HYDROTHERMAL ASSEMBLAGES OF ALUMINIAN SERPENTINE
FLORECITE AND KYANITE IN THE ZAIRIAN COPPERBELT

par

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(4 figs, 7 tables, 1 plate)

RESUME.— Plusieurs occurrences de disthène, serpentine aluminifère et florencite ont été observées dans le "Copperbelt" du Zaïre, le long d'une bande étroite comprise dans la zone à chlorite de l'arc lubilien. Elles résulteraient d'une altération hydrothermale de sédiments appartenant au "Roan Supergroup" et consisteraient en le remplacement d'un clinocllore néogène par un ensemble complexe comportant de la serpentine aluminifère, de la smectite et des interstratifiés chlorite-talc et chlorite-montmorillonite. Cette altération remplacerait également une monazite diagenétique, riche en cérium et lanthane, par une monazite essentiellement cérièse et une florencite riche en lanthane. La présence de disthène, parmi les minéraux argileux, pourrait être attribuée à des conditions locales de haute pression engendrée par une brècciation intense des sédiments du "Roan Supergroup". Ces manifestations locales de haute pression semblent confirmées par l'existence d'autres associations de haute pression, comme celle à phengite - chlorite - phlogopite - disthèse observée dans la zone à biotite de l'arc lubilien. Ces observations et l'interprétation qui en découle peuvent être rapprochées des récentes découvertes, en Zambie, de roches à faciès "white schist" et autres associations de haute pression, localisées dans une portion plus méridionale de l'arc lubilien.

ABSTRACT.— Several occurrences of kyanite–aluminian serpentine–florencite have been observed in the Zairian Copperbelt in a narrow band located in the chlorite zone of the Lubilian metamorphic belt. These occurrences are interpreted as the result of hydrothermal alteration of sediments belonging to the Roan Supergroup. This alteration resulted in the replacement of a neogenic clinocllore by a complex series consisting of aluminian serpentine, smectite, chlorite–talc and interstratified chlorite–montmorillonite. This alteration also replaced a diagenetic monazite containing cerium and lanthanum by a monazite containing essentially cerium and a florencite rich in lanthanum. The presence of kyanite among the clay minerals is tentatively attributed to local high pressure conditions caused by the intense brecciation of the sedimentary rock of the Roan Supergroup. Occurrences of local high pressures are apparently confirmed by the existence of high pressure assemblages such as phengite–chlorite–phlogopite–kyanite in the biotite zone of the Lubilian belt. These observations and resulting interpretation may be paralleled with the recent discoveries in Zambia of "whiteschists" and other high pressure assemblages located in the Lubilian belt just south of the area being studied.

INTRODUCTION

A La-rich Florencite, \((\text{La, Ce})\text{Al}_2(\text{PO}_4)_3(\text{OH})_6\), has been recently discovered in the Copper Province of Shaba (Lefebvre & Gasparini, 1980). This mineral was found associated with Ce-rich monazite in the copper-cobalt deposit of Shituru (fig. 1) among hydrothermally altered rocks belonging to the transition between the Kibamba Group and the Mwashya Group (upper part of the Roan Supergroup).

Lately, florencite was also recognized in the Lower Group of the Kambove West deposit. The aluminium phosphate is accompanied with minor monazite in rocks that underwent a hydrothermal alteration similar to the one observed in the Shituru deposit.

Florencite was also described in dolomitic siltstones close to veins or fractures cutting across the Mines Group of the Kabolela deposit. These veins contain kyanite and clay assemblages similar to those found in the two previous occurrences.

Veins containing kyanite and clay minerals were known long ago in the Mines Group of the Luishia depo-

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Figure 1. Location of the known kyanite occurrences in the Shaba section of the Lufilian belt with the distribution of the metamorphic zones.

sit (Burttgenbach, 1925; Legraye, 1926). In the Luvisi
wish deposit, some of these veins yield rather coarse
kyanite crystallizations. Similar assemblages were suc-
cessively located in the Star of Congo deposit (gisement
de l'Etoile; Lefebvre & Calleux, 1975) and in a Cu-Ni
prospect in the Menda anticline (Lefebvre, 1976). The
preceeding list of florencite and/or kyanite occurrences
advocate the importance or at least, the extension of this
hydrothermal activity in the Zairian Copperbelt.

Other kyanite occurrences are known in the Ka-
tangian rocks such as the kyanite, chlorite, phengite
and phlogopite assemblages observed along the Lufunfu
river, close to the Zambian border (Jamotte, 1933) and
in the Mwashya Group of the Kibamba anticline. In this
same anticline, hematitic sandstones of the Kibamba
Group contain Mg-chlorite, silitmanite, kyanite and
quartz forming assemblages similar to the chlorite-
kyanite-quartz schists found interlayered with "White-
schists" (talc-kyanite schists) in the Zambian portion
of the Lufilian belt (Vrána & Barr, 1972).

The purpose of this paper will be to describe these
mineralogical assemblages and to discuss the implication
of these crystallizations in regard to the metallogeny,
the tectonism and the metamorphism of the Southern
Shaba.

Among the hydrothermal minerals emphasis has been
placed on the kandite material which appears to
consist of a new occurrence of the rather rare alumini-
unserpentine (or Si-rich amesite) synthetized by Roy &
Roy (1954) and by Gillery (with Hill, 1959) and obser-
ved in nature in only a few locations (Shirozu, 1958;
Bailey & Tyler, 1960; Jahanbagloo & Zoltai, 1968;
Zhukov, 1971).

The rather complex cortege of clay minerals
accompanying the kandite was superficially described
by routine qualitative clay mineral analysis. Further
detailed studies will be undertaken by the State Uni-
versity of Liège (Belgium).

FLORENCITE FROM SHITURU

As described in a recent paper (Lefebvre & Gas-
parrini, 1980), the florencite from Shituru has been
observed in the Shituru Formation which corresponds
to the passage from the continental red beds of the
Kibamba Group to the lagoon dolomites of the Mwa-
shya Group (uppermost part of the Roan; Lefebvre,
1978). In sample 1 (drill hole S102, 101 m depth),
florencite is present as tiny rhombohedral and pseudo-
cubic crystals with a grain size averaging between 15
and 60 microns (Plate Ia) and accounts for 3 % of
the volume. Florencite, together with local aggregates
of Ce-rich, La-deficient euhedral monazite were relat-
ed to possible posttectonic hydrothermalism. This
alteration transformed a pre-existent Mg-chlorite into a complex assemblage of clay minerals with kandite as a dominant component.

