

STRONTIUM-ISOTOPIC GEOCHEMISTRY OF THE MBUJI MAYI AND KUNDELUNGU KIMBERLITES (ZAIRE, CENTRAL AFRICA)

D. DEMAIFFE and M. FIEREMANS

Laboratoires Associés de Géologie—Pétrologie, Université Libre de Bruxelles, 1050 Bruxelles (Belgium)

Laboratorium voor Structurele Geologie, Katholieke Universiteit, 3000 Leuven (Belgium)

(Received August 20, 1980; accepted for publication November 21, 1980)

ABSTRACT

Demaiffe, D. and Fieremans, M., 1981. Strontium-isotopic geochemistry of the Mbuji Mayi and Kundelungu kimberlites (Zaire, Central Africa). *Chem. Geol.*, 31: 311–323.

In Zaire (Central Africa), two main kimberlitic fields have been recognized: one at Mbuji Mayi (Kasai province) of Late Cretaceous age and the other on the Kundelungu plateau (Shaba province).

At Mbuji Mayi the kimberlite breccia (blueground) contains rounded nodules of what has been called “primary kimberlites”; these nodules show the typical porphyritic texture (two generations of olivine phenocrysts) of many kimberlites; the matrix consists mainly of phyllitic and calcitic material. These rocks may be classified as micaceous kimberlites, contrary to the Kundelungu samples which are mostly of the basaltic type.

In both areas, the kimberlites contain the “discrete nodule associations” (Nixon and Boyd, 1973): grains of pyrope, Cr-diopside and magnesian ilmenite. Chemically, they are remarkably similar to the South African, Lesotho and Yakutian rocks.

The initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are in the range 0.7040–0.7045 which points to a mantle origin for the kimberlitic magma, with no crustal influence. Rare carbonate inclusions in the kimberlite nodules have the same Sr-isotope composition which suggests a genetic relation between the carbonates (carbonatitic magma?) and the kimberlitic magma.

The Cr-diopsides have a $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.7031 ± 0.0002 which is significantly lower than that of the kimberlites; this implies that these diopsides are more probably xenocrysts from the upper mantle than a crystallizing phase in the kimberlites.

INTRODUCTION

In Central Africa and more specifically in Zaire, kimberlite pipes have long been recognized in two main areas (Fig. 1): (1) in the East Kasai province, at Mbuji Mayi, formerly Bakwanga (De Magnée, 1946); and (2) in the Shaba province, intruding the Precambrian rocks of the Kundelungu plateau [first mentioned in the literature by d’Andrimont (1913) and by Stützer (1913); more completely studied by Verhoogen (1938)].

In the last ten years, two International Kimberlite Conferences have been organized (in 1973 and 1977) so that many new ideas have been proposed

(Fig. 2):

(1) An Archean basement composed mainly of granitic gneisses, the Dibaya Complex, which is older than 2700 m.y. (Delhal et al., 1975).

(2) A thick sequence of Proterozoic sandstones and stromatolitic dolomitic limestones known as the Mbuji Maji Supergroup; these rocks were deposited between 1300 m.y. (the main tectonic phase of the Kibarian orogeny) and 950 m.y., the extrusion age of doleritic lavas at the top of the limestone sequence.

(3) Mesozoic sandstones of the Lualaba series.

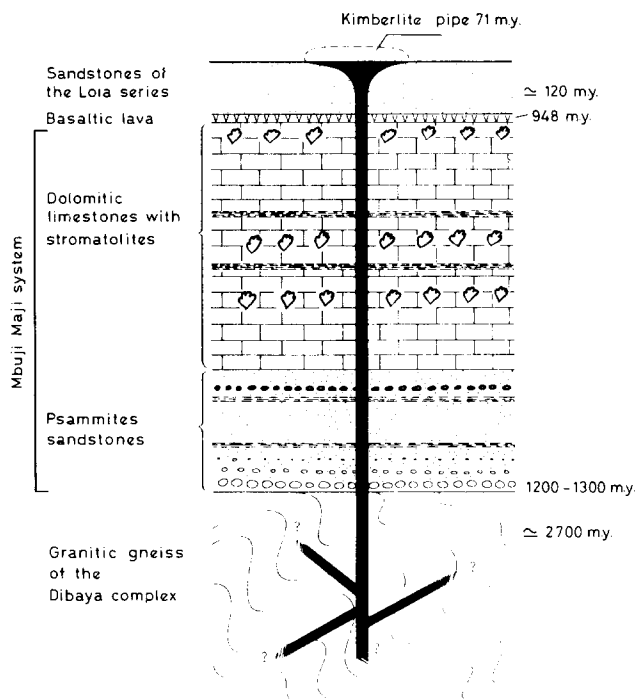


Fig. 2. Schematic stratigraphic sequence intruded by the Mbuji Maji kimberlite pipes.

