DIVERSITY OF VEGETATION COMMUNITIES IN RELATION TO SOIL HEAVY METAL CONTENT AT THE SHINKOLOBWE COPPER/COBALT/URANIUM MINERALIZATION, UPPER SHABA, ZAIRE

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DIVERSITY OF VEGETATION COMMUNITIES IN RELATION TO SOIL HEAVY METAL CONTENT AT THE SHINKOLOBWE COPPER/COBALT/URANIUM MINERALIZATION, UPPER SHABA, ZAIRE

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SUMMARY. — A study was made of plant communities and soils of the Shinkolobwe copper/cobalt/uranium mineralized outcrop in Shaba Province, Zaire. The site has not been accessible until recently because of restrictions based on strategic and military considerations since the discovery of radioactive minerals at this site in 1915. Some 11 different plant communities were identified, all controlled by the nature of the substratum and its chemical composition. The site is remarquable in that it includes in a single locality (Milestone XIII) most of the different plant communities found on other sites in Shaba. An ecotone with its belt of chlorotic *Uapaca robynsii* is particularly well defined. The site contains an endemic fern, *Actiniopteris* sp. nov., found elsewhere only in the Mindingi area (Mirungwe hill). From the eleven phytogeochemical transects of Shaban copper/cobalt anomalies already published and from other unpublished field observations, a synthesis is provided, completing the noteworthy studies of DUVIGNEAUD & DENAEYER-DE SMET (1958-1963).

RÉSUMÉ. — *Diversité des communautés végétales en relation avec la teneur du sol en métaux lourds au gisement cupri-cobalti-uranifère de Shinkolobwe, Haut-Shaba, Zaïre.* — Une étude des communautés végétales et des sols a été effectuée au gisement de cuivre-cobalt-uranium de Shinkolobwe dans la Région administrative du Shaba au Zaïre. Ce site n'était, jusqu'il y a peu, pas accessible pour des raisons stratégiques et militaires bien que la découverte de minerais radioactifs y remonte à 1915. Quelque onze communautés végétales furent identifiées, toutes sous la dépendance du substrat et de sa composition chimique. Le site est remarquable en ce qu'il inclut, en une seule localisation (Borne XIII) la plupart des communautés végétales observées jusqu'ici sur les autres gisements du Shaba.

Un écotone avec sa ceinture à *Uapaca robynsii* chlorotiques est nettement défini. Le site héberge une fougère endémique, *Actiniopteris* sp. nov., observée ailleurs seulement dans les alentours du gisement de Mindingi (Colline Mirungwe). A partir des onze transects phytogéochimiques des anomalies cupro-cobaltifères du Shaba déjà publiés ainsi que d'autres observations de terrain inédites, une synthèse est réalisée, qui complète les études pertinentes de Duvigneaud & Denaeyer-De Smet (1958-1963).

INTRODUCTION

The southwest of Shaba Province, Zaire, is famous for its copper/cobalt deposits (Brooks *et al.* 1985) that stretch in a broad zone from Kolwezi in the west to Lubumbashi in the east (Figure 1). This mineralized zone is known as the Shaban Copper Arc. Although known principally for its copper and cobalt, the region also countains uranium and other radioactive minerals which were the main source of uranium for the American "Manhattan Project" that produced the world's first atomic bombs.

Uranium was first discovered in the Shaban Copper Arc on January 22nd, 1913 by a prospector who found at Luiswishi (about 15 km from Elisabethville, now known as Lubumbashi), a yellow mineral that he did not recognize. Van der Maelen (Chief chemist of the Union Minière) provisionnaly identified this mineral in situ, as an oxide of uranium. According to Vanderlinden (1991) the identification was later confirmed in Brussels by H. Buttgenbach (future Professor at the University of Liège).

At first the Union Minière had no interest in the uranium mineralization as their primary

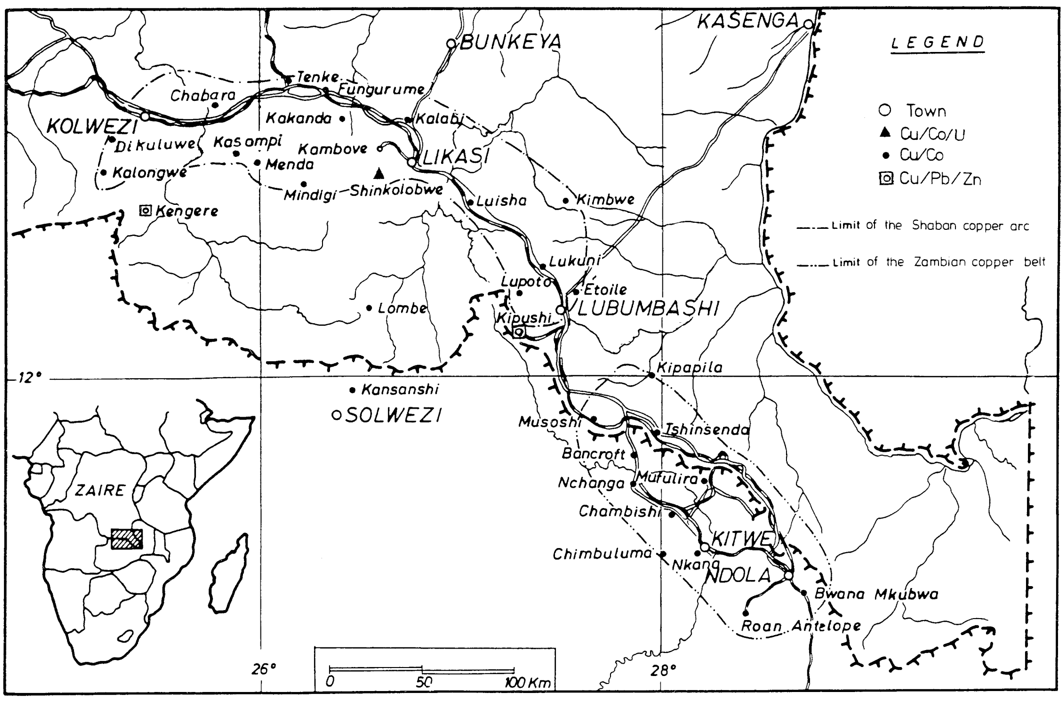

Fig. 1. — The Shaban Copper Arc (after François 1973, modified).

