WHOLE ROCK PLATINUM GROUP ELEMENT GEOCHEMISTRY OF KIMBERLITIC ROCKS - A WINDOW INTO THE NATURE OF THE DIAMONDIFEROUS MANTLE

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INTRODUCTION

Low degree partial mantle melts (<1%) such as kimberlite and related rocks (i.e. lamprophyre and lamproite) are to date the main carriers of economic quantities of diamond to the Earth's surface. They have been well characterized for lithophile trace and isotopic compositions (see Mitchell, 1995 for an overview). However, apart from one study (McDonald et al., 1995) the whole rock siderophile element geochemistry of such mantle samples has been neglected. Whether the whole rock platinum group element (PGE) content of kimberlitic rocks is primary or the result of contamination, has remained debatable (e.g. McDonald et al., 1995; Pearson et al., 1995). The aim of this study is to resolve this issue, and also to investigate the potential applications of whole rock PGE (Os, Ir, Ru, Pt, Re) data to diamond exploration. The latter may be a natural corollary to whole rock PGE geochemistry of kimberlites, if the latter indeed arises due to contamination, because sulfides are the most common diamond inclusion phase, and are also the main hosts of PGEs in the mantle. During the course of this study a new analytical technique was developed for the direct analysis of PGEs in incompatible element-rich kimberlitic samples. The technique is described more fully in Pretorius et al. (in press). The advantage of the new technique over Ni-S fire assay, as used by Macdonald et al. (1995) is the elimination of high and inconsistent Pt-blanks, which may obscure important trends in the whole rock PGE data. The sampling strategy in this study is also more broad and includes kimberlites, melnoites and lamproites from three continents and various tectonic settings in order to gain a greater understanding of the controls on PGE geochemistry on a global scale. The samples used in this study are listed in Table 1. The tectonic setting and whole rock PGE geochemistries of the samples are discussed in detail in Pretorius et al., submitted. McDonald et al. (1995) were able to discriminate on versus off craton kimberlites based on whole rock Os/Ir ratios >1 and < 1, respectively. In this study we show that whole rock Pt/Ir ratios on a global scale, are geochemically more robust discriminants of the nature of the underlying mantle through which kimberlitic diatremes erupt. This is likely because Pt and Ir are more easily fractionated from one another than Os and Ir in the mantle, and may serve as more sensitive proxies for the nature of the underlying mantle. In addition, by comparing the PGE signatures of the mantle inclusion suites with those of the respective hosts, it is possible to resolve whether the whole rock PGE geochemistry of kimberltic rocks is primary or not.

THE SOURCE OF PGES IN KIMBERLTIC ROCKS

All kimberlites were analyzed between two and three times in order to evaluate nugget effects. Reference materials were analyzed in order to obtain estimates of analytical accuracy and precision (~15% RSD, see Pretorius et al., in press). From a geochemical standpoint, it is highly unlikely that low-degree
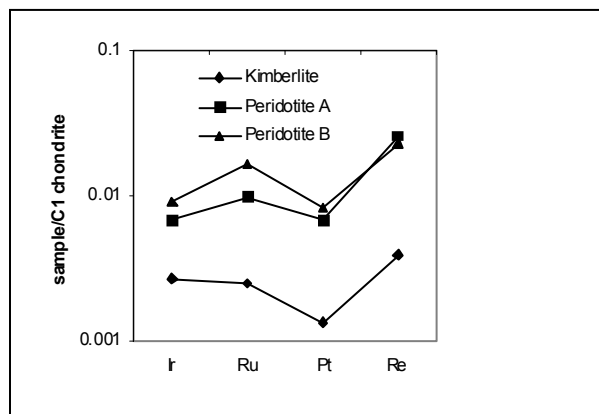

Figure 1: Comparison between the PGE pattern of host kimberlite and two entrained mantle peridodites from Letlhakane.