The Late Cretaceous age (71 m.y.) of the kimberlite emplacement has been determined by the U/Pb method applied to zircon (Davis, 1977).

The Kundelungu kimberlites were divided by Verhoogen (1938) into a Western group of fourteen pipes probably situated on a N-S fracture and an Eastern group of ten pipes more irregularly distributed. The isotopic age of these pipes is not known; stratigraphically the emplacement time is post-Kundelungu (= Upper Precambrian) and pre-Miocene; it is possibly Cretaceous as in the case for other kimberlites in Africa (Davis, 1977).

ANALYTICAL METHODS

The major-element composition has been determined by wet-chemical methods for the Mbuji Mayi samples (M. Fieremans and Ottenburgs, 1979) and by X-ray fluorescence spectrometry (Collectif Interuniversitaire de Géochimie Instrumentale — Dr. J.C. Duchesne).

After dissolution by a HF—HClO₄ acid mixture, the Sr was separated on a classical ion-exchange column. This procedure was repeated twice to concentrate Sr and remove Ca, especially in the case of carbonates. The Sr-isotope composition was measured by thermoionisation with a single Re filament on a TH5 Varian Mat[®] mass spectrometer of the “Centre Belge de Géochronologie”. The values are normalized to a ⁸⁶Sr/⁸⁸Sr ratio of 0.1194. Ten determinations of the Eimer and Amend[®] Sr standard yield an average ⁸⁷Sr/⁸⁶Sr of 0.70807 ± 7 (1σ).

PETROGRAPHY AND CHEMICAL COMPOSITION

C. Fieremans (1977), using the Russian nomenclature, described the Mbuji Mayi kimberlites as xeno-tuff-breccias: they contain numerous fragments of all sizes (from a few millimetres to several metres) of the country rocks, abundant eclogitic nodules and the typical “discrete nodule associations” described by Nixon and Boyd (1973) in the South African kimberlites, i.e. grains of pyrope, green Cr-diopside and magnesian ilmenite. The kimberlite breccia, which is in fact a blueground, also contains rounded nodules (2–15 cm) of what has been called “primary kimberlite”. The petrographic description of the five available nodules has been published elsewhere (M. Fieremans and Ottenburgs, 1979). Only a brief summary is given here; although sometimes altered, these nodules display the typical porphyritic texture with two generations of olivine crystals pseudomorphosed to phlogopite and calcite. The matrix consists essentially of very fine-grained phyllitic (green Cr-chlorite, hydromica) and calcitic material with minor amounts of apatite, magnetite and rutile. These rocks may be described as micaceous kimberlites.

The kimberlite nodules occasionally contain carbonate inclusions. The first idea is to attribute these fragments to rocks of the Mbuji Mayi dolomites but their internal structure, for example, the presence of a lath-shaped mineral, and their chemical composition (ankeritic calcite) could point to a deep-seated origin. Carbonate globules in kimberlites are not exceptional: they have been described for example by von Eckermann (1966) in the Alnö Complex. They could correspond to immiscible droplets of a carbonate material in the kimberlitic silicate liquid as suggested by the experimental work of Franz and Wyllie (1967).

Most of the Kundelungu kimberlites are of the basaltic type; they are often porphyritic with rather fresh olivine phenocrysts (two generations); the matrix consists of very fine-grained chloritic material with variable amounts of ilmenite, magnetite and perovskite. Some pipes (i.e. Chingululu) have a

carbonate matrix which, following Verhoogen (1938), could be of primary origin. The Kashioba pipe* is a porphyritic micaceous kimberlite with phlogopite and olivine phenocryst in a matrix of calcite, perovskite, mica and monticellite. All the kimberlites contain discrete nodules of pyrope and Cr-diopside.

The major-element composition of eleven kimberlites has been determined on five samples for the Mbuji Mayi field (M. Fieremans and Ottenburgs, 1979), five samples from the Kundelungu field and one sample of micaceous kimberlite of Camuanzanza (Angola). These analyses are reported in Table I and plotted (Fig. 3) in the classical *AFM* diagram and in the triangular diagram proposed by Dawson (1967) to take account of the volatile content. It is obvious from these diagrams that the kimberlites of Zaire are chemically very close to those of Lesotho and South Africa (Gurney and Ebrahim, 1973) and of Yakutia (Ilupin and Lutz, 1971). However, the Mbuji Mayi samples are slightly richer in volatiles because of the high carbonate content of the matrix. The Kundelungu samples plot closer to the *M*-apex than most other kimberlites.