efforts were centred around the exploitation of copper, particularly as World War I was progressing at that time. In 1915 however, another prospector, major R. R. Sharp, discovered uranium on another site, Shinkolobwe (Figure 1), at some considerable distance from Elisabethville. Sharp noted (VANDERLINDEN 1991) that : "something yellow suddenly caught my attention. It was only a heavy stone that I examined cursorily. Then my interest was evoked by its weight, a sure sign to an old prospector, of the presence of minerals. I seemed to have remembered something similar from Luiswishi where they had found a pocket of radioactive uranium... We set to work with pick and shovel and were able to establish the existence of a vein that followed the crest of the hill... The seam was designated under the name of Shinkolobwe" (Authors translation).

Several days later the mineral was identified by E. Roger, metallurgical engineer of the "Union Minière".

On December 5th, 1921, the first 12 tons of radioactive minerals from Shinkolobwe arrived at Antwerp, and the first grams of radium were produced at the installations of Oolen (Belgium) that were visited by Marie Curie in the following year. Annual production of crude uranium ores during the period 1920-1939 averaged 280 tons with a maximum of 1300 in 1930. The production of radium reached 78 grams in 1939 (VANDERLINDEN 1991). During World War II, the mines of the Belgian Congo (now Zaire) were virtually the only source of radioactive elements for the Allied Powers war effort and the mining activities at Shinkolobwe were developed extensively during this period. The mine ceased operations shortly after World War II due to complete working out of the mineral. This was coincidental with the discovery of cheaper and more accessible uranium deposits in the United States and elsewhere.

At Shinkolobwe, ores contain pitchblende and its derived minerals ; there are many different kinds recognizable by their green, yellow or orange colour : chalcolite or torbernite (phosphouranate of copper), curite (uranate of lead), kasolite (silico-uranate of lead), schoeppite (oxide of uranium), etc.

The botanical significance of Shinkolobwe is related only indirectly to the presence of radioactive minerals since the concentrations of uranium are not high enough to affect the vegetation to any significant degree. However, because of the strategic importance of uranium minerals, security considerations prevented access to the region, and indeed despite the extensive descriptions of the copper/cobalt flora of Shaba Province carried out by DUVIGNEAUD (1958, 1959), and DUVIGNEAUD & DENAEYER-DE SMET (1963), these scientists were unable to visit Shinkolobwe. After the cessation of mining activities, access was further prevented by the presence of a large army base at Shinkolobwe. Following the abandonment of the army base at Shinkolobwe, it has now become possible to carry out botanical work at this site. Several visits by the senior author culminated in a study by the National Geographic Society (Tropmetex) of 1990 (BROOKS *et al.* 1992) in which plant communities were identified and soil and plant collections made, at the Milestone XIII site. The results of these studies are reported below.

SITE DETAILS AND CLIMATE

The Shinkolobwe area is located at 26° 33′ 45″ E, 11° 03′ 25″ S some 25 km southwest of Likasi. Three sites were investigated at Shinkolobwe and these are shown in Figure 2. The site altitude is about 1350 m. Though well within the tropics, the climate is tempered by the elevation. The year is divided into two main seasons, the wet one and the dry one. The wet season lasts from November to early April. During this period the rain falls during a mean of 114 days. In January the rainfall is around 250 mm and the mean monthly maximum and minimum temperatures are 26°C and 16°C respectively. In July there is no rainfall and the temperatures are 26°C and 6°C respectively. During the second part of the dry season (September-October), dry warm conditions prevail with extreme temperatures of 32°C and 14°C during October.

MATERIALS AND METHODS

Records of vegetation structure and composition were made at two levels. Firstly, a structural-physiognomic survey was performed, based on the classification presented at the Yangambi Conference (C.S.A./

