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# The Late Holocene palaeoenvironment in the Lake Njupi area, west Cameroon: implications regarding the history of Lake Nyos

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**Abstract**—Lake Njupi, 1 km east of Lake Nyos, on the Cameroon Volcanic Line, was formed by the damming of a local crustal depression. Two cores from Lake Nyos were analysed which penetrated sediments at the margin of the lake. The older deposits give an age of 3400 years BP and this date is proposed as a minimum age for Lake Njupi. Sedimentological, palynological and geochemical studies of a 2 m section provide an opportunity to reconstruct the Late Holocene environmental history. It is an organic-rich deposit (organic carbon up to 30%) with an abundant Silicospongia spicules fraction. An obvious sedimentary homogeneity is interrupted by 5 fine to coarse layers with sandy quartz and lignitic remains. Such inputs were denoted by carbohydrate maxima or sometimes by phenolic compounds. This study confirms the evidence of an arid period culminating between 2500 and 2000 yrs BP. This crisis began around 3000 yrs BP in the rain forest area of West Cameroon and also further to the south in Congo. Lake Njupi, situated today in a mostly grassland savanna environment known as the "Grass Fields", provides evidence for environmental changes from a mosaic of forest and savanna before 2500 years BP to a savanna characterised by high grass pollen contents (75 to 85%), with small islands of forest. The mountain vegetation characterised by *Podocarpus* and *Olea capensis* retreated around 2300 years BP at the time *Elaeis guineensis* (the Oil Palm) began its extension as a pioneer tree, later providing opportunities for its domestication by man. © *1997 Elsevier Science Limited.*

**Résumé**—Le lac Njupi, au sein de la ligne volcanique du Cameroun, s'est constitué par barrage d'une dépression à 1 km à l'Est du lac Nyos. Les deux sondages du lac Nyos analysés ont traversé les sédiments déposés aux marges du lac. Les dépôts les plus anciens sont datés à 3400 BP, cet âge est proposé comme un minimum pour l'apparition du lac Njupi. Des études sédimentologiques, palynologiques et géochimiques d'une coupe de 2 m permettent de reconstituer l'histoire fini-holocène de cet environnement. Il s'agit d'un dépôt tourbeux (plus de 30% de carbone organique) avec une importante fraction de spicules siliceux de Spongiaires. La sédimentation a été relativement régulière, entrecoupée seulement durant les 800 ans du dépôt, de cinq lamines plus grossières caractérisées par des grains de quartz et de gros débris ligneux. Ces flux sont soulignés par des concentrations de carbohydrates ou parfois par des composés phénoliques bien conservés. Cette étude confirme et précise l'existence d'une phase aride qui s'intensifie ici entre 2500 et 2000 ans BP. Cette crise climatique qui a débuté vers 3000 ans BP est ,en fait, très générale dans l'Afrique Centrale Atlantique (sud Cameroun). Le lac Njupi, situé aujourd'hui dans un paysage essentiellement composé de savanes d'où sa dénomination de " Grass Fields", permet d'observer avant 2500 ans BP un paysage mixte de forêt et savane en mosaïque, puis son évolution vers une savane avec quelques îlots forestiers, couvert défini alors par 75 à 85% de pollens herbacés. La végétation montagnarde, caractérisée par *Podocarpus* et *Olea capensis* , régresse vers 2300 ans BP, au moment où *Elaeis guineensis* (le Palmier à Huile) initie son expansion, d'abord comme un arbre pionnier, offrant ainsi ultérieurement à l'Homme l'opportunité de sa culture. 

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## INTRODUCTION

Lake Monoun and Lake Nyos were both the sites of a catastrophic gas ($CO_2$) out burst in August 1984 and August 1986. The second of these events caused the death of about 1700 people in the Northwest Province of Cameroon (Morin and Pahai, 1986; Freeth, 1990, 1992). These are unique examples of when a sudden and voluminous gas release has been observed and documented. But scientific controversy continues on the exact process of such catastrophes. Three possibles sources for the released gas are volcanic, plutonic or biogenic. If the last one was ruled out by the $\delta^{13}C$, helium and $^{14}C$ isotope data (Kling *et al.*, 1987), there was still a debate between the volcanic hypothesis with high-temperature gas linked to an eruptive process (Tazieff, 1989; Barberi *et al.*, 1989) and the plutonic hypothesis, with relatively cool gas released from a magma chamber below the earth's surface (Kling *et al.*, 1987). More recently, Freeth (1992) specified that most of the carbon dioxide had been released from within the lake, but that winds from the northeast caused the southern migration of the cold surface water and thus disturbed the lake's stratification. Surficial circulation possibly caused gas-rich water to rise. A recent model (Zhang, 1996) improved the knowledge of the cause of this massive release of carbon dioxide. The mathematical model of an eruption fountain requires that the pressure profile inside the rising conduit must be near the hydrostatic gradient in the surrounding water column. For a proposed maximum $CO_2$ concentration in the bottom water of 0.43 mol $kg^{-1}$, fountain heights in excess of 150 m could be reached (Evans, 1996).

At the time of writing, this discussion should include other problems. For example, the gas content of the bottom water has increased in both lakes, due to a slow recharge in $CO_2$ at depth; and the pyroclastic dam impounding the Lake Nyos waters may collapse (Freeth, 1988). Within this framework, the shallow Lake Njupi, 1 km east of Lake Nyos would be able to provide a sedimentary testimony on the recent geological history of the evolution of the Lake Nyos crater. It is thus felt that the same geological mechanisms which formed the Nyos maar were also involved in forming Lake Njupi.

This paper is a contribution to the knowledge of the Late Holocene palaeoenvironment changes. In contrast to the Barombi-Mbo area (Giresse *et al.*, 1994), where the present vegetation is dominated by evergreen forest and patches of semi-deciduous forest, the Nyos-Njupi area is mainly covered by savanna. In the present study, the temporary dry phase at around 2500-2000 yrs BP can be documented by the palynological record together with organic matter analysis on 2 m drill core sections collected on the shore and on the island of Lake Njupi.

## GEOLOGICAL BACKGROUND

The study area is located on the "Cameroon Volcanic Line", a large fracture zone marked by a chain of alkaline volcanoes which runs from Annobon Island in the Atlantic Ocean, up to the area of the Oku Mountains in the Northwestern Province of Cameroon and beyond. The higher volcanic activity along the Cameroon Line dates back to about 30 Ma (Fitton, 1980), but evidence of very recent activity can be observed along the whole line.

The Nyos maar formed in the Precambrian basement and consists of a granitic intrusion with associated migmatites and orthogneiss (Peronne, 1969). Granitic rocks (coarse-grained quartz monzonite) crop out over a large part of the surrounding area. Lake Njupi corresponds to a shallow depression in a field of young alkali basalt cinder cones, flows and maars. Thus Lake Njupi is not a crater lake, although its formation was related to local volcanic activity which induced a stream blockage, either by the Njupi cone and flows (Zogning, 1986, 1991; Lockwood and Rubin, 1989) or by a landslide debris flow from the northeast flank of the Nyos maar (Fig. 1).