STRONTIUM ISOTOPE COMPOSITION

The Sr-isotope composition previously reported for the kimberlites is very variable: Mitchell and Crockett (1971) measured $^{87}\text{Sr}/^{86}\text{Sr}$ ratios ranging from 0.7058 to 0.7160 for apparently fresh South Africa kimberlites; Bolivar and Brookins (1979) reported values as high as 0.713 for some North American pipes and Paul (1979) has obtained comparable results (initial ratios between 0.703 and 0.7102) for Indian kimberlites. This situation is probably partly due to alteration and interaction of the kimberlites with groundwater. Indeed, samples carefully selected on the basis of freshness criteria (olivine morphology, texture and uniformity of the groundmass, etc.) have lower $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, in the range 0.7038–0.7048 (Barrett and Berg, 1975): leaching experiments sometimes give more radiogenic leachable Sr (Paul, 1979) but do not always explain the variable isotopic composition (Bolivar and Brookins, 1979).

The Rb and Sr contents and the Sr-isotope composition measured on Mbuji Mayi and Kundelungu kimberlites and related rocks are reported in Table II and plotted as a histogram in Fig. 4. The Rb and Sr contents are very variable: from 150 to 1400 ppm Sr and from less than 5 to 89 ppm Rb. For most of the *Mbuji Mayi kimberlitic nodules* and the *Kundelungu kimberlites*, the Sr-isotopic initial ratio, calculated from the measured ratio assuming an age of 71 m.y. (Davis, 1977), is close to 0.7040–0.7045. These values are comparable with those reported by Barrett and Berg (1975) for fresh South African basaltic kimberlites. It is perhaps surprising to find such low values for the apparently altered (olivine pseudomorphosed) Mbuji Mayi rocks, but

*The sample described by Verhoogen (1938) is unfortunately no longer available.

TABLE I

Major-element chemistry of the Mbuji Mayi and Kundelungu kimberlites

	Mbuji Mayi**1										Kundelungu					Angola	
	Nod 1	Nod 2	Nod 3	Nod 5	Nod 6	Kun 1	Kun 2**2	I5 C	MI	M2	Verh.**3	Ang 1	Ang 1				
SiO ₂	33.46	35.94	31.70	40.63	30.25	32.84	49.92	29.00	29.63	31.25	29.94	32.38	32.38				
TiO ₂	1.06	0.59	0.62	1.64	1.41	1.78	1.35	1.74	2.92	2.58	2.55	3.38	3.38				
Al ₂ O ₃	3.01	5.20	4.04	3.67	3.81	2.40	3.31	1.85	3.30	3.01	5.40	3.33	3.33				
Fe ₂ O ₃	6.95	4.00	4.64	4.25	5.50	10.85	8.94	10.83	11.54	10.82	8.97	12.93	12.93				
FeO	1.37	2.78	2.25	2.32	1.81						4.50						
MnO	0.14	0.13	—	0.18	0.19	0.22	0.14	0.21	0.23	0.20	0.02	0.19	0.19				
MgO	15.35	14.62	16.63	10.00	15.92	35.80	30.12	34.51	29.28	30.67	27.31	27.72	27.72				
CaO	16.11	13.46	18.83	16.55	15.28	5.37	4.41	8.41	8.02	6.22	10.99	7.97	7.97				
Na ₂ O	0.15	0.25	0.10	0.06	0.06	<0.2	0.59	<0.2	<0.2	<0.2	0.74	<0.2	<0.2				
K ₂ O	0.20	1.05	tr.	1.27	0.98	0.24	0.83	0.51	0.02	—	0.35	0.15	0.15				
P ₂ O ₅	0.78	0.10	0.62	1.83	0.87	0.46	0.21	0.41	0.69	0.63	0.42	0.42	0.42				
H ₂ O	9.37	9.25	20.80	2.89	9.26	8.86	n.d.	9.67	10.75	11.15	4.17	10.97	10.97				
CO ₂	12.11	11.01		13.91	14.28	1.43	n.d.	2.02	4.00	3.45	4.20	0.44	0.44				
Total	100.06	98.38	99.61	99.20	99.62	100.47	99.82	99.40	100.59	100.19	99.56	100.10	100.10				

*1 From Fieremans and Ottenburgs (1979).

**2 H₂O and CO₂ contents have not been determined; the chemical composition is given on an anhydrous basis.

**3 From Verhoogen (1938).

tr. = trace.

