

HYDROTHERMAL ASSEMBLAGES OF ALUMINIAN SERPENTINE FLORENCITE AND KYANITE IN THE ZAIRIAN COPPERBELT ¹

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 lufilien. Elles résulteraient d'une altération hydrothermale de sédiments appartenant au "Roan Supergroup" et consisteraient en le remplacement d'un clinochlore 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 cérifère 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 brécciation 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 - disthène observée dans la zone à biotite de l'arc lufilien. 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 lufilien.

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 Lufilian 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 clinochlore 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 Lufilian 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 Lufilian belt just south of the area being studied.

INTRODUCTION

A La-rich Florencite, $(La,Ce)Al_3(PO_4)_2(OH)_6$, has been recently discovered in the Copper Province of Shaba (Lefebvre & Gasparrini, 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-

¹ Manuscrit reçu le 15 avril 1981.

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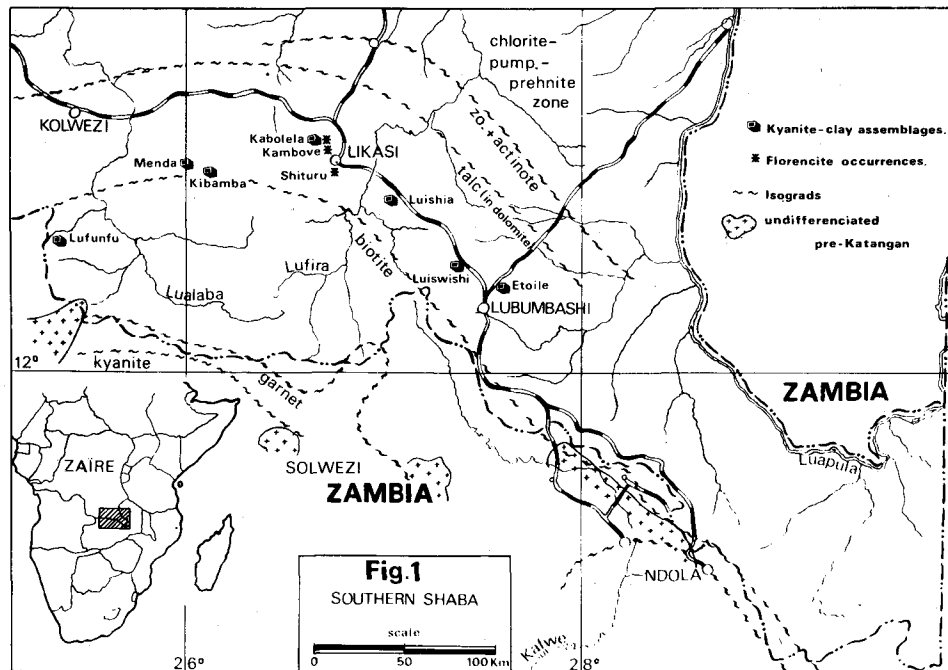


Figure 1.- Location of the known kyanite occurrences in the Shaba section of the Lufilian belt with the distribution of the metamorphic zones.

sit (Buttgenbach, 1925 ; Lefebvre, 1926). In the Luiswishi deposit, some of these veins yield rather coarse kyanite crystallizations. Similar assemblages were successively located in the Star of Congo deposit (gisement de l'Etoile ; Lefebvre & Cailteux, 1975) and in a Cu-Ni prospect in the Menda anticline (Lefebvre, 1976). The preceding 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 Katangian 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, sillimanite, kyanite and quartz forming assemblages similar to the chlorite-kyanite-quartz schists found interlayered with "Whiteschists" (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 aluminian serpentine (or Si-rich amesite) synthesized by Roy & Roy (1954) and by Gillery (with Hill, 1959) and observed in nature in only a few locations (Shirozu, 1958 ; Bailey & Tyler, 1960 ; Jahanbagloo & Zoltai, 1968 ; Zhukov, 1971).

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

FLORENCITE FROM SHITURU

As described in a recent paper (Lefebvre & Gasparri, 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 lagoonal dolomites of the Mwashya Group (uppermost part of the Roan ; Lefebvre, 1978). In sample # 1 (drill hole S102, 101 m depth), florencite is present as tiny rhombohedral and pseudocubic crystals with a grain size averaging between 15 and 60 microns (Plate 1a) and accounts for 3 % of the volume. Florencite, together with local aggregates of Ce-rich, La-deficient euhedral monazite were related 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 (00 l) 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 (00 l) 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-

