Geoderma, 43 (1988) 229-247
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

Some Podzols on Bateke Sands and their Origins, People's Republic of Congo

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(Received March 26, 1986; accepted after revision July 12, 1988)

ABSTRACT

Schwartz, D. 1988. Some podzols on Bateke sands and their origins, People's Republic of Congo. Geoderma, 43: 229-247.

The morphology and composition of specimen podzols in Bateke land were investigated with special attention to the organic matter. Data were obtained on the amounts, the ratios between two carbon isotopes and the radiocarbon ages for certain horizons. These data were combined with information on palaeoclimates and archaeology to reconstruct the history of development of two profiles.

Available evidence indicates that podzolization proceeded in more than one stage. The first and main stage is believed to have occurred between 40,000 and 30,000 years B.P. under forest cover and the influence of a fluctuating groundwater table. Ortsteins formed during this stage persist in the soils. Later stages of podzolization have added lamellae of organic matter to pre-existing A2 horizons of some profiles. The soils thus have a complex history. This may also be true of podzols in other tropical regions.

INTRODUCTION

A primary objective of the investigation has been to improve understanding of the origin of podzols in Bateke land. (The concept of podzols followed in this paper is that of CPCS, 1967). Improved understanding of the genesis of specimen podzols in one part of the tropics might in turn provide better insight into the origins of similar soils elsewhere.

Podzols occur under a wide range of conditions in tropical regions, most commonly formed in sandy regoliths. Rainfall ranges from 700 to 7200 mm/year and may be distributed over a span anywhere from 5 to 12 months long (Klinge, 1969). Vegetative cover reported on the soils include steppe, savanna, bush savanna, dry forest, rainforest and swamp forest (Richards, 1941; Klinge, 1968). Drainage conditions range from excessive to poor with the wetness due to either perched or groundwater tables (Klinge, 1968).

The occurrence of podzols under such a wide range of environmental con-

0016-7061/88/$03.50

ditions implies either or both of several pathways of genesis in their formation or of changes in environments since the soils were formed. Most soil scientists consider the soils to have been formed under current conditions (Klinge 1965; Andriesse, 1968, 1969; Tan et al., 1970; Brammer, 1973; Denis, 1974; Turenne, 1977; Lucas et al., 1983; Lekwa and Whiteside, 1986; Brabant, 1987; Dubroeucq and Blancaneaux, 1987; ...). Some individuals believe, however, that one or more of climate (Klinge, 1969), vegetation (Faivre et al., 1975) and drainage conditions (Flexor et al., 1975) have changed since the podzols were formed. Additional evidence is needed to resolve the disagreement. The present paper is an effort to provide some additional evidence.

ENVIRONMENT AND SOILS

Bateke land consists of two geomorphological entities shown in Fig. 1. The central and smaller part comprises plateaux with very gentle slopes (<3‰) and altitudes between 850 and 600 m. The plateaux grade into zones of hills with valleys draining either to the Congolese Depression in the north or to the "Stanley Pool" in the south. A zone of hills and valleys forms the outer and larger part of Bateke land. The valleys have been differentiated into bottoms and terraces. Near Brazzaville, the terraces are a few to as many as 30 m above present valley floors. This range in relief is attributed to considerable variations in the base level of the Congo River and its tributaries during the Upper Pleistocene (Giresse et al., 1981). In contrast, the valleys draining toward the Congolese Depression have terraces no more than a few meters above the bottoms. The terraces in those valleys were formed during the Maluekian period listed in Fig. 2 (Giresse et al., 1981; Schwartz, 1985).

The country rock is sandy. The plateaux and hills have been developed in Tertiary sands and sandstones known as the Bateke sands (Le Maréchal, 1966). The underlaying substratum in the region consists of the Stanley Pool sandstone of Cretaceous age, a kaolinic, polymorphic rock.

The climate is characterized by a long dry season, 3 to 4.5 months, centred in July and August. Rainfall, mostly due to thunderstorms, ranges from 1400 to 2100 mm, depending on latitude and altitude. The mean annual temperature is 25°C.

The principal soils of the region are deep, sandy members of the ferrallitic group (Denis, 1974). These are chiefly identified as Ferralic Arenosols in the FAO-Unesco legend. Part of the soils, however, are podzols. Most of the soils are under bush savannas of various kinds.

DISTRIBUTION AND GENERAL NATURE OF THE PODZOLS

The podzols occupy the lower part of landscapes. On the plateaux, they occur in small closed depressions. In the hilly areas, they occur in valley bottoms and

