	1186	1216	85	72	0	906	0	169	208	0	0	1688	212	81
483861	118	1282	1448	53	66	0	868	0	100	120	0	0	921	232	93
483862	235	1051	530	55	73	0	1882	29	212	240	0	0	1252	320	280
483863	174	1348	1399	103	66	0	525	0	79	97	0	0	969	219	56
483864	269	1721	1287	106	78	1	897	13	172	287	0	0	1119	311	214
488810	142	1586	1164	51	89	41	1105	7	124	149	0	0	770	142	176
488822	144	1435	937	88	88	68	1298	20	148	156	0	0	1158	173	207
488823	178	1700	1168	84	90	53	975	9	113	141	0	0	925	153	177
488825	147	1337	1017	87	85	50	1181	10	223	127	0	0	631	100	148

Analyses were performed by X.R.F. at Geological Survey of Denmark (GEUS). Elements in ppm..

Appendix C

**Western Greenland
Platinum Group Elements**

Appendix C (I) W. Greenland

PGE element concentrations for Western Greenland peridotite xenolith suite

Samp No.	Measured						Chondrite normalised					
	Os (ppb)	Ir (ppb)	Ru (ppb)	Pt (ppb)	Pd (ppb)	Re (ppb)	Os (ppb)	Ir (ppb)	Ru (ppb)	Pt (ppb)	Pd (ppb)	Re (ppb)
474521	1.0446	1.1398	1.4909	0.6002	0.1820	0.1518	0.0021	0.0025	0.0021	0.0006	0.0003	0.0040
474527	4.2898	4.0602	7.9618	3.1621	1.7298	0.0742	0.0088	0.0088	0.0112	0.0032	0.0031	0.0020
474535	0.8640	0.6564	2.3405	0.5940	1.4415	0.0313	0.0018	0.0014	0.0033	0.0006	0.0026	0.0008
474538	2.8579	3.0480	5.8000	0.5120	0.1770	0.1198	0.0059	0.0066	0.0081	0.0005	0.0003	0.0032
474544	1.2550	1.0395	33.4081	1.0807	0.5047	0.0494	0.0026	0.0023	0.0468	0.0011	0.0009	0.0013
474545	2.8770	2.6408	3.7921	0.0359	0.0211	0.0183	0.0059	0.0058	0.0053	0.0000	0.0000	0.0005
474546	3.0600	3.1569	6.0698	0.3601	0.0070	0.0199	0.0063	0.0069	0.0085	0.0004	0.0000	0.0005
474547	5.0238	3.8176	1.6366	4.1146	0.0209	0.0557	0.0103	0.0083	0.0023	0.0041	0.0000	0.0015
474551	0.9638	0.7992	1.2304	0.0345	0.0464	0.0354	0.0020	0.0017	0.0017	0.0000	0.0001	0.0009
474555	2.6719	3.2265	4.8334	1.7155	0.4468	0.1101	0.0055	0.0070	0.0068	0.0017	0.0008	0.0029
474557	0.8925	0.8015	2.2639	0.2703	0.0708	0.2896	0.0018	0.0017	0.0032	0.0003	0.0001	0.0076
474568	4.1940	3.8480	7.5259	38.7340	2.7005	0.0689	0.0086	0.0084	0.0105	0.0390	0.0049	0.0018
474570	2.4190	2.2570	4.3958	6.0460	4.6462	0.0384	0.0050	0.0049	0.0062	0.0061	0.0084	0.0010
474576	0.9611	0.9809	1.1797	0.0745	0.0125	0.0444	0.0020	0.0021	0.0017	0.0001	0.0000	0.0012
474577	1.9499	2.7007	8.1162	2.7771	0.3588	0.0440	0.0040	0.0059	0.0114	0.0028	0.0006	0.0012
488836	3.1087	5.4371	2.7410	0.8810	0.4213	0.1353	0.0064	0.0118	0.0038	0.0009	0.0008	0.0036
488850	1.6502	2.3422	4.2211	0.4672	0.0559	0.0507	0.0034	0.0051	0.0059	0.0005	0.0001	0.0013
488858	0.8902	0.8497	1.5064	1.5336	2.4896	0.1630	0.0018	0.0019	0.0021	0.0015	0.0045	0.0043
488866	1.4795	1.3758	Neg No.	0.4827	0.2945	0.0085	0.0030	0.0030	Neg No.	0.0005	0.0005	0.0002
488869	2.3519	2.4773	2.6577	0.8340	0.3148	0.0353	0.0048	0.0054	0.0037	0.0008	0.0006	0.0009
488882	21000.6870	2.7628	5.7303	1.0724	0.3989	1.5884	43.2113	0.0060	0.0080	0.0011	0.0007	0.0418
488883	1.7609	1.9270	0.2914	0.3457	0.2009	0.0773	0.0036	0.0042	0.0004	0.0003	0.0004	0.0020
488890	0.0466	0.8042	4.2792	0.3674	0.8740	0.0615	0.0001	0.0018	0.0060	0.0004	0.0016	0.0016
488892	3.9073	2.8700	9.9970	1.3978	0.4706	0.0241	0.0080	0.0063	0.0140	0.0014	0.0008	0.0006

Chondrite normalised = measured value / value for chondrite PGE elements

Appendix C (II) W.Greenland PGE

PGE for Western Greenland peridotite xenolith suite

Samp No.	$^{187}\text{Os}/^{188}\text{Os}$	$^{187}\text{Re}/^{188}\text{Os}$	(Pd/Ir) <i>n</i> (ppb)	(Re/Ir) <i>n</i> (ppb)	yOs	Mg#	Myr			Gyr		
							T _{RD}	T _{RD Erup}	T _{MA}	T _{RD}	T _{RD Erup}	T _{MA}
474521	0.113990	0.698598	0.15968	1.60869	-13	91.5	2046	2998	3308	2.0	3.0	3.3
474527	0.112733	0.083137	0.42604	0.22074	-9	92.0	2217	2331	2745	2.2	2.3	2.7
474535	0.1247802	0.174639	2.19591	0.57672	-0.4	89.8	552	797	935	0.6	0.8	0.9
474538	0.108576	0.201371	0.05807	0.47476	-14	90.6	2781	3054	5188	2.8	3.1	5.2
474544	0.112842	0.189326	0.48555	0.57440	-10	90.8	2202	2461	3920	2.2	2.5	3.9
474545	0.108017	0.030574	0.00800	0.08376	-13	93.0	2857	2898	3073	2.9	2.9	3.1
474546	0.1084369	0.031298	0.00223	0.07628	-13	92.6	2800	2843	3018	2.8	2.8	3.0
474547	0.1097824	0.053281	0.00546	0.17628	-12	92.6	2618	2691	2985	2.6	2.7	3.0
474551	0.1078785	0.176611	0.05809	0.53562	-14	92.3	2876	3114	4845	2.9	3.1	4.8
474555	0.115726	0.198114	0.13848	0.41214	-8	91.1	1808	2080	3348	1.8	2.1	3.3
474557	0.118250	1.560720	0.08833	4.36440	-17	91.7	1460	3587	-555	1.5	3.6	-0.6
474568	0.110947	0.078943	0.70179	0.21628	-11	89.8	2460	2568	3009	2.5	2.6	3.0
474570	0.119720	0.076368	2.05857	0.20551	-4	88.6	1257	1363	1530	1.3	1.4	1.5
474576	0.107816	0.221675	0.01278	0.54620	-15	89.3	2884	3183	5888	2.9	3.2	5.9
474577	0.116342	0.108460	0.13285	0.19670	-7	91.5	1723	1873	2304	1.7	1.9	2.3
488836	0.110469	0.209116	0.07749	0.30056	-12	90.1	2525	2809	4881	2.5	2.8	4.9
488850	0.106755	0.147663	0.02385	0.26166	-15	92.8	3027	3226	4582	3.0	3.2	4.6
488858	0.120077	0.880974	2.92998	2.31713	-10	86.2	1208	2422	-1144	1.2	2.4	-1.1
488866	0.1133116	0.027742	0.21406	0.07497	-9	83.7	2138	2176	2285	2.1	2.2	2.3
488869	0.110217	0.072137	0.12707	0.17217	-11	91.9	2559	2658	3070	2.6	2.7	3.1
488882	0.1139149	0.000364	0.14440	6.94441	-8	91.2	2056	2056	2058	2.1	2.1	2.1
488883	0.108130	0.210863	0.10426	0.48454	-14	93.0	2842	3127	5523	2.8	3.1	5.5
488890	0.1250400		1.08672	0.92330								
488892	0.108240	0.029567	0.16397	0.10122	-13	90.9	2827	2867	3033	2.8	2.9	3.0