Two samples from Shituru (Tables 1 and 2) were examined as oriented aggregates on glass slides. Sample #1 and sample #2 showed a long spacing at 28.4 and 29.2 Å respectively, when air-dry, at 31.1 and 33.8 Å when treated with ethylene glycol; heating at 550° C gave spacings at 23.0 and 26.5 Å respectively. The sequence of higher order reflections is almost complete and rather regular and has been ascribed to a regular montmorillonite-chlorite mixed layer for sample #1 and to a regular montmorillonite-swelling chlorite mixed layer for sample #2.

In addition to the reflections related to the long spacing mineral, reflections corresponding to very minor amounts of swelling chlorites and random mixed layers were also observed.

However, the main clay mineral component in these two samples is a kandite characterized by a (00l) sequence of harmonic reflections at 7.10 Å (001), 3.55 Å (002) and 2.367 Å (003) which remain stable after glycolation. Upon being heated to 550° C, these reflections show only a slight decrease of intensity. The reflection at 13.6 Å that appeared after heat treatment of sample #1 could indicate a certain degree of order in the dehydration process of the kandite material (Brindley, in Brown, 1972). Leaching by warm dilute HCl resulted in a notable decrease of intensity of all the (00l) reflections.

The existence of weak reflections at 4.76 Å and 2.85 Å that tend to diminish or disappear after heat treatment favor the existence of minor amounts of chlorite. This is further supported by the reflection at 14 Å which remains after the swelling or collapse of the other reflections which were previously superimposed on it.

The semi-quantitative evaluation of the content of the clay minerals (Tables 1, 2, 3 and 4) was made using the method of Strasbourg’s Clay Laboratory (Thorez, 1976).

**Florencite from Kambove**

The Cu-Co mineralizations of Kambove are located at a distance of 30 km north-west of Shituru (fig.1). The Kambove West deposit lies in the lower part of the Mines Group which forms a faulted, inclined syncline completely surrounded by an extensive tectonic breccia (Cailteux, 1977 b). Underneath, and separated from the lagoonal dolomites of the Mines Group by a thin zone of tectonic breccia (about 5 m in thickness), one observes a normal succession of the red beds belonging to the Lower Group (lowermost part of the Roan ; Cahen, 1974). These red beds consist principally of grits, sandstones and siltstones characteristic of intertidal and continental environments. These rocks, as well as the detrital beds of the Mines Group, are ordinarily rich in a neogenic Mg, Al-chlorite which is rather uniform in composition in most of the Cu deposits of Shaba (Oosterbosch, 1960). Below the Kambove West deposit, this chlorite has been transformed into a complex suite of clay minerals clearly defining a zonation pattern (fig. 2). The rocks of the Mines Group and the heterolithic breccias have a clay fraction almost essen-

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**Figure 2.** Semi quantitative distribution of the clay minerals observed in the Lower Group of the Kambove West deposit.

1. dolomites
2. siltstone
3. fine sandstone
4. sandstone
5. quartzitic sandstone
6. grit
7. fractured zones
8. monogenetic tectonic breccia
9. polygenetic tectonic breccia
10. kandite
11. chlorite
12. talc
13. chlorite-talc regular mixed layer
14. various random mixed layer
15. smectite.
Kambove deposit
d. hole Kw 206

Core n°719
dol.
qz.

Core n°762

Core n°805

Core n°817
qz.
distance Å
3 4 5 6 8 10 14 22 Å

Figure 3.— X-ray diffraction on the main clay assemblages observed in the Lower Group of the Kambove West deposit (unoriented samples).

tially composed of the original neogenic chlorite (clinochlore; Foster, 1962; mineral #1 in Tables 5, 6 and 7). The monogenetic breccia that results from the attrition of the base of the lower Group (fig. 2) is successively enriched in smectite and kandite as one progresses inside the Lower Group unaffected by brecciation.

The core # 817, from drill hole 206 (fig. 3 and table 3) selected among the samples of this monogenetic breccia showed, when examined as oriented aggregates on glass slides, an x-ray diffraction spectrum which suggested the presence of a vermiculite. That is to say, a (001) sequence of harmonic reflections at 14.24 Å (relative intensity: 60; asymmetry towards small angles), 7.11 Å (relative intensity: 80), 4.73 Å (relative intensity: 60; asymmetry towards small angles), 3.55 Å (relative intensity: 60) and 2.85 Å (relative intensity: 20). Three more basal reflections at 4.83 Å, 3.69 Å and 2.886 Å (partly dolomite) were attributed to a smectite with a characteristic expansion of the (001) to about 17 Å with ethylene glycol and a collapse of the first order (9.5 Å) after heat treatment. The displacement of the smectite reflections indicated that the sequence of reflections attributed to vermiculite was actually a result of the superposition of reflections related to different minerals. These minerals are mostly chlorites, some being similar to the ones observed in the Mines Group and in the heterolitic breccia of Kambove West (table 7, analysis n° 1), others are very comparable to the leptochlorite of Kibamba (see below; table 7, analysis n° 2), with a characteristically more intense (004) reflection at 3.55 Å. Remaining basal reflections observed after the different treatments led to the identification of swelling chlorite–chlorite mixed layers and a trace of partially desaturated vermiculite or randomly interstratified structures with montmorillonite and chlorite (table 3).

The core # 762, which corresponds to a massive, pinkish-red grit, was particularly rich in a clay mineral, greenish in color, with a soapy touch. The X-ray diffraction analysis of this material yielded a rather diffe-
rent spectrum compared to that of the chlorite or kandite-rich assemblages. A long spacing is present at 26 Å (table 4) associated with an almost complete sequence of harmonic reflections, remaining unaffected after glycolation or heating. These characteristics correspond to a regular interstratification of two unexpandable minerals, likely a chlorite and a mica. However, microprobe qualitative analysis failed to detect the presence of potassium in any of the investigated clay minerals of sample #762. This mineral, resulting from the interstratification of unexpandable minerals, differ from chlorite and kandite by a slightly higher refringence. A quantitative microprobe analysis of this interstratified mineral shows a chemical composition similar to chlorite except for a higher silica content and a lower loss of ignition (table 7, analysis n° 7).

