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COMPARATIVE STUDY OF THE KIMBERLITES OF BAKWANGA (NORTH GROUP) AND BAKWA-KALONJI (SOUTH GROUP) IN EAST KASAI, DEMOCRATIC REPUBLIC OF CONGO.

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ABSTRACT

The presence of kimberlites in the Democratic Republic of Congo has been known since BUTTGENBACH reported a typical 'yellow ground' in Katanga as early as 1908, and prospecting work before and after 1914 had already identified twenty-four pipes in the province. In eastern Kasai, the local Kimberlite, which crosses the entire Precambrian (Socle and its overburden) as well as the sandstone Mesozoic and is covered by the Tertiary, is found in two groups, namely the Northern Group, also known as the Bakwanga Kimberlites, and the Southern Group, known as the Bakwa-Kalonji Kimberlites. With the same age, dated to the Cretaceous and quantified at 71.3 million years, a comparative scientific study of the two groups of kimberlites in East Kasai is of interest in order to gain an insight into the primitive magmatism that created them. To this end, we have set ourselves the objective of taking stock of geochemical knowledge of the Bakwanga and Bakwa-Kalonji kimberlite massifs (accessible to our sampling) in order to better interpret and compare, from a petrological point of view, the genesis, composition and nature of these kimberlite intrusions.Based on our studies, we found that the Kimberlitic formations studied (Bakwanga and Tshibwe Kimberlite) are all characteristic of ultrabasic (or silica-undersaturated), mafic and not ultramafic, hyperalkaline, ultrapotassic, volatile-rich (H_2O and CO_2) magmatism of the lamproite or orangite group, showing clear crustal alteration or contamination and originating in the upper mantle. These two groups differ in terms of the lithology of the host rock (limestone and/or dolomite for the northern group and sandstone for the southern group). In terms of the proportion of xenoliths in the respective kimberlites, there is a total absence of sedimentary xenoliths, particularly limestone and dolomite, and incidentally sandstone, in the southern kimberlites. Gabbro-dioritic xenoliths are more abundant in the southern group than in the north, and xenoliths from basement rocks are more abundant and dominant in the north than in the south.)

Keywords: Kimberlitic massif, North Group, South Group, magmatism, petrology.

1. INTRODUCTION

The presence of kimberlites in the Democratic Republic of Congo has been known since BUTTGENBACH reported a typical 'yellow ground' in Katanga as early as 1908, and prospecting work before and after 1914 had already identified twenty-four pipes in the same province [1]. In eastern Kasai, the local Kimberlite, which crosses the entire Precambrian (Socle and its overburden) as well as the sandstone Mesozoic and is covered by the Tertiary, is found in two groups, namely the North Group, also known as the Bakwanga Kimberlites, and the South Group, known as the Bakwa-Kalonji Kimberlites[2].
The Northern Group is made up of 13 massifs (points), 9 of which are aligned East-West and 4 are contiguous. 7 would be Pipes, 2 are located on the North-East axis oblique to the alignment of the

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majority of the massifs known to date. 2 others are remote and are located on the left bank of the Kanshi river at least 10 km from the others. These kimberlites are located within the MIBA mining polygon, which is bounded to the east and south-east by the Mbujimayi River and to the north and west by the Kanshi River. The Southern Group comprises 6 massifs discovered to date, the largest of which follows an East-West (E-W) to West-North-West to East-South-East (WNW-ESE) trend along a gabbronoritic dyke. In this work, only the Tshibwe massif was sampled for analysis. The TSHIBWE massif is located 52 km south-west of the town of Mbuji-Mayi and lies within the geographical area bounded by longitudes 23°15‘and 23°20’ east and latitudes 6°15‘and 6°20’ south. It covers an area of approximately 69 hectares. The Tshibwe massif is ellipsoidal in shape; the long axis running East-West is 1502.293 m long, while the short axis running North-South is 720 m long. Its highest altitude is around 720 m. Having the same age, dated to the Cretaceous and quantified at 71.3 million years [3,4], a comparative scientific study of the two groups of kimberlites in eastern Kasai would be of interest in order to gain an insight into the primitive magmatism that put them in place.We set ourselves the objective of reviewing the geochemical knowledge of the Bakwanga and Bakwa-Kalonji kimberlite massifs (accessible to our sampling) in order to better interpret and compare, from a petrological point of view, the genesis, composition and nature of these kimberlite intrusions.Our fieldwork was supplemented by more recent data from drilling and borehole surveys carried out on certain Bakwanga kimberlite massifs and the Tshibwe massif at Bakwa-Kalonji.