Chondrite normalised = measured value / value for chondrite PGE elements

Appendix D (I) Kaapvaal

Major element oxides Kaapvaal cratonic peridotite xenolith suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Total	Ref
FRB 135	0.0617	43.9400	1.5331	47.5069	0.5762	0.0103	0.1132	5.9100	99.65	†
FRB 492	0.2058	43.7600	1.6467	46.9512	0.7925	0.0000	0.1235	6.0900	99.57	†
FRB 983	0.1044	46.1600	1.1797	44.9427	0.4593	0.0626	0.1148	6.5100	99.53	†
FRB 999	0.1263	45.2600	0.9897	45.3576	0.7160	0.1158	0.1263	6.8500	99.54	†
FRB 1007	0.0855	46.7500	0.8548	45.4415	0.5663	0.0748	0.1068	5.9500	99.83	†
FRB 1008	0.1386	44.8000	1.2157	45.5400	0.7571	0.1706	0.1173	6.2100	98.95	†
FRB 1009	0.1701	43.1800	1.7114	45.9848	1.0205	0.0744	0.1382	7.2400	99.52	†
PHN 4257	0.0840	44.3700	1.4285	46.8029	0.5462	0.0840	0.1155	6.1900	99.62	†
PHN 4259	0.0826	43.6800	1.6840	47.3579	0.7852	0.0103	0.1136	5.9400	99.65	†
PHN 4265	0.0828	43.1300	1.5731	48.4564	0.6934	0.0103	0.1138	5.5900	99.65	†
PHN 4274	0.0633	45.3800	0.9603	46.8624	0.4221	0.0106	0.1055	5.8600	99.66	†
FRB 347	0.1355	44.4700	1.7413	46.4935	0.7612	0.0104	0.1251	5.9000	99.64	†
FRB 348	0.1239	42.6000	1.8480	47.3876	1.1769	0.0103	0.1342	6.3400	99.62	†
FRB 823	0.0922	43.3600	1.5570	46.7105	1.1370	0.0205	0.1434	6.5400	99.56	†
LBM 9	0.0415	40.0500	2.5395	49.2248	1.4097	0.0311	0.1244	6.3300	99.75	†
LBM 11	0.1400	41.8900	1.4400	48.5700	0.7600	0.0300	0.1200	6.2900	99.24	†
LBM 16	0.0400	43.2600	1.3000	47.5000	0.9000	0.1000	0.2300	6.3200	99.65	†
MB 3	0.0800	43.8400	0.0800	46.3500	0.9200	0.0500	0.1100	6.3300	97.76	†
MB 4	0.0100	46.8000	1.3900	43.5100	0.7200	0.0600	0.1100	6.6800	99.28	†
MB 7	0.1000	44.0000	1.4300	46.5200	0.9500	0.0300	0.1000	6.0500	99.18	†
MB 12	0.1400	42.9500	1.4700	47.3900	1.0300	0.0400	0.1100	6.1600	99.29	†
MB 13	0.1000	43.3900	1.5600	47.4800	0.7400	0.0200	0.1000	5.9500	99.34	†
AJE 62	0.0500	42.6700	1.5100	48.0700	0.8000	0.0300	0.1100	6.0500	99.29	†
EJB 4	0.1300	42.4300	1.5100	47.1000	1.2800	0.0300	0.1200	6.6500	99.25	†
EJB 48	0.0600	45.5300	1.1300	45.5800	0.6400	0.0400	0.1000	6.2600	99.34	†
BD 2384	0.0300	44.3900	1.6700	45.4000	0.7200		0.1200	6.8700	99.20	†
PHN 2762	0.0300	44.2300	1.3900	47.0500	0.6000	0.0100	0.1000	5.9600	99.37	†
FRB1350	0.0800	42.6700	1.6800	46.5400	1.4300	0.0100	0.1100	6.8400	99.36	†
FRB 932	0.1042	45.2400	1.7410	46.2763	0.6359	0.0208	0.0938	5.5400	99.65	□
FRB 978	0.1579	45.6200	1.2947	45.6522	0.8000	0.0842	0.1263	5.8000	99.54	□
FRB 1013	0.1266	45.5200	1.0230	45.0837	0.7488	0.1476	0.1266	6.7200	99.50	□
PHN 4254	0.0316	45.8200	1.0443	46.7180	0.3375	0.0316	0.1055	5.5100	99.60	□
PHN 5596	0.0758	47.4300	0.7361	43.7519	0.3247	0.0866	0.1082	7.0900	99.60	□

Cont.

Appendix D (I) Kaapvaal

Major element oxides Kaapvaal cratonic peridotite xenolith suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Total	Ref
FRB 1402	0.0858	46.5600	0.9544	44.9019	0.3110	0.0322	0.0858	6.7100	99.64	□
FRB 1404	0.1050	44.9000	1.4589	46.7895	0.4723	0.0210	0.0840	5.8200	99.65	□
FRB 1409	0.1151	44.7000	1.6421	46.8376	0.6171	0.0209	0.0837	5.6200	99.64	□
FRB 1422	0.0845	45.9400	1.1718	46.0074	0.3695	0.0211	0.0845	5.9900	99.67	□
FRB 1447	0.0743	46.1100	1.1988	45.7228	0.3395	0.0106	0.0849	6.1100	99.65	□
FRB 451	0.0500	46.0200	1.0900	45.6500	0.2600	0.0000	0.1200	6.0200	99.21	Δ
FRB914	0.0700	42.9500	1.3500	47.3900	0.8600	0.0400	0.1300	6.3900	99.18	Δ
FRB919	0.0400	46.1300	1.2000	44.7300	0.5200	0.0100	0.1100	6.5000	99.24	Δ
PHN4258	0.0300	46.9200	0.7700	45.2200	0.1500	0.0400	0.1000	6.0500	99.28	Δ
PHN4531	0.0900	45.7900	1.1800	45.4800	0.4000	0.0100	0.1200	6.1100	99.18	Δ
PHN5236	0.0400	43.6200	2.4600	46.1800	0.8700	0.0000	0.1100	5.9700	99.25	Δ
PHN5244	0.1900	46.5700	1.0600	43.7200	0.4900	0.0300	0.1200	6.9600	99.14	Δ
PHN5245	0.0500	45.9300	1.1000	44.9100	0.4000	0.0100	0.1000	6.7800	99.28	Δ
PHN5248	0.0100	49.1500	0.5100	43.3700	0.0900	0.0000	0.0700	6.1500	99.35	Δ
PHN5254	0.0800	44.1200	1.4100	44.8100	1.5900	0.0500	0.1200	6.9800	99.16	Δ
PHN5266	0.0500	44.3600	1.4600	46.1400	0.8600	0.0100	0.1200	6.2200	99.22	Δ
FRB1419	0.0500	45.9700	0.9900	45.4600	0.4600	0.0100	0.0800	6.3100	99.33	Δ
FRB1425	0.0700	43.1800	1.6500	47.5200	0.7900	0.0100	0.0900	5.9400	99.25	Δ
FRB1429	0.0700	44.6400	1.2500	46.8900	0.5500	0.0000	0.0900	5.8000	99.29	Δ
FRB1431	0.0600	44.4900	1.1300	46.9200	0.5600	0.0100	0.0900	6.0200	99.28	Δ
FRB1434	0.0500	44.6600	1.2100	46.8700	0.4900	0.0100	0.0900	5.9200	99.30	Δ
FRB1435	0.0500	47.4300	0.7600	44.4800	0.2800	0.0100	0.0800	6.2400	99.33	Δ
FRB1450	0.0700	45.5800	1.1000	45.7300	0.5500	0.0100	0.0800	6.2000	99.32	Δ
FRB1353	0.0300	45.4500	0.8100	45.8600	0.3300	0.0100	0.1000	6.6700	99.26	Δ
FRB1374	0.0700	46.8100	0.9800	43.9500	0.6300	0.0400	0.0900	6.6600	99.23	Δ
FRB1382	0.0900	42.8600	1.8900	45.5000	2.1500	0.0600	0.1100	6.6300	99.29	Δ
FRB-1007		47.0269	0.8477	45.0559	0.5616	0.0742	0.1060	5.9887	99.66	‡
FRB-1008		45.0808	1.2024	45.8191	0.7489	0.1688	0.1160	6.2522	99.39	‡
FRB-999		45.5455	0.9874	45.2514	0.7143	0.1155	0.1260	6.8923	99.63	‡
FRB-1009		42.5603	1.6709	44.8953	0.9963	0.0726	0.1349	7.1375	97.47	‡
FRB-135		44.2497	1.5333	47.5119	0.5763	0.0000	0.1132	5.9436	99.93	‡
FRB-492		44.0342	1.6431	46.8480	0.7907	0.0000	0.1232	6.1295	99.57	‡
FRB-983		46.4517	1.1769	44.8374	0.4583	0.0521	0.1146	6.5550	99.65	‡

cont.

Appendix D (I) Kaapvaal

Major element oxides Kaapvaal cratonic peridotite xenolith suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Total	Ref
PHN-4254		46.1594	1.0440	46.7078	0.3375	0.0316	0.1055	5.5509	99.94	‡
PHN-4257		44.6566	1.4273	46.7661	0.5457	0.0840	0.1154	6.2368	99.83	‡
PHN-4258		47.2482	0.7792	45.5318	0.1474	0.0421	0.1053	6.0933	99.95	‡
PHN-4259		43.9456	1.6827	47.3213	0.7846	0.0619	0.1136	5.9768	99.89	‡
PHN-4265		43.4266	1.5731	48.4565	0.6934	0.0000	0.1138	5.6330	99.90	‡
PHN-4274		45.6691	0.9602	46.8615	0.4221	0.0000	0.1055	5.8972	99.92	‡
FRB 932		45.5068	1.7394	46.2359	0.6354	0.0208	0.0937	5.5701	99.80	○
FRB 978		45.9331	1.2920	45.5550	0.7983	0.0840	0.1260	5.8334	99.62	○
FRB 1013		45.8328	1.0201	44.9599	0.7467	0.1578	0.1262	6.7568	99.60	○
FRB 1402		46.8244	0.9536	44.8636	0.3107	0.0321	0.0857	6.7476	99.82	○
FRB 1404		45.1688	1.4577	46.7523	0.4719	0.0210	0.0839	5.8556	99.81	○
FRB 1409		44.9835	1.6409	46.8021	0.6166	0.0209	0.0836	5.6538	99.80	○
FRB 1422		46.1961	1.1710	45.9746	0.3692	0.0211	0.0844	6.0253	99.84	○
FRB 1447		46.4007	1.1985	45.7113	0.3394	0.0000	0.0848	6.1487	99.88	○
PHN 4254		46.1594	1.0440	46.7078	0.3375	0.0316	0.1055	5.5509	99.94	○
PHN 5596		47.7384	0.7356	43.7250	0.3245	0.0865	0.1082	7.1412	99.86	○
FRB 914		43.2695	1.3606	47.7356	0.8621	0.0415	0.1350	6.4294	99.83	◆
FRB919		46.4719	1.2092	45.0646	0.5212	0.0136	0.1147	6.5111	99.91	◆
FRB1353		45.7869	0.8142	46.2047	0.3321	0.0075	0.0964	6.7196	99.96	◆
FRB1374		47.1409	0.9863	44.2555	0.6295	0.0420	0.0944	6.7045	99.85	◆
FRB1382		43.1400	1.9037	45.8031	2.1638	0.0624	0.1144	6.6774	99.86	◆
PHN5236		42.1767	2.3783	44.6453	0.8429	0.0010	0.1104	5.7611	95.92	◆
PHN5244		46.8201	1.0608	43.9601	0.4888	0.0312	0.1248	6.9943	99.48	◆
PHN5245		45.9020	1.1018	44.8858	0.3958	0.0053	0.0963	7.5380	99.93	◆
PHN5248		49.4734	0.5110	43.6562	0.0870	0.0000	0.0761	6.1777	99.98	◆
PHN5254		44.4430	1.4232	45.1441	1.6011	0.0523	0.1256	7.0224	99.81	◆
PHN5266		44.6736	1.4690	46.4759	0.8647	0.0052	0.1250	6.2511	99.86	◆
PHN4531		46.1401	1.1847	45.8361	0.3984	0.0063	0.1258	6.1408	99.83	◆
FRB1419		46.2648	0.9979	45.7553	0.4671	0.0106	0.0849	6.3557	99.94	◆
FRB1425		43.4733	1.6586	47.8470	0.7923	0.0106	0.0951	5.9751	99.85	◆
FRB1429		44.9268	1.2573	47.2004	0.5553	0.0031	0.0943	5.8370	99.87	◆
FRB1431		46.4879	1.1049	45.7922	0.5422	0.0102	0.0921	5.8682	99.90	◆