This analysis indicated no evidence of K, Na nor Ca and could be interpreted as the result of the interstratification of chlorite, relatively enriched in Al compared to the leukenbergite from Kambove West (table 7, analysis n° 1) and a theoretical talc. A closer examination of the X-ray spectrum of this interstratified clay mineral indicates that most of the basal reflections satisfy the following relation:

\[ \frac{1/d}{(00k)} = \frac{0.75}{d(00k)} \text{chlorite} + \frac{0.25}{d(00k)} \text{talc} \]

possibly indicating that the clay mineral is related to a 3:1 chlorite-talc regular mixed layer. The structural formula based on the chemical analysis of this mineral and calculated for a \(0_4 \) \((\text{OH})_{26}\) unit (table 7, analysis n° 7) is compatible with the 3:1 interstratification of an Al-enriched leukenbergite

\[
\frac{[(\text{Mg}_{0.04}\text{Fe}^{3+}_{0.06}\text{Al}_{1.70})^{+1.30}(\text{Si}_{2.72}\text{Al}_{1.28})^{+1.28}]}{5.80}
\]

\[O_{10.02}(\text{OH})_{7.98} + 0.02\]

and a theoretical talc.

It is interesting to observe in the structural formula of this Al-enriched chlorite that the excess of alumina, compared to the normal leukenbergite from Kambove, is located in the octahedral layer resulting in an excess of positive charge which is partly compensated by the deficiency in the number of octahedral positions occupied. This deviation which characterizes the lepto-chlorites as defined by Hey (1962, p. 495) is also observed in some of the chlorites from core samples #775 to #820 of the Kambove West drill hole 206, in the kamite of Shituru and Kambove and in the Si-enriched leukenbergite of Kibamba (discussed anon, and table 7).

This unusual tri-octahedral chlorite-talc mixed layer (d(060) = 1.531) is accompanied, in core #762, with smaller reflections at 7.08 Å, 4.81 Å and 3.62 Å (table 4). After treatment with ethylene glycol, a well marked asymmetry is formed on the lower angle side of the 14 Å reflection (partly attributed to the 002 chlorite-talc reflection) with a discrete apex at 17.28 Å. The expansion of the higher order reflections related to this 17 Å reflection, reveal the existence of stable and relatively sharp reflections remaining at 7.09 Å and 3.55 Å, indicating the presence of minor kandite. When heated to 550°C the 17 Å reflection shifts to 12.6 Å disclosing a very weak reflection at 14.2 Å (minor trace of chlorite ?). The behaviour of the (001) reflection (14-17-12 Å) and higher order reflection indicate the presence of swelling chlorite-montmorillonite random mixed layer as well as minor kandite and possible traces of chlorite. Temperatures above 500°C result in the almost complete destruction of the chlorite-talc mixed layer as well as the kandite, while the chlorite-montmorillonite mixed layer remains almost unaffected with a very intense (001) reflection and imperceptible higher order reflections. Leaching of the clay material from core #762 by warm dilute HCl results in the complete decomposition of all the clay mineral components.

The clay mineral of core #719, a pinkish sandstone rich in hematite, yielded a relatively simple spectrum composed of harmonic reflections of a kandite, similar to the one described in Shituru (7.09 Å, relative intensity : 100 ; 3.55 Å, relative intensity : 90 ; 2.368 Å, relative intensity : 30) and an isolated, symmetrical reflection at 15 Å (fig. 3). Glycolation and heat treatment do not affect the kandite reflection. On glycolation, the 15 Å reflection shifts to about 16.5 Å. Heating the sample at 550°C for one hour induces the formation of a very broad reflection with a d-spacing value ranging between 12 and 17 Å and a rather diffused apex at about 14 Å. This behaviour can be related to a randomly interstratified swelling chlorite-montmorillonite or possibly an irregular interstratification of the (7-14) type.

The ratio between the amount of kandite and the mixed layer is relatively constant in the upper half of the Lower Group. The uppermost part of this sequence, close to the chlorite rich-tectonic breccia, is relatively richer in mixed layer and contains minor amounts of talc (fig. 2).

In the Kambove West deposit, florencite has been found at the bottom of the Lower Group, embedded in the clay aggregates principally composed of kandite, ortho-and/or lepto-chlorites, regular mixed layer with
Figure 4. Electron-microprobe X-ray spectra of florecite and monazite from Zaire.

chlorite and possibly talc, swelling chlorite and montmorillonite. The clay material accounts for 25 to 30% of the sample and differs from that of the Shituru deposit by the size (up to 300 microns), the habit (characteristic hexagonal sections across rhombohedral crystals; plate 1b) and the proportions of the rare-earths which appear to vary across the grains. Spectra obtained by energy-dispersive spectrometry, show similar chemical compositions for the minerals from Shituru and Kambove with, however, an irregular distribution of the rare-earth elements in the Kambove crystals (fig. 4). Monazite is very frequent in the Kambove West deposit as euhedral, isolated grains, disseminated at the base of the Mines Group (Cailleux, 1977a). In these monazites, Ce is found to be the major rare-earth element associated with La, Pr, Nd, Sm and Gd, in decreasing order of importance. On the other hand, the monazite observed in the altered rocks belonging to the Lower Group of the Kambove West deposit are subhedral and have cerium as the only rare-earth constituent (fig. 4). In the Shituru deposit, a very similar association of La-rich florecite and Ce-rich monazite has been described in the same kind of environment (Lefebvre & Gasparini, 1980), and has been interpreted as resulting from a differential leaching of the more soluble rare-earth elements from the original monazite, leaving behind a relatively enriched Ce-monazite. The more soluble rare-earth elements were redeposited at distance to form La-rich florecite.