The Nyos maar was preceded by a brief period of extrusion of basalt, which is exposed along the north and northeast shores of the lake. After

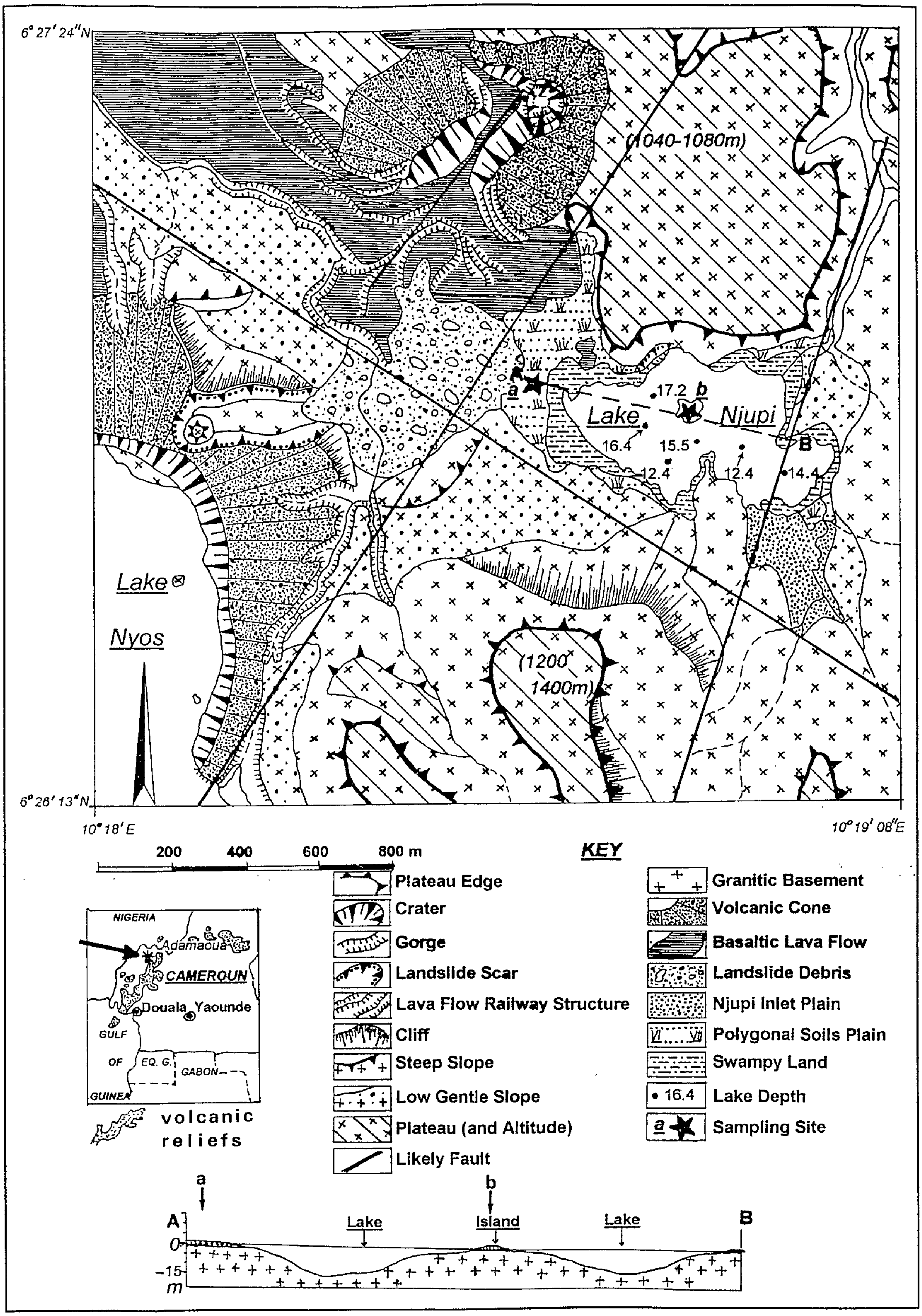



*Figure 1. Study area showing geomorphological environments, location of sections 'a' and 'b' and the A-B topographic profile of Lake Njupi. Some depth records are indicated on the Lake Njupi area.*

this first phase, the violence of the explosive activity increased and the initial explosion crater gradually widened. Lockwood *et al.* (1988) suggested that the Nyos maar is the youngest volcanic feature in the immediate area and obviously of Recent age, as indicated by the limited erosion and weathering. Two datable carbonised samples were found at the base of the pyroclastic accumulation. The first sample consisted of partially carbonised, coarse, rounded wood fragments associated with a stream conglomerate which gave a radiocarbon age of 5140±200 yrs BP. But this wood was considered by the authors (Lockwood *et al.*, 1988) as allochthonous and exposed to magmatic $CO_2$ absorption of radiogenically "dead" $CO_2$. Consequently, it reflects an anomalously old radiocarbon age (Lockwood and Rubin, 1989). Recently, Freeth (1994) pointed out that some samples from the Lake Nyos area have also yielded anomalous $^{14}C$ ages due to contamination by $^{14}C$-free carbon. The second sample consisted of carbonised rootlets of trees in the upper part of lateritic soil, and at the base of the pyroclastic dam, were dated at 400±100 yrs BP and according to Lockwood *et al.* (1988) this would indicate the true age of the Nyos maar.

It is suggested that the pyroclastic surge deposits, which were originally sedimented around the entire Nyos crater, are now exposed discontinuously around the lake's southern end. Thus the Lake Njupi basement is essentially granitic without any evidence of autochthonous volcanic rocks. The relationship between the history of the Nyos maar and the blockage of Lake Njupi is one of the objectives of this study.

## GEOMORPHOLOGICAL SETTING OF LAKE NJUPI

Lake Njupi, which has a roughly trapezoid shape, has a surface area of approximately 20 hectares. The lake is shallow with two 15 m deep central basins. It has a dish-shaped morphology, a narrowish littoral platform and it is divided in two equal parts by a central island (Fig. 1). During the February dry season, the waters of Lake Njupi have a distinct thermal stratigraphy with a thermocline at about 8 m with surface temperatures ranging from 25 to 27°C and temperatures at depth of ~21°C.

The Njupi shoreline presents two types of morphology: cliffs and plains. The cliffs are developed at the north and south of the lake and are cut into old granitic rocks with lateritic soils or into young sequences of lava flows and pyroclastic surge deposits. The plains exhibit narrowish and peripheral developments, except to the southeast where a deltaic zone has formed at the inlet of the Njupi River. Generally, exhumed land with mud-crack polygons and swamp were observed, mostly in the west (Fig. 1).

The River Njupi is the only seasonal influent; the lithology of its catchment is essentially granitic.

The mean lake level has fallen 1 m since October 1977, as confirmed by aerial photography. This is accounted for by the active erosion of the exsurgence to the northeast.

