

Lithostratigraphy, volcanism, paleomagnetism and palynology of Quaternary lacustrine deposits from Barombi Mbo (West Cameroon): preliminary results

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Abstract

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We present preliminary results from the study of 23.50-m core from Lake Barombi Mbo, representing the last 25,000 years. The lake is in an explosion crater formed during Quaternary time. The very laminated sediment is composed mostly of clay containing 5–10% organic carbon. Each couplet is commonly composed of a basal lamina rich in quartz, plant debris, muscovite and sponge spicules, and of a more clayey upper lamina often with siderite. A perturbed section near the base of the core, before ca. 21,000 yr B.P., could be the result of a violent release of gas, such CO₂, comparable to the recent Nyos gas eruption.

The paleomagnetic studies exhibit high-frequency oscillations interpreted as paleosecular variations of the local geomagnetic field. This first record obtained on the African continent can be closely compared to the type record obtained in Western Europe.

The pollen results demonstrate the presence of a forest refuge in West Cameroon during the last great arid period, ca. 18,000 yr B.P. When equatorial forest was broken up, elements of montane vegetation spread to the lowlands. These phenomena resulted from a drying and cooling climate.

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Introduction

Sediments, regularly deposited over millenia in the depths of lakes, contain detailed records of physical and biological parameters, corresponding to diverse conditions of the environ-

ment or the biosphere.

The Cameroon Ridge extends from Mount Cameroon to the Adamaoua Plateau (Fig. 1) (Gèze, 1943; Cornacchia and Dars, 1983; Fitton and Dunlop, 1985). On that Ridge volcanic activity began in Cretaceous time and has con-

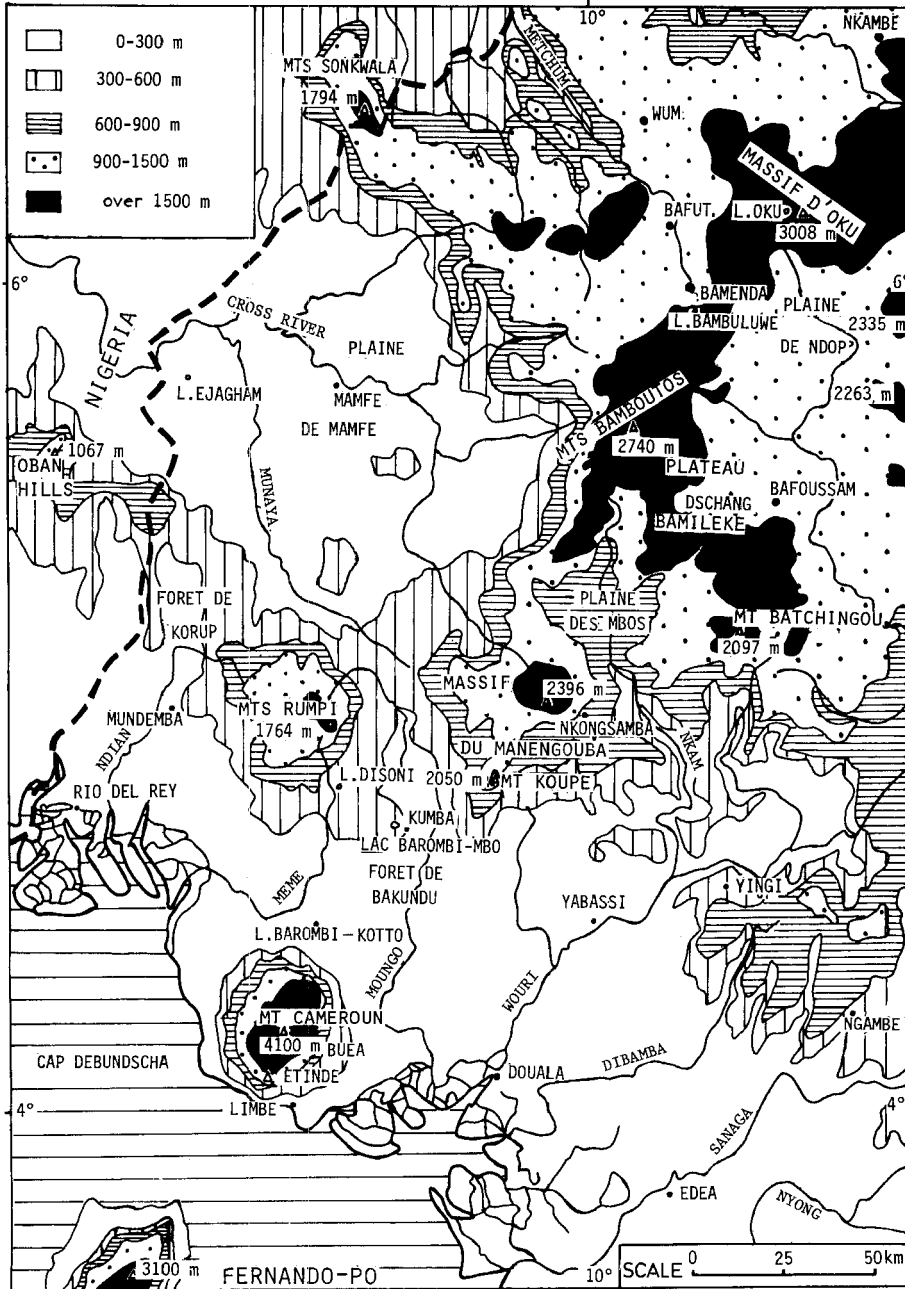


Fig. 1. West Cameroon: sketch map with position of lake Barombi Mbo (from Maley and Brenac, 1987).

tinued until modern times (Dumort, 1968; Gouhier et al., 1974; Morin et al., 1985; Deruelle et al., 1987). The limnology of 35 natural crater lakes is described by Kling (1987, 1988).

The chosen site was Barombi Mbo, situated in the rain forest of West Cameroon (Letouzey, 1968, 1985), near the town of Kumba, about 60 km NNE of Mount Cameroon (Fig. 2). At an altitude of 301 m, the lake occupies an explosion crater, or maar, that cuts into basaltic Upper Black Series and penetrates the subjacent crystalline basement (Dumort, 1968). Two K/Ar dates, ranging from 4.7 to 1.1 Ma were obtained

on a basaltic lava flow which crops out on the northeastern shore of the lake (see appendix). The large difference between these two dates could be related to alteration and particularly to sodium dissolution indicated by a low $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratio (G. Cornen, pers. commun., 1988). In this case, the oldest date, 4.7 ± 0.5 Ma corresponds probably to the less altered sample and is, at the present, the best approximation, meaning that the lake formation may go back to Pliocene time (see Note 1 added in proof).

