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RESEARCH ARTICLE

STREAM SEDIMENT CARTOGRAPHY OF KIMBERLITE OCCURRENCES IN KIMPANGU AND ITS SURROUNDINGS (CENTRAL KONGO, DEMOCRATIC REPUBLIC OF THE CONGO) USING GEOCHEMICAL SIGNATURES OF HEAVY MINERALS

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ABSTRACT

Microscopic analysis and interpretation of the geochemical signatures of heavy minerals collected during stream sediment execution in the Kimpangu agglomeration and surrounding area have revealed the existence of four mineralogical families: ilmenites, garnets, spinels and pyroxenes. The geochemical signatures of these minerals confirm that they belong to Lherzolitic and pyroxenitic enclaves for the first three families, and to continental enclaves for pyroxenes. These mantle and crustal enclaves were eroded by kimberlitic magma, the two intrusions of which are located at Mbanza Yanga and south of Kimpangu.

KEYWORDS

Enclaves, Garnets, Ilmenites, Lamproite, Kimberlite, Pyroxenes, Spinels, Stream sediment.

1. INTRODUCTION

Kimpangu, an extra-customary center located south of the town of Mbanza-Ngungu, in the province of Kongo Central (Figure 1), lies between 14°58'00'' and 15°04'00'' East longitude and between 05°44'00'' and 05°52'00'' South latitude.

Alteration of very dense rock masses detected by airborne gravimetry in the sedimentary terrains of the West-Congolian Group overlying the Congo Craton in and around the Kimpangu agglomeration has unearthed heavy mineral grains suggestive of the presence of kimberlite, one of the host rocks for diamonds (Evans, 2004; De Wit, 2006; Michiel et al., 2015). Of crucial industrial importance as a trap for diamond mineralization, these very dense rock masses were described in just a few lines laying the primary foundations for their geological understanding by (Kapapa, 2011). Published data on stable-area volcanism in the Congo Craton are exceptionally scarce, being confined to a small number of kimberlites in Kasai (Congo) and Angola hence the presence of very dense rock masses at Kimpangu remains poorly understood and is thought to be in a developmental stage (Demaiffe et al., 1999).

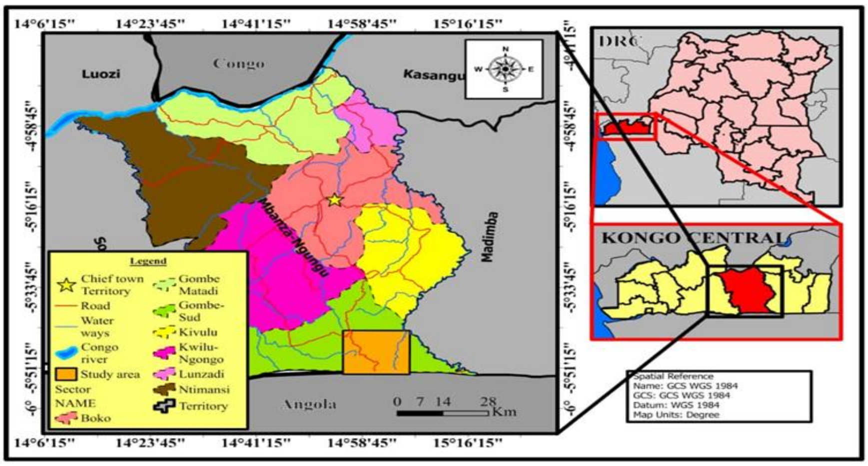

Figure 1: Location of the Kimpangu extra-customary center in the province of Central Kongo.

Abreal (2010) points out that very dense rock masses contain high-pressure, high-temperature xenocrysts stripped from mantle sources their geochemical signatures can help characterize the lithological nature of very dense rock masses(Fesq, 1976; Sobolev et al., 1971; Mvuemba,

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1982; Meyer, 1987; Gurney, 1989; Kampata, 1993; Morgan, 1995; Field and Smith, 1998; Abreal, 2010). Although these heavy mineral grains harvested from an environment are not endemic to kimberlites, lamproites, carbonatites and komatites, they still provide specific geochemical information on the lithological nature of the parent rock and its associates. And as Marchand (2005) argues, geologists are successfully exploiting heavy mineral associations as tracers to investigate and identify the lithological nature of very dense rock masses predisposed to rapid weathering.