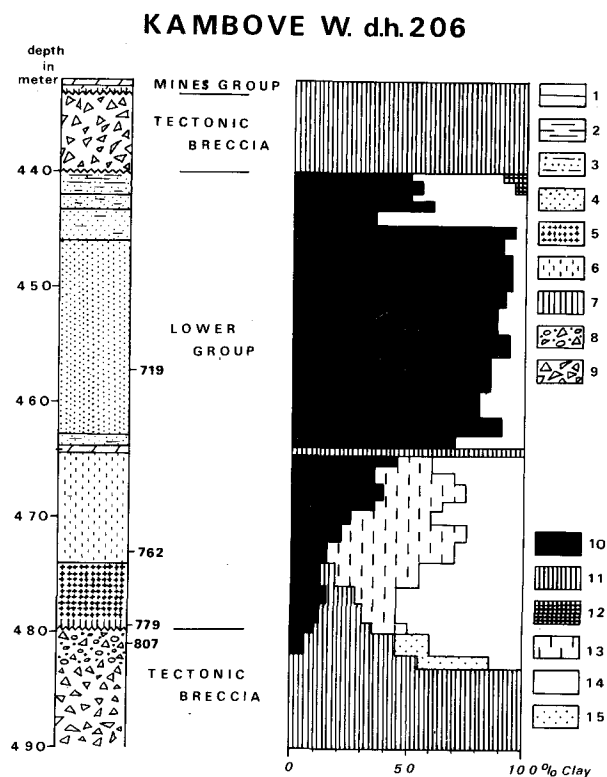


Figure 2.- Semi quantitative distribution of the clay minerals observed in the Lower Group of the Kambove West deposit.

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

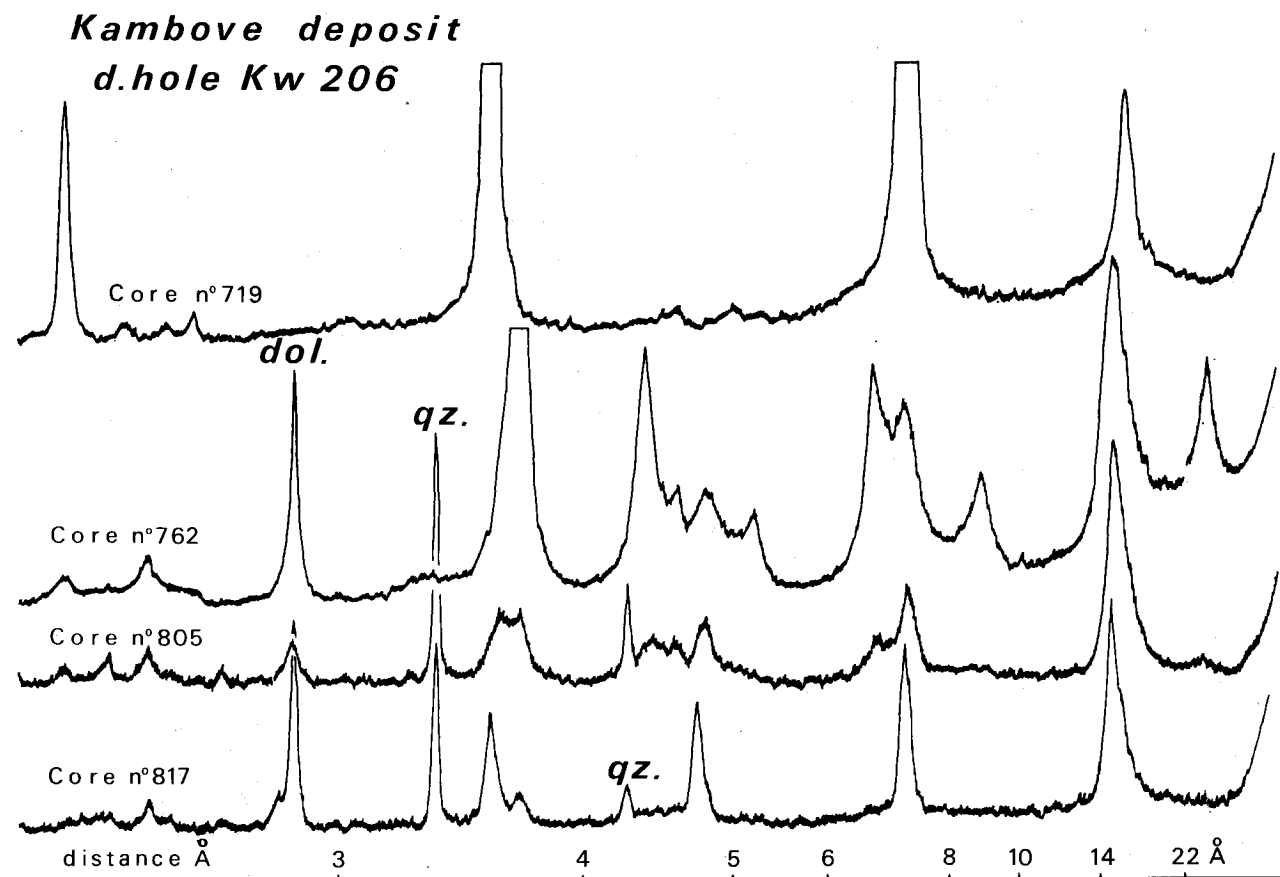


Figure 3.- X-ray diffraction on the main clay assemblages observed in the Lower Group of the Kambove West deposit (unoriented samples).