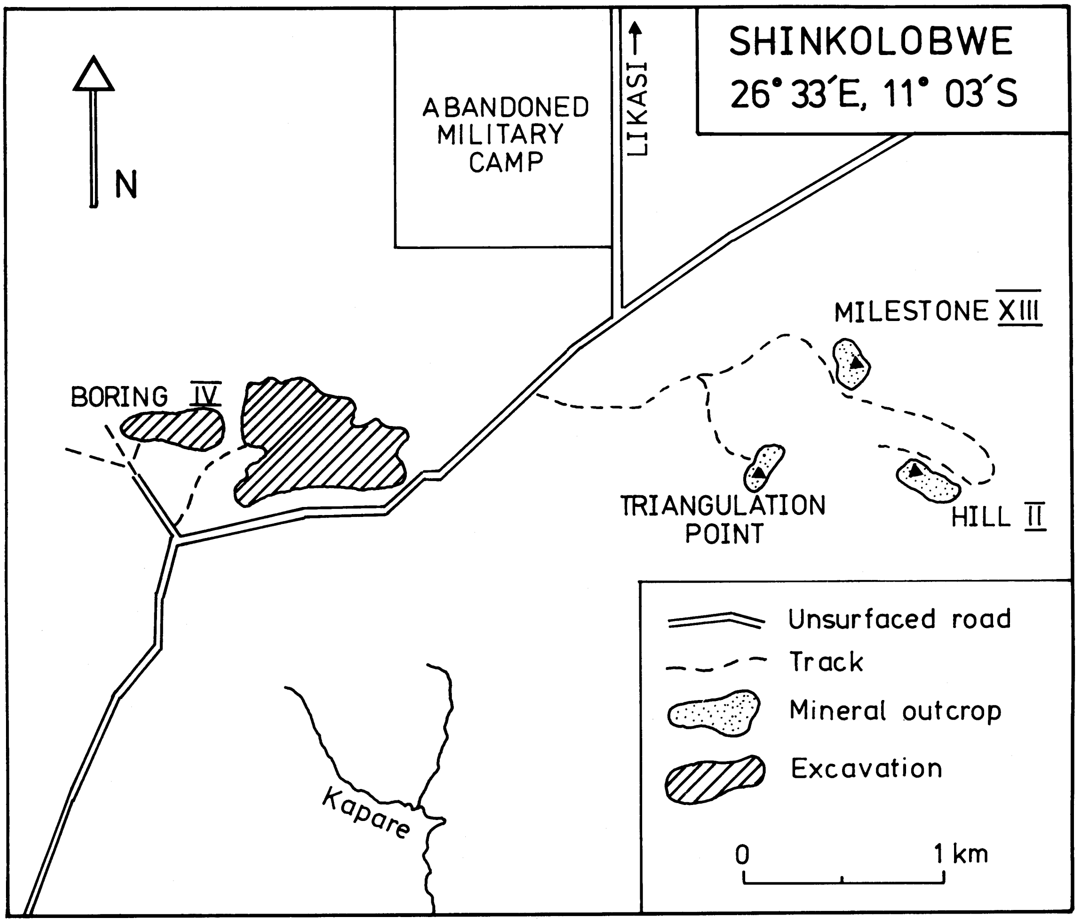

Fig. 2. — The Shinkolobwe area showing study sites.

C.C.T.A. 1956). Then, using the Zürich-Montpellier phytosociological method (Werger 1977), all plant species were listed and given a double coefficient of abundance-dominance and sociability after exploration of surfaces greater than the minimum area assessed. In each relevé, dominants and other associated plants were identified.

Soils were sieved with 1 mm mesh diameter and digested with hydrofluoric acid in Teflon beakers heated over a sandbath. After heating to dryness, the residues were redissolved in 2M hydrochloric acid with gentle warming. The soil/acid ratio was 1/50. The solutions were analyzed by a Beckman atomic absorption spectrometre.

For chemical analysis, the plant material (usually leaves) was disintegrated in a mill and the resultant powder dried at 65°C in a drying oven. The samples were then placed in 50 ml borosilicate squat beakers and ashed at 500°C until oxidation was complete (usually after about 3-4 hours). The ash was dissolved in 2M hydrochloric acid with gentle warning and with a final 1/50 ash/acid ratio.

RESULTS AND DISCUSSION

a. *vegetation*

Milestone XIII

A list of about 80 plants recorded from mineralized outcrops at Shinkolobwe is given in Table 1. Eleven different plant communities (A-L) including their principal characterizing species

TABLE 1

Species recorded on mineralized outcrops at Shinkolobwe

A. —	Miombo woodland		Dominant tree species :
	Caesalpiniaceae		*Brachystegia spiciformis* Benth.
	Euphorbiaceae		*Pseudolachnostylis maprouneifolia* Pax
	Combretaceae		*Combretum mechowianum* O. Hoffm.
	Combretaceae		*Combretum molle* R. Br. ex G. Don
A1. —	Termite mound		
	Rhamnaceae		*Ziziphus mucronata* Willd.
	Ebenaceae		*Diospyros lycioides* Desf. subsp. *sericea* (Bernh. ex Krauss) de Winter
	Rutaceae		*Zanthoxylum chalybea* Engl.
	Bignoniaceae		*Markhamia obtusifolia* (Bak.) Sprague
	Apocynaceae		*Diplorhynchus condylocarpon* (Müll. Arg.) Pichon
	Connaraceae		*Rourea orientalis* Baillon
	Passifloraceae		*Adenia lobata* (Jacq.) Engl.
	Begoniaceae		*Begonia princeae* Gilg. var. *princeae*
	Adiantaceae		*Adiantum patens* Willd. subsp. *oatesii* (Bak.) Schelpe
	Selaginellaceae		*Selaginella tenerrima* A. Braun ex Kuhn
	Davalliaceae		*Nephrolepis undulata* (Afz. ex Sw.) J. Sm.
	Davalliaceae		*Arthropteris orientalis* (J. F. Gmel.) Posth.
	Polypodiacae		*Pleopeltis excavata* (Bory ex Willd.) Sledge
B. —	Shrubby savanna belt		
	Euphorbiaceae	M & R 2413	*Uapaca robynsii* De Wild.
	Clusiaceae	M 4202	*Harungana madagascariensis* Lam. ex Poir.
	Hymenocardiaceae	M 6760	*Hymenocardia acida* Tul.
	Loranthaceae	T.M.Ex. 283	*Phragmanthera cornetii* (Dewèvre) Polh. & Wiens
	Fabaceae	M 13077	*Indigofera sutherlandioides* Welw. ex Bak.
	Fabaceae	M 11807	*Droogmansia munamensis* De Wild.
	Asteraceae	T.M.Ex. 277	*Helichrysum kirkii* Oliv. & Hiern
	Dipsacaceae	M 7893	*Cephalaria katangensis* Napper
	Apiaceae	T.M.Ex. 276	*Physotrichia muriculata* (Hiern) Droop & Towsend
	Campanulaceae	T.M.Ex. 279	*Walhenbergia capitata* (Bak.) Thulin
	Tiliaceae	M & R 2071	*Triumfetta likasiensis* De Wild.
	Fabaceae	M 13079	*Adenodolichos rhomboideus* (O. Hoffm.) Harms
	Acanthaceae	M 13081	*Thunbergia oblongifolia* Oliv.
	Lamiaceae	M 13068	*Haumaniastrum rosulatum* (De Wild.) Duvign. & Plancke
	Athyriaceae	B & M 814	*Athyrium schimperi* Moug.
	Sinopteridaceae	M 13078	*Aspidotis schimperi* (Kunze) Pic.-Serm.
	Fabaceae	M 11806	*Aeschynomene* sp.
C. —	Steppe savanna		
	Poaceae	M & R 2401	*Loudetia simplex* (Nees) Hubb.
	Poaceae	M & R 2187	*Monocymbium ceresiiforme* (Nees) Stapf
	Poaceae	T.M.Ex. 30	*Diheteropogon grandiflorus* (Hack.) Stapf
	Euphorbiaceae	T.M.Ex. 197	*Acalypha cupricola* Robyns
	Caesalpiniaceae	M 13075	*Cryptosepalum maraviense* Oliv.
	Rubiaceae	M 11671	*Manostachya ternifolia* Martins
	Tiliaceae	M 13074	*Triumfetta likasiensis* De Wild.
	Commelinaceae	T.M.Ex. 295	*Cyanotis longifolia* Benth.
	Iridaceae	M & R 2058	*Gladiolus gregarius* Welw. ex Bak.