The catchment area of the lake spreads over about 8 km² on the inside walls of the maar, composed by a tuff ring (cf. Lorenz, 1986), and

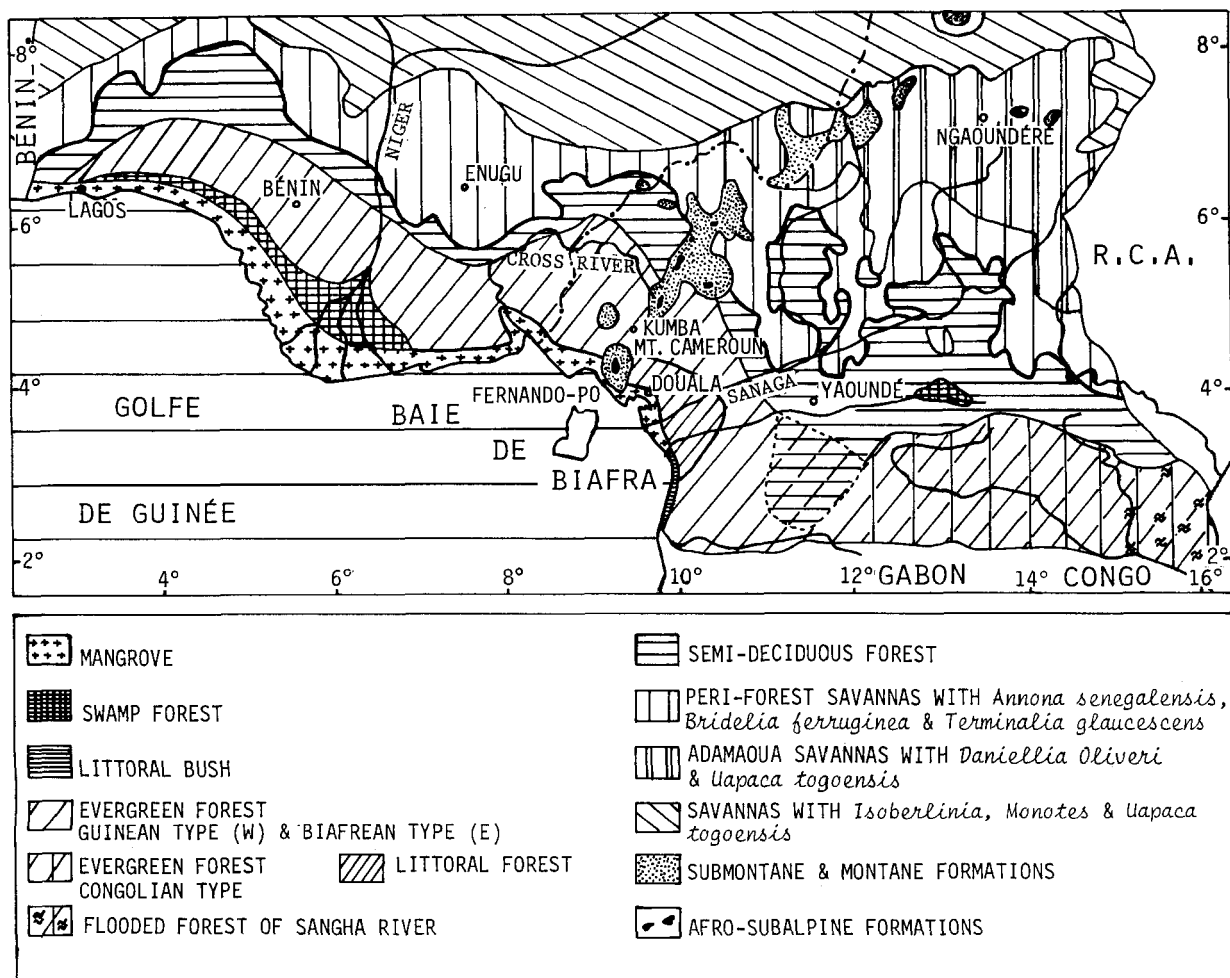


Fig. 2. Schematic map of vegetation along the Bay of Biafra, partly adapted from Letouzey, 1968 (from Maley and Brenac, 1987).

to the west on the floor of a second older maar (Fig. 3). In the western sector of the second crater, Precambrian crystalline rocks crop out. These rocks have an important influence on the sediment deposited in the lake. An outlet stream, which has cut the almost vertical southeast wall of the youngest crater, drains the lake through a very steep-sided gorge.

Coring operations on Barombi Mbo were conducted from a floating platform 6×6 m in size, using a Kullenberg sampler modified by Livingstone for use in lakes. Seven cores were raised in the central zone of the lake. Six of them were taken around point A (BM-1 to BM-6) in about 110 m of water and a seventh (BM-10) at

point D, about 400 m east of point A, in about 100 m of water (Fig. 3). Three other cores (BM-7 to BM-9) were taken near the mouth of the tributary entering the lake from the west, between 60 and 30 m depth (Fig. 3 points B and C). Mainly the preliminary results of the study of the longest core, BM-6, with a length of 23.50 m, are reported in this paper.

Lithostratigraphy

Seismic reflection and gassy zones

Before coring, a preliminary examination of the sediments was made by seismic reflection