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Appendix D (I) Kaapvaal

Major element oxides Kaapvaal cratonic peridotite xenolith suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Total	Ref
FRB1434		44.9672	1.2159	47.1893	0.4926	0.0052	0.0943	5.9620	99.93	♦
FRB1435		47.7253	0.7680	44.7492	0.2773	0.0107	0.0853	6.2881	99.90	♦
FRB1450		45.8558	1.1087	46.0127	0.5544	0.0105	0.0837	6.2278	99.85	♦
FRB451		46.3383	1.1020	45.9675	0.2649	0.0032	0.1166	6.0592	99.85	♦
PHN4258		47.2460	0.7792	45.5297	0.1474	0.0421	0.1053	6.0924	99.94	♦
PHN5232		45.1505	1.1882	45.7759	0.8651	0.0208	0.1251	6.6451	99.77	♦
PHN5246		44.2702	1.3937	46.1074	0.9819	0.0317	0.1373	6.7295	99.65	♦
Average	0.0834	45.0493	1.2872	46.0445	0.6654	0.0350	0.1081	6.2625	99.50	

† Pearson et al, 1995. Low T

□ Boyd et al, 1993

Δ Pearson et al., 1995. spinel peridotite

‡ Boyd and Mertzman, 1987 garnet peridotite

○ Boyd et al, 1993 garnet harzburgite

♦ Boyd et al, 1999 Kaapvaal root, spinel peridotite

Appendix D (II) Canadian

Major element oxides Canadian cratonic peridotite suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Cr ₂ O ₃	NiO	Ref
9-12		46.82	0.34	42.64	0.35	0.05	0.10	6.37	0.33	0.31	†
9-13		45.33	0.53	44.47	0.54	0.02	0.10	6.19	0.32	0.26	†
10-8		44.07	1.13	44.88	0.76	0.02	0.11	6.77	0.42	0.29	†
10-12B		45.46	0.65	45.24	0.63	0.05	0.10	6.00	0.35	0.28	†
11-18		47.72	0.41	43.82	0.25	0.02	0.10	6.08	0.20	0.31	†
23-9		44.62	0.67	45.63	0.28	0.02	0.10	5.87	0.38	0.29	†
39-4		44.46	1.18	44.98	0.56	0.02	0.10	6.19	0.39	0.29	†
39-23		46.43	1.28	42.08	0.92	0.04	0.10	6.68	0.53	0.31	†
41-2		42.58	1.20	48.67	0.41	0.01	0.10	5.16	0.45	0.24	†
44-12		42.87	1.05	41.41	0.25	0.02	0.08	6.45	0.41	0.31	†
10-456'		42.30	0.95	44.30	1.75	0.05	0.12	7.12	0.41	0.27	†
40-16		43.91	0.74	46.37	0.36	0.03	0.10	5.87	0.51	0.28	†
53-10		41.98	0.64	38.80	0.74	0.06	0.09	8.02	0.41	0.37	†
10-11		45.69	1.21	43.56	0.95	0.05	0.11	6.71	0.38	0.28	†
10-12A		44.16	1.25	44.46	0.90	0.04	0.11	6.60	0.39	0.28	†
21-1		43.58	0.66	45.89	0.54	0.03	0.12	6.64	0.43	0.28	†
22-4		42.85	1.41	45.10	1.21	0.04	0.12	7.01	0.48	0.27	†
28-15		41.85	1.49	44.18	0.84	0.10	0.12	7.11	0.41	0.28	†
41-4		44.67	0.72	43.87	0.67	0.04	0.12	7.11	0.37	0.31	†
21-3		42.59	1.53	42.05	1.50	0.15	0.12	7.89	0.30	0.29	†
8-7		45.58	0.64	46.00	0.60	0.02	0.10	5.78	0.28	0.26	†
5-3		39.86	1.88	39.19	1.45	0.06	0.10	8.42	0.40	0.32	†
10-9		44.33	0.82	42.71	1.07	0.07	0.13	7.93	0.43	0.32	†
11-22		41.31	1.61	44.35	1.78	0.08	0.14	7.28	0.85	0.26	†
13-2		44.15	0.47	41.77	0.79	0.05	0.12	7.90	0.29	0.30	†
21-2		45.67	0.81	41.76	0.47	0.08	0.12	8.09	0.43	0.32	†
23-1		44.82	0.82	42.65	0.65	0.05	0.12	7.71	0.48	0.32	†
26-9		39.11	2.53	41.61	3.13	0.18	0.15	9.31	0.40	0.23	†
39-3		43.46	1.34	41.25	1.46	0.12	0.12	7.23	0.44	0.31	†
39-10		44.70	0.94	42.30	0.59	0.04	0.12	8.29	0.40	0.30	†
40-9		45.50	0.73	42.61	0.58	0.06	0.13	8.36	0.33	0.31	†
NK1-5		41.54	1.95	42.33	1.44	0.07	0.12	7.75	0.85	0.30	□
NK2-3		41.82	2.90	42.40	1.98	0.09	0.13	7.20	1.04	0.31	□
cont.											

Appendix D (II) Canadian

Major element oxides Canadian cratonic peridotite suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Cr ₂ O ₃	NiO	Ref
NK2-10		45.54	1.25	41.55	1.22	0.03	0.11	7.43	0.53	0.32	□
NK3-20		37.62	3.22	43.33	3.22	0.10	0.13	7.60	0.67	0.28	□
NK3-25		39.52	4.29	41.48	2.13	0.21	0.13	7.42	1.09	0.25	□
NK1-2		44.51	1.31	41.83	1.11	0.03	0.11	7.40	0.52	0.32	□
NK1-3		44.29	1.34	41.05	0.82	0.03	0.11	7.46	0.60	0.33	□
NK1-6		43.60	1.26	40.54	0.41	0.02	0.10	7.13	0.68	0.33	□
NK1-7		43.72	1.58	41.40	0.72	0.03	0.10	7.09	0.70	0.31	□
NK1-17		45.35	0.81	41.18	0.49	0.01	0.11	7.04	0.68	0.31	□
NK1-18		44.93	0.79	42.94	0.54	0.03	0.10	6.97	0.51	0.35	□

† Kopylova & Russell, 2000, Slave, Jericho

□ Schmidberger & Francis, 1999

Appendix D (III) Tanzanian

Major element oxides Tanzanian cratonic peridotite suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Ref
LB1 ave		48.09	0.40	44.52	0.25	0.08	0.12	6.48	†
LB6 ave		48.57	0.67	42.21	0.57	0.14	0.13	7.52	†
LB7 ave		49.18	0.57	41.87	0.28	0.13	0.14	7.69	†
LB8 ave		48.66	0.35	43.98	0.19	0.07	0.12	6.57	†
LB 9 ave		49.05	0.37	43.39	0.22	0.06	0.12	6.72	†
LB 11 ave		47.33	0.86	43.97	0.31	0.04	0.13	7.33	†
LB 16 ave		47.36	0.61	43.87	0.41	0.14	0.13	7.38	†
LB21 ave		50.22	0.31	41.90	0.54	0.11	0.12	6.70	†
LB 22 ave		46.96	0.69	44.06	0.40	0.08	0.13	7.61	†
LB 23 ave		48.19	0.55	43.23	0.42	0.03	0.13	7.35	†
LB 29 ave		47.48	0.90	43.78	0.31	0.07	0.13	7.25	†
LB 31 ave		45.95	1.04	44.36	0.98	0.04	0.14	7.41	†
LB 36 ave		46.42	0.90	44.58	0.63	0.07	0.13	7.11	†
LB 39 ave		44.91	0.87	45.11	0.73	0.16	0.14	7.88	†
LB 55 ave		47.28	0.78	44.09	0.42	0.09	0.13	6.96	†
LB61 ave		48.66	0.51	43.10	0.24	0.11	0.13	7.14	†
LB33 ave		47.60	0.62	42.96	0.71	0.35	0.13	7.48	†
LB26 ave		48.44	0.47	43.26	0.18	0.15	0.14	7.29	†
LB 17 ave		45.79	0.57	45.16	0.43	0.25	0.14	7.56	†
LB 18 ave		48.04	0.43	42.36	0.39	0.11	0.13	8.46	†
LB 19R ave		46.56	0.84	42.97	0.47	0.09	0.15	8.66	†
LB 14 ave		49.91	0.33	42.14	0.04	0.08	0.12	7.30	†
KAT 1 WSU		45.97	0.65	45.54	0.39	0.11	0.11	7.04	†
KAT 17 WSU		43.28	0.41	44.80	0.64	0.06	0.13	10.55	†
LB2 AVERAGE		46.86	1.20	44.36	0.51	0.07	0.13	6.72	†
LB4 AVERAGE		44.21	1.57	45.20	1.09	0.03	0.13	7.65	†
LB12 ave		42.90	2.02	44.47	1.82	0.05	0.15	8.50	†
LB24 ave		46.68	1.24	44.15	0.62	0.06	0.13	7.07	†
LB34 ave		46.86	0.70	42.06	0.44	0.19	0.14	9.50	†
LB45 ave		39.67	3.99	44.40	2.81	0.21	0.16	8.55	†
LB50-1		44.93	1.39	44.52	0.99	0.05	0.14	7.93	†
LB50-2		44.95	1.34	44.64	0.97	0.05	0.14	7.88	†
LB53 ave		44.90	1.77	43.54	1.37	0.13	0.14	8.11	†
89-661		48.41	0.70	42.68	0.95	0.08	0.09	6.82	□

cont..



