Bulletin de la Société belge de Géologie Bulletin van de Belgische Vereniging voor Geologie	101/1-2	pp 9-39	Bruxelles Brussel	Ed.1993

DIAMOND IN ITS PRIMARY ROCKS WITH SPECIAL REFERENCE TO THE DIAMOND DEPOSITS OF MBUJIMAYI, EAST KASAI, ZAIRE

by

Mark R. FIEREMANS [1] *& Carlos L. FIEREMANS* [2] [3]

ABSTRACT

Although the first diamond of Kasai (Zaire) was found already in 1907, one wil have to wait until 1946 before a kimberlite could be localized.

The diamond deposits of Mbujimayi (East Kasai) are subdivided into :

- primary deposits in rocks belonging to the kimberlite clan;
- secondary deposits, detrital formations, in gravels, the most ancient of which are represented by red argillaceous sandy deposits, with kaolien nodules, and the youngest by the actual river gravels.

The kimberlitic formations of Mbujimayi are described with, as "background", the most recent scientific data available as to the the kimberlite - and lamproite - clans of rocks.

A review is thus given of the geological situation of the intrusions, in addition to the petrography and geochemistry of the rocks, whose facies points to a crater and/or diatreme facies (epiclastic and/or pyroclastic breccias and tuffs).

The lower crust and mantle xenoliths are essentially eclogites, whilst, between the megracrysts, the intergrowths rutile-silicate deserve to be mentioned particularly.

The inclusions in the Kasai diamonds, which seem to indicate a peridotitic paragenesis, are also the subject of a detailed description.

A review of the Mbujimayi diamond deposits would not be complete without referring to the prospection methods and to the methods of reserve evaluation, influenced by the erratic character of the deposits (karst topography !) and the high grades. Mining and treatment methods are also reviewed.

RESUME

Si le premier diamant du Kasaï (Zaïre) fut trouvé en 1907, on devra attendre 1946 avant qu'une kimberlite n'y soit localisée.

Les dépôts de diamant de Mbujimayi (Kasaï oriental) sont subdivisés en:

- dépôts primaires dans des roches de la famille des kimberlites;
- dépôts secondaires, détritiques, dans des formations graveleuses, dont les plus

---

[1] Miba-Mbujimayi.

[2] Hofveld 20 - B-1730 Asse.

[3] paper based on communication presented at Diamond Symposium, Antwerp, 24.11.1989.

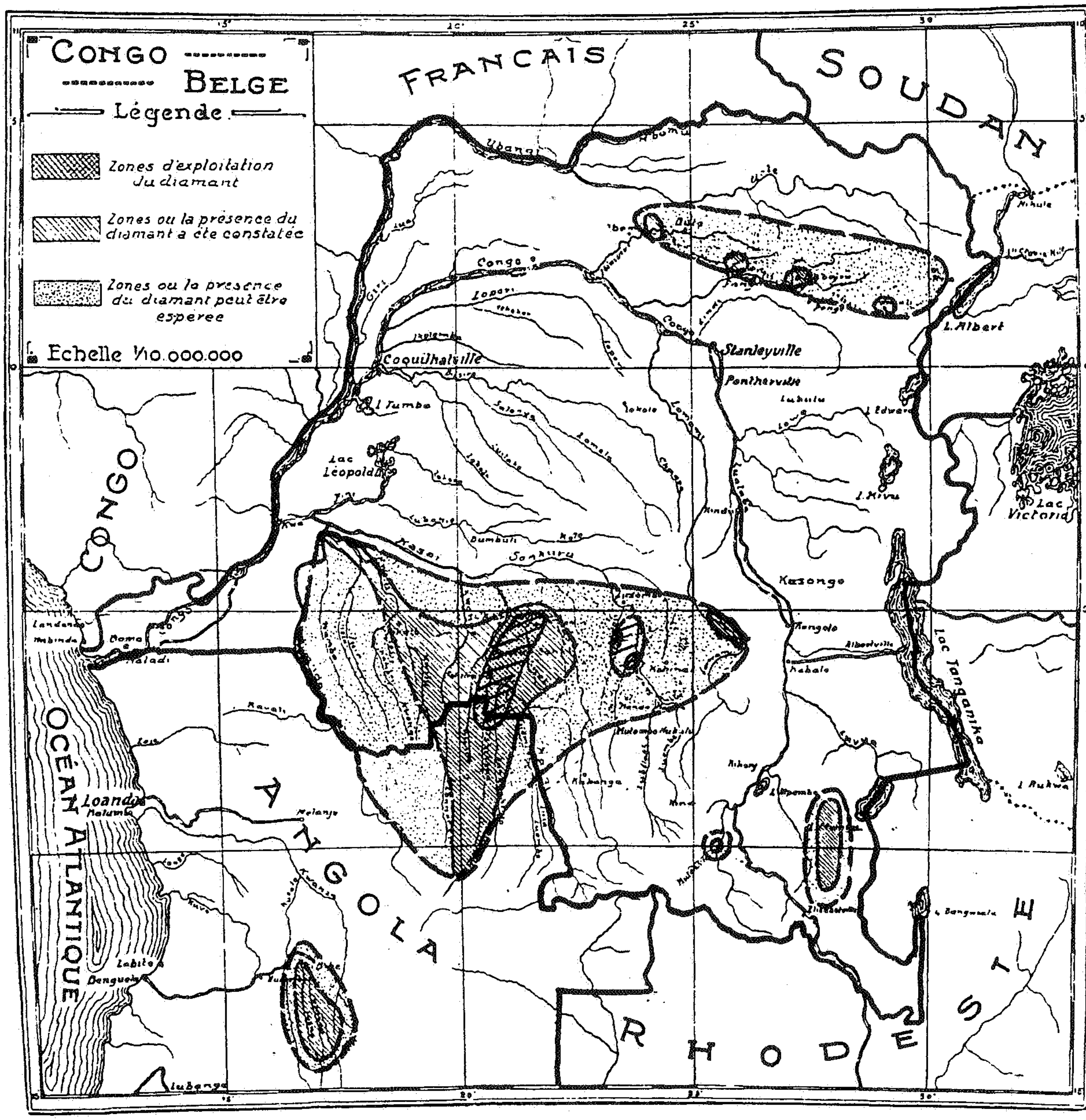

Figure 1: The diamond fields of Zaire. Reproduction of the map published by H. de Rauw in 1923.

anciennes sont représentées par des dépôts sablo-argileux rouges à boules de kaolin, et les plus jeunes par les graviers de la rivière.

Les formations kimberlitiques de Mbujimayi sont décrites avec, comme "toile de fond", les données scientifiques les plus récentes à notre disposition sur les clans des kimberlites et des lamproïtes.

Un aperçu est ainsi donné de la situation géologique des intrusions, ainsi que de la pétrographie et de la géochimie des roches dont le faciès est un faciès de cratère et/ou de diatrème (brèches et tuffs épiclastiques et/ou pyroclastiques).

Les xénolithes en provenance de la croûte terrestre inférieure ou du manteau sont essentiellement des éclogites, tandis que parmi les mégacristaux, les symplectites rutile-silicate méritent une attention particulière.

Les inclusions dans les diamants du Kasaï, qui semblent désigner une paragenèse

péridotitique, font également l'objet d'une mention détaillée.

Une description des dépôts diamantifères de Mbujimayi ne serait pas complète si l'on ne mentionait pas les méthodes de prospection et d'évaluation des réserves, influencées par le caractère erratique des dépôts (topographie karstique !) et par les teneurs élevées. Les méthodes d'exploitation et de traitement sont également décrites.

SAMENVATTING

Alhoewel de eerste diamant in de Kasai provincie (Zaire) gevonden werd in 1907 zal men moeten wachten tot 1946 vooraleer een kimberliet werd gelokalizeerd.

De diamantafzettingen van Mbujimayi (Oost-Kasai) kunnen gerangschikt worden als volgt:

- primaire afzettingen in rotsen van de familie van kimberlieten;
- secundaire afzettingen, detrietische formaties in grinten waarvan de oudste vertegenwordigd zijn door rood kleiachtig - zand formaties met kaolin - knollen en de jongste door de actuele rivier-grinten.

De kimberliet-formaties van Mbujimayi worden beschreven met als achtergrond de actueel beschikbare wetenschappelijke informatie over de kimberliet en lamproiet-clans.

Een overzicht van de meest recente gegevens beschikbaar over de Mbujimayi-kimberlieten laat toe de aandacht te trekken op de specifieke intrusie - vormen alsmede op de petrografische structuur die toelaat deze formaties te beschrijven als xeno-tuf-breksies, van het diatreem en krater-facies (epiclastica en pyroclastica).

De aandacht gaat ook naar de xenolieten, hoofdzakelijk eclogieten, en de megacrysten met de uitzonderlijke rutiel-silicaat vergroeiingen.

Een gedeelte word gewijd aan de recente geochemische gegevens alsook aan de inclusies in de diamanten die schijnen te wijzen op een peridotietische paragenese.

Een overzicht van de diamant-afzettingen van Mbujimayi zou niet volledig zijn zonder te wijzen op de prospectiemethodes en de methodes van evaluatie van de reserves die wel beinvloed worden door het erratische karakter van de afzettingen (karst-topografie !) en de hoge gehaltes. Ook de ontginnings- en verwerkings methodes worden beschreven.

KEY WORDS

Diamond, deposits, kimberlite, Mbujimayi, mining, treatment.

MOTS-CLES

Diamant, dépôts, kimberlite, Mbujimayi, exploitation, traitement.

SLEUTELWOORDEN

Diamant, afzettingen, kimberliet, Mbujimayi, ontginning, verwerking.

1. INTRODUCTION

This publication gives an account of the current status of knowledge about the diamond deposits of Eastern Kasai in Zaire, together with some general information on kimberlites and lamproites. It was our aim to review earlier articles and to include some unpublished data.

Diamonds are found in Zaire over wide areas, scattered throughout the country. Although only one official diamond mining company exists (the "Minière of Bakwanga" or MIBA, located in East Kasai province), a lot of small concessions and illicit miners contribute an even more important part of the total annual production of diamonds in Zaire: in 1988, MIBA exported 8.091.769 carats, whilst the "parallel" production was estimated at 14 million carats.

The first diamonds in Zaire were found in the beginning of the century (1903 - Mutendele - Shaba). For the majority of the occurrences, the ultimate origin of the diamonds is actually known; nevertheless, the origin of some sporadic, though sometimes systematic occurrences (for example at Aruwimi-Ituri area, Maniema area, etc..) still remains "enigmatic". The origin of these diamonds is often difficult to determine: diamond indeed, due to its great hardness and chemical resistance can withstand movements over great distances either by water, in the gravels of actual rivers or old conglomerates - eventually by sea in coastal deposits -, either by wind, in eolian desert sands. While its original associated minerals may be destroyed early, diamond may resist different successive transport-cycles, and every direct connection with its place of origin may thus be wiped out.

But even in its rock of origin - kimberlite, lamproite - diamond remains a strange mineral and even today it is not really known where it has crystallized. Even the age of crystallization of diamonds is controversial and one of the most outstanding facts that has been gathered about diamonds in the last decennium is that diamonds can be much older than their primary host rocks. This was first mentioned by Kramers (1977) in a study of sulfide inclusions in diamonds of Finsch, Kimberley and Premier Mine. Ages of 3.000-3.300 m.y. were later on determined by Richardson *et al.* (1984) on inclusions of peridotitic garnet in diamonds from Finsch and Kimberley whilst the kimberlitic eruptions only date back to 90 m.y.

An exhaustive description of the inclusions in diamonds was given by Meyer (1987). Especially mentioned are olivine, garnet, pyroxene, spinel and sulfides. On the basis of their chemical composition they were subdivided into two main groups: an ultramafic group and an eclogitic group. Tentatively, a subordinate group was added by Meyer (1987): a calc-silicate or grospydite group, based on the presence of Ca-rich inclusions (garnets and clinopyroxenes) in diamonds from S.E. Australia. These different groups of inclusions reflect the different geochemical environments in which the diamonds were formed.

Recently, Sobolev and Shatsky (1990) suggested that certain (micro-) diamonds found in some alluvial deposits in Northern Australia, revealing strongly negative $\delta^{13}C$ values, may derive from highly metamorphic terranes. These conclusions were based on the occurrence of identical micro-diamonds in metamorphic rocks. As diamonds of eclogitic affinities in kimberlite and lamproite pipes also reveal abnormally negative values of $\delta^{13}C$, Sobolev concludes that the carbon was derived from recycled crust. This also implicates that some diamonds may thus have an even more complicated history than originally thought.

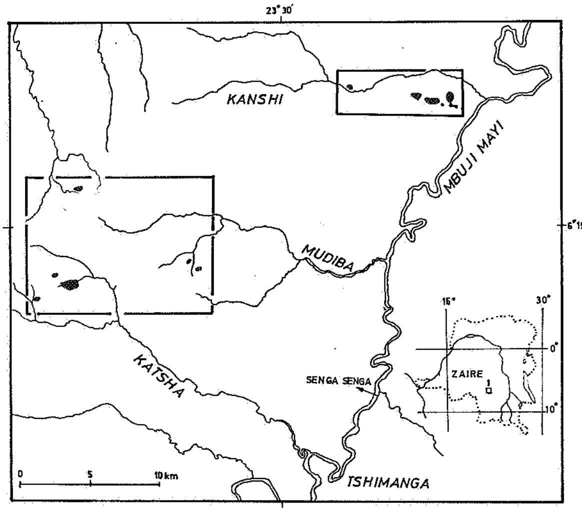

Figure 2: Occurrence of kimberlite pipes in East Kasai, Zaire.