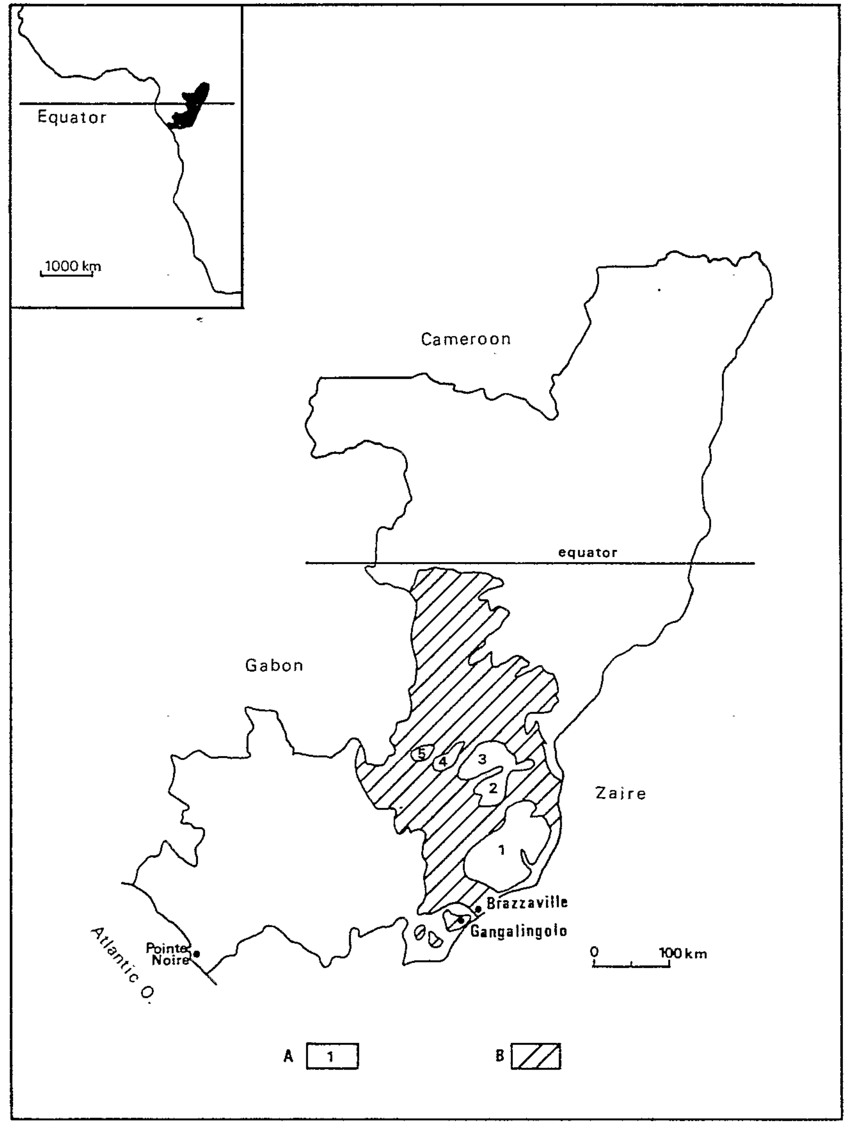

Fig. 1. Distribution of Bateke sands in Peoples Republic of Congo. A. Table land or plateaux areas: 1-Mbe; 2=Ngo; 3=Nsa; 4=Djambala; 5=Koukouya. B. Hill and valley areas.

CHRONOLOGY	CLIMATIC TENDENCIES	PRINCIPAL EVENTS	PREHISTORIC CULTURE
SUBACTUAL			
500?		human influences- relative climatic drying	Neolithic 2000
----3000 KIBANGIAN	wet	forest revival- nouakchotian transgression on coastline-mangrove	Tshitolian
12000 LEOPOLDVILLIAN	18000 arid	savanna and steppe vegetation- deposit of the +7m terrace in the Stanley Pool- ogolian recession of sea-littoral dunes	Lupembian
30000 NJILIAN	wet	forest revival- inchirian transgression on coastline-mangrove	
40000 MALUEKIAN 70000 ?		savanna vegetation-deposite of the + 20 m terrace in the Stanley Pool- preinchirian recession of sea.	Stanley pool I Stanley pool II = Sangoan

Fig. 2. Chronology of the latter part of the Quaternary plus climatic tendencies, principal events and prehistoric cultures (from: Giresse, 1978; Giresse et al., 1981; Lanfranchi-Salvi, 1984).

on terraces where they occupy level or slightly depressed positions rather than slopes.

The sites of the podzols are locally called "loussekes". This is a vernacular name for *Loudetia simplex*, one of two main graminae growing on the soils. The other main species is *Monocymbium ceresiiforme*.

Two kinds of loussekes are recognized, one wet or hydromorphic and the other dry. This distinction is based on the present drainage conditions of the loussekes. A few include both wet and dry elements, even small swamps. As used in this paper, the term lousseke refers to bodies of podzols on which the two species of graminae are dominant.

The differences between the wet and dry loussekes are related to the water table. A wet or hydromorphic lousseke has a perched water table at the soil surface during the rainy season. That water table disappears during the dry

season. A dry lousseke, on the other hand, either has no perched water table or has one so deep that it does not affect the upper horizons of the soil profile. Wherever present, the water table is perched on top of a humic ortstein. The nature of the ortstein will be discussed later in the paper.

A podzol profile in a wet lousseke has the following sequence of horizons: A1, A1/A2, B21h, B22h and B23h (the horizon notations are defined by Schwartz et al. (1986a), after C.P.C.S. (1967) and Righi (1977). The horizon sequence is illustrated in Fig. 3A. A detailed description and some analytical data for a specimen profile from a wet lousseke are given in the Appendix.

Distinctions among the parts of the B2h horizons are appreciable. The B21h horizon is compact but not cemented. Micromorphological data (Schwartz, 1985) show that the B21h horizon is also higher in silt than the overlying and underlying horizons. The B21h has a high bulk density and seems comparable to the densipans described by Wells and Northey (1985). In contrast to the B21h horizons, the B22h and B23h horizons are cemented. Together, they form a humic ortstein very low in iron extractable by dithionite. The total content of organic matter in a 2-m thick ortstein ranges from 2200 to 2270 t/ha (after