In December 1986, four months after the catastrophic and voluminous release of carbon dioxide gas from Lake Nyos (August 1986), a recurrent event of a central reddish spot on the water surface with an outburst was reported simultanously in Lake Nyos and Lake Njupi. As the two lakes are not hydrologically connected, this occurrence is accounted for by the high probability that these two neighbouring lakes are located on a conjugated fracture system and served by the same outburst of underground fluids (Chevrier, 1990; Tazieff, 1989).

## SAMPLING AND METHODS

Two sections have been analysed in the exhumed bank: section 'a' in the western plain and section 'b' in the central island (Fig. 1).

The 'a' section in the western area was studied in greater detail. Every 20 cm, the total C was measured by dry combustion in a LECO CS 125 carbon analyser. Total organic carbon was also analysed after decarbonatation with 2 N HCl. The difference between the two is related to the carbonate content (here siderite). After the determination of the water content, each sample was fine sieved to 50 microns. The sand fraction was examined by stereoscope and the clayey fraction by X-ray diffraction (XRD) using a Co source. Selected samples were impregnated with resin and the microstrutures studied in thin section. A scanning Hitachi microscope was coupled to an EDVR Tracor microprobe in order to study the shape and composition of the sediment particles.

Tracers and constituents indicating the nature of organic fluxes and their origin were analysed. Pollen assemblages were determined at similar intervals to those of organic C measurements. The analysis by pyrolysis-gas chromatography-mass spectrometry at the Institut Quimic de Sarria (Barcelona) was used for quantitatively determining the major 'building blocks' of complex polymers and condensation products.

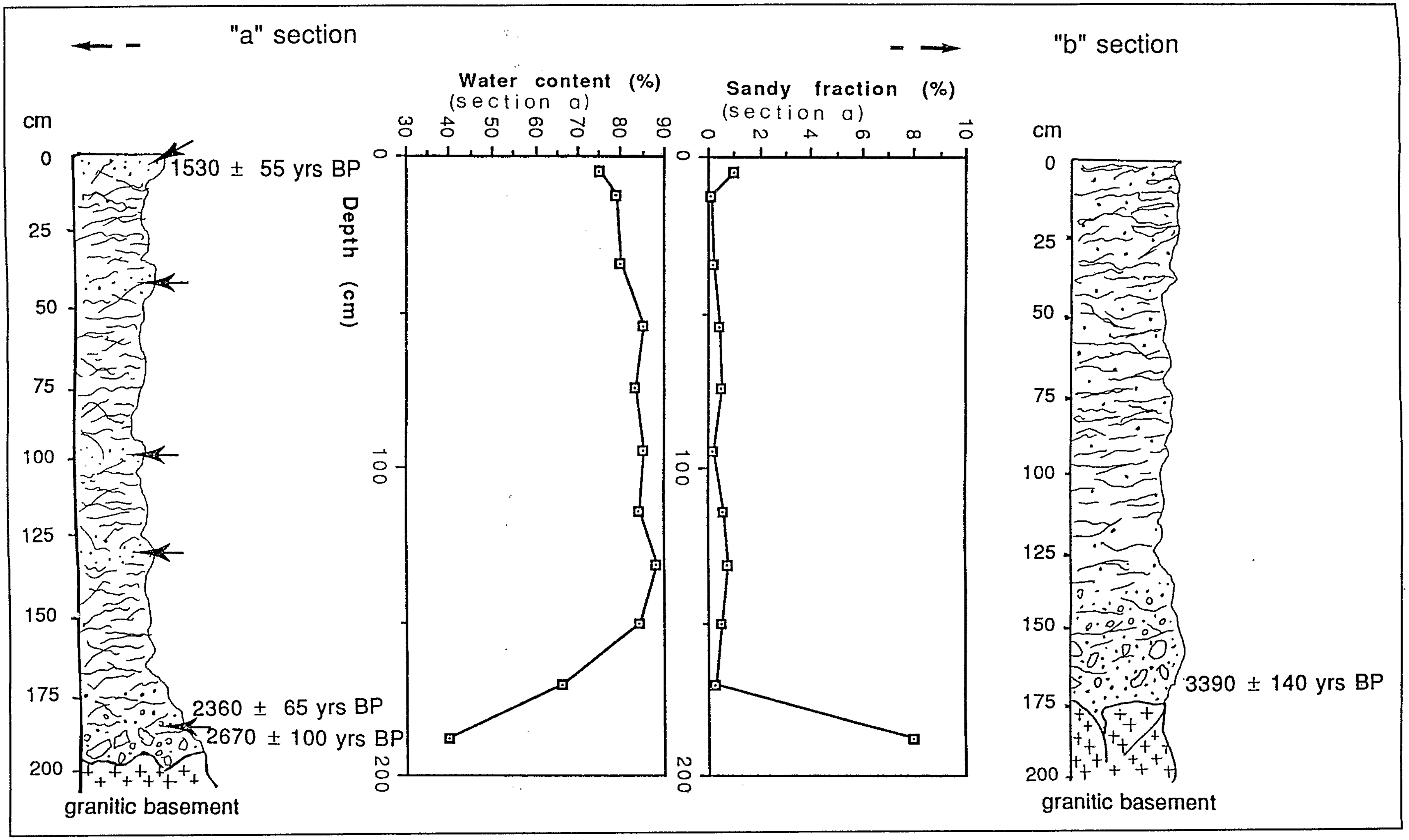



*Figure 2. Schematic profiles of the two studied sections 'a' and 'b'. The water content and sandy fraction distribution are both for section 'a' only. The silty layers (arrows) are interpreted as being the equivalent of maxima inputs. In 'a' and 'b' the bottom layers exhibit heterogeneous pebbles (granite and basalt).*