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 (00 ℓ) 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 heterolithic breccia of Kambove West (table 7, analysis n° 1), others are very comparable to the lepto-chlorite 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).

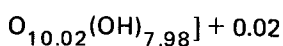
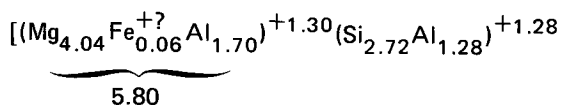
The core # 762, which corresponds to a massive, pinkish-red grit, was particularly rich in a clay mineral, greenish in color, with a soapy touch. The X-ray diffraction analysis of this material yielded a rather diffe-

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 leuchtenbergite 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 :

$$1/d(00\ell) = 0.75/d(00\ell) \text{ chlorite} + 0.25/d(00\ell) \text{ talc}$$

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 $O_{4.0}(\text{OH})_{2.6}$ unit (table 7, analysis n° 7) is compatible with the 3:1 interstratification of an Al-enriched leuchtenbergite



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 leuchtenbergite 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 leptochlorites 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 kandite of Shituru and Kambove and in the Si-enriched leuchtenbergite of Kibamba (discussed anon, and table 7).

This unusual trioctahedral 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 ; 2.366 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 leptochlorites, regular mixed layer with

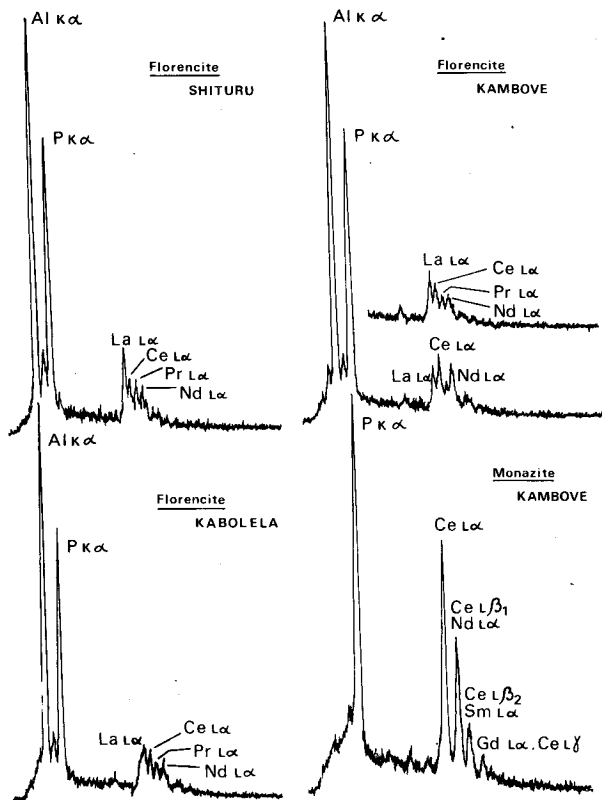


Figure 4. Electron-microprobe X-ray spectra of florencite and monazite from Zaire.

chlorite and possibly talc, swelling chlorite and montmorillonite. The clay material accounts for 25 to 30% by volume of the whole rock which consists of a heavily fractured massive, pinkish grey, quartzitic sandstone. Florencite accounts for approximately 5% of the total 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 (Cailteux, 1977 a). 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 florencite and Ce-rich monazite has been described in the same kind of environment (Lefebvre & Gasparrini, 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 florencite.

FLORENCITE FROM KABOLELA

Florencite 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 florencite grains, show that the chemical composition is almost identical to the Shituru florencite with La as the most abundant rare-earth element (fig. 4). The florencite crystals are associated with anhedral neogenic kyanite and are disseminated in carbonaceous and dolomitic siltstones. Combined, florencite 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 peripherally. 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 examination 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 ($N_y = 1.566 \pm 0.002$) are slightly lower than those of the Mg-chlorite described in the same deposits (Kambove chlorite : $N_y = 1.575 \pm 0.001$). The birefringences of kandite and clinocllore 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 powder 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 (11ℓ) reflections and the almost complete (02ℓ) series of reflections is a manifestation of the 6-layer structure of this serpentine. The presence of (20ℓ) reflections with relatively higher intensities of the reflections with odd ℓ compared with those with even ℓ 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 belonging to the (00ℓ) series were observed. Also, the (13ℓ) reflections observed in the spectrum obtained from random 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 ordinarily 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 parameter 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 serpentine structure with b remaining constant. The cation and hydroxyl differences that exist between the serpentines and the chlorites from Kambove could be responsible for the alteration of the a and c parameters in the newly formed phases, with the subsequent loss of the ortho-hexagonal symmetry of the serpentines ($a \neq b/\sqrt{3}$) and possibly implying a preferential distribution of Si replacing Al and Al replacing Mg parallel to the y direction.