2. STUDY AREA

2.1. Geographically speaking

The kimberlite massifs of the North Group are located in the MIBA mining area, commonly known as the mining polygon (with a surface area of 6,000 km2), approximately 17 km south-west of the town of Mbuji-Mayi, in the territory of Lupatapata, locality of Bakwa Tshimuna, Madiatu grouping, Tshilengi district in the province of Kasaï Oriental. These kimberlite deposits lie between parallels 6° and 7° south latitude and 23° and 24° east longitude. The relief of the study area is a low plateau whose altitude generally varies between 600 and 800 m [5]. This low plateau slopes from south to north and has gently undulating surfaces [6]. Kasai Oriental has a type A climate according to the Koppen classification. It is a humid tropical climate with an average annual temperature ranging from 25°C in the north to 22.5°C in the south of the province. The daytime temperature in the coldest month is over 18°C. Annual temperature variations are not significant. They vary between 1.5 and 2° depending on the season [6].The kimberlite massifs of the Southern Group are located between parallels E: 23°15‘and E: 23°30’ and meridians S: 06°00‘and S: 06°10’, at altitudes of between 600 and 650 m. They lie approximately 50 km south-west of Mbuji-Mayi in the Miabi territory in the Province of Kasai-Oriental in the DRC, and access to the site is relatively easy. The roads in this area are accessible (by 4x4 vehicle and motorbike) during both the wet and dry seasons (Figure. 1). We have the two-season tropical climate that prevails throughout the Kasai [7,8]. The soil is more lateritic and the vegetation is characterised by a mixture of savannahs, shrub savannahs of various types, gallery forests and remnants of protophytic forests [9]. From a morphological point of view, this zone is a peneplain.

The Tshibwe kimberlite massif is surrounded :

- To the west by the Kakongo kimberlite massif,
- To the south-west by the Ndaye kimberlite massif;
- To the north by the Tshiniama kimberlite massif;
- To the north-east, via the Tshiambila and Tshinkasa kimberlite massifs.

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Table 1. Summary of the kimberlite massifs of Eastern Kasai

Group and No.order		Names of massifs	Year from Discovery	Gr. axe M	Pet. Axe M	Périm	Surf Ha	Taill P/C	No. of surveys			Situation Of
									Caro	Wirt	Foraky	
GROUP SUD	1	Tshibwe	1955	1502	720	3500	69	13		0	1	2010
	2	Tshinkas	1956	330	110	770	2,6			0		-
	3	Ndaye	1959	270	70	800	6,3			0		-
	4	Tshinyam	1960	180	150	490	1,6			0		-
	5	Kakongo	1977	270	45	680	1.4			0		-
	6	Tshambil	1981	135	80	340	1,3			0		-
GROUPE DE BAKWANGA	7	Massif 1	1946	800	450	2100	23	8	107	21		2002
	8	Massif 2	1947	270	150	750	2,4	8	8	0		2002
	9	Massif 3	1947	430	300	1300	16,9	8	90	0		2000
	10	Massi 3	2003	260	210	850	2,0	6	41	3		2004
	11	11Massif4	1947	110	70	250	2,3	8	24	4		1994
	12	Massif 5	1947	575	275	1500	10	8	66	11	17	2001
	13	Massif 6	1948	353	206	1150	5,6	5	37	2		2004
	14	Massif 7	1948	175	110	550	1,45	9	5	1	1	2007
	15	Massif 8	1949	230	60	650	1,6	9	15	3	1	2005
	16	Massif 9	1950	150	100	961	1,0	9	0	0		2006
	17	Massif 10	1950	160	120	570	1,48	6	18	4		2005
	18	Massif 11	1997	360	110	980	3,7	4	48	6		2004
	19	Massif 12	2003	107	82	340	0,8	5	12			2004
	20	Massif 13	2004	110	70	189	0.75	3				2004

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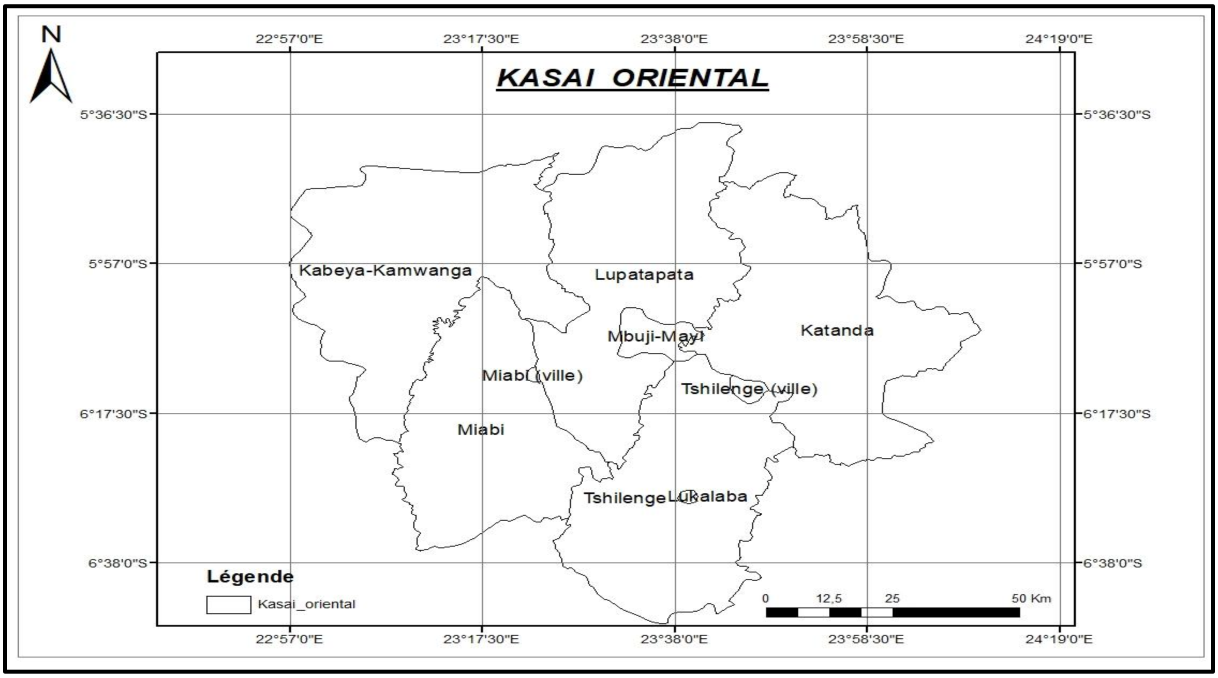

