QUATERNARY RESEARCH **50**, 34–45 (1998)
ARTICLE NO. QR981979

Late Holocene Climatic Changes in Western Equatorial Africa Inferred from Pollen from Lake Sinnda, Southern Congo

Annie Vincens

Centre Européen de Recherche et d'Enseignement de Géosciences de l'Environnement CEREGE, BP 80, 13545 Aix-en-Provence cedex 04, France

Dominique Schwartz

ORSTOM *Centre d'Etudes et de Recherches Eco-Géographiques CEREG, 3 rue de l'Argonne, 67083 Strasbourg cedex, France*

Jacques Bertaux

Institut Français de Recherche Scientifique pour le Développement en Coopération ORSTOM, Ile de France, 32 avenue Henri Varagnat,
93143 Bondy cedex, France

Hilaire Elenga

CEREGE, BP 80, 13545 Aix-en-Provence cedex 04, France

and

Christian de Namur

ORSTOM *Laboratoire de Biomathématiques, service 462, Université de St Jérôme, 13397 Marseille cedex 13, France*

Received May 15, 1997

Pollen analysis of two cores from the Lake Sinnda, located in one of the driest areas of the southern Congo, reveals a history of vegetation and climate in this region during the past 5000 yr. A major change centered around 3000–2500 yr B.P. is indicated by an abrupt decrease in forest pollen and by a corresponding increase in grassland pollen. Concurrent drying up of the lake shows that climate, in particular aridity, was the major cause of this change. This paleoclimatic reconstruction conforms with evidence for drier conditions in other parts of western equatorial Africa, such as the development of isolated enclosed savannas and of heliophilous forested formations. The aridity is recorded more fully at Lake Sinnda than at the previous studied ones. It probably lasted longer, from 4200 to 1300 yr B.P., and was more progressive than previously inferred. The aridity predates agriculture marked by pollen of the oil palm at Lake Sinnda. © 1998 University of Washington.

INTRODUCTION

A late Holocene arid event in western equatorial Africa has been inferred from pollen analysis of lacustrine deposits (Richards, 1986; Maley, 1991, 1996; Elenga, 1992; Elenga *et al.*, 1992, 1994, 1996; Vincens *et al.*, 1994, in press a; Reynaud-Farrera, 1995, 1997; Reynaud-Farrera *et al.*, 1996) and soils (Schwartz *et al.*, 1986, 1990, 1992; Schwartz, 1991). This event left its legacy in present landscapes of the region (Schwartz *et al.*, in press; Vincens *et al.*, in press b). For example, it was probably responsible for opening of the forests synchronous with the extension of grasslands in many regions of Congo, Gabon, and Cameroon, effects of which remain evident today. However, opinions are still divided about the event's origin (climatic or anthropogenic), timing, and geographical distribution.

Here we consider the arid event in light of new pollen data from Holocene deposits in the Niari valley, south Congo. The pollen results described here complement mineralogical (Bertaux *et al.*, in press) and phytolith (Alexandre, 1996; Alexandre *et al.*, 1997) data obtained in the same area, as well as previous pollen studies from western equatorial Africa.

GENERAL SETTING

The Niari valley is located in the southern part of Congo, several degrees south of the equator (Fig. 1a). The valley is parallel to the Atlantic coast, from which it is separated by the Mayombe massif in the west. Its eastern part is delimited by the Chaillu massif (Fig. 1b).

Climatically, this region, lying in the rainshadow of the Mayombe where rainfall is about 1500 mm/yr, is one of the

0033-5894/98 $25.00

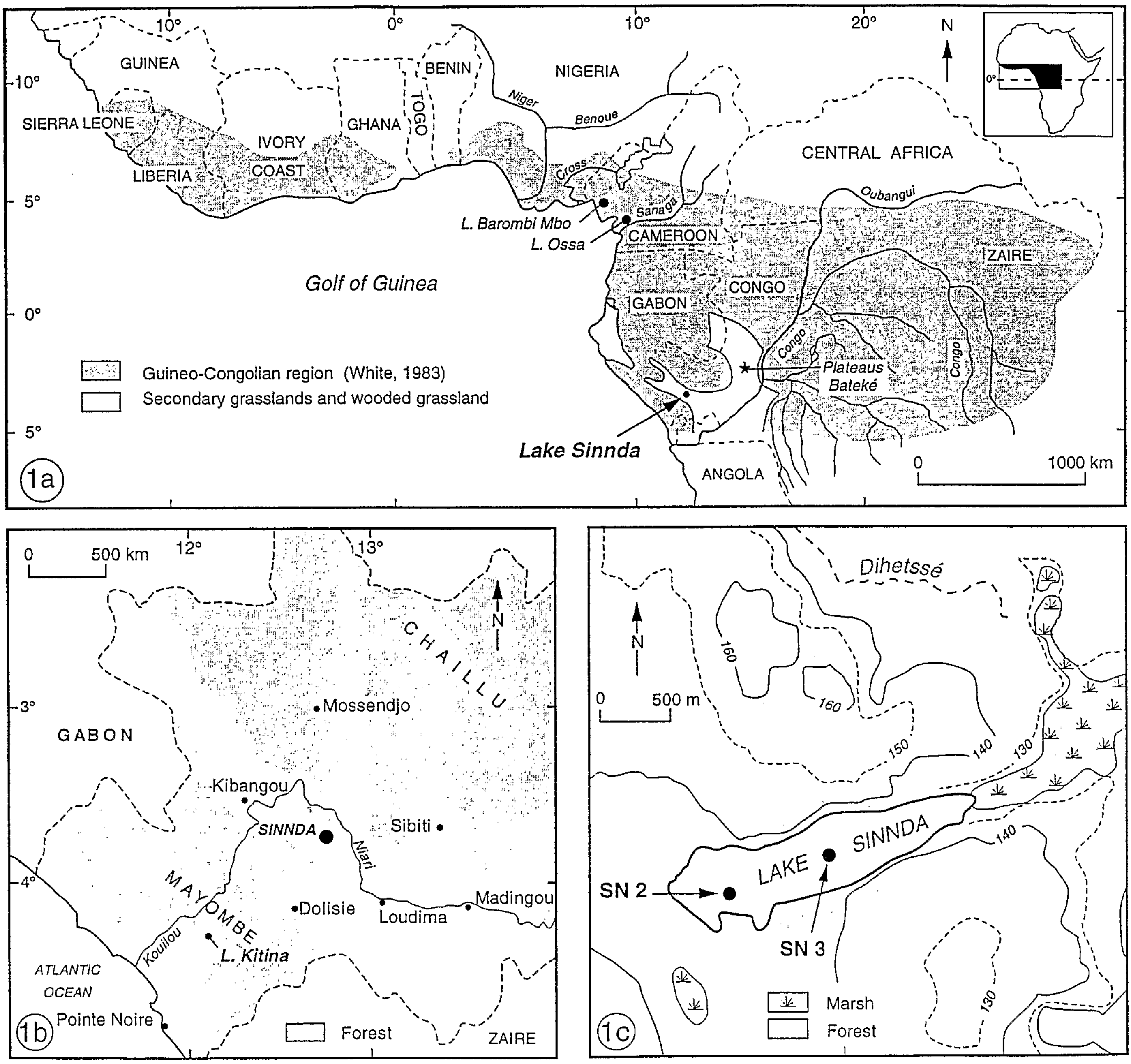


FIG. 1. Location maps. (a) Western equatorial Africa. (b) South Congo, and (c) core sites at Lake Sinnda.

driest areas of western equatorial Africa. The mean annual rainfall is 1100 mm, with a distinct dry season from mid-May to mid-October (Mpouza and Samba-Kimbala, 1990).