- ★ Angola kimberlite
- △ Kundelungu kimberlite
- ◇ Mbuji Mayi primary kimberlite nodules
- ⊙ MK Micaceous kimberlite } (DAWSON, 1967)
- ⊙ BK Basaltic kimberlite } (DAWSON, 1967)
- LK Lesotho kimberlite } (GURNEY and
- SAK South Africa kimberlite } EBRAHIM, 1973)
- YK Yakutia kimberlite (ILUPIN and LUTZ, 1971)

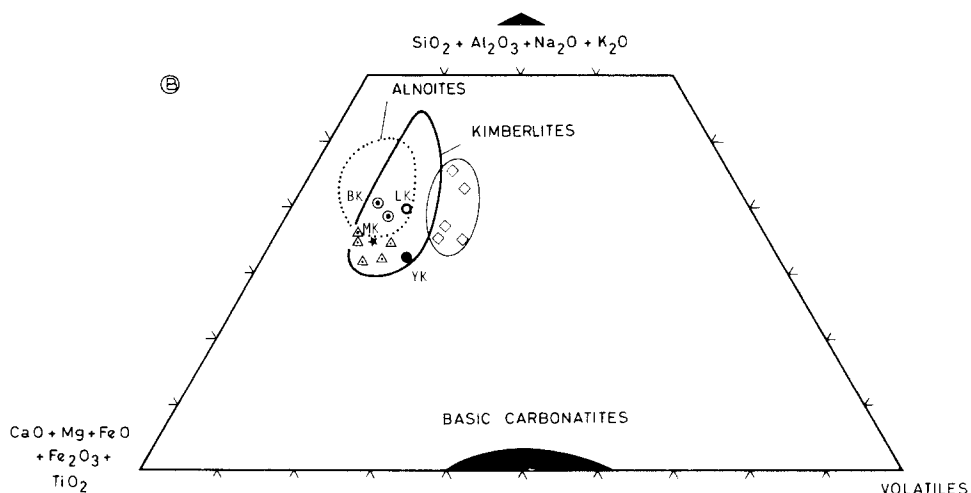
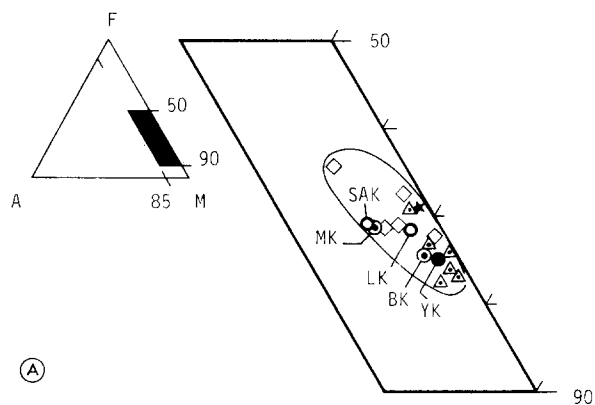


Fig. 3. A. AFM diagram for the analyzed kimberlites.

B. Dawson's (1967) diagram for the analyzed kimberlites. Comparison with the Lesotho and South Africa kimberlites (Gurney and Ebrahim, 1973) and with the Yakutia kimberlites (Ilupin and Lutz, 1971).

TABLE II

Rb, Sr and $^{87}\text{Sr}/^{86}\text{Sr}$ data for the Mbuji Mayi, Kundelungu and Angola kimberlites and associated rocks and minerals