Appendix D
Cratonic Data
Major Elements

Appendix D (III) Tanzanian

Major element oxides Tanzanian cratonic peridotite suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Ref
89-662		49.64	0.17	41.21	0.09	0.05	0.11	8.57	□
89-663		47.28	0.69	41.94	0.36	0.10	0.11	9.13	□
89-664		47.92	0.19	42.19	0.31	0.15	0.12	8.92	□
89-669		45.09	0.57	42.11	1.81	0.10	0.12	9.76	□
89-671		46.71	0.42	40.55	0.09	0.13	0.14	11.62	□
89-672		49.42	0.19	41.91	0.95	0.06	0.08	7.22	□
89-674		45.57	0.86	43.59	1.06	0.11	0.12	8.44	□
89-675		46.15	0.92	45.56	0.62	0.05	0.10	6.37	□
89-676		33.97	0.67	46.20	7.71	0.14	0.16	10.83	□
89-678		48.86	0.26	42.03	0.30	0.07	0.11	8.19	□
89-680		46.33	1.23	44.67	0.82	0.03	0.10	6.67	□
89-719		47.78	1.09	43.47	0.55	0.02	0.09	6.84	□
TZ 2-16		48.68	1.28	43.85	0.21	0.03	0.07	5.74	□
BD730		42.96	2.49	45.24	1.48	0.08	0.09	7.33	□
89-772		46.01	0.11	40.56	0.66	0.00	0.15	12.46	Δ
89-773		49.24	0.39	44.12	0.11	0.01	0.08	5.98	Δ
89-774		51.94	0.10	41.35	0.16	0.00	0.08	6.27	Δ
89-776		51.57	0.09	41.73	0.58	0.02	0.09	5.86	Δ
89-777		48.17	0.17	41.33	1.36	0.05	0.16	8.51	Δ
89-778		49.56	0.22	40.93	0.28	0.05	0.11	8.83	Δ
89-780		51.00	0.12	41.49	0.48	0.03	0.10	6.72	Δ

† Lee & Rudnick (Unpublished)

Δ Rudnick et al. 1993

□ Rudnick et al. 1993

Appendix D (IV) Siberian

Major element oxides Siberian cratonic peridotite suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Total	Ref
UV 191/89		49.30	0.28	42.72	0.33	0.01	0.11	7.20	99.94	†
UV 563/89		45.98	1.07	45.08	0.33	0.02	0.10	7.30	99.90	†
UV 564/89		44.59	1.09	44.94	1.69	0.04	0.13	7.27	99.74	†
UV 565/89		45.39	1.08	44.56	1.40	0.03	0.10	7.21	99.77	†
UV 111/91		47.50	0.45	45.00	0.39	0.00	0.10	6.44	99.88	†
UV 65/92		46.81	1.32	44.37	0.54	0.01	0.12	6.58	99.76	†
UV 34/93		43.82	1.38	47.54	0.78	0.04	0.10	6.12	99.77	†
UV 105/93		45.70	0.59	46.05	0.56	0.02	0.23	6.58	99.73	†
UV 215/93		43.98	1.33	46.72	0.90	0.02	0.12	6.70	99.77	†
Uv 274/89		48.24	0.61	42.23	1.03	0.09	0.10	7.51	99.81	†
Uv 285/89		48.13	0.56	42.46	0.99	0.09	0.10	7.50	99.83	†
Uv 293/89		47.02	0.76	43.27	1.26	0.06	0.11	7.33	99.81	†
Uv 306/89		45.66	1.21	44.22	0.67	0.02	0.12	7.92	99.82	†
Uv 417/89		39.33	3.69	44.88	2.94	0.19	0.19	8.33	99.55	†
Uv 485/89		47.45	0.86	43.08	0.96	0.06	0.11	7.34	99.87	†
Uv 25/91		45.96	1.30	44.15	0.72	0.01	0.12	7.60	99.86	†
Uv 100/91		42.05	3.65	45.76	1.48	0.01	0.18	6.68	99.80	†
Uv 51/93		45.43	0.37	45.47	0.35	0.07	0.13	7.87	99.69	†
Uv 76/93		43.93	1.05	46.49	0.54	0.07	0.13	7.47	99.67	†
Uv 178/93		45.55	0.70	44.28	1.04	0.02	0.25	7.93	99.78	†
Uv 219/93		45.17	1.01	44.64	1.04	0.04	0.25	7.64	99.80	†
52/76		46.27	0.51	44.06	0.66	0.12	0.10	8.20	99.92	†
74/89		44.05	1.27	44.99	1.19	0.11	0.10	8.07	99.77	†
107/89		46.20	0.53	44.31	0.64	0.05	0.14	7.99	99.85	†
115/89		44.42	1.47	44.89	1.06	0.10	0.13	7.80	99.88	†
228/89		44.10	0.72	45.72	0.84	0.13	0.10	8.23	99.83	†
239/89		44.93	0.68	44.59	1.22	0.12	0.14	8.11	99.78	†
246/89		42.66	1.59	45.58	1.14	0.17	0.10	8.64	99.88	†
267/89		41.01	2.70	44.98	2.55	0.20	0.14	8.17	99.76	†
424/89		45.28	0.85	44.56	1.02	0.10	0.14	7.91	99.87	†
61/91		44.88	0.75	44.90	1.69	0.11	0.12	7.37	99.83	†
121/91		46.19	0.72	44.53	1.09	0.11	0.12	7.06	99.83	†
51/92		43.05	1.17	44.55	1.64	0.18	0.13	9.03	99.76	†
cont..										

Appendix D (IV) Siberian

Major element oxides Siberian cratonic peridotite suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Total	Ref
70/92		46.59	0.54	44.08	0.90	0.09	0.14	7.48	99.82	†
74/92		41.07	1.06	44.13	2.57	0.16	0.14	10.48	99.61	†
76/92		45.38	0.62	44.41	0.97	0.02	0.14	8.02	99.55	†
80/92		44.91	0.63	44.62	0.77	0.15	0.11	8.59	99.79	†
32842		43.02	1.75	45.57	1.50	0.11	0.11	7.74	99.80	†
128/93		43.63	1.37	44.49	1.38	0.09	0.23	8.50	99.68	†
166/93		44.21	0.96	45.02	1.31	0.08	0.15	8.04	99.78	†
813		45.93	0.77	44.02	0.88	0.13	0.13	7.96	99.82	†

† Boyd et al, 1997

Appendix D (V) East Greenland

Major element oxides E. Greenland cratonic peridotite suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Cr ₂ O ₃	NiO	Ref
1-7a		47.06	1.15	43.80	0.10	0.01	0.18	6.75	0.92	0.31	†
36171		49.41	0.27	43.94	0.08	0.00	0.19	6.02	0.06	0.33	†
1-15A		49.25	0.85	41.77	0.73	0.02	0.20	5.91	1.23	0.35	†
1-15B		48.42	0.50	43.42	0.21	0.01	0.19	6.99	0.24	0.33	†
1-16A		49.66	0.29	42.97	0.13	0.00	0.19	6.52	0.21	0.34	†
1-16B		47.39	0.67	44.40	0.24	0.01	0.18	6.81	0.28	0.31	†
1-16C		48.62	0.91	42.65	0.12	0.01	0.19	6.64	0.85	0.33	†
1-17B		49.13	0.46	42.91	0.18	0.01	0.19	6.72	0.39	0.34	†
36178		47.55	0.50	44.93	0.11	0.01	0.18	6.49	0.23	0.31	†
36179		48.68	1.50	41.69	0.08	0.01	0.20	6.92	0.89	0.34	†
36180		46.94	1.51	43.44	0.26	0.01	0.19	6.66	0.97	0.31	†
1-21A		49.22	0.57	43.19	0.07	0.00	0.19	6.27	0.46	0.33	†
1-21B		46.92	0.71	44.76	0.27	0.01	0.18	6.59	0.55	0.30	†
1-22A		49.84	0.75	42.69	0.06	0.01	0.19	5.62	0.81	0.34	†
1-22b		49.74	0.24	43.67	0.07	0.00	0.19	6.01	0.06	0.34	†
36201		47.23	0.91	44.36	0.22	0.01	0.18	6.43	0.63	0.31	†
36202		49.24	0.43	43.54	0.08	0.00	0.19	6.21	0.29	0.33	†
2-12a		48.10	1.23	42.79	0.08	0.01	0.19	6.43	1.14	0.32	†
2-12b		48.71	1.02	42.03	0.06	0.01	0.19	6.69	1.26	0.34	†
2-15A		49.56	0.38	42.47	0.05	0.00	0.19	6.92	0.40	0.35	†
2-15B		49.15	0.92	41.85	0.06	0.01	0.20	6.63	1.17	0.34	†
2-16A		50.22	1.07	39.57	0.02	0.01	0.21	6.70	2.17	0.37	†
2-16B		49.23	0.40	43.47	0.07	0.00	0.19	6.22	0.40	0.33	†
36210		48.30	1.28	42.27	0.09	0.01	0.19	7.07	0.76	0.33	†
36212		48.41	0.91	39.13	0.02	0.01	0.21	9.00	2.28	0.37	†
36213		51.26	0.24	40.73	0.02	0.00	0.20	6.47	1.05	0.37	†
2-24a		47.63	0.80	43.74	0.40	0.01	0.18	6.93	0.27	0.32	†
2-24Aa		47.55	1.29	43.40	0.34	0.01	0.19	6.71	0.48	0.32	†
2-24Ab		44.98	0.54	46.05	0.41	0.01	0.17	7.72	0.11	0.28	†
2-24b		50.05	0.38	43.09	0.06	0.00	0.19	5.83	0.36	0.34	†
36216		46.12	1.43	44.18	0.61	0.02	0.18	6.49	0.93	0.30	†
36217		49.49	0.53	42.38	0.08	0.00	0.19	6.88	0.42	0.35	†
36219		44.64	0.76	43.33	0.37	0.01	0.18	9.61	1.07	0.31	†
cont.											