Thus, in the present study, the main problem is to delimit the outcrop areas of these very dense rock masses and to characterize their lithological nature by comparing the geochemical signatures of Kimpangu heavy minerals with those of kimberlitic and lamproitic rocks recognized worldwide.

2. Geological Context

The main stratigraphic assemblages (Figure 2) recognized in Central Kongo are:

- The supra-crustal formations of the 2,1 Ga Boma-Tombagadio migmatitic and gneissic complex (Cahen, 1978; Cibambula, 2016);

Cover formations (De Ploey et al., 1968; Tack et al., 2001; Cailteux et al., 2015; Delpomdor et al., 2015; Cibambula, 2016) represented by the West-Congo Supergroup (Neoproterozoic-Lower Paleozoic) subdivided into three groups, from bottom to top: the Zadinian Group, the Mayumbian Group and the West-Congolian Group; the Inkisi Formation (Devonian); the Coastal Sedimentary Group (Meso-Cenozoic) and the Kalahari Group (Paleogene-Neogene).

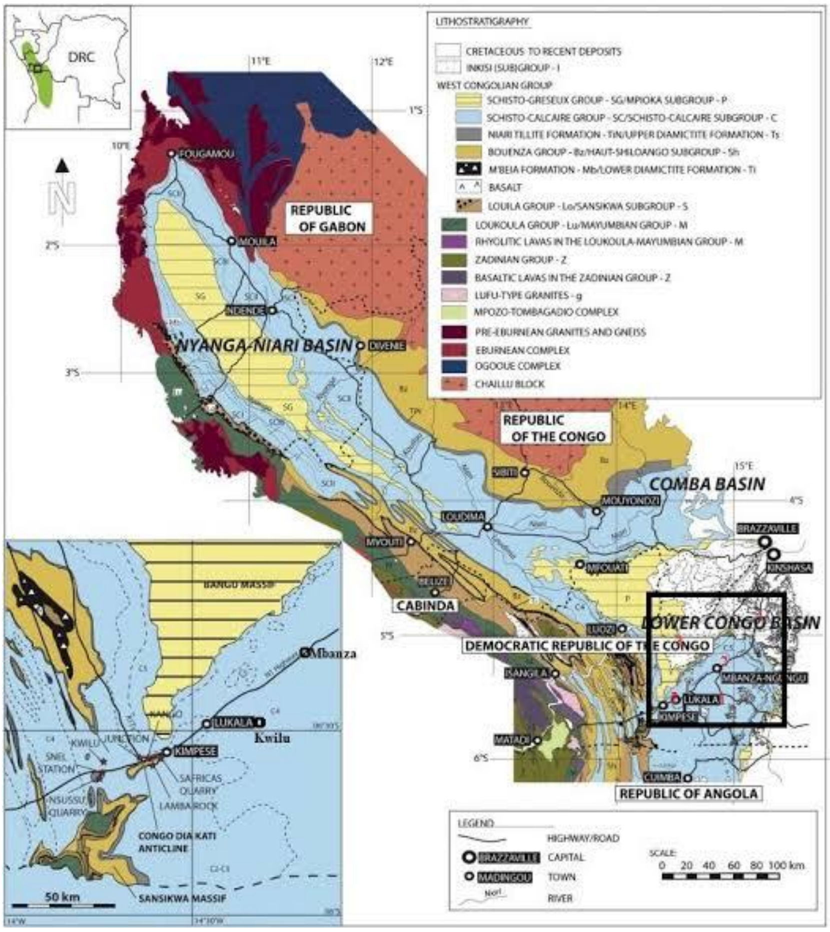

Figure 2 : Carte géologique du Kongo Central (Lepersonne, 1973).

The lithostratigraphic column of the Kimpangu area includes, from the oldest to the most recent, the following tabular units:

- The West Congolian Group represented by the Schisto-Calcareous Subgroup composed of shales, calcareous shales, massive clayey and sometimes dolomitic limestones with numerous cherty intercalations of the Lukunga Formation;

- The Kalahari Group, represented by the more or less clayey siliceous sandstone beds of the Polymorph Sandstone Formation and the barely consolidated sands of the Ochre Sand Formation.