The valley's vegetation is placed by White (1983) in the Guineo–Congolian phytogeographical region, where grasslands and wooded grasslands extend north toward Gabon and south to Angola (Fig. 1a). These grasslands are generally dominated by one or two species of Gramineae (Poaceae) which represent more than 80% of the total herbaceous biomass. The woody biomass is dominated by *Annona arenaria, Psorospermum febrifugum, Bridelia ferruginea,* and *Strychnos* sp., and locally by *Hymenocardia acida* (Duvigneaud, 1949; Koechlin, 1961; Descoings, 1969).

Lake Sinnda, whose Holocene sediments we cored and analyzed, is located along the Niari river, north of Loudima (12°48′15″ E, 3°50′08″ S) at 128 m altitude (Fig. 1b). The nearby vegetation includes grasslands dominated by *Hyparrhenia diplandra,* as well as woody species, mainly *Annona senegalensis, Psorospermum febrifugum,* and *Bridelia ferruginea,* but not *Hymenocardia acida* (Descoings, 1969).

The northern and southern steep shores of the lake have forests dominated by *Celtis* sp., *Millettia laurentii* associated with *Ceiba pentandra, Alchornea cordifolia,* and in swampy areas by *Alstonia boonei* (Fig. 1c). Many climbers are present, particularly *Landolphia.* The forests also contain *Elaeis guineensis* (oil palm) and *Mangifera indica* attributable to human occupation mainly related to fishing. The flat eastern shore has marshes dominated by Cyperaceae.

MATERIAL AND METHODS

Two sediment cores for palynological analysis (SN 2 and SN 3) were raised in 1992 (Fig. 1c). They contained 3.80 and 2.47 m of sediments, respectively, and were recovered using a vibracorer (Martin and Flexor, 1987) in water 4.70 and 3.50 m deep. Only one of these cores, SN 2, whose preliminary pollen results have been recently published (Vincens *et al.,* 1994), has been the subject of multidisciplinary studies such as mineralogy (Bertaux *et al.,* 1996, in press) and phytoliths (Alexandre, 1996; Alexandre *et al.,* 1997).

Lithology of the Cores

Both cores are dominated by clayey sediments, apparently without primary lamination (Fig. 2, 3). The cores further share a major lithological change, located at 0.80 m in SN 2 and between 1.55 and 0.73 m in SN 3. The basal sediments are gray clay, which grades upward to black, organic-rich mud with many plant remains. In core SN 2, mudcracks full of organic matter similar to the uppermost sediments are present between these two main lithological facies (Fig. 2). They have been previously interpreted as evidence for temporary desiccation of the lake at the site of SN 2 (Vincens *et al.,* 1994). Core SN 3 contains pale gray clay, with some interstratified organic-rich layers, that is interpreted as a pedogenetic gley horizon (Fig. 3). Otherwise, core SN 3 lacks lithologic evidence of a hiatus from drying of the lake.

Radiocarbon Dating

We obtained five conventional radiocarbon ages and seven accelerator mass spectrometry (AMS) ages on bulk organic matter. The ages are reported only in radiocarbon years except in Table 1, which gives equivalent ranges in calibrated years.

The ages show that the cored sequences expend back to about 5200 yr B.P. In the most complete and well-dated sequence, SN 2, the drying up of the lake inferred from lithology can be dated between 3800 and 1330 yr B.P., the youngest age being obtained from the base of sediments filling the mudcracks (Fig. 2).

Pollen

From the two cores, a total of 88 samples (SN 2, 56; SN 3, 32) of about 1 cm^3 were analyzed at intervals ranging from 2 (upper part of SN 2) to 20 cm. The resulting time resolution ranges from 20 to 200 yr. A pollen sum of at least 320 to 440 pollen grains was counted for each sample. Identifications were based on the reference collection of some 7000 slides present in the Laboratoire de Géologie du Quaternaire-CNRS, CEREGE, Aix-en-Provence.

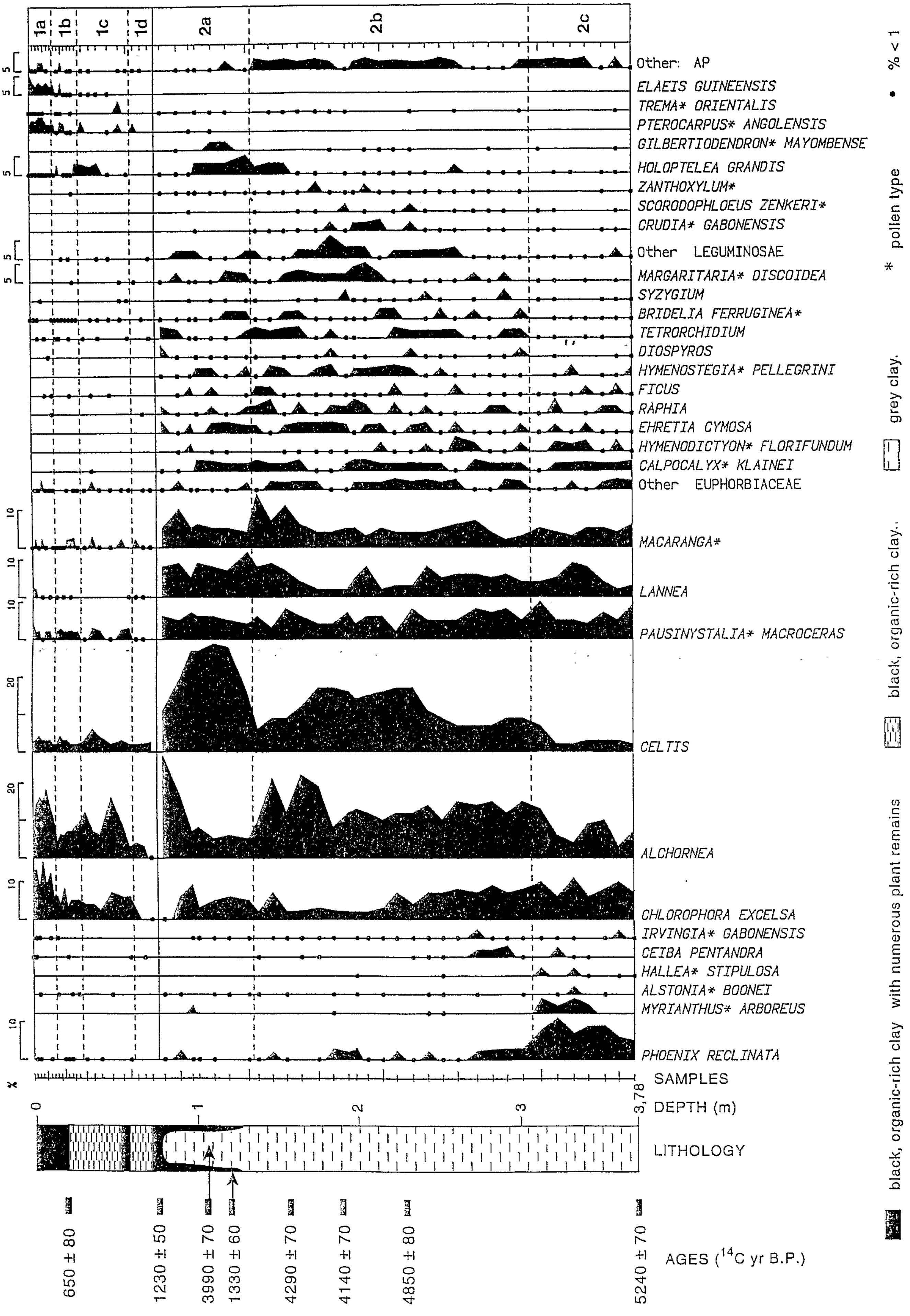
The pollen assemblages are diverse in all the samples analyzed, particularly in the lowest part of the two cores, with a maximum of 88 taxa found in one sample (Fig. 4). A total of 149 taxa has been identified. Whenever possible, the identifications were made at the species, genus, or family level, or with a ''type'' designation if the family (or genus) contains several genera (or species) of identical pollen morphology. The taxa are classified in relation to the physiognomy of the plants which produced them (trees and shrubs, herbs (terrestrial or aquatics), climbers). This classification is based on the ''Flore du Congo Belge et du Ruanda-Urundi'' (1948–1963), the ''Flore du Congo, du Rwanda et du Burundi'' (1967–1971), the ''Flore d'Afrique centrale (Zaïre, Rwanda, Burundi) (1972–1985), and the ''Flore du Gabon'' (1962–1995).