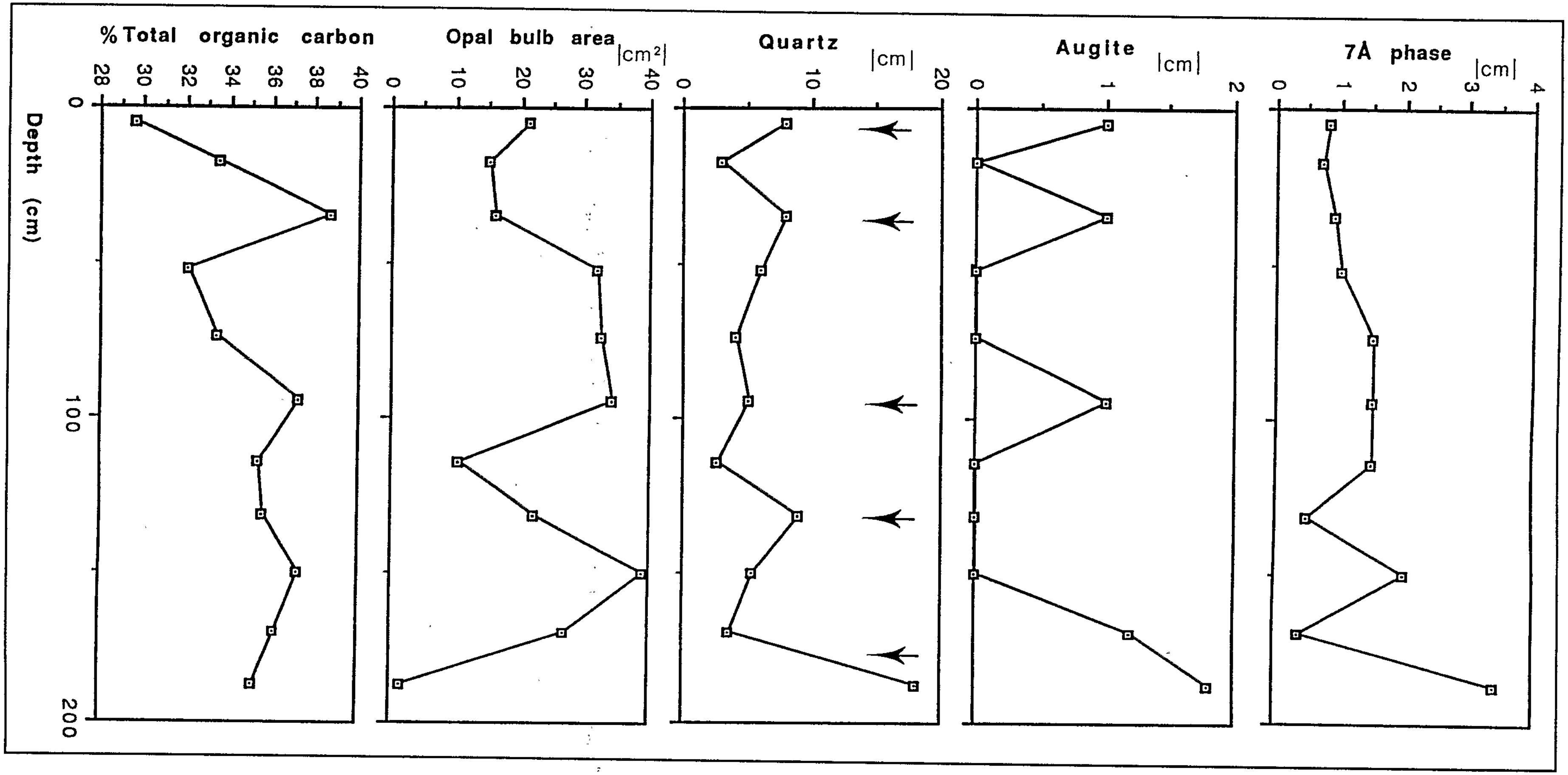



*Figure 3. Vertical distribution versus organic C (wt%), the bulb area (cm²) of opal and peak lengths (cm) of quartz, augite and 7Å clay minerals as measured by XRD for section 'a'. The arrows show the maxima terrigeneous inputs.*

For this study, a CDS Pyroprobe 1000 heated filament with a Pt coil probe was used, coupled directly to a Perkin-Elmer 8700 gas chromatograph equipped with a 30 m length polyethylene glycol bonded phase silica capillary column (Supelcowax 10 M). Pyrolysis products were injected in the spitless cold trap at room temperature for 2 min. The oven column temperature was held at 50°C for 2 min, then programmed to increase by 6°C $min^{-1}$ to 240°C. Pyrolysis products were identified on line by pyrolysis-gas chromatography-mass spectrometry (PY-GC-MS) coupling (HP 5995 mass spectrometer).

The chronology has been determined from radiocarbon dates on the bulk samples (M. Fournier, Labotatoire de Géochronologie ORSTOM Bondy, France and J. Evin, Centre de datation par le radiocarbone, Lyon).

## RESULTS

In the two sections studied (Fig. 2), the granitic bed-rock was reached at two metres depth. The deposit is made of peat overlying more sandy and clayey sediments although the sedimentation of the central island section is a little sandier and coarser. Some basaltic and granitic pebbles were also observed. Four ages were determined using $^{14}C$ geochronology. The lower level of the 'b' section was dated at 3390±140 yrs BP (OBDY 600). The base level of section 'a' is younger: 2670±100 (OBDY 750) for 195-200 cm and 2360±65 yrs BP (Ly 6520) for 195-180 cm; the older age of the sample of core 'b' could be related to reworked topsoil during the initial formation of the lake. The top level of the same section was dated 1530±55 yrs BP (Ly 6521). The sedimentological, geochemical and palynological analyses of the sediments were particularly based on section 'a'.

### Sedimentology

Except for the bottom of the section where the sandy fraction (>50 μm) is higher than 8%, the sediment consists of a mostly peaty deposit with a total organic carbon (TOC) content varying from 29.7 to 38.4% (Fig. 3). There are abundant and various plant residues which were partially degraded before buried in sediments of the lake. A relatively large proportion of the particles were carbonised in each level of this section (Fig. 4c). Characeae oogons were also observed in the whole section. The other main sedimentary phase is composed of a very important accumulation of Silicospongia spicules (Fig. 4d); some spheroidal colonies are well preserved (Fig. 4a) in the upper layers. This opal phase was quantified by X-ray diffraction by measuring the bulb areas as defined in previous papers (Eisma and van der Gast, 1971; Lapaquellerie, 1987); such a method can be considered valuable for estimating relatively high contents. This phase represents 24-40% of the whole sediment. The siliciclastic phase is only a minor component of the sediment (except the basal level; Fig. 4b), but the relative abundance was difficult to express as such very organic samples were imperfectly washed at 50 microns. However, XRD on the whole sediment was used and applied to the semi-quantitative quartz content (Fig. 3) and five input phases were observed during the 800 years represented by the section. The quartz grains are unworn and unsorted (40-300 mm) and are associated with reworked feldspars (mostly plagioclase), green minerals (mainly augite) and some basaltic glass and scoria. The clayey fraction is mainly composed of 7Å minerals (kaolinite+halloysite; 75-90%) with some 10Å minerals (illite+muscovite). This fraction shows a vertical distribution that does not correspond to those of the sandy minerals: a decrease in the upper levels is observed.

Siderite and vivianite are the two authigenic minerals that have originated from the most anoxic environments of the Cameroonian lakes (Giresse *et al.*, 1991). In the Njupi section they were ubiquitous, but only at very small amounts: mineral carbon is too rare to be measured by a carbon analyser.