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 structure, 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 formulae 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 sacrificed 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 fractures, 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 chalcopryrite in veins cutting across and impregnating wallrocks composed of carbonaceous shales of the Mines Group. Another major component of these veins consisted of sericite (?) and muscovite (?) isolating the kyanite from the encrusting chalcopryrite and apparently resulting from the hydrothermal alteration of the former. These veins also contained quartz, apatite and rutile, but no dolomite.

In a similar environment (S.D. lithostratigraphic unit of the Mines Group) several kyanite rich veins were recently observed outcropping in the Luiswishi deposit as well as in the Menda Cu-Ni project, respectively about 100 km south-east and west of the Shituru deposit (fig. 1). The collected samples were rather weathered and almost essentially composed of kyanite in large

stubby crystals (up to 3 cm in Luiswishi) frequently wrapped by massive chalcopyrite. The kyanite is currently corroded and locally (some occurrences from Luiswishi) rimmed by a finely crystallized or medium grained flaky material which was identified by X-ray diffractometry 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 Zairian Copperbelt consists of basic volcanic ashes and is principally composed of chlorite, tourmaline, ilmenite and rutile, monazite and very minor quartz (Lefebvre & Cailteux, 1975). In close contact to the veins, the basic ash is enriched in abundant euhedral 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 outines, partly altered into pyrophyllite and diasporite aggregates.

CHLORITE-KYANITE ASSEMBLAGES

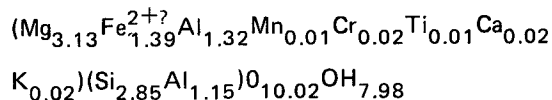
Several samples containing kyanite have been drawn from isolated outcrops along the Lufunfu river. A younger age than that of the Roan was attributed to these rocks by Jamotte (1933). However, a more detailed geological study of the area seems to indicate that these kyanite-bearing rocks and the associated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

The intrusive rocks are gabbroic in composition and contain abundant retrograde actinolite and epidotized andesine together with Na-rich amphibole and dipyre. The accessory minerals are quartz, calcite, biotite, ilmenite and traces of pyrite and sphene (Jamotte, 1933). Another kind of rock was observed in this area. These rocks are massive and particularly rich in phengite, chlorite (brunsvigite ; Foster, 1962) and

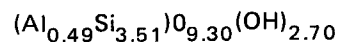
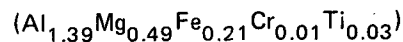
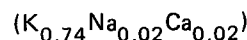
quartz. They also contain some mica with a very weak pale brown pleochroism and minor quantities of ilmenite and rutile, hematite, kyanite and possibly sillimanite (optical identification of relatively fine grains).

These unusual kyanite-bearing rocks were interpreted 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 (Kabompo dome ; fig. 1). To these magmatic metasomatic events, Jamotte associated the occurrence, in the close neighbourhood of this batholite (Lualaba Signal), of important masses of rocks principally composed of quartz, corundum, diasporite and rutile which were observed and described by Cesaro and Bellière (1921) and Bellière (1932). Since, it has been demonstrated that these crystalline rocks exposed at the Zaire-Zambia border, along the center of the Lufilian Belt, are pre-Katangan rocks belonging to late tectonic basement domes, the hypothesis of metasomatism related to young Katangan intrusive bodies is no longer possible to sustain.

Another occurrence of this chlorite-phengite-phlogopite-kyanite assemblage is known from brecciated and slightly weathered shales of the Mwashya Group in the Kibamba anticline (south-east extension of the Menda anticline ; fig. 1). Due to consecutive tectonic brecciation and mineral recrystallizations, the texture is massive with large xenoblastic pale brown biotite superposed on subidioblastic and poikiloblastic flakes of colourless chlorite and, replacing short, rectangular, colourless 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 :

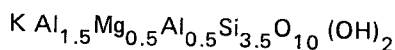


which corresponds to a brunsvigite or an iron-rich clinocllore. The analysis of the idioblastic dioctahedral phengite recalculated on a basis of 12 (O,OH) gives :

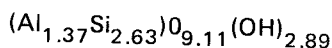
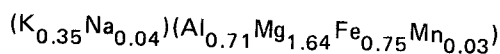


showing excess silicon linked with almost equal amounts

of Mg in the octahedral layer and approaching the composition of an ideal phengite



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



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 aluminian 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 aluminian serpentines by the absence of excess water in the structural formula.