Lamiaceae	M 13068	*Haumaniastrum rosulatum* (De Wild.) Duvign.
Acanthaceae	M 13073	*Crabbea kaessneri* S. Moore

D. — Steppe

Velloziaceae	M 12832	*Xerophyta equisetoides* Bak. var. *equisetoides*
Velloziaceae	M 12129	*X. equisetoides* Bak. var. *trichophylla* Smith & Ayensu
Cyperaceae	M & R 2064	*Ascolepis metallorum* Duvign. & G. Léonard
Poaceae	M & R 2056	*Eragrostis racemosa* (Thunb.) Steud.
Cyperaceae	M 11658	*Bulbostylis cupricola* Goetghebeur
Commelinaceae	M 13064	*Commelina zigzag* Duvign.
Xyridaceae	M 13071	*Xyris dissimilis* Malme
Rubiaceae	M 11671	*Manostachya ternifolia* Martins
Lamiaceae	M 13076	*Becium grandiflorum* (L.) Pic.-Serm. var. *ericoides* (Duvign. & Plancke) Sebald
Iridaceae	M & R 2058	*Gladiolus gregarius* Welw. ex Bak.

E. — Swards

Poaceae	M & R 2065	*Sporobolus congoensis* Franch.
Asteraceae	T.M.Ex. 280	*Anisopappus davyi* S. Moore
Iridaceae	T.M.Ex. 65	*Lapeyrousia erythrantha* (Klotzsch ex Klatt) Bak. var. *welwitschii* (Bak.) Marais ex Geerinck *et al.*
Poaceae	M & R 2056	*Eragrostis racemosa* (Thunb.) Steud.
Velloziaceae	M 12129	*Xerophyta equisetoides* Bak. var. *trichophylla* Smith & Ayensu

F. — Crevice vegetation on rocky outcrops with malachite

Actniopteridaceae	T.M.Ex. 278	*Actiniopteris* sp. nov.

G. — Rocky steppe savanna

Poaceae	M & R 2068	*Sacciolepis transbarbata* Stapf
Poaceae	M & R 2401	*Loudetia simplex* (Nees) Hubb.
Sinopteridaceae	B & M 815	*Pellaea longipilosa* Bonap.
Sinopteridaceae	M 13060	*Pellaea pectiniformis* Bak.
Iridaceae	T.M.Ex. 65	*Lapeyrousia erythrantha* (Klotzsch ex Klatt) Bak. var. *welwitschii* (Bak.) Marais ex Geerinck *et al.*
Velloziaceae	M 12832	*Xerophyta equisetoides* Bak. var. *equisetoides*
Lamiaceae	M 13066	*Aeollanthus subacaulis* (Bak.) Briq. var. *linearis* (Burk.) Ryding
Cyperaceae	M 11801	*Bulbostylis pseudoperennis* Goetghebeur

H. — Wooded savanna

Mimosaceae	M 6483	*Albizzia adianthifolia* (Schum.) W.F. Wight
Mimosaceae	M 12348	*Albizzia antunesiana* Harms
Hymenocardiaceae	M 6760	*Hymenocardia acida* Tul.
Olacaceae	M 12429	*Olax obtusifolia* De Wild.
Apocynaceae	M 11842	*Strophanthus welwitschii* (Baill.) K. Schum.
Rubiaceae	T.M.Ex. 292	*Fadogia* sp.
Asteraceae	T.M.Ex. 247	*Lopholaena deltombei* Duvign.
Asteraceae	T.M.Ex. 227	*Vernonia turbinella* S. Moore
Fabaceae	M 13077	*Indigofera sutherlandoides* Welw.
Euphorbiaceae	T.M.Ex. 197	*Acalypha cupricola* Robyns
Apiaceae	M 13807	*Peucedanum nyassicum* Wolff
Acanthaceae	M 11800	*Barleria descampsii* Lindau
Sinopteridaceae	T.M.Ex. 282	*Pellaea longipilosa* Bonap.
Poaceae	M & R 2401	*Loudetia simplex* (Nees) Hubb.

J. —	Rocky steppe savanna (bottom)		
	Proteaceae	M 9871	*Protea madiensis* Oliv. subsp. *madiensis*
	Iridaceae	M & R 2058	*Gladiolus gregarius* Welw. ex Bak.
	Iridaceae	T.M.Ex. 65	*Lapeyrousia erythrantha* (Klotzsch ex Klatt) Bak. var. *welwitschii* (Bak.) Marais ex Geerinck *et al.*
	Poaceae	M & R 2056	*Eragrostis racemosa* (Thunb.) Steud.
	Lamiaceae	M & R 2062	*Aeollanthus subacaulis* (Bak.) Briq. var. *linearis* (Burk.) Ryding
	Anemiaceae	B & M 821	*Mohria lepigera* (Bak.) Bak.
K. —	Rocky steppe savanna (top)		
	Apiaceae	M 11799	*Diplolophium zambesianum* Hiern
	Lamiaceae	M 11797	*Tinnea coerulea* Gürke
	Rubiaceae	M 11671	*Manostachya ternifolia* Martins
	Lamiaceae	M & R 2062	*Aeollanthus subacaulis* (Bak.) Briq. var. *linearis* (Burk.) Ryding
	Cyperaceae	M 12163	*Bulbostylis* cf. *bozumensis* Cherm.
	Sinopteridaceae	B & M 816	*Cheilanthes similis* Ballard
	Sinopteridaceae	B & M 818	*Cheilanthes angustifrondosa* Alston
	Sinopteridaceae	B & M 817	*Aspidotis schimperi* (Kunze) Pic.-Serm.
	Schizeaceae	B & M 819	*Anemia angolensis* Alston
L. —	Open sward		
	Lamiaceae	M 11802	*Haumaniastrum katangense* (S. Moore) Duvign. & Plancke
	Cyperaceae	M 11658	*Bulbostylis cupricola* Goetghebeur

are described in the text below. Figure 3 is a diagrammatic representation of the plant communities found at Milestone XIII and two other nearby sites. The elemental content of the soils is given in Table 2.