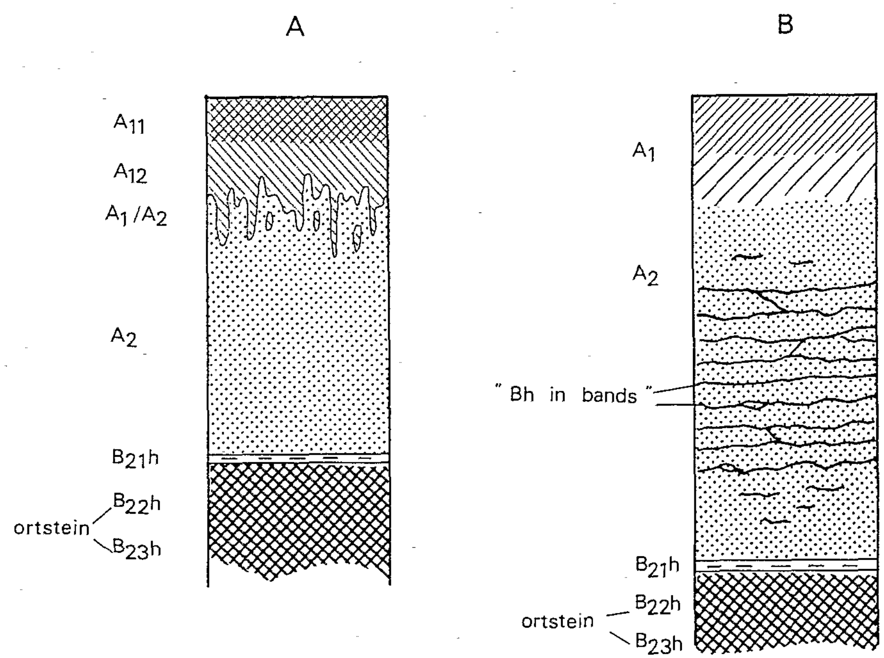

Fig. 3. Diagrams of typical podzol profiles in Bateke sands. A. Wet or hydromorphic lousseke. B. Dry lousseke.

measuring in only two profile pits at Gangalingolo), most of which (more than 90%) is extractable with pyrophosphate. The C/N ratio is between 40 and 80. The B23h horizon may contain a small amount of allophane (Schwartz et al., 1986a). As is brought out later in this paper, the ortstein is a key to the evolution of the podzols.

The profile of a podzol in a dry lousseke is illustrated in Fig. 3B. Such profiles normally have thicker A2 horizons than those in wet loussekes. Moreover, the "dry" profiles have fine, subhorizontal, organic lamellae or a "Bh in bands" within the A2 horizon. On the other hand, the B21h, B22h and B23h horizons of profiles in dry loussekes are identical with those in wet loussekes.

CHARACTERISTICS AND ORIGIN OF SPECIMEN PODZOLS

Profiles in the ORSTOM concession, Brazzaville

Site and soil descriptions

The ORSTOM concession occupies a tabular surface or small plateau with an altitude between 305 and 311 m (Fig. 4). The fortuitous discovery of prehistoric tools in the area prompted archaeological excavations, which, in turn, provided opportunities for examination of soils and furnished information on the thickness of the Bateke sands and on the topography of the underlying Stanley Pool sandstone. Thickness of the Bateke sands is represented in the cross-section in Fig. 4. The sandstone has a plane surface at an elevation of ca 299 m, terminated on the east by a drop in the form of a cliff ca 5 m high. All of the land surface is covered by the Bateke sands; the sandstone does not outcrop.

At the boundary between the plateau and the valley of the brook "Malades du Sommeil" is a well-drained podzol formed in Bateke sands at an altitude between 305 and 295 m. It consists of a partially truncated A2 horizon with "Bh in bands", over B21h, B22h and B23h horizons in downward succession (Fig. 3B). These rest on the Stanley Pool sandstone. The B22h and B23h horizons are parts of a humic ortstein with a maximum thickness of about 1 m. The ortstein wedges out toward the cliff and is absent from the profile to the east; the podzol is replaced by a ferrallitic soil. The transition from one kind of soil to the other is a few metres in length. The humic ortstein extends from the podzol for a few metres under the ferrallitic soil (Fig. 4) where the uppermost few centimetres of that ortstein are impregnated with iron oxides.

Prehistoric stone tools lie directly on the upper surface of the ortstein but are not found within it. Made from sandstone, the tools are especially common between the B21h and B22h horizons (Fig. 5) in pit No. 2, the location of which is shown in the cross-section in Fig. 4. The tools are also present between the ferrallitic soil and the underlying ortstein in the pit shown as PZO 10 in the cross-section. At pit No. 2 (Fig. 4) ca 3000 items were collected from an area