Pollen results are presented in standard percentage diagrams on Figures 2 and 3 with the samples arranged along a depth scale. Only the major taxa, considered to be the most important ones in the interpretation of the palaeoenvironment of Lake Sinnda by their abundance and their consistent presence, were plotted with the GPAL3 program (Goeury, 1988). Sums include all pollen and spore types, except indeterminables. Zonation of the pollen diagrams was done by visual inspection.

POLLEN RESULTS AND INTERPRETATION

The two pollen records show similar trends, with a major abrupt change at 0.80 and 0.69 m in SN 2 and SN 3, respectively (Figs. 2 and 3). This change coincides with lithologic evidence for drying up of the lake—the top of the mud cracks in SN 2 and the top of the pedogenetic gley horizon in SN 3. The change allows definition of two main pollen zones. The ages of the zone boundaries proposed here (and subsequently for the subzones) are based on the assumption of a constant sedimentation rate and on interpolation between two uncalibrated ^{14}C ages.

FIG. 2. SN 2 pollen from Lake Sinnda showing relative percentages of selected taxa. The pollen sum includes all pollen taxa; indeterminables are excluded.


1a
1b
1c
1d
2a
2b
2c
Other: AP
ELAEIS GUINEENSIS
TREMA* ORIENTALIS
PTEROCARPUS* ANGOLENSIS
GILBERTIODENDRON* MAYOMBENSE
HOLOPTELEA GRANDIS
ZANTHOXYLUM*
SCORODOPHLOEUS ZENKERI*
CRUDIA* GABONENSIS
Other LEGUMINOSAE
MARGARITARIA* DISCOIDEA
SYZYGIUM
BRIDELIA FERRUGINEA*
TETRORCHIDIUM
DIOSPYROS
HYMENOSTEGIA* PELLEGRINI
FICUS
RAPHIA
EHRETIA CYMOSA
HYMENODICTYON* FLORIFUNDUM
CALPOCALYX* KLAINEI
Other EUPHORBIACEAE
MACARANGA*
LANNEA
PAUSINYSTALIA* MACROCERAS
CELTIS
ALCHORNEA
CHLOROPHORA EXCELSA
IRVINGIA* GABONENSIS
CEIBA PENTANDRA
HALLEA* STIPULOSA
ALSTONIA* BOONEI
MYRIANTHUS* ARBOREUS
PHOENIX RECLINATA
5
10
20
%
SAMPLES
0
1
2
3
3,78
DEPTH (m)
LITHOLOGY
650 ± 80
1230 ± 50
3990 ± 70
1330 ± 60
4290 ± 70
4140 ± 70
4850 ± 80
5240 ± 70
AGES (^{14}C yr B.P.)
• % < 1
* pollen type
grey clay.
black, organic-rich clay..
black, organic-rich clay with numerous plant remains