	Rb (ppm)	Sr (ppm)	$^{87}\text{Rb}/$ ^{86}Sr	$^{87}\text{Sr}/^{86}\text{Sr} \pm 2\sigma_{\text{M}}$	$(^{87}\text{Sr}/$ $^{86}\text{Sr})_0$ (s)
MBUJI MAYI					
(a) <i>Primary kimberlite nodules:</i>					
Nodule 1 — center	19* ²	473—472* ²	0.1152	0.70429±0.00030 0.70430±0.00040	0.7041
Nodule 1 — border	18* ²	638—603* ²	0.083	0.70410±0.00060 0.70420±0.00040	0.7041
Nodule 2	85.7—85* ²	218—203* ²	1.136	0.71100±0.00050	0.7099
Nodule 4	77.5—75* ²	147—139* ²	1.523	0.70620±0.00060	0.7045
Nodule 5	52.7—54* ²	1,386—1,347* ²	0.1104	0.70467±0.00040	0.7045
Nodule 6		551		0.70470±0.00030	
(b) <i>Bluegrounds:</i>					
516D	33.6* ²	244* ²	0.3890	0.71096±0.00040	0.7105
515	22.9* ²	218* ²	0.2966	0.70858±0.00032	0.7083
(c) <i>Carbonate inclusions in kimberlite nodules:</i>					
K1	<5* ²	472* ²	<0.0080	0.70450±0.00030	<0.7045
K2	<5* ²	599* ²	<0.0010	0.70400±0.00050	<0.7040
(d) <i>Diopside megacrysts:</i>					
A-Di single grain (1 cm)		120.2		0.70297±0.00018	
B-Di single grain (2 cm)		124.3		0.70323±0.00015	
C-Di composite of small chips		116.0		0.70273±0.00035	
D-Di composite of small chips		129.9		0.70330±0.00030	
KUNDELUNGU					
Kun 1	36.5	405	0.2610	0.70455±0.00021	0.7043
Kun 2	36.8	249	0.4285	0.70828±0.00051	0.7078
15 C	34.9	481	0.2097	0.70395±0.00060	0.7038
15 D	32.8	677	0.1403	0.70435±0.00041	0.7042
M1	3.8	389	0.0281	0.70404±0.00050	0.7040
M2	4.8	408	0.0338	0.70447±0.00040	0.7044
M3	3.1	345	0.0261	0.70463±0.00030	0.7046
E-Di diopside composite		557		0.70340±0.00054	
ANGOLA					
Ang 1	4.5	486	0.0270	0.70328±0.00023 0.70330±0.00050	0.7032

*¹ The initial ratio is calculated, from the measured ratio, for the in situ decay of ^{87}Rb assuming an age of 71 m.y. (Davis, 1977).

*² Rb and Sr concentrations determined by X-ray fluorescence spectrometry (M. Delvigne and F. Durez — M.R.A.C.); the other data by isotope dilution.

as was already pointed out by Mitchell and Crockett (1971):

“serpentinisation of kimberlites is considered by most petrologists to be a deuteric phenomenon and exchange of material with meteoric water is not envisaged.”

These low $^{87}\text{Sr}/^{86}\text{Sr}$ values are comparable to those obtained for MORB and oceanic island basalts (Hofmann and Hart, 1978). Kimberlites appear as directly derived from the mantle, without any crustal influence. This con-

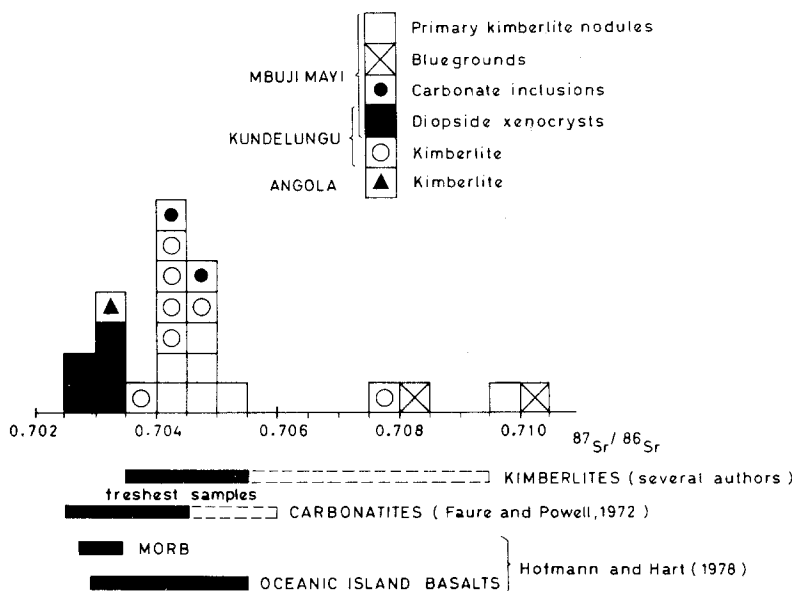


Fig. 4. Histogram of the $^{87}\text{Sr}/^{86}\text{Sr}$ initial ratios obtained for the Mbuji Mayi, Kundelungu and Angola kimberlites and related rocks.

clusion is in agreement with the preliminary Nd-isotopic determination made by Basu and Tatsumoto (1978).

Two Mbuji Mayi rocks which are petrographically deeply weathered and two tuff-breccias (bluegrounds) have much higher ratios of up to 0.710 which reflects crustal contamination by the Precambrian country rocks and/or interactions with groundwaters.