3. Methodology

3.1 Field Data

In the field, De Beers' delineation of the Kimpangu very dense rock mass alteration zone, based on gravity data acquired and interpreted by the Initiative for the Geological Exploration of Congo in 2022, has enabled us to envisage three sampling axes: the Kilombo II - Kimbele Yanga axis; the Mbanza Bangu - Ngongo axis and the Vululu - Kivindu axis (Figure 4). Along these axes, stream sediment prospecting with a view to going back to the alluvium feeding areas, took place from downstream to upstream of permanent or temporary watercourses whose flow direction is identified using the Silva brand geologists' compass. At each station, 10 liters of alluvium collected using a shovel are stripped of their clay fraction in a 4 mm mesh sieve driven by a rotating movement under a jet of water. The bystanders collected in a plastic basin are placed in a bag labelled with a serial number preceded by the initials KP, the name of the Kimpangu extra-customary center.

3.2 Laboratory Data

In the laboratory, the concentration of heavy minerals, after rinsing in distilled water and drying in an oven at a temperature between 23 and 250°C, consisted of sieving on a column of 2 mm, 1 mm and 500 µm sieves at the Sedimentology and Surficial Geology Laboratory of the Geosciences Department of the University of Kinshasa. On fractions ranging from 2 to 1 mm, heavy minerals were distinguished by manual sorting under a Leica EZ4D binocular loupe with X8 magnification. For fractions less than 1mm in diameter, sorting was carried out by densimetry using a gravimetric separator. For each mineralogical fraction, oxides of major elements were determined using a Cameca CAMEBAX electron microprobe equipped with four vertical dispersion wavelength spectrometers (WDS) using ZA correction routines at the Geochemistry Laboratory, University of Cape Town, South Africa. Detection limits for most oxides are below 0,08% by weight, but below 0.04% for SiO_2, $Al2O_3$, MgO and CaO. Exceptions are detection limits of 0,11 wt.% for $Cr2O3$, MnO and NiO in some mineral phases.

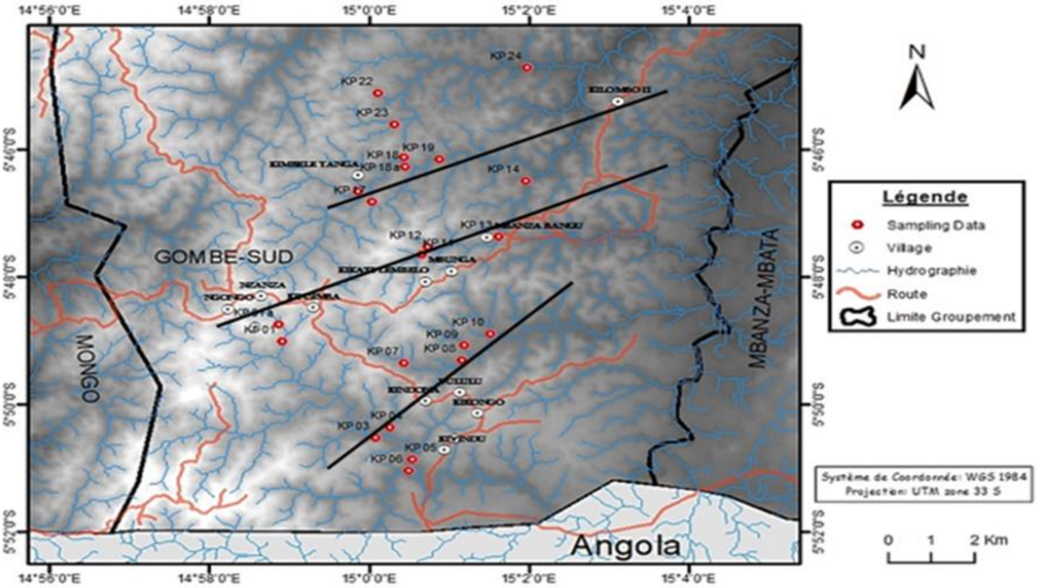

Figure 4: Heavy mineral sampling map.

4. Results

These results are based on microscopic and geochemical analysis.