**FLORECITE FROM KABOLELA**

Florecite has been observed in the Kabolela Cu-Co deposit which is located approximately 12 km north-west of Kambove West (fig. 1). The aluminium phosphate of rare-earth occurs in the middle of the Mines Group, athwart the contact between the S.D. and the C.M.N. lithological units (Lefebvre, 1976). The crystals are relatively coarse (up to 350 microns, in size), euhedral, with frequent, hexagonal or rhombic outlines in thin sections, and apparently zoned about a dark core (plate 1c). Electronmicroprobe spectra collected from the florecite grains, show that the chemical composition is almost identical to the Shituru florecite with La as the most abundant rare-earth element (fig. 4). The florecite crystals are associated with anhedral neogenic kyanite and are disseminated in carbonaceous and dolomitic siltstones. Combined, florecite and kyanite account for 12 percent by weight of the total rock. At the same stratigraphical level, dolomites and sandstones are cut across by thick veins (up to 15 cm in thickness) containing quartz, chlorite, dolomite and chalcopyrite. Comb-textured kyanite is locally very abundant in these veins, accompanied with a pearly white clay material that replaces dolomite peripherically. An X-ray diffraction investigation of the clay mineral yielded a pattern identical to the one described in core 719 from the Lower Group of the Kambove West deposit; that is to say, an assemblage composed of abundant kandite and minor random mixed layer.

**DESCRIPTION OF THE KANDITE**

The kandite-rich material from Shituru, Kambove and Kabolela is pearly white, massive with, on a macroscopical scale, a foliated, rarely conchoidal, fracture. On a microscopical scale, the kandite has a lamellar habit. The coarsest crystals observed in Kambove West, rarely exceed 70 microns. In the Shituru deposit, some flakes
may attain a length of 250 microns. Microscopical exa-
mination of very fine kandite particles sedimented on a
glass slide shows the existence of very rare hexagonal,
platy crystals (plate 1, d and e). The refraction indices
of kandite (Nγ = 1.566 ± 0.002) are slightly lower than
those of the Mg-chlorite described in the same deposits
(Kambove chlorite: Nγ = 1.575 ± 0.001). The birefrin-
gences of kandite and clinochlore are similar and do not
exceed 0.011. The kandite crystals are biaxial positive
with a very small angle between the two optic axes.
They show a good cleavage, fast along with an almost
straight extinction.

In the X-ray diffraction pattern of the kandite,
the presence of a (060) reflection at 1.535 and a 7 Å
sequence of basal reflections that disappear on heating
to 600° C suggest a serpentine-like structure. The pow-
der pattern of this serpentine can be best indexed in
terms of a 6-layer structure and compares rather well
with the 6(2)-layer Al-lizardite identified from the
Tracy mine, Michigan (table 5). The presence, in the
X-ray pattern of the serpentine from Shituru, of some
(110) reflections and the almost complete (020) series
of reflections is a manifestation of the 6-layer structure
of this serpentine. The presence of (200) reflections
with relatively higher intensities of the reflections with
odd k compared with those with even k suggests that the
serpentine might have a 2-layer structural periodicity.

The platy character of the Zairian serpentine is
confirmed by the spectrum obtained from oriented
surface aggregates where only the reflections belong-
ing to the (00X) series were observed. Also, the (130)
reflections observed in the spectrum obtained from ran-
dom aggregates of this serpentine cannot be produced
by a cylindrical structure. These characteristics favour
an antigorite or a lizardite structure for this serpentine.
Finally, one must conclude that the lizardite structure
for the Zairian serpentine is the most probable as the
absence of a reflection at 1.563 Å, which would ordi-
narily be associated with the (060) reflection observed
at 1.535 Å, eliminates the possibility of antigorite (see
table 5, spectrum # 3).

The b parameter (see table 6) of the unit-cell of
the serpentine from the Zairian deposits are within the
range (9.19 Å to 9.21 Å) obtained by Chernosky (1975)
for similar Al-contents of synthetic serpentines (the Al
content of the Zairian serpentines is estimated at about
x = 1.35 and corresponds to the mean of the Al content
in the tetrahedral and octahedral sheets). This param-
eter is also very similar to the b parameters of the Mg-
chlorite from Kambove West (as well as the Si-enriched
chlorite from Kibamba described below) suggesting a
possible conversion from a chlorite structure to a serpen-
tine structure with b remaining constant. The cation
and hydroxyl differences that exist between the serpen-
tines and the chlorites from Kambove could be respon-
sible for the alteration of the a and c parameters in the
newly formed phases, with the subsequent loss of the
orthohexagonal symmetry of the serpentines (a ≠ b/√3)
and possibly implying a preferential distribution of Si
replacing Al and Al replacing Mg parallel to the y di-
rection.

By comparison with the structural formula of the
Kambove chlorite, the Zairian serpentines differ by the
addition of Si cations in the tetrahedral sheet with, as
a possible consequence, the displacement of Al cations
from the tetrahedral sheet to the octahedral sheet.
To account for the total amount of alumina in the struc-
ture, additional Al cations must have been introduced,
from an external source, into the octahedral sheet while
Mg was expelled from the brucite-like layer in order to
maintain an overall charge balance. The serpentine for-
mlae are more hydrous than the one of the chlorite
from Kambove (see table 7). In order to verify this
observation, a small quantity of the serpentine rich
material from Kambove (KW 207, 321 m) was sacri-
ficed for thermogravimetric analysis. The application of
this method indicated the presence of a significant
weight loss (about 14.5 %) within a temperature range
of 600 to 650° C.

SERPENTINE-KYANITE ASSEMBLAGES

The first description of kyanite in veins and frac-
tures, in the Shaba province of Zaire, was made by
Buttgenbach (1925) in the Luishia deposit. Further
studies completed in 1941 by de Magnée, emphasized
the association of kyanite and chalcopyrite in veins
cutting across and impregnating wallrocks composed
of carbonaceous shales of the Mines Group. Another
major component of these veins consisted of sercite
(? ) and muscovite (?) isolating the kyanite from the
encrusting chalcopyrite and apparently resulting from
the hydrothermal alteration of the former. These veins
also contained quartz, apatite and rutile, but no dolo-
mite.

In a similar environment (S.D. lithostatigraphic
unit of the Mines Group) several kyanite rich veins
were recently observed outcropping in the Luishishi deposit
as well as in the Menda Cu-Ni prospect, respectively
about 100 km south-east and west of the Shituru de-
posit (fig. 1). The collected samples were rather weathe-
red and almost essentially composed of kyanite in large
stubby crystals (up to 3 cm in Luiswishi) frequently
wrapped by massive chalcopyrite. The kyanite is cur-
rently corroded and locally (some occurrences from 
Luiswishi) rimmed by a finely crystallized or medium 
grained flaky material which was identified by X-ray 
diffactometry as pyrophyllite. In several samples from 
Luishia, a whitish, chlorite-like material was observed 
as fracture filling in the kyanite. The same material 
was found associated with kyanite and chalcopyrite in 
the Menda vein. The X-ray spectra obtained on this 
material indicated an assemblage similar to the one 
observed in the core # 719 from Kambove West; that is 
to say abundant aluminian serpentine and variable 
amounts of a randomly interstratified clay mineral.