kimberlitic partial melts will contain part per billion concentrations of PGEs, such as is common in mantle peridotites. The PGE content of mantle melts is generally a function of the degree of sulfide extraction from the source, and this in turn is directly related to the degree of partial melting of the source. Typically, only relatively high-degree partial mantle melts (>10-20 % such as komatiites, bonninites, high-MgO basalts) extract sufficient PGE-rich sulfides to attain ppb-level

concentrations (e.g. Peach et al., 1990; Barnes and Maier, 1999). Basalts, which typically undergo up to ~10% partial melting, contain only part per trillion levels of PGEs. Whole rock PGE analysis of some peridotite inclusions hosted in the kimberlitic samples (i.e. Letlhakane and Somerset Island) showed unequivocally that kimberlites, inherit their whole rock PGE signatures through disaggregation and assimilation of PGE-rich sulfides and alloys included in high PGE-content peridotites (e.g. Fig. 1). Although Re-Os systematics have been used in the past to characterize the source regions of kimberlites and lamproites, correlations between the whole rock Re/Os ratios and Os concentrations of a variety of samples in this study, are correlated strongly with the nature and history of the underlying mantle (Fig. 2).

Fig. 2 are from Lambert et al., (1995) and Graham et al. (1999). Leucite Hills lamproite erupts through highly metasomatised or delaminated lithosphere).

Correlations between the whole rock Pt/Ir and Ru/Pt ratios of the kimberlitic rocks and the nature of the xenolith inclusion suites found in them were excellent. Diatremes that erupted through on craton, depleted mantle, have low whole rock Pt/Ir and high Ru/Pt ratios. Conversely, diatremes that erupted through young, fertile (i.e. off craton) mantle have high whole rock Pt/Ir and low Ru/Pt ratios (Fig. 3). These correlations, although offset from, are consistent with the trend shown by discrete sulfides found respectively as inclusions in silicates from on and off craton peridotites and shown in Fig. 3 (e.g. Alard et al., 2000).
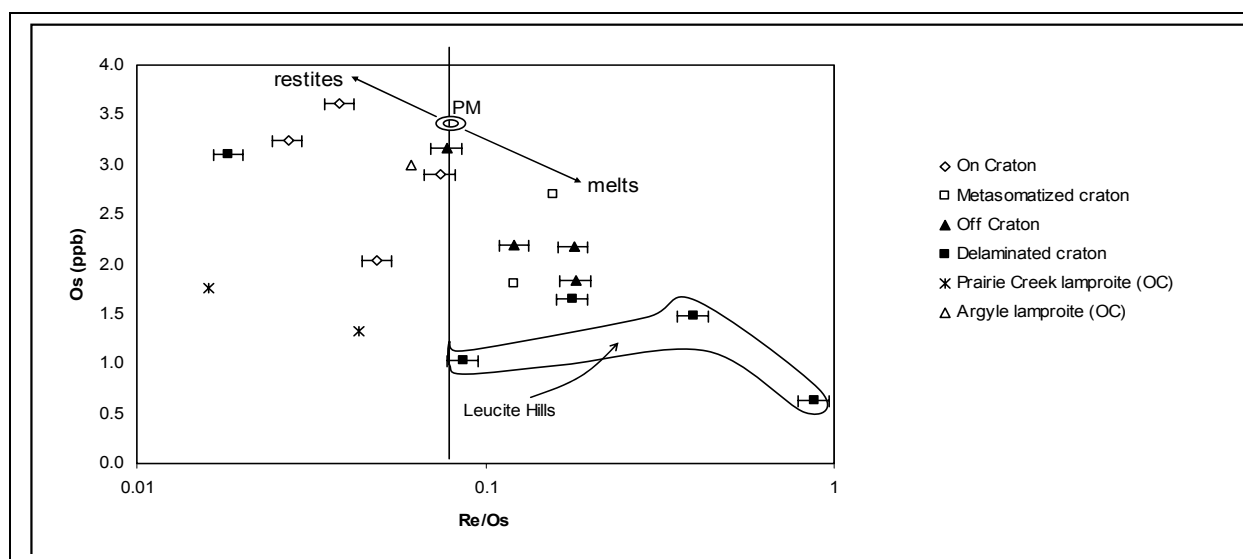

Figure 2: Whole rock Os (ppb) versus Re/Os ratio for various kimberlite, melnoite and lamproite samples from this study. PM=primitive mantle. Trends for mantle restites and melts relative to PM are shown for reference.