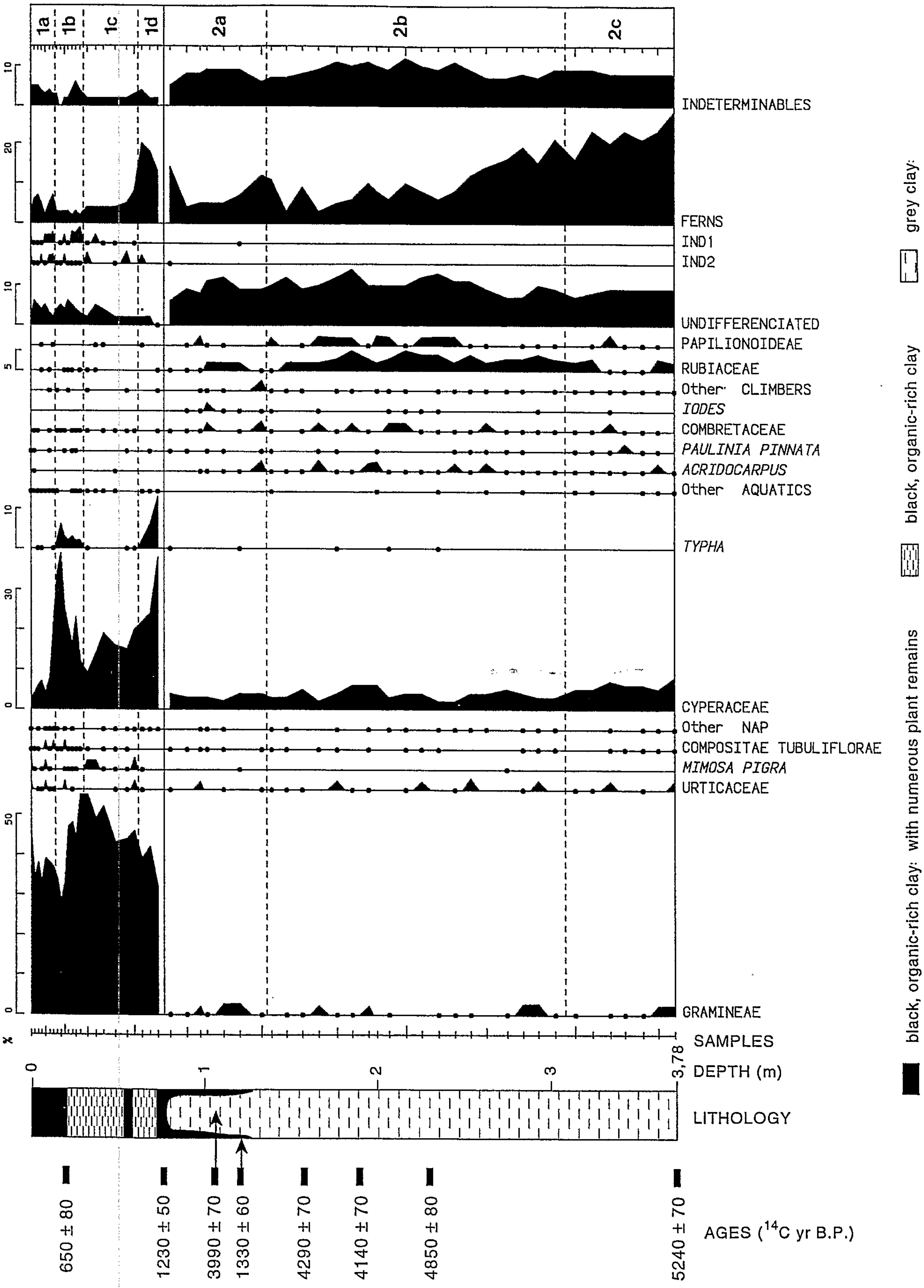


FIG. 2—*Continued*

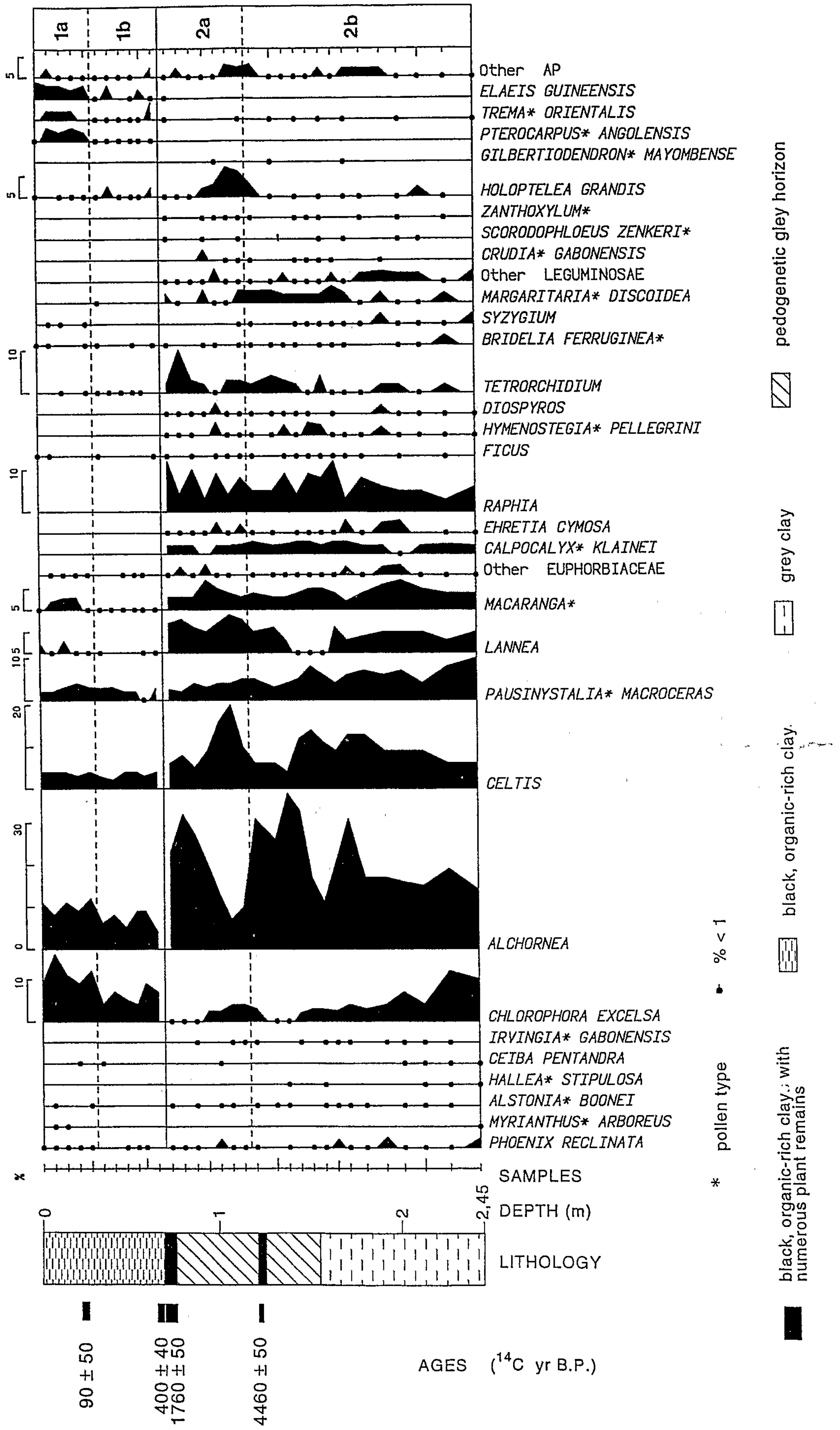


FIG. 3. SN 3 pollen from Lake Sinnda showing relative percentages of selected taxa. The pollen sum includes all pollen taxa; indeterminables are excluded.

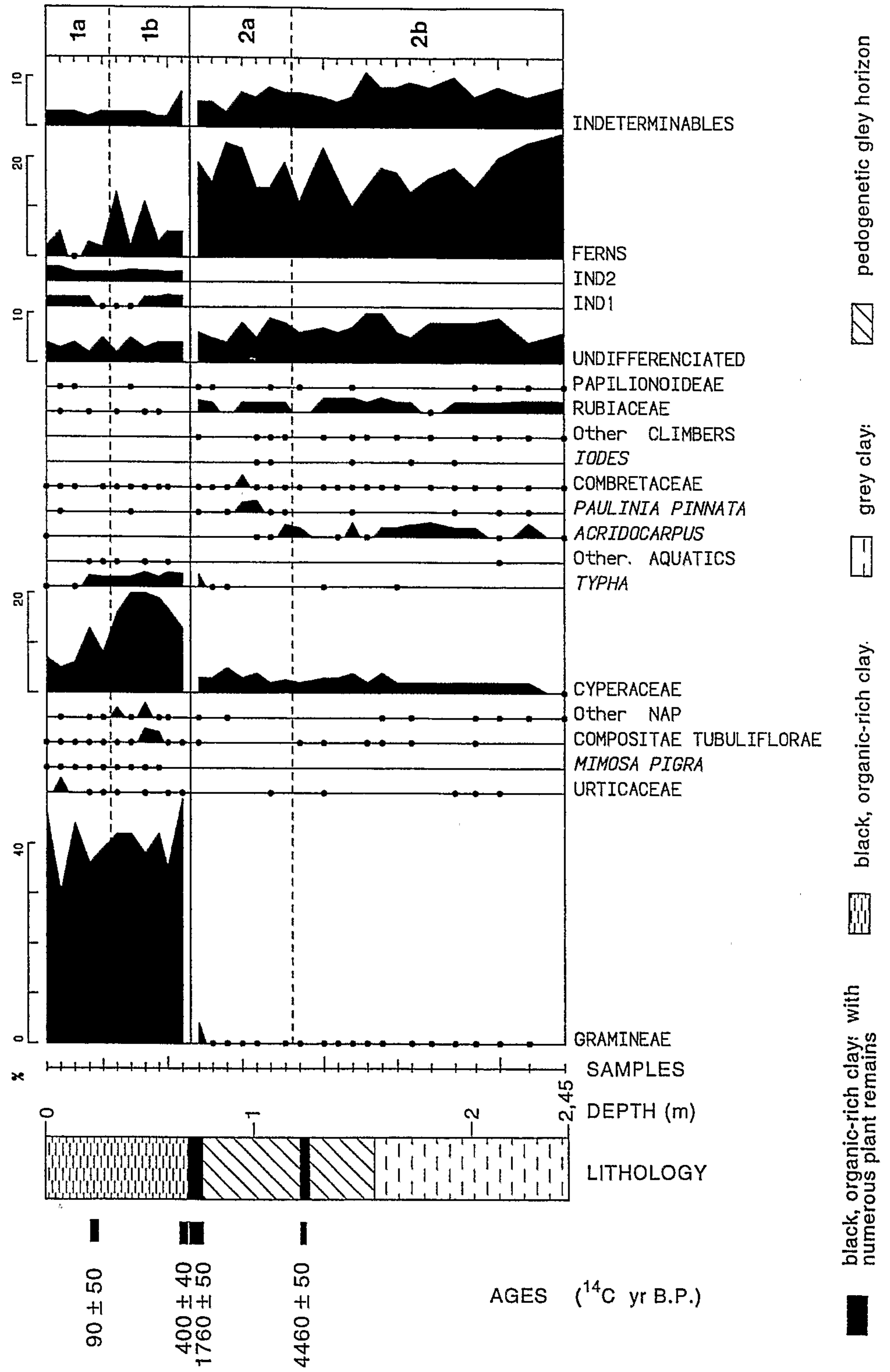


FIG. 3—*Continued*

Zone 2 (SN 2; 3.80–0.80 m; SN 3; 2.47–0.69 m. 5240–3800 yr B.P.). This pollen zone has a diverse assemblage (Fig. 4) with arboreal taxa reaching 50–80% of the total pollen sum. The main components are *Chlorophora excelsa*, *Alchornea*, *Celtis*, *Pausinystalia*-type, *Lannea*, and *Macaranga*. Climbers (*Acridocarpus*, Combretaceae, *Paulinia pinnata*, *Iodes*) are common. Herbaceous taxa, particularly Gramineae (generally less than 1%), are scarce. The assem-