The Milestone XIII location is one of the best sites in Shaba to show the effect of copper and cobalt upon the vegetation. Figure 4 is a photograph taken from the rocky summit of the site, looking across to the ecotone towards a miombo woodland. Near the summit, the copper content of the soil is about 10%, decreasing to 5% almost at the bottom of the slope. Here, the ecotone is characterized by a belt of *Uapaca robynsii* De Wild., a large shrub typical of such ecotones throughout the Shaban Copper Arc. This plant is often found over soils containing as much as 350 μg/g copper and cobalt (Malaisse *et al.* 1979). Here, below these soil concentrations the *Uapaca* thickets are replaced by the ubiquitous woodland. At higher concentrations the *Uapaca* leaves show increasing chlorosis and the plant ceases to grow when the content of copper in the soil exceeds about 1000 μg/g. Figure 5 shows the *Uapaca* belt at the base of the Milestone XIII outcrop. The cut-off is extremely sharp and there is ample evidence of leaf chlorosis on the side of the thicket facing the mineralization, whereas there is none on the side facing the woodland in the background.

From Figure 3, it is clear that there are 8 distinct plant communities at Milestone XIII. These are in general typical of other mineralized sites in Shaba.

At the base of Milestone XIII, the woodland (A) dominated by *Brachystegia* spp. and where termite mounds (A1) are scattered gives way to the narrow belt of *Uapaca robynsii* (B) as part of the shrubby savanna belt containg also *Tinnea coerulea, Helichrysum kirkii* (Fig. 6), *Wahlenbergia capitata, Triumfetta likasiensis, Haumanias-*

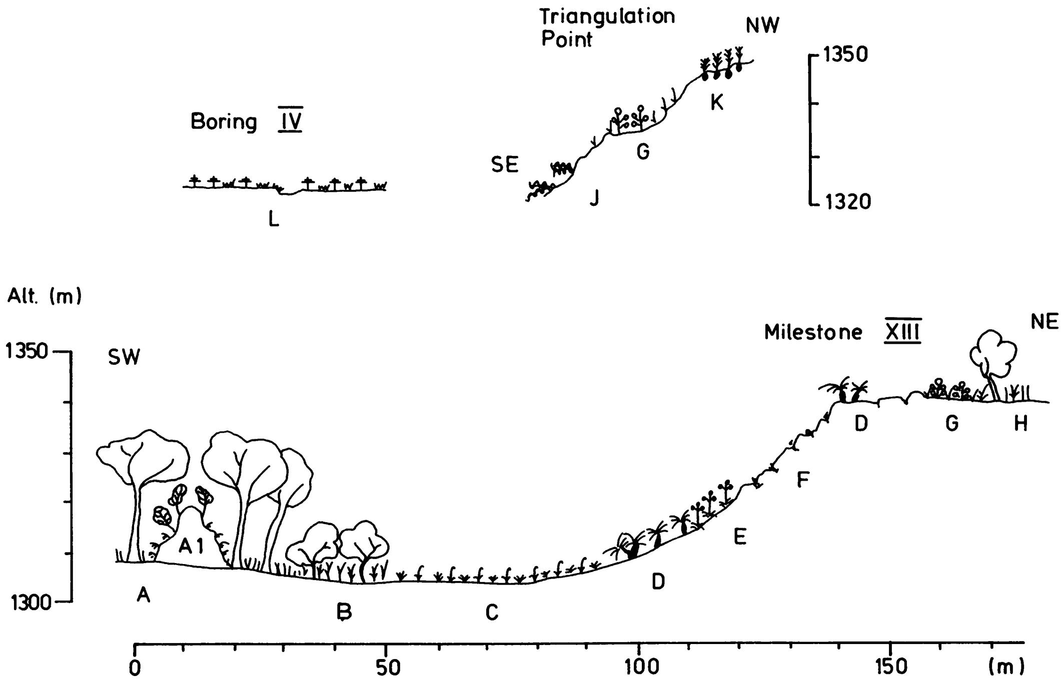

FIG. 3. — Schematic representation of plant communities at three study sites at Shinkolobwe.

FIG. 4. — View downhill from summit of Milestone XIII, Shinkolobwe. Note the band of *Uapaca* thickets at the bottom delineating the ecotone with the open forest in the background. Photo A. Baker.

