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West Cameroon Quaternary lacustrine deposits: preliminary results

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Abstract - We present preliminary results from the study of a 23.50 m core (BM-6) representing the last 25 000 years. The core was collected in Barombi Mbo, an explosion crater lake formed probably during the Quaternary. The finely laminated sediment are composed mostly of dark brown to green clay rich organic matter (5-10% organic carbon). Each couplet is commonly composed of a lower unit rich in quartz, plant debris, muscovite and sponge spicules, and of a more clayey upper unit often with siderite ($FeCO_3$) crystals. The average periodicity for one couplet is between 6 and 20 radiocarbon years.

The pollen results, which are compared with those of another forested site in Ghana, demonstrate the presence of a forest refuge in West Cameroon during the last major arid period, about 18 000 years BP. At the same time that equatorial forest was broken up, elements of montain vegetation descended to the lowlands. To provide an explanation for these phenomena marked by a drying and cooling of the climate, modern examples of extensions of montain biotopes to low altitude are described. These localized extensions are due to the persistence of cloud cover, often of stratiform type, generated over the relatively cold water of ocean upwellings. Such lowering of sea-surface temperature might be the primary regional cause of the changes of climate and vegetation that occurred in humid tropical Africa. The upwelling, presently synchronous throughout the Guinea Gulf, amplify the trade winds, which could account for the observed changes inland.

Résumé - On présente les résultats préliminaires de l'étude d'une carotte de 23,50 m (BM-6) représentant les derniers 25 000 ans. La carotte a été collectée dans le Barombi Mbo, un cratère d'explosion formé probablement durant le Quaternaire. Les sédiments finement laminés sont composés principalement d'argile brun sombre à vert, riche en matière organique (5-10% de carbone organique). Chaque micro-séquence est généralement composée d'une unité de base riche en quartz, débris de plantes, muscovite et spicules d'éponge, et d'une unité supérieure plus argileuse avec souvent des cristaux de sidérite ($FeCO_3$). La périodicité moyenne de chaque micro-séquence est de 6 à 20 années radiocarbone.

Les résultats polliniques, qui sont comparés avec ceux d'un autre site forestier au Ghana, démontrent la présence d'un refuge forestier dans l'Ouest Cameroun durant la dernière période aride majeure, il y a environ 18 000 ans. En même temps que la forêt équatoriale se fragmentait, des éléments de végétation montagnarde descendaient à basse altitude. Afin de fournir une explication de ces phénomènes caractérisés par un assèchement et un refroidissement du climat, des exemples actuels d'extensions de biotopes montagnards à basse altitude sont décrits. Ces extensions localisées sont dûes à la persistance de couvertures nuageuses, souvent de type stratiforme, qui se forment au-dessus des remontées d'eaux froides océaniques (upwellings). De tels abaissements des températures de surface pourraient être la cause première régionale des changements de climat et de végétation survenus en Afrique tropicale humide. Les upwellings, actuellement synchrones à travers l'ensemble du Golfe de Guinée, amplifient l'action des alizés qui pourrait ainsi rendre compte des changements observés sur le continent africain.

INTRODUCTION

Research on Quaternary deposits, particularly lacustrine, is developing today in many regions. Putting past phenomena in perspective permits better understanding of the modern climate, and also of certain exceptional events of climatic, volcanic or limnologic nature.

There are many lakes of volcanic origin on the Cameroonian Highland, extending from Mount

Cameroon to the Adamaoua Plateau (Fig. 1) (Geze, 1943; Cornacchia and Dars, 1983; Fitton and Dunlop, 1985). The limnology of most of these lakes is described by Kling (1988). The volcanic activity has continued from the Upper Cretaceous until modern times for Mount Cameroon (Dumort, 1968; Gouhier *et al.*, 1974; Morin *et al.*, 1985; Deruelle *et al.*, 1987).

The chosen site was lake Barombi Mbo which is situated in the zone of the Rain Forests of West Cameroon (Letouzey, 1968, 1985), near the town of Kumba, about 60 km NNE of Mount Cameroon. With a water level at an altitude of 301 m, the lake is about 2 km in diameter and has a maximum depth of 110 m. The lake occupies an explosion crater, or maar (Lorenz, 1986), cut into the basaltic **Upper Black Series** and penetrating the subjacent crystalline basement (Dumort, 1968). Five K/Ar age determinations have been obtained from a basaltic lava flow situated on the north eastern shore of the lake. Four dates are bracketed between 1.0 and 1.16 M.a. yr with a sigma maximum of 0.4 M.a. yr, and another 4.7 ± 0.07 M.a. yr and thus oblige to reject the oldest date (Cornen, in prep.).

