9th International Kimberlite Conference Extended Abstract No. 9IKC-A-00125, 2008

The Kimberlites and Related Rocks of the Kuruman Kimberlite Province, Kaapvaal Craton, South Africa

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Introduction

The Kuruman kimberlite province is comprises of 16 intrusive bodies (Figure 1) and contains some of the oldest known kimberlites (>1.6 Ga). These kimberlites were intruded across the western margin of the Archean Kaapvaal Craton following a major collisional orogeny (ca 1.75 Ga). While most kimberlites intrude through subcontinental lithospheric mantle (SCLM) that has undergone multiple episodes of metasomatism, the Kuruman province may provide a unique opportunity to examine a relatively undisturbed section of the SCLM across an ancient craton margin.

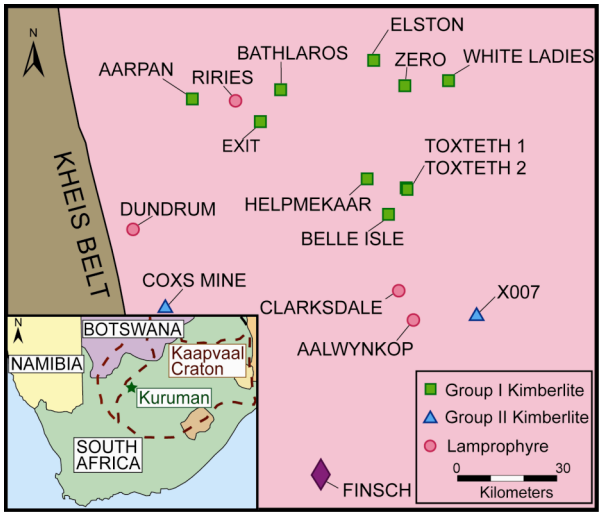

Figure 1. Map showing the location and petrographic classification of the Kuruman kimberlite province.

The Kuruman kimberlites can be subdivided petrographically into five groups: (a) Group I kimberlites (b) evolved, carbonatitic Group I kimberlites, (c) Group II kimberlites, or 'orangeites' (Mitchell, 1995), (d) transitional lamprophyric kimberlites, (e) lamprophyres. Shee et al. (1989) noted that there was a change in the petrographic character of the Kuruman kimberlites from east to west, progressing from typical Group I kimberlites, through evolved Group I kimberlites, to lamprophyres. This study has also found a progression towards more lamprophyric and Group II bodies to the south.

Groundmass Perovskite

Groundmass perovskites occur in samples of the Bathlaros, Elston, Helpmekaar, White Ladies, X007 and Zero kimberlites. The size and the morphology of the perovskite crystals varies significantly between pipes. In X007 perovskite is rare and occurs as small rounded crystals that are typically 10 to 30 µm in size. In the Bathlaros pipe, perovskite is abundant (up to 10 vol%) and occurs as large brown, semi-opaque cauliform-shaped grains typically 200 to 400 µm in size. Pervoskites from Elston, Helpmekaar and Zero are typically well-preserved euhedral grains on the order of 40 to 70 µm for Helpmekaar and Elston and 20 to 40 µm for the Zero pipe. The White Ladies kimberlite contains rounded, patchy grains that are typically on the order of 30 to 50 µm across. The perovskite grains generally occur as discrete crystals set in a serpentine-calcite matrix and commonly show a necklace microstructure around olivine macrocrysts. Alteration of perovskite is variable and pipe-dependent with grains being resorbed or replaced by later minerals, including rutile, ilmenite, titanite and calcite.

A large proportion of the perovskites display zonation. The most common zonation pattern involves a decrease in rare earth elements (REE) and Th from core to rim (Figure 2a and 2c). Less frequently observed zonation patterns include a reversed trend (Figure 2b) in which the rim is enriched in REE and Th, while a fine-scale, oscillatory zoning occurs rarely (Figure 2d).