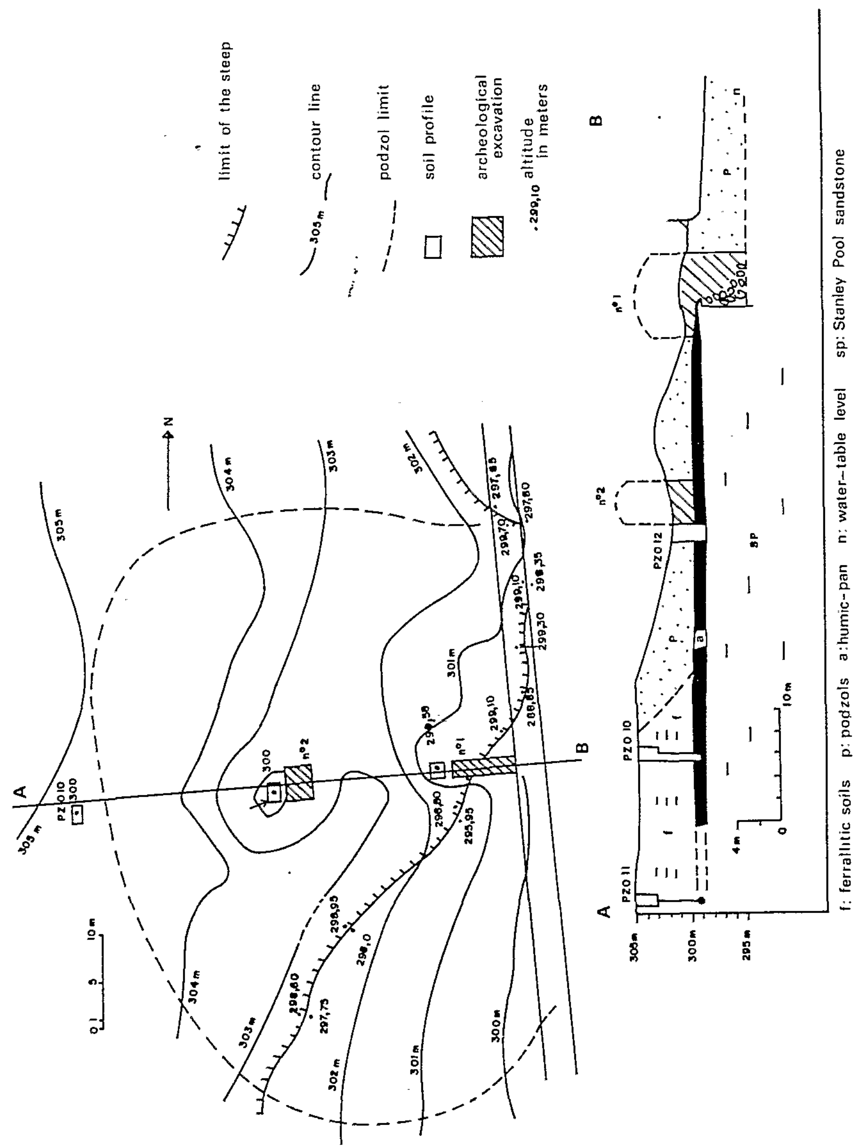

Fig. 4. Contour map of the ORSTOM concession, Brazzaville, and a cross-section diagram to show locations of profiles and archaeological excavations.

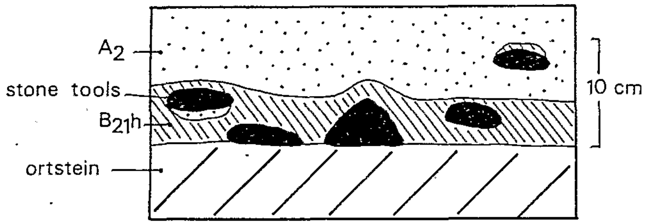

Fig. 5. Schematic position of the stone tools on the upper surface of the humic ortstein.

of 9 m^2 of the upper surface of the ortstein. This level is clearly an undisturbed prehistoric site.

Tentative chronology of podzol development

The evolution of the podzol profiles in the ORSTOM concession seems best attributed to a succession of stages. More than one interval of soil genesis under differing environmental conditions is needed to accommodate the sequences of horizons and their characteristics.

Following the deposition of the Bateke sands and removal of iron oxide coatings from the sand grains, the first stage is thought to have been formation of a hydromorphic podzol. This inference is based on the identity of the ortstein in the podzols in the ORSTOM concession with those of the wet loussekes of the region as a whole.

At some time after the first hydromorphic podzol was formed, it was truncated down to the ortstein. That such truncation occured is inferred from two lines of evidence. One is the presence of prehistoric tools and rock fragments from their manufacture on the upper surface of the ortstein. The other is presence of the ortstein immediately beneath a ferrallitic soil.

Once exposed, the ortstein seems to have formed a stable land surface for an unknown period of time. Evidence for persistence of the ortstein at the land surface consists of prehistoric stone tools and the residues from a tool-making industry on the upper surface. The general shapes of the stone tools indicate that they are from the Tshitolian culture of 12,000–9,000 years B.P.. (Lanfranchi, 1988). Additional evidence of human occupation is an exceptionally high content of phosphorus (12‰) in the upper part of the ortstein (Schwartz, 1985). In comparison, the content of phosphorus in the ortstein at Gangalingolo (cf. infra) ranges from 0.05‰ (upper part) to 0.35‰ (lower part). This last value corresponds to the mean content of phosphorus in soils of the Brazzaville area (Schwartz, 1985).

A new cycle of sedimentation followed human occupation of the site. The new sediments covered the artifacts and provided parent materials in which the new podzols and the ferrallitic soils were developed. The new podzols have A2 horizons with "Bh in bands", as do the soils in the dry loussekes.

The probable time-periods for the formation of the major horizons can be estimated from ages of stream terraces, the stone tools and their position in the vertical section, the occurrence and distribution of the ortstein and available radiocarbon data. These last data are discussed in a subsequent section.

The stream terraces on which podzols have been developed were themselves formed in the Maluekian period. In Brazzaville, terrace deposits of the Djoué, the principal tributary of the Congo river, are known for this period at the altitude of 290–295 m, 20 m above the present level of the Djoué (Giresse et al., 1981). All podzols in this town are located at an altitude between 295 and 305 m, either they are on stream terraces (large streams), or not (small streams and brooks). This altitude can be connected with the base level of streams during the Maluekian period, 70,000–40,000 years B.P. (Schwartz, 1985). If the latter figure is used as the close of terrace or base level formation, podzolization (this term is used as defined by CPCS, 1967) could not have begun prior to 40,000 years B.P. Consequently, the ortstein is thought to have developed after 40,000 years B.P. Presence of human artifacts from 12,000 years B.P. on top of the ortstein demonstrates that it had been formed earlier. The full period within which the ortstein could have been formed can thus be bracketed fairly well. Estimates as to the actual period of formation are more open to question. I believe that the ortstein was formed between 40,000 and 30,000 years B.P. The Leopoldvillian period (Fig. 2) from 30,000 to 12,000 years B.P. had an arid climate under which strong podzolization would have been improbable. This is my basis for assigning the development of podzols with ortstein to the period between 40,000 and 30,000 years B.P.