TABLE 1

List of ^{14}C Dates and Calibration into Calendar Years (Stuiver and Reimer, 1993) in the SN 2 and SN 3 Cores from Lake Sinnda

Core	Sample depth (cm)	Age (^{14}C yr B.P.)	Lab number	Age (cal. yr B.P.)
SN 2	16–19	650 ± 80	Bondy 1108	664–547
	74–79	1230 ± 50	Bondy 1106	1231–1210 1185–1067
	106–108	3990 ± 70	Beta 62248[a]	4527–4404 4363–4359
	120–125	1330 ± 60	Beta 66671[a]	1294–1222
	155.5–158	4290 ± 70	Beta 66672[a]	4872–4827 4741–4739
	190–192	4140 ± 70	Beta 62249[a]	4825–4744 4735–4531
	232.5–235	4940 ± 80	Beta 66673[a]	5742–5597
	379–380	5240 ± 70	UtC 2359[a]	6168–6148 6098–6065
SN 3	20–25	90 ± 50	Bondy 1347	
	60–65	400 ± 40	Bondy 1348	504–439 350–334
	65–73	1760 ± 50	Bondy 1352	1716–1602 1593–1575
	119–120	4460 ± 50	UtC 3589[a]	5254–5182 5130–5113 5064–4982

[a] AMS dates.

blages imply a forested environment around Lake Sinnda between 5200 and 3800 yr B.P., with climatic conditions more humid than today.

In core SN 2, the most complete sequence, changes in the proportions of the major arboreal taxa suggest three pollen subzones corresponding to three successional stages of this forested environment.

—*Subzone 2c* (SN 2, 3.80–3.15 m; 5240–5100 yr B.P.). In this subzone, the abundance of *Phoenix reclinata,* associated with *Myrianthus*-type, *Alstonia*-type, *Hallea*-type, and Pteridophyta (monolete-type), implies that a swampy forest surrounded the lake. Subzone 2c may record the first Holocene filling of the lake, corresponding to the onset of humid conditions known from other parts of western equatorial Africa at 9500–9000 B.P. (Giresse *et al.,* 1982; Maley, 1991, 1996; Elenga *et al.,* 1994). The lake-filling hypothesis is supported by macrofaunal evidence for open woodland rather than forested vegetation at 7000 yr B.P. in the Niari valley (Van Neer and Lanfranchi, 1986). Alternatively, subzone 2c corresponds to a dry episode within the humid period, so that swamps expanded into a lowered lake.

—*Subzone 2b* (SN 2, 3.15–1.39 m; SN 3, 2.47–1.17 m; 5100–4200 yr B.P.). This subzone is characterized by a gradual increase of *Celtis* and *Alchornea* contemporaneous with a decrease of the Moraceae, Pteridophyta, and the swampy forest elements, particularly *Phoenix reclinata.* The forest arboreal components include many taxa (mainly Leguminosae and Euphorbiaceae) reaching more than 1% of the pollen sum. The occurrence of *Raphia* and of some *Syzygium* implies local swamps.

—*Subzone 2a* (SN 2, 1.39–0.80 m; SN 3, 1.17–0.69 m; 4200–3800 yr B.P.). A great increase of *Celtis* is registered in this subzone, where it accounts for 26–29% of the

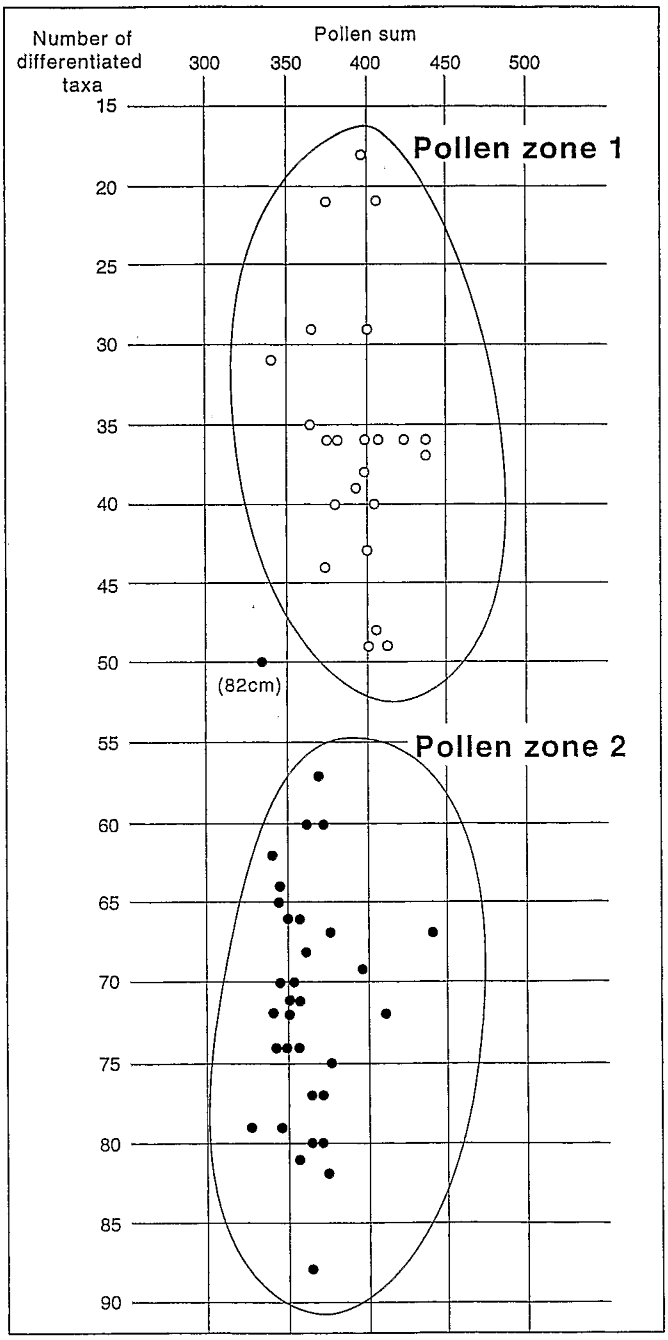


FIG. 4. Diversity of the differentiated pollen taxa in the core SN 2 from Lake Sinnda related to pollen sum.

pollen sum (35–38% of the total arboreal pollen). In both cores the *Celtis* is associated with *Holoptelea grandis.* The abundance of these two taxa in the vicinity of Lake Sinnda indicates an evolution of the forest toward a semideciduous facies that entails drier and/or more seasonal climates (with a longer dry season) in the Niari valley than during the rest of zone 2. The uppermost deposits of this subzone show increasing percentages of *Alchornea* at the expense of *Celtis* and *Holoptelea grandis,* associated in core SN 3 with *Tetrorchidium.*

Zone 1 (SN 2, 0.80–0 m; SN 3, 0.69–0 m; 1300 yr B.P. to present). This upper pollen zone registers distinctly different pollen assemblages than in zone 2. The assemblages are less diverse (Fig. 4) and the dominant components are herbaceous taxa, mainly Gramineae, that indicate a development of open grasslands in the vicinity of the lake from 1300 yr B.P. onward. These grasslands replaced the forest environment that had prevailed between 3800 and 1300 yr B.P. Many forest taxa, mainly Leguminosae, are missing. Others are recorded by pollen so scarce (less than 1%) that they probably were not living at or near the lake.