The *carbonate inclusions* in the Mbuji Mayi primary kimberlite nodules have $^{87}\text{Sr}/^{86}\text{Sr}$ ratios (0.7040–0.7045) identical to those for the kimberlites and significantly lower than the values obtained for the surrounding dolomitic limestones (see below). Other authors have obtained similar low values for carbonates associated with kimberlites. For example, Brookins and Watson (1969) measured values around 0.7040 for what they called “primary carbonate” of the Bachelor Lake kimberlite; Allsopp and Kramers (1977) also obtained 0.7040 for the “leachable carbonate component”. It thus appears plausible to relate the carbonates genetically to the kimberlites, which points to a carbonatitic origin* of the carbonate inclusions [$^{87}\text{Sr}/^{86}\text{Sr}$ ratios of carbonatites are in the range 0.702–0.707 with a mean of 0.7034 ± 0.0003 (Faure and Powell, 1972)].

This thesis has already been proposed by M. Fieremans and Ottenburgs (1979), considering the occurrence of baddeleyite in the kimberlite.

*Detailed mineralogical data tend to refute the commonly held view that kimberlites and carbonatites are genetically related (Mitchell, 1979). This does not change our conclusions.

Large, green *Cr-diopside crystals* (1–2 cm) have also been studied: the mean of five determinations (four from Mbuji Mayi and one from Kundelungu) on two single crystals and three composites of several fragments is 0.7031 ± 0.0002 (2σ). This value is significantly lower than that for the kimberlites which implies that the diopsides are not a crystallizing phase in the kimberlitic magma. They may be considered as xenocrysts probably related to the sheared lherzolite nodules often found as xenoliths in the kimberlites (Nixon and Boyd, 1973). This value (0.7031) is in agreement with the data of Barrett (1975), Shimizu (1975) and Kramers (1977) on similar nodules from South Africa and could correspond to the isotopic composition of a part of the mantle beneath Central Africa 70 m.y. ago. The Sr content of the diopside is rather low, around 120 ppm, except for the Kundelungu sample (550 ppm).

TABLE III

Rb, Sr and $^{87}\text{Sr}/^{86}\text{Sr}$ data for the dolomitic limestones of the Mbuji Mayi supergroup

Sample	Rb (ppm)	Sr (ppm)	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr} \pm 2\sigma_M$
B IIa stromatolitic limestone	<5*	31*		0.70794 ± 0.00035
B IIb – 31317 limestone	<5*	125*		0.70600 ± 0.00045
B IIb – 31369 limestone	<5*	665*		0.70550 ± 0.00040
B IIb – 31369 calcite vein	<5*	192*		0.70570 ± 0.00040
B IIc – 165/4 limestone	13*	44*	0.829	0.7159 ± 0.00040
B IIId – 31490 stromatolitic limestone	<5*	34*		0.70564 ± 0.00025
B IIe – 31685 limestone	15*	159*	0.179	0.71060 ± 0.00060

*Rb and Sr concentrations determined by X-ray fluorescence spectrometry (M. Delvigne and F. Durez – M.R.A.C.).

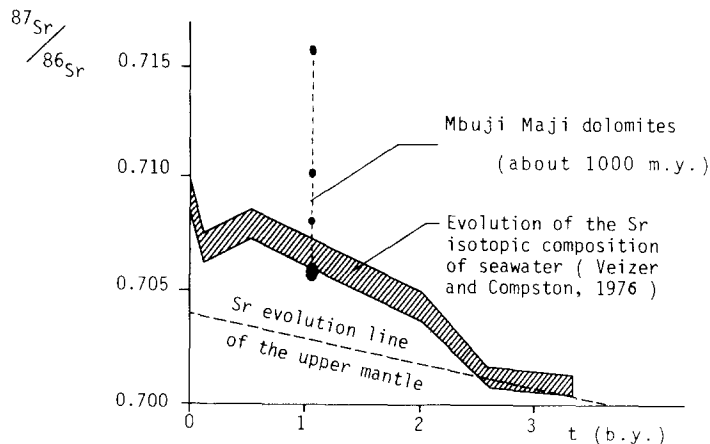


Fig. 5. $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of the Mbuji Mayi dolomites plotted on the Veizer and Compston (1976) diagram showing the evolution with time of the Sr isotopic composition of sea water.

