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# A depleted mantle source for kimberlites from Zaire: Nd, Sr and Pb isotopic evidence

D. Weis <sup>\*,\*\*</sup> and D. Demaiffe

*Laboratoires Associés Géologie-Pétrologie-Géochronologie, Université Libre de Bruxelles, Avenue F.D. Roosevelt, 50, B-1050 Bruxelles (Belgium)*

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Nd and Sr isotopic compositions in kimberlites from Zaire indicate a time-integrated depleted mantle source ( $\epsilon_{Nd} = +6$  to  $+2$  and  $^{87}Sr/^{86}Sr = 0.7040$ ). Slight upper crust contamination is reflected only by the Pb isotopic system. Differences in the isotopic compositions of kimberlites from two kimberlite provinces, Mbuji Mayi and Kundelungu, point to the existence of regional heterogeneities in the subcontinental mantle, with a range comparable to that observed in the suboceanic mantle. This suggests that the deep mantle (asthenosphere) has comparable characteristics under the oceans and under the continents.

Cr-diopside megacrysts, with a more depleted signature ( $\epsilon_{Nd} = +6.5$  and  $^{87}Sr/^{86}Sr = 0.7030$ ) than their host kimberlites, could either be xenocrysts derived from a higher level within the mantle and incorporated during the ascent of the kimberlites or, alternatively to an early crystallization stage from a “proto-kimberlitic magma” which was subsequently mixed with an enriched mantle component. These data preclude a primary undifferentiated mantle from being the source of these kimberlites.

## 1. Introduction

Kimberlites contain varied populations of xenoliths from the subcontinental mantle and the lower crust [1] and, as such, their geochemical and isotopic (Sr, Pb and Nd) compositions can be used to characterize their source region—the subcontinental mantle—and to compare this with the suboceanic mantle.

Recent results on Sr and Nd isotopic compositions have indicated a wide range of values. The very first Nd isotopic studies [2,3] showed that most kimberlites have initial epsilon Nd values ( $\epsilon_{Nd}$ ) close to zero, which was interpreted as re-

sulting from a relatively undifferentiated chondritic mantle source (actually, 6 of the 9 reported values have slightly positive  $\epsilon_{Nd}$  values:  $+1.0$  to  $+3.2$ ). Basu et al. [4] recently reendorsed this first interpretation in spite of values up to  $+4$ . Kramers et al. [5] also reported positive  $\epsilon_{Nd}$  values ( $+1.8$  to  $+4.1$ ) with  $^{87}Sr/^{86}Sr$  ratios ranging from 0.70386 to 0.70461 for five South African kimberlites, suggesting a slight time integrated depletion of light rare earth elements (LREE) in the source. Cr-diopside megacrysts included in these kimberlites have distinct isotopic features: their  $\epsilon_{Nd}$  values range from  $+3.8$  to  $+7.4$  and  $^{87}Sr/^{86}Sr$  ratios from 0.7028 to 0.7036 [5]. These data plot in the left upper part of the  $^{143}Nd/^{144}Nd$  versus  $^{87}Sr/^{86}Sr$  diagram and fall within the mantle array defined by oceanic basalts, of either tholeiitic or alkaline affinities [6–8]. Smith [9] also found these depleted characteristics for South African basaltic (type I) kimberlites while an enriched upper man-

\* Present address: The Lunatic Asylum of the Charles Arms Laboratory, Division of Geological and Planetary Science, California Institute of Technology, Pasadena, CA 91125, U.S.A.

\*\* FNRS Charge de recherches.

the source is required for micaceous (type II) kimberlites (initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios from 0.7074 to 0.7109 and  $\epsilon_{\text{Nd}}$  from  $-5$  to  $-9$ ). Moreover, diopsides from micaceous garnet lherzolite nodules in kimberlites from the Kimberley area in South Africa [10] have  $\epsilon_{\text{Nd}}$  values between  $-1$  and  $-6$  for  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios between 0.7047 and 0.7075; this shows the existence of both depleted and enriched mantle sources beneath southern Africa. Kimberlites and lamproites from the West Kimberley district (western Australia) [11] also have negative  $\epsilon_{\text{Nd}}$  values ( $-7$  to  $-15$ ) and even higher  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios (up to 0.718). The authors rule out crustal contamination so that the subcontinental mantle source of these rocks must be highly enriched in LREE and large-ion lithophile elements in general.