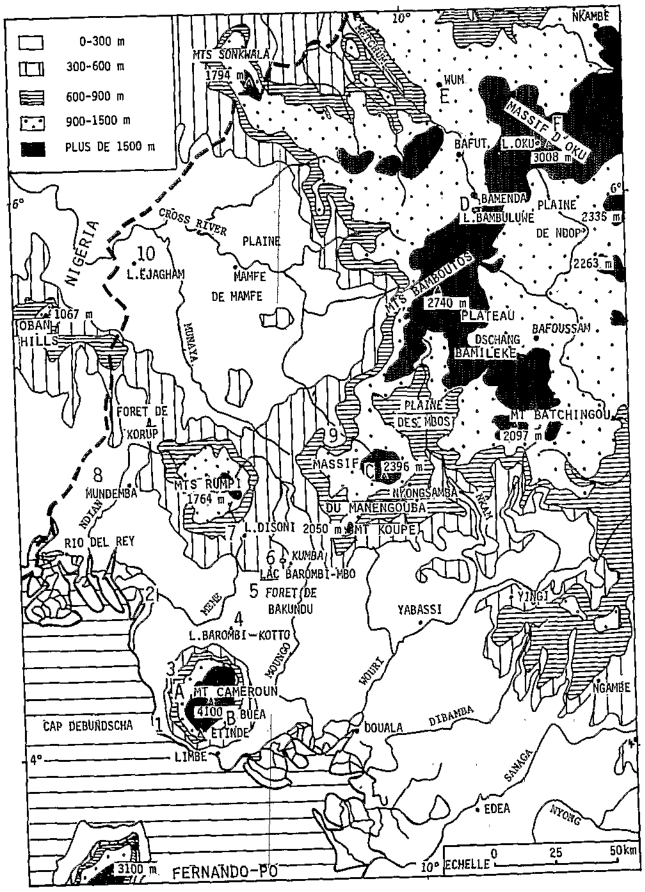

Fig. 1. West Cameroon : sketch map with position of Lake Barombi Mbo (from Maley et Brenac, 1987).
Fig. 1. L'Ouest Cameroun : croquis topographique avec la position du lac Barombi Mbo (extrait de Maley et Brenac, 1987).

LITHOSTRATIGRAPHY

Seven cores were raised from the central zone of the lake under about 110 m of water, using a Kullenberg sampler modified by D. A. Livingstone for use in lakes. For this paper, attention is mainly confined to the longest core, BM-6 (23.50 m).

Principal sedimentary characteristics

The sediment consists essentially of very well laminated dark gray clay, rich in organic material (averaging 5-10% organic carbon) (Fig. 2). Very dark levels, up to 10 cm thick, alternate with brownish-yellow levels no more than several millimeters thick. The couplets are of unequal thickness (1 mm to 4 cm), dependent upon the laminae of which they are composed. The commonest and most complete micro-sequence displays several steps in couplet accumulation (Figs. 3 and 4):

- the basal lamina, brown to black in colour, is rich in micaceous particles visible to the naked eye, plant detritus that is sometimes rather coarse (wood, leaves), and sponge spicules or, more rarely, diatom frustules. This lamina can be as much as 5 cm thick and indicates deposition of mainly detritus.
- the upper lamina is composed of gray to bluish clay which becomes green toward the top of the unit where there are yellow cristals of siderite and sometimes rhodochrosite. The siderite is usually in the form of prisms several microns across, and which determine the color at the top of each of the microsequences; often the lamina contains a yellow layer of siderite concretions of millimeter scale.

The accumulation of the basal lamina corresponds mostly to allochtonous deposition, indicating a maximum of mineral and organic sedimentation. The upper lamina corresponds to calmer conditions in the catchment area, because during this period sedimentation was dominated by the settling of essentially clay-size particles from suspension. Development of the siderite concretions occurred only during a slowing of the pace of sedimentation, because prolonging the time of reaction at the sediment-water interface is favorable to minerogenesis.

Perturbed section to the base of the core (Fig. 2)

Below 21 m (ca. 21 000 years BP) the base of the core presents a perturbed section. The present-day available dates show that this section could be reversed beginning near 21 m. The displaced sediments were deposited originally in the central zone of the lake. Indeed, because these sediments are fine, similar to those from the central zone, they cannot be turbidites or slumpings coming from the deltaic slope where the sediments are very much

Fig. 2. Stratigrafic log of BM6 core taken in the center of the lake Barombi Mbo.
Fig. 2. Log stratigraphique de la carotte BM6 prélevée au centre du lac Barombi Mbo.

coarser. A cause of the displacement could be due to a distant turbidite pushing the sediment, but this argument is weakened because none of the seven cores raised in the central zone has intercalations of coarse sediments. For this reason the best explanation could be some volcanic