4.1 Microscopic Analysis

Microscopic observations (Figure 5) of the heavy minerals collected in the vicinity of the Kimpangu extra-customary center have identified four mineralogical fractions:

a) Garnets

Easily identified by their vitreous luster, two populations are discernible: one translucent and the other opaque. Translucent garnets with smooth to indented rims (KP03, KP04, KP06, KP07, KP08, KP22, KP24, KP23) are red, orange, light gray, pinkish and yellow. In contrast, the opaque olive, khaki, dark beige and blackish varieties sometimes show square (KP07), pentagonal (KP24) or trapezoidal (KP04) faces, and are subrounded with smooth edges.

b) Chromites

Black to black-brown in color with a greasy, matte or submetallic luster, the opaque, elongated chromite grains also show two populations: one angular to subangular with indented edges (KP03, KP04, KP06, KP22, KP23 and KP24) and the other subrounded with smooth edges (KP05).

c) Ilmenites

With their metallic luster and black color, opaque ilmenite grains are also grouped into two populations: one with subrounded, opaque, beige garnet inclusions (KP24); the other angular, subangular to subrounded with indented edges (KP03, KP04, KP05, KP06, KP07, KP08, KP22, KP23).

d) Pyroxenes

Dark brown with indented edges, the two grains encountered are opaque (KP03 and KP04) and have rectangular shapes with two cleavage planes forming an angle of around 90°.

4.2 Geochemical Analysis

Tables 1, 2, 3 and 4 show the contents by weight of major element oxides for each of the mineral fractions described above.

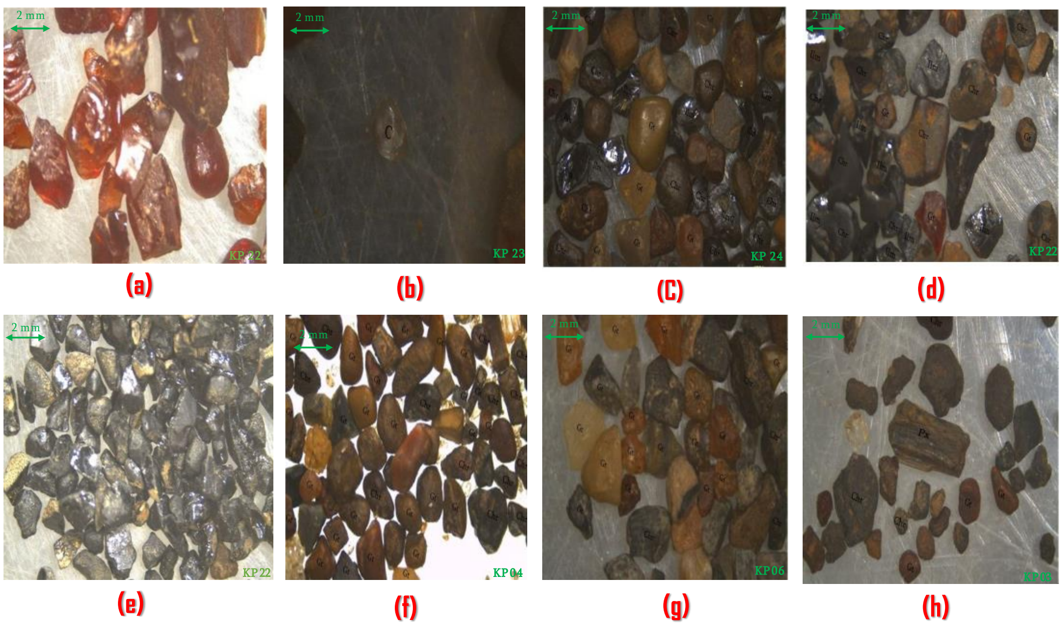

Figure 5: Microscopic views of heavy mineral concentrates. (a) Translucent red garnet grains with vitreous luster. (b) Diamond grain with adamantine luster. (c) Garnet grains (gt) with olive, orange, yellow and light-gray colors; black chromite (chr) and black ilmenite (ilm). (d) Pompenian red and dark beige garnet (gt) grains; black ilmenite (ilm); and black-brown chromite (chr). (e) Subangular grains of ilmenite (ilm) with metallic luster. (f) Beige, pink, yellow and black garnet (gt), dark-brown pyroxene (px) and black chromite grains. (g) Grains of pink, yellow, light grey and orange garnet (gt) and black chromite (chr). (h) Grain of dark-brown pyroxene (px); beige garnet (gt) and black chromite (chr).

Table 1: Weight content of major element oxides in garnets.