In an attempt to further characterize the source regions of kimberlites, we present additional Nd, Sr and Pb isotopic data for kimberlites from Zaire.

## 2. Sample description

Detailed petrographic, trace element geochemical and Sr isotopic data of Zaire kimberlites have been published elsewhere [12,13]. Two kimberlitic provinces have been recognized in Zaire (see location map in Demaiffe and Fieremans [12]); in the East Kasai province at Mbuji Mayi (formerly Bakwanga) [14,15], and in the Shaba province intruding the Precambrian rocks of the Kundelungu plateau [16]. At Mbuji Mahi, "primary" kimberlites (these kimberlites are not depleted in volatile elements; they probably crystallized at high pressure, presumably as sills or dykes, and were incorporated later in the breccia) occurring as rounded (2–15 cm) nodules (autoliths) in the diamondiferous breccia ("yellow grounds") have been analysed. They have typical porphyritic texture with two generations of olivine phenocrysts. Following the classification of Dawson [1], they were considered as of the micaceous type because they contain phlogopite as macrocryst as well as groundmass phase (this phlogopite is often retrogressed to chlorite). The similarity with Smith's type II kimberlites [9] is not clear on the basis of the data we have. Indeed, in the Kimberley area, there are varieties of basaltic (type I) kimberlites,

found in dykes, which contain some mica but have  $^{87}\text{Sr}/^{86}\text{Sr}$  around 0.704 [43], indicating that the occurrence of mica is not sufficient evidence to attribute kimberlites to Smith's [9] group II. The Cr-diopsides contain 0.4–0.8%  $\text{Cr}_2\text{O}_3$  and hence belong to the Cr-poor series as defined by Eggler et al. [17]. Together with garnet and ilmenite, the Cr-diopsides constitute the typical "megacryst suite" [1]. The emplacement of the Mbuji Mayi kimberlites has been dated at 71 m.y. using U-Pb on zircons [18]. On the Kundelungu plateau, the kimberlites are of the basaltic type and contain large rounded olivine phenocrysts. Only whole-rock samples have been studied. These kimberlites have not been dated and the emplacement age is assumed to be 71 m.y., i.e. Cretaceous, as many other kimberlites in Africa [18]. Such an age was therefore used to calculate initial isotopic ratios.

## 3. Analytical techniques

The analytical techniques used in this study have already been described in references [13] for Sr, [19] for Nd and [19,28] for Pb and are recalled in the footnotes of Tables 1 and 2. Lead was separated following a modification of the Manhès et al. [20] technique while Nd separation is done following the Cerrai and Testa [21] technique adapted by Richard et al. [6]. Blanks were always in the nanogram range (Nd: 1 ng, Pb: 1.2–1.5 ng and Sr: 15–20 ng) and insignificant in comparison to the sample content (microgram range). The isotopic analyses were done on a Finnigan MAT 260 mass spectrometer. Repeated analyses of the different standards give:  $^{87}\text{Sr}/^{86}\text{Sr} = 0.71022 \pm 3$  ( $2\sigma_m$ ) for NBS 987,  $^{143}\text{Nd}/^{144}\text{Nd} = 0.512665 \pm 35$  for BCR1 and a mass fractionation factor of  $1 \pm 0.3\%$  per amu on the basis of 25 analyses of NBS 981.

## 4. Results and discussion

### 4.1. Sr and Nd isotopes

Sr isotopic compositions have been measured in 11 Mbuji Mayi "primary" kimberlitic nodules and in 7 Kundelungu kimberlites. These data were previously published [13] and are reported again

TABLE 1  
Sr and Nd isotopic data <sup>a</sup> for the kimberlites of Mbuji Mayi and Kundelungu, Zaïre