2. HISTORICAL REVIEW OF THE DIAMOND FINDS IN KASAI PROVINCE (ZAIRE)

The earliest diamond discovery (by Janot) dates back to 1907: Tshiminina River, West Kasai. The crystal found was nevertheless only identified as a diamond in 1909 (Lancsweert & Buttgenbach).

As to the Eastern Kasai region, the first diamonds of the Mbujimayi River were recovered at Lukelenge by Young in 1918. As most of them where industrial and completely different from the diamonds found in West Kasai, they are described as "Lublilash-type" diamonds".

As early as 1923, de Rauw reviewed the occurrences of diamond in Zaire. The map he published is quite accurate and nearly up-to-date (fig. 1). He also noted the difference between the mineralogical compositions of the Western Kasai concentrates (tourmaline, staurolite, kyanite) and those of the Mbujimayi area (ilmenite, pyrope, diopside).

Although the mineral association in Mbujimayi should have indicated the proximity of a primary origin, the first kimberlite was only discovered in 1946 by de Magnée. It was located in close vicinity to the house of the Manager of the "Minière du Bécéka" and the Company had to realize that, in fact, the mining-town was built on top of pipe nr. 1 and the related diamond-bearing gravels.

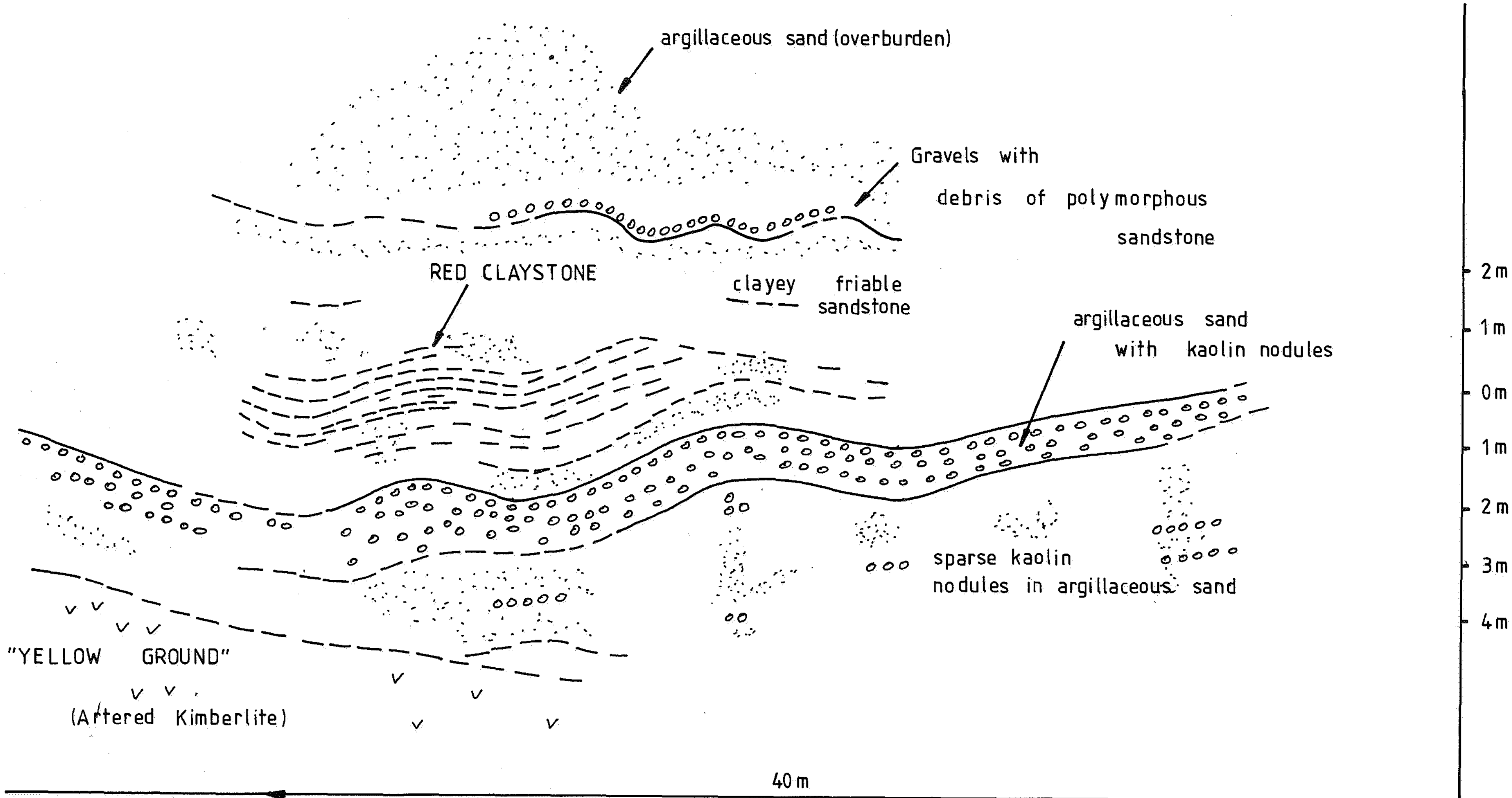

Figure 3: Sketch of the kaolin-nodule formation.

The same fate befell the new hospital which was built on the Disele plateau at ± 3 km of the first kimberlite occurrence. A prospecting pit dug through a 30 m argillaceous-sandy overburden discovered a strange "gravel" composed mainly of pure kaolin nodules (Pl. 1, photo 1): a diamond grade of nearly 1.000 carats/m^3 proved the presence of a very rich deposit and the mine management hesitated between destroying the hospital and building a new one, or finishing it and pushing back the new construction until the end of mining of the surrounding deposits. The latter possibility was finally decided upon.

The discovery of kimberlite pipe nr. 1 was the starting-point of a large-scale, systematic prospection of the high terraces and hills of the Bakwanga area (Bakwanga is the name of the original population), and to continue the examination of the valley flats and low terraces. Seven other pipes were discovered consecutively in the Bakwanga area (fig. 2).

However, the kimberlites and associated minerals could not explain the presence of diamonds and associated minerals in the alluvia of the Mbujimayi River and tributaries (Mudiba and Katsha) upstream of Bakwanga. Extensive prospections, consisting mainly of pitting, proved the existence of five other pipes in this area South of Mbujimayi (fig. 2). The most important among these, the Tshibua pipe, has a surface area of ± 30 ha.

3. CLASSIFICATION OF THE DIAMOND DEPOSITS OF KASAI

Early descriptions and classifications of the kimberlites and diamondiferous gravels were given by Wasilewsky (1950) and Polinard (1951). Due to their alteration and appearance as clastic material the kimberlites were not recognized as pipes but considered to be transported eluvial material. Later, more detailed petrographic work and drilling information proved the existence of a root related to crater facies kimberlite (C. Fieremans, 1953, 1961b, 1966 and Meyer de Stadelhofen, 1963).

A detailed account and classification of the diamond deposits in both West and East Kasai provinces and Angola was given by C. Fieremans in 1960.

As to the Mbujimayi area in particular we propose the following description of diamondiferous deposits.

3.1. PRIMARY DEPOSITS

Kimberlitic breccias and tuffs representing crater- and diatreme facies; some facies may represent sedimentary infillings and can be described as epiclastic kimberlites; the hypabyssal facies is only represented by autholiths, it is not exposed nor cut through by bore-holes. Two areas of intrusions can be distinguished (fig. 2):

1a) the Bakwanga area with ten "massifs" (in fact 8 pipes);
1b) the Bakwa-Kalonji or Katsha area with five pipes.

3.2. DETRITAL DEPOSITS

2a) Sandy-argillaceous deposits with kaolin nodules (Pl. 1, photo 1 and fig. 3): when not eroded these deposits always occur on top of the kimberlite pipes; they may extend slightly over the rims of the pipes; they never contain polymorphic sandstone boulders and thus may be considered of pre-polymorphic sandstone or pre-Kalahari age; they were probably formed by a kind of lateritization of the rim formations of the kimberlitic crater and form an infilling of this crater.

2b) Hill-side gravels (Pl. 1, photo 2): they form a constant layer of variable thickness covering the late-tertiary peneplain or the diverse quaternary denudation surfaces. A constant characteristic of these gravels is the presence of silicified sandstone pebbles and boulders belonging to the "polymorphous sandstone" formation of the base of the tertiary. Besides these they consist of quartz, silicified limestone, agate and chalcedony, set in a red sandy-argillaceous matrix. They are generally badly sorted, subangular to subrounded.

The origin of these deposits relates to very variable ages going from the end of the tertiary to recent times. Reworking of the gravels in subsequent depositional cycles resulted only in moderate increase of roundness of the pebbles. Although the actual hydrographic network may have been active since the end of the tertiary, the gravels must often be considered as pediments or flash-flood and sheet-wash deposits. A relation with the actual river-system is not always obvious, in particular when the gravels are covered by 40 m overburden of red argillaceous sand. Moreover, in the Mbujimayi area, where the substratum is composed of dolomitic limestones with little or no mesozoic cover, the karst topography heavily complicates the depositional surface and style of the deposit. Nevertheless, in the diamond mining area a relation with the actual river system seems logical since only a braided river model can explain the diamond distribution and its relation to the kimberlites in that area. Figure 4 tentatively explains a gradual shifting of the rivers Kanshi and Mbujimayi from an old (end-tertiary) situation to their actual course. Some buried channels, well known to the mining people, delivered as much as 100 cts/m^3 in the vicinity of kimberlite pipes.

The hill-side gravels in the area of the Southern group of pipes on the contrary are much more regular. They cover quite smoothly the precambrian granites and the mesozoic Lualaba sandstones and kimberlites.

3.3. ALLUVIAL DEPOSITS

directly related to the actual river system, these deposits can be subdivided in:

3a) high- and low terrace deposits and valley floor deposits; particularly along the Mbujimayi, Sankuru and Lubi rivers and tributaries (Kanshi, Katsha, Mujila).

3b) riverbed deposits: this concerns in particular the gravels of the Mbujimayi and Sankuru rivers downstream of Tshimanga; their mining has started fifteen years ago either by diverting the river or by dredging (Pl. 1, photo 5). In fact, one has to differentiate between the "actual" deposits, recently formed and subject to being displaced from year to year, and the deposits bearing evidence of an old activity of the Mbujimayi, for example the giant pot-hole of Senga-Senga: more than 100 m wide and 20 m deep, it contained 100.000 m^3 of gravel and produced 5.000.000 carats of diamonds (see Pl. 1, photos 3 & 4). The hollowing-out of this pot-hole and its filling up by gravels and big psammite boulders denote an activity of the river far more important than the actual one.

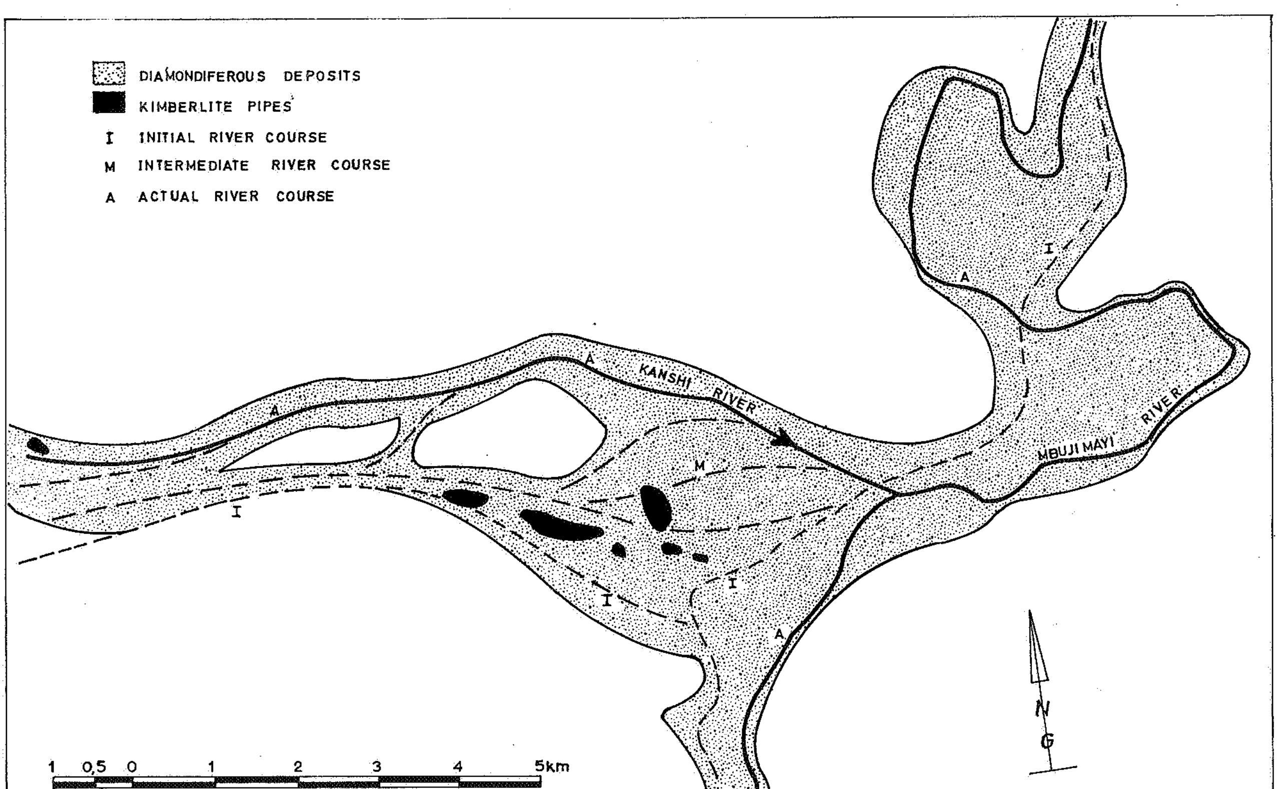

Figure 4: Diamondiferous deposits along the Kanshi and Mbujimayi rivers in the Mbuijmayi area; interpretation as resulting from gradual shifting of river channels.