To confirm that the carbonate inclusions in the kimberlite nodules cannot be xenoliths of the surrounding *stromatolitic dolomitic limestones* intruded by the pipes, we have measured the Sr-isotope composition of seven representative samples of different facies of these dolomites (Table III) which are marine carbonates (Raucq, 1970). The mean of the four lowest values is 0.7057 ± 0.0003 which is significantly higher than the values obtained for the carbonate inclusions. Still higher ratios of up to 0.715 have been measured for dolomites with some detrital components*. The value 0.7057 is useful to better delineate (Fig. 5) for the Proterozoic (~1000 m.y.; Cahen, 1973), the Sr-isotopic evolution trend of the Precambrian seawater as determined by Veizer and Compston (1976) using marine carbonates of different ages.

CONCLUSIONS

(1) The Mbuji Mayi and Kundelungu kimberlitic rocks are true kimberlites on the basis of both their petrography and whole-rock chemistry.

(2) The low $^{87}\text{Sr}/^{86}\text{Sr}$ initial ratio (0.7040–0.7045) suggests a mantle origin without crustal contamination for the kimberlitic magma.

(3) A probable cogenetic relation between the kimberlite and carbonate nodules is proposed on the basis of the Sr-isotopic geochemistry.

(4) The Cr-diopside discrete nodules ($^{87}\text{Sr}/^{86}\text{Sr}$: 0.7031 ± 0.0002) are not related to the kimberlites; they are considered to be xenocrysts of the upper mantle.

ACKNOWLEDGEMENTS

The Mbuji Mayi and Angola samples were provided by Ir. C. Fieremans while Prof. De Magnée provided some of the Kundelungu samples.

X-ray fluorescence determinations were supervised by Dr. J. Delhal (MRAC, Tervueren) and Dr. J.C. Duchesne (Liège) for the Rb–Sr concentrations and the major-element composition, respectively.

Dr. J. Delhal and Prof. L. Cahen critically read an early draft of this paper.

The present study was carried out as part of the program of the “Centre Belge de Géochronologie”.

REFERENCES

- Allsopp, H.L. and Kramers, J.D., 1977. Rb–Sr and U–Pb age determinations on Southern African kimberlite pipes. Ext. Abstr. 2nd Int. Kimberlite Conf., Santa Fe, N.M.
 Anonymous, 1979. Notice explicative de la feuille Mbuji Mayi (S7/E23) (carte géologique au 1/20.000^e). Dép. Mines Serv. Géol. Républ. Zaïre, Kinshasa, 50 pp.
 Barrett, D.R., 1975. The genesis of kimberlites and associated rocks: strontium isotopic evidence. In: L.H. Ahrens, J.B. Dawson, A.R. Duncan and A.J. Erlank (Editors), Phys. Chem. Earth, 9: 637–653.

*The authors have measured the whole-rock Sr not the Sr of the carbonate alone.