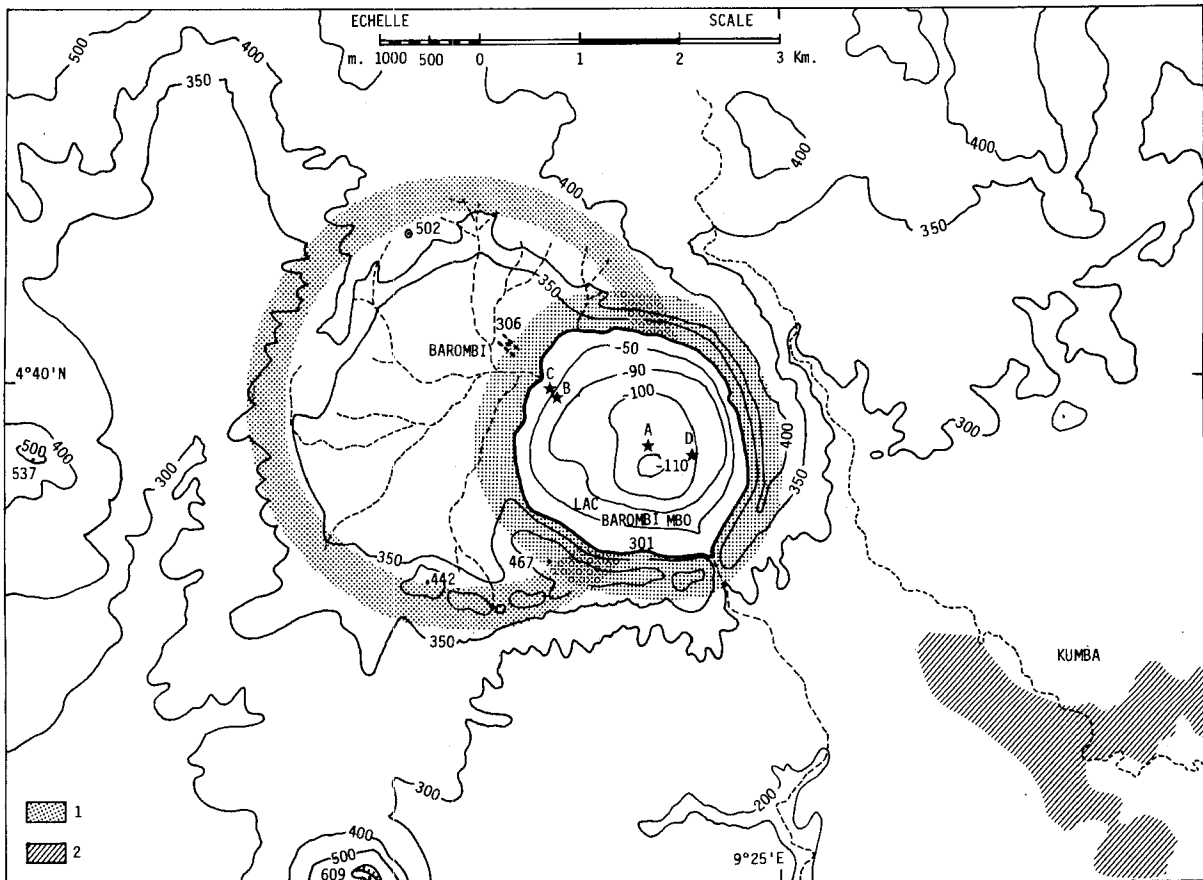


Fig. 3. Topographical map of lake Barombi Mbo area. Adapted from I.G.N. map, Paris (scale 50,000; sheet DOUALA-BUEA 3b/NB 32-IV-3b). 1: ring zone of the two craters. 2: Kumba city area. The altitude of the lake is 301 m above sea level; the black stars A, B, C, D are the four coring spots; the main isobaths are 50, 90, 100, 110 m.

(Kelts et al., 1986). The 3.5-kHz system used has a power of 10 kW and transmits a pulse every 0.5 to 1.0 s (Kelts et al., 1986). This signal normally penetrates 40 m of soft lacustrine sediment (e.g., in the Lake of Zürich), but could not penetrate more than 3–6 m of uniformly layered sediment at Barombi Mbo, except near the foot of the deltaic slope, at the western part of the lake, where a mound appears to be a slump deposit.

When the cores were opened, the sediment frequently contained bubbles of gas, indicating that such bubbles, even under the considerable hydrostatic pressure of the lake, blocked the penetration of the seismic signal. Gassy zones were seen in eight cores:

BM-1, in the uppermost meter and between 3.60 and 3.90-m depth;

BM-4, between 0.50 and 1 m;

BM-5, between 2.90 and 4.30 m;

BM-6, between 2 and 3.60 m;

BM-7, all of the 2.45 m cored;

BM-8, between 2.30 and 3.60 m;

BM-9, between 0.65 and 1.65 m and between 1.80 and about 2.90 m;

BM-10, between 1.80 and 2 m.

By contrast, cores BM-2 and BM-3 contain no gassy zone. The phenomenon is discontinuous with variable thickness. The gas was not sampled but that is expected to take place in the future.

During work in 1987 by an ORSTOM team (Maley et al., 1987), similar gas inclusions were found in other lakes of West Cameroon: in cores about 80 cm long from Lake Bambuluwé (about 11 km SSE of Bamenda) and at lake Nyos (Pourchet et al., 1988, 1990-this issue; Piboule et al., 1990-this issue). By contrast, two short cores (ca. 1 m) raised in 1985 at two different points in Lake Bambuluwé, consisted, for one taken by Kling, of an upper 15–20-cm layer of clastic material overlying darker micaceous mud, and for the other taken by Kelts et al. (1986), of dark, laminated fine sediment without gas. The phenomenon is thus discontinuous even within a single lake.

Principal characters of the sediments

The sediment consists essentially of dark gray clay, rich in organic material (averaging 5–10% of organic carbon) and very strongly laminated through all the section studied (Fig. 4). Very black layers, up to 10 cm thick, alternate with brownish-yellow layers no more than several millimeters thick. This general character is rather similar to that of the Miocene deposits in the lacustrine basin of Anloua (Adamaoua) which have recently been analyzed with respect to their richness in giant crystals of vivianite (Oustrière, 1984).

The couplets are of unequal thickness (1–40 mm) according to the laminae of which they are composed. The commonest and most complete microsequence displays several steps in couplet accumulation (Figs. 5, 6):

(1) The basal lamina, brown to black, is rich in micaceous particles visible to the naked eye, plant detritus that is sometimes rather coarse (wood, leaves), and in sponge spicules or, more rarely, diatom frustules. This lamina can be as much as 5 cm thick and indicates maximal deposition of detritus.

(2) The upper unit is composed of gray to bluish clay which becomes green towards the top of the unit where there are yellow crystals of siderite and sometimes traces of rhodochrosite (Fig. 7). The siderite is usually in the form of little prisms of several microns which determine the color and end each of the microsequences; often the lamina contains a yellow layer of siderite concretions of millimeter scale.

The accumulation of the basal lamina corresponds to a maximum in allochthony of the sedimented particles, indicating a paroxysm of mineral and organic sedimentation. In contrast, the upper lamina corresponds to calmer conditions in the catchment, with settling of essentially clayey fine particles from suspension. Development of the uppermost concretions of siderite expresses a slowing of the pace of sedimentation and a concentration of carbonate at the sediment–water interface, two conditions favorable to mineralogenesis.

The principal mineral components

Sand particles with a diameter less than 50 μm constitute 2–8% of the sediment.

Episodically, and especially in the lower part of the core, one can see grains of quartz which are markers of allochthonous phases. Higher sand contents correspond either to concentrations of



Fig. 4. Barombi Mbo. Stratigraphic log of core BM-6 raised from the lake center.