Figure1. Geographical map of the province of Kasaï-Oriental

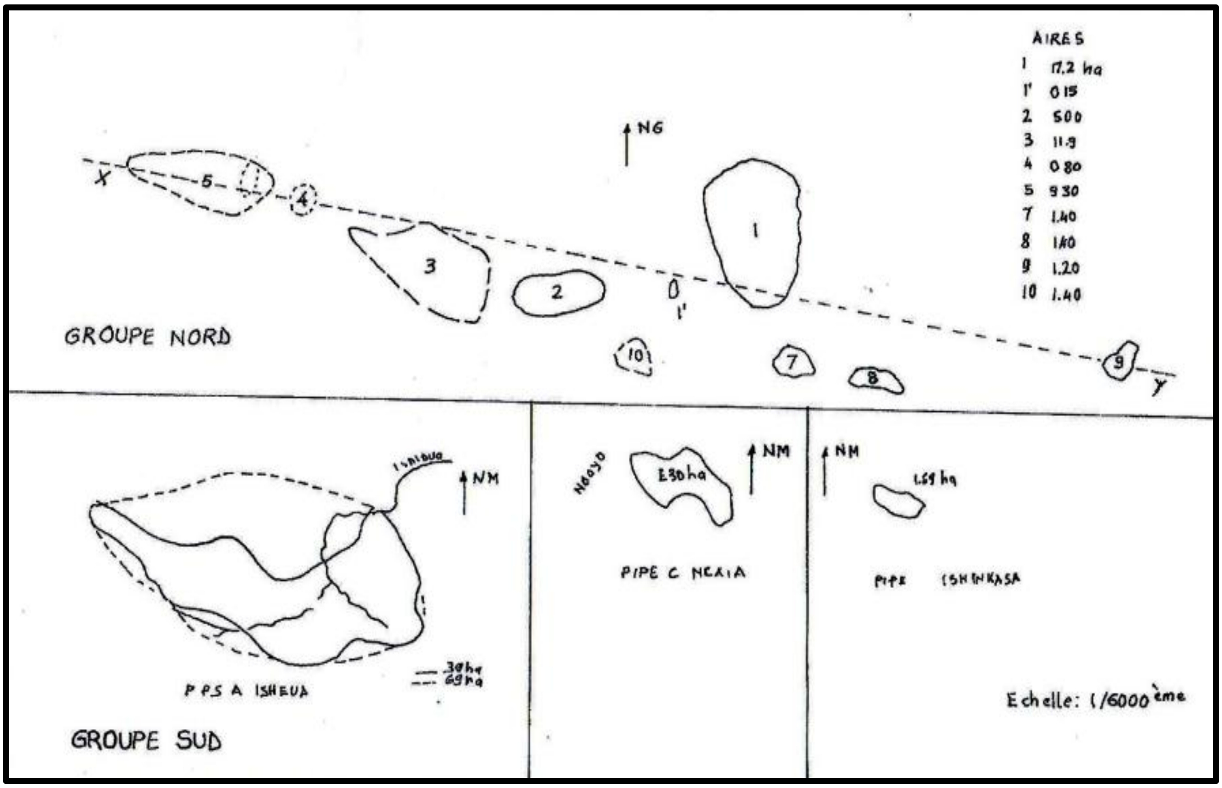

Figure 2. Schematic section showing the massifs of the North and South group

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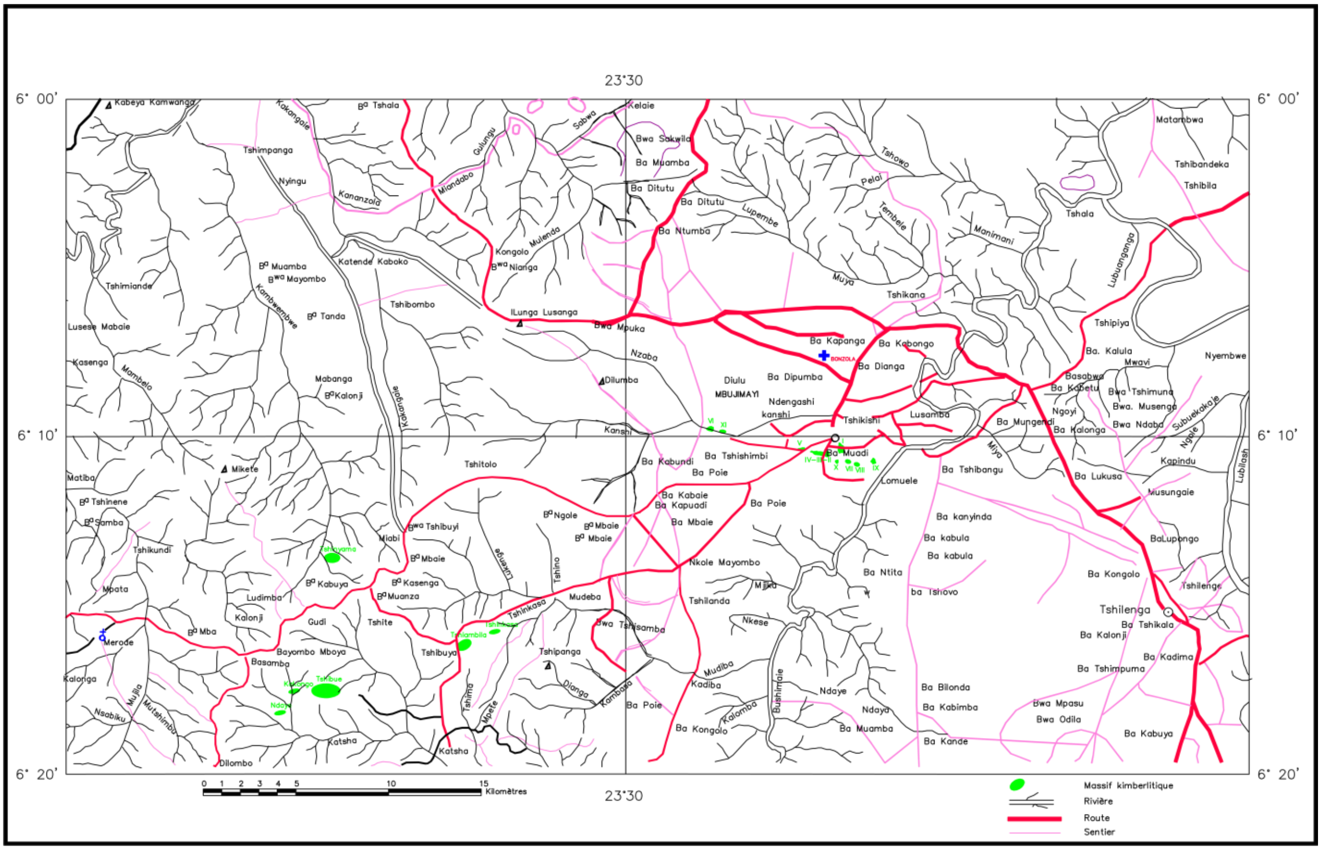

Figure 3.Location of the kimberlite massifs of Eastern Kasai (North and South groups)

Geologically speaking, the main stratigraphic formations in East Kasai on the Mbujimayi degree square are as follows [2]:

- Proterozoic basement formations:

These include the Upper Luani gneisses, the Archean-age Dibaya gabbronoritic and migmatite complex, the Luiza meta-sedimentary complex, the Lulua volcano-sedimentary complex and the Mbuji-Mayi supergroup of Neoproterozoic age.

- Phanerozoic overburden formations:

It should be noted at the outset that the Paleozoic is totally absent and that the overlying formations are Mesozoic, Tertiary and Quaternary. For the Mesozoic, these are the conglomerates and sandstones of the lower Kasai series; for the Tertiary and Quaternary, the polymorphous sandstones (Palaeogene) and ochre sands of the Kalahari system; sands, gravels and alluvium of the low-lying alluvial plains.

It should also be noted that the Bakwanga kimberlite flows may have traversed the following formations:

- The Precambrian granitic basement,
- The Mbuji-Mayi supergroup,
- Mesozoic sandstone layers.

With regard to kimberlite, it should be noted that it is one of the rare potassic ultrabasic rocks, rich in volatile elements (CO_2+H_2O), occurring as a diatreme, dyke or sill.

Kimberlites are the products of continental intraplate magmatism, with occurrences in the heart of the craton or at its edge. No occurrences have been described in the oceanic environment or in young folded zones [10] [11] [12]

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Texturally, three genetic types have been defined [13]: Crater facies, diatreme facies and hypabyssal facies, each associated with a particular style of magmatic activity and characterised by petrographic types such as crater facies shows that kimberlitic magma rarely appears as lava, The diatreme facies is often dominated by kimberlitic breccias containing angular fragments of the surrounding rocks, whereas the hypabyssal facies shows a typical kimberlitic rock without pyroclastic fragments. With regard to kimberlite nomenclature, since 2002 MIBA has adopted a terminology based on rock composition and inspired by the literature [13,14,15].
The main difference between the kimberlites of these two groups is the absence, or rather the rarity, of carbonate xenoliths (enclaves) in the southern branch, a difference linked to the lithology of the host rock [16]

Table 2. Average distribution of xenoliths in the kimberlites of Eastern Kasai (Meyer de Standelhofen, 1963)