4. KIMBERLITES AND LAMPROITES

4.1. GENERALITIES: DEFINITIONS AND STRUCTURAL CHARACTERISTICS

The primary host rocks of diamonds are: kimberlites and lamproites ; rare occurrences of microdiamonds have also been found in eclogites, peridotites and recently in metamorphic rocks (Sobolev & Shatsky, 1990).

4.1.1. Definitions

Definitions have not been lacking during the last 25 years; besides international kimberlite conferences (1973: Capetown; 1977: Santa Fe; 1982: Clermont-Ferrand; 1986: Perth), symposia and workshops about diamonds and their host-rocks have been held throughout the world. We would also like to mention Dawson (1980), Mitchell (1986) and Milashev (1984) who reviewed much of the literature in books devoted to kimberlites.

Notwithstanding the abundant literature published at each occasion, and the numerous definitions of kimberlites (Dawson, 1967, 1970 & 1980 ; Skinner & Clement, 1979; Clement *et al.*, 1979 & 1984; Mitchell, 1979 & 1986; Kovalski, 1963; Milashev, 1963 & 1984; Artsybasheva *et al.*, 1964; Frantsesson, 1970; Marakushev, 1982), we feel inclined to go back to the original definitions given by Carvill in 1887-1888 and Wagner in 1914. In a very condensed form, Carvill Lewis described the "harde-bank" of the Kimberley Mines as a "*serpentinized porphyritic volcanic peridotite of basaltic structure*". Wagner distinguished between: a basaltic variety, poor in mica (the kimberlite of Lewis) and a lamprophyric variety, rich in mica.

Although the name "basaltic" is not a good choice (the rock does not contain any plagioclase), the two varieties distinguished by Wagner may, sensu lato, be compared to the "Group I" and "Group II" kimberlites of Smith *et al.* (1985) and Skinner (1989).

The most recently revised definition of kimberlite is from Mitchell (1986):

"*Kimberlites are a clan of volatile-rich (dominantly* CO_2*) potassic ultrabasic rocks. Commonly, they exhibit a distinctive equigranular texture resulting from the presence of macrocrysts (and in some instances megacrysts) set in a fine-grained matrix. The megacryst/macrocryst assemblage consists of rounded euhedral crystals of magnesium ilmenite, Cr-poor titanian pyrope, olivine, Cr-poor clinopyroxene, phlogopite, enstatite and Ti-poor chromite. Olivine is the dominant member of the macrocryst assemblage. The matrix minerals include: second generation euhedral primary olivine and/or phlogopite, together with perovskite, spinel (titaniferous magnesian aluminous chromite, titanian chromite, members of the magnesian ulvöspinel-ulvöspinel-magnetite series), diopside (Al- and Ti-poor), monticellite, apatite, calcite, and primary late-stage serpentine (commonly Fe-rich). Some kimberlites contain late-stage poikilitic eastonitic phlogopites. Nickeliferous sulphides and rutile are common accessory minerals. The replacement of early-formed olivine, phlogopite, monticellite, and apatite by deuteric serpentine and calcite is common. Evolved members of the clan may be devoid of, or poor in, macrocrysts, and composed essentially of calcite, serpentine, and magnetite, together with minor phlogopite, apatite and perovskite.*"

The name lamproite was used for the first time by Niggli & Beger in 1923 to designate a potassium-rich mafic to ultramafic alkalic igneous rock (Bergman, 1987). In comparison to nearly all other igneous rocks, they show high to very high K/Na and K/Al ratios. Niggli and Beger distinguished two subtypes in the lamproite family, on the basis of the very special compositions and mineralogy of rocks occurring in the Leucite Hills (Wyoming) and in S.E. Spain. In fact, these rocks rather remained petrological pecularities, till the discovery of the diamondiferous lamproites of Ellendale and Argyle (N.W. Australia). The first diamonds in the lamproites of the Fitzroy Valley were discovered in the Ellendale area in 1976 (Atkinson *et al.*, 1984). As a consequence of this certain rocks that were described before as kimberlites are reclassified as lamproites, for example the Murfreesboro "kimberlite" of Prairie Creek in Arkansas (Smith & Skinner, 1984).

Lamproites are a group of rocks characterized by the presence of a series of titanium-rich minerals which may occur as principal, subordinate or accessory phases: Ti-phlogopite, ti-tetraferriphlogopite, potassium-titanium richterite and priderite...

Typically lacking in lamproites are: nepheline, sodalite, haüyn, noseane, melilite, plagioclase, monticellite, melanite, kalsilite...

Chemically, lamproites are characterized by a high percentage of SiO_2 (40-55 %), an ultra-potassic ($K_2O/Na_2O > 3$), a perpotassic ($K_2O/Al_2O_3 > 1$) and peralkine [$(K_2O + Na_2O)/Al_2O_3 > 1$] character. They are enriched in incompatible elements (Ti, REE, Sr, Ba, Zr), whilst they also show high grades in compatible elements (Co, Ni, Cr, Sc).

To the contrary of kimberlites, glassy varieties of lamproites may occur.

4.1.2. Structural and textural characteristics of kimberlites and lamproites

Mitchell (1989) gives a review of textural genetic classifications of kimberlites and presents the characteristics of the three groups of rocks currently 'en vogue': (1) crater facies, (2) diatreme facies (3) hypabyssal facies. The relationship between these rocks is illustrated on fig. 5, taken from Mitchell (1986, p. 30). The sills, dykes and root zone represent the hypabyssal facies kimberlites.

We refer in particular to the same author (Mitchell, 1986, 1989) and to Bergman (1987) for a comparison between the kimberlites and lamproites. In table 1, we have tried to condense some salient differences as to textural, genetic and structural features.

4.2. THE MBUJIMAYI KIMBERLITES

As already mentioned the Mbujimayi kimberlite field is composed of two clusters of pipes. There is no evident tectonic relation between the two groups of kimberlites, but both form and situation of the pipes are highly indicative of EW linear trends. The alignment of the Northern pipes is interpreted as related to a crustal fissure of at least 10 km length (C. Fieremans, 1977a) (fig. 7). One pipe with N-S orientation is possibly situated on a secondary fault, perpendicular to the first one (pipe n° 1, fig. 6). Notwithstanding the evidence, this hypothetical fault is not revealed by airbone magnetic reconnaissance survey carried out in 1970 by "Hunting Geophysics" on behalf of "Société Minière de Bakwanga" over its concession. The eventual deep structural relations between the kimberlites and the basement are probably masked by the largely non-magnetic limestones intruded by the kimberlites. Four of the five pipes of the Southern group (which display an E-W elongated surface expression) are localized at, or near, the intersection of NE trending faults and a basic dyke striking EW.

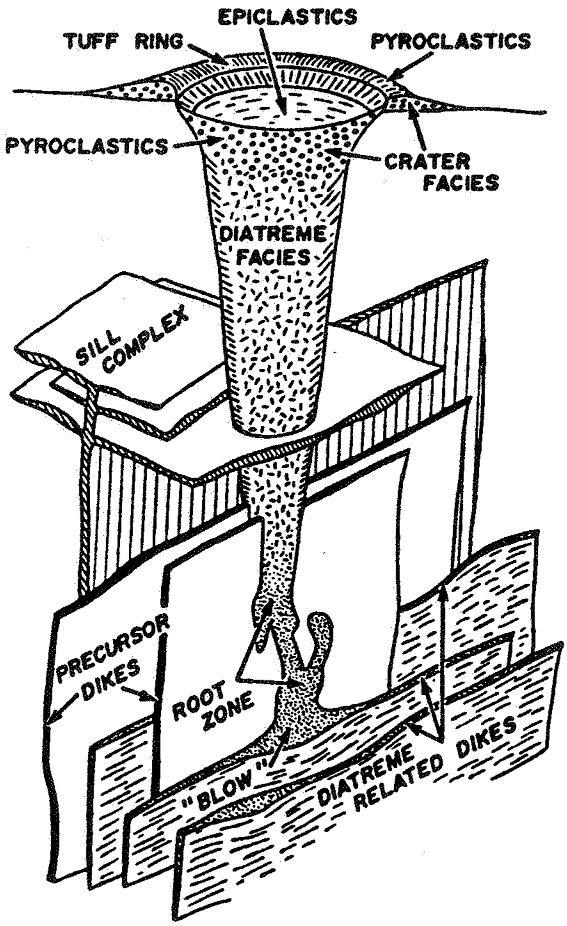

Figure 5: Model of an idealized kimberlite magmatic system from R.H. Mitchell, 1986, p. 30.

KIMBERLITES	*LAMPROITES*
CRATER FACIES	
Aerial activity not or rarely preserved: - tuff-rings: only exceptionally preserved - lavas: mostly absent (one case: Igwesi Hills, Tanzania) - pyroclastic and epiclastic rocks: tuffs and epiclastic rocks are common	Manifestation of aerial activity abundant: - tuff-rings: present and cinder-cones described - lavas: frequent; lava lakes described - pyroclastic rocks (tuffs) and epiclastic rocks similar to kimberlites and maars
DIATREME FACIES	
- Tuffisitic kimberlites and tuffisitic kimberlite breccias (autolithic and heterolithic) - Lapilli-sized kimberlite-clasts termed "pelletal lapilli" are characteristic (Mitchell, 1989) - Matrix fine grained (serpentine and micro-crystalline diopside), mostly deep surface weathering, replacement by clay minerals and secondary calcite.	According to Mitchell (1989), "*recognition of a lamproite diatreme facies is not required. Accordingly, lamproites may be placed into either a crater facies or a hypabyssal facies*"
HYPABYSSAL FACIES	
- Formed by crystallization of volatile-rich magma ($H_2O + CO_2$) - Glass-bearing varieties unknown - The "root zones", dykes and sills show textures of igneous rocks - The "hypabyssal facies" has been divided into "kimberlites" and "kimberlite breccias" (with more than 15 % clasts - Mitchell, 1989) - Segregation textures are characteristic - Repeated intrusions may have occurred.	- Lamproite intrusions show relatively "quiet" emplacements; the original magmas are much less volatile-rich and show low CO_2 contents - Absence of primary calcite, but presence of glass and richterite - Lamproite rocks may occur as sills, dykes; volcanic rocks and consolidated lava - Intrusions similar in character to other basic magmas - Segregation-textures are not characteristic - Repeated intrusions possible.

Table 1: A comparison between kimberlites and lamproites (textural genetic and structural features).

The late Cretaceous age of the kimberlite emplacement has been deduced from stratigraphic evidence (C. Fieremans, 1966) and confirmed by the U/Pb method applied to zircon (Davis, 1977). The kimberlites of the Northern group intrude successively the three geological units characteristic of the region (Anonymous, 1979; Demaiffe & M. Fieremans, 1981):

- an Archean basement, mainly composed of granitic gneisses, the Dibaya Complex, which is older than 2.7 Ga;
- a thick sequence of unmetamorphosed, gently warped Proterozoic sandstones and stromatolitic dolomitic limestones - the Bushimayi Supergroup; these rocks are older than 950 Ma, the extrusion age of the doleritic lavas at the top of the limestone sequence;

- undisturbed, mainly arenaceous sediments of the Lualaba series (Cretaceous).

The kimberlites of the Southern group, situated beyond the area of occurrence of the Mbuji-Mayi limestones, intrude only the first and last members of this sequence.

4.2.1. Emplacement and form of the pipes

Figure 7 shows an E-W longitudinal profile of one pipe of the Northern group (pipe nr. 3): it consists of a small nearly circular feeder pipe of approximately 45 m diameter intruding limestones and abruptly expanding to a crater at the contact of the limestones with the overlying Lualaba loose red sandstones. The kimberlitic material, largely composed of red epiclastic rocks represents the infilling of an undeep trench of ±300 m width. This trench, which probably formed at the time of eruption of all the pipes of the Northern group, is evidenced by subvertical crater walls at the N and S borders. Figure 8 also shows a geological map, at level 560 m of that pipe nr. 3, deduced from core drilling according to a 40 m by 80 m grid. It is easy to distinguish four eruption phases emerging from the same feeder pipe. To each eruption belongs a distinct (elliptical) crater; each of them is asymetrical and partly filled with green kimberlite breccias and tuffs showing graded bedding and cross-bedding (Pl. 2, photos 7 & 9). Filling of the crater was afterwards completed by red tuffaceous or breccious clayey sandstones. One of the mining faces shows clear evidence of a crater lake deposit through a 10 to 30 cm thick layer of intensively bioturbated red clay. This crater lake dates from the period between the first and second eruption phases. Fossils were not found. Monogenic collapse breccias of the Lualaba sandstones locally occur at the subvertical border of the trench walls. The red epiclastic material shows often higher diamond grades but smaller stone sizes. The diamond grade of the green kimberlite pyroclastics decreases progressively from the oldest to the youngest facies.