Samples/Lot#	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeOt	MnO	MgO	CaO	Na_2O	K_2O	Total
KP03	*41,10*	*0,23*	*21,64*	*1,96*	*10,10*	*0,59*	*18,84*	*5,07*	*0,03*	*0,001*	*99,56*
KP04	*37,59*	*0,09*	*20,34*	*0,01*	*28,69*	*1,09*	*6,94*	*1,94*	*0,01*	*0,001*	*96,70*
KP06	*41,63*	*0,08*	*20,18*	*5,16*	*7,96*	*0,43*	*19,58*	*3,99*	*0,02*	*0,001*	*99,03*
KP07	*42,70*	*0,81*	*21,50*	*1,48*	*6,81*	*0,30*	*20,80*	*4,84*	*0,05*	*0,001*	*99,29*
KP08	*42,30*	*0,81*	*20,90*	*0,95*	*9,43*	*0,31*	*20,50*	*4,64*	*0,08*	*0,001*	*99,92*
KP22	*41,25*	*0,15*	*21,34*	*2,80*	*10,19*	*0,62*	*18,95*	*4,08*	*0,02*	*0,001*	*99,40*
KP24	*40,61*	*0,24*	*18,07*	*6,85*	*8,94*	*0,48*	*18,95*	*5,66*	*0,01*	*0,001*	*99,81*
KP23	*41,44*	*0,19*	*20,92*	*3,31*	*9,02*	*0,21*	*19,36*	*5,15*	*0,02*	*0,001*	*99,62*

Table 2: Weight content of chromite major element oxides.

Sample/Lot #	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeOt	V_2O_3	MnO	MgO	ZnO	Total
KP22	*0,23*	*7,81*	*6,45*	*40,31*	*32,14*	*0,26*	*0,32*	*11,54*	*0,01*	*99,07*
KP22	*0,29*	*8,19*	*9,23*	*42,12*	*30,41*	*0,22*	*0,01*	*9,20*	*0,05*	*99,72*
KP22	*0,15*	*7,30*	*6,53*	*41,26*	*31,61*	*0,20*	*0,35*	*11,75*	*0,06*	*99,21*
KP23	*0,01*	*1,64*	*11,13*	*50,43*	*23,80*	*0,22*	*0,22*	*8,47*	*0,12*	*96,04*
KP23	*0,03*	*1,99*	*21,25*	*45,99*	*9,23*	*0,26*	*0,23*	*19,20*	*0,06*	*98,24*
KP23	*0,10*	*0,56*	*7,54*	*58,07*	*18,86*	*0,11*	*0,22*	*11,61*	*0,01*	*97,08*
KP05	*0,01*	*1,61*	*11,27*	*49,64*	*24,04*	*0,23*	*0,25*	*10,14*	*0,08*	*97,27*
KP05	*0,38*	*1,28*	*11,30*	*50,98*	*20,39*	*0,13*	*0,18*	*12,29*	*0,05*	*96,98*
KP05	*0,44*	*0,31*	*12,017*	*52,82*	*18,84*	*0,13*	*0,15*	*11,90*	*0,01*	*96,62*

Table 3: Weight content of ilmenite major element oxides.

Sample/Lot #	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeOt	MnO	MgO	CaO	Nb_2O_5	NiO	V_2O_3	Total
KP05	*0,001*	*50,96*	*0,47*	*0,67*	*35,52*	*0,33*	*9,10*	*0,03*	*0,05*	*0,02*	*0,07*	*98,13*
KP03	*0,001*	*50,16*	*0,52*	*0,07*	*37,31*	*0,28*	*9,24*	*0,03*	*0,06*	*0,060*	*0,14*	*97,89*
KP06	*0,001*	*49,04*	*0,52*	*0,01*	*38,34*	*0,25*	*9,21*	*0,02*	*0,13*	*0,05*	*0,20*	*97,77*
KP07	*0,001*	*48,93*	*0,84*	*5,63*	*31,60*	*0,21*	*10,23*	*0,01*	*0,03*	*0,15*	*0,18*	*97,83*
KP08	*0,001*	*49,72*	*0,41*	*0,10*	*36,74*	*0,30*	*9,40*	*0,02*	*0,12*	*0,05*	*0,20*	*97,06*
KP22	*0,001*	*52,87*	*0,50*	*0,92*	*30,24*	*0,94*	*11,35*	*0,02*	*0,11*	*0,07*	*0,15*	*97,19*
KP23	0,001	54,14	0,56	1,53	29,05	0,47	12,06	0,03	0,10	0,10	0,07	98,12

Table 4: Pyroxene major element oxide content by weight.