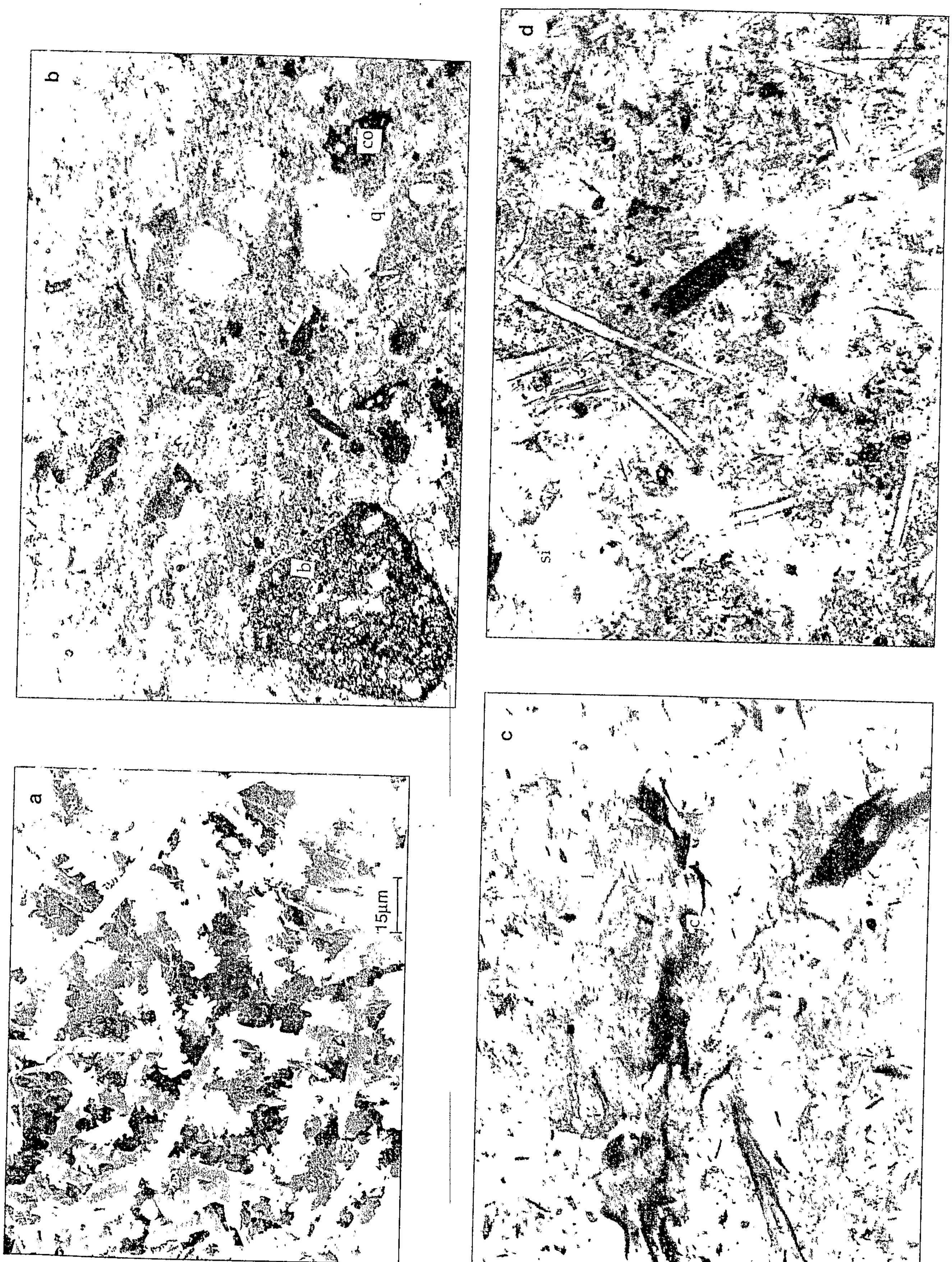
Thin section examinations indicate a brown organic matrix with very few clayey components. Biogenic particles are composed of Spongiae spicules, diatom cellular residues and an organic amorphous mass. In a few places, nebula-like masses of very small (4-10 μm) siderite prisms were observed. In the basal level of section 'a', spicules show lamina concentrations interlayered in an unsorted quartz deposit. This structure is similar to a lacustrine biogenic sedimentation with lower but significant discharges from the Njupi River.

To summarise, three main original sources can be considered during these 800 years:

*i)* an autochthonous and biogenic siliceous phase;

*ii)* a vegetal particular phase with mainly allochthonous components; and

*iii)* a siliciclastic phase that is a small fraction of the deposit. This phase is related to five inputs of coarse particles, which are derived from both granitic catchments and previous pyroclastic accumulations.


a
b
c
d
15µm

**Palynology**

Pollen analyses were done on 10 samples of the 'a' section, from bottom to top, at 15, 52, 69, 86, 123, 163, 179, 184, 191 and 195 cm (Fig. 5). Sixty two different pollen taxa were determined. Just above the conglomeratic level, the sample dated at about 2360 yrs BP exhibited a relatively high percentage of trees (47.5%), which corresponds to a forest/savanna mosaic with important forest islands. After around 2300 yrs BP, a strong regression of the arboreal pollen occurred, (less than 10%). This means a sudden change in the regional vegetation related to a climatic aridification (see later). After 2300 yrs BP a weak reforestation occurs, probably following a climatic improvement. However, until the top of the section (dated about 1530 yrs BP) the regional landscape remained distinctly more open than before, because the arboreal pollen percentages oscillated beween 15 and 25% (typical savanna values). During this last period, the presence of rare forest islands is attested by the low percentages of typical forested taxa (*Milicia, Celtis, Margaritaria, Alchornea* and *Macaranga*).

In parallel with the evolution of the regional vegetation, the fluctuations of the local aquatic milieu is shown by the variation of two typical taxa: *Cyperaceae* and *Nymphaea*. At the base of the section, before 2300 yrs BP, the relatively high percentages of these two taxa imply large scale spreading of marsh conditions, linked to a low or medium lake level. At about 2300 yrs BP, during the abrupt aridification indicated above, which is responsible of a short drying of the lake and its shores, these taxa decreased sharply. At 69 cm (around 1800 yrs BP) a strong rise of *Nymphaea* is observed, linked to a lowering of the lacustrine level and, at the same time, a diminution of some arboreal taxa (*Milicia* and *Alchornea*).

The montane forest, which is characterised by the pollens of two typical taxa — *Podocarpus* and *Olea capensis* (syn. *O. hochstetteri*) — also exhibited large fluctuations. The two samples situated above the conglomerate contain relatively important percentages of these two taxa: 1 and 2.5% for *Podocarpus*, 5 and 17% for *Olea capensis*. During the dry period, the montane elements and the arboreal pollens are strongly reduced. Indeed the *Podocarpus* pollen disappears completely and that of *Olea capensis* is reduced to 0.5%, with the values remaining very low until the top of the section.

The pollen of the oil palm *Elaeis guineensis* exhibits an extension in the low middle half of the section, beginning its extension during the arid phase around 2300 yrs BP. This pollen disappeared temporarily after the dry climatic oscillation at 69 cm (around 1800 yrs BP). The oil palm is classically linked to human activity, however, it must be considered that, before being cultivated, this tree was a pioneer in the African forest, particularly near its northern margin where a natural palm belt of *ca* 150 km long was described (Letouzey, 1978; Maley and Brenac, *in press*).

**Geochemical analysis of organic matter**

The organic matter was analysed with the objective of determining the succession in the organic fluxes starting with the slopes with less trees and from the bottom to the top of the core.