A different configuration is created by the eruptions of one of the kimberlites of the Southern group, known as the Tshibua pipe (fig. 8). The pipe measures 500 m by 240 m at a depth of 150 m below the actual erosion level and exhibits very steep walls (up to 70°) down to 300 m, the lowest limit of the drilling operations. The internal topography of the pipe is also shown on figure 8 (kimberlitic rocks extend subhorizontally beyond the outer contour which represents the prospection limits). The flat lying superstructure of the pipe consists of a sequence of subhorizontal layers of kimberlite, sandy tuffs and breccias, and fine sandstones up to 20 m thick (possibly of aeolian origin). Collapse breccias composed of elements of the Lualaba sandstones occur in some places along the crater wall. At least five eruption phases can be distinguished, each major phase separated from the other by a considerable period of time such as to allow the accumulation of the sandstone layers (10 to 20 m thick). While the first eruptions mainly carry inclusions of sedimentary rocks, the latest eruptions contain principally fragments of the gabbroic dyke intruded by the kimberlite in this area. Peridotite nodules have never been found and the eclogite nodules (Mvuemba-Ntanda, 1980) are different from those of the Northern group of kimberlites (C. Fieremans, 1966).

4.2.2. Petrography

Exhaustive petrographic studies of the kimberlite pyroclastics and their various inclusions were published by Wasilewsky (1950), Meyer de Stadelhofen (1963) and C. Fieremans (1966). According to the Russian nomenclature (Rabhkin *et al.*, 1962), C. Fieremans (1977a) described the diatreme facies as xeno-tuff breccias. These breccias contain numerous fragments of the country rocks and various nodules (see brief description below). Kimberlite fragments form a conspiceous part of the breccia (Pl. 2, photo 8). They occur frequently as small debris in thin sections of the bluegrounds and tuffs and are rarely found as larger rounded nodules of what has been called "primary kimberlites" (C. Fieremans, 1966). In fact they represent the hypabyssal facies of the Mbujimayi kimberlites. Their petrographic descriptions have already been published (M. Fieremans & Ottenburgs, 1979a; Demaiffe & Fieremans, 1981; M. Fieremans *et al.*, 1984) so that only a brief summary is given below. Thirteen nodules were available, the largest one (nodule 1, see figure 1 in M. Fieremans *et al.*, 1984) having a diameter of ca 15 cm. The kimberlite nodules are generally extensively altered but nevertheless, two gener-

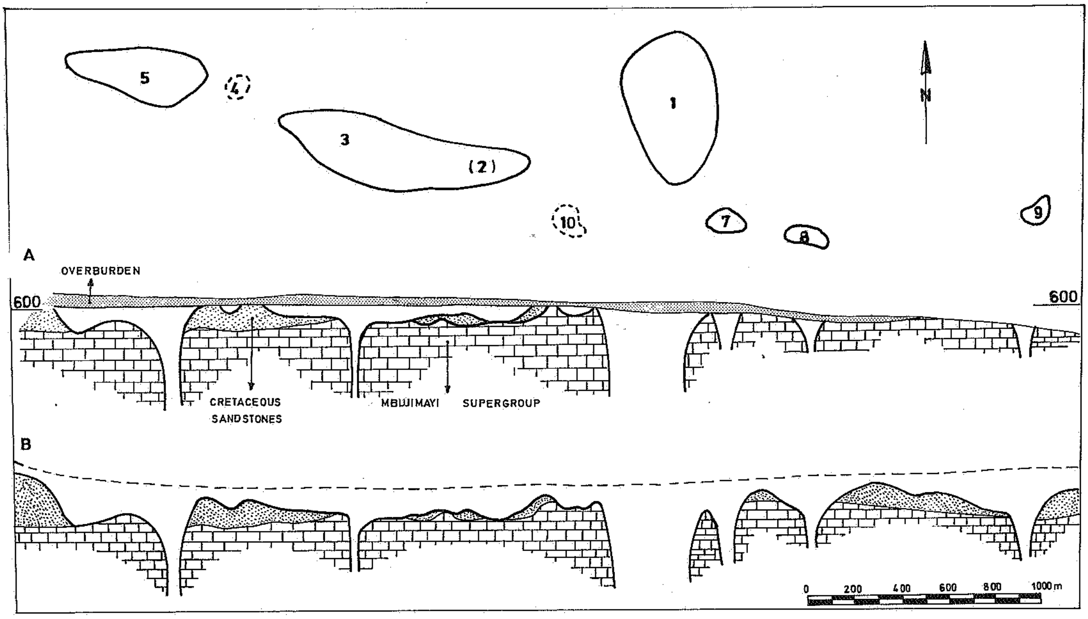

Figure 6: Linear relation between the pipes of the northern group (pipe 6 to the west not shown); A: longitudinal profile; B: theoretical reconstruction of the profile before erosion to actual level.

ations of euhedral olivine phenocrysts (transformed to phlogopite + calcite + saponite) can still be recognized in most samples. Abundant Cr-chlorite macrocrysts (up to 5 mm) give the Mbujimayi kimberlites the appearance of micaceous type kimberlite. The very fine-grained matrix is essentially made of an aggregate of idiomorphic chlorite, saponite and carbonate. Magnetite, apatite and rutile are finely dispersed in the groundmass while Cr-spinel is completely lacking.

The kimberlites are carbonate-rich (24-27 %; mainly calcite); although sometimes of secondary origin (as thin veinlets crosscutting the phenocrysts), the calcite is regarded as a late-stage primary phase occurring either as isolated grains in the groundmass or as poikilitic crystals enclosing the olivine pseudomorphs (Fieremans & Ottenburgs, 1979a).

Several large carbonate inclusions figure prominently in one nodule. A cogenetic relation between these inclusions and the kimberlite is suggested on the basis of the isotope geochemistry (cf. infra).

4.2.3. Mantle xenoliths and megacryst suite

The megacryst suite and the deep-seated (lower crust, mantle) xenoliths have been thoroughly studied by Mvuemba-Ntanda (1980). Eclogite nodules are preponderant while peridotitic-pyroxenitic xenoliths are completely lacking. Most of the eclogites appear as rounded xenoliths (3 to 5 cm with few samples up to 12 cm). The rocks generally have an equigranular texture while few samples (up to 12 cm) display a banded texture with alternating garnet-rich and clinopyroxene-rich bands. Besides garnet and omphacitic clinopyroxene that dominate the mineral assemblages, rutile and occasionally phlogopite and a (secondary) amphibole are the main accessories. In the Tshibua pipe, two samples of peraluminous, kyanite-bearing eclogites have been observed.

The megacryst suite (= discrete nodules of Nixon and Boyd, 1973) essentially consists of centimeter-sized grains of garnet, clinopyroxene and ilmenite. Enstatite has never been found. Chemically, two populations of clinopyroxenes have been identified (see fig. 9, from Mvuemba-Ntanda, 1980): (i) Na- and Al-rich omphacitic crystals compa-

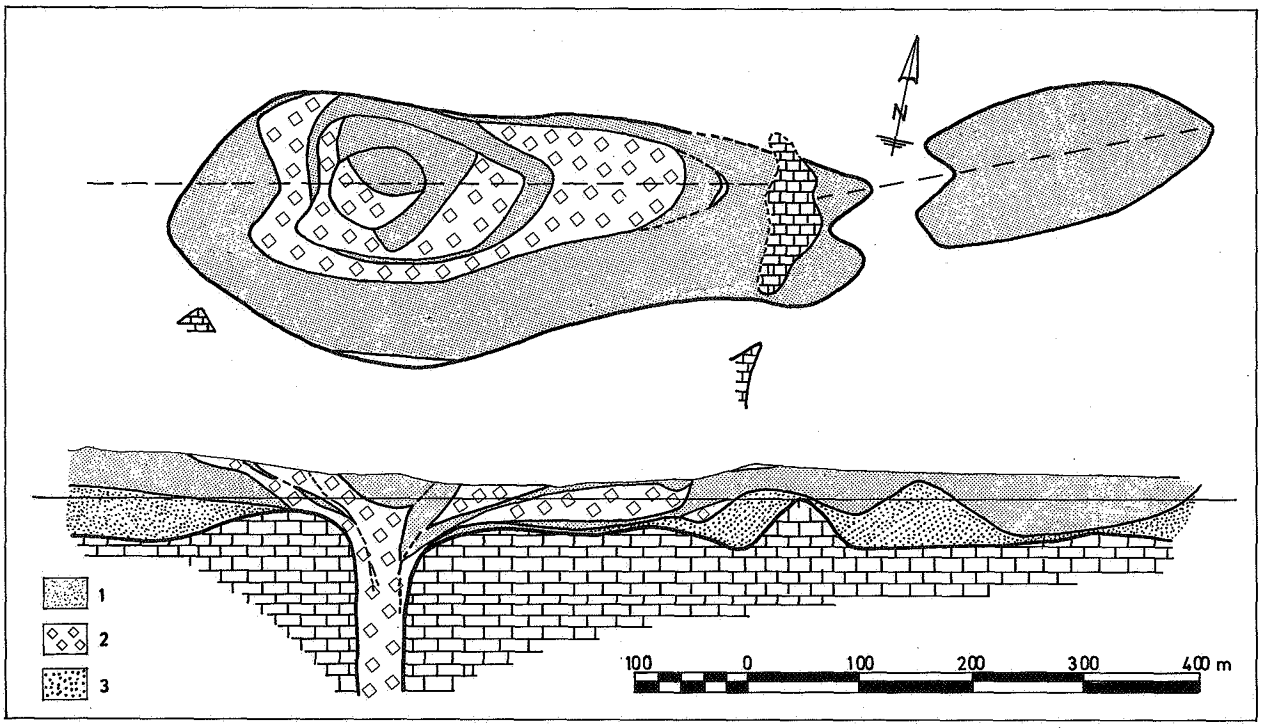

Figure 7: Pipe n ° 3 (northern group): geological map (level: 560 m) and longitudinal profile; 1: Lualaba sandstones on top of dolomites of Mbujimayi supergroup; 2: green kimberlite breccias and tuffs; 3: red epiclastics.

rable to eclogitic pyroxenes and (ii) Cr-poor (0.5-0.8 % Cr_2O_3) diopsides, poor in Al and Na. The garnet compositions also fall into two distinct groups (fig 10): (i) magnesian (Mg/Mg + Fe: 0.83 to 0.90), Cr-rich (1 to 7 % Cr_2O_3) pyropes with 4-5 % CaO, characteristic of lherzolitic parageneses (Sobolev, 1977) and (ii) intermediate (Mg/Mg + Fe = 0.60), Cr poor (< 1 % Cr_2O_3) garnets with 5.5 to 7 % CaO, quite comparable to eclogitic garnets. Ilmenite megacrysts are Mg- (10 to 14.5 % MgO) and Cr- (1.5 to 4 %) rich with a Mg-Cr anticorrelation.

Rutile most commonly occurs as large (up to 4.5 cm) rutile-silicates intergrowths (Ottenburgs & M. Fieremans, 1979). X-ray diffraction allows the identification of antigorite and sepiolite, considered as secondary minerals after a primary Mg-rich pyroxene. The intergrowths are believed to have originated from partial melting of a phlogopite garnet-peridotite.

Rare aluminous megacrysts have been found: corundum (0.5 cm; 1.1 % Cr_2O_3) and lath-shaped kyanite (up to 1 cm) , they both probably derived from kyanite-bearing eclogites.

M. Fieremans & Ottenburgs (1979b) also described quite abundant, rounded, large (0.5 to 1 cm) zircon crystals which is not uncommon in kimberlite (Kresten *et al.*, 1975) but they also observed Ti-rich baddeleyite occurring either as coatings on zircon grains or as isolated large (0.5 cm) grains. The latter are considered to have crystallized from a carbonatitic melt prior to kimberlite intrusion.

Chlorite occurs as very large (up to 1 cm) discrete megacrystic nodules (M. Fieremans & Ottenburgs, 1979a): under the microscope, these nodules resolve as an intricate network of quartz and chlorite. These chlorites have both high MgO (28-30 %) and FeO (13 to 18 %) contents; they are biaxially negative with small 2V values. They are similar to those of Sierra Leone (Tompkins *et al.*, 1984).

4.2.4. Geochemistry

Geochemical data for kimberlites are generally difficult to interpret because, as it was stated in the petrography section, these rocks are frequently deeply altered; they have a brecciated nature and hence contain numerous fragments of all sizes of the country rocks wherein they intrude. The geochemical data summarized below were obtained on kimberlite nodules of hypabyssal facies.

4.2.4.1. Major elements

Discussion on the major element chemistry of the Mbuji-Mayi kimberlites was presented by Demaiffe & Fieremans (1981) and Fieremans *et al.* (1984).

Kimberlites are strongly undersaturated, highly magnesian and volatile rich rocks. The Na_2O content is usually low while the variable K_2O content reflects the amount of modal phlogopite, P_2O_5 content is quite high for ultrabasic rocks (tab. 2). The Mbuji-Mayi samples are significantly enriched in volatiles relatively to average kimberlite which reflects their high carbonate content and is probably due to the hypabyssal (undegassed) nature of the studied nodules. In the AFM diagram (fig. 11), most of the data are well clustered.