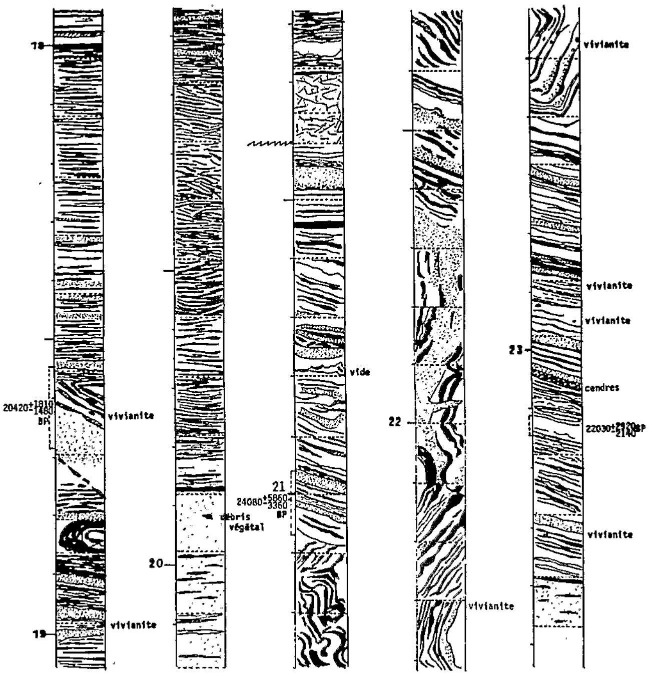

Fig. 2(continued). Stratigrafic log of BM6 core taken in the center of the lake Barombi Mbo.
Fig. 2(Suite). Log stratigraphique de la carotte BM6 prélevée au centre du lac Barombi Mbo.

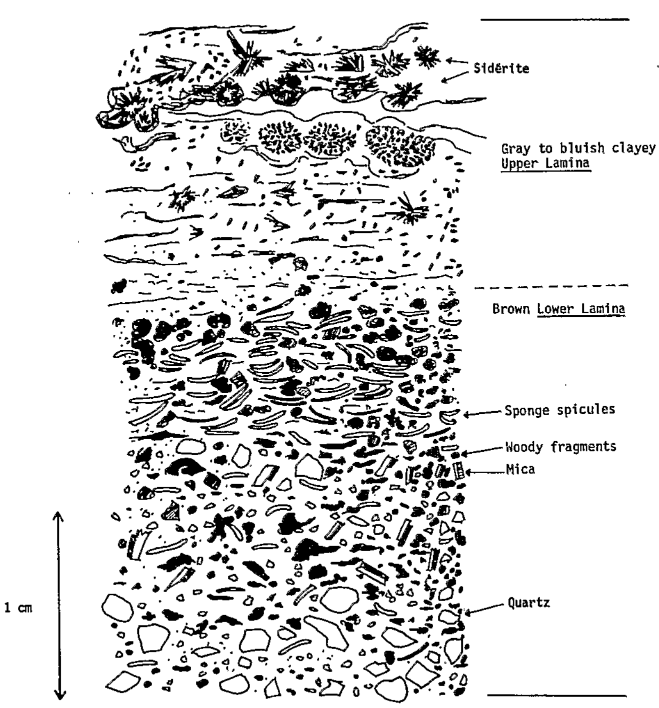

Fig. 3. Core BM6 - Typical microsequence with a coarse lamina below and a more clayey upper lamina with neoformation of siderite.
Fig. 3. Carotte BM6 : Microséquence type avec à la base une lamine grossière et vers le haut une lamine plus argileuse avec néoformation de sidérite.

explosions related, for example, to violent release of gas CO_2, which happens sometimes in maars (Chivas *et al.*, 1987)(about violent release of CO_2

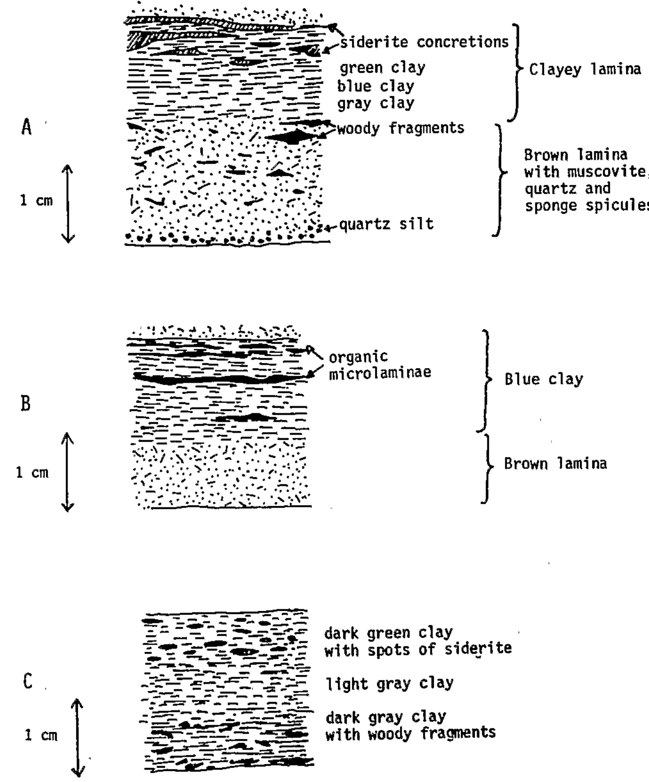

Fig. 4. Core BM6: **Three types of microsequence.**
A- The lower lamina is coarse and rich in organic matter and the upper lamina is with neoformation of siderite. This microsequence is frequent during the relatively dry phase (cf. Zone IIb, Fig. 6). B- Intermediary type of microsequence: reduction of 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. 4. Carotte BM6 : **Trois types de microséquences.**
A- La lamine inférieure est grossière et riche en matière organique et la lamine supérieure comporte des néoformations de sidérite. Cette microséquence est fréquente durant les phases relativement arides (cf. Zone IIb, Fig. 6). B- Micro-séquence de type intermédiaire : réduction de la lamine grossière et lamine supérieure sans sidérite. La néoformation a été probablement bloquée par le commencement d'une nouvelle microséquence. C- Microséquence avec seulement une lamine argileuse : typique de l'Holocène.