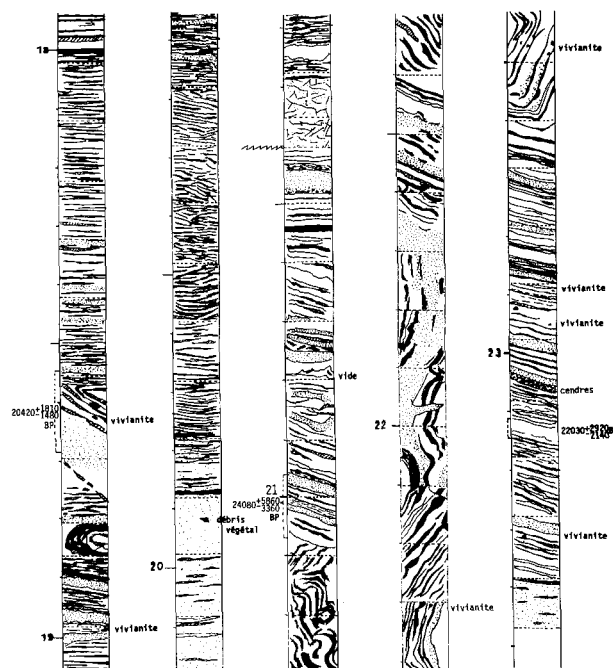


Fig. 4. (continued). Bas of core BM-6.

authigenic siderite or to deposits of volcanic ash (see below).

The clay minerals consist of kaolinite and calcium or magnesium montmorillonite. The kaolinite seems to be generally more abundant in the more detritic levels, but also in the beds of Holocene age.

Siderite is in the form either of rather large automorphic crystals of some dozens of microns or, more frequently, in the form of very small prismatic crystals (2–5 μm).

Vivianite appears sometimes in the form of small crystals on the millimeter scale which are associated, most often, with the upper sideritic laminae.

Perturbed section at the base of the core

The base of the core, below 21 m (see Note 2 added in proof), is formed by a large perturbed section with a date of ca. 29,000 yr B.P. near the top (date obtained after the drawing of Fig. 4). Note that the sediment from 18.30 m (ca. 20,500 yr B.P.) to the base belongs to the same

pollen zone, Zone I (Fig. 10). During coring operations, by taking several small cores 1 m long, we discovered that the laminated sediments are present only in the central zone below about 90 m deep. From this fact, because the sediments of the displaced section are *laminated and fine*, similar to those from the central zone, they cannot be turbidites or slumpings coming from the deltaic slope where the sediments are *unlaminated and very much coarser*. The cause of the displacement could be due to a distant turbidite pushing the sediment, but because none of the seven cores raised in the central zone has intercalations of coarse sediments, another explanation is necessary. As hypothesis, because Barombi Mbo is located in a maar, this perturbed section could also be due to some volcanic explosions related, for example, to violent release of gas, such CO_2 , which happens sometimes in maars (cf. Chivas et al., 1987) (about CO_2 in Cameroon lakes see also Sigurdsson, 1987; Sigurdsson et al., 1987; Kling et al., 1987; Pourchet et al., 1988, 1990-this issue; Piboule et al., 1990-this issue, and several other papers, in this issue).

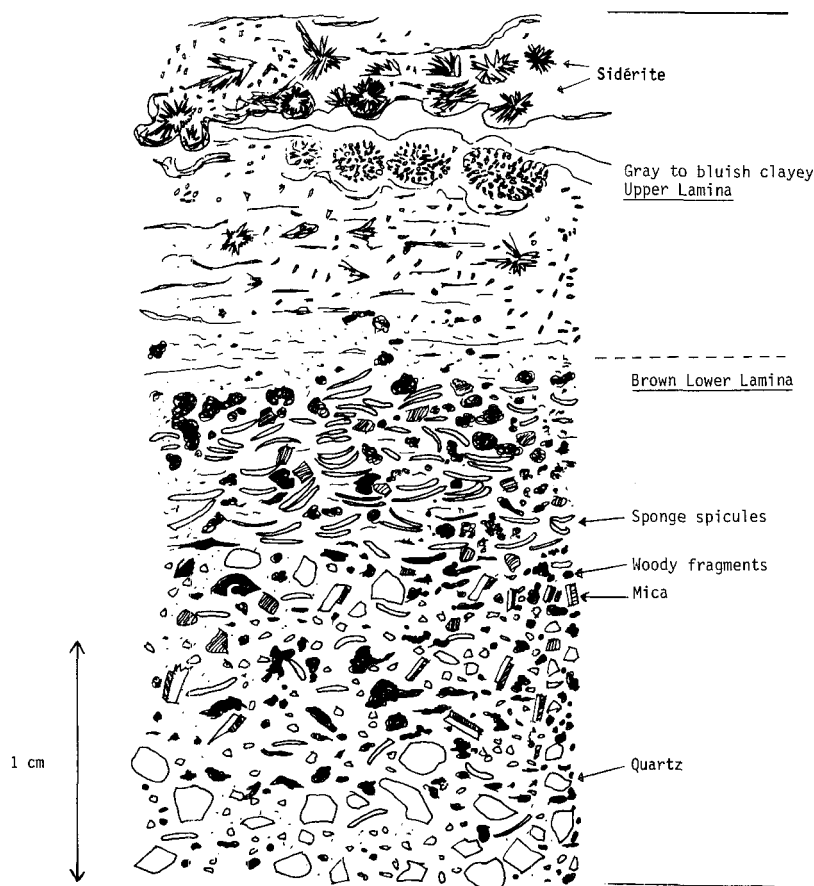


Fig. 5. Barombi Mbo. Core BM-6. Typical microsequence with a coarse lower lamina and a more clayey upper lamina with neoformation of siderite.

Regional volcanism

A certain number of ash beds on a millimeter to centimeter scale are seen between 11.5 m and 18 m (Fig. 4), related to a phase of regional volcanism which is thus dated between about 10,000 and 18,000 yr B.P. Petrographic examinations of ashes and basaltic scoria sampled in one of the about 80 perfectly preserved volcanic cones which are found between 20 and 30 km to the east of the lake, in the region of Tombel and of Loum, exhibit similar compositions (G. Cornen, pers. commun., 1988). These recent vents have covered the region with basaltic ash, lapilli and scoria (Dumort, 1968).

Radiochronology and sediment accumulation rate (Fig. 8)

Seven radiocarbon dates have been obtained so far from core BM-6 based on total carbon and one based on organic carbon only (dating by Fournier). This organic carbon date (9.95 m: 8480 (+440/-420) yr B.P.) is similar to a total carbon date, quite on the same point of the section (10 m: 8850 (+500/-470) yr B.P.). This result means that the precipitation of carbonates was quasi synsedimentary.