Samples	Rb <sup>b</sup>	Sr <sup>b</sup>	$\frac{87\text{Rb}}{86\text{Sr}}$	$\frac{87\text{Sr}}{86\text{Sr}}$ <sup>c</sup>	$\left(\frac{87\text{Sr}}{86\text{Sr}}\right)_{71 \text{ m.y.}}$	$\frac{143\text{Nd}}{144\text{Nd}}$ <sup>c</sup>	$\epsilon_{\text{Nd}}^{\text{RE},d}$	Nd <sup>e</sup>	Sm <sup>e</sup>	$\frac{147\text{Sm}}{144\text{Nd}}$ <sup>f</sup>	$\left(\frac{143\text{Nd}}{144\text{Nd}}\right)_{71 \text{ m.y.}}^g$	$\epsilon_{\text{Nd}}^{71 \text{ m.y.}}$	$T_{\text{DM}}^h$
<i>Mbuji Mayi</i>													
Nod 1 core	19*	473	0.1152	0.70429 ± 30	0.7041	0.512732 ± 38	1.8	36.4	5.1	0.0852	0.51269	2.8	389
rim	18*	638	0.0830	0.70420 ± 40	0.7041								
Nod 2	85.7	218	1.1360	0.71100 ± 50	0.7099								
Nod 4	77.5	147	1.5230	0.70620 ± 60	0.7045								
Nod 5	52.7	1386	0.1104	0.70467 ± 40	0.7045	0.512888 ± 21	4.9	103	14.6	0.0857	0.51285	5.9	212
Nod 6	—	551		0.70470 ± 30									
Nod 11 core	19.3	668*	0.0830	0.70450 ± 8	0.7044	0.512680 ± 17	0.8	87	11.0	0.0764	0.51264	1.9	421
rim	19.6	682	0.0830	0.70446 ± 14	0.7044								
Nod 12	16.8	596	0.0546	0.70416 ± 10	0.7041	0.512760 ± 28	2.4	42	5.6	0.0800	0.51272	3.4	344
Nod 13	11.2	29	1.1130	0.71017 ± 30	0.7090	0.512678 ± 16	0.8	31	3.9	0.0755	0.51264	1.9	421
Nod 14	13.5	1780	0.0219	0.70404 ± 10	0.7040								
Carbonate inclusions	5*	472*	0.008	0.70450 ± 30		0.512767 ± 32	2.5	14	2.6	0.1102	0.51272	3.3	429
	5*	599*	0.001	0.70400 ± 50									
Diopside A		120		0.70297 ± 18		0.512929 ± 46	5.7	6.3	1.3	0.1296	0.51287	6.3	245
B		124		0.70323 ± 15		0.512967 ± 45	6.4	5.9	1.4	0.1445	0.51290	6.9	217
<i>Kundelungu</i>													
K1	36.5	405	0.2610	0.70455 ± 21	0.7043	0.512813 ± 12	3.4	66	7.1	0.0650	0.51278	4.6	258
K2	36.8	249	0.4285	0.70828 ± 51	0.7078								
15c	34.9	481	0.2097	0.70395 ± 60	0.7038	0.512828 ± 13	3.7	65	7.1	0.0680	0.51280	4.9	244
15d	32.8	677	0.1403	0.70435 ± 41	0.7042								
M1	3.8	389	0.0281	0.70404 ± 50	0.7040								
M2	4.8	408	0.0338	0.70447 ± 40	0.7044								
M3	3.1	345	0.0261	0.70463 ± 30	0.7046								

<sup>a</sup> The analytical procedures used in this study have been published in [12] and [13] for Sr and the REE and in [19] for Nd.

<sup>b</sup> Concentrations (ppm) determined by X-ray fluorescence spectrometer (\*) (Tervueren), or by isotope dilution.

<sup>c</sup> Ratios ± 2σ<sub>m</sub>.

<sup>d</sup> Calculated for bulk earth values:  $^{143}\text{Nd}/^{144}\text{Nd} = 0.512638$  and  $^{147}\text{Sm}/^{144}\text{Nd} = 0.1966$  [21].

<sup>e</sup> Concentrations (ppm) determined by INAA [13].

<sup>f</sup> Calculated following Wasserburg et al. [23]. All ratios normalized for a  $^{146}\text{Nd}/^{144}\text{Nd} = 0.7219$ .

<sup>g</sup>  $\lambda(^{147}\text{Sm}) = 6.54 \times 10^{-12} \text{ y}^{-1}$ .

<sup>h</sup> Calculated following the model of DePaolo [24], expressed in m.y.