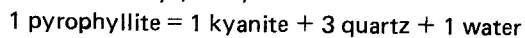
DISCUSSION

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-hematite
2. Quartz-feldspathic assemblages (rutile)
 - quartz-microcline-albite-muscovite
 - quartz-albite-microcline-magnesianiebeckite-hematite
3. Calcareous assemblages
 - calcite-dolomite-quartz
 - talc-dolomite-magnesite
 - talc-phengite-chlorite-microcline
4. Basic assemblages (sphene or rutile)
 - albite-actinolite-chlorite-epidote-(calcite-quartz)
 - phlogopite-chlorite-quartz-(hematite)
5. Iron rich assemblages
 - siderite-dolomite-hematite-quartz
 - dolomite-calcite-hematite

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

The kyanite-pyrophyllite-quartz assemblages of Luiswishi 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) :



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 aluminian 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 heterolithic 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

description (Lefebvre & Gasparrini, 1980). A syntectonic origin for the kyanite-aluminian serpentine-florencite assemblages would explain the crystallization of kyanite instead of a lower pressure and temperature polymorph like andalusite which has never been observed in the Lufilian Belt. The tectonism in Shaba is peculiar and resulted in the formation of a huge breccia (several hundred kilometers in extension) composed of randomly oriented blocks up to two kilometers long, isolated in a pseudoconglomerate that originated from the attrition of softer horizons (Demesmaeker *et al.*, 1962) probably originally rich in evaporitic sediments. Such a phenomenon may have induced locally high hydrostatic pressures at relatively low temperatures. These high pressures would have also favoured the crystallization of 6-layer lizardite which has a slightly smaller volume than the 1-layer serpentine structures (Gillery, 1959).

The kyanite-sillimanite-chlorite assemblage observed in the hematitic sandstones of the Kibamba anticline may be related to the kyanite-serpentine assemblages described further north. In the Kibamba area, the grade of the metamorphism is slightly higher and biotite starts to crystallize in the pelitic rocks. Knowing that aluminian serpentine is a metastable mineral that tends to be transformed into a chlorite of similar composition at temperatures over 450 to 500° C (Gillery, 1959), one may assume that the "leptochlorite" from Kibamba (tables 5, 6 and 7) is the recrystallized equivalent, in the biotite zone, of the serpentine preserved in the chlorite zone. However, the presence of sillimanite in addition to kyanite may not be attributed to this increase of regional metamorphism since the kyanite-sillimanite inversion is extremely sluggish and forms more commonly as fibrolite crystals independent of the pre-existing aluminosilicate. The relationship between the two aluminosilicates observed under the microscope seems to indicate a simultaneous crystallization (plate 1 g) and since sillimanite may form at temperatures as low as 410° C (based on experimental work by Weill, 1966), still largely within the stability range of the 6-layer aluminian serpentine, one may attribute to this sillimanite a hydrothermal origin similar to that of kyanite and the serpentine.

The chemistry of this hydrothermal alteration is manifested by striking mineralogical changes. The original chlorite is transformed into serpentine and various interstratified minerals composed of chlorite, swelling chlorite and montmorillonite the composition of which infers the presence of water, silica and minor alumina enrichments. The bulk silica content of

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 euhedral monazite containing cerium, lanthanum and other rare-earth elements recrystallizes as anhedral to euhedral 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 aluminian serpentine, namely, a narrow range about the point $P = 4 \text{ Kb}$ and $T = 430^\circ \text{ C}$ 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 biotite isograd. 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 Lufilian belt, confirming the possible existence of local high pressure (and temperature) likely related strictly to the chaotic tectonism of Shaba. The cyclopean breccias of the Lufilian 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 clinocllore 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 clinocllore is not discussed in this paper, it also has a rather uniform composition in most of the deposits of the Zairian copperbelt 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 diaspore substitute for kyanite. In the biotite zone, kyanite associated with sillimanite, appears to be more stable, while the presence of a Si-enriched clinocllore 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. Gasparrini (Minmet Scientific Ltd.). Special thanks is extended to T. Nangreaves 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 unusual assemblage talc-phengite-microcline (plus rutile) or the assemblage talc-chlorite-microcline (plus rutile).*

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TABLE 1. Basal spacing (in Å) from oriented films of unsaturated clay minerals from the Shituru deposit. (sample #1; d.hole S102, 101 m depth; florencite rich horizon).

Air-dry				Glycol					550°C/1H						
<i>d</i>	(001)			<i>d</i>	(001)					<i>d</i>	(001)				
	A	B	C		A	B	C	D	E		A	B	C	D	E
28.44			(001)	31.06			(001)			23.04			(001)		
				16.67					(001) ?						
				15.50			(002)								
				14.41				(001)							
14.23		(001)	(002)	14.27		(001)				13.91		(001)		(001)	
										13.56				or (001)	
										12.92					(001)
										12.30			(002)		
9.44	br		(003)	10.32			(003)								
				8.68					(002) ?						
				7.76			(004)			7.66			(003)		
7.09	(001)	(002)	(004)	7.09	(001)	(002)		(002)		7.09	(001)	(002)			
										6.79				(002)	
				6.50			(005)			6.63					(002) ?
										6.22			(004)		
5.79 *			(005)	5.16			(006)								
				4.82				(003)							
4.71		(003)	(006)	4.76		(003)									
				4.27 *					(004)	4.26					(003)
										4.11			(006)		
				3.88			(008)								
				3.61				(004)							
3.55	(002)	(004)	(008)	3.56	(002)	(004)				3.55	(002)	(004)			
										3.51			(007)		
				3.44 *			(009)			3.38				(004)	
				3.26 *					(005)						
				2.896 (a)					(005)						
2.840		(005)	(00,10)	2.846		(005)				2.841			(008)		
				2.835			(00,11)			2.837		(005)			
2.575			(00,11)	2.578			(00,12)								
2.379			(00,12)												
2.368	br	(003)	(006)												
mean of															
d(002) :	7.10	14.19	28.45		14.24	31.16	14.39	16.85			14.12	23.92	13.55	12.99	
variance:	0.000	0.001	0.034		0.001	0.203	0.012	0.162			0.015	0.776	0.001	0.041	

- 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).