Although Re is an incompatible element, it is only mildly so, and if kimberlites erupt through highly metasomatised (i.e. Re-enriched) mantle, the possibility of Re and Os contamination from entrained peridotites cannot be ignored (Pretorius et al., submitted). Fig. 2 suggests that whole rock Re-Os systematics of low degree mantle melts are unlikely to be a true reflection of the source of such magmas, and instead reflect the nature of the underlying mantle through which the magmas erupt as a result of contamination. (Data for Argyle and Prairie Creek lamproites which erupt through cratonized (i.e. depleted) Proterozoic mantle on

Compared to on and off craton silicate enclosed sulfides, metasomatic sulfides (i.e. interstitial) have the highest Pt/Ir and lowest Ru/Pt ratios (e.g. Alard et al., 2000). The highest Pt/Ir ratios for on craton kimberlite samples were for those samples with seismic and xenolith evidence that the underlying mantle has been subjected to extensive metasomatism (i.e. Premier). The only exceptions to the general trend in Fig. 3, are lamproite samples, which had consistently high Pt/Ir ratios, irrespective of the nature of the underlying mantle. This is thought to result from unique Pt-enrichment processes related to lamproite source development (see Pretorius et al., submitted). As shown on Fig. 3 there is very good separation of on versus off craton samples based on whole rock Ru/Pt and Pt/Ir ratios. Whole rock PGE data thus appears to provide a

means to assess the the nature of the underlying mantle (i.e. depleted cratonic, fertile off cratonic) through which kimberlitic and melnoitic diatremes erupted, without prior knowledge of the diamond indicator or peridotite inclusion suite. For example, although the Letlhakane kimberlite pipes erupt through the Magondi Mobile Belt at surface, the pipes are actually rooted in the western edge of the Zimbabwe craton (e.g. Stiefenhofer et al., 1997). The whole rock Ru/Pt vs. Pt/Ir ratios reflect this as they plot in the field occupied by other on craton kimberlites in the study e.g. Fig. 3. The obvious benefit of this technique is that pipes that have sampled potentially diamondiferous depleted mantle at depth can be discriminated, irrespective of the surface geology.