All the dating results are presented in Figures 4 and 8. One can note that for the Upper Pleistocene and Lower Holocene, the ac-

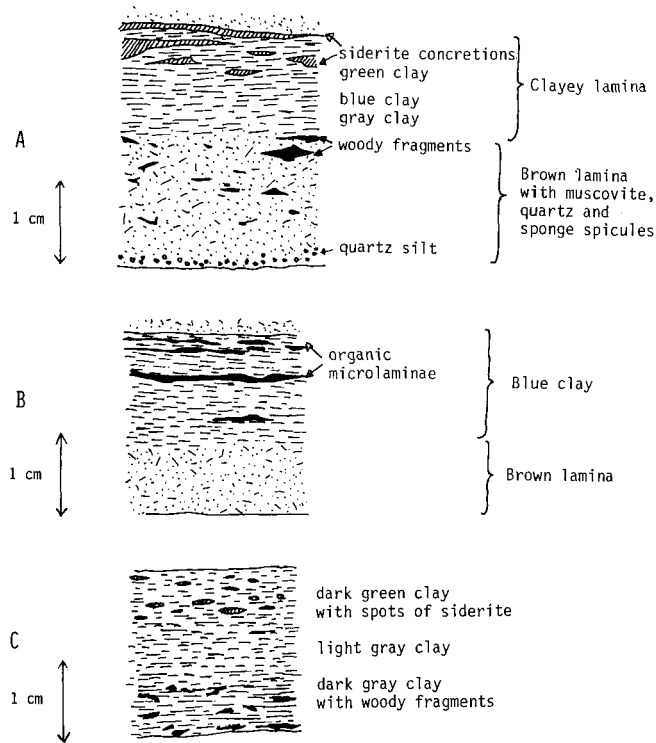


Fig. 6. Barombi Mbo. Core BM-6. Three types of microsequence. (A) . The lower lamina is coarse and rich in organic matter and the upper lamina is with neoformation of siderite. This microsequence is frequent during the relatively dry phase (cf. Zone IIb, Fig. 10). (B). Intermediary type of microsequence: reduction of the coarse lamina and upper lamina without siderite. The neoformation was probably impeded by the beginning of a new microsequence. (C). Microsequence with only one clayey lamina: typical of Holocene time.

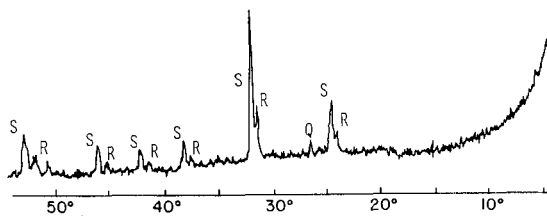


Fig. 7. Barombi Mbo. X-Ray diffraction analysis on a carbonate microlamina (core BM-7). The spikes are identified as the minerals Siderite (S), Rhodochrosite (R), and Quartz (Q).

cumulation rate was 66 cm per 1000 years at Lake Bosumtwi, situated at a neighboring latitude in the rain forests of Ghana (Talbot et al., 1984) and for Barombi Mbo ca. 72 cm per 1000 years (between ca. 24,080 and 8850 yr B.P. on BM-6). But an important difference

must be noted between these two lakes: at Bosumtwi the laminae are approximately one per radiocarbon year (counting by Livingstone), whereas at Barombi Mbo the average time is between 6 and 20 radiocarbon years for one lamina (cf. Maley, 1988; Giresse et al., in prep.).

The resumption of erosion dated between 12,000 and 11,000 yr B.P. in some large equatorial basins, such as the Congo-Zaire basin (Giresse et al., 1982), is not recorded in Barombi Mbo, maybe because the forest cover remained important there (see below).

Paleomagnetism

The progress recently made in magnetostratigraphic research led to the description of (geologically) high-frequency oscillations, call-

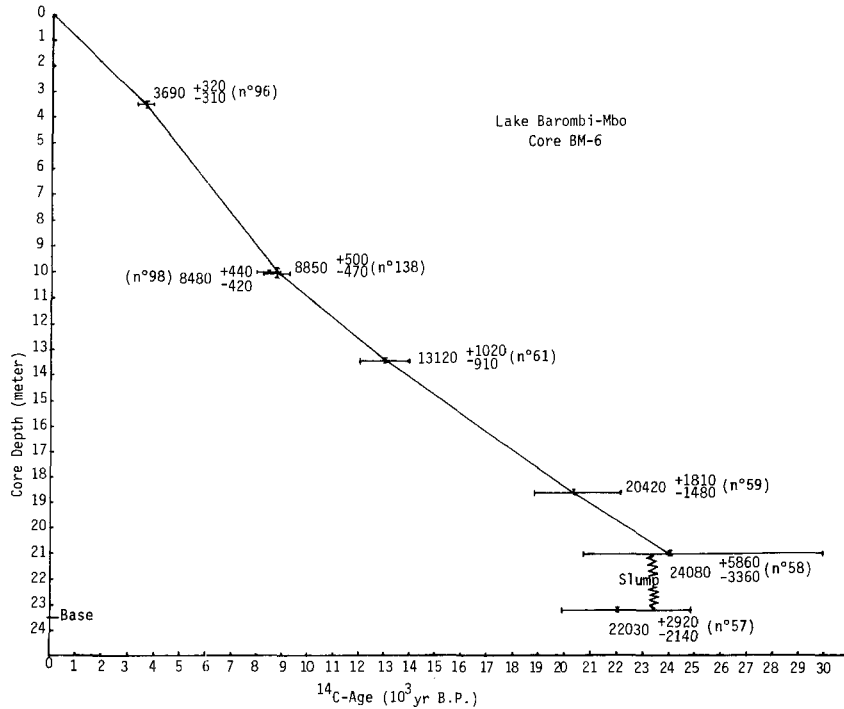


Fig. 8. Barombi Mbo. Sediment-age-depth relationship for core BM-6. For each radiocarbon date vertical bars represent the section of the core submitted for analysis; horizontal bars represent the standard deviations. The Laboratory number (BONDY) is printed by each date. The calculated sediment accumulation rates are ca. $65 \text{ cm } 10^{-3} \text{ yr}$ between 21 and 18.6 m; ca. $71 \text{ cm } 10^{-3} \text{ yr}$ between 18.6 and 13.4 m; ca. $79 \text{ cm } 10^{-3} \text{ yr}$ between 13.4 m and 10 m; ca. $127 \text{ cm}/1000 \text{ yrs}$ between 10 and 3.45 m; ca. $93 \text{ cm } 10^{-3} \text{ yr}$ between 3.45 m and top.

ed *secular variations* of the local geomagnetic field. These variations in declination and inclination provide an efficient tool for tele-correlation and chronology of Holocene and Upper Pleistocene profiles, when the sedimentation rates range between 10 cm and 1 m per 1000 years.