in some Cameroon lakes - Monoun, Nyos, etc -cf. Sigurdsson *et al.*, 1987; Kling *et al.*, 1987; Sigurdsson, 1987; Piboule *et al.*, this issue; Pourchet *et al.*, 1988). The top part of the Barombi Mbo sediment contains frequently bubbles of gas; the sampling of this gas is expected in the future. The composition and origin of this gas (magmatic or sedimentary) will probably bring important data for this discussion.

Principal mineral components

Sand particles with a diameter less than 50 micrometers constitute 2 to 8% of the sediment. Episodically and especially in the lower part of the core, one can see grains of quartz which are markers of allochtonous phases. Higher sand contents correspond either to concentrations of authigenic siderite or to deposits of volcanic ash.

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 and rhodochrosite are in the form either of rather large automorphic crystals of some dozens of microns across or, more frequently, in the form of very small prismatic crystals (2-5 micrometers). Vivianite appears in the form of millimiter scale crystals which are associated most often with the upper sideritic laminae.

RADIOCHRONOLOGY, SPEED OF SEDIMENTATION AND PALEOMAGNETISM

When this paper was writed, seven radiocarbon dates, based on total carbon and one on organic carbon only, have been obtained on the BM-6 core (age determinations by M. Fournier) (Fig. 5). The date on organic carbon was performed on the same section (10 m: 8850 +500, -470 yrs BP) as one of the total carbon determination (9.95 m: 8480 +440, -420 yrs BP). This result means that the

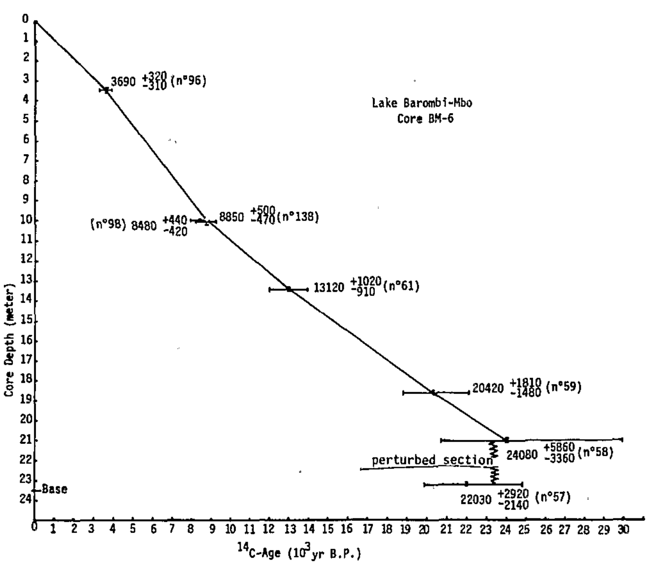

Fig. 5. Sediment age depth relationship for core BM6. For each radiocarbon date vertical bars represent the section of the core submitted for analysis; horizontal bars represent the standard deviations. The Laboratory numbers (Bondy) are printed by each date. The calculated sediment accumulation rates are ca. 65 cm/1000 years between 21 and 18.6 m; ca. 71 cm/1000 years between 18.6 and 13.4 m; ca. 79 cm/1000 years between 13.4 and 10 m; ca. 127 cm/1000 years between 10 and 3.45 m; ca. 93 cm/1000 years between 3.45 m and the top.

Fig. 5. Relation entre la profondeur et l'âge du sédiment pour la carotte BM6. Pour chaque datation au radiocarbone les barres verticales représentent la section utilisée : les barres horizontales représentent les déviations standards. La numérotation du Laboratoire de Bondy est donnée près de chaque date. Le calcul des vitesses moyennes de sédimentation donne ca. 65 cm/1000 ans entre 21 et 18, 6 m; ca. 71 cm/1000 ans entre 18,6 et 13,4 m; ca. 79 cm/1000 ans entre 13,4 et 10 m; ca. 127 cm/1000 ans entre 10 et 3,45 m; ca. 93 cm/1000 ans entre 3,45 m et le sommet.

precipitation of carbonates was quasi-synsedimentary.

For the upper Pleistocene and until early Holocene, it is interesting to note that at lake Bosumtwi, situated at a similar latitude in the Rain Forest of Ghana, the rate of sedimentation was 66 cm/1000 yrs (Talbot *et al.*, 1984) and for Barombi Mbo the rate was 72.2 cm/1000 yrs (between ca. 24 080 and 8850 yrs BP on BM-6). But an important difference must be noted between Bosumtwi and Barombi Mbo: 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.