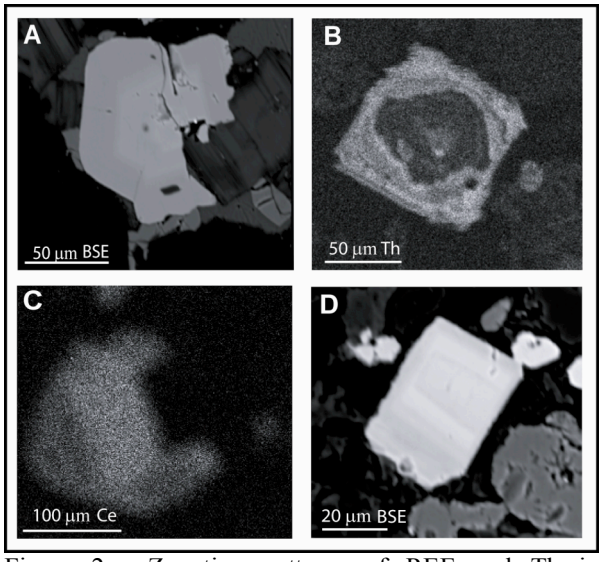

Figure 2. Zonation patterns of REE and Th in Kuruman perovskites.

The perovskites have $CaTiO_3$ contents that range between 75 mol% (Zero) and 96 mol % (Bathlaros) with an average value of 86 mol% (Figure 3a). The Kuruman perovskites show a large range in REE contents from ≤0.11 to 9.68 wt% with an average 5.32 wt% REE_2O_3 and SrO contents of ≤0.35 to 1.04 wt%, average 0.48 wt%. The REE contents of perovskites from different pipes are distinct (Figure 3b), with variations of up to 6 mol% between pipes. White Ladies has the lowest REE contents (average of 2.61 wt% REE_2O_3 and 0.41 wt% SrO) and Zero has the highest (average of 8.24 wt % REE_2O_3 and 0.47 wt% SrO). Other elements present in significant amounts include NaO (≤0.03 to 1.60 wt%, average 0.57 wt%), FeO_T (≤0.07 to 5.34 wt%, average 2.16 wt%) and Nb_2O_5 (0.33 to 5.86 wt%, average 1.54 wt%.)

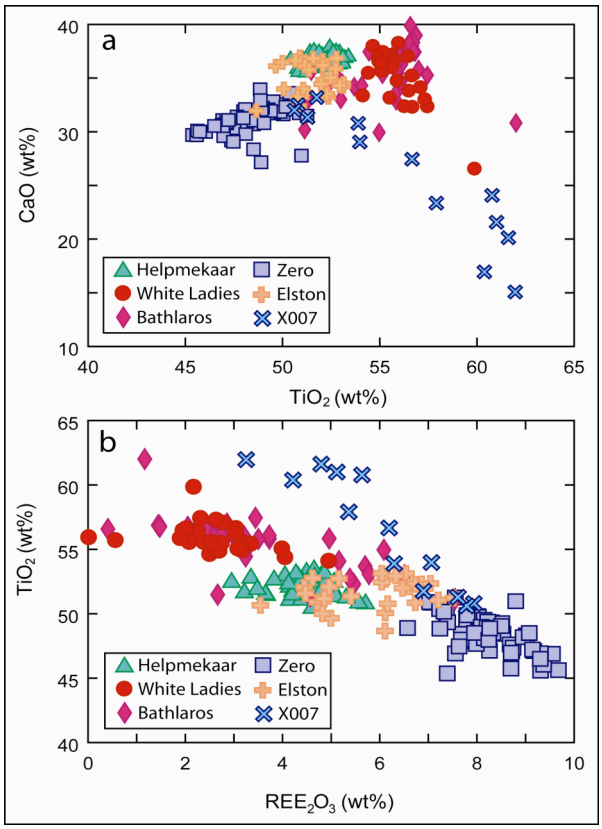

Figure 3. Variations in major- and minor- element contents of Kuruman groundmass perovskites. Where REE_2O_3 includes La_2O_3, Ce_2O_3, and Nd_2O_3.