Rocks	Groupe Nord	Groupe Sud (Tshibwe)
Grained ultrabasic rocks	2%	1%
Gritty gabbro-dioritic rocks	1%	60%
Microlitic rocks	≥1%	2%
Sandstone rocks	3%	2%
Rocks of the Base	83%	≤1%
Carbonate rocks	10%	30%
Mesozoic non-pulverised sandstone-clay rock	-	1%

Kasai kimberlite is a breccia and Meyer de Standelhofen (1963) was able to demonstrate the existence of three types of kimberlitic breccia: leached breccia, cemented breccia and kimbelite autoliths.Fieremans, Demaiffe and Ottenburgs (1979) carried out a series of relatively detailed chemical analyses of the nodules they studied and concluded that they were volatile-enriched kimberlites. These highly gas-laden hydrothermal vents are thought to be rich in CaO, and Cibumba and Onya (2010) agree that this kimberlite was contaminated at crustal level during its ascent. Based on lithostratigraphic arguments, Fieremans (1966) postulated a Cretaceous age for the Kasai kimberlite and Davis (1966 and 1977) determined an age of 71.3 million years from zircons, which confirms Fieremans' hypothesis.

3. METHODS AND MATERIALS

This analytical study was based on rock samples taken from the Bakwanga and Bakwa-Kalonji kimberlite outcrops, as well as samples taken from cores drilled from the Bakwanga kimberlites.
In order to better approach our study of the petrology and geochemistry of these kimberlites, 10 total chemical analyses of the rock samples taken were carried out at the chemistry laboratory of the Centre de Recherches Géologiques et Minières (CRGM) in Kinshasa.
The kimberlite samples analysed were distributed as follows:

- Six samples from the Minière de Bakwanga mining polygon where the kimberlites of the North Group outcrop (samples M1a, M2, M7, M8, M11 and M12b);
- Four samples taken from the current SACIM mining concession where the Tshibwe kimberlite massif outcrops (samples St1, St2, St3 and St4).

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3.1. Data presentation

Table 3. Samples of kimberlitic rock taken from the North and South groups

Massif	N°	Geodetic coordinates	Kimberlitic facies
M1	1a	Alt : 570 m S : 06°10'17,6'' E : 23°36'37,9''	Greenish kimberlite, soft to coarse-grained.
M2	2	Alt : 559 m S : 06°10'29,9'' E : 23°36'09,3''	Reddish Kimberlite with medium to coarse grains.
M7	7	Alt : 565 m S : 06°10'43,1'' E : 23°36'43,3''	Kimberlite with a reddish to greenish tinge and medium to coarse grains.
M8	8	Alt : 575 m S : 06°10'38,7'' E : 23°36'47,6''	Kimberlite with a greenish to reddish hue and coarse to medium grains.
M11	11	Alt : 592 m S : 06°09'58,7'' E : 23°32'52,8''	Medium-grained greenish to greyish kimberlite
M12	12b	Alt : 553 m S : 06°10'38,5'' E : 23°36'38,9''	Medium to coarse-grained greenish kimberlite
Tshibwe	St1	Alt : 661 m S : 06°17'31,1'' E : 23°21'50,7''	Soft, coarse-grained, greenish to yellowish kimberlite.
Tshibwe	St2	Alt : 661 m S : 06°17'28,3'' E : 23°21'40,7''	Soft, coarse-grained, greenish to yellowish kimberlite.
Tshibwe	St3	Alt : 660 m S : 06°17'24,3'' E : 23°21'39,74''	Greenish kimberlite with a dark tendency, soft and coarse-grained.
Tshibwe	St4	Alt : 658 m S : 06°17'23,8'' E : 23°21'42''	Soft, coarse-grained, greenish to yellowish kimberlite.

The chemical analyses cover 9 major elements (Si, Al, Fe, Mg, Ca, K, Na, P and Ti), 4 trace elements (Cu, Ni, Cr and Co) and 2 volatile elements (H_2O and CO_2).
The chemical compositions of the samples analysed are set out in table 4 below.

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Table 4. Chemical compositions of Kimberlite from Bakwanga and Bakwa-Kalonji (Tshibwe)

	Kimberlites of Bakwanga						Kimberlite from Bakwa-Kalonji (Tshibwe)			
Parameters (%)	M1a	M2	M7	M8	M11	M12	ST1	ST2	ST3	ST4
SiO_2	44,70	44,94	44,12	44,80	44,00	44,70	44,95	44,50	44,90	44,28
H_2O et CO_2 (110°C)	15,98	8,89	12	13,14	13,35	14,57	11,1	12,43	10,24	18,02
Humidity (H_2O)	3,12	9,52	7,11	6	6,05	4,83	8	6,72	9	11,2
Mg	9,14	9,20	9,00	8,75	8,95	9,05	9,00	9,05	9,12	8,0
Fe_2O_3	6,16	7,00	7,01	6,45	6,15	7,00	7,00	7,15	7,00	7,0
K_2O	13,00	13,13	13,23	13,72	14,70	11,52	11,29	13,05	12,14	13,26
Na_2O	2.08	2,16	2,15	2,00	1,50	2,15	2,15	2,00	2,16	1,42
CaO	1,14	1,15	1,10	1,10	1,10	1,15	1,10	1,00	1,12	2,24
TiO_2	1,96	1,84	1,96	2,00	2,25	2,00	2,80	2,05	1,86	1,64
Al_2O_3	2,00	2,04	2,00	1,94	2,01	1,95	2,06	1,96	2,00	1,98
P_2O_5	0,02	0,01	0,03	0,08	0,10	0,06	0,5	0,01	0,06	0,02
CuO	0,02	0,02	0,02	0,02	0,03	0,02	0,05	0,01	0,06	0,01
Nickel	0	0	0	0	0	0	0	0	0	0
Chrome	0	0	0	0	0	0	0	0	0	0
Cobalt	0	0	0	0	0	0	0	0	0	0
Total	99,32	99,89	99,73	100	100,09	99	100	99,93	99,66	98,99
Ultrapotassic: Molar:K_2O/Al_2O_3	6,5	6,44	6,62	7,07	6,64	5,9	5,48	6,66	6,07	6,69