For the study of paleomagnetism, the BM-6 core was sampled from 4 m deep to the base with cubic plastic boxes (8 cm^3) pushed in the sediment and separated by intervals of 2–3 cm. The upper part of lacustrine sediments was sampled in the same way on BM-2, from 0 to 5 m deep. This short core was taken close to BM-6, near point A (see above). Before any treatment, the remanent magnetization of all samples (about 750) was measured on a DIGICO fluxgate spinner magnetometer. This preliminary measure showed that the magnetiza-

tion directions, resulting from depositional and postdepositional processes, have a good coherence and have reliably recorded the geomagnetic signal. The complete results are presented and discussed in Thouveny and Williamson (1988).

Twenty samples were submitted to stepwise alternating field treatments from 5 to 80 mT. Analyses of orthogonal demagnetization diagrams and intensity diagrams (J/J_0) show that the natural remanent magnetization (NRM), after the removal of a small viscous component (step of 10 or 15 mT), is reduced to a very stable component.

This profile of secular variations, one of the first obtained for the African continent (cf. Tiercelin et al., 1987), has been compared to the type curve of secular variations during Holocene time and the Late Pleistocene

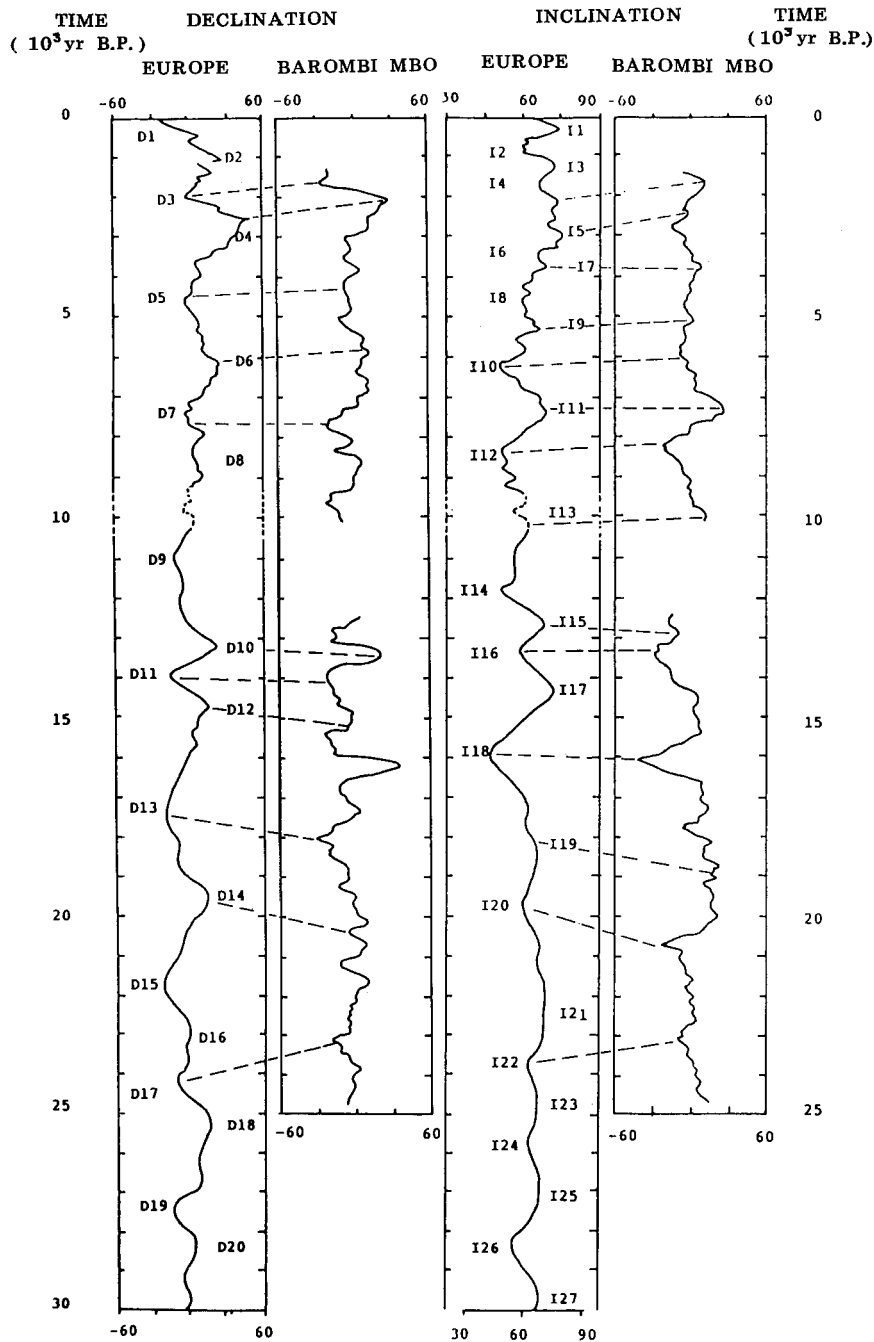


Fig. 9. Paleomagnetic records and numbering of secular variations spikes: Declination (*D*) and Inclination (*I*). Comparison of the Barombi Mbo record (core BM-6 and, for the last 4 millenia, BM-2) with the "European record" on the interval ca. 1000 to 25,000 years BP. Each record is presented on its own and original radiocarbon time scale. The "European record" is composed before 10,000 years BP by the Lac du Bouchet mean curve and for Holocene time by the U.K. type curve (cf. Turner and Thompson, 1981; Smith and Creer, 1986; Thouveny and Williamson, 1987).

reconstructed from several sites in western Europe (Great Britain: Turner and Thompson, 1981; Creer and Tucholka, 1983; France, Lac du Bouchet: Thouveny, 1983; Thouveny et al., 1985; Creer et al., 1986). These sites are on a longitude close to that of Barombi Mbo. This comparison (Fig. 9) exhibits a similarity in the form and frequency of spikes between the inclination and declination curves defined in the two regions. One can easily see that the characteristic succession of inclination spikes I15–I20, considered as a good marker over Western Europe (Thouveny et al., 1985), is present in Barombi Mbo between 12,000 and 20,000 yr B.P. Thus, the inclination and declination spikes in Barombi Mbo were numbered according to these curves. However, some spikes do not occur exactly at the same time on the two records. Considering that neither the absolute value, nor the sign of these shiftings are constant and their extent is lower than the standard deviation of radiocarbon dates, it could be possible that the shiftings might be linked to errors associated with dating procedures.