Sample/Lot #	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeOt	MnO	MgO	CaO	Na_2O	Total
KP03	40,68	1	15,84	8,38	3,16	3,30	0,29	20,88	6,04	97,57
KP04	40,87	0,92	15,74	8,6	2,52	3,98	0,27	20,55	6,1	99,55

5. Discussion and Interpretation

5.1 Lithology of The Recharge Area

For each of the heavy minerals collected, the lithology of the probable source rocks is constrained by geochemical signatures and the various variation and/or classification diagrams proposed by Coleman (1956), Fikpe et al. (1995), Mitchell (1995), Morimoto (1998), Grutter (2004), Morris (2002) and Wyatt et al. (2004).

a) For garnets

The most widely used tracers in kimberlite research campaigns (Abréal, 2010), the projection of Kimpangu garnets in Coleman's (1965) Mg-Fe-Ca ternary diagram (Figure 6A) shows them to be pyrope-type pyralspites with MgO contents ranging from 2, 39 to 21.10% (KP04, KP06, KP07, KP08, KP 22, KP23 and KP24) and almandine with FeO contents of 10 to 28% (KP03, KP04, KP06, KP22, KP23, KP24). In general, these minerals are frequently found in micaschists, eclogites, gneisses, peridotites and kimberlites. In the latter, garnets are, according to Schulze (2003), xenocrysts contained in enclaves of peridotites, pyroxenites and eclogites torn out by kimberlite or lamproite magmas as they ascend through the lithosphere. However, the projection of these pyralspites in the Cr_2O_3 versus CaO variation diagram (Figure 6B) proposed by Grutter (2004) indicates that the lithosphere in the Kimpangu area is essentially lherzolitic and to a lesser extent pyroxenitic and eclogitic. Subchromic grains with low CaO contents indicate that magmas have also torn fragments of rock from the continental crust (Sobolev, 1971; Mitchell, 1986; Canil and Wei, 1992; Mitchell, 1995; Griffin et al., 1999; Schulze, 2003; Doyle et al., 2004; Grütter et al., 2006; Abreal, 2010). As for subcalcic chromiferous garnets, which are very rare in the Kimpangu area, they may come from Harzburgite enclaves whose debris is transported from Angola to the Kimpangu area by the Mfulezi River.

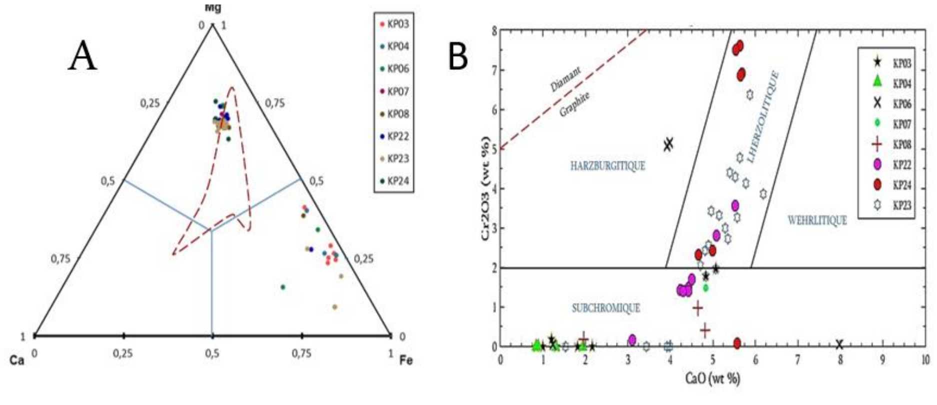

Figure 6: Geochemical characterization of garnets collected in the Kimpangu area according to the classification diagram (a) of Coleman (1965) and the variation diagram (b) of Gurney and Moore (1993) modified by Grutter (2004).

b) For ilmenites

The two ilmenite varieties collected in the vicinity of the Kimpangu extra-cumulative center are picroilmenites with MgO contents ranging from 6 to 12% (KP03, KP04, KP05, KP06, KP07, KP08, KP22, KP23, KP24), with the exception of sample KP04, which contains pyrophanites with Mn contents ranging from 39 to 47%. In nature, picroilmenites are frequently found in kimberlites, lamproites and peridotites, while pyrophanites are found in granites, amphibolites and serpentinites. Constraining these source rocks using the TiO_2 versus MgO variation diagram (Figure 7a) of Wyatt et al. (2004), the picroilmenites are kimberlites and the pyrophanites are probably serpentinites. Due to their angular shape, pyrophanite grains are much more closely related to serpentinites produced by the alteration of nearby kimberlite than to the granites and amphibolites non-existent in the Kimpangu area (Wyatt, 2004; Marchand, 2005; Lafrance, 2006; Ashchepkov, 2013; Ene, 2014). This pyrophanite reaction origin supports, according to the ternary diagram (Figure 6b) of Mitchell (1995), the primary origin of picroilmenites by fractional crystallization of a kimberlitic magma.