Paleomagnetic studies have led to the description of well defined declination and inclination oscillations which can be attributed to palaeosecular variations of the local geomagnetic field (Thouveny *et al.*, 1987). The comparison of the successive inclination peaks can be individually identified with those found in Western Europe, in spite of small chronological discrepancies (Thouveny and Williamson, 1988).

PALYNOLOGY

Only the lower half of core BM-6, from the base to about 11 000 yrs BP, has been studied in detail so far (wenn the paper was writed) and 28 samples spaced every 30 or 60 cm have been analyzed (Fig. 6). Samples at 2 or 3 m intervals have also been studied from the upper part of the core (Maley and Brenac, 1987).

The following principal results are to be noted:

- From the base of the core, with an age of more than 24 000 yrs BP to a level with an age of about 20 000 yrs BP, pollen of Gramineae, Cyperaceae and shoreline plants are scarce (Gramineae is between 6 and 15%). Among the arboreal pollen, the montane Olive *Olea hochstetteri* is relatively abundant with percentages between 10 and 30%. *Phoenix reclinata* (Palmae), which is often associated today with *Olea hochstetteri* in the Cameroon Highlands (Letouzey, 1978), is also relatively frequent in this section. Besides these two montane taxa, pollen of forest taxa are abundant with percentages between 60 and 75%. Among these, Caesalpiniaceae and Euphorbiaceae are particularly well represented. Importance of Caesalpiniaceae is a major characteristic of evergreen forest.
- Around 20 000 yrs BP a very sharp change occurs in the pollen spectra. Montane olive pollen decreases to between 5 and 15%. Forest taxa decrease as well, particularly Caesalpiniaceae and Euphorbiaceae. Percentages of arboreal pollen oscillate around 40% until 14000 yrs BP.

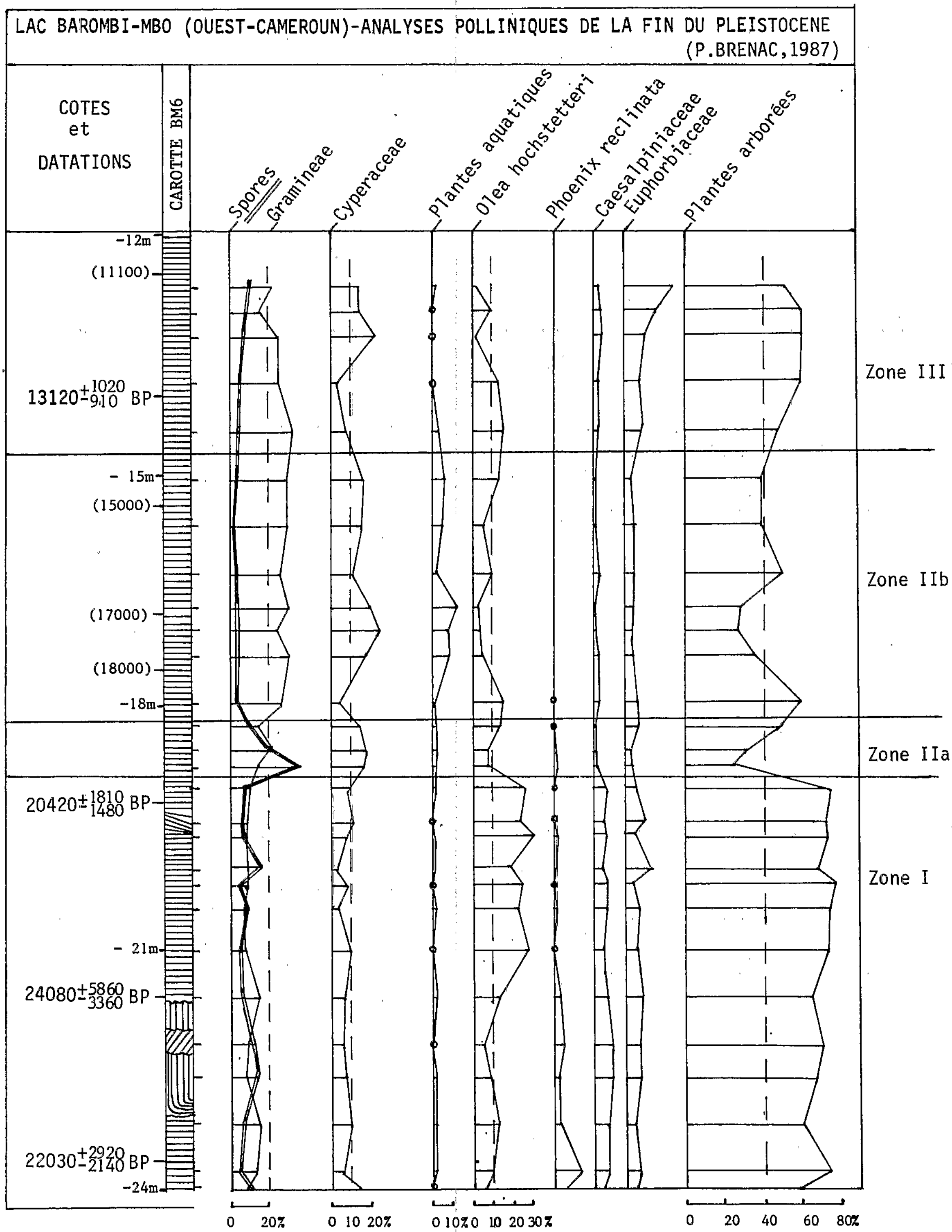

Fig. 6. Pollen analysis of the lower part of core BM6 (from 23.5 to 11 m); variations of major taxa (analysis by P. Brenac). Below 21 m a perturbed section interrupts the continuity of pollen spectra: this section seems to be reversed.

