KIMBERLITE INCLUSIONS AND CHLORITE NODULES FROM THE KIMBERLITE-BRECCIA OF MBUJI-MAYI (EASTERN KASAI) ZAIRE.

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ABSTRACT. - Mineralogical and petrological investigations have been carried out on samples of the kimberlite breccia of Mbuji-Mayi, and on a suite of primary kimberlite inclusions and quartz-chlorite nodules.
        Petrographical and chemical characteristics are presented together with trace element and Sr isotopic determinations. The kimberlite nodules are shown to represent relatively uncontaminated material of hypabyssal character.
        We also wanted to emphasize the primary nature of the matrix calcite and the magmatic origin of carbonate inclusions, as well as to describe some peculiar autometamorphic transformations which involve phlogopitisation of olivine and formation of a "primary" chlorite.
        Finally, a hypothetical intrusion sequence is proposed.

INTRODUCTION.

        Kimberlite-breccias are known in Eastern Kasai, Zaïre, at several points (de MAGNEE 1946; WASILEWSKY 1950; MEYER de STADELHOFEN 1963; C. FIEREMANS 1966, 1977). They are the basis of one of the biggest diamond-mining centers of the world; nevertheless little is known abouth the petrology of these breccias. They occur in cup-shaped basins with or without small roots or pipes (C. FIEREMANS 1977) and are named "massifs" by the local mining people.
        The purpose of this study will be to describe more accurately some petrographic and chemical characteristics of the breccia and its "primary" kimberlite fragments or nodules, while likewise examining some enigmatic but frequently occurring quartz-chlorite nodules.

I. THE KIMBERLITE BRECCIA.

        The kimberlite breccia of Mbuji-Mayi of probably late cretaceous age (C. FIEREMANS 1966; zircon age 71.3 m. y. DAVIS 1977) intrudes the old basement complex, mainly composed of granitic

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gneisses known as the Dibaya complex, the precambrian sandstones
and dolomitic limestones of the Bushimayi complex, and the mesozoïc,
often friable, sandstones of the Loïa-series (ancient Lualaba series).
    Exhaustive petrographic studies of the breccia and its va-
rious inclusions were published by WASILEWSKY (1950), MEYER de
STADELHOFEN (1963) and C. FIEREMANS (1966).
    With the exception of a more specific determination of the
secondary minerals described as serpentine of serpentinitic material
by these authors, little could be added to their excellent descrip-
tions. In fact we only could identify saponite and phlogopite, oc-
curing as the replacement products of the olivine crystals.
    Having at our disposal three specimens of the blue ground
("brèche cimentée") taken at different levels, we performed three
chemical analyses (table 1) which are compared to an analysis of
blue ground taken from a near surface level (C. FIEREMANS 1966).
The yellow ground ("brèche lessivée") occurs at the surface proper.
Due to the brecciated character and the amount of extraneous mate-
rial (the breccia was called a "xeno-tuff breccia" by C. FIEREMANS
1977) no definite conclusion can be formulated. Nevertheless we can
establish that, where CaO and Sr have been leached from the yellow
ground, MgO is unaffected; Mg is mainly present as a component of
saponite and phlogopite.
    In the blue ground specimens on the other hand, the CaO
content is quite constant. Its presence and the low Ca/C ratios
(see table 1) are an expression of the numerous dolomite xenoliths
derived from the precambrian Bushimayi system.

Table 1 - Chemical analysis of the kimberlite breccia at different levels.

		Blue ground (a) 403 m	Blue ground (a) 220 m	Blue ground (b) near surface	Yellow ground (a) surface
Wt %	SiO_2	58.16	42.15	51.61	60.21
	Al_2O_3	3.38	3.05	6.46	3.62
	Fe_2O_3	1.69	2.89	3.15	6.32
	FeO	2.42	3.67	0.66	0.86
	MnO	0.10	0.11	–	0.10
	MgO	9.84	16.61	12.21	10.69
	CaO	5.83	8.67	6.52	0.82
	Na_2O	0.12	0.12	0.35	0.12
	K_2O	1.07	0.57	0.75	0.41
	H_2O^+			5.04	
	H_2O^-	8.09	10.36	0.44	14.58
	CO_2	8.07	10.64	11.44	–
	TiO_2	0.43	0.35	0.47	0.63
	P_2O_5	0.12	0.13	0.47	0.14
	TOTAL	99.32	99.32	99.57	98.50
	Ca/C	0.54	0.62	0.37	–
ppm	Rb	34	23		20
	Sr	244	218		17
	Zr	91	56		81
	Y	7	5		66

(a) Total analyses : analyst D. COETERMANS
    Rb, Sr, Zr, Y : analysts M. DELVIGNE - F. DUREZ.
(b) C. FIEREMANS (1966)

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II. THE KIMBERLITE NODULES

        The kimberlite fragments form a conspicuous part of the breccia. They occur frequently as small debris in thin sections of the blue ground, and are only rarely found as larger rounded nodules. Mentioned for the first time by WASILEWSKY (1950) they were described in some detail by C. FIEREMANS (1966). They were called by the authors "kimberlite primaire" in contrast to the blue ground which was called "brèche kimberlitique secondaire", in order to emphasize its secondary nature, which was at first a matter of controversy (sedimentary or volcanic ?). The volcanic nature of the breccia was afterwards established by C. FIEREMANS (1966, 1977).
        Due to their rarity only five nodules of "primary kimberlite" were available for this study. One of these (n°1), is completely rounded, and has a diameter of   15 cm (see photo 1). A subrounded nodule with a diameter of 6 cm (n°2) was found in a borecore at 324 m depth. The three others (n°4, 5 and 6) are small rounded nodules of 2-3 cm in diameter. The two first nodules come from "massif" n° 5, whereas the three small ones were found in "massif" n° 1.

A. PETROGRAPHY

        The original nature of the rock is obscured by the extensive alterations it underwent. Nevertheless, the particular textures described from kimberlites of other parts of the world can still be recognized. In particular the porphyritic nature with two generations of (pseudomorphosed) olivine crystals is conspicuous (see photo 2).

1. **Nodules 1, 2 and 6** : since the petrographic characters of these three nodules are virtually identical they will be described together.