The same clay assemblage was identified from 
some veins cutting across the Minerai vert Formation 
(R.A.T. grises) of the Star of Congo deposit (drill hole 
283, Etoile deposit, north of Lubumbashi; fig. 1). 
The Minerai vert Formation which forms the base of the 
Mines Group to the East of the Zaïrian Copperbelt 
consists of basic volcanic ashes and is principally com-
posed of chlorite, tourmaline, ilmenite and rutile, 
monazite and very minor quartz (Lefebvre & Capteux, 
1975). In close contact to the veins, the basic ash is 
enriched in abundant euhehedral quartz and most of 
the original mineral components are recrystallized. 
The veins themselves contain, together with aluminian 
serpentine and interstratified clay minerals, abundant 
kyanite with ragged outlines, partly altered into pyro-
phyllite and diaspore aggregates.

**CHLORITE--KYANITE ASSEMBLAGES**

Several samples containing kyanite have been 
drawn from isolated outcrops along the Lufunfu river. 
A younger age than that of the Roan was attributed to 
these rocks by Jamotte (1933). However, a more detail-
ed geological study of the area seems to indicate that 
these kyanite-bearing rocks and the associated mafic 
intrusive bodies are part of a thick succession of carbo-
nated and argillaceous rocks belonging to the base of 
the Mwashya Group or to formations comprised be-
 tween the former group and the Mines Group.

The intrusive rocks are gabbroic in composition 
and contain abundant retrograde actinolite and epido-
tized andesine together with Na-rich amphibole and 
dipyr. The accessory minerals are quartz, calcite, 
biotite, ilmenite and traces of pyrite and sphene (Jamot-
te, 1933). Another kind of rock was observed in this 
area. These rocks are massive and particularly rich in 
phengite, chlorite (brunsvigite; Foster, 1962) and 
quartz. They also contain some mica with a very weak 
pale brown pleochroism and minor quantities of ilme-
nite and rutile, hematite, kyanite and possibly sillima-
nite (optical identification of relatively fine grains).

These unusual kyanite-bearing rocks were interpri-
ted by Jamotte as the results of intense greisenisations 
of sedimentary rocks that he related to the intrusion of 
an important granitic batholite, located 35 km south of 
the Lufunfu area (Kabombo dome; fig. 1). To these 
magmatic metamorphic events, Jamotte associated the 
occurrence, in the close neighbourhood of this batho-
lite (Lualaba Signal), of important masses of rocks prin-
cipally composed of quartz, corundum, diaspore and 
rutile which were observed and described by Cesaro 
and Bellière (1921) and Bellière (1932). Since, it has 
been demonstrated that these crystalline rocks ex-
posed at the Zaïre–Zambia border, along the center of 
the Luflian Belt, are pre-Katangan rocks belonging to late 
tectonic basement domes, the hypothesis of metasos-
matisms related to young Katangan intrusive bodies 
is no longer possible to sustain.

Another occurrence of this chlorite--phlogopite-- 
phengite--kyanite assemblage is known from brecciated 
and slightly weathered shales of the Mwashya Group in 
the Kibamba anticline (south–east extension of the Men-
da anticline; fig. 1). Due to consecutive tectonic breccia-
ciation and mineral recrystallizations, the texture is 
massive with large xenoblastic pale brown biotite super-
posed on subidioblastic and poikiloblastic flakes of co-
lourless chlorite and, replacing short, rectangular, co-
loiuless phengite. Other accompanying minerals are 
dolomite, quartz and pyrite and traces of formless 
kyanite, closely related to the biotite. From optical 
observations, it is evident that the biotite results from 
chlorite and phengite transformations, possibly with the 
release of quartz and kyanite. The composition of the 
chlorite obtained by microprobe analysis yielded the 
following formula:

\[(Mg_{0.31}Fe_{0.73}Al_{1.28}Mn_{0.007}Cr_{0.002}Ti_{0.01}Ca_{0.02})\]

\[K_{0.03}(Si_{0.85}Al_{1.15})O_{10}OH_{7.98}\]

which corresponds to a brunsvigite or an iron-rich epi-
clochlore. The analysis of the idiomorphic diotahedral 
phengite recalculated on a basis of 12 (0,0H) gives:

\[(K_{0.74}Na_{0.02}Ca_{0.02})\]

\[(Al_{1.39}Mg_{0.49}Fe_{0.21}Cr_{0.01}Ti_{0.03})\]

\[(Al_{0.49}Si_{3.61}O_{9.30}(OH)_{2.70}\)

showing excess silicon linked with almost equal amounts
of Mg in the octahedral layer and approaching the composition of an ideal phengite

\[ \text{K}_1.5\text{Al}_{1.5}\text{Mg}_{0.5}\text{Al}_{0.5}\text{Si}_{3.5}\text{O}_{10}(\text{OH})_2 \]

by means of the characteristic substitution Mg Si – Al Al. The structural formula of the trioctahedral biotite can be written as follows:

\[ (\text{K}_{0.35}\text{Na}_{0.04})(\text{Al}_{0.71}\text{Mg}_{1.64}\text{Fe}_{0.75}\text{Mn}_{0.03}) \]
\[ (\text{Al}_{1.37}\text{Si}_{2.63})_0.91(\text{OH})_{2.89} \]

It can be identified to a vermiculitized iron-rich phlogopite. Energy-dispersive spectrometry of kyanite crystals confirmed the presence of Si and Al as the only element constituents. This phlogopite-kyanite assemblage indicates relatively high pressure and temperature that seem incompatible with the overall low grade metamorphism (greenschist facies) which characterizes the center of the Lufilian Belt.