Two important points are to be underlined:

(1) The periodicities most frequently encountered (time spans between two successive spikes) are equivalent to those observed in Europe (Smith and Creer, 1986), i.e. they vary around 1400 and 2300 years for inclination and around 2000 years for declination.

(2) The rotation of the virtual geomagnetic pole (VGP) is with a clockwise dominance (ca. 60% clockwise rotation). So it could seem that the dynamics of non-dipolar field sources are dominated by a westward drift.

In conclusion, if this remarkable similarity between these two records at the same longitude is confirmed by the study of other cores from this lake and other of this region, we will be able to show that the influence area of non-dipolar field sources can spread over a large latitudinal belt. This would imply that the validity area for a type curve of secular variations would be latitudinally very large,

like here between about 50°N to 4°N (Thouveny and Williamson, 1988). The comparison of these paleomagnetic curves from Barombi Mbo (declination and inclination) with type-paleomagnetic curves recorded in Western Europe, shows that the radiocarbon dates obtained *in situ* are quite close with the ages deduced from paleomagnetic tele-correlations (Figs. 8 and 9).

Palynology and paleoclimatology

Palynology

Only the lower half of core BM-6, from the base to about 12 m (ca. 11,000 years BP), has been analyzed in some detail so far (Fig. 10). From the upper part of the lacustrine sediments, some samples at 2- or 3-m intervals have also been studied (Maley and Brenac, 1987).

The pollen spectra of the lower half of core BM-6 was subdivided into several pollen zones (Brenac, 1988):

Zone I, from ca. 24,000 to 20,000 yr B.P., is characterized by an evergreen forest formation, rich in Euphorbiaceae and Caesalpinaceae, to which is associated a montane element characterized by *Olea hoschstetteri*. Pollen of this tropical mountain olive tree comprises between 20 and 30% of the total in this zone. At this time the climate was very wet but cooler than the present. Today in Cameroon, such vegetation exists in cloud forest (Letouzey, 1985; Brenac, 1988).

Zone II, extending from 20,000 to ca. 14,000 yr B.P., is characterized by a lowering of arboreal taxa and an increase of pollen grains of Gramineae, Cyperaceae and shoreline plants. The montane element was also present at this time, but with lower percentages, between 5 and 15%. These data suggest a drier climate leading to the lowering of the lake level and also to some opening of the forested environment.

Zone III, after 14,000 yr B.P., is characterized

by a new extension of forest environment and a more humid climate. For the Holocene section of the sediments, the samples analyzed so far show the dominance of forest vegetations of semi-deciduous or sempervirent types.

Paleoclimatology

Two principal conclusions are deduced from the pollen analyses:

- (1) Large remains of rain forest persisted in

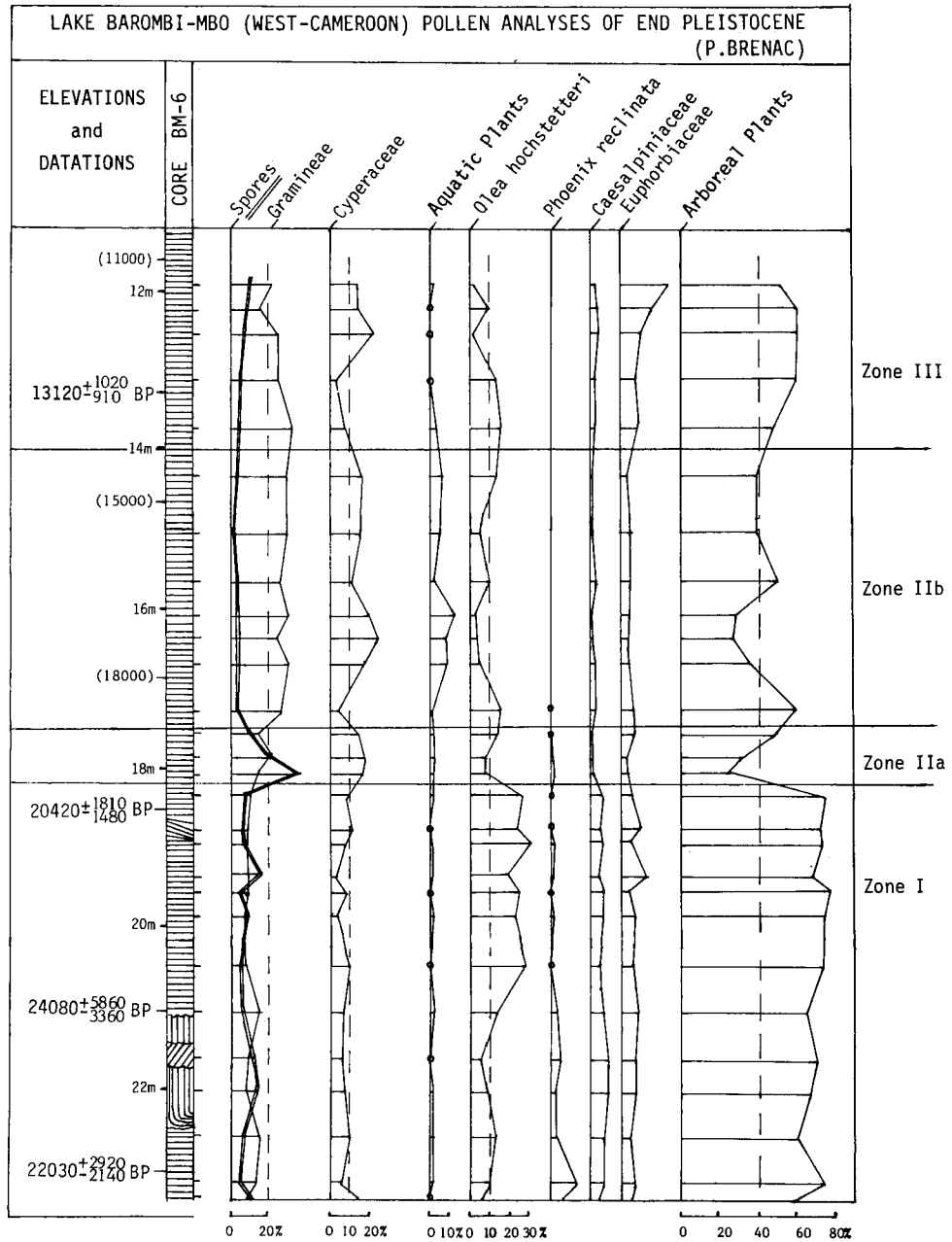


Fig. 10. Barombi Mbo. Pollen analyses of the lower part of core BM-6 (from 23.5 m to 11 m), with the variations of major taxa and the pollen Zones. Below 21 m a perturbed section interrupts the continuity of the record (from Brenac, 1988).