1a. **The phenocrysts.**

        A first generation of olivines consists of large ($\emptyset$ up to 2 cm) rounded   or erratically shaped crystals. They are completely replaced by a pseudomorphous aggregate of phlogopite, calcite and saponite. The phlogopite aggregates, pseudomorphous after olivine, mimic features such as mesh textures and hourglass textures possibly indicating a previous serpentinization phase. Later replacement of the phlogopite leads at first to the occurrence of calcite and quartz between the phlogopite flakes (pleochroic from yellow green to colourless) while in more advanced stage, calcite and quartz may invade the olivine, or form a core connected to the border by fine calcite veins. Ovoïd pyroxene grains (in part replaced by calcite and quartz), chlorite (see below), and rare chromite can form inclusions in the olivine pseudomorphs. In nod. 6 calcite and dolomite were observed as replacement products, but quartz was lacking.
        Chlorite crystals of size up to 5 mm have a medium birefingence and are biaxially negative, with a very small optic angle. By means of the X-ray diffraction technique this chlorite was classified as a member of the Kämmererite-Kotschubeite group. Their pleochroism (γ blue green > α = β yellow green) would indicate a relatively low chromium content (NEUHAUS 1960, BURNS 1970).
        Often these chlorites are intergrown with monocrystalline quartz which occurs as lenses between the chlorite cleavage planes and has the aspect of an injected phase. Greater abundance of quartz gives rise to a lateral expansion of the chlorite booklets producing "swollen" shapes (see photos 3 and 4).
        Infilling of quartz along one specific cleavage place can result in a uniform quartz layer within one chlorite crystal.

Although these chlorite-quartz units occur mostly isolated within the breccia, they also were found enclosed by first generation olivine.

The presence of three small nodular bodies, connected by narrow calcite-quartz veins, and consisting of quartz intimately interlaced with chlorite, indicates that these textures originated during the quartz-calcite replacement phase.

1b. The groundmass.

Typical elements of the kimberlite groundmass are the second generation euhedral olivines (ϕ < 1 mm), and the euhedral chlorite crystals. Here also olivine is completely replaced by phlogopite and saponite. The chlorite crystals exhibit the same mineralogical characteristics as the larger chlorites described above. Zoned and twinned composite crystals have been observed (see photo 5). They occur in a mainly calcitic and saponitic mass which is difficult to resolve under the microscope. Magnetite is a constant and uniformly dispersed groundmass mineral. Apatite and rutile are present but not frequent. Specific for nodule 1 are very small microliths of a highly birefringent mineral with straight extinction. Possibly it concerns calcite pseudomorphs after melilite.

In nodule 2 we also observed small crystals of sphene and acicular clinopyroxene.

Sphene rimmed by opaque material, and brookite are minor phases in nod. 6.

In nodule 2 the chlorites have been partially replaced by phlogopite. The chlorite megacrysts are surrounded by a wide, dark brown pleochroic rim of phlogopite.

These relations are less clear when the phlogopitisation evolves along cleavage planes and the observation is rendered even more difficult for the groundmass flakes where the relations sometimes seem to be inversed. The chlorites of nod. 6 show a colourless rim of phlogopite. In the groundmass of this nodule, phlogopite and chlorite occur side by side.

1c. The xenoliths.

Pyrope and magnesian ilmenite are typomorphic minerals of kimberlite and as such we only observed their presence in the kimberlite. Among the garnets unaltered specimens occur next to grains surrounded by a large, brown, nearly opaque, or green keliphytic border.

Of some garnets nothing is left but a small core surrounded by green fribroradious vermiculite with very small inclusions of a brown spinel.

Truncated specimens attest to a keliphitisation prior to brecciation.

Large brown biotite flakes occur isolated or associated with pyroxene grains.

A plagioclase aggregate, a gneissic xenolith and fragments of red sandstone, occuring in nod. 1 leave no doubt of their origin in the basement complex.

Nodule 2 contains an inclusion of an eclogitic rock severely affected by calcitic and chloritic alteration, and also showing the secondary phlogopitisation of chlorite observed in nod. 2.

Most conspicuous is the presence in nodule 1 of several large (up to 4 cm) angular inclusions of a light gray coloured carbonate rock, the origin of which is quite enigmatic (see photo 1). The first idea is to attribute these fragments to the limestone-dolomite series of the Bushimayi -system, but their petrographic (and chemical) characteristics suggest a deep-seated origin for this carbonate rock.

Microscopically the rock has a micritic aspect, it is seen to consist of a turbid mass of very fine grained carbonate crystals. Typical of these inclusions are the randomly oriented, or dendrically arranged, lath shaped crystals of a brown coloured carbonate mineral (probably a ferruginous dolomite) (see photo 6). One of the inclusions shows an embayment of kimberlitic material.

1d. The carbonates.

Beside the inclusions of carbonate rock described above the nodules contain a high proportion of carbonates (mainly calcite, sometimes dolomite or ankerite) occurring in a variety of ways :
- as thin veinlets with granular or fibrous texture. In nodules 1 and 2 some of these veinlets contain quartz. They are found cross-cutting as well as curving around the phenocrysts, and are probably responsible for the observed carbonatisation and silicification of the phenocrysts. In certain veinlets one may occasionnally remark an isolated crystal of euhedral chlorite or phlogopite.
- as isolated grains, or aggregates of anhedral calcite.
- as dispersed calcite in the phyllitic groundmass.
- as fine rimlets of calcite enveloping some pseudomorphs after first generation olivine.
- remarkable in nodule 6 are the frequent round specks of phlogopitic material surrounded by a chaplet-like rim of calcite. They may represent a similar alteration of the second generation olivines.
- in vugs with calcite rims and ankerite cores, where the calcite shows a centrally directed dog tooth structure.

2. Nodule 4 :

Is of grey-green colour; but with a darker central core. This zoning is also distinct in thin section :
- a border zone consisting of a very fine phyllitic groundmass enclosing small chloritised phlogopite crystals and some calcite grains.
- a zone of chloritised phlogopite enveloped in a granular mass of small round phlogopitic specks surrounded by calcite chaplets; some quartz grains.
- a central zone of less chloritised phlogopite, sometimes interlaced with quartz. Often of erratic outlines the quartz grains, however, sometimes indicate idiomorphic outlines and one can possibly imagine them to be pseudomorphous after olivine. Calcite grains are less abundant.
The opaque minerals present are magnetite and leucoxene. They are uniformly dispersed throughout the zones.
The phyllitic material shows a parallel arrangement. Chemical analyses were performed; both of the central and marginal zone.

3. Nodule 5 :

The nodule shows a straight contact of two kimberlite types differing only in the size of the phenocrysts (see photo 7). The olivine is pseudomorphously replaced by quartz and minor calcite. According to the euhedral outlines and the small sizes of these pseudomorphs, they probably represent second generation olivine.
In the second type of kimberlite, pseudomorphs of quartz after olivine occur in only one generation of fine grained crystals. Phlogopitised chlorite phenocrysts occur only in the layer with the larger olivine pseudomorphs.
In both kimberlites the olivine pseudomorphs are enclosed in a mosaic of poikilitic calcite crystals. Euhedral chlorites,

largerly transformed into a colourless phlogopite are sparsely dispersed among those oikocrysts and define a planar texture parallel to the contact plane of the two kimberlites.

A similar parallel texture of the altered olivines is less pronounced.

Frequent apatite crystals are randomly dispersed within the calcitic groundmass. Brookite and rutile occur in accessory amounts and may be surrounded by an opaque rim.