4.2.4.2. Trace elements

Trace element data have been thoroughly discussed by M. Fieremans *et al.* (1984). Only the main conclusions are given below. The ranges of some trace elements contents are shown in table 3, together with data from the literature (Dawson's, 1980 compilation). Generally speaking, the Mbujimayi kimberlites are comparable to the other kimberlite occurrences (Dawson, 1980; Nixon *et al.*, 1981). The transition elements contents

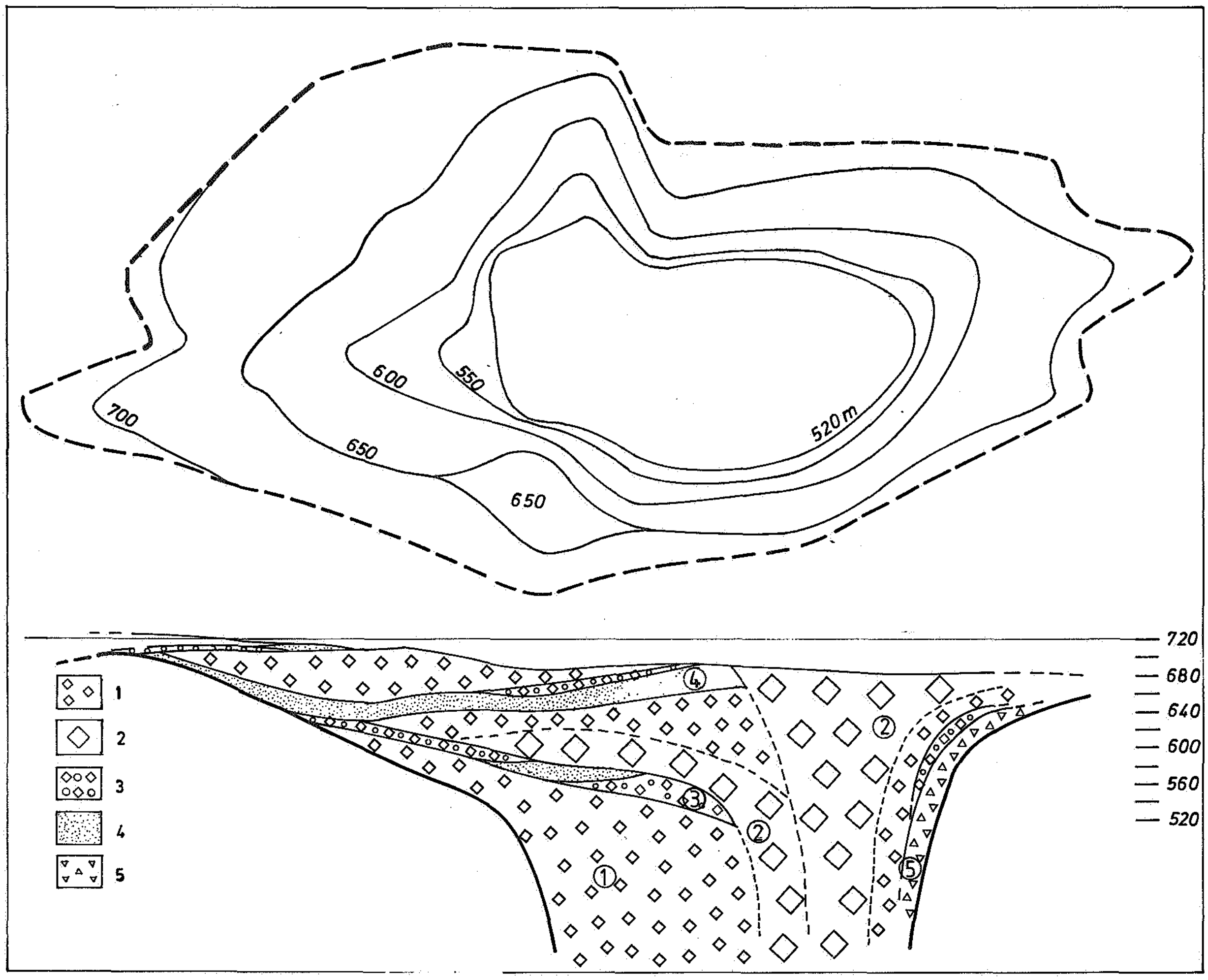

Figure 8: Tshibua pipe (northern group): topographic contour map of crater walls as deduced from drilling, and longitudinal profile; 1: kimberlite breccias and tuffs with predominantly sedimentary rocks inclusions; 2: kimberlite breccias with almost exclusively gabbro inclusions; 3: "sandy" kimberlite breccias; 4: fine sandstones; 5: monogenic breccias of Lualaba sandstones.

(Sc, Co, Cr) are moderately high. All the samples have high total REE abundances (170 up to 860 ppm) with strongly LREE enriched chondrite-normalized patterns. The La content varies from 44 to 206 ppm as in many other kimberlites but the HREE is surprisingly low (less than 0.8 ppm Yb) leading to high (La/Yb)N ratios (70-258).

In that respect, the Zaire kimberlites are more comparable to the lamproites of Western Australia: (La/Yb)N = 50 to 145 (Fraser *et al.*, 1985; Demaiffe *et al.*, 1990).

Most of the samples have virtually parallel, smooth REE patterns without Eu anomaly. The Sr content is high (150 up to 1390 ppm) which results from the high calcite modal abundance in the matrix. In spite of the micaceous appearance of the rocks, all, but two, samples have less than 50 ppm Rb and hence have low Rb/Sr ratios (< 0.1).

4.2.4.3. Radiogenic isotope geochemistry

Isotopic characteristics of the Mbujimayi kimberlites have been discussed by Demaiffe & Fieremans (1981), Fieremans *et al.* (1984), Weis & Demaiffe (1985, and Demaiffe *et al.* (1990). A summary of the isotopic data is given in table 4 (Demaiffe *et al.*, 1990). Remarkably, the samples are comparable to Group I kimberlites ("basaltic variety") of South Africa.

4.2.4.4. Stable isotope geochemistry

Carbon and Nitrogen isotopic composition of the diamonds have been measured and discussed by Javoy *et al.* (1984) on milligram-size and gram-size samples.

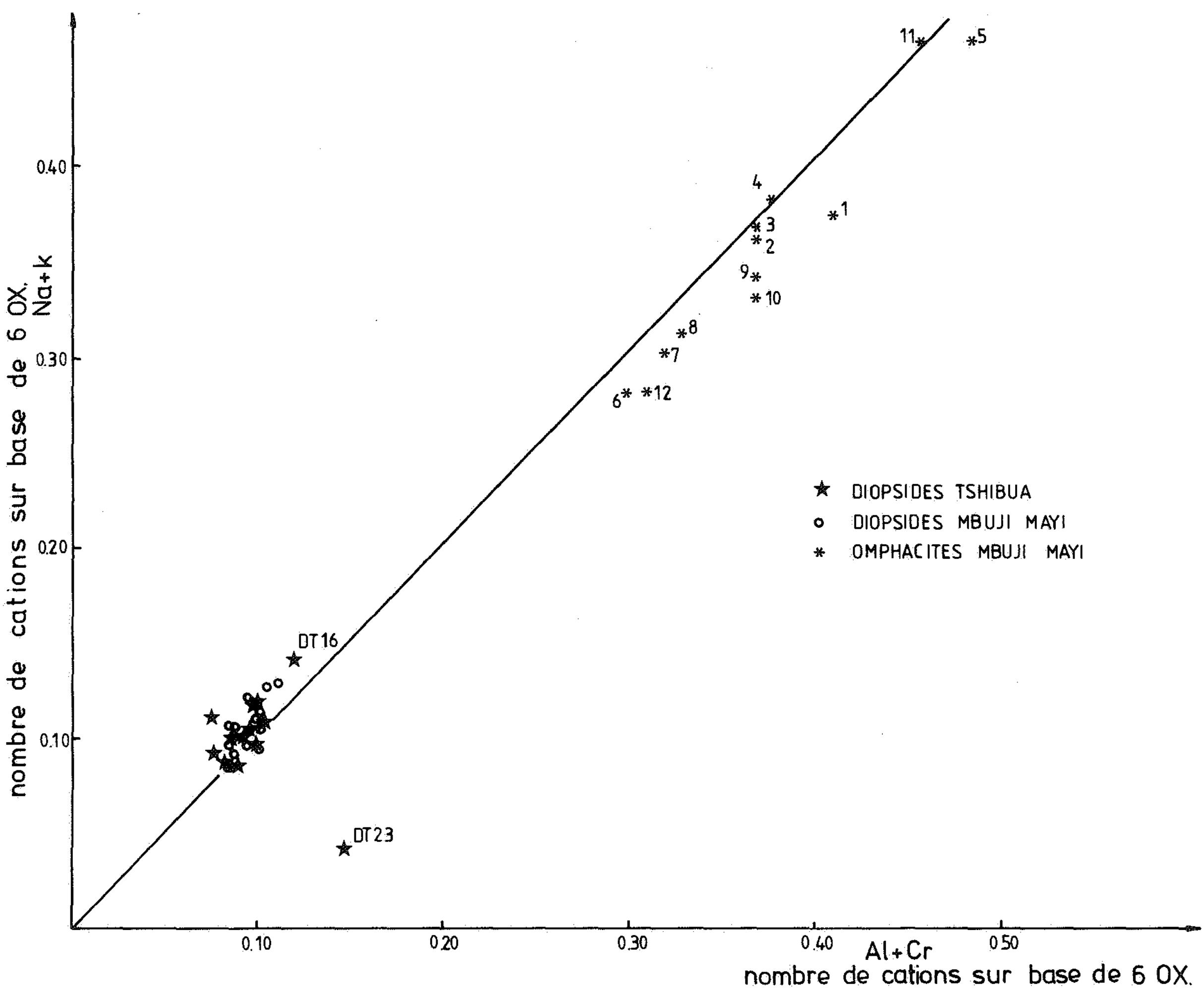

Figure 9: Diagram (Al + Cr) vs. (Na + K) in the clinopyroxenes from Mbujimayi. From Mvuemba Ntanda (1980) (fig. I.13).

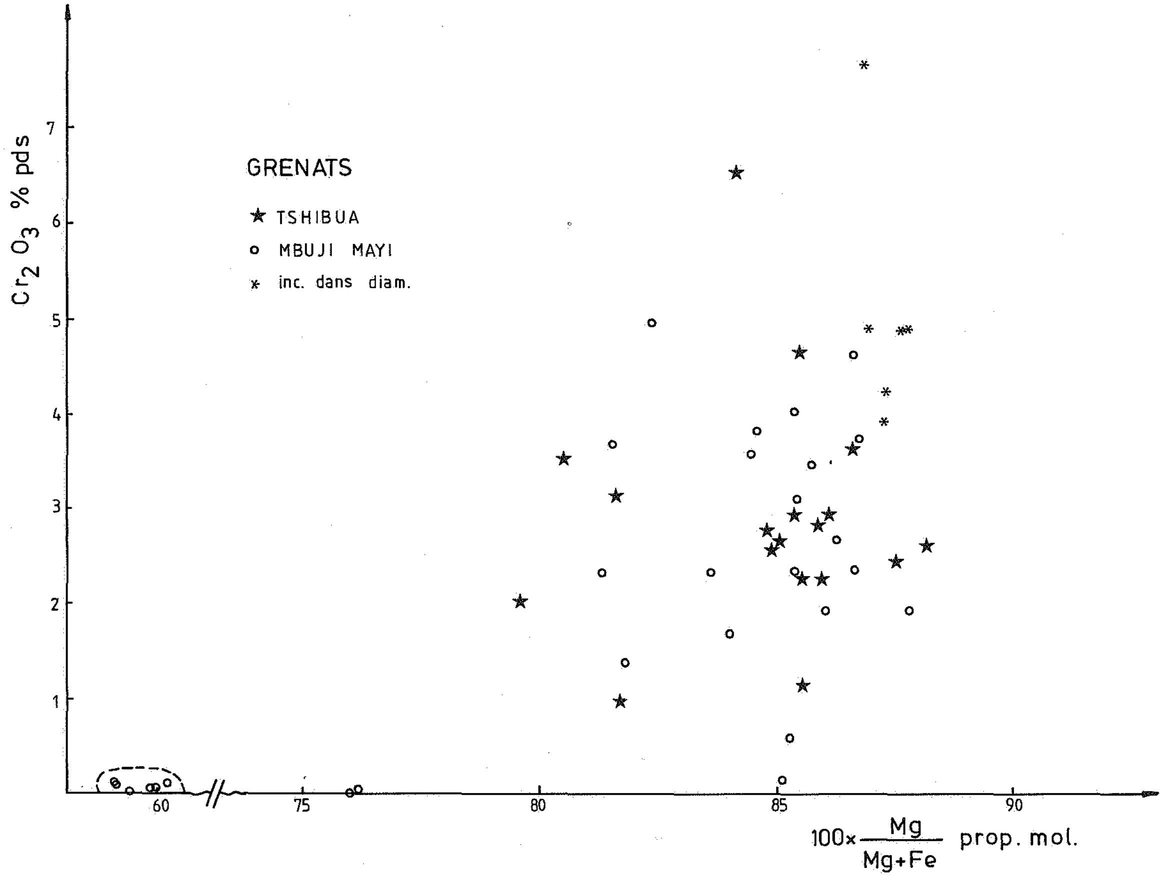

Figure 10: Diagram Mg/Mg + Fe vs. Cr_2O_3 in the garnets from Mbujimayi. From Mvuemba Ntanda (1980) (fig. I.13).

The $\delta^{13}C$ range of values are comparable to the values measured on South African and Siberian diamonds (fig. 12). The Mbujimayi values for $\delta^{13}C$ ‰ vs. PDB are compared to the frequency distribution curve published by Deines (1989) (fig. 12). The values for the large diamonds (gram-size samples) are identical to the values of the fragments and vary between -4.6 and -10.5 ‰.

Values of δ^{13} measured on carbonates from "primary" kimberlite nodules vary from -5,5 to -11,8 ‰ and are thus quite comparable with the values from diamonds, which refers to a deep-seated origin of the carbon of the carbonates.