c) For spinels

The grains harvested in the vicinity of the Kimpangu extra-customary center are picotites. Their nature is confirmed by Cr_2O_3 contents ranging from 40 to 61% (Table 2). Constituting ultrabasic rocks, they are found, according to the Cr_2O_3 versus TiO_2 variation diagram (Figure 8) by Fipke et al. (1995), in kimberlites and/or lamproites for certain grains in samples KP22 and KP23. On the other hand, other grains in these samples, and all those in sample KP05, belong to the non-discriminating domain typical of peridotitic xenocrysts (Harte and Gurney 1981; Marchand, 2005; Lafrance, 2006; Lenaz et al., 2009).

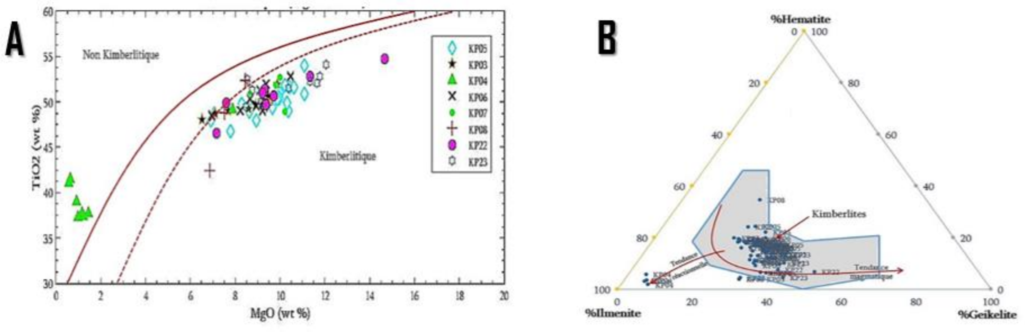

Figure 7: Geochemical characterization of ilmenites collected in the Kimpangu area according to the variation diagram (a) of Wyatt et al. (2004) and the ternary diagram (b) of Mitchell (1995) contrasting ilmenite-geikilite-hematite.

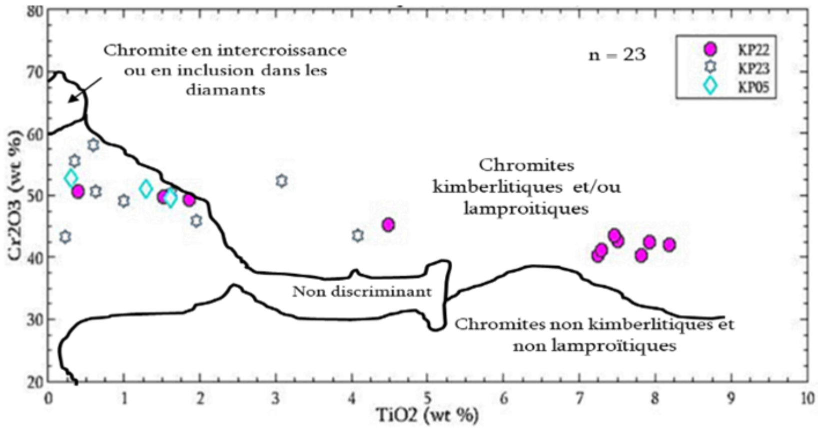

Figure 8 : Cr_2O_3 versus TiO_2 diagram (Fipke et al., 1995).

d) For pyroxenes

These are wollastonites with Fe_2O_3 contents of between 2% and 3% (Figure 9a). Their projection in the Cr-Al-Na ternary diagram (Figure 9b) by Morris (2002) rules out a kimberlitic source. Their origin is thought to result from the metamorphism of silicate carbonate rocks (Nimis, 1998; Morris et al., 2002; Quirt, 2004).