Ilmenite, and magnetite, rimmed by hematite, are frequent and in both types gain in abundance towards the contact plane of these kimberlites.

B. CHEMISTRY.

A total chemical analysis of each of the five nodules was performed by atomic absorption and emission spectrophotometry.

Analysis of nod4(rim) was performed by X-ray fluorescence methods.

The results are presented in table 2. A comparison is made with analyses of kimberlites from different parts in the world and with a mean analysis of micaceous and basaltic kimberlite, taken from DAWSON (1968) (see Figure 1).

Analyses 1, 2, 3, 5 and 6 show a very good agreement and permit to form a general notion of the primary kimberlite of Mbuji-Mayi :
- Al_2O_3 (average value 3.95 %) and total iron (average 6.72 % calculated as FeO) are very constant. The Fe^{3+} amount is always larger than the Fe^{2+} content.
- CaO, after substraction of normative apatite, amounts to 13-19 %. The proportion Ca/C close to unity excludes the presence of a substantial dolomite quantity. Mg is mainly a component of chlorite, phlogopite and saponite. Calcite calculated from CaO amounts to a percentage of 24-27 %.
- Compared to the other nodules, the SiO_2 content of samples 5 and 4 (core) is higher, while the MgO and H_2O contents are significantly lower. This is an accordance with the low amount of chlorite and the presence of quartz in these two nodules.
- The K_2O values reflect the variable phlogopite content, which is more abundant in nodules 5 and 4 (core), and is practically absent in nodules 1 and 4(rim).
- P_2O_5 is remarkably high in nod 5 and permits to calculate 4.3 % normative apatite.

The zoned character of nod 4 is suggested to have resulted from metasomatic processes of magmatic origin. The rarity of the observed processes, however, makes it difficult to determine the stage at which they occurred.

FESQ et al. (1975) recommend the use of the proportions Si/Mg (0.88) and Mg/Mg+Fe (0.86) to define the degree of crustal contamination of the magma. These values, however, must be considered in our case with cautiousness due to the widespread silification.

A comparison with the average composition of kimberlite rocks from other parts in the world, and the diagrams of figure 1, show that the Mbujimayi-kimberlite is rich in volatiles and carbonates; the MgO content is accordingly lower; TiO_2, total iron, and Al_2O_3, although somewhat lower, are quite comparable.

The general agreement with the average South-African kimberlite (GURNEY and EBRAHIM 1973) however, is remarkable. GURNEY and EBRAHIM (1973) state that the divergencies between the average composition of South-African kimberlites and the Lesotho kimberlites is apparently due to "a high proportion of samples of dyke kimberlite in the South-African average (35 out of 80)". They think that the pipes during their emplacement would lose more volatiles than dykes, which would explain that "dyke rocks tend to be more micaceous and more carbonated".

Therefore this close agreement could indicate a more hypabyssal cha-
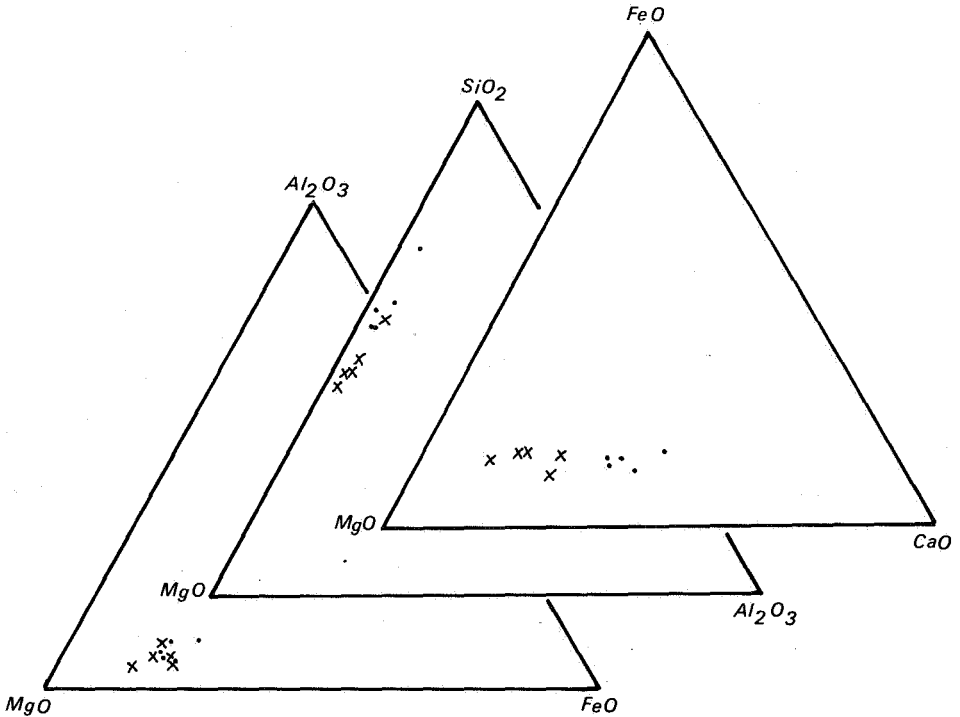racter of the Mbujumayi material.

Fig. 1 – Triangular diagrams for the kimberlite nodules of Mbujimayi (dots),
and average kimberlite compositions as presented in Table 2, plotted
as cation proportions.
Nod 4 was not represented because of its zoned character.

        Table 3 figures the contents of the selected trace ele-
ments Zr, Y, Rb and Sr, determined by X-ray fluorescence methods.
These contents fall within the range of some South-African kimber-
lites as defined by FESQ et al. (1975) and KABLE et al. (1975).
        A clear relation can be established between the contents
of Rb and K, Sr and Ca, Y and P. Such relations are usual and are
in accordance with the generally observed associations of these ele-
ments. They are expressed in the mineralogical composition by the
presence of phlogopite, calcite and apatite respectively.

        These trace elements were also determined at three diffe-
rent levels of the Precambrian Bushimayi limestone-dolomite system
(see table 4). The lower values in these limestones indicate that
their assimilation by a kimberlite magma only could have a lowering-
effect on the amounts of the trace elements.
        The relatively low amounts of trace elements in the blue
ground breccia (see table 1), are an expression of the numerous li-
mestone fragments.

Table 2 : Chemical analysis of kimberlite nodules and carbonate inclusions, compared to average kimberlite compositions.