The new cycle of sedimentation that buried the ortstein in the ORSTOM concession is believed to have started after 12,000 years B.P., as would the development of the podzol profiles with A2 horizons and "Bh in bands".

Soil in lousseke at Gangalingolo

Site and soil descriptions

This lousseke is located at 17 km southwest of Brazzaville in a little plain limited to the west and north by hills, and to the southeast by the Congo valley. The central part is a wet lousseke, and the fringing part is a dry lousseke. The altitude ranges between 293 and 283 m. That is lower than in the ORSTOM concession, because the Gangalingolo area is downstream from Brazzaville.

In the wet part of the lousseke, which is the main part, the soils are essentially podzols with an ortstein of 2 m thick. This type of soil is illustrated in Fig. 3A. Analytical data are given in the Appendix. In the lower part of the wet lousseke, near brooks, the A1 horizon is replaced by peaty horizons. The soils in the dry part of the lousseke have no "Bh in bands" in the A2 horizon; the water table affects this horizon during only a few weeks in the wet season.

TABLE I

Identification of plant root remains in the ortstein of the podzol at Gangalingolo (from Dechamps et al., 1988)

Profile No.	Species
GASC 1	*Pterocarpus tinctorius*
	Monopetalanthus microphyllus
GASC 2	*Monopetalanthus microphyllus*
GASC 7	*Grewia* sp.
GASC 9	*Monopetalanthus microphyllus*
	Monopetalanthus durandii
GASC 30	*Monopetalanthus microphyllus*
GASC 65	*Monopetalanthus letestui*
GASC 66	*Monopetalanthus heitzii*
GASC 83	*Monopetalanthus microphyllus*
	Monopetalanthus letestui
GASC 600	*Monopetalanthus durandii*

Root remains in the ortstein

Numerous root remains representing several species have been observed in situ in the ortstein. The root remains mostly represent the genus *Monopetalanthus* (Dechamps et al., 1988) which is a *Cesalpinacea* normal to rain forests (Table I). Represented among the root remains are those of *M. heitzii, M. durandii* and *M. letestui,* species which occur at the present time only in the Monts de Cristal of Gabon and in equatorial Guinea, i.e., in areas with annual rainfall between 2000 and 2500 mm and a dry season no longer than three months. At the same time, these species are not characteristically found in hydromorphic environments, nor growing in wet soils. Arranged in intertwined networks, some root remains have angular cross-sections. The combination of the plant species with the distribution pattern and nature of the root remains indicates (1) that the species were growing in the soil as the ortstein was being formed, and (2) that the cementation occurred during a relatively dry period, i.e., as the soils were "drying out". Had the plants been growing prior to induration of the present ortstein, the roots would not be expected to have the angular cross-sections nor the tangled networks. That cementation occurred during a period of relative desiccation is in agreement with the observations of Righi (1977) on podzols in the Landes du Médoc in France and with the opinion of De Coninck (1980).

Isotopic ratios ($^{13}C/^{12}C$) of the soil organic matter

The ratios of the two carbon isotopes in the organic matter in soils are like those of the plants from which it was derived. Among plants, the ratios differ with the type of photosynthesis (Deines, 1980). In the Peoples Republic of Congo, Schwartz et al. (1986b) have shown that the $^{13}C/^{12}C$ ratios of organic matter derived from forest and savanna vegetation differ appreciably. Such ratios can therefore serve as a key to general sources of organic matter found in the soils.

TABLE II

The $^{13}C/^{12}C$ ratios of organic matter from several horizons of the podzol and of some plant parts at Gangalingolo (from Schwartz et al., 1986b)

Sample No	Sample	^{13}C (‰)
GASC 1-1	A1 horizon	−13.3
GASC 1-2	A2 horizon	−24.3
GASC 1-3	B21h horizon	−25.2
GASC 1-a	Humic-ortstein, upper part	−27.5
GASC 1-b	Humic-ortstein, median part	−27.5
GASC 1-c	Humic-ortstein, lower part	−27.4
GASC R	Roots of *Monopetalanthus* sp.	−28.8
MC	Aerial organs of *Monocymbium ceresiiforme*	−13.8
LS	Aerial organs of *Loudetia simplex*	−15.2

The $\delta^{13}C$ (standard PDB) of the organic matter in the podzol at Gangalingolo differs with depth in the profile, as shown in Table II. The value for the A1 horizon is comparable to that of savanna grasses. In contrast, the values for the B21h horizon and ortstein are comparable to those of forest species. The value for the A2 horizon is intermediate but more like those of underlying than overlying horizons. From these data I inferred that the podzol profile had been formed under forest cover, some time after which it was occupied by savanna vegetation.

Radiocarbon dating of organic matter

Radiocarbon ages of the organic matter in the B21h horizon, in two parts of the humic ortstein and in the remains of a plant root, are given in Table III. Interpretation of these ages requires some prior explanation.