The oxygen isotopic composition of the carbonates ($\delta^{18}O$ varies between 13.3 and 23.5 ‰ relative to SMOW) is much higher than in primary carbonatites, as illustrated in fig. 13, which points to meteoric-hydrothermal fluid interactions during the pipe emplacement (Demaiffe *et al.*, 1990).

The nitrogen concentration measured in the large diamonds ranges from 100 to 2100 ppm, and $\delta^{15}N$ ranges from +6,0 to -11,2 ‰ (Javoy *et al.*, 1984).

All average concentrations but one are greater than 750 ppm. Thus all the diamonds but one belong to the IA type. The values are anti-correlated with the N concentrations which, according to Javoy *et al.* (1984), suggests two types of models: either a Rayleigh distillation process (a fractionation model) or a mixing model where an N-rich source poor in 15N is mixed with an N-poor source richer in 15N.

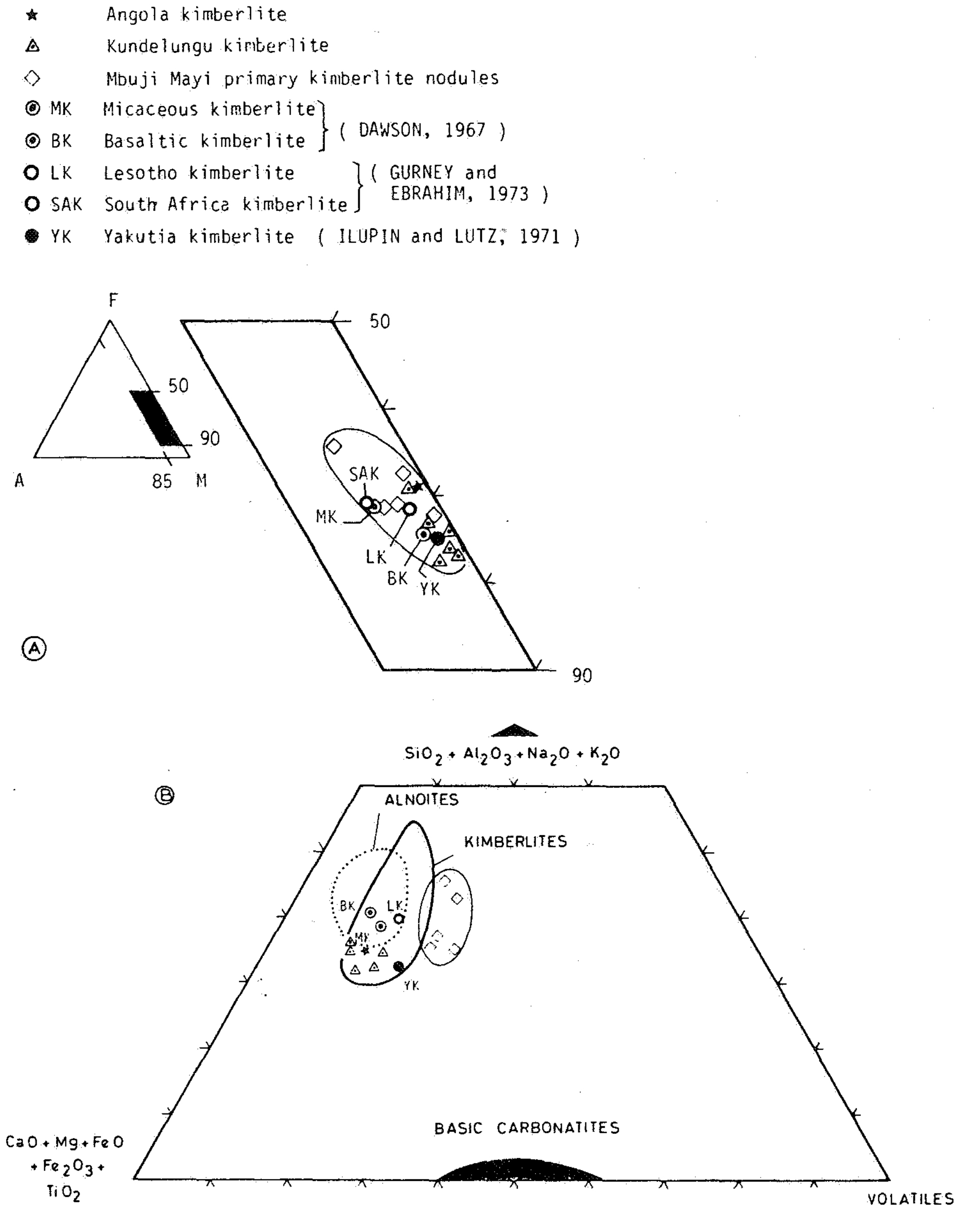

Figure 11: AFM diagram for the Mbujimayi primary kimberlite nodules + Dawson's diagram. From fig. 3 *in* Demaiffe *et al.* (1981).

	1	2	*3*	*4*	5	*6*
wt % volatile free						
SiO_2	38.4	53.3	34.4	25.7	32.1	36.3
TiO_2	2.6	3.0	1.06	3.0	2.0	1.0
Al_2O_3	4.7	9.1	3.95	3.1	2.6	3.2
FeO	11.3	6.3	7.72	12.7	9.2	8.4
MnO	0.18	0.1	0.13	0.2	0.2	0.2
MgO	28.7	12.1	14.5	23.8	28.5	29.7
CaO	11.3	5.8	16.05	14.1	8.2	6.0
Na_2O	0.5	1.4	0.12	0.2	0.2	0.1
K_2O	1.4	7.2	0.7	0.6	1.1	3.2
P_2O_5	0.9	1.3	0.84	1.1	1.1	1.1
wt % original analyses						
H_2O+	6.6	2.7	8.23	7.7	9.7	6.0
CO_2	5.6	2.8	12.34	8.6	4.3	3.6
Atomic ratios						
MgO/MgO+FeO	81.2	74	77.2	78.7	86.1	87.6
K_2O/Na_2O	5.0	7.0	3.9	2.0	3.8	21.3
K_2O/Al_2O_3	0.4	0.9	0.19	0.21	0.47	0.9

Table 2: Representative compositions of kimberlites and lamproites.

1. Mean of 550 kimberlites (s.c. Bergman, 1987)
2. Mean of 284 lamproites (s.c. Bergman, 1987)
3. Mean of 5 kimberlite nodules from Mbujimayi
4. Group Ia kimberlites from South Africa (Smith *et al.*, 1985)
5. Group Ib kimberlites from South Africa (Smith *et al.*, 1985)
6. Group II, micaceous kimberlites, South Africa (Smith *et al.*, 1985).

5. DIAMONDS AND THEIR INCLUSIONS

A crystallographic description of the Mbujimayi diamonds was given by Polinard (1929, 1930, 1931a, 1931b). He distinguished three categories:

a. coloured and opaque diamonds;
b. translucent diamonds;
c. transparent diamonds.

Each of these categories possesses its own crystal forms. The coloured and opaque varieties for instance show an affinity for the cubic habitus, the octaedron and rhombododecaedron. The regular cube with "frosted" surface is frequent and typical. Very characteristic also are the "coated" diamonds where a transparent core is surrounded by an opaque rim.

Besides the regular crystals Polinard also describes "diamonds in complex agglomerations of crystals" and the "diamonds with confused crystallization". These two latter types often have voluminous forms.

Commercially, three varieties are distinguished: the gem, the near-gem and the crushing boart. The proportions between these varieties may vary according to the situation of the market prices. Ordinarily, the gem variety constitutes 4-5 % in weight of the total, the near-gem 20 %, and the crushing boart 75 %.

Inclusions in the Mbujimayi diamonds were studied by Mvuemba-Ntanda (1980). About 200 diamonds were sought out and the inclusions extracted by means of an ordinary "crushing device". 41 inclusions were studied at the Purdue University (U.S.A.), using a MAC 400 electron probe.

	1	*2*	*3*	*4*
Transition elements				
Sc	5.6 - 21	7 - 30	16.5 - 18.7	17.8
Cr	570 - 2550	550 - 2900	-	4300 - 6000
Co	25 - 85	35 - 130	61 - 87	85 - 132
Rare earth elements				
La	44 - 206	26 - 200	33 - 61	2.5 - 4
Yb	0.23 - 0.84	0.9 - 2	0.65 - 1.36	0.07 - 011
(La/Yb)N	70 - 258	31 - 170	14.4 - 56	21
REE	170 - 860	83 - 807	140 - 270	18 - 22
LIL elements				
Th	5.6 - 35	4.54	5.8 - 8.9	< 0.3
U	0.5 - 4.8	0.6 - 18.3	1.7 - 3.6	0.6 - 0.7
Ta	5.6 - 32	1.4 - 21.3	1.7 - 3.5	29 - 59
Rb	13.5 - 85	0 - 350	63 - 162	-
Sr	147 - 1386	40 - 1900	675 - 897	116 - 227

Table 3: Selected geochemical data for kimberlites and diopside megacrysts from Mbujimayi (in ppm), (from Demaiffe *et al.*, 1986).

1. Mbujimayi kimberlites (Fieremans *et al.*, 1984)
2. Dawson's (1980) compilation
3. Finsch mine (Fraser *et al.*, 1985)
4. Mbujimayi diopside megacrysts (Fieremans *et al.*, 1984)

The following inclusions were determined:

- olivine: only 2 grains were found: their grade in forsterite (91,4 and 93,4 %) make them fall into the category defined by Meyer and Boyd (1972) for the micro-crystalline inclusions in diamonds (Fo_{91}- Fo_{95}).

- clinopyroxene: diopside, omphacite and jadeite-clinopyroxene. Whereas the Cr-diopside was considered to belong to the lherzolitic paragenesis, the two other pyroxenes were considered to belong to an eclogitic, eventually kyanite-eclogitic paragenesis.

- garnet: two types were described:

- a chromium pyrope;
- a garnet of the type pyrope-almandine-grossularite.

Certain pyropes (with a CaO < 3 %) belong to the harzburgitic paragenesis of Sobolev; others (with CaO up to 13,5 %) are ranged in the wehrlitic paragenesis. The garnets of the series pyrope-almandine-grossularite are mainly eclogitic.

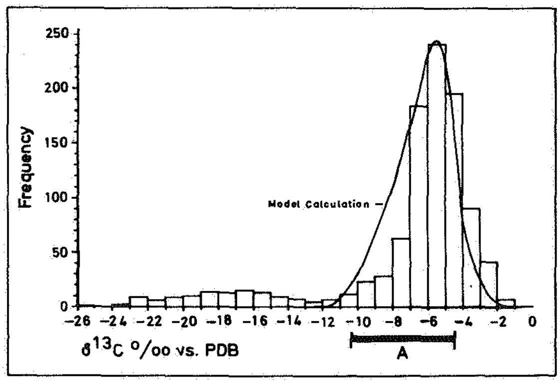

Figure 12: Summary frequency distribution of $\delta^{13}C$ of kimberlite diamonds from Russia and Southern Africa (after P. Deines, 1989), with indications of the range for Mbujimayi diamonds (A).

- kyanite: classified in the kyanite-eclogite or grospydite paragenesis;

- rutile: rather frequent;

- ilmenite: only one ilmenite was found as inclusion. Its composition approaches the megacrystal one (magnesian and chromium-ilmenite). Sobolev ranges the

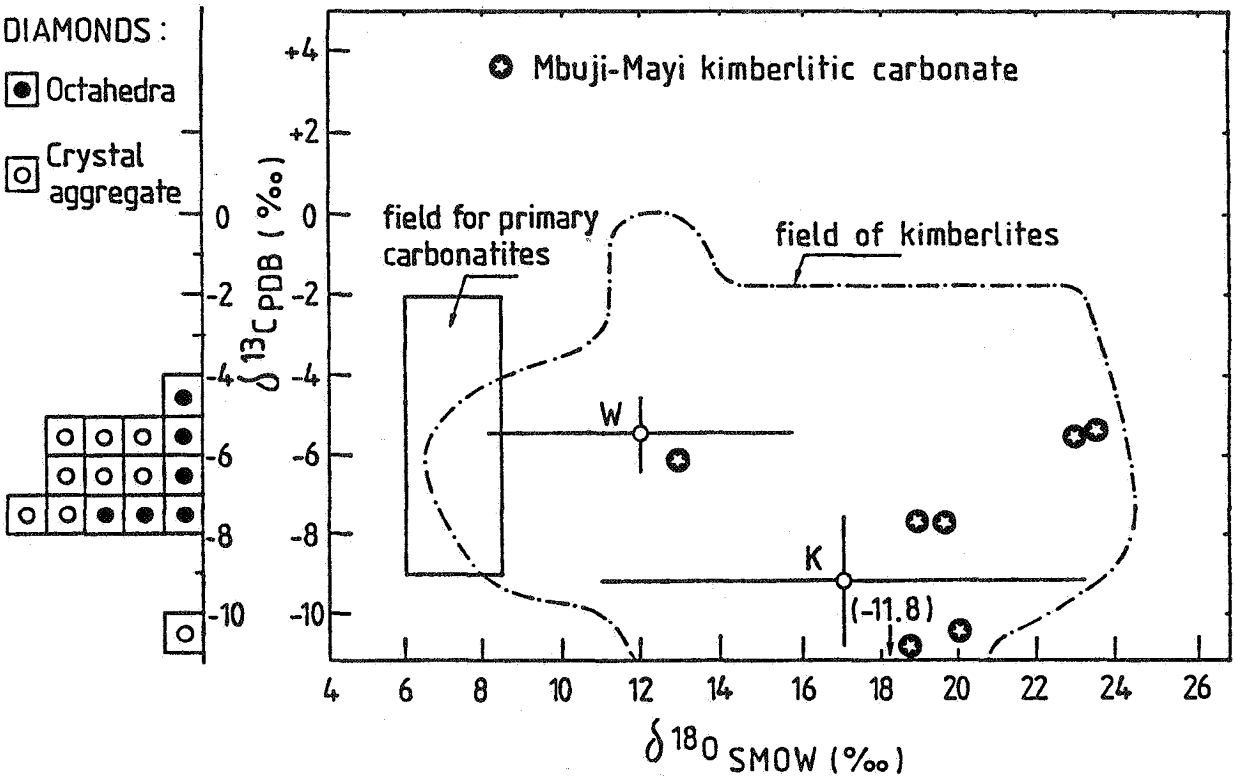

Figure 13: Oxygen isotopic composition of the carbonates (from Demaiffe *et al.*, 1986).

magnesian ilmenites in a peridotitic paragenesis;

- zircon: only one inclusion;

- sulfides: are forming the largest category of inclusions; the most frequent is pyrrhotite;

- associations of minerals: no peridotitic assemblage was found, whereas three eclogitic assemblages were mentioned;

- epigenetic inclusions: goethite, graphite, quartz, hematite.