	Nod.1	Nod.2	Nod.3 (a)	Nod.4 core	Nod.4 rim	Nod.5	Nod.6	Micaceous kimberlite (b)	Basaltic kimberlite (b)	Lesotho kimberlite (c)	S. African kimberlite (c)	Yakutian kimberlite (d)	Carbonate inclusion 1 in nod.1	Carbonate inclusion 2 in nod.1
SiO_2	33.46	35.94	31.70	63.22	31.78	40.63	30.25	31.10	35.2	33.21	36.36	27.64	13.02	6.33
Al_2O_3	3.01	5.20	4.04	3.98	3.95	3.67	3.81	4.90	4.40	4.45	5.13	3.17	0.26	0.29
Fe_2O_3	6.95	4.00	4.64	5.22	9.60	4.25	5.50	-	-	6.78	-	5.40	0.70	0.92
FeO	1.37	2.78	2.25	1.79	n.d.	2.32	1.81	10.50	9.80	3.43	7.71	2.75	0.26	0.20
MnO	0.14	0.13	-	0.12	0.18	0.18	0.19	0.10	0.11	0.17	0.16	0.13	0.14	0.23
MgO	15.35	14.62	16.63	5.92	13.41	10.00	15.92	23.9	27.9	22.78	17.43	24.31	11.69	12.74
CaO	16.11	13.46	18.83	5.68	16.23	16.55	15.28	10.6	7.6	9.36	11.16	14.13	39.84	42.18
Na_2O	0.15	0.25	0.10	0.11	0.14	0.06	0.06	0.31	0.32	0.19	0.42	0.23	0.15	< 0.05
K_2O	0.2	1.05	tr	1.68	0.26	1.27	0.98	2.10	0.94	0.79	1.52	0.79	< 0.05	< 0.05
H_2O^+	9.37	9.25	⎫	2.73	7.40	2.89	9.26	5.90	7.4	8.04	-	7.89	2.29	2.32
H_2O^-			⎬ 20.80							2.66				
CO_2	12.11	11.01	⎭	4.16	11.89	13.91	14.28	7.10	3.3	4.58	-	10.84	33.12	37.64
TiO_2	1.06	0.59	0.62	2.72	3.27	1.64	1.41	2.03	2.32	1.97	0.98	1.65	< 0.05	< 0.05
P_2O_5	0.78	0.10	-	0.88	1.39	1.83	0.87	0.66	0.72	0.65	0.55	0.55	0.25	0.34
TOTAL	100.06	98.38	99.61	98.21	99.50	99.20	99.62	-	-	99.37	-	-	101.82	103.34
Ca/C	0.98	0.95	-	0.85	1.07	0.80	0.78	-	-	-	-	-	-	-
Mg/Mg+Fe	0.78	0.80	0.82	0.62	0.73	0.74	0.81	0.81	0.84	0.81	0.80	0.85	-	-

Analysis of nodules 1, 2, 4 core, 5, 6 and carbonate inclusions : analyst D. Coetermans
Analysis of nodule 4 rim : analysts M. Delvigne and F. Durez ;total iron determined as Fe_2O_3
(a) C. Fieremans (1966)
(b) Dawson (1963)
(c) Gurney and Ebrahim (1973)
(d) Ilupin and Lutz (1971)

Table 3 - trace elements of kimberlite nodules, and kimberlite breccia from
          Mbujimayi, compared to kimberlites from Southern-Africa; values in ppm.

	Nod. 1	Nod. 2	Nod. 4 core	Nod. 4 rim	Nod. 5	South-Afr. Kimberl. range (a)	Basutol. kimberl. (b)	Benfont sills kimberl. (c)
Rb	18	85	75	17	54	4-120	21	9
Sr	537	203	139	303	1350	183-1520	445	995
Zr	145	55	118	132	291	106-304	445	260
Y	10	5	9	18	17	8-19	46	4

Nodules 1 to 5 : analysts : M. DELVIGNE -F. DUREZ, MRAC

(a) Rb and Sr : FESQ et al. (1975)
    Zr, Y : KABLE et al (1975)

(b) DAWSON (1962)

(c) DAWSON and HAWTHORNE (1973)

Table 4 - trace elements of two carbonate inclusions in nodule 1,of three niveaus
          of the precambrian Bushimayi system compared to examples from the
          literature; values in ppm.

	Carbon. inclus.1 nod. 1	Carbon. inclus.2 nod. 1	Limest. 31.685	Dolomitic limest. 31.369	Dolomite 165-4	Average carbonate rock (a)	Average carbona- tite (b)	Benfont. calcitic layer (c)
Rb	1	0	15	4	13	70 ± 40		5
Sr	472	599	159	665	44	475 ± 50	2450	2795
Zr	74	109	40	126	29	17 ± 4	83	5
Y	5	6	9	0	11	13 ± 3	96	3

Carbonate inclusions and dolomites: analysts : M. DELVIGNE - F. DUREZ, MRAC.

(a) GRAF (1960)

(b) GOLD (1963)

(c) DAWNSON and HAWTHORNE (1973)

        Notwithstanding the difficulty to draw definitive con-
clusions from only five analyses there seems to be a positive cor-
relation between P, Ti, Zr, Sr and Y (see figure 2). These elements
are generally considered as non volatile and less mobile.
        Other sympathetic variations between these elements were
established by KABLE et al. (1975) for South-African kimberlites
and by STERN and ELTHON (1979) for basic dikes and lavas. They
explained these relations as a primary magmatic effect caused by
crystal liquid fractionation processes.
        The correlation between Ti and P, and correlations of both
Ti and P with Zr and Y, as well as the correlation between Ti and K,
would indicate a late stage enrichment of these elements in the re-
sidual melt, thus marking the phlogopitization of chlorite as a
late stage magmatic process, rather than a hydrothermal.

It must be pointed out that nodules 4 and 5 which are richest in Ti, K, P and Zr contain one generation olivine.

Interpretation of the good correlations between Mg/Fe and Ti, and Mg and Ti, as a result of magmatic differentiation must be regarded with some circumspection, since there is no distinct correlation of Mg/Fe or Mg with the trace elements.
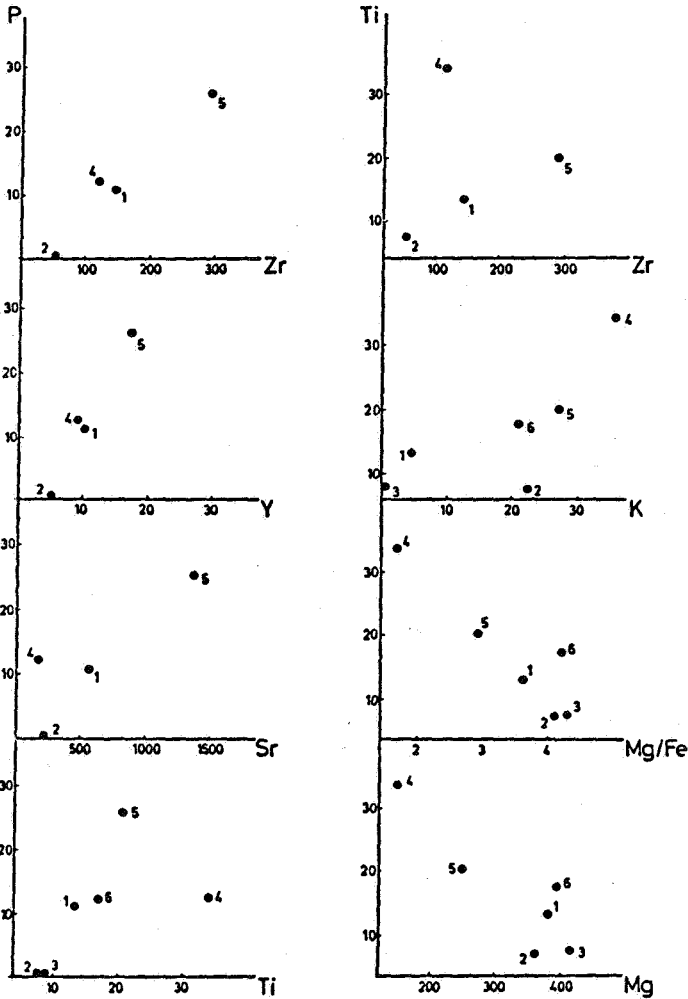