Air-dry				Glycol				550°C/1H					
<i>d</i>	(001)			<i>d</i>	(001)			<i>d</i>	(001)				
	A	B	C		A	B	C	D		A	B	C	D
29.23		(001)		33.85		(001)			26.52		(001)		
14.64	br ^(h)	(002)	(001)	31.31 *				(001)	19.80 *				(001)
				16.98	br ^(h)	(002)			13.98			(001)	
				15.76 *?			(001)	(002)	12.78 (h)		(002)		
				11.12 *		(003)			10.04				(002)
8.48				8.36 *		(004)							
				7.82				(004)					
7.11	(001)	(004)	(002)	7.10	(001)		(002)		7.12	(001)		(002)	
5.84 *		(005)		6.79		(005)			6.40		(004)		
				5.69 *		(006)							
				4.89 *		(007)							
4.75			(003)	4.73 *			(003)		4.76			(003)	
4.16 *		(007)		4.50				(007)?					
3.65 *		(008)							4.27		(006)		
3.55	(002)		(004)	3.55	(002)		(004)		3.55	(002)		(004)	
				3.37		(00,10)							
				3.08		(00,11)							
2.848			(005)						2.811 *			(005)	
2.650 *		(00,11)											
2.452		(00,12)											
2.366	(003)		(006)	2.367	(003)		(006)		2.364	(003)		(006)	
mean of													
d(002) :	7.10	29.14	14.29			33.83		31.40			25.83	14.16	
variance :	0.000	0.076	0.025			0.076		0.012			0.161	0.011	

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.

TABLE 3. Basal spacing (in Å) from oriented films of unsaturated clay minerals from the Kambove deposit. (sample #1: d. hole Kw 206, core N^o 817, 483 m depth).

Air-dry			Glycol			550°C/1H					
<i>d</i>	⁽⁰⁰¹⁾ A B		<i>d</i>	⁽⁰⁰¹⁾ A B C			<i>d</i>	⁽⁰⁰¹⁾ A B C D			
14.24 (s)	(001)	(001)	17.8		(001)	14.16	(001)		(001)		
			14.8	(001)	(001)	12.93 *				(001)	
			7.35		(001)	9.51		(001)			
7.11	(002)	(002)	7.19	(002)		7.11	(002)		(002)		
			5.70		(003)	6.51				(002)	
4.83		(003)	4.93 *		(003)						
4.73 (s)	(003)		4.76	(003)		4.75	(003)	(002)	(003)		
			4.58 *		(004)						
3.69		(004)	3.72		(004)						
3.55	(004)		3.55	(004)	(005)	3.55	(004)		(004)		
2.886 (a)	(005)		2.959		(006) (005)	3.19 *		(003)		(004)	
2.846	(005)		2.835	(005)							
			2.519		(007)						
			2.405	(006)	(006)						
mean of											
d(00 $\bar{2}$) : 14.22				14.38	17.73	14.73	14.21	9.53	14.21	12.90	
variance : 0.000				0.044	0.127	0.021	0.001	0.001	0.001	0.012	

- A. mineral of the chlorite group (45%).
- B. smectite (30%).
- C. swelling chlorite-chlorite[±]regular mixed layer (25%).
- D. possibly montmorillonite-chlorite random mixed layer (traces).

- * very weak reflection.
- (s) asymmetry towards small angles.
- (a) dolomite reflection.

TABLE 4. Basal spacing (in Å) from oriented films of unsaturated clay minerals from the Kambove deposit.
(sample #3: d.hole Kw 206, core No 762, 473 m depth).

Air-dry			Glycol				550° C/1H			
<i>d</i>	(001)		<i>d</i>	(001)			<i>d</i>	(001)		
	A	B		A	B	C		A	B	C
25.86	(001)		25.90	(001)			25.81	(001)		
14.63 (1)	(002)	(001)	17.28		(001)		14.2 (1)*?	(002)		
			14.60 (1)	(002)			12.58 ^(s)		(001)	
8.70	(003)		8.70 ^(s) br	(003)	(002)		8.70 *	(003)		
7.08		(002)	7.09 ^(s) br			(001)	7.10			(011)
6.59	(004)		6.59	(004)			6.58 *	(004)		
5.19	(005)		5.15 ^(h) br	(005)			6.23 *		(002)	
4.81		(003)					5.19 *	(005)		
4.37	(006)		4.38	(006)	(004)		4.37	(006)		
3.69 ^(h)	(007)		3.69	(007)			4.143 *		(003)	
3.62							3.70	(007)		
3.54		(004)	3.55 ^(h)		(005)	(002)	3.55 *			(002)
2.886 ^(a)	(009)	(005)					3.116 *		(004)	
2.53	(00,10)		2.862 br	(009)	(006)		2.886 ^(a)	(009)		
			2.53	(00,10)			2.53	(00,10)(005)		
			2.474 br		(007)					
2.368	(00,11)(006)		2.368	(00,11)	(003)		2.367 *	(00,11)		(003)
mean of										
d(002) :	25.96	14.34		25.93	17.41	7.10		25.96	12.52	7.10
variance :	0.080	0.030		0.091	0.035	0.000		0.076	0.007	0.000