In the same Kibamba anticline, pinkish hematiferous sandstones belonging to the Kibamba Group contain abundant quartz, colourless chlorite, and large (up to 4 mm in length) poikilitic crystals of kyanite and sillimanite (plate 1 f and g). Compared to the former assemblage, Mg-chlorite, kyanite, sillimanite assemblage indicates lower P and T conditions but which are still too high for normal metamorphic terranes characterized by a greenschist facies. The colourless chlorite which seems in perfect equilibrium with kyanite and sillimanite has an X-ray spectrum very similar to the one of a Mg-rich chlorite (tables 5 and 6) except for the relative intensities of the basal reflections. As for the aluminium serpentine of Kambove and Shituru, examination of the structural formula of the Kibamba chlorite indicates a Si-enrichment and a possible substitution of Al for Mg in the octahedral layers with a resulting increase of positive charges partly compensated by octahedral position deficiencies (table 7; sample #2). The Kibamba chlorite differs from the aluminium serpentines by the absence of excess water in the structural formula.

**DISCUSSION**

The rather frequent occurrences of kyanite in the Zairian Copperbelt is unexpected considering the grade of metamorphism that affects the area. If one examines fig. 1, all the kyanite occurrences, with the exception of the samples from the Lufunfu river, belong to a narrow zone located on the low grade side of the biotite isograd. The more common assemblages observed along this zone are:

1. Pelitic assemblages (in every case with rutile) 
   quartz-muscovite or phengite-chlorite-albite
   quartz-phengite-chlorite-kyanite

2. Quartz-feldspathic assemblages (rutile) 
   quartz-microcline-albite-muscovite
   quartz-albite-microcline-magnesioriebeckite-kyanite

3. Calcareous assemblages 
   calcite-dolomite-kyanite
   talc-dolomite-magnesite
   talc-phengite-chlorite-microline

4. Basic assemblages (sphe or rutile) 
   albite-actinolite-chlorite-epidote-(calcite-kyanite) 
   phlogopite-chlorite-kyanite-(hematite)

5. Iron rich assemblages 
   siderite-dolomite-kyanite-kyanite 
   dolomite-calcite-kyanite

These assemblages are characteristic of the chlorite zone of the greenschist facies. The substitution of pyrophyllite for kyanite in the kyanite-alumina serpentinite assemblages of the Luiswihi, Star of Congo and, possibly the Luishia deposit, confirms the incompatibility of kyanite with the surrounding metamorphic terranes.

The kyanite-pyrophyllite-kyanite assemblages of Luiswihi and the kyanite-pyrophyllite-diaspore assemblage of the Star of Congo deposit probably result from the following reactions experimentally investigated by Haas and Holdaway (1973):

1. **Pyrophyllite** = 1 kyanite + 3 quartz + 1 water
2. **Pyrophyllite** + 6 diaspor = 4 kyanite + 4 water

These reactions impose an upper temperature and pressure limit on the stability range of pyrophyllite which coincides with the chlorite zone in pelitic schists. From this, one may make the reasonable assumption that the simultaneous crystallization of kyanite and aluminium serpentine is related to alterations (likely hydrothermal) predating the main phase of the metamorphism in Shaba.

In the Kambove West deposit, the substitution of serpentine for chlorite is observed only in the beds belonging to the Lower Group and the portion of the tectonic breccia that results directly from its fracturation (monogenic breccia, fig. 2). On the contrary, the surrounding heterolitic breccia contains the same original chlorite as the one described in the mineralized zones of the Mines Group. These observations indicate that the chlorite-serpentine substitution occurred prior to or contemporary with the main stage of tectonism; contradicting the hypothesis of a posttectonic origin for the florencite from Shituru as proposed in a previous
The altered rock is increased as abundant quartz crystallizes locally. Hematite and dolomite do not appear to be affected by this transformation. Kyanite (and sillimanite) is formed, implying rather high aluminium activities.

Finally, a diagenetic euahedral monazite containing cerium, lanthanum and other rare-earth elements recrystallizes as anhedral to euahedral crystals of monazite with the less soluble cerium as the only rare-earth element. The residue of this transformation is redeposited, at distance, in the form of La-rich aluminium phosphate. To summarize, the main elements involved in this alteration are Si, Al, P, La and water. Since most of these elements were present in the system before the alteration and considering the extremely low mobility of aluminium, the hydrothermal alteration responsible for the crystallization of kyanite and serpentine must have consisted principally of the action of water under special conditions of temperature and pressure. A lower limit of the pressure and temperature for this hydrothermal alteration may be roughly estimated considering the stability range of kyanite and aluminum serpentine, namely, a narrow range about the point P = 4 Kb and T = 430° C with a possible higher temperature to account for the formation of sillimanite.

Two occurrences of kyanite have been reported in the biotite zone of the Lufilian Belt; one in the Kibamba anticline, the other in the Lufunfu river area, both are located a short distance from the biotiteograd. In the Kibamba anticline, kyanite crystallizes in brecciated dolomitic siltstones principally composed of phengite and chlorite. Optical examination of this material indicates the possibility of a reaction between the phengite and the chlorite to give phlogopite and a minor amount of kyanite. This reaction is commonly observed in natural rocks with high Mg/Fe ratios or in rocks free of garnet or staurolite and at thermodynamic conditions corresponding to high pressure and temperature (Bird & Fawcett, 1973); that is to say at least 600° C and 6 kb. It is certain, however, that such a high pressure would not be necessary in the case of the Kibamba sample due to the presence of additional Fe++ in the system and also by conditions of water pressure being less than total pressure. As a matter of fact, the abundance of dolomites among the sediments of the Lufilian Belt as well as in the Kibamba sample, suggests the possible existence of high CO₂ content in the fluid phase, at the expense of the water activity; it must be kept in mind that huge volumes of dolomite in the Kolwezi-Likasi-Lubumbashi alignment have been
transformed into massive talcose bodies (1). Thus the kyanite-phlogopite assemblage is not necessarily indicative of pressure and temperatures as high as those inferred by experimental studies. Nevertheless, this assemblage remains an anomaly in the biotite zone of the Luflilian belt, confirming the possible existence of local high pressure (and temperature) likely related strictly to the chaotic tectonism of Shaba. The cycloean breccias of the Luflilian belt extends towards the south, across the Zambia-Zaire border, in the Solwezi area where talc-kyanite-quartz schists, phlogopite-kyanite-quartz schists and Mg-chlorite-kyanite-quartz schists have been recently discovered (Vrána & Barr, 1972 ; Vrána, 1975) among rocks of the Roan Supergroup, that underwent a medium grade metamorphism characterized by a much lower pressure and temperature than one would expect for the formation of 'whiteschists', possibly repeating on a different P and T level the situation observed in Shaba.