Figure 2 - Plots of P, Ti, Mg, Mg/$_{Fe}$ all in cation proportions x1000, and trace elements in ppm; numbers of nodules refer to tables 2 and 3. Because of alteration of nodule 4, only the amounts determined in the core were represented.

III. THE CHLORITE NODULES.

The kimberlite breccia (blue ground) of Mbujimayi contains a series of dark green rounded inclusions, of up to 10 cm thick, often with a "satinous" lustre. Their origin is quite enigmatic and they certainly deserve a description.

Mostly surrounded by a rim of chlorite - which gives them their satinous appearance - they resolve under the microscope as a very composite and intricate network of quartz and chlorite. Quartz is the major mineral and forms radiating or plume structures often occurring in fine parallel layers. Chlorite is localized between the acicular quartz crystals or forms nests exhibiting crenulation (see photo 8).

The crenulation cleavage developed within the chlorite is continuous with the plumose arrangement of the quartz crystals. Thus we interpret the textures of these nodules as resulting from an introduction of quartz between the cleavage of chlorite units, followed by replacement of the chlorite.

Three chemical analyses were performed and are listed in table 5. Since the nodules apparently only contain quartz and chlorite, the chemical composition of the chlorite can be inferred by calculation, assuming a general chlorite formula of

$$(Mg, Fe, Al)_{12} \quad (Si, Al)_8 O_{20} \quad OH_{16}.$$
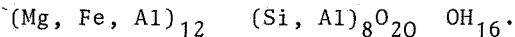
The chlorite is chromiferous : chromium (determined by X-ray fluorescence methods) varies from 300 to 572 ppm.

Although the calculated chlorite compositions (see table 5) can only be regarded as an approximation, they permit us to classify the chlorites into a group of chromiferous magnesium chlorites, probably a Cr-clinochlore or Cr-sheridanite (classification of TRÖGER 1969), of which they show the diffraction patterns.

Like the chlorites from the kimberlite nodules these chlorites are biaxially negative with a small 2 V, and have $n\gamma$ close to 1.550. The remarkable resemblance with the transformed chlorite phenocrysts from the primary kimberlite nodules, leave no doubt about the origin of the quartz-chlorite nodules derived from a primary kimberlite.

Table 5 - Chemical analysis and trace element content of three quartz-chlorite nodules; calculated chlorite composition.

wt %	Quartz-chlorite nodules			Calculated chlorite		
	1	2	3	1	2	3
SiO_2	79.83	76.19	82.99	27.60	26.84	29.76
Al_2O_3	3.09	3.85	2.53	15.62	15.66	14.22
Fe_2O_3	2.06	2.85	1.42	10.42	11.59	7.98
FeO	0.86	1.25	0.80	4.35	5.08	4.50
MnO	0.01	0.02	0.02	-	-	-
MgO	5.89	7.06	5.56	29.78	28.71	31.26
CaO	0.14	0.29	0.25	-	-	-
Na_2O	0.10	0.06	0.06	-	-	-
K_2O	< 0.10	0.16	0.16	-	-	-
H_2O	6.08	7.70	5.53	12.22	12.12	12.34
CO_2	-	-	-	-	-	-
TiO_2	< 0.05	0.13	0.16	-	-	-
P_2O_5	0.19	0.07	0.06	-	-	-
TOTAL	98.40	99.63	99.54	100.00	100.00	100.00
ppm						
Rb	12	16	9			
Sr	6	5	3			
Zr	24	26	23			
Y	0	0	0			
Cr	572	490	300			
$Fe/_{Fe+Mg}$	0.20	0.17	0.17			

Total analyses : D. COETERMANS - Rb, Sr, Zr, Y : analysts M. DELVIGNE - F. DUREZ.

IV. DISCUSSION AND SUMMARY.

The kimberlite breccia ("brèche secondaire" - "blue ground") is a typical volcanic breccia with a high proportion of extraneous material. The composition changes little at deeper levels. Except the leaching of calcite in the superficial yellow ground there is no indication of any meteoric influence on the calcite content, which is even smaller than in the primary kimberlite nodules. Apparently we may conclude that the surrounding dolomite system had little influence on the calcite content, the source of which is believed to be partially primary.

The "primary" kimberlite nodules show the typical texture and composition of a kimberlite, which may, due to the amount of phlogopite and chlorite, be termed as "micaceous". The typical occurrence of olivine in two generations has been recognized, notwithstanding the complete disappearance of the crystals by pseudomorphic replacement. Phenocrysts of often partially or totally phlogopitized chlorite, garnet (which although not chemically analyzed in this study, certainly may be termed a pyrope) and ilmenite crystals up to 0,5 cm, occur beside these olivine pseudomorphs. They are set in a groundmass of calcite and saponite in which one may distinguish fine euhedral chlorite flakes and magnetite grains.

Special attention was given to the major phases of the nodules, the carbonates and the chlorites.

Since the Mbujumayi kimberlites intruded a thick (1000 m - RAUCQ 1970) sequence of precambrian limestones and dolomites one must enquire whether the calciferous matrix of the kimberlite nodules is to be regarded as primary or derived from the dolomites by processes of hydrothermal alteration or assimilation.

Several other authors had to deal with analogous problems and since the debates of WATSON (1955) and FRANZ and WYLLIE (1968) a new tendency grew to regard some of the calcite in kimberlites as a late stage primary mineral. Most of our observations are in accordance with such a statement :
- the way calcite occurs in nodule 1 (see above) shows some analogies with structures described by CLARKE and MITCHELL (1975) and by CLEMENT (1975), as indicative of carbonate liquid immiscibility.
- poikilitic texture of carbonate and parallel orientation of the sheet minerals in nod. 5 are considered to be primary features.
- carbonate inclusions in nod. 1 bear no petrographical resemblance to the precambrian limestones. Instead the habit of the acicular crystals may be compared to the descriptions given by DAWSON and HAWTHORNE (1973) of some "dendritic calcite crystals" from the Benfonteyn sills. They interpreted this texture as a "quench product".
On a chemical basis decisive conclusions regarding the magmatic nature of these inclusions are not possible. A plot of the analysis within the CaO-MgO-FeO diagram of VERWOERD (1967) could show a position between sövite and beforsite. A sedimentary carbonate rock, however, would plot in a similar way.