4. RESULTS AND DISCUSSION

SiO2 contents vary from 44.00% to 44.94% in the Bakwanga kimberlite and from 44.28% to 44.90% in the Tshibwe kimberlite. With SiO2 contents of less than 45%, the rocks studied belong to the family of ultrabasic rocks [16, 18, 1]. In both Bakwanga and Tshibwe kimberlites, Al_2O_3 contents are very low (1.99% on average for Bakwanga and 2% for Tshibue) and typical of phlogopite- or diopside-rich kimberlites [19, 20]. In addition, Clément (1982) introduced a contamination index (CI) to assess the effects of alteration and/or crustal contamination:

$CI = (SiO_2+Al_2O_3+Na_2O)/(MgO+_2K_2O)$.

This index estimates the proportion of clays and tectosilicates in relation to olivines and phlogopites, as SiO_2, Al_2O_3 and Na_2O are added during any crustal contamination. A value of less than 1 indicates a fresh or uncontaminated kimberlite. A value of 1 to 1.5 is acceptable for a kimberlite rich in phlogopite or diopside [19, 21]. After calculating the C.I of the Bakwanga and Tshibwe kimberlites, their quotients vary from 1.23 to 1.56, indicating that these rocks (North and South groups) are altered and have undergone crustal contamination. In these two sectors, the rocks studied have very low MgO contents (8.75 - 9.20% at Bakwanga and 8.00 - 9.12% at Tshibue) compared with those at De Beers Mine in South Africa (MgO: 32.30%) [16]. These low MgO contents in the Bakwanga and Tshibwe Kimberlites are due to the probable elimination of magnesia following pronounced alteration of these rocks. With MgO contents of less than 12% [22], the rocks studied are mafic and not ultramafic.

Indeed, projected in the SiO_2 - Al_2O_3 diagram (Figure 4), the contents of these elements in the kimberlite of two groups under study occupy the domain of altered and contaminated kimberlites. With Na2O contents (1.50 - 2.16 % and 1.42 - 2.16 % respectively for Bakwanga and Tshibue) higher than 1 and K_2O contents well above 3 % (11.53 - 14.7 % for Bakwanga and 11.29 - 13.26 % for Tshibue), as

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well as silica contents of between 25 and 55 %, the kimberlites studied correspond to hyperalkaline, potassic magmatic rocks close to lamproites.
This resemblance to lamproites is evident from the CaO - SiO_2 and CaO - Al_2O_3 diagram (Figure 5), in which the points representative of the kimberlites under study migrate towards the lamproite field, probably as a result of their highly altered state, as revealed by macroscopic observations (see Table 4).The K_2O/Al_2O_3 molar ratio is systematically greater than 3 (K_2O/Al_2O_3 molar ratio: 5.9 - 7.07 for the Bakwanga kimberlite and 5.48 - 6.66 for the Tshibue kimberlites) confirms the ultrapotassic nature of the rocks studied and classifies them as Group II kimberlites, described as 'Orangéites' by Mitchell (1995), which are also particularly rich in volatiles (H_2O + CO_2), indicating very violent explosive emplacement. With regard to minor elements, traces of copper were found in the kimberlites under study (Cu: 0.02 - 0.03 % at Bakwanga and 0.01 - 0.06 at Tshibue), irrefutable proof of crustal contamination, but traces of nickel and chromium were not identified.
The kimberlites at Bakwanga and Tshibwe have high TiO_2 content but low rutile content.