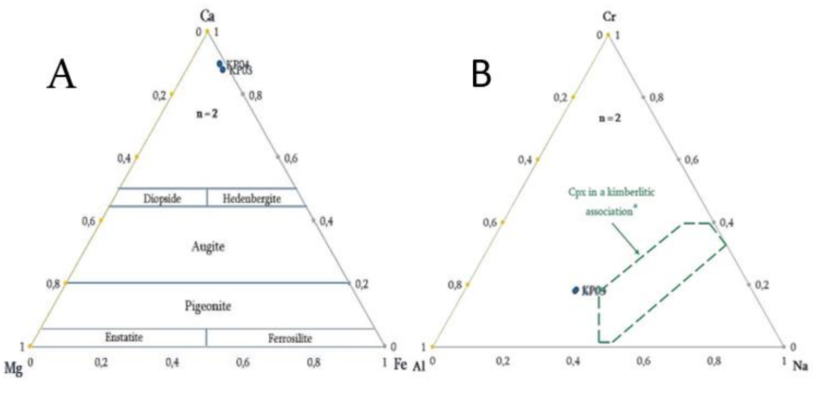

Figure 9: Geochemical characterization of pyroxenes collected in the Kimpangu area using the classification diagram (a) by Morimoto (1998) and the ternary diagram (b) by Morris (2002).

5.2 Location of Feeding Areas

The existence of two mineralogical populations among garnet grains suggests the occurrence of different types of lherzolitic or pyroxenitic enclaves: some pyrope magnesiferous and others almandine ferriferous. But given the ionic radius gap of 0,08 between Mg^{2+} and Fe^{2+}, the

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substitution of pyrope for almandine as well as their coexistence within lherzolitic and pyroxenitic enclaves is therefore possible (Gurney, 1984; Mitchell, 1986; McCandless et al.,1989; Aubouin et al., 1993; Mitchell, 1995; Brey, 1991; Digonnet, 1997; Bell and Moore, 2004; Chepurov et al., 2013; Hill, 2015; Ivanic, 2016). With regard to the two ilmenite varieties, we support the presence of pyrophanite serpentinite by alteration of picroilmenite kimberlite. In the case of chromites, the kimberlitic source is unique, despite the peridotitic nature of their enclaves. Of all these heavy minerals, only the wollastonites have a deep continental origin. The increase in size and decrease in angularity of heavy mineral grains from Vululu to Kivindu and from Kilombo II to Mbanza Yanga indicate the existence of two feeding areas (Figure 10): one in the locality of Mbanza Yanga and the other to the south of Kimpangu. The location of these feeder areas around Kimpangu rules out the origin of the heavy minerals in the regional source rocks of the Kasai-Angola cratonic block, linking them solely to the densely altered rock masses in the foreland of the West Congo chain.

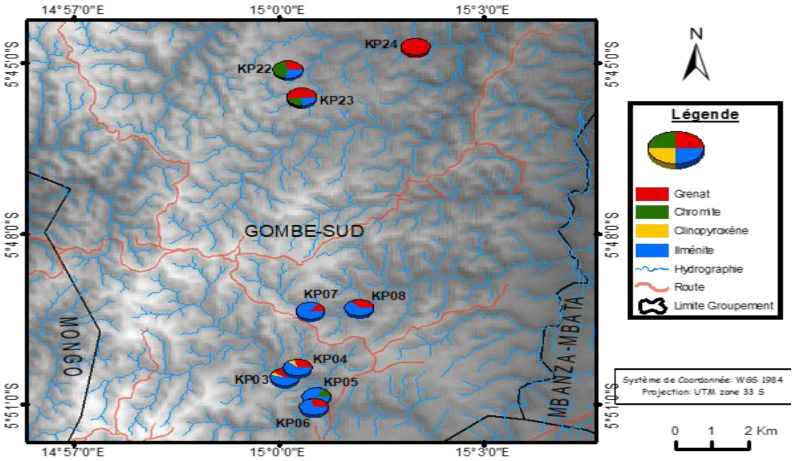

Figure 10: Location of heavy mineral supply areas at Mbanza Yanga (1) and south of Kimpangu (2).

6. Conclusion

In conclusion, the very dense Kimpangu rock masses contain lherzolitic and pyroxenitic mantle enclaves, highlighted by the geochemical signatures of garnet and chromite, as well as those of the continental crust constrained by wollastonite chemistry. The picroilmenites are evidence of the kimberlitic magma that brought these enclaves with it during its ascent, whose serpentinization generated pyrophanites. The intrusions of this kimberlitic magma are, as demonstrated by the granulometric increase and morphoscopic variation of all these detrital minerals, located one at Mbanza Yanga and the other south of Kimpangu.

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