Large changes in the frequencies of marshy herbaceous taxa in the SN 2 sequence, mainly the Cyperaceae and *Typha,* allow the definition of four subzones within zone 1. Each of these subzones is linked more to lake level fluctuations than to widespread vegetational changes.

—*Subzone 1d* (SN 2, 0.80–0.63 m; 1300–1100 yr B.P.). This subzone has high percentages of Cyperaceae, *Typha,* and Pteridophyta (monolete-type). These taxa imply the presence of local marshes at the core site SN 2. Subzone 1d marks the start of the filling of Lake Sinnda after its dessication between 3800 and 1300 yr B.P.: it implies the re-establishment of more humid climatic conditions in this area.

—*Subzone 1c* (SN 2, 0.63–0.31 m; 1100–800 yr B.P.). A decrease in aquatic taxa in this subzone shows that at the core site SN 2, swampy vegetation disappeared as lake level rose. An abundance of arboreal taxa such as Moraceae, *Alchornea,* some *Celtis,* and *Pausinystalia*-type, indicates the beginning of a recolonization of the shores by forests similar to the ones found today north and south of the lake. Pollen of *Elaeis guineensis* (oil palm) is found for the first time in this subzone (0.49 m). Though only one or two grains, it provides the first evidence of human agricultural activity around Lake Sinnda.

—*Subzone 1b* (SN 2, 0.31–0.14 m; SN 3, 0.69–0.30 m; 800–550 yr B.P.). A new expansion of swampy taxa implies a new drop of lake level, certainly related to a short arid phase. Additional *Elaeis guineensis* implies increased agricultural activity.

—*Subzone 1a* (SN 2, 0.14–0 m; SN 3, 0.30–0 m; 550 yr B.P. to present). Swampy taxa decrease, probably from new rise in lake level. Forests, including *Elaeis guineensis;* develop until the present day.

DISCUSSION

The Late Holocene Arid Event in Western Equatorial Africa

Pollen evidence from western equatorial Africa has previously shown that an important change occurred during the late Holocene. During this event, forests, which were more extensive in this region during early and middle Holocene, underwent floristic, structural, and paleogeographical changes (Richards, 1986; Maley, 1991, 1996: Elenga, 1992: Elenga *et al.,* 1992, 1994, 1996; Vincens *et al.,* 1994, in press a; Reynaud-Farrera, 1995, 1997; Reynaud-Farrera *et al.,* 1996).

The change, centered around 3000–2500 yr B.P., is synchronous with a large extension of grasslands in many regions of Cameroon, Gabon, and Congo. While some authors have ascribed it to climatic change, others favor an anthropogenic one (Schwartz, 1992). Today it is clear that the development of savannas and their maintenance in these regions are the result of three main successional and/or cumulative factors: climatic stress, local edaphic environment, and (more recently) fires set by people (Schwartz *et al.,* 1995, in press). But details about this dry event, including its onset, termination, spatial variation, and temporal pattern, remain matters of debate (Maley, 1997; Vincens *et al.,* in press b).

The change in pollen assemblages of the two sedimentary sequences from Sinnda between 3800 and 1300 yr B.P. is related to a major climatic event—a time of exceptional aridity that dried up the lake completely. Consequently human impact as early as 3000 yr B.P. can be excluded as a primary reason why forest was replaced by grassland around the lake. Moreover, concurrent changes have been registered in several regions of western equatorial Africa, mainly in Congo (Bateke plateaus and Lake Kitina, Figs. 1a, 1b) and Cameroon (Lakes Ossa and Barombi Mbo; Fig. 1a). These changes, which include development of heliophilous forests and/or isolated enclosed savannas, indicate a widespread event of climatic origin.

Concerning the timing of the arid event, the data from Lake Sinnda, the driest site studied in western equatorial Africa, point to a longer and a less abrupt change than previously proposed in this part of Africa (Elenga, 1992; Maley, 1992, 1997; Schwartz, 1992; Elenga *et al.,* 1994). The new pollen data show a major change to semideciduous trees in the forests surrounding the lake as early as 4200 yr B.P. This change can be interpreted in terms of drier (lower mean annual rainfall) and/or more seasonal climatic conditions than before, maybe with a longer dry season. Phytoliths analyses of core SN 2 show that Gramineae coexisted with the forests, which had probably became interspersed with savannas (Alexandre, 1996; Alexandre *et al.,* 1997). This climatic interpretation also agrees with a decrease of quartz and kaolinite content and an increase of calcite and talc from

4300 yr B.P. onward at core SN 2. These mineralogical changes imply a reduction in rainfall (Bertaux *et al.*, 1996, in press). The end of the arid event is probably marked by the refilling of Lake Sinnda, dated to 1300 yr B.P.

The western equatorial African forests reacted to the aridity in various floristic, structural, and paleogeographical ways. These responses can be explained in terms of the former local stability (or fragility) of each site before 3000 yr B.P. Such a stability (or fragility) and the distribution of present forest ecosystems are governed mainly by local climatic and edaphic conditions (Baumgartner, 1978; Richards, 1981; Furley *et al.*, 1992).

It now seems clear that at Sinnda, climatic and edaphic conditions prevented the maintenance of forested ecosystems during the arid event. The annual rainfall was below the minimum values for their survival while low water availability occurred in the clayey soils (Schwartz *et al.*, 1995). Under such critical conditions, a change in floristic composition from 4200 yr B.P. onward logically preceded the complete disappearance of the forests between 3800 and 1300 yr B.P.

At sites where the arid event allowed the survival of forests, such as around Lakes Ossa and Barombi Mbo in Cameroon (Maley, 1992; Reynaud-Farrera, 1995, 1997; Reynaud-Farrera *et al.*, 1996) and Lake Kitina in Congo (Elenga *et al.*, 1996), no early, drastic, and irreversible perturbations occurred about 4000 yr B.P. Forests persisted with only local openings after 2700 yr B.P. (development of heliophilous formations or of enclosed savannas). Humid forests rich in Caesalpiniaceae persisted near Lakes Ossa and Barombi Mbo until 2700 and 2500 yr B.P., respectively. This persistence has been linked to the occurrence of stratiform clouds and permanent fog over the region (Maley and Elenga, 1993).

On the Bateke plateaus and along Congo's Atlantic coast, climatic conditions were critical, but during the arid event soils remained moist. This soil moisture, linked to the lack of drainage, compensated for a deficit in rainfall, so that forests persisted locally until 3000 yr B.P. (Elenga, 1992; Elenga *et al.*, 1992, 1994).

We thus infer that the arid event is recorded more fully at Lake Sinnda than at sites where the (climatic and/or edaphic) environment allowed forests to survive. The new data obtained from Lake Sinnda, complemented by those from Kitina (Elenga *et al.*, 1996; Bertaux *et al.*, in press), further argue for a more continuous and progressive trend toward aridity, with a maximum probably centered around 3000–2500 yr B.P. We found no evidence for the succession of shorter and abrupt dry intervals proposed by Maley (1992, 1997).