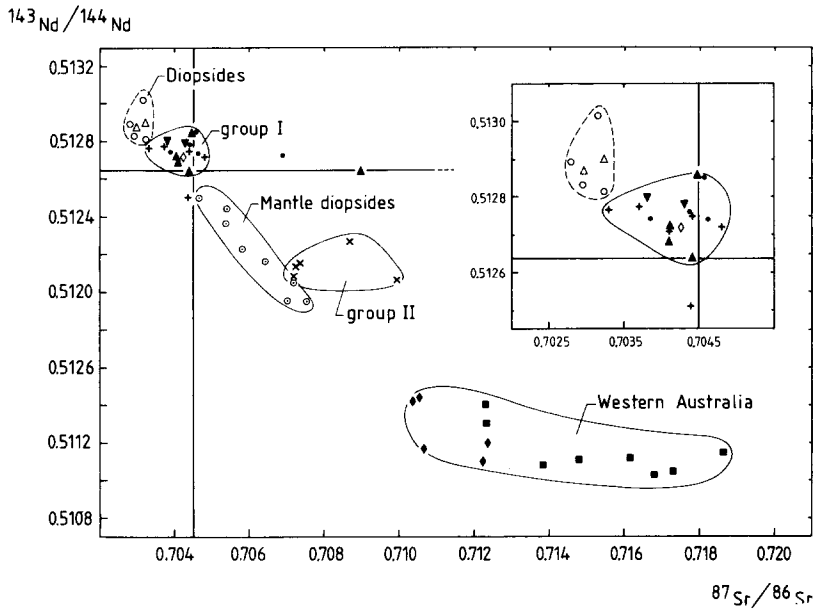


Fig. 1. Nd and Sr initial ratios (71 m.y.) for Zaire kimberlites. *Mbuji Mayi*:  $\blacktriangle$  = kimberlite,  $\triangle$  = diopside,  $\diamond$  = carbonate inclusion; *Kundelungu*:  $\blacktriangledown$ . Reported data from the literature for comparison—*South Africa*:  $\bullet$  = kimberlite,  $\circ$  = diopside megacryst (90 m.y.; [5]);  $+$  = group I (non-micaceous) kimberlite (80–114 m.y.),  $\times$  = group II (micaceous) kimberlite (114–150 m.y.; [9]);  $\odot$  = diopside from micaceous garnet nodules (75 m.y.; [10]); *Western Australia*:  $\blacksquare$  = lamproite,  $\blacklozenge$  = kimberlite (20 m.y.; [11]). Actual bulk earth values are given for reference only ( $^{143}\text{Nd}/^{144}\text{Nd} = 0.512638$ ;  $^{87}\text{Sr}/^{86}\text{Sr} = 0.7045$ ) considering that the age corrections are within analytical error for most of the samples because of their young ages (<100 m.y.).

here because it is interesting to compare them with the Pb and Nd results. Nd isotopic compositions have been measured in 5 Mbuji Mayi and 2 Kundelungu samples (Table 1, Fig. 1). Initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of Mbuji Mayi kimberlites fall in the narrow range 0.7040–0.7045, except for the two more altered samples (Nod 2 and Nod 13). For the Kundelungu kimberlites, the range of initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios is 0.7038–0.7046, except for Kun 2. The initial  $^{143}\text{Nd}/^{144}\text{Nd}$  ratios are 0.51264–0.51285 ( $\epsilon_{\text{Nd}} = +1.9$  to  $+5.9$ ) and 0.51278–0.51280 ( $\epsilon_{\text{Nd}} = +4.6$  and  $4.9$ ) respectively for the Mbuji Mayi and Kundelungu samples.

In the  $^{143}\text{Nd}/^{144}\text{Nd}$  versus  $^{87}\text{Sr}/^{86}\text{Sr}$  diagram, the kimberlites of Zaire plot within the mantle array defined by oceanic basalts [6–8]. The sample Nod 13 which has a significantly higher  $^{87}\text{Sr}/^{86}\text{Sr}$  value has also a very low carbonate content (less than 0.5%  $\text{CO}_2$  as compared with the 5–15% in the other samples [13]) and a very low Sr content (29 ppm), suggesting a loss of carbonate and conse-

quently of Sr. A contamination by some common Sr introduced via groundwater may then explain the high  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio. Nod 2 and Kun 2 have also higher  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios, comparable to the blueground (i.e. brecciated and deeply altered kimberlitic pipes) values (0.71096–0.70858), which may be indicative of secondary fluid interactions [13]. A 1-cm-diameter carbonate inclusion from Nod 1 of Mbuji Mayi has  $^{87}\text{Sr}/^{86}\text{Sr}$  and  $^{143}\text{Nd}/^{144}\text{Nd}$  ratios undistinguishable from those of the host kimberlite. Moreover, this carbonate has a LREE-enriched chondrite-normalized pattern similar to those of the kimberlites [13]. These geochemical data suggest that the carbonate is genetically related to the kimberlite.