Fig. 6. Analyses polliniques de la partie inférieure de la carotte BM6 (de 23,5 m à 11 m); variations des taxons majeurs (analyses de P. Brenac). En-dessous de 21 m une section perturbée interrompt la continuité des spectres polliniques : cette section semble être renversée.

During the same period, grass pollen increases to 25%, as do the Cyperaceae and aquatic plants.

- Between about 14 000 and 10 000 yrs BP the forest taxa increase again, with percentages close to 60%. Among the tree taxa, some representatives of the semi-deciduous forest, such as *Celtis*, replace those of the evergreen forest present before 20 000 yrs BP. One notes also several pioneer forest taxa. At the same time the pollen of Gramineae decrease to about 20% around the beginning of the Holocene. During this phase montane olive pollen rises once more, especially around 13 000 yr BP.

- Between 10 000 yrs BP and today, the few data so far available (Maley and Brenac, 1987) suggest a relatively stable vegetation dominated by semi-deciduous forest accompanied by many pioneer forest taxa.

In conclusion, until 10 000 yrs BP three principal stages in the vegetation and climate can be recognized:

- Between 24 000 and 20 000 yrs BP, a cool and humid climate. The association between some montane taxa and a typical lowland evergreen forest flora, is found today in Cameroon, for example, on the hill summits around Yaoundé (between 900 and 1200 m)(Achoundong, 1985). On the lowlands around these hills, the forest is semi-deciduous, but on hill summits, because of the greater frequency of cloud cover, the climate is more humid and cool, favoring this particular association, which is, in fact, a **cloud forest.**
- Between 20 000 and 14 000 yrs BP, a relatively dry and cool climate. The increase of Cyperaceae and shoreline plants is probably an indication of low water level, reflecting a decrease in rainfall. This increase in herbaceous plants, however, was not enough to indicate the disappearance of forest, as was the case in the region of lake Bosumtwi, Ghana, where, during the same epoch, the percentage of grass and sedge pollen attained values from 91 to 94% (Maley, 1986, 1987) comparable to modern spectra from the Sahel (cf. Maley, 1981). Islets of forest, therefore, remained around Barombi Mbo, accompanied by a sharp increase in more open formations.
- After 14 000 yrs BP the climate became more humid again, but not as cool as before 20 000 yrs BP.

PALEOBIOGEOGRAPHY

The Forest Refuges (Fig.7)

The pollen data presented here are particularly important because they show that during the last great arid phase, the rain forest disappeared in Ghana, particularly around lake Bosumtwi, but persisted in West Cameroon.

For several decades various biogeographers have poured over this question. Based on the floristic richness of the different sectors of the African forest block, Aubreville first in 1949, then in 1962, presented a scheme of possible forest refuges during arid phases, insisting already on the importance of refuges in the Cameroon - Gabon sector. Next Richards (1963) presented several details for the Cameroon sector. This botanist, studying the vegetation of the Bakundu Forest