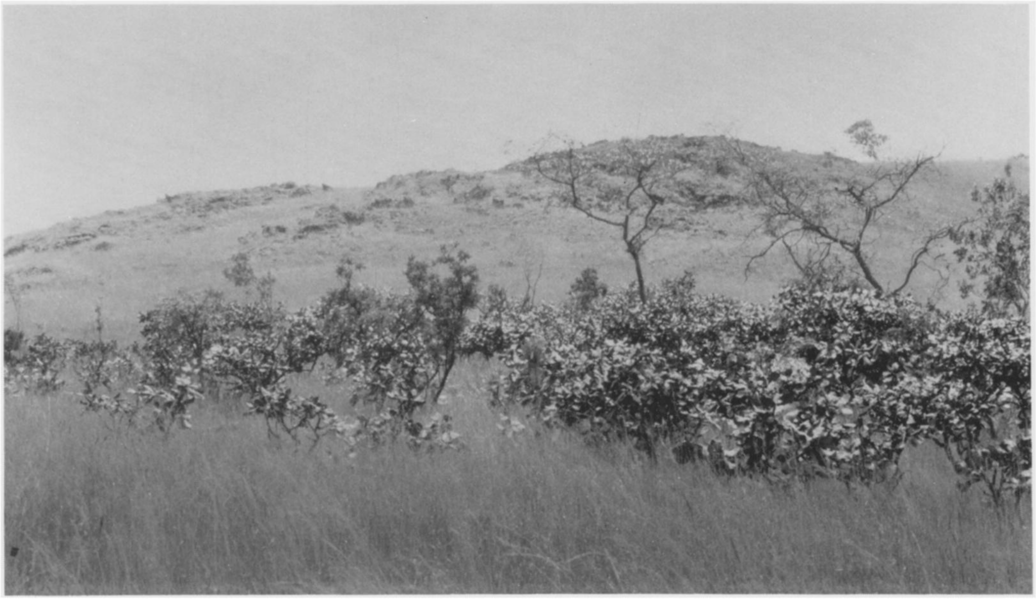

Fig. 5. — View of the *Uapaca* band at the ecotone at the base of the Milestone XIII copper deposit. Note the chlorosis on the side facing the mineralization. Photo A. Baker.

Fig. 6. — *Helichrysum kirkii* in the *Uapaca robynsii* shrubby savanna belt. Photo A. Baker.

FIG. 7. — View of the *Sporobolus congoensis* sward. Photo A. Baker.

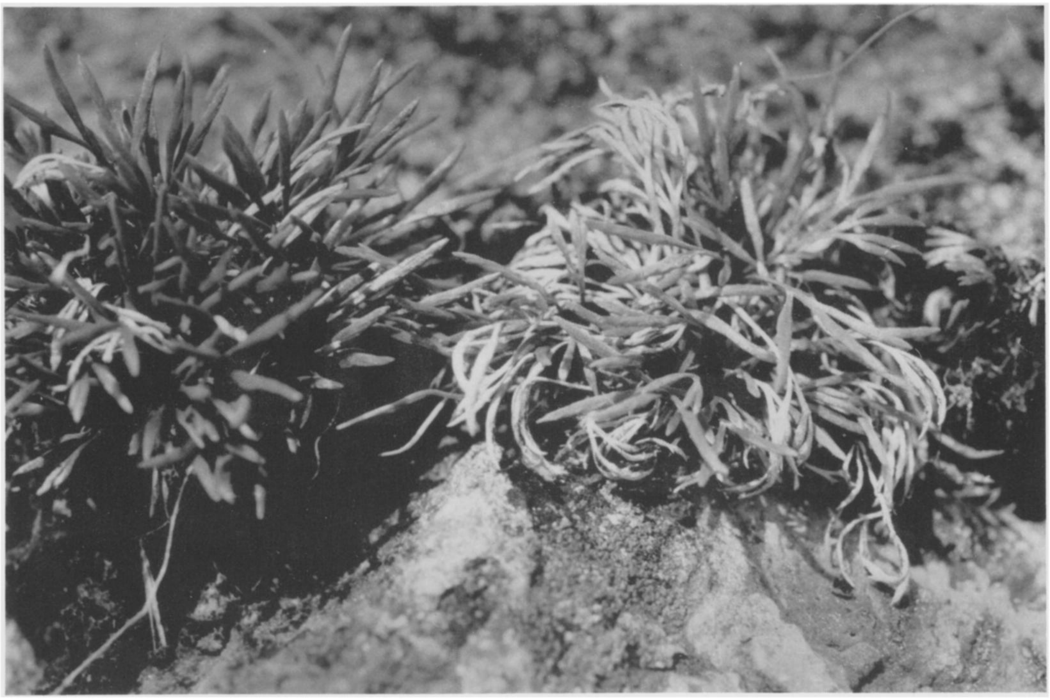

FIG. 8. — *Actiniopteris* sp. nov. on a rocky crevice. Photo A. Baker.

TABLE 2

Heavy metals concentrations (% weight, oven-dried soil) in soils from the Shinkolobwe area, Shaba, Zaire

	Plant community							
Element	A	D	E	F	G	J	K	L
Copper	0.018	5.09	6.88	10.85	0.12	0.175	0.086	0.55
Cobalt	0.0015	0.11	0.013	0.031	0.29	0.126	0.170	0.99
Nickel	0.001	0.02	0.005	0.023	0.056	0.034	0.028	0.98
Manganese	n.d.	0.15	n.d.	n.d.	n.d.	n.d.	n.d.	0.56
Zinc	n.d.	0.02	n.d.	n.d.	n.d.	n.d.	n.d.	0.02
Iron	n.d.	3.12	n.d.	n.d.	n.d.	n.d.	n.d.	2.55

n.d. = not determined
A — miombo woodland (forêt claire), D — steppe, E — swards, F — crevice vegetation on rocky outcrops with malachite, G, J and K — rocky steppe savanne, L — open sward.

trum rosulatum and *Phragmanthera cornetii* (hemiparasite on *Uapaca*).

Further uphill where the slope is still gentle, the shrubby savanna merges into the steppe savanna community (C) dominated by *Loudetia simplex, Monocymbium ceresiiforme, Diheteropogon emarginatum, Acalypha cupricola*, and *Cryptosepalum maraviense* as also noted in the vicinity of Fungurume by SHEWRY *et al.* (1979). The soils that support this plant community contain up to 5000 μg/g copper and 350 μg/g cobalt.

As the slope becomes steeper, but still near the base of the hill, the soils have a much higher copper content 50,000 μg/g (= 5%) and the cobalt concentration reaches 1000 μg/g. These toxic soils support Velloziaceae steppe (D) dominated by two taxa of *Xerophyta, Ascolepis metallorum, Eragrostis racemosa*, and *Bulbostylis cupricola*. It is noteworthy than a physiognomically similar Velloziaceae-dominated steppe community is found over nickel mineralization in central Brazil (BROOKS *et al.* 1990).