Two diopside megacrysts from Mbuji Mayi have distinctly lower  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios (0.703) and slightly higher initial  $^{143}\text{Nd}/^{144}\text{Nd}$  ratios ( $\epsilon_{\text{Nd}} = +6.3$  and  $+6.9$ ) than the associated kimberlites but also fall in the mantle array.

Our data for the two groups of Zaire kimberlites and the Mbuji Mayi diopside megacrysts are

very similar to those reported by Kramers et al. [5] for South African samples which requests the presence of a slightly depleted subcontinental reservoir in the mantle under large areas of the African continent. In contrast, the negative  $\epsilon_{Nd}$  and positive  $\epsilon_{Sr}$  values obtained by Menzies and Murthy [10] on diopsides from micaceous garnet lherzolite nodules in South African kimberlite pipes, imply also the existence of an enriched reservoir in the mantle. These source regions for volcanic rocks with enriched geochemical properties could also result from either patent or cryptic metasomatism of upper mantle peridotites [25]. The spatial relations between the enriched and slightly depleted reservoirs within the subcontinental mantle are actually unknown: the enriched reservoir could occur either as a continuous layer or as pockets in the depleted mantle.

In Zaire kimberlites, both basaltic type kimberlites from the Kundelungu pipes and micaceous type from the Mbuji Mayi pipes have Nd and Sr isotopic compositions in the range of Smith's group I kimberlites, i.e. basaltic type kimberlites of South Africa. There is no evidence at present for the existence of enriched upper mantle source for Zaire kimberlites. This may imply that these rocks belong only to the group I of Smith [9].

#### 4.2. Pb isotopes

Ten samples (6 from Mbuji Mayi and 4 from Kundelungu) have been analysed for whole-rock Pb isotopic compositions (Table 2, Fig. 2).

In contrast to their Sr and Nd isotopic compositions, which were relatively uniform in the two areas, the Pb isotopic compositions of the two kimberlitic provinces are clearly distinct. The Mbuji Mayi samples show a narrow range of 18.13–18.60 in  $^{206}Pb/^{204}Pb$  ratios, 15.51–15.59 in  $^{207}Pb/^{204}Pb$  ratios and 38.53–39.08 in  $^{208}Pb/^{204}Pb$  ratios. The spread is much larger for the Kundelungu kimberlites, namely 18.32–19.79, 15.61–15.69 and 38.26–39.82 for the same ratios respectively. In the  $^{207}Pb/^{204}Pb$  versus  $^{206}Pb/^{204}Pb$  diagram, the data for the Kundelungu define an approximately linear array whose slope could correspond to an "age" of 350 m.y.

The correction for in-situ U decay in 71 m.y. is very small for the Mbuji Mayi samples because of their low U content (< 1.5 ppm) and low U/Pb ratios; it is larger for the Kundelungu samples because of higher  $^{238}U/^{204}Pb$  ratios (20–82). Nevertheless, upon age correction the data groups remain quite distinct. Kundelungu kimberlites have slightly higher  $^{207}Pb/^{204}Pb$  ratios than Mbuji Mayi

TABLE 2

Pb isotopic compositions <sup>a</sup> and Pb and U concentrations for the Zairean kimberlites