diamond growth occurs during craton formation or later metasomatic growth in depleted craton keels (which have subchondritic Pt/Ir ratios), and that major mafic metasomatic events cause chemical or thermal resorption of diamonds, and suprachondritic Pt/Ir ratios. Diamond grades for selected Southern African and Chinese kimberlites are shown plotted relative to absolute concentrations of Pt and Ir in replicate samples of kimberlite in Fig. 4. The highest grade kimberlites (e..g Venetia, Bellsbank and Shengli) plot exclusively on or below a line of subchondritic Pt/Ir ratio (~1.5). Conversely, low grade kimberlites plot both below and above the Pt/Ir=1.5 line, while subeconomic kimberlites plot exclusively above the Pt/Ir=1.5 ratio line.
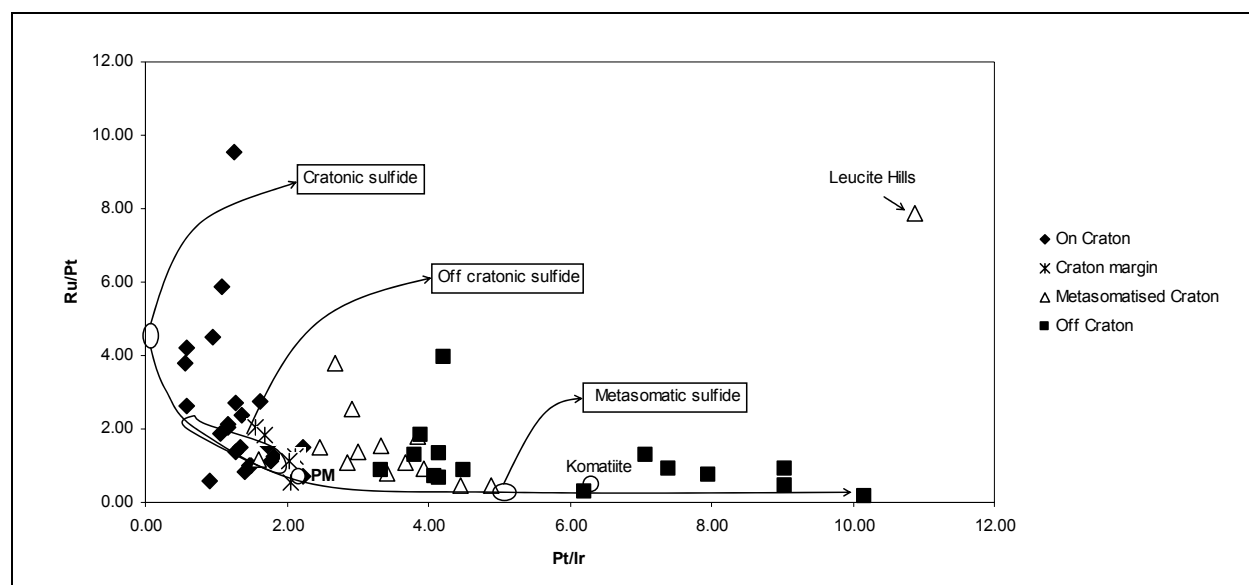
Figure 3: Whole rock Pt/Ir versus Ru/Pt ratios in samples from this study according to the type of mantle lithosphere intruded. Fieldsfor on and off craton and interstitial metasomatic sulfide (after Alard et al., 2000) are also shown. PM=primitive mantle.

Subchondritic whole rock Pt/Ir ratios (<2) thus appear to be a good proxy for the sampling of depleted cratonic lithosphere whereas suprachondritic Pt/Ir (>2) ratios appear to reflect the sampling of metasomatised cratonic or off cratonic lithosphere (Pt/Ir >~4) respectively, in kimberlites and melnoites.

Diamond grade vs. whole rock Pt/Ir ratio

A correlation between diamond grade and whole rock Pt/Ir ratio of kimberlites may be expected assuming that

Venetia and Bellsbank appear to sample the same diamondiferous horizon seeing as they both plot on or close to the Pt/Ir=1.5 ratio, and moreover appear to reflect the carrying capacity of the respective kimberlites, i.e. higher carrying capacity is reflected in higher absolute abundances of Pt and Ir (Venetia), in turn reflecting a higher degree of physical disaggregation and incorporation of the potentially diamondiferous horizon into the kimberlite. Bellsbank has lower diamond grade and lower abundances of Pt and Ir, and suggests that the physical mechanism of mantle entrainment of the same diamondiferous horizon was less efficient beneath Bellsbank. The mantle beneath New Elands appears to contain less diamonds than beneath Venetia or Bellsbank as its grade is lower but it appears to have a similar carrying capacity to Venetia. Sulfides are not necessarily genetically related

to diamond growth and hence PGE signature of a mantle segment (see Pretorius et al., submitted). Hence, highly subchondritic whole rock Pt/Ir ratios, while very likely to reflect the sampling of depleted cratonic lithosphere, are not necessarily also a reflection of high

Table 1: Geographic location and magma type of samples analyzed for PGEs in this study. *=Group 2 kimberlite, OC=on craton, CM=craton margin, OFC=off craton, MC=metasomatised craton.