West Cameroon during the last great arid phase (ca. 20,000 to 15,000 yr B.P.), whereas pollen and geologic data from other parts of equatorial Africa (Maley, 1987, 1989), such as, for example, from lake Bosumtwi in Ghana (Talbot et al., 1984; Maley, 1987, 1989) show that the forest fragmented and disappeared in many places. The data of Barombi Mbo, on the one hand confirm the previous hypothesis formulated by some biogeographers (cf. Maley, 1987, 1989) that a forest refuge existed in West Cameroon during arid phases, and on the other hand give a chronological framework to this phenomenon. All these data, associated with many presentday biogeographic maps and data, concerning particularly the areas of great richness in taxa and endemics, permit the construction of a schematic map of forest refuges (Fig. 11).

(2) Montane vegetation spread to the lowlands at the time of the rain forest fragmentation, indicating a cooling of probably similar value to that deduced with pollen data for Bosumtwi in Ghana, i.e. at least 3° – 4° C

(Maley and Livingstone, 1983; Maley, 1987, 1989).

Conclusions

The preliminary results presented here show the very laminated nature of the Barombi Mbo Upper Quaternary sediments which are rich in clay, organic matter and frequently with neoformations of siderite or rhodochrosite concretions. The core studied contains several fine-ash beds between ca. 10,000 and 18,000 yr B.P., related to regional volcanic activity. A perturbed section could be the result of a violent release of gas. The paleomagnetic record obtained in Barombi Mbo led to the description of well-defined declination and inclination oscillations, attributed to paleosecular variations of the local geomagnetic field. The comparison of the successive inclination peaks can be individually identified with those found in Western Europe, in spite of small chronological discrepancies. The pollen analyses can prove the presence of a forest refuge in West

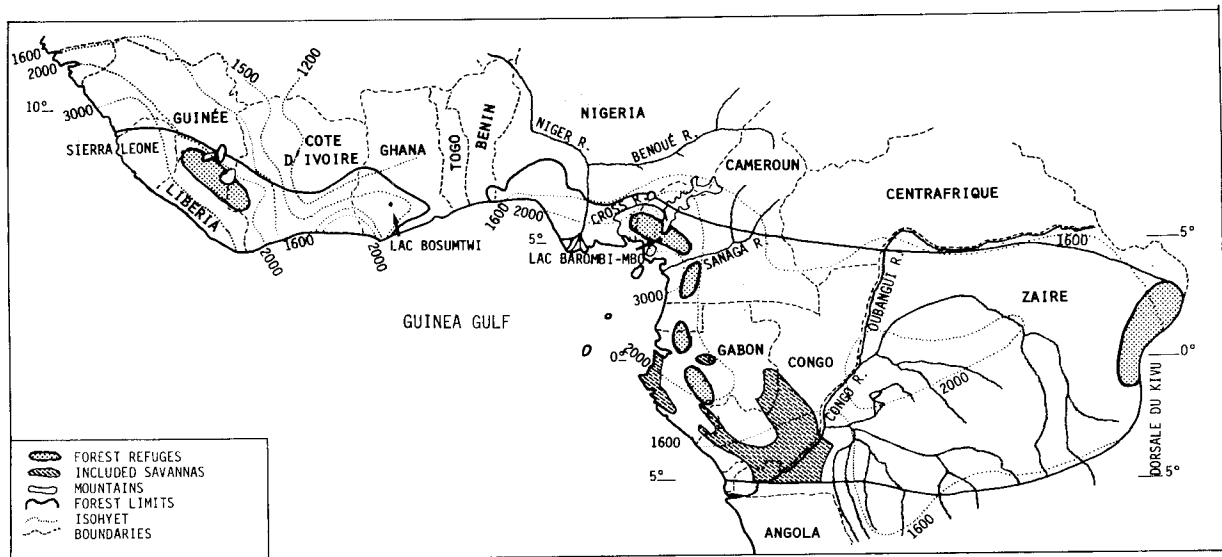


Fig. 11. Schematic map with refuges of lowland rain forests during the last great arid phase (ca. 20,000 to 15,000 yr B.P.) (adapted from Maley, 1987). The present-day conditions (included savannas, forest limits and isohyets) are adapted from White (1983).

Cameroon during the last great arid and cool period (ca. 18,000 yr B.P.), coupled with the spreading to lowland of montane vegetation.

Appendix

Potassium argon analysis (Y. Bandet)

Potassium measurement of sample no. 1. The potassium content of this sample was measured by atomic absorption spectroscopy (Centre de Recherches Pétrographiques et Géo-chimiques de Nancy). The coefficient of variation was 1.8% for duplicate analysis.

Argon measurement of sample no. 1. Sample was run as whole rock. Argon analysis was done by isotope dilution technique, with an ^{38}Ar tracer. The spectrometer is an A.E.I Ms 20 used in static mode. Ionic currents are measured with a CARY 401 vibrating reed electrometer. The tracer calibration is done by reference to the USGS LP6 B10 biotite (sample 11-II-C4) whose radiogenic argon is fixed at $1.93000 \text{ E-9 mol g}^{-1}$.

The potassium decay constants are those recommended by the 25th International Geological Congress (Steiger and Jager, 1977). Estimate of conventional age precision was calculated with the Cox and Dalrymple formula (Cox and Dalrymple, 1967).

Weight	% K ₂ O	$^{40}\text{Ar}/^{40}\text{Ar}_t$	Conv. age	$\pm \sigma$
<i>Barombi basalt no. 1</i>				
0.8090	1.61	0.0400	1.16	0.40
0.8175	1.61	0.0700	1.10	0.20
<i>Barombi basalt no. 2</i>				
?	0.49	0.0770	4.50	0.50
?	0.49	0.0470	4.90	0.50

Sample no. 1 was collected by Maley and measured by Bandet (Toulouse) and no. 2 was collected by Kling on the same outcrop and measured by Krueger Enterprises Inc. (Cambridge, U.S.A.).

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Notes added in proof (June 1990):

(1) Two more K/Ar dates were obtained by Y. Bandet on the Barombi basalt: $1.0 \pm 0.3 \text{ Ma}$ and $1.1 \pm 0.4 \text{ Ma}$ (see Introduction and Appendix). These new results and also the construc-

tion of an isochrone diagram oblige to reject the oldest date (4.7 ± 0.5 Ma) in favor of an age close to 1 Ma (Cornen et al., in prep.).

(2) Several new radiocarbon dates obtained for the lower part of the core show that the discontinuity close to 21 m, just above the perturbed section (dated ca. 29,000 yr B.P. near the top), is dated ca. 21,000 yr B.P. (Giresse et al., in prep.).

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