Samples	$^{208}Pb/^{204}Pb$ <sup>b</sup>	$^{207}Pb/^{204}Pb$ <sup>b</sup>	$^{206}Pb/^{204}Pb$ <sup>b</sup>	Pb <sup>c</sup>	U <sup>c</sup>	$^{238}U/^{204}Pb$	$^{207}Pb/^{204}Pb$ <sup>d</sup>	$^{206}Pb/^{204}Pb$ <sup>d</sup>
<i>Mbuji mayi</i>								
Nod 1 core	38.527 ± 5	15.592 ± 1	18.386 ± 1	9.1	0.6	4.18	15.590	18.340
Nod 2	38.791 ± 6	15.558 ± 2	18.598 ± 2	3.9	0.5	8.16	15.554	18.508
Nod 11 core	38.619 ± 39	15.584 ± 13	18.426 ± 22	6.2	1.4	13.93	15.577	18.272
Nod 12	38.667 ± 9	15.589 ± 4	18.476 ± 3					
Nod 13	38.694 ± 7	15.573 ± 2	18.385 ± 2					
Nod 14	39.083 ± 8	15.507 ± 2	18.128 ± 2					
<i>Kundelungu</i>								
Kun 1	38.256 ± 9	15.605 ± 4	18.315 ± 4	9.6	3.1	20.40	15.594	18.089
15c	39.815 ± 6	15.688 ± 2	19.792 ± 3	3.8	2.8	49.22	15.662	19.247
M1	39.558 ± 5	15.674 ± 2	19.711 ± 3	6.0	7.5	81.82	15.631	18.805
M3	39.510 ± 8	15.668 ± 3	19.425 ± 4	3.2	2.6	52.96	15.640	18.838

<sup>a</sup> The analytical procedure used in this study for analysing the Pb isotopic compositions has been described in [28].

<sup>b</sup> Ratios  $\pm 2\sigma_m$ . All ratios corrected for mass fractionation monitored by repeated analyses of the NBS 981 Pb standard [26]:  $1.0 \pm 0.3\%$  per amu.

<sup>c</sup> Determined by isotope dilution, in ppm.

<sup>d</sup> Values corrected for in-situ U decay for 71 m.y. with  $\lambda(^{238}U) = 0.155125 \times 10^{-9} \text{ y}^{-1}$  and  $\lambda(^{235}U) = 0.98485 \times 10^{-9} \text{ y}^{-1}$  [27].

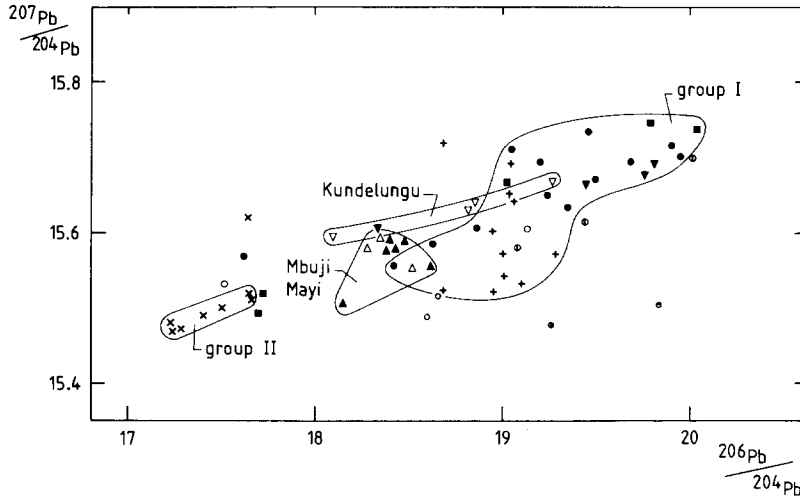


Fig. 2.  $^{207}\text{Pb}/^{204}\text{Pb}$  versus  $^{206}\text{Pb}/^{204}\text{Pb}$  diagram for African kimberlites. *Zaire kimberlite*:  $\nabla$  = Kundelungu,  $\triangle$  = Mbuji Mayi (open symbols: correction for in-situ decay in 71 m.y.); *South Africa*:  $\bullet$  = kimberlite,  $\blacksquare$  = autolith in these samples [5,29];  $+$  = group I,  $\times$  = group II kimberlites [9]; metasomatic and "MARID" (heavy symbols) xenoliths:  $\circ$  = K-richterite,  $\square$  = clinopyroxene,  $\ominus$  = apatite [30].

kimberlites. In Fig. 2, our data for Zaire kimberlites are compared to other data on kimberlites, taken from the literature. Data obtained by Kramers [29] and Smith [9] for Lesotho, Kimberley and Bellsbank kimberlites of South Africa are characterized by a very large scatter of their Pb isotopic ratios. Micaceous type II kimberlites have less radiogenic Pb isotopic compositions indicative of an origin in a low U/Pb source region. Sep-

arated mineral fractions from mantle-derived xenoliths (including the "MARID" suite) from the Bultfontein mine have been interpreted along the lines of metasomatic changes emphasizing the role of K-richterite as a sink for Pb [30]. In Fig. 3, other data from the literature are reported for comparison: (a) some continental flood basalts (Deccan traps and Tasmanian dolerites [32]) as an example for the continental lithosphere showing