Sample	Location	Magma type
Sukkertoppen (OC)	Greenland	melnoite
Sarfartoq (CM)	Greenland	melnoite
Holsteinborg (OFC)	Greenland	melnoite
Cross (OFC)	BC, Canada	kimberlite
Picton (OFC)	ON, Canada	kimberlite
Ham (MC)	Somerset Island	kimberlite
Jos (MC)	Somerset Island	kimberlite
Tunraq (MC)	Somerset Island	kimberlite
Elwin Bay (MC)	Somerset Island	kimberlite
Leucite Hills (MC)	Wyoming, USA	lamproite
Masontown (OFC)	Penn., USA	kimberlite
Ison Creek (OFC)	Kentuckey, USA	kimberlite
Shengli #1 (OC)	China	kimberlite
Fuxian #50 (MC)	China	kimberlite
Fuxian #42 (MC)	China	kimberlite
Obnazhenaya(MC)	Siberia	kimberlite
Venetia (OC)	South Africa	kimberlite
Bellsbank (OC)*	South Africa	kimberlite
National (OC)	South Africa	kimberlite
New Elands (OC)*	South Africa	kimberlite
Premier (OC)	South Africa	kimberlite
Frank Smith (OC)	South Africa	kimberlite
Letlhakane (OC)	Zimbabwe	kimberlite
Gibeon (OFC)	Namibia	kimberlite

diamond potential. Other factors such as kimberlite carrying capacity, related to exsolution of CO_2 as a function of kimberlite magma composition (e.g. Brey et al., 1991), relative to the depth of the diamond bearing horizon, and the history of diamond growth and resorption in this mantle horizon prior to kimberlite eruption, are important factors controlling the diamond potential of cratonic kimberlites.

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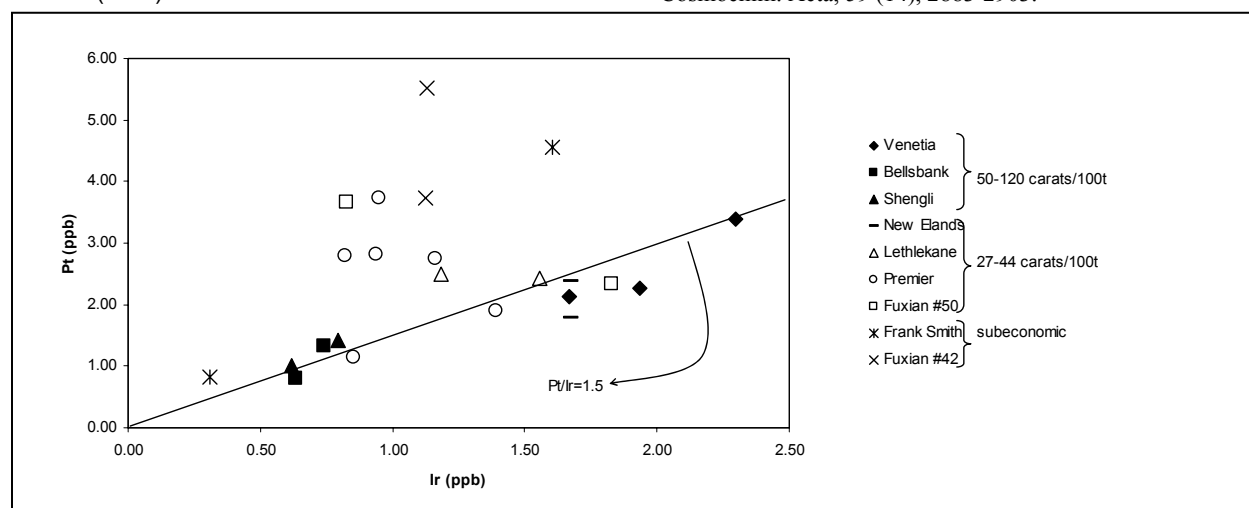
Figure 4: Pt and Ir abundance and P/It ratios vs. diamond grade for selected kimberlites in this study.

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