Chondrite-normalized REE distribution patterns for the Kuruman perovskites are shown in Figure 4. The perovskites are characterized by extreme enrichment in the LREE, with La and Ce values ranging from 4620 to 39300 and 6070 to 97900 ppm, respectively. Within individual kimberlites there is little variation and the REE_N patterns are similar between different kimberlite pipes.

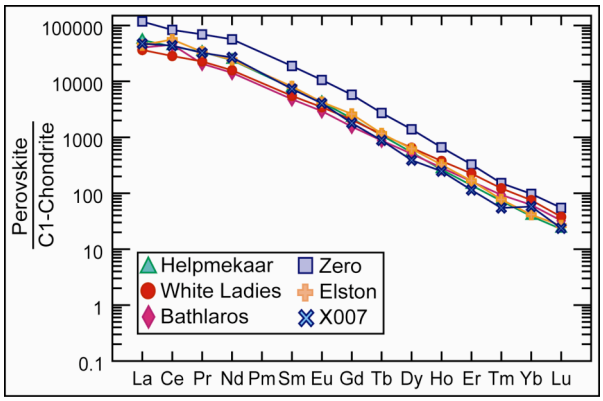

Figure 4. Averaged REE_N concentrations (ppm) of the Kuruman perovskites, normalized after McDonough and Sun (1995).

U-Pb Dating

At present, the age of the Kuruman kimberlite province is poorly constrained. The age for this province is defined by a single mica Rb-Sr isochron age of 1694 ± 42 Ma from the Bathlaros pipe and three errorchron ages of approximately 1606 Ma, 1635 Ma, and 1674 Ma from the Zero, Elston and Riries intrusives, respectively (Shee et al., 1989).

In situ LAM-ICPMS U-Pb dating of perovskite (see Batumike et al., 2008) was conducted to determine the sequence of eruption. The resulting U-Pb data (Figure 5, Table 1) yield eruption ages ranging from 124 ± 16 Ma (X007) to 1607 ± 96 Ma (White Ladies).

Pipe	Age (Ma)	Upper Intercept (Ma)	MSWD
Helpmekaar	1303 ± 190	3052 ± 320	5.9
Zero	1147 ± 240	3213 ± 280	17
Bathlaros	506 ± 71	2692 ± 100	50
White Ladies	1607 ± 96	4531 ± 140	35
Elston	1265 ± 220	3295 ± 320	11
X007	126 ± 16	5059 ± 12	0.35

Table 1. Summary of the obtained U-Pb ages from the Kuruman perovskites.

The U-Pb inverse-Concordia plots reveal a large spread in the data, reflecting large isotopic heterogeneity within individual pipes. Large age errors and MSWDs are obtained for all pipes, excepting X007, and the upper intercept "ages" (reflecting the $^{207}Pb/^{206}Pb$ of the initial Pb component) are unrealistically low (Table 1). The measured ages therefore are unrealistic, with the exception of White Ladies and X007. The Kuruman perovskites are atypical in that they have high Th contents and this high radiogenic ^{208}Pb. Except for X007, perovskites from all of the Kuruman kimberlites show large variations in initial lead compositions and multiple spot analyses on single grains also record this heterogeneity (Figure 5c). These abnormal U-Pb systematics of the Kuruman perovskites may have resulted from heterogeneous initial lead compositions, reflecting some form of multi-component mixing before and during the crystallization of the perovskite.