(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 5. X-ray powder data of the chlorites from Kambove and Kibamba and of the kandite from Shituru.

1.		2.			3.		4.		
<u>d_{meas.}</u>	<u>I/I₀</u>	<u>d_{meas.}</u>	<u>I/I₀</u>	<u>hkl</u>	<u>d_{meas.}</u>	<u>I/I₀</u>	<u>d_{meas.}</u>	<u>I/I₀</u>	<u>hkl</u>
14.19	35	14.3	32	001					
7.10	100	7.11	76	002	7.11	100	7.09	100	006
4.73	69	4.73	76	003	4.91	<1	-		103
4.601	25	4.603	21	020	4.61	12	4.60	40 br	020
3.548	80	3.552	100	004	4.50	20 br	4.51	6 br	022
2.839	22	2.842	29	005	4.33	9	4.37	6	023;113
2.654	11	2.655	9	201;131	4.26	10 *	4.23	10	024
2.581	21	2.583	37	202;131	4.10	6	4.04	8	025
2.531	44	2.539	66	201;132	3.99	5	-	-	115
2.432	30	2.438	49	203;132	-	-	3.86	20	026
2.369	12	2.376	22	006	3.61	24	3.60	8 br *	117
2.257	15	2.253	17	204;133	3.55	78	3.56	70 br *	00,12
-		2.062	8	134	3.48	3	-		028;118
-		2.025	9	007	-	-	3.29	6	029
1.999	27	2.002	24	204;135	3.13	8	3.12	6	02,10
1.878	12	-		206	-	-	2.965	2	02,11
1.815 *	-	1.829	39	205;136	2.81	7	2.802	10	02,12
-		1.732	6	207	2.65	8	-		130
1.673	19	-			2.64	14	-		131
1.660	14	1.660	27	206;137	2.626	12			132
1.564	19	1.563	13	208;137	2.597	11			202
1.534	28	1.535	43	060	2.577	14	2.614	35	203
1.499	10	1.500	10	062	2.556	13	-		204;134
1.454	12	1.459	7	063	2.495	25	2.492	80	205;206
-		1.417	4	00,10	2.380	24 br	-		207
-		1.407	5	064	2.367	17	2.372	25 *	00,18
1.393	15	1.393	10	208;139	2.275	8	2.318	35	209
1.315	10	1.318	9	070;139	2.131	9	2.130	35	20,12
1.288	14	-		209;066	2.006	11 br	1.999	2 *	20,14 ?
1.220	7	-		13,10;20,11	1.938	13	1.938	45 br	20,15;02,20
1.182	19	-		00,12	1.883	6	1.886	2	20,16
					1.772	4	1.767	16	20,18;00,24
					1.728	4	1.734	2	02,23;310 ?
mean d(001)		mean d(001)					1.695	2	316 ?
14.195		14.215			1.665	9	1.658	6 *	316;02,24
							1.624	2 br	319 ?
					1.610	5	1.611	20 br	319;20,21
					1.535	20	1.533	50 *	060
					1.505	11			
					1.494	11	1.500	25 *	066
					1.477	10	1.474	25	13,24 ?
					-		1.409	20	06,12
					1.386	1	-		31,18
					1.355	4	1.353	10	06,15 ?

Plus 14 lines.

1. Leuchtenbergite, Kambove West, Mine Group (R.A.T. gr.).
 3. Kandite, Shituru, passage Kibamba-Mwashya Group.

2. Si-enriched leuchtenbergite, Kibamba, Kibamba Group.
 4. 6(2) layer Al-lizardite, Tracy Mine, Negaunee Michigan, U.S.A. (A.S.T.M. No. 13-4).

TABLE 6. Unit-cell dimensions of the chlorites from Kambove and Kibamba and of the kandite from Shituru.

	1	2	3		4
a(Å)	5.318(2)	5.396(2)	5.297(2) 5.232(1)		5.315
b(Å)	9.203(2)	9.207(2)	-		9.206
c(Å)	14.297(2)	14.351(3)	42.570(26)	42.613(9)	42.64
$\beta(^{\circ})$	96.891(12)	98.046(28)	90.00	90.00	90.00
V(Å ³)	694.56 (19)	705.87 (22)	1034.76 (96)	2052.82 (53)	-
n*	15	15	28	24	
	monoclinic cell		hexagonal cell	orthorhombic cell	orthorhombic cell

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.