Appendix D (V) East Greenland

Major element oxides E. Greenland cratonic peridotite suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Cr ₂ O ₃	NiO	Ref
10990		42.86	3.00	43.32	2.00	0.04	0.18	6.77	1.71	0.28	†
2-31a		49.88	0.47	42.02	0.11	0.00	0.20	6.93	0.35	0.36	†
2-32a		48.36	0.43	44.21	0.09	0.00	0.18	6.49	0.21	0.32	†
12086		50.86	0.30	41.59	0.03	0.00	0.20	6.38	0.61	0.36	†
4-24a		48.73	1.24	42.56	0.07	0.01	0.19	6.34	0.83	0.33	†
4-24b		50.26	0.55	39.98	0.02	0.01	0.21	7.18	1.77	0.37	†
4-25a		49.94	1.21	41.18	0.06	0.01	0.20	6.50	0.86	0.35	†
4-26a		48.81	0.55	43.12	0.14	0.00	0.19	6.94	0.23	0.34	†
4-26b		47.12	1.05	43.81	0.35	0.01	0.18	6.73	0.72	0.31	†
36277		44.87	1.38	44.61	0.95	0.02	0.18	7.54	0.39	0.29	†
36279		47.53	0.95	43.77	0.14	0.01	0.18	6.87	0.51	0.32	†
429285a		48.27	0.45	44.52	0.10	0.00	0.18	6.24	0.22	0.32	†
42928.5		47.23	1.30	43.41	0.10	0.01	0.19	6.00	1.73	0.31	†

† Bernstein et al. 1998

Appendix E

Non-cratonic Data Non-European Major Elements

Appendix D (VI) W. Australia

Major element oxides W. Australia cratonic peridotite suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Ref
N23		46.48	0.75	44.96	0.80	0.04	0.07	6.64	†
N25		44.81	1.06	47.32	0.24	0.06	0.07	6.15	†
N40		47.68	0.57	44.00	0.56	0.07	0.08	6.73	†
N48		43.99	1.10	46.52	0.97	0.03	0.06	6.94	†

† Jaques et al, 1990

Appendix E (I) African

Non-cratonic major element oxides African peridotite xenolith suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Total	Ref
<u>Africa, East African Rift, Ethiopia</u>										
ET69		40.79	2.65	45.65	2.71	0.03	0.12	7.89	99.84	∞
ET46		42.15	2.10	44.99	2.52	0.03	0.13	7.80	99.73	∞
ET84		47.00	0.85	44.01	0.50	0.02	0.11	7.44	99.92	∞
ET57		45.70	1.08	44.28	0.95	0.01	0.12	7.78	99.92	∞
ET27		46.65	0.78	43.62	0.49	0.04	0.13	8.21	99.92	∞
ET35		46.00	0.73	44.27	0.82	0.02	0.12	8.00	99.96	∞
ET74		36.74	2.74	46.73	6.40	0.12	0.09	6.79	99.60	∞
ET75		37.62	4.00	45.21	4.29	0.17	0.13	8.27	99.68	∞
ET48		39.31	3.25	45.31	3.11	0.12	0.14	8.52	99.76	∞
ET80		39.17	3.33	44.98	3.48	0.11	0.13	8.57	99.77	∞
ET36		44.10	1.75	43.74	1.44	0.07	0.12	8.66	99.88	∞
ET42		45.82	1.29	43.41	1.21	0.05	0.13	8.02	99.93	∞
<u>Africa</u>										
Ka196		38.04	2.23	43.45	3.94	0.38	0.17	11.48	99.70	≠
Ka197		39.76	2.52	46.33	2.78	0.09	0.14	8.11	99.74	≠
Ka198		39.77	2.44	45.95	2.71	0.14	0.14	8.61	99.76	≠
Ka199		38.26	3.14	46.90	3.07	0.15	0.13	7.99	99.65	≠
Ka200		41.21	2.00	45.81	2.43	0.05	0.14	8.20	99.84	≠
Ka201		45.42	1.57	42.79	1.56	0.05	0.14	8.32	99.84	≠
Ka202		42.04	2.02	45.09	1.48	0.15	0.16	8.74	99.68	≠
Ka203		45.36	1.22	44.64	0.99	0.09	0.12	7.43	99.85	≠
Ka204		40.02	3.66	44.50	2.83	0.15	0.14	8.30	99.59	≠
Ka205		45.47	1.20	45.07	0.79	0.06	0.11	7.13	99.84	≠
Ka206		38.97	3.06	45.74	3.33	0.16	0.13	8.20	99.59	≠
Ka207		41.72	2.14	45.14	2.80	0.11	0.12	7.75	99.77	≠
Ka208		44.62	1.12	44.49	1.20	0.08	0.13	8.24	99.88	≠
<u>Algeria, Hoggar</u>										
Ka209		41.51	2.34	44.41	1.84	0.23	0.15	9.20	99.69	Φ
Ka210		40.46	2.54	46.24	2.65	0.07	0.13	7.60	99.70	Φ
Ka211		39.87	3.33	44.52	2.86	0.10	0.14	8.81	99.64	Φ
Ka212		39.87	3.46	44.67	2.98	0.11	0.13	8.55	99.77	Φ

cont..

Appendix E (I) African

Non-cratonic major element oxides African peridotite xenolith suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Total	Ref
<u>Algeria, Hoggar cont..</u>										
Ka213		35.62	3.84	46.41	3.29	0.17	0.16	10.20	99.70	Φ
Ka214		38.40	3.93	46.13	2.53	0.11	0.14	8.57	99.81	Φ
Ka215		34.92	4.55	47.79	3.79	0.14	0.15	8.37	99.71	Φ
Ka216		40.97	2.03	46.73	2.24	0.07	0.13	7.65	99.84	Φ
Ka217		41.09	2.23	45.80	2.32	0.06	0.14	8.19	99.84	Φ
Ka218		40.89	2.25	45.89	2.43	0.07	0.14	8.17	99.84	Φ

∞ Bedini et al, 1997, East African Rift.

≠ Dautria & Girod, 1987, Africa

Φ Dupuy et al, 1986, Algeria, Hoggar

Oxides in wt.%

Appendix E (II) Australian

Non-cratonic major element oxides Australian peridotite xenolith suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Total	Ref
SE Australia										
FG 2604		47.67	1.08	43.27	0.58	0.02	0.13	7.13	99.89	†
FG 2669		46.22	0.86	44.39	0.76	0.00	0.13	7.47	99.84	†
FG 2640		43.87	1.02	43.77	0.97	0.03	0.15	10.04	99.85	†
FG 2728		43.43	2.13	44.42	2.31	0.01	0.13	7.39	99.81	†
FG 2700		42.74	1.45	44.18	2.87	0.00	0.11	8.30	99.66	†
FG 2642		40.86	3.00	45.52	2.52	0.06	0.13	7.71	99.80	†
VIC 2730		43.50	1.43	45.89	0.87	0.03	0.11	8.02	99.86	□
VIC 2736		43.08	1.44	46.55	0.88	0.03	0.12	7.85	99.95	□
VIC 2769		41.93	2.02	44.99	1.85	0.07	0.13	8.77	99.76	□
VIC 84-402		43.80	1.32	45.07	0.86	0.04	0.13	8.69	99.91	□
VIC 84-413		35.58	2.91	45.06	2.62	0.84	0.16	10.79	97.96	□
VIC 84-438		39.12	2.56	43.23	3.74	0.35	0.15	9.38	98.54	□
VIC 85-168		41.92	1.48	44.41	1.13	0.12	0.15	10.51	99.73	□
70965		41.29	0.99	44.28	4.33	0.08	0.15	8.28	99.40	Δ
70969		44.87	0.49	42.11	2.27	0.04	0.16	9.53	99.47	Δ
70972		44.31	0.69	43.28	3.60	0.02	0.13	7.47	99.50	Δ
70987		43.43	1.02	43.61	2.03	0.15	0.15	9.19	99.59	Δ
70997		42.07	0.92	42.68	3.82	0.10	0.16	9.89	99.64	Δ
71000		42.25	1.22	42.94	3.79	0.06	0.15	8.68	99.09	Δ
71001		42.92	0.93	41.56	2.74	0.10	0.18	10.06	98.50	Δ
71004		43.20	1.46	42.40	3.40	0.20	0.14	8.72	99.51	Δ
71007		43.10	1.12	43.80	2.39	0.06	0.14	8.89	99.51	Δ
7108		41.71	1.09	42.11	3.17	0.05	0.16	10.78	99.08	Δ
2631		43.65	0.94	43.29	2.75	0.07	0.15	8.34	99.19	Δ
E. Australia										
BM 20		43.34	1.74	44.43	1.25	0.11	0.13	8.86	99.86	‡
GN 14		40.46	3.14	45.27	2.44	0.06	0.13	8.51	100.00	‡
GN 13		44.55	1.04	44.97	1.21	0.02	0.12	7.99	99.90	‡
GN 24		39.01	2.45	43.32	3.47	0.26	0.18	11.09	99.79	‡
GN 5		45.61	0.62	42.91	1.58	0.06	0.14	8.57	99.49	‡
BM 18		40.95	0.80	44.19	0.80	0.06	0.17	12.86	99.82	‡
cont..										