The applications of radiocarbon data to organic matter in soils have largely been based on the assumption that additions and losses have occurred continuously and at a rather uniform rate throughout the period of accumulation (Guillet, 1972, 1979). According to this principle, the mean residence time (MRT) of the organic matter corresponds closely to half of the interval since accumulation started. In other words, if the MRT is 2000 years, accumulation began 4000 years ago. This interpretation seems valid if accumulation began rather recently and has continued to the present. The interpretation is not likely to be valid, however, if the radiocarbon age of the organic matter is high. Thus, for example, if the radiocarbon age is 25,000 years or more, doubling the figure for the onset of accumulation no longer seems valid. The curve for ra-

TABLE III

The radiocarbon of ^{14}C ages of organic matter in the B21h horizon, the ortstein and one of the plant root remains in the ortstein of the profile at Gangalingolo (from: Schwartz et al., 1985; Schwartz, 1985)

Sample No.	Sample	Depth (cm)	Age B.P.
Ny 1064	B21h horizon	110	10400 ± 150
Ny 1015	Humic ortstein upper part	125–135	29400 ± 800
Ny 1016	Humic ortstein median part	195–205	38500 ± 2000
Gif 6054	Roots of *Monopetalanthus* sp.	112–135	≥ 30000

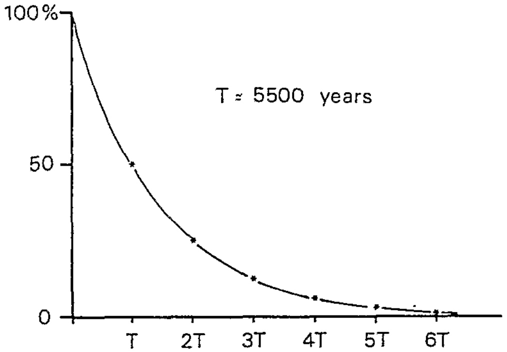

Fig. 6. Graph showing decay of ^{14}C against time.

diocarbon ages is exponential (Fig. 6) and forms a straight line only for short distances. For ages exceeding 25,000 years, the curve becomes almost horizontal, which means that a very small change in the amount of ^{14}C corresponds to large changes in age. The MRT calculated for samples in which accumulation occurred over a long period does not represent half of that period, as can be shown by a simple example. If the decay of ^{14}C occurred over an interval of 33,000 years, the ratio of atoms of age zero to atoms of age 33,000 is about 100:2. To state this in another way, for every 100 atoms of ^{14}C which age zero there are two with age 33,000 years. If identical numbers of atoms with those two ages were mixed the mixture would have an approximate age of 5500 years, whereas the MRT should be 16,500 years, a difference of slightly more than 10,000 years. This indicates that a radiocarbon age of 25,000 years or more should not be taken as the MRT but needs another interpretation.

As pointed out in an earlier section of the paper, podzolization is believed to have begun for this profile no more than 40,000 years ago. The radiocarbon age of the organic matter in the median part of the humic ortstein given in Table III is near that figure. Consequently, this suggests that the radiocarbon or ap-

parent age is closer to the real age than to the MRT. This gains support from the evidence that podzolization did not continue in the soils for the last 40,000 years. If it had, the organic matter in the upper part of the ortstein would have an apparent age much lower than 29,500 years (Table III). The radiocarbon ages for the parts of the ortstein are thus consistent with the chronology proposed in an earlier section for the formation of the ortstein between 40,000 and 30,000 years B.P. For that reason, the ortstein is considered a fossil horizon.

Further support for considering the ortstein to be ancient and fossil is provided by the radiocarbon age of the root remains. That age is absolute. Moreover, it is essentially the same as the value for the oldest part of the ortstein. The correspondence in ages of the root remains and the organic matter in the ortstein also supports the hypothesis that radiocarbon ages greater than 25,000 years are reasonable approximations of real ages.

The radiocarbon age of organic matter in the B21h horizon (Table III), on the other hand, is much less than 25,000 years and cannot be considered the actual age. That horizon could have been formed during the Kibangian period (12,000 years B.P. to present) but the actual time of its formation remains uncertain. Even so, the radiocarbon age suggests that formation was not recent and may have occurred during the early part of the period.

History of podzolization

An attempted reconstruction of the history of podzolization at the two sites is given in Fig. 7. The history differs in some respects at the two sites because of the truncation of the original profiles in the ORSTOM concession but not at Gangalingolo.

The first step after deposition of the Bateke sands is believed to have been removal of the iron oxides from the sand grains. This may have occurred during the Maluekian period at Gangalingolo and in the ORSTOM concession. Such removal of oxides could have preceded the primary interval of podzolization.

A second stage is thought to have been the primary and major interval of podzolization. During that stage, the A2, B22h and B23h horizons were formed at the Gangalingolo site and the ancient A2, B22h and B23h horizons at the ORSTOM concession site. Those horizons are believed to have been formed under forest cover and under the influence of a fluctuating water table during the Njilian period (40,000 to 30,000 years B.P.). Cementation of the B22h and B23h horizons into ortstein could have occurred during the transition to the Leopoldvillian period (30,000 to 12,000 years B.P.). This possibility was mentioned in an earlier section of the paper.

Sometime during the Leopoldvillian period, the podzols in the ORSTOM concession were truncated so that the orstein was exposed at the land surface. It is also possible that the podzols were truncated just before the human occupation, at the beginning of the Kibangian period (12,000 B.P. to present).