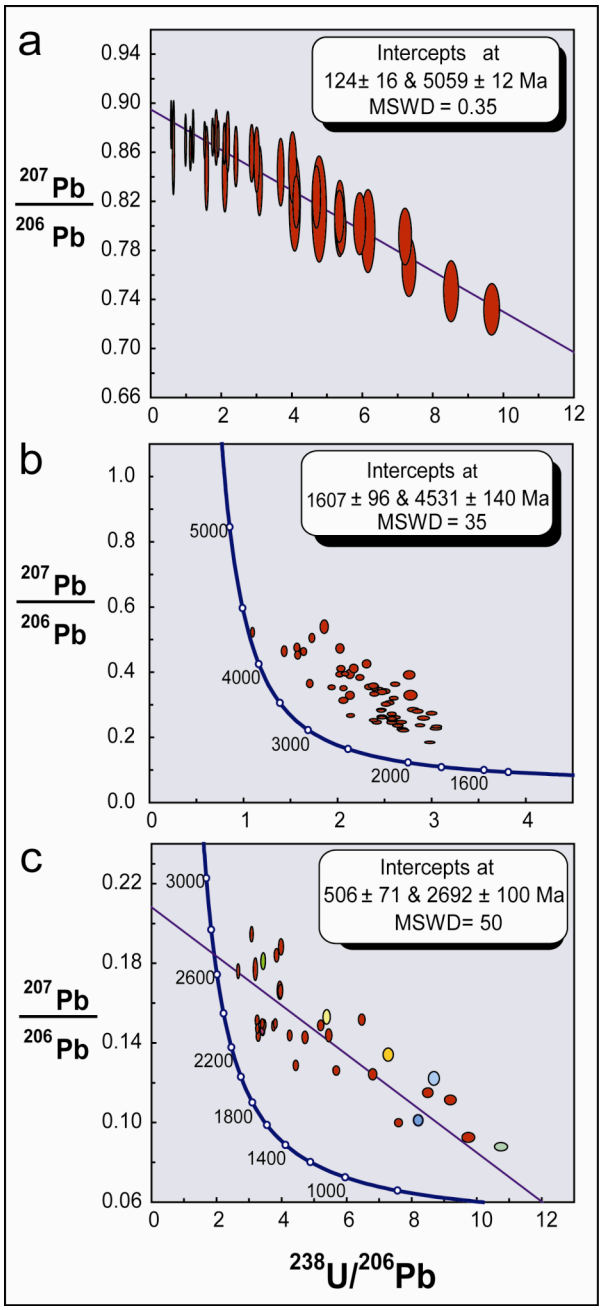

Figure 5. U-Pb inverse-Concordia plots for X007 (Figure 5a), White Ladies (Figure 5b) and Bathlaros (Figure 5c). Coloured data points on Figure 5c correspond to rim (dark) and core (light) analyses on single grains.

Sr and Nd Isotopes

Preliminary *in-situ* LAM-MC-ICPMS analysis of Sr and Nd isotopes in perovskite has shown considerable variation. The $^{87}Sr/^{86}Sr$ contents varied between 0.70396 and 0.71011, with the majority of samples having values in the lower end of this range (Figure 6). The Nd contents are more tightly constrained with values of $^{143}Nd/^{144}Nd$ between 0.51093 and 0.51164 (excluding the anomalous Zero sample #344; Figure 6). These values are similar, though still slightly enriched, to that of the bulk Earth at the time of kimberlite emplacement.

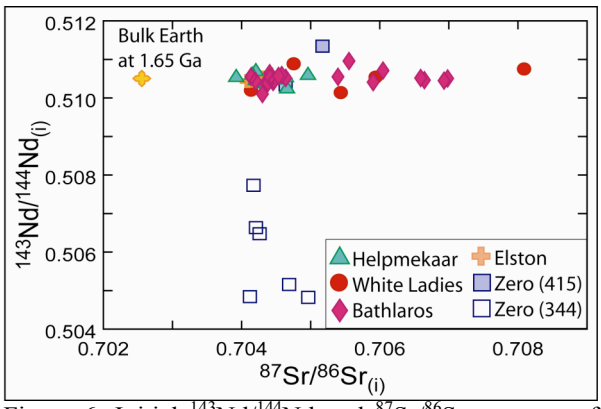

Figure 6. Initial $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ contents of perovskite compared with the composition of the bulk earth

Preliminary Conclusions

The kimberlites of the Kuruman province are unusual kimberlites. They show a change in petrographic character from east to west, and toward the south. The perovskites are also atypical, having high REE contents and high Th contents. The U-Pb systematics of the perovskites are complicated by high radiogenic Th contents and large isotopic heterogeneities within individual kimberlites, and within single grains. Preliminary Sr and Nd analyses in perovskite yield Nd values that are equivalent to the bulk Earth at 1.65 Ga and Sr values that are more radiogenic than bulk Earth.

References

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