Appendix E (II) Australian

Non-cratonic major element oxides Australian peridotite xenolith suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Total	Ref
GN 8		41.30	1.99	44.81	1.97	0.03	0.14	9.05	99.30	‡
GN 4		39.37	2.84	44.95	2.69	0.03	0.14	9.09	99.11	‡
GN 11		41.06	1.67	45.08	3.09	0.08	0.14	8.06	99.18	‡
GN 16		38.70	3.38	44.98	3.07	0.07	0.14	8.84	99.18	‡
GN 20		39.82	2.50	45.32	2.63	0.04	0.14	8.78	99.23	‡
GN 12		39.28	2.67	45.16	3.09	0.05	0.14	8.70	99.10	‡
GN 2		38.49	2.12	44.13	2.37	0.04	0.17	11.88	99.20	‡
GN 6		45.27	0.53	43.54	1.72	0.02	0.14	8.55	99.77	‡
GN3		38.90	2.91	43.65	4.19	0.16	0.14	9.08	99.04	‡
Australia, Queensland										
Ka180		39.06	3.17	45.44	2.55	0.11	0.17	9.09	99.60	⊙
Ka181		38.71	3.37	45.07	3.29	0.10	0.15	8.91	99.61	⊙

† Frey & Green, 1974

□ McDonough, unpublished

Δ Yaxley et al, 1991

‡ Stoltz & Davies, 1988, E. Australia

⊙ Griffin et al, 1987, Australia, Queensland

Oxides in wt.%

Appendix E (III) Mongolian

Non-cratonic major element oxides Mongolian peridotite xenolith suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Total	Ref
Mongolia										
Mo101		37.48	4.48	45.03	4.17	0.19	0.13	7.70	99.18	•
Mo102		42.43	2.62	44.29	2.39	0.07	0.13	7.53	99.45	•
Mo103		43.28	2.34	44.21	1.80	0.05	0.13	7.57	99.38	•
Mo104		41.63	3.03	44.56	2.25	0.11	0.13	7.81	99.53	•
Mo105		35.94	5.29	45.97	4.36	0.21	0.13	7.33	99.23	•
Mo-z/1		37.15	4.29	42.75	6.83	0.18	0.13	7.92	99.24	•
MHP 79/1		39.15	4.23	44.57	2.97	0.15	0.13	8.07	99.27	•
MHP 79/2		38.21	4.40	45.31	3.26	0.17	0.13	7.83	99.32	•
MHP 79/3		41.86	3.24	43.96	2.28	0.10	0.13	7.88	99.45	•
MHP 79/4		42.20	3.13	44.15	2.04	0.10	0.13	7.76	99.52	•
Mo 4230/16		37.53	4.57	44.73	3.93	0.23	0.13	8.25	99.37	•
Mo 22		40.20	3.56	44.24	2.78	0.13	0.14	8.27	99.32	•

• Press et al, 1986, Mongolia

Oxides in wt.%

Appendix E (IV) China

Non-cratonic major element oxides China peridotite xenolith suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Total	Ref
S.E. China										
M33		34.16	5.43	46.28	5.40	0.31	0.13	7.80	99.50	◇
M38		37.44	3.98	46.19	3.44	0.18	0.12	8.46	99.81	◇
M31		38.64	3.61	45.37	3.29	0.19	0.14	8.46	99.71	◇
M6		39.11	3.72	45.21	2.98	0.14	0.13	8.43	99.72	◇
M44		42.55	2.44	44.47	1.91	0.09	0.12	8.26	99.85	◇
M24		43.15	1.65	45.20	1.79	0.03	0.12	7.98	99.93	◇
NS28		41.56	2.24	45.47	1.92	0.07	0.13	8.33	99.73	◇
M40		47.38	0.88	42.95	0.58	0.06	0.12	7.97	99.94	◇
M25		44.24	0.90	45.66	0.83	0.03	0.11	8.12	99.90	◇
NS25		39.25	1.34	42.37	3.80	0.21	0.20	12.41	99.59	◇
China, Hannuoba										
Ka174		40.74	2.70	45.13	2.21	0.06	0.14	8.84	99.82	◆
Ka175		42.36	2.28	43.70	1.84	0.06	0.14	9.46	99.85	◆
Ka176		40.28	2.73	45.69	2.54	0.09	0.13	8.36	99.81	◆
Ka177		42.55	1.93	45.28	1.56	0.07	0.13	8.36	99.87	◆
Ka178		42.01	1.71	45.73	1.94	0.05	0.13	8.30	99.88	◆
Ka179		44.33	1.28	44.38	1.24	0.02	0.13	8.54	99.93	◆

◇ Qi et al, 1995, S.E. China

◆ Song & Frey, 1989, China, Hannuoba

Oxides in wt.%

Appendix E (V) Beni Bousera

Non-cratonic major element oxides Beni Bousera, Morocco peridotite xenolith suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO ⁺	Total	Ref
GP13	0.3	39.79	3.45	44.91	3.01	0.14	0.15	8.19	99.94	†
GP91	0	46.35	0.72	43.91	0.56	0.02	0.14	8.27	99.97	†
GP132	0.47	46.11	1.28	42.99	0.82	0.03	0.14	8.13	99.97	†
GP189	0.1	43.63	2.04	44.29	1.88	0.04	0.14	7.86	99.98	†
GP191	0.31	41.11	3.09	44.13	2.8	0.11	0.15	8.29	99.99	†
GP220	0.58	44.68	1.61	43.91	1.44	0.02	0.14	7.6	99.98	†
GP178	0.15	46.99	0.91	42.78	0.83	0.05	0.13	8.13	99.97	†
GP222	0.31	41.17	2.89	44.89	2.43	0.12	0.15	8.05	100.01	†
GP240	0.51	40.73	3.13	44.73	2.16	0.11	0.14	8.01	99.52	†

† Pearson et al, 2004

Oxides in Wt. %

Appendix E (VI) Vitim

Non-cratonic major element oxides Vitim, Siberia peridotite xenolith suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Total	Ref
314-72	0.17	40.11	2.62	44.56	2.03	0.11	0.13	8.36	98.09	†
314-74	0.2	41.8	2.84	44.2	2.35	0.1		7.91	99.40	†
314-6	0.11	43.75	1.53	44.45	1.4	0.06		7.53	98.83	†
314-58	0.3	39.6	3.93	44.3	3.28	0.15		8.16	99.72	†
314-59	0.33	39.9	3.4	44.4	3.54	0.12		7.84	99.53	†
313-6	0.3	38.95	3.88	43.95	3.04	0.15		8.3	98.57	†
313-54	0.36	38.7	4.1	44.6	3.42	0.16		7.9	99.24	†
313-102	0.33	36.66	4.65	45.25	3.37	0.13	0.15	8.17	98.71	†
313-104	0.36	38.08	3.7	44.92	3.45	0.16	0.14	8.24	99.05	†
314-5a	0.11	43.7	1.43	42.9	0.5	0.08		10.01	98.73	†
313-05	0.24	39.15	3.41	44.45	2.83	0.12		7.92	98.12	†

† Pearson et al, 2004

Oxides in Wt. %

Appendix F
Non-cratonic Data
European
Major Elements

Appendix F (I) Hungarian

Non-cratonic major element oxides Hungarian peridotite xenolith suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Total	Ref
Hungary										
Bo-1022		45.87	1.32	44.39	0.64	0.02	0.12	7.62	99.98	†
Szg-1001		39.84	3.98	44.43	3.09	0.15	0.15	8.08	99.72	†
Szg-1087		32.54	3.83	52.02	4.86	0.05	0.12	6.39	99.81	†
Szt-1002		39.31	3.53	45.58	3.34	0.08	0.14	7.82	99.81	†
Szt-1006		41.23	2.96	44.08	2.57	0.16	0.13	8.61	99.74	†
Szg-1009		40.60	3.50	44.74	2.69	0.10	0.13	8.06	99.82	†
Szt 1016		45.47	0.95	45.06	0.65	0.02	0.12	7.72	99.99	†
Szt 1033		41.50	2.12	45.66	1.85	0.08	0.14	8.59	99.95	†
Szt 1034		44.68	1.31	44.46	1.15	0.04	0.13	8.11	99.88	†
Szt 1106		38.72	3.65	44.15	4.59	0.16	0.14	8.28	99.69	†
Szt 1108		39.68	3.51	45.09	3.00	0.14	0.13	8.22	99.79	†
Szt 1116		44.84	1.26	44.12	1.06	0.04	0.13	8.43	99.88	†
Szt-1120		38.82	3.94	45.71	2.97	0.12	0.14	8.17	99.87	†
G-1055		40.31	3.19	44.12	3.17	0.14	0.13	8.70	99.77	†
G-1067		41.79	2.05	45.73	1.96	0.04	0.12	8.28	99.97	†
G-1071		40.24	3.05	44.60	3.15	0.11	0.12	8.59	99.86	†

† Embey-Isztin et al, 1989, Hungary

Oxides in Wt. %

Appendix F (II) Romanian

Non-cratonic major element oxides Romanian peridotite xenolith suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Total	Ref
Romania										
BG01		45.87	0.92	43.62	1.49	0.03	0.12	7.92	99.97	□
BG02		39.88	3.06	44.59	3.24	0.12	0.13	8.68	99.71	□
BG04		42.89	2.04	44.34	1.74	0.10	0.12	8.26	99.49	□
BG07		39.10	3.65	45.33	3.03	0.15	0.12	8.40	99.78	□
BG09		40.39	3.06	45.15	2.63	0.12	0.13	8.18	99.67	□
BG10		41.92	2.84	44.33	2.54	0.10	0.12	7.95	99.80	□
BG15		40.61	3.23	45.11	2.84	0.12	0.12	7.86	99.90	□
BG16		43.51	2.30	44.14	1.83	0.08	0.12	7.91	99.90	□
BG18		41.06	2.78	44.39	2.72	0.12	0.13	8.27	99.47	□
BGt.3		39.61	3.82	45.19	3.21	0.15	0.13	7.69	99.80	□
Bgt.6		37.72	4.29	45.39	4.06	0.18	0.13	7.99	99.76	□
Bgt.7		39.42	3.73	44.99	3.16	0.15	0.13	8.26	99.86	□
Bgt.13		38.99	3.90	45.13	3.25	0.17	0.13	8.20	99.76	□
Bgt.17		36.45	4.24	46.95	3.45	0.21	0.13	8.39	99.81	□
Bgt.18		41.58	2.51	44.54	2.07	0.09	0.13	8.99	99.91	□
Bgt.19		42.16	2.67	44.33	2.30	0.09	0.13	8.20	99.89	□
Bgt.21		42.27	2.43	44.70	2.15	0.08	0.12	8.14	99.90	□
Bgt.22		42.32	2.52	44.36	2.14	0.08	0.12	8.32	99.86	□
BC-01		38.49	2.98	44.21	2.82	0.10	0.19	10.97	99.76	□
BC-02		40.46	3.42	44.33	2.93	0.12	0.15	8.28	99.69	□
BC-09		43.13	2.00	44.39	2.04	0.05	0.13	8.21	99.95	□
LGR.9		41.13	3.22	44.31	2.76	0.10	0.13	8.08	99.74	□