Trace elements cannot be used in our debate on the primary origin of carbonate. Only the markedly higher Sr value for nodule 5 indicates such a magmatic origin. Compared to the precambrian rocks, the kimberlite nodules show generally somewhat higher values for their trace elements.

Sr^{87}/Sr^{86} were determined by D. DEMAIFFE (Belgian Centre for Geochronology) on a marginal and central sample of nodule 1, as well as on the two large carbonate inclusions which all yielded a value of 0.704. This is indicative of largely uncontaminated material, derived from a magma at great depth (BROOKINS 1967, BROOKINS and WATSON 1967, BARRETT and BERG 1975). Since the carbonate inclusions in nod. 1 and the kimberlite itself have an identical Sr^{87}/Sr^{86} ratio, a genetic relationship is suggested.

Further isotopic studies by D. DEMAIFFE, comparing the nodules to the kimberlite breccia and to samples of the Bushimayi

system, will be presented in a later paper.

The chlorites occurring as - often phlogopitized - pheno-crysts and as a compound of the groundmass pose a special problem. MITCHELL (1970) describes "bright green chlorite" as an alteration product of phlogopite and notes the development of "a chromium-rich Kaemmererite" chlorite in the Swartruggens fissure kimberlite. In our case on the contrary, the chlorite appears rimmed by phlogopite which in certain cases can also replace it entirely.

In this context the above mentioned phlogopitization of the olivine crystals must be noted also. LUTH (1967) quoted by MITCHELL (1970) has experimentally shown that under certain conditions bioti-te may form by resorption of olivine.

FAWCETT and YODER (1966) note the formation of Mg-chlorite under conditions of temperature and pressure prevailing in deep sea-ted regions. The reaction is :
- enstatite + forsterite + spinel + vapour = Mg-chlorite.
Comparing this reaction with the reaction quoted by Luth :
- forsterite + liquid + vapour = phlogopite + enstatite
one may argue that phlogopitization of olivine and formation of chlo-rite resulted from a coupled reaction to be written as the sum of the reactions quoted above. The temperature-pressure conditions prevai-ling somewhere between the conditions of the separate reactions could well be in accordance with the conditions of crystallization of a kimberlitic magma.

The ultimate phlogopitization of the chlorites would than result from a late stage progressive enrichment of K_2O in the resi-dual melt.

The quartzification of the olivine crystals in some nodules and the introduction of quartz between the chlorite planes must con-stitute an ultimate transformation phase of some parts of the intru-sion which nevertheless took place before the disruption of the pri-mary kimberlite.

The quartz-chlorite nodules probably constitute aggregates of chlorite in which quartz intruded between the cleavages and part-ly replaced the chlorite.

V. CONCLUSIONS.

The petrographic and chemical characteristics of the "pri-mary kimberlite" nodules and fragments indicate a deep-seated origin of these rocks which probably solidified as dyke-like bodies. This corresponds entirely with the description of the occurrences given by C. FIEREMANS (1977) who postulated that the massifs of kimberlite tuff-breccia probably were situated on East-West "crustal fissures".

The deep seated original kimberlite magma surely was the ob-ject before and after solidification of many transformations, the real nature of which it is difficult to grasp, due to their multipli-city and the lack of evidence.

Hypothetically we may state the following stages :
- First, (the original magma being very calcic) the slow differentiation and crystallization of lenses or dykes of a carbonatic rock in hi-gher levels of the crust.
- Second a stage of rapid rise (fluidized system ?) of the kimberli-tic magma in fissures of the crust under high pressure, charged with gases mostly composed of H_2O and CO_2. The originally formed carbonatic lenses are pulverized and the fragments enclosed as fo-reign rock inclusions. The rapid rise brings about a rapid coo-ling and avoids the digestion of the lumps. In this stage too the olivines are phlogopitized and the eventual interstitial aphanitic groundmass is chloritized and carbonatized. A mixture of chlorite and carbonate grows as groundmass, whilst the olivines are pseudo-morphosed either by phlogopite or phlogopite + calcite.

- In a third stage of autometamorphism one may postulate the more complete transformation of the rock under the influence of rest-solutions and gases : formation of more carbonates crystallizing as veinlets or nests of calcite-ankerite.
  A phlogopitization (influence of K_2O) of certain chlorite rims also occurs in this stage.
- In a fourth stage some pseudomorphs are saponitized, and quartz forms as a replacement product, or infiltrates the chlorite aggregates in such a way as to form real quartz-chlorite masses.
- It's only at a fifth stage that, under the influence of high pressure residual gases, these preformed dykes are pulverized and the fragments expulsed together with the extraneous rock material to form the subcircular pipes and "sacks" of kimberlite-tuff and breccia.
  The calcite impregnating this secondary breccia still may be - at least partly - of primary origin. We have not analysed in this study the subsequent meteoric transformations of the secondary breccia which implicates a leaching out of calcite in the superficial portions and the formation of a nearly pure kaolin (C. FIEREMANS, 1977).

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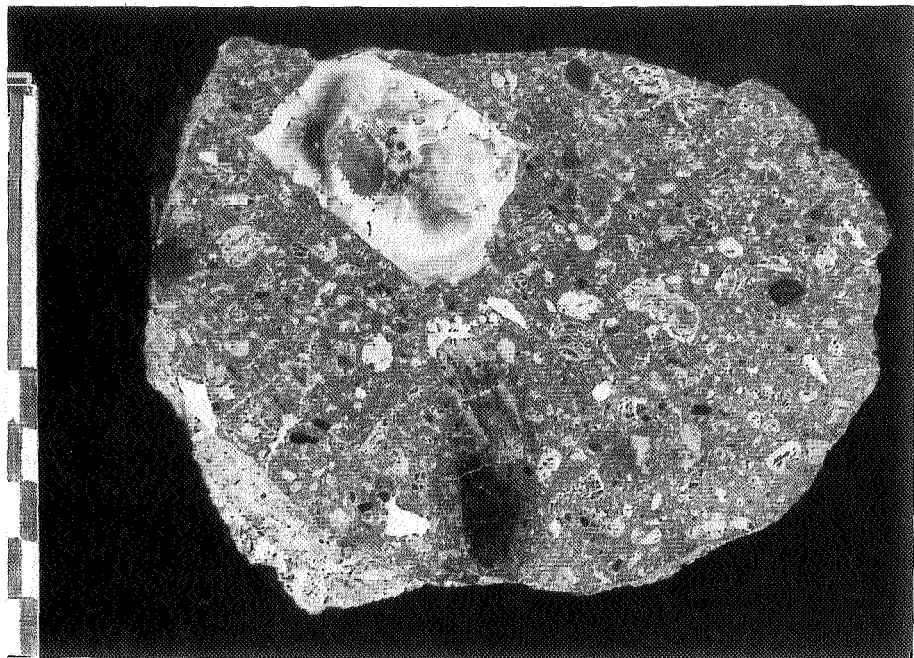565-579.*