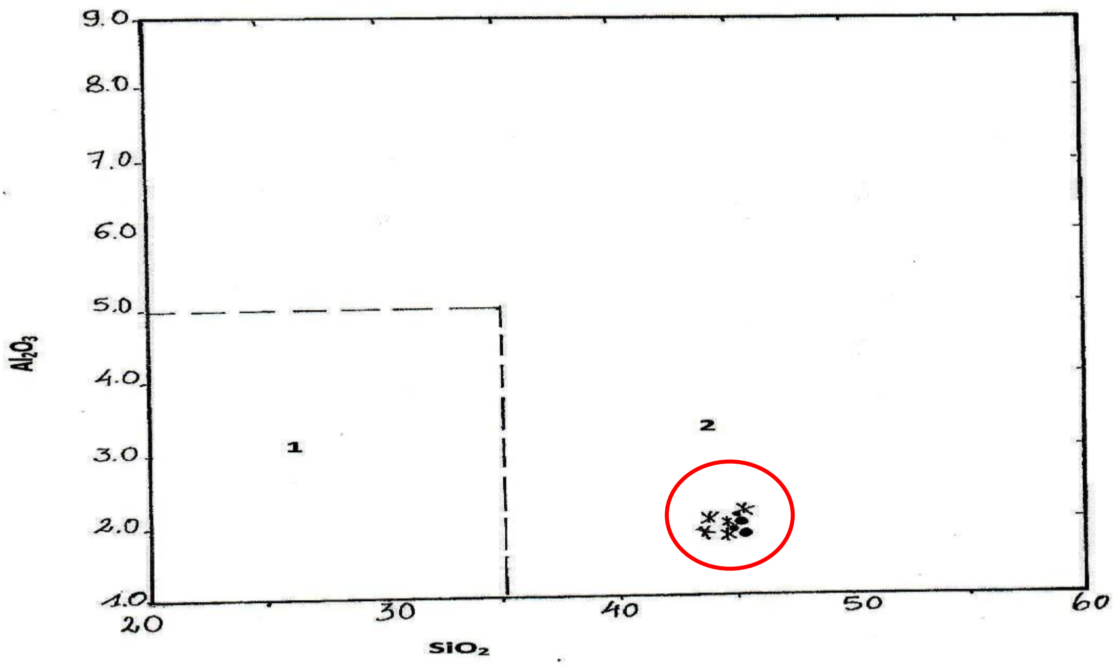

Figure 4. Position of the Bakwanga (*) and Tshibwe (•) kimberlites in the Al_2O_3 - SiO_2 diagram.

Area:
1. Area of healthy, uncontaminated Kimberlites
2. Contaminated and altered kimberlites.