CONCLUSIONS

A La-rich florencite has been observed at several locations in the Shaba province of Zaire. The aluminium phosphate of rare-earth systematically occurs in sedimentary rocks belonging to the Roan Supergroup of the Katangan Sequence, in deposits characterized by Cu and Co mineralizations. The florencite is frequently accompanied with a Ce-rich, La-deficient monazite which appears to result from the alteration of a diagenetic monazite with a leaching of the more soluble rare-earths. These mineralogical changes are attributed to a hydrothermal alteration which is also responsible for the replacement of a neogenic clinohlore by a complex series of clay minerals principally composed of aluminian serpentine with, from one deposit to another, rather uniform optical, chemical and diffractometric characteristics. The associated clay minerals are smectites, chlorites, swelling chlorites and the interstratified minerals of the former. In the Kambove West deposit a regularly interstratified clay mineral could be identified with a 3:1 chlorite-talc interlayered texture.

Although the origin of the neogenic clinohlore is not discussed in this paper, it also has a rather uniform composition in most of the deposits of the Zaïrian coppperbelt and is assumed to be contemporaneous with the Cu-Co mineralizations. The hydrothermal alterations responsible for the crystallization of the clay mineral cortège and the florencite would then be related to a post-mineralization event resulting in local remobilization of the copper to account for the presence of some chalcopyrite (quartz and dolomite) in narrow veins described in the Kabolela, Menda, Luishia and Luiswishi deposits. It would be interesting, at this point, to refer to a short note from Bateman and Jensen (1963), describing on the basis of sulfur isotope composition, a chalcopyrite, kyanite, quartz vein sample from the Luishia deposit as outside the range of sedimentary or biogenic origin.

Kyanite is also present in some of these hydrothermal assemblages and has been interpreted as possibly related to the existence of local high pressure conditions induced by the high-stress and chaotic tectonism that characterized the Central African Copperbelt.

Syn- and posttectonic metamorphic conditions tend to destroy the stability of the Al-serpentine-kyanite assemblage. In the chlorite zone of the greenschist facies, pyrophyllite and disappo substitute for kyanite. In the biotite zone, kyanite associated with sillimanite, appears to be more stable, while the presence of a Si-enriched clinohlore is tentatively attributed to the high temperature inversion of Al-serpentine. The kyanite-sillimanite-chlorite-quartz assemblage observed in the Kibamba anticline would then result from the effect of a prograde metamorphism of Al-serpentine-kyanite- (sillimanite ?) assemblages of high pressure hydrothermal affinity as opposed to the concept of a retrograde reaction of high pressure talc-kyanite as suggested by Vrána and Barr (1972) for the Zambian occurrences.

ACKNOWLEDGEMENTS

The authors wish to thank professor J.J. Fawcett (University of Toronto) for helpful discussions. Microprobe analyses were provided by C. Gasparini (Minmet Scientific Ltd.). Special thanks is extended to T. Nancreaves for having typed the manuscript.

(1) Incidentally, it should be noted that careful investigations of these talc-rich rocks did not reveal the existence of kyanite as suggested by Vrána (1975). The most frequent assemblages found in these rocks are the usual assemblage talc-phengite-muscovite (plus rutile) or the assemblage talc-chlorite-microcline (plus rutile).
BIBLIOGRAPHY


TABLE 1. Basal spacing (in Å) from oriented films of unsaturated clay minerals from the Shituru deposit. (sample #1; d.hole 5302, 107 m depth; Florencite rich horizon).

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- A. mineral of the kandite group (75%).
- B. mineral of the chlorite group (15%).
- C. montmorillonite-chlorite regular mixed layers (10%).
- D. swelling chlorite-chlorite mixed layers or chlorite with a montmorillonite behaviour (traces).
- E. possibly montmorillonite-chlorite random mixed layer (traces).

* very weak reflection.
br broad reflection.
(a) dolomite reflection.
TABLE 2. Basal spacing (in Å) from oriented films of unsaturated clay minerals from the Shituru deposit. (Sample #2: d.hole S102, 100 m depth).

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- A. mineral of the kandite group (70%).
- B. montmorillonite-swelling chlorite regular mixed layers (15%).
- C. mineral of the chlorite group (10%).
- D. possibly swelling chlorite or montmorillonite-chlorite regular mixed layers (5%).

* very weak reflection.
br broad reflection.
(h) asymmetry towards high angles.
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|                  | 0.001 0.001 0.001 | 0.012            |

A. Mineral of the chlorite group (45%).  
B. smectite (30%).  
C. sweling chlorite-chlorite-regular mixed layer (25%).  
D. possibly montmorillonite-chlorite random mixed layer (traces).  

\(*\) very weak reflection.  
\(^\text{*}\) asymmetry towards small angles.  
\(^\text{a}\) dolomite reflection.
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</table>

(1) = reflections omitted in taking mean d(002).

---

A. chlorite-unexpandable Mg-mineral regular mixed layer (55%).
B. swelling chlorite-montmorillonite random mixed layer (30%).
C. mineral of the kandite group (15%).

* very weak reflection
(s) asymmetry towards small angles.
(h) asymmetry towards high angles.
(a) dolomite reflection.
<table>
<thead>
<tr>
<th>1.</th>
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<th>4.</th>
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<tr>
<td>$d_{\text{meas.}}$</td>
<td>$l/l_0$</td>
<td>$d_{\text{meas.}}$</td>
<td>$l/l_0$</td>
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<td>14.19</td>
<td>35</td>
<td>14.3</td>
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<td>7.10</td>
<td>100</td>
<td>7.11</td>
<td>76</td>
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<td>76</td>
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<tr>
<td>1.815 *</td>
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<td>1.829</td>
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<tr>
<td>-</td>
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<td>-</td>
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<tr>
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<td>-</td>
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<td>209;066</td>
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<td>-</td>
<td>00;12</td>
</tr>
<tr>
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<table>
<thead>
<tr>
<th>mean $d(001)$</th>
<th>mean $d(001)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.195</td>
<td>14.215</td>
</tr>
</tbody>
</table>

br - broad reflection
* - intensity at least partly due to another phase.
TABLE 6. Unit-cell dimensions of the chlorites from Kambove and Kibamba and of the kandite from Shituru.