- Barrett, D.R. and Berg, G.W., 1975. Complementary petrographic and strontium isotope ratio studies of South African kimberlites. In: L.H. Ahrens, J.B. Dawson, A.R. Duncan and A.J. Erlank (Editors), *Phys. Chem. Earth*, 9: 619–635.
- Basu, A.R. and Tatsumoto, M., 1978. Nd isotopes in mantle derived rocks and minerals and the evolution of the earth's mantle. *Short Papers of 4th Int. Conf. Geochronol., U.S. Geol. Surv., Open-file Rep. 78-701*, pp. 28–30.
- Bolivar, S.L. and Brookins, D.G., 1979. Geophysical and Rb–Sr study of the Prairie Creek, Arkansas kimberlites. In: F.R. Boyd and H.O.A. Meyer (Editors), *Kimberlites, Diatremes and Diamonds: Their Geology, Petrology and Geochemistry*. Am. Geophys. Union, Washington, D.C., pp. 289–299.
- Brookins, D.G. and Watson, K.D., 1969. The strontium geochemistry of calcite associated with kimberlite at Bachelor Lake, Quebec. *J. Geol.*, 77: 367–371.
- Cahen, L., 1973. Corrélation de certaines séries du Précambrien du Zaïre à la lumière de l'étude des stromatolithes et des données de géochronologie radiométrique. *Mus. R. Afr. Centr., Tervueren, Dep. Géol. Minéral., Rapp. Annu. 1972*, pp. 38–51.
- d'Andrimont, R., 1913. Note sur une visite aux pipes diamantifères des Monts Kundelungu. *Ann. Soc. Géol. Belg.*, 40: 8–19.
- Davis, G.L., 1977. The ages and uranium contents of zircons from kimberlites and associated rocks. *Ext. Abstr. 2nd Int. Kimberlite Conf., Santa Fe, N.M.*
- Dawson, J.B., 1967. A review of the geology of kimberlite. In: P.J. Wyllie (Editor), *Ultramafic and Related Rocks*. Wiley, New York, N.Y., pp. 241–251.
- Delhal, J., Ledent, D. and Pasteels, P., 1975. L'âge du complexe granitique et migmatitique de Dibaya (région du Kasai, Zaïre) par les méthodes Rb/Sr et U/Pb. *Ann. Soc. Géol. Belg.*, 98: 141–154.
- De Magnée, Y., 1946. Présence de kimberlite dans la zone diamantifère de Bakwanga. *Bull. Soc. Belge Géol.*, 56: 127–132.
- Faure, G. and Powell, J.L., 1972. *Strontium Isotope Geology*. Springer, Berlin, 188 pp.
- Fieremans, C., 1966. Contribution à l'étude pétrographique de la brèche kimberlitique de Bakwanga. *Mem. Inst. Géol. Univ. Louvain*, 24(1): 1–92.
- Fieremans, C., 1977. Mode of occurrence and tectonic control of the kimberlite bodies in East Kasai (Zaire). *Ext. Abstr. 2nd Int. Kimberlite Conf., Santa Fe, N.M.*
- Fieremans, M. and Ottenburgs, R., 1979. Kimberlite inclusions and chlorite nodules from the kimberlite breccia of Mbuji Mayi (Eastern Kasai) Zaire. *Bull. Soc. Belg. Géol.*, 88: 205–224.
- Franz, G.W. and Wyllie, P.J., 1967. Experimental studies in the system CaO–MgO–SiO₂–CO₂–H₂O. In: P.J. Wyllie (Editor), *Ultramafic and Related Rocks*, Wiley, New York, N.Y., pp. 323–326.
- Gurney, J.J. and Ebrahim, S., 1973. Chemical composition of Lesotho kimberlites. In: P.H. Nixon (Editor), *Lesotho Kimberlites*. Lesotho Natl. Dev. Corp., Maseru, pp. 149–158.
- Hofmann, A. and Hart, S.R., 1978. An assessment of local and regional isotopic equilibrium in the mantle. *Earth Planet. Sci. Lett.*, 38: 44–62.
- Iupin, I.P. and Lutz, B.G., 1971. The chemical composition of kimberlite and the questions on the origin of kimberlite magma. *Sov. Geol.*, 6: 61–73.
- Kramers, G.D., 1977. Lead and strontium isotopes in inclusions in diamonds and in mantle-derived xenoliths from Southern Africa. *Ext. Abstr. 2nd Int. Kimberlite Conf., Santa Fe, N.M.*
- Mitchell, R.H., 1979. The alleged kimberlite–carbonatite relationship: additional contrary mineralogical evidence. *Am. J. Sci.*, 279: 570–589.
- Mitchell, R.H. and Crockett, J.H., 1971. The isotopic composition of strontium in some South African kimberlites. *Contrib. Mineral. Petrol.*, 30: 277–290.
- Nixon, P.H. and Boyd, F.R., 1973. The discrete nodule association in kimberlites from northern Lesotho. In: P.H. Nixon (Editor), *Lesotho Kimberlites*, Lesotho National Development Corporation, Maseru, pp. 67–75.

- Paul, D.K., 1979. Isotopic composition of Sr in Indian kimberlites. *Geochim. Cosmochim. Acta*, 43: 389—394.
- Raucq, P., 1970. Nouvelles acquisitions sur le système de la Bushimay. *Ann. Mus. R. Afr. Cent., Sci. Geol.*, 69, 156 pp.
- Shimizu, N., 1975. Geochemistry of ultramafic inclusions from Salt Lake crater, Hawaii and from Southern African kimberlites. In: L.H. Ahrens, J.B. Dawson, A.R. Duncan and A.J. Erlank (Editors), *Phys. Chem. Earth*, 9: 655—669.
- Stützer, O., 1913. Über ein feldspathreiches, knollenartiges Mineralaggregat der Luanza Pipe im Kundelungu (Katanga, Belgisch Kongo). *Z. Dtsch. Geol. Gesells., Monatsh.*, 4: 226—228.
- Veizer, J. and Compston, W., 1976. $^{87}\text{Sr}/^{86}\text{Sr}$ in Precambrian carbonates as an index of crustal evolution. *Geochim. Cosmochim. Acta*, 40: 905—914.
- Verhoogen, J., 1938. Les pipes de kimberlite du Katanga. *Ann. Serv. Mines, Com. Spéc. Katanga*, 9: 1—49.
- Von Eckermann, H., 1966. Progress of research on the Alnö carbonatite. In: O.F. Tuttle and J. Gittins (Editors), *Carbonatites*, Wiley, New York, N.Y., pp. 3—32.