□ Vaselli et al, 1995, Romania

Oxides in Wt. %

Appendix F (III) Italian

Non-cratonic major element oxides Italian peridotite xenolith suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Total	Ref
Italy										
Ka182		38.78	3.68	44.83	3.36	0.14	0.17	8.61	99.58	Δ
Ka183		39.71	3.85	42.98	3.78	0.24	0.17	8.84	99.57	Δ
Ka184		40.39	3.13	42.89	3.58	0.12	0.18	9.38	99.67	Δ
Ka185		38.75	4.27	43.46	1.10	0.30	0.26	11.43	99.57	Δ
Ka186		39.62	2.84	43.81	3.44	0.18	0.18	9.64	99.71	Δ
Ka187		39.80	2.88	44.35	2.15	0.28	0.19	10.14	99.79	Δ
Ka188		43.29	1.77	39.89	0.82	0.25	0.23	13.28	99.54	Δ
Ka189		41.96	2.60	42.88	2.01	0.16	0.19	9.64	99.43	Δ
Ka190		37.79	3.92	44.81	3.56	0.17	0.17	8.98	99.40	Δ
Ka191		42.27	3.26	43.19	1.48	0.12	0.17	8.66	99.16	Δ
Ka192		39.11	3.29	42.16	3.71	0.36	0.20	10.63	99.46	Δ
Ka193		41.89	1.80	41.25	1.72	0.27	0.22	12.57	99.72	Δ
Ka194		39.65	3.67	45.27	3.23	0.13	0.15	7.59	99.67	Δ
Ka195		38.75	5.79	43.43	3.59	0.19	0.16	7.76	99.67	Δ
Ka225		49.67	0.30	41.30	0.25	0.01	0.12	8.28	99.94	‡
Ka226		45.97	0.67	45.22	0.45	0.01	0.12	7.50	99.93	‡
Ka227		45.67	1.01	43.66	1.50	0.05	0.12	7.78	99.79	‡
Ka228		46.63	1.08	42.98	0.51	0.03	0.13	8.54	99.90	‡
Ka229		45.53	1.13	44.49	0.87	0.04	0.13	7.67	99.86	‡
Ka230		44.58	1.31	41.92	3.24	0.07	0.14	8.44	99.70	‡
Ka231		44.62	1.33	44.45	0.95	0.02	0.15	8.33	99.85	‡
Ka232		45.29	1.56	43.96	1.18	0.01	0.12	7.80	99.93	‡
Ka233		41.68	1.99	45.81	2.24	0.02	0.13	7.92	99.80	‡
Ka234		41.78	2.05	46.30	1.44	0.04	0.14	8.05	99.81	‡
Ka235		41.36	2.52	45.63	2.12	0.05	0.13	7.94	99.75	‡
Ka236		39.38	2.84	46.71	2.58	0.11	0.14	8.04	99.80	‡

Δ Morten, Italy

‡ Dupuy et al, 1987

Oxides in Wt. %

Appendix F (IV) British

Non-cratonic major element oxides British peridotite xenolith suite

Sample	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	CaO	TiO ₂	MnO	FeO*	Total	Ref
<u>British Isles</u>										
Ka219		42.69	2.13	44.75	2.38	0.07	0.12	7.75	99.90	○
Ka220		39.28	2.55	45.60	3.72	0.21	0.12	7.80	99.27	○
Ka221		41.36	2.49	44.82	2.72	0.20	0.06	8.10	99.76	○
Ka222		41.97	2.12	44.53	2.52	0.07	0.14	7.95	99.30	○

○ Hunter & Upton, British Isles

Oxides in Wt. %

Appendix G

Other Peridotite Suites Platinum Group Element Data

Appendix G (I) Kaapvaal xenolith suite Pearson et al, 1995.

Samp No.	Measured						Chondrite normalised					
	Os (ppb)	Ir (ppb)	Ru (ppb)	Pt (ppb)	Pd (ppb)	Re (ppb)	Os (ppb)	Ir (ppb)	Ru (ppb)	Pt (ppb)	Pd (ppb)	Re (ppb)
FRB1431	1.7610	2.04	2.93	315	0.299	0.0110						
FRB1382	3.7911	2.89	4.64	5.94	4.65	0.1288						
Low-T Spinel												
FRB979#	0.8040					0.1330	0.0017					0.0035
FRB1001#	3.5700					0.1160	0.0073					0.0031
PHN2600	0.6250					0.0350	0.0013					0.0009
PHN5266	3.2500					0.1180	0.0067					0.0031
PHN5254	6.1300					0.1060	0.0126					0.0028
PHN5275	8.2300					0.1030	0.0169					0.0027
Low-T Garnet												
*F556	1.7300					0.0340	0.0036					0.0009
*F865	1.3800					0.0860	0.0028					0.0023
*F866	2.6600					0.0810	0.0055					0.0021
FRB921	2.6600					0.0530	0.0055					0.0014
FRB1350	3.3900					0.0260	0.0070					0.0007
PHN1569	2.6100					0.0790	0.0054					0.0021
*BD2125	0.0190					0.0410	0.0000					0.0011
PHN2302	1.5100					0.0150	0.0031					0.0004
PHN2823	9.2000					0.0730	0.0189					0.0019
PHN2825	1.4100					0.0950	0.0029					0.0025
PHN5273	3.1700					0.0320	0.0065					0.0008
PHN5595	4.2400					0.1350	0.0087					0.0036
High-T Garnet												
FRB909	1.6900					0.0510	0.0035					0.0013
PHN1596	5.9400					0.0740	0.0122					0.0019
PHN1611	1.2600					0.2850	0.0026					0.0075
PHN5239	1.5400					0.1000	0.0032					0.0026
PHN5267	5.3300					0.0600	0.0110					0.0016
K7-318	2.4500					1.0300	0.005041					0.0271

* = diamond bearing samples

Appendix G (II) Beni Bousera xenolith suite, Pearson et al, 2004

Samp No.	Measured						Chondrite normalised					
	Os (ppb)	Ir (ppb)	Ru (ppb)	Pt (ppb)	Pd (ppb)	Re (ppb)	Os (ppb)	Ir (ppb)	Ru (ppb)	Pt (ppb)	Pd (ppb)	Re (ppb)
GP13	3.5780	3.2800	6.7100	6.6500	5.8500	0.3300	0.0074	0.0071	0.0094	0.0067	0.0105	0.0087
GP91	17.5220	4.7000	7.4000	7.0300	6.5800	0.0890	0.0361	0.0102	0.0104	0.0071	0.0118	0.0023
GP132	4.5300	4.1500	7.4600	9.7200	2.0700	0.0760	0.0093	0.0090	0.0104	0.0098	0.0037	0.0020
GP189	3.4400	3.2300	6.4900	6.7700	5.4000	0.1680	0.0071	0.0070	0.0091	0.0068	0.0097	0.0044
GP191	3.6300	3.2700	6.3600	6.7000	6.4800	0.2680	0.0075	0.0071	0.0089	0.0067	0.0117	0.0071
GP220	0.9195	3.3600	0.4030	4.3900	4.4600	0.0280	0.0019	0.0073	0.0006	0.0044	0.0080	0.0007
GP178	3.2800					0.1910	0.0067					0.0050
GP222	3.4100					0.2010	0.0070					0.0053
GP240	3.7900					0.2520	0.0078					0.0066

Appendix G (III) Vitim, Pearson et al, 2004

Samp No.	Measured						Chondrite normalised					
	Os (ppb)	Ir (ppb)	Ru (ppb)	Pt (ppb)	Pd (ppb)	Re (ppb)	Os (ppb)	Ir (ppb)	Ru (ppb)	Pt (ppb)	Pd (ppb)	Re (ppb)
314-72	0.8310	3.0100	4.7700	3.7200	2.0500	0.0390	0.0017	0.0066	0.0067	0.0037	0.0037	0.0010
314-74	0.4120	2.5300	4.3300	3.5200	2.1900	0.0700	0.0008	0.0055	0.0061	0.0035	0.0039	0.0018
314-6	0.4130	2.4300	6.2400	4.9500	2.1900	0.0250	0.0008	0.0053	0.0087	0.0050	0.0039	0.0007
314-58	0.9790	3.2600	6.4100	3.3000	2.4800	0.0530	0.0020	0.0071	0.0090	0.0033	0.0045	0.0014
314-59	0.4580	2.4600	4.1300	3.5900	2.3600	0.0670	0.0009	0.0054	0.0058	0.0036	0.0042	0.0018
313-6	0.7910	2.5500	4.8500	3.2100	1.6300	0.0250	0.0016	0.0056	0.0068	0.0032	0.0029	0.0007
313-54	0.8890	2.5800	6.9300	3.6100	2.0900	0.0240	0.0018	0.0056	0.0097	0.0036	0.0038	0.0006
313-102	0.5540	1.7000	3.4800	3.0200	1.9600	0.0690	0.0011	0.0037	0.0049	0.0030	0.0035	0.0018
313-104	0.7580	2.3900	4.8100	4.2300	2.5500	0.0260	0.0016	0.0052	0.0067	0.0043	0.0046	0.0007
314-5a	1.9000	3.8700	7.0500	2.8000	0.6340	0.0220	0.0039	0.0084	0.0099	0.0028	0.0011	0.0006
314-5b	0.4300	3.8800	7.0800	3.3200	0.8700	0.0220	0.0009	0.0085	0.0099	0.0033	0.0016	0.0006
313-05	0.9400	2.1700	4.0800	3.0600	1.7500	0.0160	0.0019	0.0047	0.0057	0.0031	0.0031	0.0004
314-71	0.5240	2.3900	3.9100	1.3400	1.3000	0.0400	0.0011	0.0052	0.0055	0.0013	0.0023	0.0011
86-1	0.7190					0.0430	0.0015					0.0011
313-37	0.8980					0.0270	0.0018					0.0007
313-240	0.6880					0.0260	0.0014					0.0007
314-580	0.9980					0.0360	0.0021					0.0009
314-56	0.9230					0.0240	0.0019					0.0006