Recent Climatic Changes and Human Impact on the Landscape Dynamics

The refilling of Lake Sinnda about 1300 yr B.P. and the progressive redevelopment of local forested formations on its shores from 1100 yr B.P. onward, imply the re-establishment of more humid conditions in the region. Nevertheless, forest expansion in the Niari valley was limited by low rainfall, a long dry season, low water availability in the soils and, above all, human burning of grasslands (Schwartz *et al.*, 1995, in press). At the other studied sites of western equatorial Africa, an increase in rainfall during the last millenium is also indicated by expansion of forests around Lake Kitina, ca. 500 yr B.P. (Elenga *et al.*, 1996) and Lake Ossa, ca. 700 yr B.P. (Reynaud-Farrera, 1995, 1997), and by humid conditions on the Bateke plateaus ca. 900 yr B.P. (Elenga *et al.*, 1994). Re-establishment of humid conditions along the Congolese coast has also been inferred for 600–500 yr B.P. onward from the resumption of erosion in the Plio-Pleistocene deposits outcropping between Pointe Noire and the Kouilou River (Sitou, 1994; Sitou *et al.*, 1996).

Within this recent humid period, a brief drought dropped the level of Lake Sinnda ca. 650 yr B.P., within the interval spanned by the Little Ice Age. This drop in level is suggested by pollen evidence for a large extension of marsh. But the drought had little if any effect on the main vegetational communities occurring in the surrounding region. Like the previous arid event, the lowering of lake level ca. 650 yr B.P. cannot be attributed to human activities.

Concerning human activities in the vicinity of Lake Sinnda, the earliest agricultural evidence is found in the appearance of *Elaeis guineensis* (oil palm) at 1000 yr B.P. and its expansion after 600 yr B.P. As at the other sites, its occurrence or its expansion is registered after the widespread establishment of grassland savannas (Elenga *et al.*, 1992, 1994) or the temporary opening of the forests (Elenga *et al.*, 1996; Reynaud-Farrera *et al.*, 1996), so after the onset of the late Holocene arid event. Expansion of *Elaeis guineensis* has been linked to the settlement of proto-agricultural populations associated with Bantu-speaking groups in the region (Clist, 1991; Schwartz, 1992).

CONCLUSION

Pollen data from the Niari valley show that climate has been the major driving factor in the evolution of the environment in western equatorial Africa during the last 5000 yr B.P. The greatest floristic, structural, and paleogeographical changes to the forests in this area during the middle Holocene are linked to an arid event centered around 3000–2500 yr B.P. This event probably lasted from 4200 to 1300 yr B.P.

ACKNOWLEDGMENTS

This work is a contribution to the ECOFIT program (ECOsystèmes et paléoécosystèmes des Forêts InTertropicales), financially supported by the CNRS and the ORSTOM. We greatly appreciate the technical assistance provided by G. Buchet, C. Tatilon, and J. J. Motte (CEREGE, Aix-en-Provence). We thank all who permitted us to collect the cores. Constructive comments and editing by two anonymous reviewers and P. Barker significantly improved this manuscript.

REFERENCES

Alexandre, A. (1996). "Phytolithes, interactions sol-plante et paléoenvironnements." Unpublished thesis, Université Aix-Marseille 3.

Alexandre, A., Meunier, J. D., Lézine, A. M., Vincens, A., and Schwartz, D. (1997). Phytoliths: indicators of grassland dynamics during the Late Holocene in intertropical Africa. *Palaeogeography Palaeoclimatology Palaeoecology* **136,** 213–229.

Baumgartner, A. (1978). Tropical forests and the biosphere. *In* "Tropical Forest Ecosystems," pp. 33–60, UNESCO, Paris.

Bertaux, J., Sifeddine, A., Schwartz, D., Vincens, A., and Elenga, H. (1996). Enregistrement sédimentologique de la phase sèche d'Afrique équtoriale c. 3000 BP par la spectrométrie IR dans les lacs Sinnda et Kitina (Sud-Congo). Symposium "Dynamique à long terme des écosystèmes forestiers intertropicaux," pp. 213–215, CNRS-ORSTOM, Bondy.

Bertaux, J., Schwartz, D., Vincens, A., Siffedine, A., Elenga, H., Mariotti, A., Fournier, M., Mansour, M., and Martin, L. (in press). Enregistrement sédimentologique de la phase sèche d'Afrique centrale équatoriale vers 3000 BP par la spectrométrie IR dans les lacs Sinnda et Kitina (Sud-Congo). Actes du Symposium "Dynamique à long terme des écosystèmes forestiers intertropicaux," Bondy, 1996, Collection Colloques et Séminaires, ORSTOM ed.

Clist, B. (1991). Synthèse régionale sur le Néolithique. *In* "Aux origines de l'Afrique Centrale" (R. Lanfranchi and B. Clist, Eds.), pp. 181–183, CCF/CICIBA, Libreville.

Descoings, B. (1969). Phytogéographie. Esquisse phytogéographique du Congo. *In* "Atlas du Congo," ORSTOM, Paris.

Duvigneaud, P. (1949). Les savanes du Bas-Congo. Essai de phytosociologie topographique. *Lejeunia,* mémoire n°10.

Elenga, H. (1992). "Végétation et climat du Congo depuis 24 000 ans B.P. Analyse palynologique de séquences sédimentaires du Pays Bateke et du littoral." Unpublished thesis, Université Aix-Marseille 3.

Elenga, H., Schwartz, D., and Vincens, A. (1992). Changements climatiques et action anthropique sur le littoral congolais au cours de l'Holocène. *Bulletin de la Société géologique de France* **163**(1), 83–90.

Elenga, H., Schwartz, D., and Vincens, A. (1994). Pollen evidence of Late Quaternary vegetation and inferred climate changes in Congo. *Palaeogeography Palaeoclimatology Palaeoecology* **109,** 345–356.

Elenga, H., Schwartz, D., Vincens, A., Bertaux, J., de Namur, C., Martin, L., Wirrmann, D., and Servant, M. (1996). Diagramme pollinique holocène du lac Kitina (Congo): mise en évidence de changements paléobotaniques et paléoclimatiques dans le massif forestier du Mayombe. *Comptes Rendus de l'Académie des Sciences, Paris, série 2a* **323,** 403–410.

Flore d'Afrique centrale (Zaïre, Rwanda, Burundi) (1972–1985). Jardin Botanique National de Belgique, Bruxelles.

Flore du Congo Belge et du Ruanda-Urundi (1948–1963). Publication de l'Institut National pour l'Etude Agronomique du Congo Belge, Bruxelles.

Flore du Congo, du Rwanda et du Burundi (1967–1971). Jardin Botanique National de Belgique, Bruxelles.

Flore du Gabon (1962–1995). Museum National d'Histoire Naturelle, Paris.

Furley, P. A., Proctor, J., and Ratter, J. A. (1992). "Nature and Dynamics of Forest-Savanna Boundaries." Chapman and Hall, London.

Goeury, C. (1988). Acquisition, gestion et représentation des données de l'analyse pollinique sur micro-ordinateur. *Institut Français de Pondichéry, Travaux Section Sciences et Techniques* **25,** 405–416.

Koechlin, J. (1961). "La végétation des savanes dans le Sud de la république du Congo." ORSTOM, Paris, mémoire n°1, 305 p.

Maley, J. (1991). The African rain forest vegetation and palaeoenvironments during late Quaternary. *Climatic Change* **19,** 79–98.

Maley, J. (1992). Commentaire à la note de D. Schwartz: Mise en évidence d'une péjoration climatique entre ca. 2500 et 2000 ans B.P. en Afrique tropicale humide. *Bulletin de la Société géologique de France* **163**(3), 363–365.

Maley, J. (1996). Fluctuations majeures de la forêt dense humide africaine. *In* "L'alimentation en forêt tropicale. Interactions bioculturelles et perspectives de développement" (C. M. Hladik *et al.,* Eds.), pp. 31–52, UNESCO-CNRS-ORSTOM, Paris.