In the PY-GC-MS analysis, 23 major peaks were identified and selected. The total area represented by these 23 peaks has been considered as representing 100% for the purpose of this discussion. Pyrolysis products were grouped in five main families: 1) aromatic hydrocarbons; 2) N containing compounds; 3) carbohydrates; 4) aminosugars; and 5) phenolic compounds.

Generally, organic matter is not very degraded as the low content of aromatic hydrocarbons and high content of phenols and sugars, typical of the upper plants, show. In other respects, the low variability of the contents of indole from tryptophane pyrolysis, unstable aminoacid (Bruchet 1985), or a still of pyrrole indicative of degradation (Seres-Aspax *et al.,* 1985) also seems to testify to the fresh state of the organic matter. Therefore, these diverse markers do not show any obvious vertical evolution resulting from early diagenesis.

As the frequency curve of quartz emphasizes, the main episodes of detritic fluxes for both the sugars and the aminosugars show the pulsations of the input rhythm, except the last but one from 25 to 43 cm, which is emphasised by an extreme abundance of organic matter (more than 38% of organic C) and by a high content of phenolic compounds and an obvious decrease of aromatic hydrocarbons, which point out the fresh state of

*Figure 4. Some microfacies of section 'a'. (a) Well preserved spheroidal Silicospongia in the upper layer (0-10 cm). (b) Siliciclastic accumulation in the basal level (180-195 cm). b: basaltic fragments; q: angular quartz; co: coarse organic remains. (c) Concentration of carbonized particles (=c) in a clay and transparent matrix (65-84 cm). (d) Accumulation of Silicospongia spicules in a matrix of sideritic (=si) and organic clouds (=cl) (65-84 cm).*

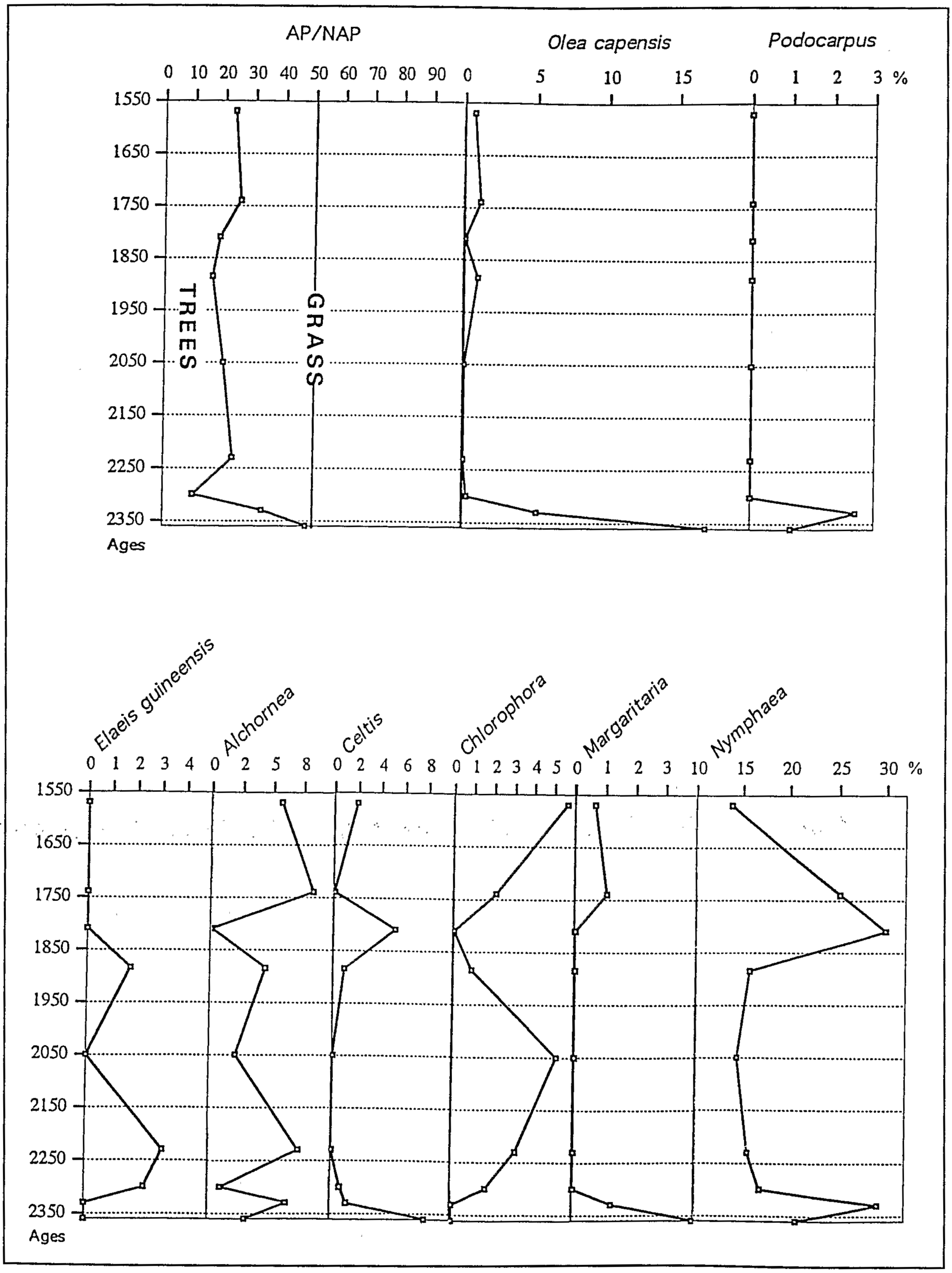



*Figure 5. Pollen diagram of section 'a' with the relative percentages (%) of the main pollen taxa. AP: arboreal pollen; NAP: non-arboreal pollen.*

the organic matter (Fig. 6). The distribution of phenolic compounds is relatively homogenous towards the bottom of the core. The furfural/pyrrole ratio also varies little with a small increase towards the bottom, as does the indole/pyrrole ratio, which is indicative of fresh material.

The N containing compounds are less abundant than in other equivalent sediments where the planktonic contribution is important (e.g. some rivers of Guyana; Gadel, *unpubl. data*). They do not seem to be related either with the quartz fluxes or with the accumulation of organic matter, but on the contrary, show a good correlation with the content maxima of opal from the sponge spicules: consequently these compounds emphasize the autochthonous production of the lake. The dephasing in the relation between the distribution of opal and the N containing compounds could be explained by the active diffusion processes of labile compounds derived from the early degradation of organic matter.

The bottom layer of the core, with a relatively high concentration of arboreal taxa and a relatively high detrital fraction, contains the only abundance of carbohydrates, (furfural) derived from the cellulose of wood debris, and a low amount of N containing compounds. Here cyclopentanone, a compound derived from pyrolysis of polycarboxylic acids (Wilson *et al.*, 1963) resulting from soil leaching, is abundant.