As a conclusion, Mvuemba-Ntanda classifies the syngenetic inclusions in the Mbujimayi diamonds in three categories (table nr. 5). The majority belongs to a peridotitic paragenesis and this notwithstanding the fact that peridotite xenoliths were never found whilst eclogite xenoliths are frequent.

Recently Navon *et al.* (1989) studied micro-inclusions in Mbujimayi diamonds and came to the suggestion that these represent a fluid ("a melt or a H_2O-C_2O-rich fluid") trapped by the diamonds during their growth. They concluded that: "The diamonds may have grown from a residual melt (or volatile rich fluid) after partial crystallization of a kimberlitic precursor at depth. The micro-inclusion bearing diamond and the kimberlites may thus have a cognate origin at depth".

	MBUJIMAYI		*SOUTH AFRICA*	
	kimberlites	Diopside megacrysts kimberlites	Group I (=basaltic) kimberlites	Group II (micaceous) kimberlites
	t = 71 Ma	t = 71 Ma	t = 80-114Ma	t = 114-150Ma
$(^{87}Sr/^{86}Sr)_t$	0.7041-0.7045	0.70297-0.70323	0.7033-0.7049	0.7074-0.7109
$\varepsilon^t Nd$	+1.9 to + 5.9	+6.3 to 6.9	+2 to +5	-5 to -9
$(^{206/204}Pb)_t$	18.27 - 18.51	-	18.67-19.27	17.21-17.64
$(^{207/204}Pb)_t$	1.555 - 15.59	-	15.52-15.72	15.47-15.62

Table 4: Initial Sr, Nd and Pb isotopic data for the Mbujimayi kimberlites and diopside megacrysts (from Weis and Demaiffe, 1985); comparison with data for South African kimberlites (Smith, 1983; Fraser *et al.*, 1985).

Ultramafic (lherzolite)	*Eclogite s.s.*	*Kyanite ecologite or grospydite*
1. Olivine 2. (Enstatite) 3. Cr Diopside 4. Cr Pyrope 5. Cr Ilmenite 6. Sulfides 7. Zircon (?) 8. Mg Chromite (?)	Pyrope-almand-gross Omphacite Rutile Sulfides Zircon (Ilmenite) (Coesite) Fe chromite (?)	Jadeitic pyroxene (calcic garnet) Kyanite Rutile Sulfides Diamond Zircon

Table 5: Summary of parageneses of inclusions, after Mvuemba Ntanda (1980).

( ) Minerals not recognized in the Kasai diamonds.

6. ASPECTS OF PROSPECTING AND MINING OPERATIONS WITH MIBA

6.1. PROSPECTING OPERATIONS

Sampling of gravels to increase reserves or to precise older data is an on going assessment of four major characteristics: (1) thickness (volume) of overburden, (2) thickness (volume) of gravel and bedrock morphology, (3) grade per unit area or volume, (4) recovery and mining factors.

Originally sampling was performed by circular hand dug pits of one square meter surface even down to depths of 40 m. Actually these are restricted to areas with less than 5 m overburden. Casings to depths of 8 m are used only to undertake pitting below the water table or in riverbed gravels. 95 % of total pitting length is performed by truck mounted grab drills of 0.6 to 1 m diameter or by a mechanical auger of 1.2 m diameter and flight of 1 m, down to 35 m depth. Older sampling grids of 80 by 80 m are now densified to 40 x 40 m and sometimes to 20 x 20 m.

As systematic dredging of river gravels is planned, prospecting is also going on in Sankuru, Mbujimayi and Kasai rivers. This is undertaken by diamond drilling and resistivity surveys to determine volume of gravel and bedrock morphology. Acquisition of a microdredge for grade determination is planned.

Volume and structure of the kimberlite pipes are determined by NQ core drilling to depths of 200 m following a grid pattern of either 80 x 40 m or 50 x 50 m grids. Older reserve evaluations were obtained from 2.5 m diameter pitting (Pl. 2, photo 6) and "8" core drilling. As these were only indicative, a "Wirth" inverse circulation drill has recently been ordered for drilling to 150 m at 0.6 m diameter.

Concentration of washed or crushed ore is effectuated by Harz-jigs or a 5 tph, heavy medium separation (HMS) cyclone module. Diamonds are recovered in the 1-16 mm size interval.

Exploration for new kimberlites follows the classical way: river gravel sampling, soil loaming (0.5-3 mm) and ground magnetic survey. In view of the mostly residual character of the soil cover and since ilmenite is abundant in the kimberlites, loaming is particularly useful.

Due to the high diamond grade (±20 cts/m^2) of the gravel in the mining area, evaluations do not need sophisticated calculation procedures. These are often simply based on the polygon method. Lognormal or exponential distributions can be applied if confidence limits are required. Geostatistics have no application: due to the erratic nature of the deposits, covering a karst topography, only pure nugget effect variograms are obtained.

6.2. MINING OPERATIONS

Stripping of up to 40 m sandy-argillaceous overburden is done according to the most classical methods applied in open-cast mining: scraper-dozer and mechanical shovel-truck combinations. A bucket-ladder excavator and two bucketwheel excavators are currently out of commission. Both gravel and kimberlite are mined by mechanical shovels and transported by trucks to the treatment plants. Ultimate transport of the gravel to the central treatment plant is carried out by a 1400 m long cable-belt conveyor.

MIBA has been using a bucket ladder dredge since 1983 to mine a large alluvial plain deposit of the Mbujimayi river at a rate of ± 500.000 m^3 per year.

6.3. TREATMENT AND RECOVERY OPERATIONS

Currently 50 % of total production stems from gravels, 25 % from kimberlites, 10 % from the dredge and 15 % from old tailings which are retreated in an individual HMS cyclone plant. Diamonds are recovered in the 1-25 mm size range.

Kimberlite treatment is achieved in two pan plants with a combined feed rate of 850 m^3 per 8 hour shift. A flowsheet is given in fig. 14. These plants deliver roughly 20 % concentrates from the feed, which are carried in secure trucks to the central treatment plant for further concentration in the Heavy Medium Separation section.

The central treatment plant with a capacity of 1100 m^3 per shift is primarily designed for the treatment of gravel. Its flowsheet is given in fig. 15. Besides a preconcentration in the 1-3 mm size ranges in a rotary pan unit, all concentration is achieved by HMS cones and cyclones.

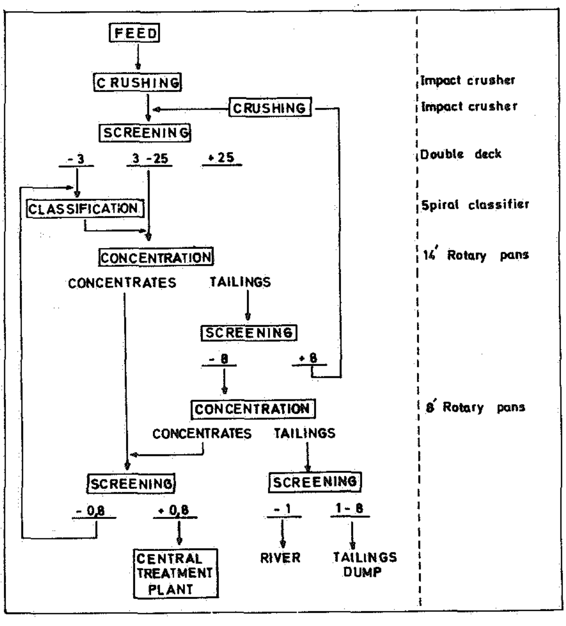

Figure 14: Simplified flow-sheet of Kimberlite Plant.

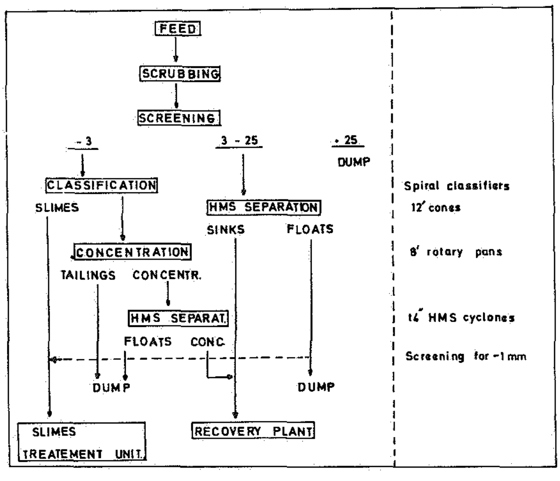

Figure 15: Simplified flow sheet of Central Treatment Plant.

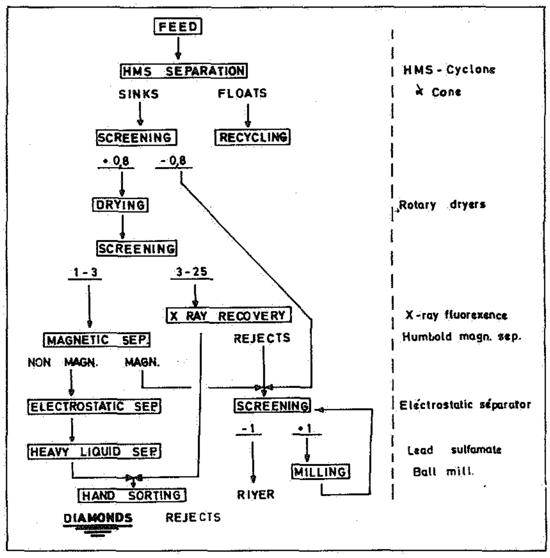

Figure 16: Simplified flow sheet of Recovery Plant.

The concentrates are collected in secure hoppers from where they are conveyed by continuous belt through a concrete tunnel to the recovery plant where the ultimate separations of diamond will take place - see fig. 16 for flowsheet. This separation is based upon the following physical properties of diamonds:

- diamonds fluorescence when submitted to X-rays. This fluorescence is detected by photo-cells which activate air-blast valves to eject diamonds from the feed stream (sortex machines);
- they are non-magnetic: most of the accompanying minerals are magnetic and can be eliminated by magnetic separators;
- diamonds are electrical insulators: in an electrostatic separator they will not become charged;
- they have a density of 3.5: separation of the lighter and heavier minerals is obtained through baths of hot lead sulfamate, the density of which can be varied from 3.2 for the lighter to 3.6 for the heavier minerals.

Finally the hyperconcentrated diamondiferous gravel is sorted by hand and the diamonds are cleaned in hydrofluoric acid. Since its inception in 1918 MIBA has produced nearly 600.000.000 cts.

ACKNOWLEDGMENTS

The authors are indebted to the Management of MIBA and, in particular, to its Chairman. The manuscript has been skillfully typed by Mrs Bakelants and Mrs Van Houtte-Iliano.

REFERENCES

ANONYMOUS, 1979 - Notice explicative de la feuille Mbujimayi (S7/E23) (carte géologique au 1/200 000e). *Département Mines & Serv. Géol. Rép. Zaïre*, Kinshasa, 50 p.

ARTSYBASHEVA, T.F., BLAGULKINA, V.A., ROVSHA, V.S. & SARSADSKIHK, N.N. - 1964 The problem of the classification of the Yakutia kimberlites based on those of the Alakit-Daldynsk diamantiferous region. *Int. Geol. Rev.*, ***6***: 1773-1781.

ATKINSON, W.J., SMITH, C.B. & BOXER, G.L., 1984 - The discovery and evaluation of the Ellendale and Argyle Lamproite diamond deposits, Kimberley Region, Western Australia. *Australasian Inst. Min. Met. Ann. Conf. Darwin*, 141-149.

BARDET, M.G., 1974 - Géologie du diamant. *BRGM*, ***83/3***.

BERGMAN, S.C., 1987 - Lamproites and other potassium-rich igneous rocks: a review of their occurrence, mineralogy and geochemistry. *Geol. Soc.*, ***Sp. Pub. 30***: 103-190.

CARVILL, L.H.C., 1987 - On a diamondiferous peridotite and the genesis of the diamond. *Geol. Mag.*, ***3/IV***: 22-24.

CLEMENT, C.R. & SKINNER, E.M.W., 1979 - A textural genetic classification of kimberlite rocks. *Kimberlite Symp.*, Cambridge (Extended Abstracts).

CLEMENT, C.R., SKINNER, E.M.W. & SCOTT SMITH, B.H., 1984 - Kimberlite redefined. *Journ. Geol.*, ***92***: 223-228.