Photo 1 - Kimberlite nodule 1, partially enveloped by blue ground breccia. The nodule shows large, oval shaped, pseudomorphs after olivine chlorite phenocrysts (black spots), and carbonate xenoliths.
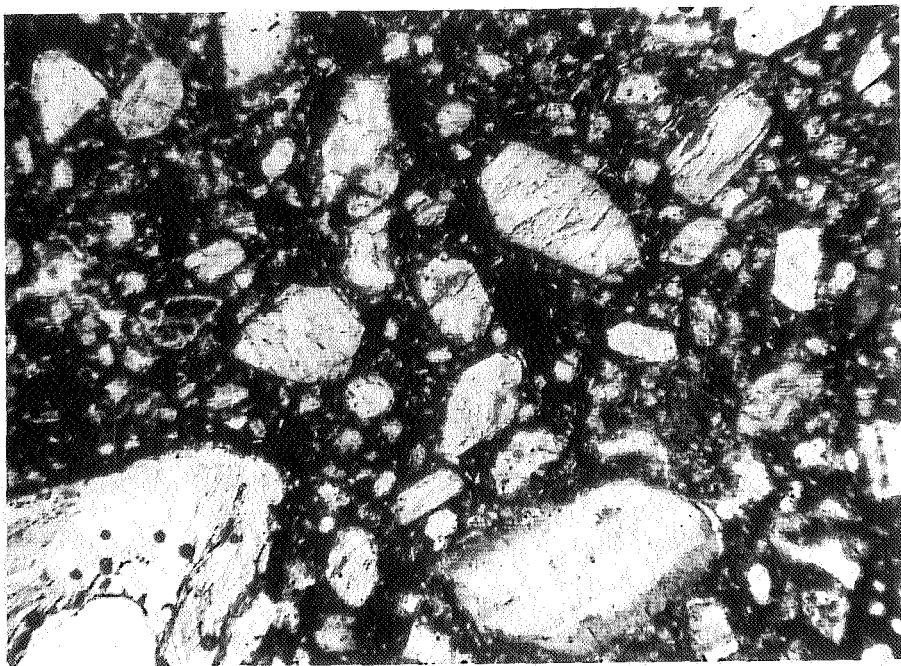

Photo 2 - Nodule 1: porphyritic texture with euhedral olivine pseudomorphs.

Photo 3 - Nodule 2: chlorite phenocrysts containing lenses of monocrystalline quartz between the cleavages. (40 x).
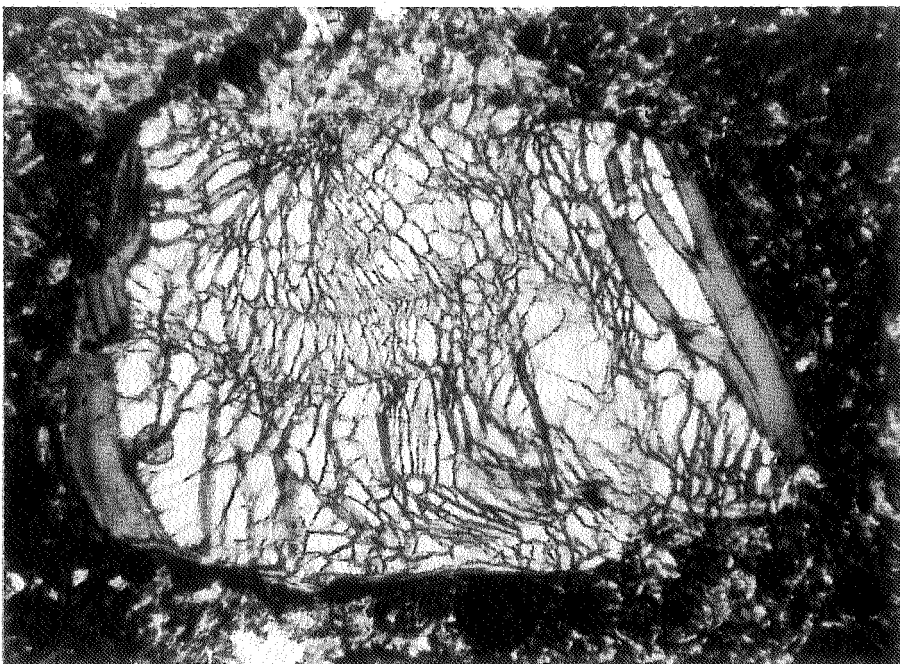

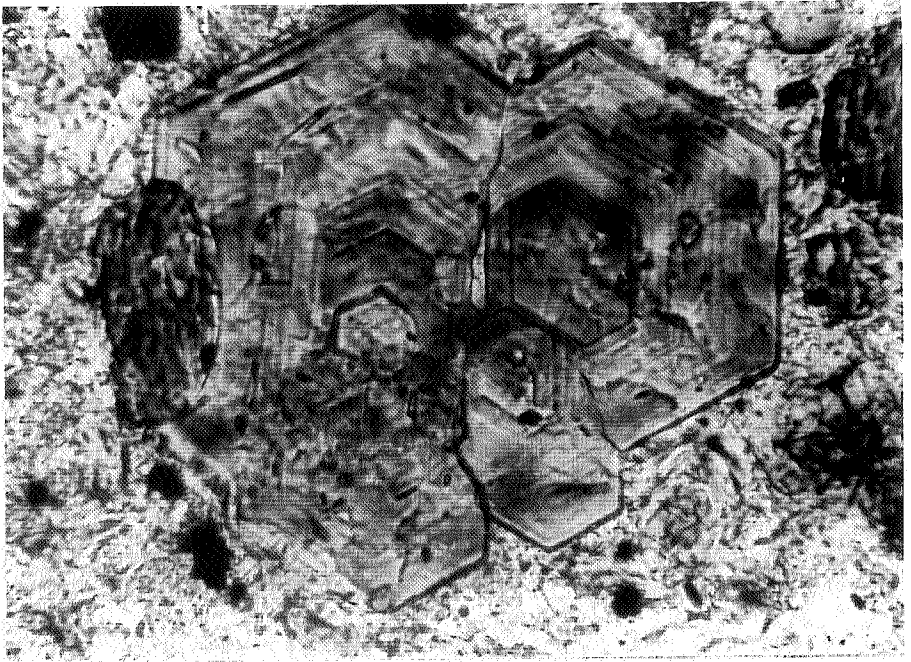Photo 4 - Nodule 2: small nodular body consisting of quartz intimately interlaced with chlorite. (50 x).