The layer that corresponds to the flooding of the lake is not still colonised by Spongiae, resulting in a relatively poor concentration of N containing compounds. It is also possible that the plant cover rich in arboreal taxa contributes to this deficiency of N containing compounds because it is recognised that herbaceous material is 2 to 3 times more rich in proteins than the deciduous species present in the proceeding layer (Gadel, *unpubl. data*). In the immediately overlying layer a peak of nitrogen containing compounds appears, corresponding principally to nitrogenous aliphatic compounds (acetonitrile), which could be associated with these same factors.

Finally, the upper layer of the core, which is seasonally emergent, is colonised by living sponges, which explains the relative abundance of N containing compounds (acetonitrile) and aminosugars (acetamide) proceeding from peptidoglycanes (Hudson *et al.*, 1982). The emergence and the development of bacterial activity could explain the abundance of aromatic hydrocarbons in this upper layer, which increase during humification processes (Bracewell *et al.*, 1980).

Some levels enriched in burnt organic matter do not present the characteristics of burnt plots. Partial combustion of organic remains causes humus ageing with carbohydrates and groups of phenols burning preferentially and an increase in aromatic hydrocarbons and some N containing compounds (Alcaniz *et al.*, 1994). These effects do not appear in these levels, excepted for the increase in pyridine content at the 70 cm level, which is rich in burnt particles.

## DISCUSSION AND CONCLUSION

### Morphostructural history

The early sedimentary history of the Lake Njupi around 3000 yrs BP coincided with the initiation of a dry climatic period. This relatively dry period extended over a large part of western and central Africa (Nigeria, Cameroon, Congo, Gabon, etc.; Schwartz, 1992; Maley, 1992, 1996a; Maley and Brenac, *in press*; Giresse *et al.*, 1994) causing soil erosion and temporary openings in the rain forest for nearly 500 years (according to radiocarbon ages). The variation of trees versus grass along section 'a' confirms this evolution (Fig. 5). This means that the formation of Lake Njupi cannot be related to the onset of a wetter climate.

In the same way, the lake level fell around 1500 yrs BP when in south Cameroon the forest extended again (Maley, 1996a). Frequently, when a lake level falls, muddy beaches appear and are quickly colonised, particularly by *Cyperaceae*. Because in section 'a' *Cyperaceae* pollen remained low near the top, it could be that the level dropped suddenly. Thus, the partial emergence of the basin cannot be directly related to the fluctuation of rainfall, but more probably to a geomorphological process.

On the whole, three main morphological events have marked the history of Lake Njupi: around 3400 yrs BP; around 1500 yrs BP and in October 1977.

The first event, which is morphostructural, consists of the damming of the Njupi Valley, creating Lake Njupi or, eventually, raising the lake level 3400 years ago. Two processes (Fig. 1) could have been responsible for this natural dam: either it was formed by the Njupi cone and lava flow, or by the debris of a large landslide which originated on the northeast flank of the Nyos maar (Zogning, 1991). A combination of the two processes is also possible.

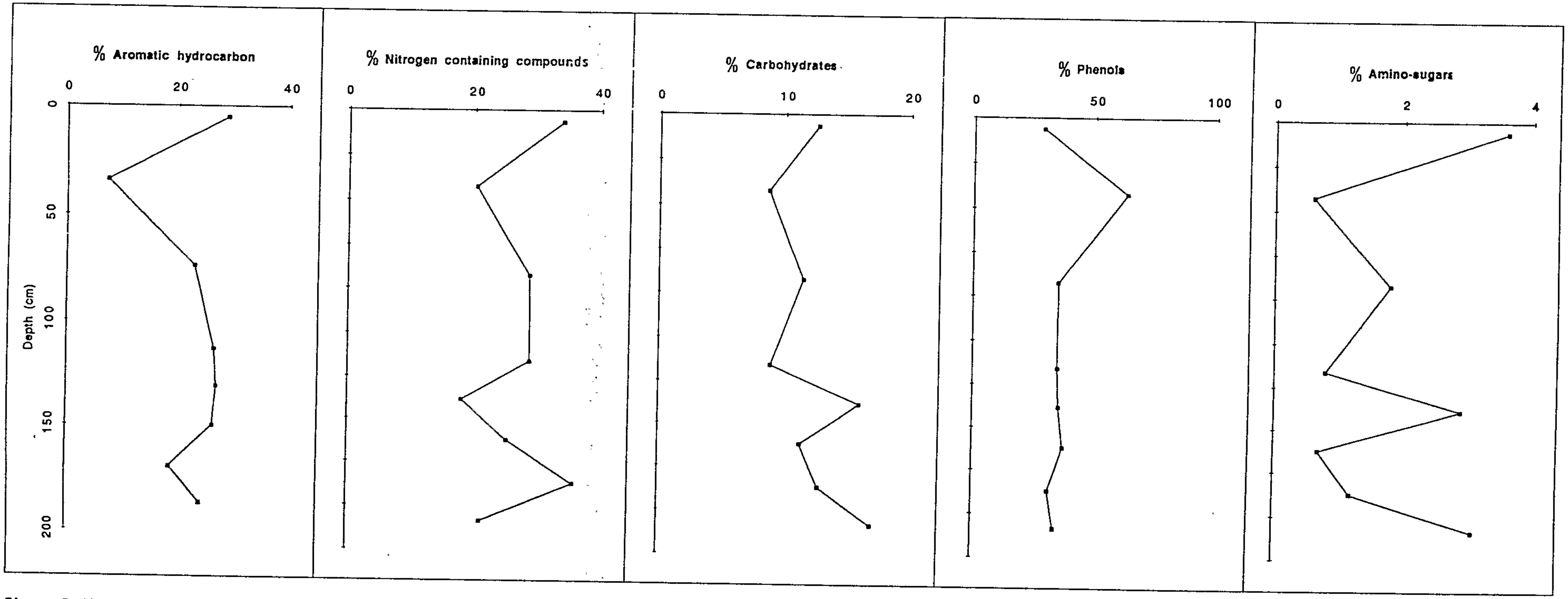



*Figure 6. Vertical distribution of the main groups of organic compounds in section 'a'.*

As indicated by the October 1977 event, the similar 1500 yrs BP event was mainly due to erosion at the base level of the spillway. Nevertheless, the December 1986 event, four months after the Nyos catastrophe, suggests that more investigations on the geochemistry of this lake and its relationship with the environs is needed.

Contrarily to Lockwood and Rubin's (1989) affirmation, the younger volcanic feature in the immediate area of Nyos is the Njupi cone and lava complex. This is confirmed by the fact that a near total absence of volcanic projections throughout the two sections studied was observed, which clearly indicates that the Nyos maar was formed before Lake Njupi. As the minimum age for this lake is 3390 yrs BP, the Nyos maar must be more than 3400 yrs BP. Perhaps the radiocarbon age of 5140 yrs BP was not contaminated and could represent the true age of Lake Nyos. The ~1850 years difference between Nyos and Njupi is reasonable when the morphological evolution of the two volcanoes is compared: weathering, hydrology network, erosion, vegetation cover, etc.