DAVIS, G.L., 1977 - The ages and uranium contents of zircons from kimberlites and associated rocks. *Ext. Abst. 2nd Intern. Kimb. Conf.*, Santa Fe.

DAWSON, J.B., 1967 - A review of the geology of kimberlite. *In*: P.J. Willie (Ed), *Ultramafic and related rocks*. Wiley, New York, 241-251.

DAWSON, J.B., 1970 - The structural setting of African kimberlite magmatism. *In*: T.N. Clifford & I.G. Gass (Eds), *African Magmatism and Tectonics*, Oliver & Boyd, Edimburgh, 321-335.

DAWSON, J.B., 1980 - Kimberlites and their xenoliths. Springer-Verlag, New York, 252 p.

DEINES, P., 1989 - Regularities in the C. and nitrogen content of the mantle, revealed through studies of diamonds and the chemistry of their inclusions. *Ext. Abstr. Workshop on Diamonds. 28th Int. Geol. Congr.*, 18-20.

de MAGNEE, I., 1946 - Présence de kimberlite dans la zone diamantifère de Bakwanga. *Bull. Soc. belge Géol.*, ***56***: 127-132.

DEMAIFFE, D. & FIEREMANS, M., 1981 - Strontium-isotopic geochemistry of the Mbujimamyi and Kundelungu kimberlites (Zaire, Central Africa). *Chem. Geol.*, ***31***: 311-323.

DEMAIFFE, D., WEIS, D. & MIDENDE, G., 1986 - A depleted mantle source for carbonaties: Sr, Nd and Pb isotope evidence from the Matongo massif (Burundi). *Terra Cognita*, ***Abstr. 3***: 201.

DEMAIFFE, D., FIEREMANS, M. & FIEREMANS, C., 1990 - The kimberlites of Central Africa: A Review. *Paper presented Int. Congr. Magmatism of Extensional Regions - Lubumbashi, Zaire, 1986*, Springer-Verlag.

DE RAUW, H., 1923 - Les gisements diamantifères du Kasaï. *Mém. Congr. Ing. A.I.Lg., 18-24 juin 1922*, 50 p.

FIEREMANS, C., 1953 - Geologie en Geochemie der Diamantvelden van Belgisch-Kongo. *Techn. Wet. Tijdschrift*, ***22/4-5***: 71-82 & 93-98.

FIEREMANS, C., 1960 - Etude Critique des Classifications des formations diamantifères du Kasaï et dans la Luanda. *Mém. Inst. Géol. Louvain*, ***21***: 249-278.

FIEREMANS, C., 1961a - Origine et répartition de la minéralisation diamantifère au Kasaï Occidental (Congo) et dans le NE de la Luanda. *Bull. Soc. belge Géol.*, ***70***: 89-95.

FIEREMANS, C., 1961b - Géologie du diamant. *Rev. quest. sc.*, 20 avril, 219-233.

FIEREMANS, C., 1966 - Contribution à l'étude pétrographique de la brèche kimberlitique de Bakwanga. *Mém. Inst. Géol. Univ. Louvain*, ***24***, 92 p.

FIEREMANS, C., 1977a - Mode of occurrence and tectonic control of the kimberlite bodies in East Kasai (Zaire). *Ext. Abstr. 2nd Int. Kimberlite Conf.*, Santa Fe.

FIEREMANS, M. & OTTENBURGS, R. 1979b - Kimberlite inclusions and chlorite nodules from the kimberlite breccia of Mbujimayi (Eastern Kasai, Zaire). *Bull. Soc. belge Géol.*, ***88***: 25-31.

FIEREMANS, M., HERTOGEN, J. & DEMAIFFE, D., 1984 - Petrography, geochemistry and Sr isotopic composition of the Mbujimayi and Kundelungu kimberlites (Zaire). *In*: J. Kornprobst (Ed). *Kimberlites-1: Kimberlites and related rocks*, Develop. in Petrology, ***11A***: 107-120.

FRANTSESSON, E.V., 1970 - The Petrology of Kimberlites (translated from the Russian by D.A. Brown). ***150***, *Department of Geology, Australian Nat. Univ. Canberra.*

FRASER, K.-J., HAWKESWORTH, C.J., ERLANK, A.J., MITCHELL, R.H. & SCOTT-SMITH, B., 1985 - Sr, Nd and Pb isotope and minor element geochemistry of lamproites and kimberlites. *Earth Planet. Sci. Lett.*, ***76***: 57-70.

HAWTHORNE, J.B., 1975 - Model of a Kimberlite Pipe. *Physics and Chemistry of the Earth.* ***9***: 1-16, Pergamon Press.

JAVOY, M., PINEAU, F. & DEMAIFFE, D., 1984 - Nitrogen and carbon isotopic composition in the diamonds of Mbujimayi (Zaire). *Earth Planet. Sci. Lett.*, ***68***: 399-412.

KOVALSKI, 1963 - The Kimberlitic Rocks of Yakutia Izdatelstvo. *Akad. Nauk. SSSR*, Moscow (Russian).

KRAMERS, J.D., 1977 - Lead and Strontium Isotopes in inclusions in diamonds and in mantle-derived xenoliths from Southern Africa. *2nd Int. Kimb. Conf.*, Santa Fe.

KRESTEN, P., FELS, P. & BERGGREN, G., 1975 - Kimberlite zircons - a possible aid in prospecting for kimberlites. *Min. Deposita*, ***10***: 47-56.

MARAKUSHEV, A.A., 1982 - The fluid regime in the formation of diamond-containing rock. *Int. Geol. Rev.*, ***24***: 1241-1252.

MEYER, H.O.A., 1987 - Inclusions in diamond. *In*: P.H. Nixon (Ed), Mantle Xenoliths. John Wiley & Sons Ltd, 501-523.

MEYER, H.O.A., 1989 - Diamond in space and time. *Workshop on diamond. 28th Int. Geol. Congr.*.

MEYER, H.O.A. & BOYD, F.R., 1972 - Composition and Origin of Crystalline Inclusions in natural diamonds. *Geochemica & Cosmochimica Acta.* ***36/11***.

MEYER, H.O.A. & HSIAO-MING TSAI, 1976 - The nature and significance of Mineral Inclusions in natural diamond: A Review. *Min. Sc. Eng.*, ***8/4***, Oct. 1976.

MEYER de STADELHOFEN, C., 1963 - Les brèches kimberlitiques du territoire de Bakwanga (Congo). *Arch. Sci.*, ***16/1***: 87-143, Genève.

MILASHEV, V.A., 1963 - The term "kimberlite" and the classification of kimberlitic rocks. *Geol. Geofiz.*, ***4***: 42-52.

MILASHEV, V.A., 1984 - Explosion pipes (Trubki Vzryva), Nedra, Leningrad. Translated by R.E. Sorkina, Springer-Verlag, 1988.

MITCHELL, R.H., 1979 - The alleged kimberlite-carbonatite relationship: Additional contrary mineralogical evidence. *Amer. J. Sc.*, ***279***: 570-589.

MITCHELL, R.H., 1986 - Kimberlites: Mineralogy, Geochemistry and Petrology. Plenum Press.

MITCHELL, R.H., 1989 - Aspects of the petrology of kimberlites and lamproites: some definitions and distinctions. *IVth I.K.C., Kimberlites and Related Rocks*, ***1***: 7-45.

MVUEMBA-NTANDA, F., 1980 - Minéralogie des mégacristaux, des xénolites éclogitiques et granulitiques et des inclusions cristallines dans les diamants provenant de la kimberlite du Kasaï Oriental, Zaïre. *Unpubl. Doct. Thesis, Univ. Louvain*, 221 p.

MVUEMBA-NTANDA, F., MOREAU, J. & MEYER, H.O.A., 1982 - Particularités des inclusions cristallines primaires des diamants du Kasaï, Zaïre. *Canad. Miner.*, ***20***: 217-230.

NAVON, O., SPETTEL, B., HUTCHEON, I.H., ROSSMAN, G.R. & WASSERBURGH, G.J., 1989 - Micro-Inclusions in diamonds from Zaire and Botswana. *Extr. Abstr. Workshop on Diamonds. 28th Int. Geol. Cong.*, 69-72.

NIXON, P.H. & BOYD, F.R., 1973 - The discrete nodule association in kimberlites from Northern Lesotho. *In*: P.H. Nixon (Ed.), Lesotho kimberlites, Lesotho National Development Corporation, Maseru, 67-75.

NIXON, P.H., ROGERS, N.W., GIBSON, I.L. & GREY, A., 1981 - Depleted and fertile mantle xenoliths from Souther African kimberlites. *Ann. Rev. Earth Planet. Sci.*, ***9***: 285-309.

OTTENBURGS, R. & FIEREMANS, M., 1979 - Rutile-silicate intergrowths from the kimberlite formations at Mbujimayi (Bakwanga, Zaïre). *Bull. Soc. belge Géol.*, ***88***: 197-203.

POLINARD, E., 1951 - Les gisements de Diamant du Bassin du Kasaï au Congo belge et en Angola. *Mém. Inst. roy. Sc. nat. Belgique*, ***7/6***: 1-37.

POLINARD, E., 1929 - Les Diamants translucides et opaques des gisements de la Bushimaie. *Ann. Soc. Géol. Belgique*, ***52/4***: 1-41.

POLINARD, E., 1930 - Les Diamants transparents des gisements de la Bushimaie. *Ann. Soc. Géol. Belgique*, ***53***: 1-37.

POLINARD, E., 1931a - Les Diamants en agglomération de cristaux et les Diamants à cristallisation confuse des gisements de la Bushimaie. *Ann. Soc. Géol. Belgique*, ***54***: 1-22.

POLINARD, E., 1931b - Les Déformations extérieures, les Propriétés internes et les Modalités de la Cristallisation des Diamants de la Bushimaie. *Bull. Acad. roy. Belgique, Cl. Sci.*, 5e sér., ***17/2***: 137-162.

RABHKIN, M., KRUTOYARSKII, M. & MILASHEV, V., 1962 - Classification and nomenclature of Yakutian kimberlites. *Tr. Issled Inst. Geol. Arktiki*, ***121***: 154-164 (Russian).

RICHARDSON, S.H., GURNEY, J.J., ERLANK, A.J. & HARRIS, J.W., 1984 - Origin of diamonds in old enriched mantle. *Nature*, ***310***: 198-202.

SKINNER, E.M.W. & CLEMENT, C.R., 1979 - Mineralogical Classification of Southern African kimberlites. *SIKC*, ***1***: 129-139.

SKINNER, E.M.W., 1989 - Contrasting Group I and Group II kimberlite petrology; towards a genetic model for kimberlites. *IVth I.K.C. Perth*, ***1***: 528-544.

SMITH, C.B., 1983 - Pb, Sr and Nd isotopic evidence for sources of Southern African Cretaceous kimberlites. *Nature*, ***304***: 51-54.

SMITH, S.B.K. & SKINNER, E.M.W., 1984 - A new look at Prairie Creek, Arkansas. *Terra Cognita*, ***2***: 210.

SMITH, C.B., GURNEY, J.J., SKINNER, E.M.W., CLEMENT, C.R. & EBRAHIM, N., 1985 - Geochemical character of Southern African kimberlites: a new approach based upon isotopic constraints. *Trans. Geol. Soc. S. Afr.*, ***88***: 267-280.

SOBOLEV, N.V., 1977 - The deep-seated inclusions in kimberlites and the problem of the upper mantle composition. Nauka Publ. Moscow (Translated by Brown, D.A. and edited by F.R. Boyd). *Amer. Geophys. Union*, 279 p.

SOBOLEV, N.V. & SHATSKY, V.S., 1990 - Diamond Inclusions in garnets from Metamorphic Rocks: a new environment for diamond formation. *Nature*, ***343***: 742-746.

TOMPKINS, L.A., BAILEY, S.W. & HAGGERTY, S.E., 1984 - Kimberlitic chlorites from Sierra Leone, West Africa: unusual chemistries and structural polytypes. *Amer. Miner.*, ***69***: 237-249.

WAGNER, P.A., 1914 - The diamond fields of South Africa. Johannesburg.

WASILEWSKY, I., 1950 - Note préliminaire sur les gisements de brèche kimberlitique de Bakwanga. *C.R. Cong. Sc., CSK*, ***2***: 291-332.

WEIS, D. & DEMAIFFE, D., 1985 - A depleted mantle source for kimberlite from Zaire: Nd, Sr and pb isotopic evidence. *Earth Planet. Sci. Lett.*, ***73***: 269-277.

Manuscript received 21.08.90 and accepted for publication 30.10.90

Plates 1 + 2

PLATE 1

Photo n°1 : Sandy-argillaceous "gravels" with kaolin pebbles. The deposits are covered by red claystones.

Photo n° 2 : "Hill-side gravels" covered by red argillaceous sand and resting on a red sand formation with sparse kaolin nodules.

Photo n° 3 : General view of the pot-hole of Senga-Senga (Mbujimayi River).


1


2


3

PLATE 2

Photo n° 4 : Gravel filling of the Senga-Senga pothole. Notice the small black dots which are all ilmenites.

Photo n° 5 : Dredge at work on an alluvial plain deposit of the Mbujimayi River.

Photo n° 6 : Hand-dug pit in weathered kimberlite (yellow ground).

Photo n° 7 : Bedding in epiclastic kimberlite from pipe n° 3.

Photo n° 8 : Kimberlite breccia (pyroclastic facies), with nodule of hypabyssal facies kimberlite (pipe n° 5).

Photo n° 9 : Pyroclastic facies kimberlite (weathered). Notice the rounded inclusion of (weathered) granite (hammer) (pipe n° 1).


4


5


6


7


8


9