Photo 5 - Zoned and twinned chlorite crystal. (870 x).
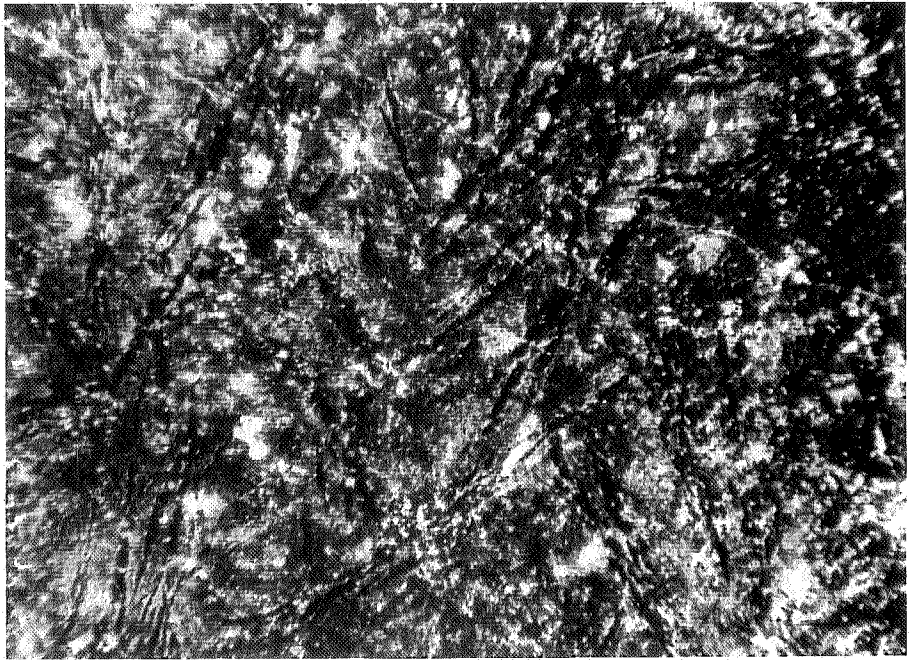
Photo 6 - Lath shaped carbonate crystals occurring in carbonate inclusion in nodule 1. (35 x).
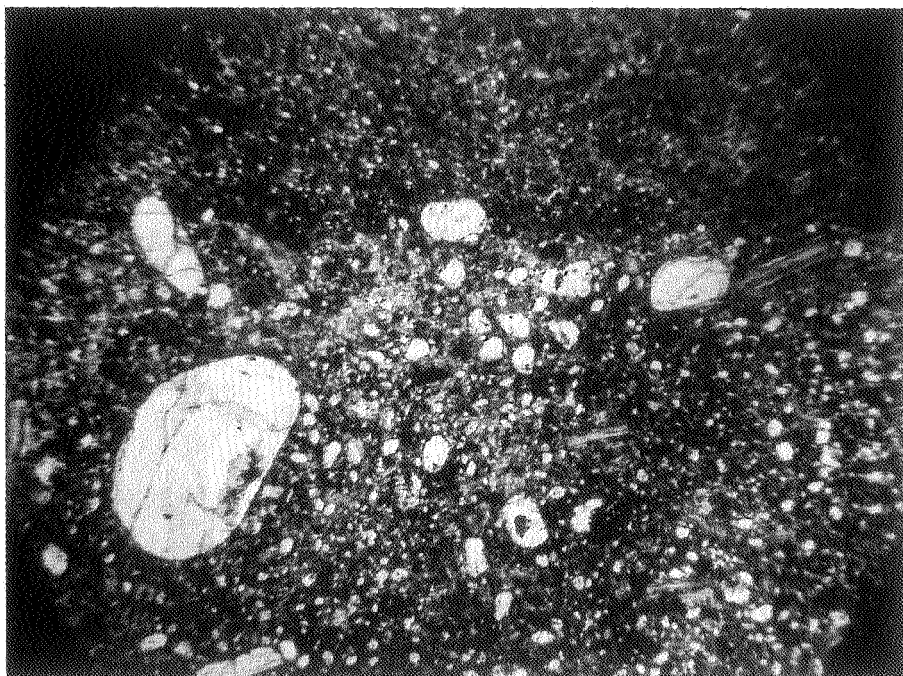
Photo 7 - Nodule 5: contact between two kimberlite types; one showing larger quartz - calcite pseudomorphs after olivine. (10 x).
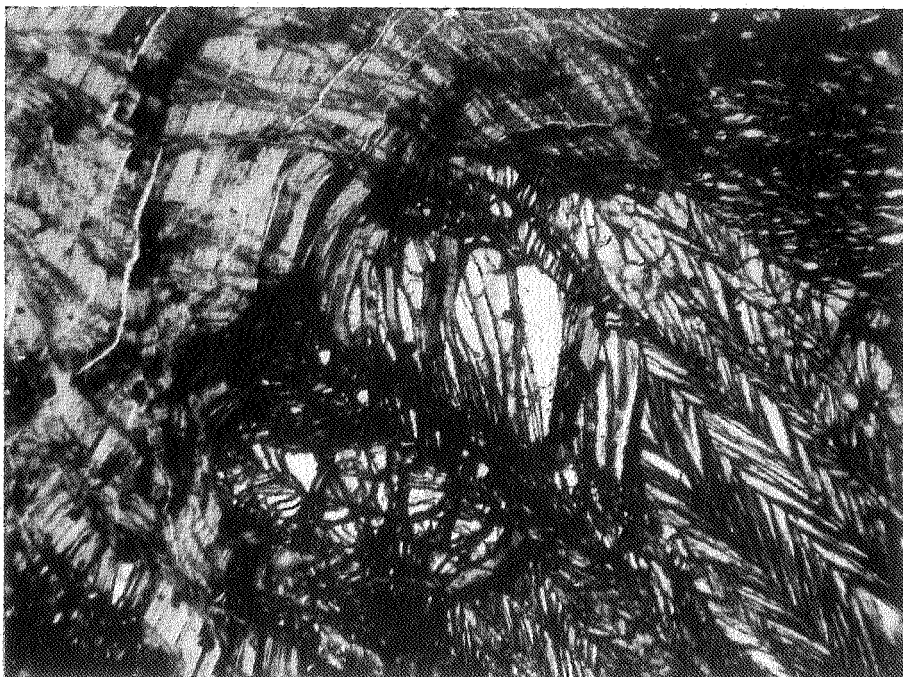
Photo 8 - Detail of quartz-chlorite nodule: the upper left part of the photo shows chlorite next exhibiting crenulation; thi: cleavage is continuous with the plumose arrangement of the quartz crystals (white), which enclose lamellae of chlorite. (35 x