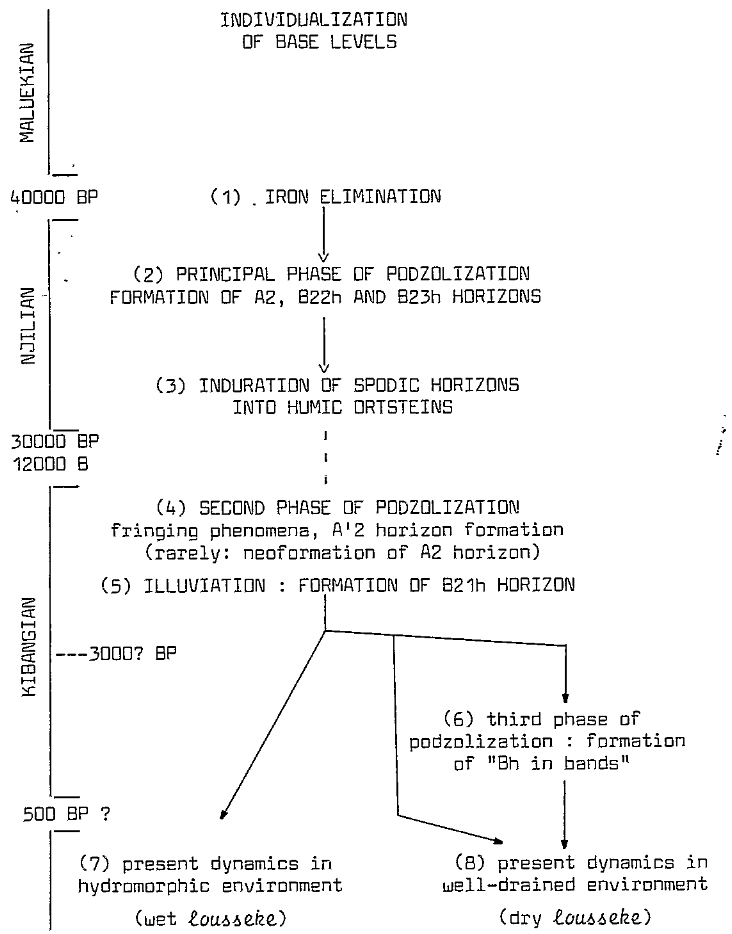

Fig. 7. Tentative reconstruction of phases in the development of podzols in the Bateke sands.

On the other hand, the profile at Gangalingolo was not truncated and does not bear any recognizable marks of change during the period.

At some time during the Kibangian period (12,000 years B.P. to present), probably in the early part, a new cycle of sedimentation covered the exposed ortstein in the ORSTOM concession. These sediments became parent materials for new podzols.

A third stage in evolution of the soils but under weaker podzolization than the second stage is thought to have occurred during the Kibangian period. In the profile at Gangalingolo, the second round of podzolization entailed the

formation of a B21h horizon in the lower part of the pre-existing A2 horizon. In the new parent materials at the ORSTOM site, the present A2 and B21h horizons are thought to have developed simultaneously. The higher silt contents of the B21h horizons suggest that both organic matter and silt were translocated into that horizon from overlying horizons during this stage. The second round of podzolization is thought to have occurred rather early in the Kibangian period because rainfall was greater at that time than later. Soil changes in the latter part of the period have been much smaller.

The podzols in several parts of Bateke land differ in drainage. Most of the podzols in the hilly areas draining toward the Stanley Pool are now well drained. The characteristics of the soils indicate, however, that they were formed under hydromorphic conditions. Base levels of the streams have been lowered in the middle section of the Congo Basin (Giresse et al., 1981) and that change has apparently improved drainage of the soils. In contrast, the podzols in the hilly areas draining toward to Congolese Basin are poorly drained with few exceptions (Delibrias et al., 1983). The podzols in the closed depressions on the plateaus remain poorly drained as well.

A fourth round of podzolization is thought to have occurred during the later part of the Kibangian period (3000 years B.P. to present). The climate had then become drier and forest had been replaced by savanna grasses. In that stage, a "Bh with bands" is thought to have been formed in the pre-existing A2 horizons of profiles in dry loussekes. Soil genesis during the period may have been affected as well by the repeated burning of vegetation.

CONCLUSIONS

Genesis od the podzols in the ORSTOM concession and in the lousseke at Gangalingolo can best be understood as due to a complex history associated with changes in the climate in the late Quaternary. Thus, the humic ortsteins in the profiles seem to have been formed between 40,000 and 30,000 years B.P., have not been formed since and are not being formed at the present time. Other horizons in the profiles, such as the B21h horizon, could have been formed in the early stages or in recent stages.

Complex histories may also have prevailed for podzols in other parts of the tropics. Thus, the podzols described by Brammer (1973) in Zambia occur in settings and have characteristics like some in Bateke land—terrace positions, grass cover, free drainage and important accumulations of organic matter. Other similar examples are podzols on terraces in Kampuchea described by Platteborze (1969) and some in Colombia described by Faivre et al. (1975).

Even so, the past differences in environmental conditions during soil formation may account for only part of the diversity among the podzols in the tropics. Those described by Boulet et al. (1982) on a plane crest in Amazonia, for example, seem to differ enough from those in Bateke land to require a different mode of genesis.

The observations on the podzols in Bateke land suggest that one working hypothesis in future studies of the genesis of podzols in the tropics should be that some or all of the horizons in the profile had been formed in a past period of time but had persisted into the present. Individual horizons or even entire profiles may be relict. This would be consistent with a concept proposed by Bryan and Teakle (1949) in Australia about 40 years ago. The concept was suggested to explain the occurrence of certain soils in Queensland not expected under present conditions. Those authors believed that the soils had been formed under environmental conditions unlike those of the present but that, once formed, the soils were resistant to change. After distinct horizons have been formed in podzols, their profiles might also exhibit resistance to change or have an inertia of their own.

ACKNOWLEDGEMENTS

Thanks are due to B. Souchier, B. Guillet and F. Toutain of the CNRS, Centre de Pédologie Biologique, Nancy, France, for the numerous fruitful discussions during my stay in their laboratory and to R. Lanfranchi of the Anthropology Laboratory, Marien N'Gouabi University in Brazzaville, who made the archaeological study. Special thanks are due to Dr. Ir. F. de Coninck, Geological Institute, Ghent, Belgium for his critical advice and his help in improving the text and for his translation into English.