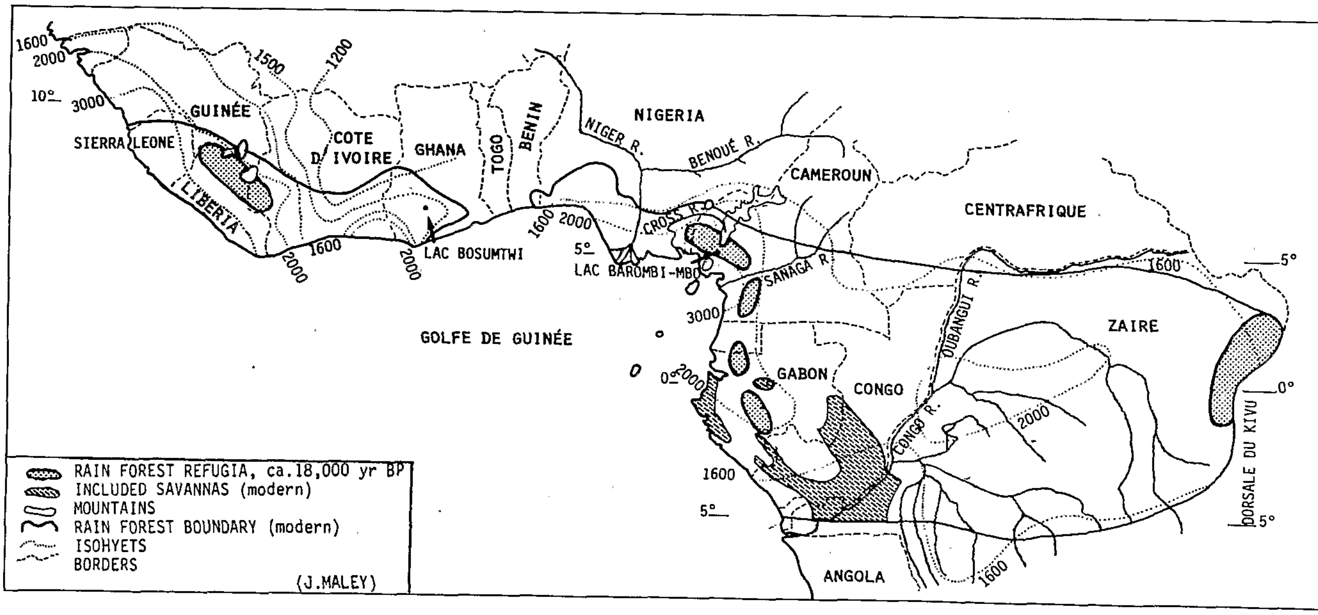

Fig. 7. Schematic map with **Refuges of lowland Rain Forests** during the last great arid phase (ca. 20 000 to 15 000 years BP) (from Maley, 1987). **The present day conditions**: (adapted from White, 1983, Fig. 5).
- **Included savannas** (Savanes incluses) (principal areas) in the present day general forest border,
- **Forest border** (Limite de la Forêt), Isohyets (Isohyètes), Mountains (Montagnes), **Boundaries** between States (Frontières).

Fig. 7. Schéma **des Refuges de Forêts Denses planitiaires** durant la dernière grande phase aride (ca. 20 000 à 15 000 ans BP) (extrait de Maley, 1987). **Les conditions actuelles** (savanes incluses, limite de la forêt et isohyètes) sont adaptées de White (1983, Fig. 5).

Reserve near Barombi Mbo, noted that its flora "is floristically richer than any other African rain forest for which comparable figures are available" (ibid.). Considering this floristic richness to be a proof of the relatively great age of this forest, Richards (ibid.) concluded that it "could be explained by assuming that they were a refuge area in which a rainforest flora survived during an episode of arid climate". Studies carried out further west in Cameroon in the primary forest of Korup, situated near the Nigerian border, demonstrated also a very great floristic (Gartlan *et al.*, 1986; Thomas, 1986) and faunistic (Gartlan, 1986) richness. Similarly these authors have shown the necessity for refuges during dry periods.

The question of forest refuges has been the subject of intense discussions and criticisms. Interesting examples are a paper by Endler (1982) who refuted the forest refuge hypothesis, and, in response, an article by Mayr and O'hara(1986), in which they discard Endler's arguments. In fact, all the authors point out that pollen analysis could bring important data to prove or reject the forest refuges. The pollen data obtained in Ghana and West Cameroon are now strong arguments in favor of these Pleistocene forest refuges.

These palynologic and floristic conclusions have been associated with various biogeographic data obtained on birds, mamals, amphibians, butterflies, etc., from Cameroon and other parts of the forested zone, as well as paleoclimatic data, in order to establish a new schematic map of forest refuges over equatorial Africa during the last great dry period (Fig. 7) (see Maley, 1987 for a more detailed discussion).

Lowland extension of montane biotopes

Among the pollen data presented above, one may note that at the same time that the forest disappeared or fragmented, montane taxa extended to the lowlands (Maley and Livingstone, 1983; Maley, 1987, 1989). This result could be understood by comparison with the modern composition of the African montane flora and fauna of middle altitudes (about 1000 to 3000 m). In fact, a great similarity has often been noted between the different mountains of equatorial Africa. For example, the plant species common to Mount Cameroon and eastern Africa are, according to Hall (1973), 53% for the montane forest and 49% for the montane prairie. One could say that today the montane biotopes exist as refuges isolated in the surrounding lowland biotopes.

In order to explain these similarities, many authors have supposed that during climatic changes and especially during cooler periods of the Quaternary, the montane faunas and floras must have extended to the lowlands and thus migrated between mountain massifs (Moreau, 1966; White, 1981; Maley, 1987, 1989).

PALEOCLIMATOLOGY: THE CLIMATIC ROLE OF OCEAN UPWELLING

In Africa today there exist some very limited regions where montane biotopes extend to low altitudes. For example, on the Atlantic coast of Africa, the hills of Freetown, Sierra Leone, rise abruptly from the sea to an altitude of about 900 m. Above 500 m they support a set of montane plants such as *Olea hochstetteri* (Morton, 1968; Maley, 1987). Farther east, on the south seaward flank of Mount Cameroon, typically montane trees (Thomas, 1985) and birds (Serle, 1964) appear above 500 m. Farther south, on the Angolan Escarpment which rises above the sea to the level of the Plateau above 1000 m, the presence of cloud forest from 200 or 300 m ASL implies that montane conditions appear already at this low altitude (Airy-Shaw, 1947; White and Werger, 1978). All these facts show that we are dealing with a non-fortuitous ecological phenomenon which extends to low altitudes the climatic conditions normally found on mountains above 1000 to 1500 m.