<table>
<thead>
<tr>
<th></th>
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<th>4</th>
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</thead>
<tbody>
<tr>
<td>a(Å)</td>
<td>5.318(2)</td>
<td>5.396(2)</td>
<td>5.297(2)</td>
<td>5.232(1)</td>
</tr>
<tr>
<td>b(Å)</td>
<td>9.203(2)</td>
<td>9.207(2)</td>
<td>-</td>
<td>9.208(2)</td>
</tr>
<tr>
<td>c(Å)</td>
<td>14.297(2)</td>
<td>14.351(3)</td>
<td>42.570(26)</td>
<td>42.613(9)</td>
</tr>
<tr>
<td>/3(°)</td>
<td>96.891(12)</td>
<td>98.046(28)</td>
<td>90.00</td>
<td>90.00</td>
</tr>
<tr>
<td>V(Å³)</td>
<td>694.56 (19)</td>
<td>705.87 (22)</td>
<td>1034.76 (96)</td>
<td>2052.82 (53)</td>
</tr>
<tr>
<td>n*</td>
<td>15</td>
<td>15</td>
<td>28</td>
<td>24</td>
</tr>
</tbody>
</table>

n* number of lines used in refining cell dimension.

1. Leuchtenbergite, Kambove West. 2. Si-enriched leuchtenbergite, Kibamba. 3. Kandite, Shituru. 4. 6(2) layer Al-lizardite, Tracy Mine, U.S.A.
TABLE 7. Chemical analyses (in %) and structural formulae of the chlorites, kandites and mixed layer from Shaba, Zaire.

<table>
<thead>
<tr>
<th></th>
<th>Column 1</th>
<th>Column 2</th>
<th>Column 3</th>
<th>Column 4</th>
<th>Column 5</th>
<th>Column 6</th>
<th>Column 7</th>
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</thead>
<tbody>
<tr>
<td>SIO₂</td>
<td>30.23</td>
<td>32.62</td>
<td>30.21</td>
<td>31.80</td>
<td>30.24</td>
<td>31.00</td>
<td>38.04</td>
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<tr>
<td>Al₂O₃</td>
<td>23.34</td>
<td>22.01</td>
<td>24.40</td>
<td>24.22</td>
<td>23.37</td>
<td>24.19</td>
<td>23.74</td>
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<td>0.13</td>
<td>n.d.</td>
<td>1.11</td>
<td>0.63</td>
<td>0.00</td>
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<tr>
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<td>2.37*</td>
<td>1.95*</td>
<td>0.13*</td>
<td>1.97*</td>
<td>1.36</td>
<td>0.70*</td>
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<tr>
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<td>0.11</td>
<td>0.00</td>
</tr>
<tr>
<td>CrO</td>
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<td>0.01</td>
<td>0.07</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>0.00</td>
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<tr>
<td>MgO</td>
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<td>30.05</td>
<td>28.31</td>
<td>28.70</td>
<td>28.61</td>
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<td>31.77</td>
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<tr>
<td>CaO</td>
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<td>0.00</td>
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<tr>
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<td>0.08</td>
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<tr>
<td>Na₂O</td>
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<td>n.d.</td>
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<td>0.06</td>
<td>0.10</td>
<td>0.00</td>
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<tr>
<td>P₂O₅</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>0.12</td>
<td>0.14</td>
<td>n.d.</td>
<td></td>
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<tr>
<td>L.O.I.</td>
<td>11.64**</td>
<td>11.98**</td>
<td>14.77**</td>
<td>14.69**</td>
<td>14.22</td>
<td>14.40</td>
<td>5.75**</td>
</tr>
</tbody>
</table>

Total 100.00 100.00 100.00 100.00 99.98 100.97 100.00


n.d. not determined.

* total Fe recalculated as FeO only.
** obtained by subtracting microprobe total from 100%.

W.A.: wet assay (Gecamines, Likasi, Zaire).

1. Leucitnerbergite, Kambove West. (Mg₄.68Fe₅.02Al₁.27Mn₀.01)(Si₂.76Al₁.12Mn₀.01)₁₀(OH)₇.09
   5.98

2. Si-enriched leuchtnerbergite, Kibamba. (K₀.10Ca₀.03Mg₄.13Fe₀.18Al₁.45Mn₀.01)₁₀(Si₂.01Al₁.00)₁₀(OH)₇.37
   5.86

3. Kandite, Shitu (S10.2,601m) (K₀.02Ca₀.02Mg₄.00Fe₀.15Al₁.59Mn₀.01)(Si₂.36Al₁.14)₁₀(OH)₇.86
   7.86

4. Kandite, Kambove (Kw0.17,320m) (Na₀.03Ca₁.02Ca₀.02Mg₄.00Fe₀.01Al₁.64)(Si₂.97Al₁.03)₁₀(OH)₇.83
   7.71

5. Massive clay mostly composed of kandite (Kw0.17,321m) (K₀.01Na₀.01Ca₀.01Mg₄.05Fe₀.16Al₁.46Mn₀.01)₁₀(Si₂.38Al₁.14)₁₀(OH)₇.86
   5.77

6. Massive clay mostly composed of kandite (Kw0.17,457m) (K₀.01Na₀.02Ca₀.01Mg₄.00Fe₀.10Al₁.55Mn₀.01)₁₀(Si₂.89Al₁.11)₁₀(OH)₇.86
   5.74

7. Reg. interstratifi. of chlorite and un-expandable Mg-mineral (Kw0.17,473m) (Mg₁₅.10Fe₀.19Al₁₅.10)(Si₁₂.15Al₃.85)₁₀(OH)₂₅.92
   20.41
PLATE 1

a. Pseudocubic crystals of florencite from the Shituru deposit.
b. Hexagonal section of a crystal of florencite from the Kambove W. deposit.
c. Hexagonal section of a crystal of florencite from Kabloela.
d. and e. Photomicrographs of hexagonal plates of aluminian serpentine (Kambove W. deposit).
f. Kibamba anticline: subidioblastic, poikiloblastic sissilmanite (Si) in a groundmass principally composed of Si-enriched leuchtenbergite (Ch), quartz (Q.) and hematite (Hm).
g. Kibamba anticline: xenoblastic to subidioblastic, poikiloblastic sillimanite (Si) and kyanite (Ky) crystals clustered in a groundmass similar to that found in f.