At a higher elevation (about half way up the hill), the copper content increases to 68,800 μg/g (6.88%) though the cobalt concentration is only 130 μg/g. This soil supports a distinctive sward (E) of *Sporobolus congoensis* (Fig. 7) interspersed with the composite *Anisopappus davyi* and abundant *Lapeyrousia erythrantha* subsp. *welwitschii* and *Eriospermum abyssinicum*.

Near the top of the hill there is an irregular landscape of cellular siliceous rocks (F) with virtually no soil but abundant malachite surfaces. The soil in the rock crevices contains up to 10.85% copper and 310 μg/g (0.03%) cobalt. The only notable plant species present is a fern, *Actiniopteris* sp. nov. (Fig. 8) found elsewhere only in the Mindingi area (Mirungwe hill, see above). At the site, it is restricted strictly to the crevices in vertical faces of copper-rich rocks where it rarely receives direct irradiance.

The Velloziaceae-dominated steppe (D) re-emerges at the summit and gives way to a rocky steppe savanna (G) with soils containing about 1200 μg/g copper and over twice as much cobalt. The main plant species present are *Loudetia simplex* and the fern *Pellaea longipilosa*. This community merges abruptly into the wooded savanna (H) characterized by the shrubs *Olax obtusifolia* and *Hymenocardia acida*.

Excavation Pit IV and Triangulation Point Hill

A limited amount of plant mapping was carried out at Triangulation Point Hill and Excavation Pit IV (Figure 3). Excavation Pit IV consists of an area of workings around the original exploration. Typical copper and cobalt contents of the soil are 5540 and 1700 µg/g respectively. The manganese content is also high (5570 µg/g). The vegetation consists of an open sward of *Haumaniastrum katangense* and *Bulbostylis cupricola*. The former is a ready colonizer of disturbed mineralized ground and was known for a long time as a geobotanical indicator of copper minerals.

Triangulation Point Hill is relatively lightly mineralized, with copper contents of 860-1750 µg/g and cobalt ranging from 310 to 2900 µg/g. The vegetation consists of a rocky steppe savanna dominated by the fern *Mohria lepigera* at the bottom (J) and *Aeollanthus subacaulis* var. *linearis* at the top (K).

b. *Copper and cobalt uptake by plants*

Table 3 presents a collation of copper and cobalt analyses for 38 plant samples collected at Shinkolobwe. It demonstrates a very wide range of metal concentrations : 6-3535 µg/g for copper and 1-1412 µg/g for cobalt. A value of $>$ 1000 µg/g was defined by Brooks *et al.* (1980) as evidence for "hyperaccumulation" of these two metals. Baker & Brooks (1989) listed 24 hyperaccumulators of copper and 26 of cobalt, 9 of which were hyperaccumulators of both metals. The present work has revealed one new hyperaccumulator of copper (*Sporobolus congoensis*) and two of cobalt (*Ascolepis metallorum* and *Gladiolus gregarius*). It has also confirmed the hyperaccumulator status for copper of the fern *Actiniopteris* sp. nov., *Haumaniastrum rosulatum* and *Anisopappus davyi* (Brooks *et al.* 1987). Copper and cobalt concentrations $>$ 700 µg/g in *Becium grandiflorum* var. *ericoides* and *Haumaniastrum rosulatum* respectively, also suggest strong accumulation of these metals. This observation confirms the known existence of active evolution of the two genera in Upper Shaba, including their responses to copper/cobalt soils. It should be noted that Sebald (1989) has distinguished for *Becium grandiflorum* var. *ericoides* two biotypes, one for the sandy high plateaux and another, "monocotyleoides", for mine sites.

The presence at Shinkolobwe, only at Boring IV, of another species of *Haumaniastrum, H. katangense*, a known hyperaccumulator of both copper and cobalt, outside its reported range (Brooks *et al.* 1992) suggests that its occurrence here is a result of mining activities. Such is the situation for a small population of the species at Kela.

The metal contents of *Aeollanthus subacaulis* var. *linearis* from Shinkolobwe reported here are considerably lower than the maximum values reported at Fungurume, Luiswishi (Brooks *et al.* 1987) and Mine de l'Etoile (Malaisse *et al.* 1978). At the last two mine sites some local populations are regarded by Ryding (1986) as being intermediate between var. *linearis* and var. *ericoides* which could explain the observed variation in metal uptake behaviour.

CONCLUDING COMMENTS

The work at Shinkolobwe has filled a gap in our knowledge of the vegetation of the copper/cobalt/uranium deposits of Shaba Province, a gap caused by the exigencies of strategic and military security since the original discovery of radioactive minerals at this site about 80 years ago. The importance of the Milestone XIII site lies not only in its filling a gap in our knowledge, but also in the fact that it represents an almost perfect example of a classical Shaban mineralized site delineated not only by the typical *Uapaca* belt at the ecotone, but also by the other plant communities found elsewhere in Shaba. Moreover, at this site, the vertical faces of rocks rich in malachite and with shaded crevices represent a unique habitat colonized only by one endemic fern. Several studies conducted in Upper Shaba present altogether a dozen transects where plant communities are related to soil heavy metal concentrations. Table 4 lists the sites where observations were carried out and the type of mineral expression concerned.

Comparisons are possible and lead to a provisional synthesis. At once, four generalizations emerge :

a. — Transitions between miombo woodland and mineralized areas are mostly sharply defined. The ecotone (a shrubby steppe- savanna) is dominated by *Uapaca robynsii* on the plateaux and at the bottom of slopes. *Olax obtusifolia* replaces it when the transition to woodland occurs above the mineralization. The presence of *O. obtusifolia* on sligthly mineralized soils has been reported from several sites in Shaba (Lupoto mine for instance, by Brooks *et al.* 1982) as well as from Copper Queen mine in Zimbabwe (Ernst 1993). *U. robynsii* also dominates the ecotone between miombo woodland and steppe-savanna developed on high plateaux covered with Kalahari sands (Malaisse 1975). Its occurrence there corresponds to the nearby position of a lateritic pan