Most authors who have considered this phenomenon have attributed it to persistence of cloud cover and fog which are particularly frequent on slopes facing the sea (Moreau, 1966; Serle, 1964; Grubb and Whitmore, 1966; Grubb, 1971). The Angolan Escarpment is a particularly important model because it shows how the abundance of cloud cover depends directly on the low clouds coming from the sea where the cold Benguela current flows. Hoflich (1972) has shown how this current produces a thick mantle of stratiform clouds which have a great influence on the climate of the neighbouring continent by reducing the rainfall and lowering the temperature there (see also Hastenrath, 1984).

Reconstruction of ocean temperatures from assemblages of Foraminifera and Radiolaria shows that at about 18 000 yrs BP the equatorial upwelling in the Gulf of Guinea, with practically no change in their position, were very intense in summer since the temperature of the surface water was 4 to 8°C lower than today (Fig. 8) (Prell *et al.*, 1976; Morley and Hays, 1979; Mix *et al.*, 1986). Further, Prell *et al.* (ibid.) have shown that during the boreal winter (February), which is the season of warmest water, the water temperature was again 3°C colder than it is today. From this fact it seems that the upwelling of cold water should have lasted almost all year long, and produced on the neighboring continent, through the intermediary of stratiform clouds, a lowering of

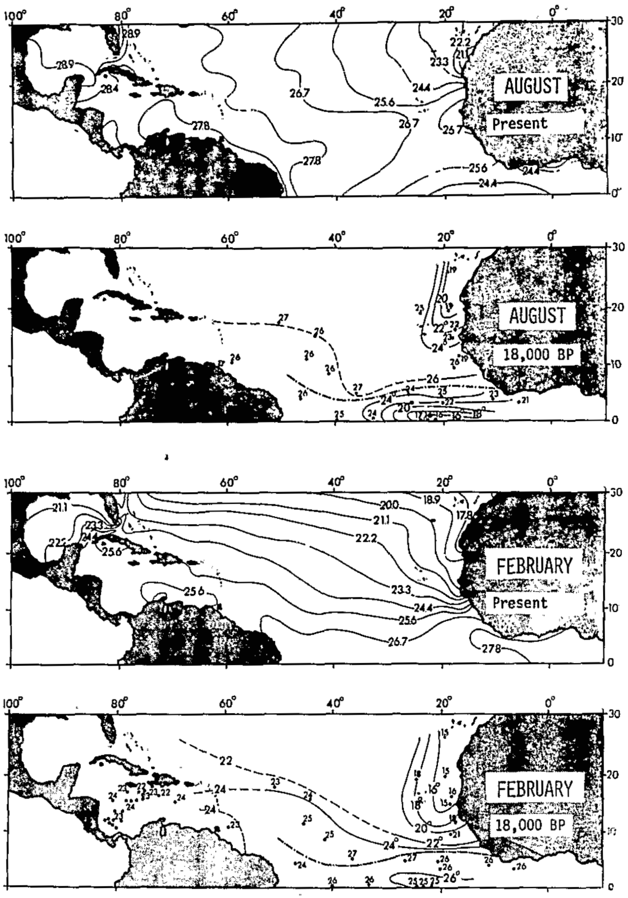

Fig. 8. Sea surface temperature estimates according to Foraminifera assemblages ca. 18 000 years BP for August and February (from Prell *et al.*, 1976, in *Geological Soc. of America Memoir*, 145, Figs. 11 and 12).

Fig. 8. Estimations des températures de surface de la mer effectuées à partir d'assemblages de Foraminifères pour la période ca. 18 000 ans BP en Août et Février (extrait de Prell *et al.*, 1976, in *Geological Soc. of America Memoir*, 145, Figs. 11 et 12).

temperature as well as a strong decrease in rainfall. One important point to be considered is that, today, throughout the Guinea Gulf, the interannual variations of the sea surface temperatures are synchronous (Merle, 1980). This fact implies that during the coldest phases of Quaternary, all the waters in the Guinea Gulf affected today by the upwelling were relatively very cold. So the phenomenon must have had a reinforced impact on the African continent. In conclusion, the synchroneity of the upwelling which amplifies the trade winds action (cf. Flohn, 1982), could have had a great part of responsability in the climatic and biogeographic changes of tropical Africa (for more detailed discussions see Maley, 1987, 1989).

CONCLUSIONS

The results presented here are preliminary. They show the finely laminated character of the lacustrine sediments, which are particularly rich in clay and organic matter. The upper part of each couplet presents frequently accumulations of siderite crystals. The average time of each couplet is between 6 and 20 radiocarbon years.

The pollen results show the presence of forest refuges in West Cameroon during the last great arid phase (ca. 18 000 yrs BP) at a time when most of the equatorial forest disappeared. In the same time montane biotopes spread to lowlands. The variations of sea surface temperatures in the Guinea Gulf, related mainly to the generation of upwelling, played a great role in these climatic and biogeographic changes.

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