	1	2	3	4	5	6	7
SiO ₂	30.23	32.62	30.21	31.80	30.24	31.00	38.04
Al ₂ O ₃	23.34	22.01	24.40	24.22	23.37	24.19	23.74
TiO ₂	0.00	0.10	0.13	n.d.	1.11	0.63	0.00
Fe ₂ O ₃	n.d.	n.d.	n.d.	n.d.	n.d.	0.04	n.d.
FeO	0.29*	2.37*	1.95*	0.13*	1.97*	1.36	0.70*
MnO	0.15	0.10	0.00	n.d.	0.11	0.11	0.00
CrO	0.00	0.01	0.07	n.d.	n.d.	n.d.	0.00
MgO	34.35	30.05	28.31	28.70	28.61	28.77	31.77
CaO	0.00	0.32	0.07	0.29	0.11	0.15	0.00
K ₂ O	0.00	0.44	0.09	n.d.	0.06	0.08	0.00
Na ₂ O	0.00	n.d.	n.d.	0.17	0.06	0.10	0.00
P ₂ O ₅	n.d.	n.d.	n.d.	n.d.	0.12	0.14	n.d.
L.O.I.	11.64**	11.98**	14.77**	14.69**	14.22	14.40	5.75**
Total	100.00	100.00	100.00	100.00	99.98	100.97	100.00
Method of Analysis	E.M.	E.M.	E.M.	E.M.	X.R.F.	W.A.	E.M.

n.d. not determined.

* total Fe recalculated as FeO only.

** obtained by subtracting microprobe total from 100%.

E.M. : electron-microprobe analyses (C. Gasparrini, Minmet Scientific Ltd., Toronto).

X.R.F. : X-ray fluorescence (X-Ray Assay Laboratories Ltd., Toronto).

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

- Leuchtenbergite, Kambove West.

$$\underbrace{(\text{Mg}_{4.68}\text{Fe}_{0.02}\text{Al}_{1.27}\text{Mn}_{0.01})}_{5.98}(\text{Si}_{2.76}\text{Al}_{1.24})_{10.91}(\text{OH})_{7.09}$$
- Si-enriched leuchtenbergite, Kibamba.

$$\underbrace{(\text{K}_{0.10}\text{Ca}_{0.03}\text{Mg}_{4.13}\text{Fe}_{0.18}\text{Al}_{1.40}\text{Mn}_{0.01}\text{Ti}_{0.01})}_{5.86}(\text{Si}_{3.01}\text{Al}_{0.99})_{10.63}(\text{OH})_{7.37}$$
- Kandite, Shituru (S102,101m)

$$\underbrace{(\text{K}_{0.02}\text{Ca}_{0.03}\text{Mg}_{4.00}\text{Fe}_{0.15}\text{Al}_{1.59}\text{Cr}_{0.01})}_{5.78}(\text{Si}_{2.86}\text{Al}_{1.14})_{9.34}(\text{OH})_{8.66}$$
- Kandite, Kambove (Kw207,320m)

$$\underbrace{(\text{Na}_{0.03}\text{Ca}_{0.03}\text{Mg}_{4.00}\text{Fe}_{0.01}\text{Al}_{1.64})}_{5.71}(\text{Si}_{2.97}\text{Al}_{1.03})_{9.17}(\text{OH})_{8.83}$$
- Massive clay mostly composed of kandite (Kw207,321m)

$$\underbrace{(\text{K}_{0.01}\text{Na}_{0.01}\text{Ca}_{0.01}\text{Mg}_{4.03}\text{Fe}_{0.16}\text{Al}_{1.46}\text{Mn}_{0.01}\text{Ti}_{0.08})}_{5.77}(\text{Si}_{2.86}\text{Al}_{1.14})_{9.87}(\text{OH})_{9.03}$$
- Massive clay mostly composed of kandite (Kw206,457m)

$$\underbrace{(\text{K}_{0.01}\text{Na}_{0.02}\text{Ca}_{0.01}\text{Mg}_{4.00}\text{Fe}_{0.10}\text{Al}_{1.55}\text{Mn}_{0.01}\text{Ti}_{0.08})}_{5.74}(\text{Si}_{2.89}\text{Al}_{1.11})_{9.86}(\text{OH})_{9.04}$$
- Reg. interstrat. of chlorite and un-expandable Mg-mineral (Kw206,473m)

$$\underbrace{(\text{Mg}_{15.12}\text{Fe}_{0.19}\text{Al}_{5.10})}_{20.41}(\text{Si}_{12.15}\text{Al}_{3.85})_{40.8}(\text{OH})_{25.92}$$

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 Kabolela.
- d. and e. Photomicrographs of hexagonal plates of aluminian serpentine (Kambove W. deposit).
- f. Kibamba anticline : subidioblastic, poikiloblastic sillimanite (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.