Table 3

Copper, cobalt and iron content of plants (µg/g dry weight) at Shinkolobwe

Species	Cu	Co	Fe
Actiniopteris sp. nov.	3 535	15	—
	2 636	98	35
Anisopappus davyi	3 504	144	158
Sporobolus congoensis	1 671	3	67
Ascolepis metallorum	860	1 118	48
Xyris dissimilis	173	9	58
Peucedanum nyassicum	169	23	78
Aeollanthus subacaulis var. *linearis*	150	144	39
	21	358	108
Pellaea pectiniformis	109	18	78
Commelina zigzag	99	64	28
Wahlenbergia capitata	98	11	96
Phragmanthera cornetii	88	74	35
Manostachya ternifolia	64	10	—
	19	8	111
Pellaea longipilosa	51	2	30
Bulbostylis cupricola	50	373	87
	20	253	21
Adenodolichos rhomboideus	44	27	75
Helichrysum kirkii	40	1	15
Barleria descampsii	31	179	48
Sacciolepis transbarbata	30	3	52
Cryptosepalum maraviense	27	16	32
Crabbea kaessneri	26	1	78
Anemia angolensis	24	7	150
Physotrichia muriculata	24	13	55
Mohria lepigera	19	118	36
Aspidotis schimperi	17	24	44
	16	1	22
Cephalaria katangensis	17	5	55
Gladiolus gregarius	14	1 412	64
Thunbergia oblongifolia	14	126	91
Diplolophium zambesianum	14	72	24
Indigofera sutherlandoides	13	3	31
Droogmansia munamensis	12	18	15
Cheilanthes angustifrondosa	12	1	82
Pellaea longipilosa	10	1	13
Athyrium schimperi	6	26	39

TABLE 4

Transects of plant communities related to soil heavy metal concentrations in Upper Shaba

Mineral expression	Site	Reference
1. — Underground anomaly poorly expressed at surface level	Dikulushi	MALAISSE *et al.* 1983
2. — Metalliferous outcrop		
2.1. on medium plateau	Etoile	MALAISSE & GRÉGOIRE 1978
2.2. on side of hill	Menda	DUVIGNEAUD 1958
	Kasompi	DUVIGNEAUD 1958
	Mindingi	DUVIGNEAUD 1959
	Fungurume (Hills I, II)	DUVIGNEAUD & DENAEYER-DE SMET 1963
	Dikuluwe	DUVIGNEAUD & DENAEYER-DE SMET 1963
	Chabara	DUVIGNEAUD & DENAEYER-DE SMET 1963
	Fungurume (Hills V, VI)	MALAISSE *et al.* 1979
	Lupoto	BROOKS *et al.* 1982
	Kasonta	BROOKS *et al.* 1982
	Shinkolobwe	Present paper

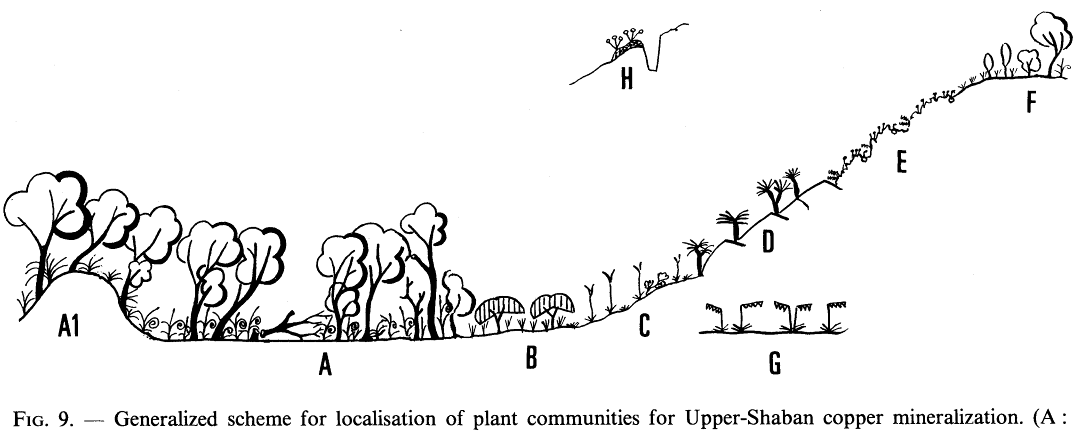

FIG. 9. — Generalized scheme for localisation of plant communities for Upper-Shaban copper mineralization. (A : Miombo open forest ; A1 : Termite mound ; B : *Uapaca robynsii* shrubby savanna belt ; C : *Loudetia simplex — Monocymbium ceresiiforme* steppe savanna with *Acalypha cupricola* as characteristic copper differential ; D : *Xerophyta* spp. stone-packed steppe ; E : Crevice vegetation on rocky outcrops ; F : *Hymenocardia acida* wooded savanna ; G : *Rendlia cupricola* sward on compacted soil ; H : *Haumaniastrum robertii* sward on reworked copper soil.

and to the movements of the water table (De Dapper & Malaisse 1979). Its distribution is restricted to these two stressed situations.

b. — Rocky outcrops on medium slopes are the preferred situation for *Xerophyta* spp. This is particularly the case on Kundelungu sandstones and dolomitic schists. These sites may be or not be mineralized.

c. — Siliceous cellular rocks generally support a typical chasmophytic vegetation, which is enriched by several endemics when heavy metal mineralization is present (*Faroa malaissei, Batopedina pulvinellata*, ...)

d. — Sites occur which are dominated by *Cryptosepalum maraviense*, a locally very gregarious plant, whose ecology is poorly known. This geofrutex appears to prefer well-drained soils which are slightly to moderately sandy. Furthermore, it occurs in open situations or under a light woodland canopy. These are sometimes slightly heavy metal mineralized.
C. maraviense has been observed on shelves in high plateaux foothills and was studied by Shewry *et al.* (1979) in the vicinity of Fungurume.

Duvigneaud & Denaeyer-De Smet (1963) have already produced a generalized scheme of plant communities for Upper-Shaban copper mineralization. Some new or more detailed aspects can now be integrated so that an up-to-date synthesis can be presented here (Fig. 9).

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