Maley, J. (1997). Middle to Late Holocene changes in Tropical Africa and other continents: paleomonsoon and sea surface temperature variations. *In* "Third Millenium BC climate change and Old World collapse" (H. N. Dalfes *et al.,* Eds.), Vol. 49, pp. 611–640, NATO ASI serie I: Global Environmental Change, Springer-Verlag, Berlin.

Maley, J., and Elenga, H. (1993). Le rôle des nuages dans l'évolution des paléoenvironnements montagnards de l'Afrique Tropicale. *Veille Climatique Satellitaire* **46,** 51–63.

Martin, L., and Flexor, J. M. (1987). Vibro-testemunhador leve: construçao, utilizaçao e possibilidades. 2° Congresso Associasion Brasileira Estudos do Quaternario, special publication, **1,** 1–2.

Mpouza, M., and Samba-Kimbata, M. J. (1990). Aperçu sur le climat de l'Afrique centrale occidentale. *In* "Paysages quaternaires de l'Afrique centrale atlantique" (R. Lanfranchi and D. Schwartz, Eds.), pp. 31–41, ORSTOM, Paris. [Collection Didactiques]

Reynaud-Farrera, I. (1995). "Histoire des paléoenvironnements forestiers du Sud-Cameroun à partir d'analyses palynologiques et statistiques de dépôts holocènes et actuels." Unpublished thesis, Université Montpellier 2.

Reynaud-Farrera, I. (1997). Late Holocene vegetational changes in South-West Cameroon. *In* "Third Millenium BC Climate Change and Old World Collapse" (H. N. Dalfes *et al.,* Eds.), Vol. 49, pp. 641–652, NATO ASI serie I: Global Environmental Change, Springer-Verlag Berlin.

Reynaud-Farrera, I., Maley, J., and Wirrmann, D. (1996). Végétation et climat dans les forêts du Sud-Cameroun depuis 4770 ans B.P.: analyse pollinique des sédiments du lac Ossa. *Comptes Rendus de l'Académie des Sciences, Paris, série 2a* **322,** 749–755.

Richards, K. (1986). Preliminary results of pollen analysis of a 6000 year core from Mboandong, a crater lake in Cameroon. *In* "The Hull University Cameroon Expedition 1981–1982. Final report" (R. G. E. Baker *et al.,* Eds.), pp. 14–28, Hull University Geography Department, Miscellaneous Series, 30.

Richards, P. W. (1981). "The Tropical Rain Forest. An Ecological Study." Cambridge University Press, Cambridge, UK.

Schwartz, D. (1991). Intérêt de la mesure du δ13C des sols en milieu naturel équatorial pour la connaissance des aspects pédologiques et écologiques des relations savane-forêt. Exemple du Congo. *Cahier de l'ORSTOM, série Pédologie,* **26**(4), 327–341.

Schwartz, D. (1992). Assèchement climatique vers 3000 B.P. et expansion Bantu en Afrique centrale atlantique: quelques réflexions. *Bulletin de la Société géologique de France* **163**(3), 353–361.

Schwartz, D., Mariotti, A., Lanfranchi, R., and Guillet, B. (1986). 13C/12C ratios of soil organic matter as indicators of ecosystem changes in Congo. *Geoderma* **39**(2), 97–103.

Schwartz, D., Lanfranchi, R., and Mariotti, A. (1990). Origine et évolution des savanes intramayombiennes (R. P. du Congo). I. Apports de la pédologie et de la biogéochimie isotopique (14C et 13C). *In* "Paysages quaternaires de l'Afrique centrale atlantique" (R. Lanfranchi and D. Schwartz, Eds.), pp. 314–325, ORSTOM, Paris.

Schwartz, D., Mariotti, A., Trouve, C., Van den Borg, K., and Guillet, B.

(1992). Etude des profils isotopiques 13C et 14C d'un sol ferralitique sableux du littoral congolais. Implications sur la dynamique de la matière organique et l'histoire de la végétation. *Comptes Rendus de l'Académie des Sciences, Paris, série 2* **315,** 1411–1417.

Schwartz, D., Dechamps, R., Elenga, H., Lanfranchi, R., Mariotti, A., and Vincens, A. (1995). "Les savanes du Congo: une végétation spécifique de l'Holocène supérieur." Actes 2° Symposium de Palynologie Africaine, Tervuren, Belgique, Publication occasionnelle CIFEG 1995/31, Orléans, 99–108.

Schwartz, D., Elenga, H., Vincens, A., Bertaux, J., Mariotti, A., Achoundong, G., Alexandre, A., Belingard, C., Girardin, C., Guillet, B., Maley, J., de Namur, C., Reynaud-Farrera, I., and Youta Happi, J. (in press)—Origine et évolution des savanes des marges forestières en Afrique centrale atlantique (Cameroun, Gabon, Congo). Approche aux échelles millénaires et séculaires. Actes du Symposium "Dynamique à long terme des écosystèmes forestiers intertropicaux," Bondy, mars 1996, collection Colloques et Séminaires, ORSTOM ed.

Sitou, L. (1994). "Les cirques d'érosion dans la région de Pointe Noire (Congo): étude géomorphologique." Unpublished thesis, Université Strasbourg.

Sitou, L., Schwartz, D., Mietton, M., and Tchicaya, J. (1996). Histoire et dynamique actuelle des cirques d'érosion du littoral d'Afrique centrale. Une étude de cas: les cirques du littoral ponténégrin (Congo). Symposium "Dynamique à long terme des écosystèmes forestiers intertropicaux," pp. 187–191, CNRS-ORSTOM, Bondy.

Stuiver, M., and Reimer, P. J. (1993). Extended ^{14}C database and revised CALIB radiocarbon calibration program. *Radiocarbon* **35,** 215–230.

Van Neer, W., and Lanfranchi, R. (1986). Une association de faune et d'industrie du Tshitolien (Age récent de la Pierre, 7000 BP) dans l'abri de Ntadi Yomba (région du Niari) en R.P. du Congo. Eléments nouveaux pour un essai de reconstitution du paysage congolais à cette époque. *Comptes Rendus de l'Académie des Sciences, Paris,* **318**(2), 1521–1525.

Vincens, A., Buchet, G., Elenga, H., Fournier, M., Martin, L., de Namur, C., Schwartz, D., Servant, M., and Wirrmann, D. (1994). Changement majeur de la végétation du lac Sinnda (Vallée du Niari, Sud-Congo) consécutif à l'assèchement climatique holocène supérieur: apport de la palynologie. *Comptes Rendus de l'Académie des Sciences, Paris,* **318**(2), 1521–1526.

Vincens, A., Elenga, H., Schwartz, D., de Namur, C., Bertaux, J., Fournier, M., and Dechamps, R. (in press a)—Histoire des écosystèmes forestiers du Sud-Congo depuis 6000 ans. Actes du Symposium "Dynamique à long terme des écosystèmes forestiers intertropicaux," Bondy, mars 1996, collection Colloques et Séminaires, ORSTOM ed.

Vincens, A., Elenga, H., Reynaud-Farrera, I., Schwartz, D., Alexandre, A., Bertaux, J., Mariotti, A., Martin, L., Meunier, J. D., Nguetspo, F., Servant, M., Servant-Vildary, S., and Wirrmann, D. (in press b). Forests response to climate changes in Atlantic Equatorial Africa during the last 4000 years B.P. and inheritance on the modern landscapes. Actes du Symposium "Dynamique à long terme des écosystèmes forestiers intertropicaux," Bondy, 1996, collection Colloques et Séminaires, ORSTOM ed.

White, F. (1983). "The Vegetation of Africa. A Descriptive Memoire to Accompany the UNESCO/AETFAT/UNSO Vegetation Maps of Africa." UNESCO, Paris.