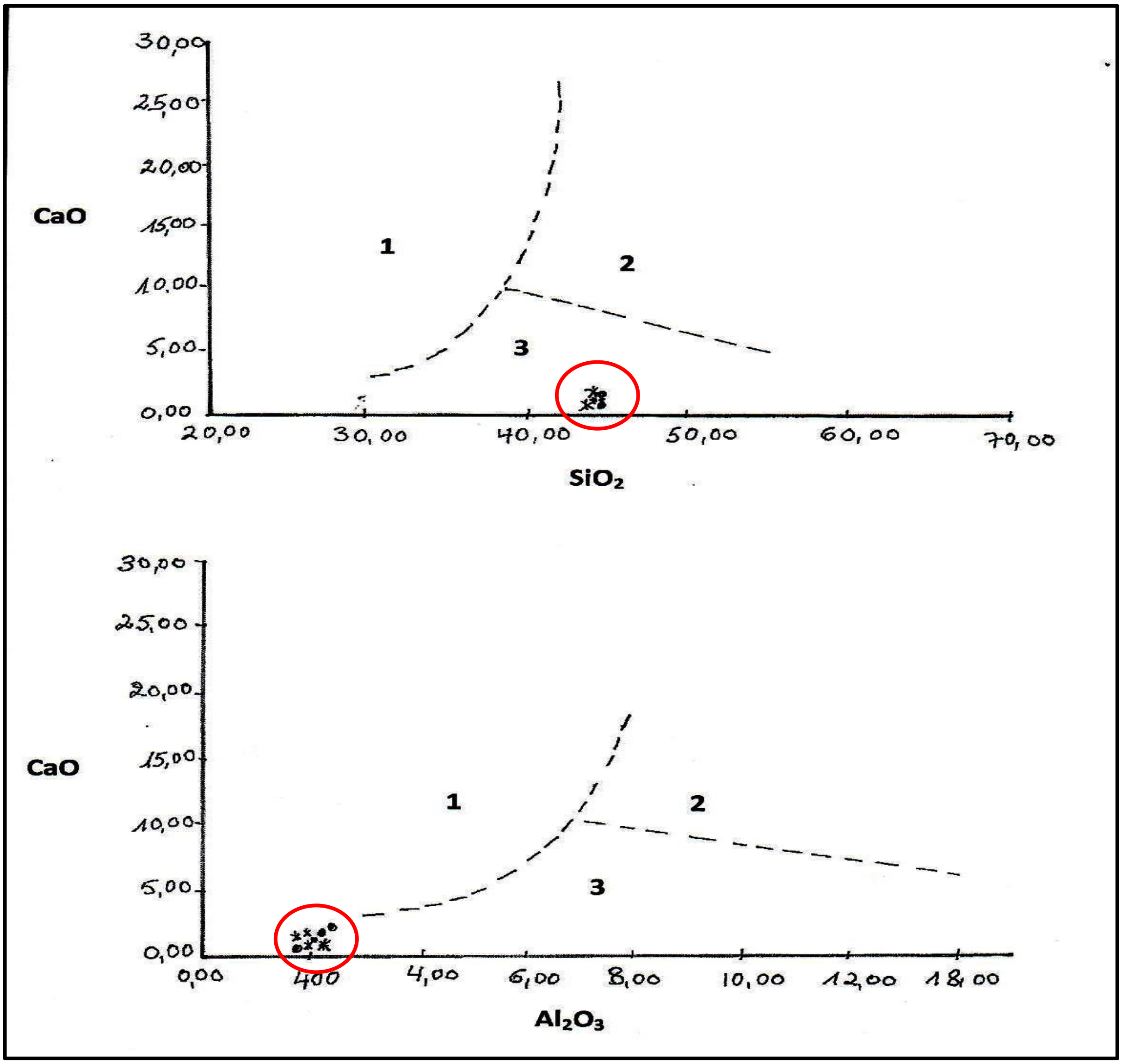

Figure 5. Position of the Bakwanga (*) and Tshibwe (•) kimberlites in the CaO - Al_2O_3 and CaO - SiO_2 diagram distinguishing the potassic/ultrapotassic rock domains from that of the kimberlites (Kampata, 1993).

1. kimberlites estate
2. lamprophyre domain
3. Lamproite domain

4.1. Petrological interpretation of North Group and South Group kimberlites

Based on the various parameters of kimberlite geochemistry mentioned above and different contents of major elements (SiO_2, H_2O+CO_2, MgO, Fe_2O_3, K_2O, Na_2O, CaO, TiO_2, Al_2O_3, P_2O_5, CuO) and trace elements, the classification standards for rocks characteristic of hyperpotassic magmatism ($K_2O>Na_2O$,

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K_2O>3% and the K_2O/Na_2O > 3% ratio, as well as Mitchell's classification (1995)[23,12],we consider that the various samples of two groups of kimberlites from Eastern Kasai analysed are characteristic:

- Ultrabasic magmatism with average silica contents of less than 45% (undersaturated with silica);
- Ultrapotassic magmatism with molar ratios of K_2O/Al_2O_3>3%;
- Mafic magmatism (not ultramafic) with average MgO contents of less than 12% in two groups. These low MgO contents are therefore due to the elimination of magnesia following the pronounced alteration of these rocks;
- Projected in the SiO_2 - Al_2O_3 diagram, the Bakwanga and Tshibwe kimberlites are crustally altered and contaminated kimberlites;
- Hyperalkaline potassic magmatism with K_2O contents and K_2O/Na_2O ratios of over 3% in all samples;
- Explosive magmatism with very high H_2O and CO_2 contents (volatile elements at 110°), which would explain their emplacement in the form of diatremes or dykes;
- magmatism in intra-continental plate zones characteristic of the Lamproite group (alkaline effusive magmatic rock particularly rich in potassium, with sanidine and/or leucite and black mica of the phlogopite type) or Orangéites of group 2 (ultrapotassic, rich in volatiles, particularly H_2O).

4.2. Other considerations

4.2.1. Lithostratigraphy:

- Generally speaking, apart from the Bakwanga kimberlites, limestone, dolomite, sandstone and sand, three kimberlitic facies have been identified based on the percentage of kimberlitic elements. These are :
  - Very soft epiclastic kimberlite (0-25% kimberlite elements),
  - Loosely consolidated Xenokimberlite (25-50% kimberlitic elements),
  - Massive kimberlite (over 75% kimberlitic elements),
  - The host rock is essentially hard limestone.

- The Tshibwe kimberlite massif has a structure made :
  - A sandy-clay cover,
  - A gravelly layer,
  - A cap of kimberlitic breccia and sandstone xenoliths, eclogitic granitic and gabbronoritic;
  - A shaft extending over 200m according to the 12 descriptive boreholes and 54 core holes drilled by SACIM. It is steeply inclined up to 70°. Its essential composition is Kimberlitic. We have :
    - ✓ Hard grey kimberlite with little sandstone inclusion;
    - ✓ Greenish red sandstone kimberlite (hard or soft chocolate);
    - ✓ Clay xenoliths;
    - ✓ Reddish kimberlite sandstone;
    - ✓ Eclogites and,
    - ✓ Gabbroritic sandstones.

4.2.2. The bedrock is essentially sandstone

From what can be seen, the kimberlite massifs of the southern group contain much less sedimentary xenoliths and in which limestone and dolomite are particularly absent than in the kimberlites of the northern group (this difference is linked to the lithology of the host rock). Gabbro-dioritic xenoliths are

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more abundant in the southern group than in the northern. Finally, xenoliths from basement rocks are more abundant and dominant in the north than in the south [24,11, 25]

CONCLUSIONS

The Kimberlitic formations studied (Bakwanga and Tshibwe Kimberlite) are all characteristic of ultrabasic magmatism (or magmatism under-saturated in silica), mafic and not ultramafic, hyperalkaline, ultrapotassic, rich in volatiles (H_2O and CO_2), of the lamproite or orangite group showing clear crustal alteration or contamination and having their source in the upper mantle.
These two groups differ in terms of the lithology of the host rock (limestone and/or dolomite for the northern group and sandstone for the southern group). In terms of the proportion of xenoliths in the respective kimberlites, there is a total absence of sedimentary xenoliths, particularly limestone and dolomite, and incidentally sandstone in the southern kimberlites. Gabbro-dioritic xenoliths are more abundant in the southern group than in the north, and xenoliths from basement rocks are more abundant and dominant in the north than in the south.

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