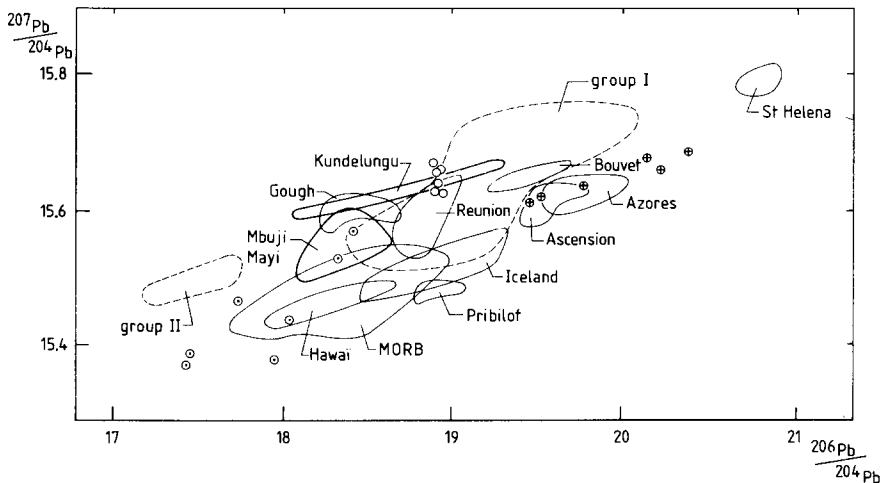


Fig. 3. Comparison in a Pb-Pb diagram between the kimberlite data and some data on mantle-derived rocks:  $\oplus$  = Ahaggar alkali basalts [31],  $\circ$  = Tasmania,  $\odot$  = Deccan continental flood basalts [32]. Oceanic island and mid-ocean ridge basalt data from the compilation of Sun [33].

the influence of continental crust contamination, (b) some alkali basalts from a shield area (the Ahaggar volcanic suite [31]) whose mantle source has isotopic characteristics comparable to those of the source of oceanic island basalts, and (c) some oceanic island basalts and mid-ocean ridge basalts [33] as examples for the oceanic mantle. These diagrams show that broadly speaking the kimberlites in general have Pb isotopic compositions comparable, but in the upper range of  $^{207}\text{Pb}/^{204}\text{Pb}$  ratios especially for the Kundelungu samples, to those of the oceanic island basalts (OIB).

### 5. Inferences about the nature of the subcontinental mantle

Isotopic data on Zaire kimberlites indicate that the primary magma was generated in the mantle, with little subsequent crustal influence, at least for the Sr and Nd isotopic systems. Nevertheless, the slightly higher  $^{207}\text{Pb}/^{204}\text{Pb}$  ratios of these kimberlites, especially for the Kundelungu pipes, compared to the OIB values may indicate slight continental contamination (as also pointed out by Kramers [29] for South Africa) even if the Sr isotopic compositions of the two groups are undistinguishable. Another explanation would be that their mantle source is different and characterized by a higher  $\mu$  value. It is nevertheless not very surprising that only the Pb isotopic system reflects continental crust influence as this system is the most sensitive to contamination because of the mobility of Pb and of the low Pb concentration in the mantle compared to its high content in the crust. Only the Pb isotopic system has been affected by contamination while the Nd-Sr systems reflect the primary characteristics of the mantle source of the Zairean kimberlites. The initial  $\epsilon_{\text{Nd}}$  (4.9 and 4.6) values of the two Kundelungu samples analysed are slightly higher than all of the Mbuji Mayi kimberlites (except Nod 5) for comparable Sr isotopic compositions.

The scale of the isotopic heterogeneities, both local (i.e. within a single kimberlite province) and regional (among provinces), is comparable to that observed in the suboceanic mantle as reflected by inter- and intra-island isotopic variations [33–35]. If they have any time significance, the Pb-Pb

regression date of the Kundelungu kimberlites (~350 m.y.) and the depleted mantle Nd model ages (220 and 430 m.y.; Table 1) calculated following DePaolo's [24] parameters for the Zaire kimberlites could point to younger (< 500 m.y.) heterogeneities in the subcontinental mantle below Zaire than in the oceanic mantle (1.5–2 b.y. [36–38]), even if they represent minimum differentiation ages.