Appendix G (IV) Slave & Namibia

Samp No.	Measured						Chondrite normalised					
	Os (ppb)	Ir (ppb)	Ru (ppb)	Pt (ppb)	Pd (ppb)	Re (ppb)	Os (ppb)	Ir (ppb)	Ru (ppb)	Pt (ppb)	Pd (ppb)	Re (ppb)
Slave												
8 to 7	2.4700	2.0300	3.4700	0.2530	0.0490	0.0060	0.0051	0.0044	0.0049	0.0003	0.0001	0.0002
10 to 12A	3.1000	2.5300	4.1600	0.3380	0.0730	0.0360	0.0064	0.0055	0.0058	0.0003	0.0001	0.0009
40 to 21	2.4300	2.5200	5.4700	2.2600	0.8560	0.0337	0.0050	0.0055	0.0077	0.0023	0.0015	0.0009
Namibia												
FRB1181	5.1100	4.9600	10.0200	5.9000	1.5600	0.0580	0.0105	0.0108	0.0140	0.0059	0.0028	0.0015
FRB1650	2.4900	3.2500	9.7900	3.1400	0.9200	0.0490	0.0051	0.0071	0.0137	0.0032	0.0017	0.0013
FRB1652	2.4700	2.5400	9.3800	3.5400	1.1800	0.0290	0.0051	0.0055	0.0131	0.0036	0.0021	0.0008
PHN5304	5.0100	4.5600	7.6900	2.9400	1.2100	0.3190	0.0103	0.0099	0.0108	0.0030	0.0022	0.0084
PHN5315	4.7500	3.6000	9.0800	4.8500	3.4300	0.1430	0.0098	0.0078	0.0127	0.0049	0.0062	0.0038
JJG2514	3.2300	2.8100	4.3700	2.7800	0.6400	0.1360	0.0066	0.0061	0.0061	0.0028	0.0012	0.0036

Slave = Kopylova & Russel, 2000

Namibia = Pearson et al., 2004

Appendix G (V) Lesotho, Pearson et al, 2004

Samp No.	Measured						Chondrite normalised					
	Os (ppb)	Ir (ppb)	Ru (ppb)	Pt (ppb)	Pd (ppb)	Re (ppb)	Os (ppb)	Ir (ppb)	Ru (ppb)	Pt (ppb)	Pd (ppb)	Re (ppb)
LET2	5.7100	5.2600	8.1700	3.7600	0.7320	0.3300	0.0117	0.0115	0.0114	0.0038	0.0013	0.0087
LET6	3.1800	1.7200	1.4200	0.1820	0.0350	0.1370	0.0065	0.0037	0.0020	0.0002	0.0001	0.0036
LET8	1.6000	1.8900	2.1600	0.2880	0.9300	0.2510	0.0033	0.0041	0.0030	0.0003	0.0017	0.0066
LET12	3.1600	2.6500	4.4400	0.5350	0.0740	0.1530	0.0065	0.0058	0.0062	0.0005	0.0001	0.0040
LET13	3.3100	3.3700	4.7000	0.8860	0.0220	0.0410	0.0068	0.0073	0.0066	0.0009	0.0000	0.0011
LET14	4.7000	4.6900	6.1900	1.5000	0.3780	0.0890	0.0097	0.0102	0.0087	0.0015	0.0007	0.0023
LET25	1.9800	2.2200	3.6500	2.1200	0.1210	0.1500	0.0041	0.0048	0.0051	0.0021	0.0002	0.0039
LET27	6.2500	5.4400	8.1200	3.9200	0.1020	0.3670	0.0129	0.0119	0.0114	0.0039	0.0002	0.0097
LET28	3.8800	3.3300	5.4100	2.4000	0.0280	0.0960	0.0080	0.0073	0.0076	0.0024	0.0001	0.0025
LET29	3.4400	1.7100	2.4500	1.4100	0.2110	0.2600	0.0071	0.0037	0.0034	0.0014	0.0004	0.0068
LET30	2.3700	2.3300	2.3800	0.2250	0.1110	0.2170	0.0049	0.0051	0.0033	0.0002	0.0002	0.0057
LET31	5.8200	4.1200	7.7400	2.6900	0.5180	0.2010	0.0120	0.0090	0.0108	0.0027	0.0009	0.0053
LET38	13.7000	8.5400	15.5200	9.6300	0.0390	0.0900	0.0282	0.0186	0.0217	0.0097	0.0001	0.0024
LET47	4.3500	4.2700	6.3900	3.3200	0.0280	0.1900	0.0090	0.0093	0.0089	0.0033	0.0001	0.0050
LET48	1.9900	2.2700	9.7300	3.1600	1.7600	0.2300	0.0041	0.0049	0.0136	0.0032	0.0032	0.0061
LET49	3.8600	3.8100	7.4400	6.7500	5.9200	0.1100	0.0079	0.0083	0.0104	0.0068	0.0106	0.0029
LET58	5.2200	4.1700	5.7100	4.2900	0.8510	0.3300	0.0107	0.0091	0.0080	0.0043	0.0015	0.0087
LET63	4.1300	3.6800	6.8800	3.7000	1.7580	0.0900	0.0085	0.0080	0.0096	0.0037	0.0032	0.0024
LET64	6.4200	6.4100	10.0000	7.4800	0.2410	0.6000	0.0132	0.0140	0.0140	0.0075	0.0004	0.0158

Appendix G (VI) Somerset Island, Irvine et al, 2003

Measured							Chondrite normalised					
Samp No.	Os (ppb)	Ir (ppb)	Ru (ppb)	Pt (ppb)	Pd (ppb)	Re (ppb)	Os (ppb)	Ir (ppb)	Ru (ppb)	Pt (ppb)	Pd (ppb)	Re (ppb)
Batty Bay												
K11A14	2.3900	2.2000	4.4300	1.9800	1.4200	0.0500	0.0049	0.0048	0.0062	0.0020	0.0026	0.0008
K11A15	2.3500	2.5000	5.4000	1.1100	6.8900	0.0200	0.0048	0.0054	0.0076	0.0011	0.0124	0.0005
K11A16	3.2500	3.6600	6.6400	4.2100	1.4000	0.0500	0.0067	0.0080	0.0093	0.0042	0.0025	0.0013
K11A17	2.5800	2.7500	6.0200	1.2500	0.9600	0.0200	0.0053	0.0060	0.0084	0.0013	0.0017	0.0005
K11A18	0.6200	0.6400	1.2300	0.0900	0.4100	0.0100	0.0013	0.0014	0.0017	0.0001	0.0007	0.0003
K12A1	3.6000	2.5600	4.5300	2.8200	1.4400	0.0500	0.0074	0.0056	0.0063	0.0028	0.0026	0.0013
K13A1	4.4900	4.4200	9.8100	7.5400	1.7700	0.1300	0.0092	0.0096	0.0137	0.0076	0.0032	0.0034
K13A3	4.2000	3.9700	7.1900	2.0800	0.5800	0.0300	0.0086	0.0086	0.0101	0.0021	0.0010	0.0008
K13A4	2.2500	3.3200	6.1900	5.2400	3.9500	0.0400	0.0046	0.0072	0.0087	0.0053	0.0071	0.0011
K13A5	3.7300	4.6600	8.6700	2.8100	1.7200	0.2200	0.0077	0.0102	0.0121	0.0028	0.0031	0.0058
K13B4	4.1800	4.2500	6.1400	8.3200	0.4600	0.0100	0.0086	0.0093	0.0086	0.0084	0.0008	0.0003
K15A4	1.8000	2.2000	7.5200	2.9200	0.6900	1.5000	0.0037	0.0048	0.0105	0.0029	0.0012	0.0395
Nord												
N1C	3.3800	3.3100	6.3100	2.1900	1.2200	0.2100	0.0070	0.0072	0.0088	0.0022	0.0022	0.0055
N2B	1.7400	1.8700	3.8500	1.5900	0.9100	0.0300	0.0036	0.0041	0.0054	0.0016	0.0016	0.0008
Nikos												
X04	3.3100	3.1000	5.2800	3.8600	3.3800	0.2300	0.0068	0.0068	0.0074	0.0039	0.0061	0.0061
X05	3.2300	2.9700	6.7800	1.9300	1.3400	0.3900	0.0066	0.0065	0.0095	0.0019	0.0024	0.0103
X06	2.8700	2.6600	6.1200	2.4000	1.6400	0.1400	0.0059	0.0058	0.0086	0.0024	0.0029	0.0037
X07	5.9500	5.9300	10.8100	5.3500	1.5000	0.0700	0.0122	0.0129	0.0151	0.0054	0.0027	0.0018
JP												
JP1-X2	3.4100	3.2100	5.6100	3.0700	2.4300	0.1100	0.0070	0.0070	0.0079	0.0031	0.0044	0.0029
JP2-X2	3.5800	3.1800	5.5700	2.9000	0.1600	0.0300	0.0074	0.0069	0.0078	0.0029	0.0003	0.0008
JP3-X	2.8900	2.8200	5.1300	2.2700	1.3700	0.0500	0.0059	0.0061	0.0072	0.0023	0.0025	0.0013
JP3-X1	2.6500	2.6500	3.4200	1.1200	0.2700	1.0900	0.0055	0.0058	0.0048	0.0011	0.0005	0.0287
JPN2	4.9100	4.6100	9.1200	4.0100	2.4800	0.0600	0.0101	0.0100	0.0128	0.0040	0.0045	0.0016
JPN3A	6.7000	6.5200	12.3800	7.5200	4.2000	0.0800	0.0138	0.0142	0.0173	0.0076	0.0076	0.0021
JPN3B	5.8100	5.7800	9.7700	5.7800	3.8200	0.1600	0.0120	0.0126	0.0137	0.0058	0.0069	0.0042
JPN4	2.9100	2.5900	4.7700	1.9300	1.4300	0.0300	0.0060	0.0056	0.0067	0.0019	0.0026	0.0008
JPN9	4.2500	3.7900	6.8700	2.8500	1.8900	0.0900	0.0087	0.0083	0.0096	0.0029	0.0034	0.0024
JPN11	2.7700	2.9300	5.1700	1.4700	0.0800	0.0300	0.0057	0.0064	0.0072	0.0015	0.0001	0.0008
JPS1	6.0700	5.6300	10.8800	4.4300	1.1800	1.6500	0.0125	0.0123	0.0152	0.0045	0.0021	0.0434
JPS4	3.4800	4.0400	7.4000	2.4200	1.4700	0.4500	0.0072	0.0088	0.0104	0.0024	0.0026	0.0118
JPS6A	4.4300	4.1500	7.8000	3.7100	2.2800	2.5800	0.0091	0.0090	0.0109	0.0037	0.0041	0.0679
JPS6B	3.9700	3.9000	7.4200	4.1700	2.5900	1.9900	0.0082	0.0085	0.0104	0.0042	0.0047	0.0524