APPENDIX

Profile description (Schwartz et al., 1986b) and analytical data (Schwartz, 1985) for a podzol in a wet or hydromorphic lousseke at Gangalingolo

A11 (0–15 cm): dark grey (4/0), dry sand, abundant roots, abundant bleached sand grains, particulate structure, organic matter localized in microaggregates, merging boundary.
A12 (15–35 cm): dark grey (5/0) dry sand, few roots, structureless, friable, merging boundary.
A1/A2 (35–55 cm): dry structureless sand, numerous tongues of organic matter corresponding to fluctuations of superficial groundwater.
A2 (55–107 cm): light grey (10YR 7/2) structureless sand, sharp horizontal boundary.
B21h (107–112 cm): grey (10YR 6/2) wet loamy sand, massive, wellcompacted but not indurated (bulk density 1.92), little organic matter, no roots, sharp wavy boundary.
B22h (112–185 cm): dark grey (4/0) humic-pan massive, cemented (bulk density 1.8), quartz grains covered with organic coating which penetrates intergranular pores, abundant tree roots, gradual transition to:
B23h (185–260 cm): brown (7.5YR 4/6) humic-pan, massive, cemented, quartz grains as above, common tree roots, deep ground-watertable at 260 cm.

Horizon notations defined by Schwartz (1985), Schwartz et al. (1986a), after: CPCS (1967) and Righi (1977).

	A11 0–15	A12 15–25	A12 25–35	A1/A2 35–55	A2 55–80	A2 80–95	A2 95–105	B21h 110	B22h 115	B22h 120	B22h 140	B22h 170	B22h 200	B23h 200	B23h 230	B23h 260	B3 270
Clay (0–2 μm)	1.1	0.9	0.9	1.1	1.0	0.9	1.5	3.1	3.3	3.2	5.3	5.8	6.0	6.4	6.3	4.6	4.5
Silt (2–20 μm)	0.7	0.7	0.4	0.7	1.3	0.4	0.6	6.2	3.3	1.3	1.7	2.2	1.6	1.4	2.3	2.0	0.4
Silt (20–50 μm)	2.3	1.6	1.7	2.2	3.3	6.7	3.2	2.3	2.9	2.0	2.8	2.9	2.5	2.6	3.1	2.3	1.9
Fine sand (50–200 μm)	42.7	35.0	37.9	40.7	42.6	50.1	43.7	41.2	43.0	35.6	41.1	39.3	38.2	37.2	39.0	35.7	44.3
Coarse sand (200–2000 μm)	52.9	50.5	59.7	55.6	53.5	41.2	51.2	46.1	44.5	41.6	41.9	41.7	41.8	41.4	42.0	54.5	47.6
Organic matter	2.3	1.1	0.5	0.2	0.1	0.1	0.1	0.9	3.1	17.8	8.1	7.7	10.1	9.4	4.5	1.0	0.9
Total (%)	102	99.8	101.1	100.5	101.8	99.3	100.3	99.8	100.1	101.4	100.9	99.6	100.2	98.4	97.2	101.1	98.6
C	13.14	6.62	2.87	1.38	0.35	0.38	0.42	5.15	18.16	102.96	47.14	44.82	58.73	54.60	26.26	5.95	5.40
N	0.420	0.396	0.210	0.126	0.091	0.084	0.028	0.273	0.422	1.575	1.078	0.987	1.064	1.050	0.518	0.182	0.224
C/N	31.3	16.9	13.7	10.9	3.8	4.5	15.0	18.9	43.0	65.3	43.7	45.7	45.4	52.2	50.6	32.7	24.1
C*/C(%)	37	/	/	/	/	/	/	80	85	97	95	96	97	97	93	95	85
pH water	4.9	5.0	5.4	5.9	6.6	6.6	5.9	5.6	4.9	3.8	4.3	4.3	4.3	4.6	4.8	5.4	5.2
pH KCl	3.4	3.7	3.9	4.1	5.6	4.9	4.8	3.9	3.5	3.1	3.3	3.5	3.7	4.0	4.2	4.4	4.2
Exchangeable bases (meq./100 g):																	
Ca++	0.01	0.04	0.07	0.04	0.03	0.06	0	0.05	0.01	0.12	0.08	0.07	0.12	0.03	0.01	0.04	0.03
Mg++	0.04	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0	0.02	0	0.01
K+	0.06	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.02	0.01	0.02	0.01	0.07	0.02	0.03
Na+	tr.	0	0.01	0.01	tr.	0	0	0	0.01	0	0	0	0	0	0	0	0.01
S	0.11	0.10	0.13	0.08	0.06	0.09	0.02	0.07	0.04	0.17	0.11	0.09	0.16	0.04	0.10	0.06	0.08
T	19.1	21.6	18.4	11.5	4.9	3.5	0.8	1.8	2.1	1.4	2.2	5.7	2.3	2.2	9.3	14.3	4.8
S/T(%)	0.6	0.5	0.7	0.7	1.2	2.6	2.5	3.9	1.9	12.1	5.0	1.6	6.9	1.8	1.1	0.4	1.7
Fe-dithionite (‰)	0.2				0.2			0.5		0.2				0.2		0.2	
Fe-oxalate (‰)	0.1				0.2			0.2		0.2				0.0		0.1	
Al-dithionite (‰)	0.2				0.1			0.4		2.2				3.7		3.1	
Al-oxalate (‰)	0.1				0.05			0.4		2.0				3.6		5.0	

C* = C extractable in H_3PO_4 and pyrophosphate.

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