From their primary depleted characteristics, the kimberlites from Zaire appear to have an origin in mantle material similar to either continental or oceanic alkali basalts. This suggests that the source region of these rocks which is inferred from experimental petrology to be deeper in the mantle than the tholeiitic basalt source region, has the same isotopic features under the oceans and under the continents. Nd-Sr-Pb isotopic data in lherzolite bearing alkali basalts [31] have led to the same conclusion. This deep mantle however appears less depleted than the MORB source mantle ( $\epsilon_{\text{Nd}} = +13$ ). Moreover, the Nd-Sr-Pb isotopic compositions of Zaire kimberlites are similar to those of the large scale domain of the South Atlantic and Southern Indian Oceans defined by Dupré and Allègre [39] for the ocean island source. More precisely, these data fall in the Sr-Pb isotopic mantle anomaly (Dupal anomaly) recently described by Hart [40] in the Southern Hemisphere mantle. This anomaly was defined mostly on the basis of the data set compiled by Zindler et al. [41] with some more data on basalts from continental environments. Our kimberlite data could imply that the Dupal anomaly exists also in the subcontinental mantle which might indicate that it results from an ancient process.

The Mbuji Mayi Cr-diopside megacrysts have significantly lower  $^{87}\text{Sr}/^{86}\text{Sr}$  (0.703) and higher  $\epsilon_{\text{Nd}}$  (+6.5) values than their host kimberlites ( $^{87}\text{Sr}/^{86}\text{Sr} = 0.7040\text{--}0.7045$ ;  $\epsilon_{\text{Nd}} = +1.9$  to  $+5.9$ ). These data point to derivation from a more depleted mantle source for the diopsides and imply that these pyroxenes are not phenocrysts of the kimberlitic magma but rather are xenocrysts whose exact origin is not known (disaggregation of lherzolite xenoliths?). Since the same differences are observed beneath South Africa [5], it appears to be a general feature of the deep mantle under

that region. Alternatively, the isotopic differences between the Cr-diopside megacrysts and their host kimberlites could result from the mixing of a "proto-kimberlitic magma" ( $\epsilon_{\text{Nd}} = +6.5$ ) which generated the Cr-diopside megacrysts with minor amounts of enriched (lithospheric) mantle, after the early Cr-diopside crystallization. Nixon et al. [42] argued for a similar relation between megacrysts and kimberlite "parents" on other grounds.

The Nd isotopic compositions reported here are distinctly positive so that the source of the kimberlitic material is unlikely to correspond to a primitive chondritic mantle as previously suggested by Basu and Tatsumoto [2–4]. Our data could reflect either a slightly depleted mantle source or, more probably, might correspond to the mixing of a depleted, MORB-type, mantle source material with very small amounts ( $\sim 1\%$ ) of an enriched mantle component. This present mixing model is the opposite of the one proposed by McCulloch et al. [11] to account for the variations in the Sr and Nd isotopic data on the West Kimberley kimberlites and lamproites ( $\epsilon_{\text{Nd}} = -7.4$  to  $-15.4$ ;  $^{87}\text{Sr}/^{86}\text{Sr} = 0.7104\text{--}0.7187$ ), i.e. mixing between a kimberlitic magma-derived from a primary enriched mantle source and a depleted, MORB-type, mantle.

## 6. Conclusions

(1) Zaire kimberlites have Nd and Sr isotopic compositions comparable to those of OIB implying a slightly depleted mantle source. The source of the kimberlitic material is unlikely to correspond to a primitive, chondritic, mantle.

(2) Our Pb and Sr data fall in the range of values reported for the large scale isotopic anomaly in the Southern Hemisphere mantle. This may imply that the deep mantle has the same characteristics under the continents and under the oceans.

(3) Isotopic differences (especially in the Pb isotopic compositions) between the two kimberlite provinces reflect regional heterogeneities in the subcontinental mantle.

(4) The more depleted isotopic signature of the Cr-diopside megacrysts could indicate either that these pyroxenes are xenocrysts or that a depleted protokimberlitic magma was contaminated by

minor amounts ( $\sim 1\%$ ) of an enriched component.

(5) Similar differences between Cr-diopside megacrysts and enclosing kimberlites are observed in South Africa, which points to the presence of a slightly depleted subcontinental reservoir in the mantle under the southern part of the African continent.

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