Consequently, the speed of the morphological evolution of the Nyos natural dam is not as rapid as concluded by Lockwood *et al.* (1988). Meanwhile, the danger of this dam collapsing is still present, but several other factors are involved, such as seismicity and seepage (Zogning, 1991).

**Sedimentary facies and geochemical characters**

The sedimentary facies from Lake Njupi were sampled in a marginal location and facies from the deeper part (15 m) of the lake were not recorded. In spite of this lack of information, these facies seem unique compared to nearby craters along the Cameroon Line (Giresse *et al.*, 1994). It is a true peaty deposit with an organic matter content of up to 60% and a very abundant siliceous biogenic fraction (spicules and accessory diatoms). Flood events from the Njupi River are less important to the over all sedimentation of section 'a', they are more obvious in section 'b' with a shorter transport pathways. However, section 'a' does show five more or less abrupt inputs of alluvial quartzose matter; the first one (180-195 cm) corresponds to the starting point of this part of the lacustrine basin. The detrital green minerals and basaltic glass and scoria probably resulted from reworking of previous pyroclastic deposits, antecedent to 3400 yrs BP.

Organic matter in the sediments is very abundant and particularly well preserved. In spite of an obvious homogeneity, several fluxes successively supplied the deposit. Some are emphasised by carbohydrates and millimetre- to centimetre-scale lignitic remains associated with an important quartzose fraction; others are denoted by phenolic compounds and fine, abundant and well preserved organic matter.

These fluctuations seem to obscure somewhat the geochemical signal of the evolution from a landscape with a forest-savanna cover (percentage of arboreal taxa near to 50%) to an open savanna environment (15-25% of arboreal taxa). Only the relative poorness of N containing compounds in the bottom layer could indicate a rain forest contribution.

**Palaeobotanical indicators**

If the pollen study of this section was not put in a more general framework, it could be concluded that the abrupt arboreal regression which intervened near the base of the Njupi section was linked to human interference. However, everywhere through tropical Africa, from the Sahel to the rain forest, all the well studied sites dated between 3000 and 2000 yrs BP exhibit a large opening of the vegetation linked to a strong grass extension, particularly in the forest regions, culminating between 2500 and 2000 yrs BP (Maley, 1992, 1996a, *in press*; Schwartz, 1992; Giresse *et al.*, 1994). Therefore, the abrupt arboreal reduction at Njupi must be linked to a climatic phenomenon. Strong erosion was also related to this climatic event and associated with the deposit of coarse sediments (gravels, pebbles) in the river valleys marking the base of a distinctive and generalised "Low Terrace" (Maley, 1981, 1992, *in press*). In some forest regions, this climatic phenomenon was also linked to large fires (Hart *et al.*, 1996). Schwartz (1992) hypothetised that this climatic drying could have caused the Bantous people after 3000 yrs BP to migrate towards the south, particularly through the forest, from their "cradle" situated between the Bénoué and the Grass Fields in west Cameroon.

Moreover, considering the mountain forest was characterised by *Olea capensis* and *Podocarpus* (only the species *Podocarpus latifolius* now survives in Cameroon; Letouzey, 1985), their strong regression after 2500 yrs BP is a general phenomenon, in the same way as its extension between 4000 and 3000 yrs BP in other sites of Cameroon, central Atlantic Africa and also east Africa (Maley, 1996b).

The general picture which appears from the comparison of the pollen data from Njupi and several lacustrine sites in south and west Cameroon (Barombi Mbo [Brenac,1988; Maley, 1992, 1996a; Maley and Brenac, *in press*], Mboandong [Richards, 1986] and Ossa [Reynaud-Farrera *et al.*, 1996]) can be characterised as follows:

*i)* before 2500-3000 yrs BP the rain forest extended further to the north than now, surrounding the Njupi area,

*ii)* around 2500-2200 yrs BP there was an abrupt retreat of the rain forest with an extension of the savannas with its grass-dominated vegetation and also many pioneer trees which characterise the "secondary" vegetation at the same time;

*iii)* at the same time, ~2500-2200 yrs BP, there was an abrupt decline or disappearance of the mountain forest, which was characterised by *Podocarpus* and *Olea*;

*iv)* the main difference between Njupi and the other sites is that after ~2000 yrs BP there was a new forest extension around the southern sites cited above, but the Njupi area remained surrounded by savannas with only small rain forest patches (mosaic landscape). From this it can be concluded that the northern edge of the forest remained south of the Njupi area;

*v)* all these data lead to the conclusion that this general retreat of the forest, including the mountain forest, resulted from a dramatic drying of the climate culminating between ~2500-2200 yrs BP and was also marked by strong erosion and deposition of coarse fluviatile sediments (Maley, 1992, *in press*);

*vi)* after 2000 yrs BP, the new rain forest extension in south Cameroon points to a return of more humid and favorable climatic conditions, probably close to those of the present day.

The pollen fluctuations of *Elaeis guineensis* must be considered in this general historical framework. This palm tree belongs to the African forest vegetation: its typical pollen first appeared in Miocene deposits of the Niger Delta. In some levels, near the end of the Tertiary, its percentage levels had already reached around 10% (Zeven, 1964). The oil palm was first a pioneer tree living naturally near the periphery of the rain forest. Indeed, in west Cameroon, in the northern part of the forest massif between the altitudes of 500 and 800 m, from Takamanda to Batibo and then to Fontem and Santchou, the botanist Letouzey (1978, 1985) described a forest belt of more than 150 km in length and 10-20 km wide, dominated by tall and numerous *Elaeis guineensis*. Letouzey (1978, 1985) considered this oil palm belt as being a natural formation based on several criteria, particularly the absence of trees classically linked to Man and cultivated in plantations. The natural pioneer behaviour of the oil palm is very obvious in the pollen records of the sites listed by Letouzey (1978, 1985). In the longest record of the Barombi Mbo, going back to ~25,000-28,000 yrs BP (Maley, 1996a), the pollen grains of the oil palm first appear with low percentages (~1-3%) in the Early Holocene at the same time as the first forest extension (Maley and Brenac, *in press*). This first strong extension commenced at the beginning of the dry phase described above, reaching ~8 to 10% between 2800-2400 yrs BP and following exactly the pollen spike of *Alchornea* type *cordifolia*, another important pioneer tree. Then, the pollen of the oil palm regressed to very low values during the end of the dry phase at around 2000 yrs BP. Finally, there was a second and more important extension phase between ~1600-800 yrs BP, with maximum values between ~10-13%, at the same time as other pioneer trees like *Milicia* (Maley and Brenac, *in press*). Some villages and plantations are present today in the catchment area of this lake. In the present day lacustrine sediment, the amount of oil palm pollen is ~5%.

Considering these data, the more conservative way to interpret the pollen result from Njupi is to estimate that during the first *Elaeis guineensis* peak (between ~2800-2400 yrs BP) the behaviour of the oil palm was exclusively natural, but after 2000 yrs BP (interpolated), during the new forest extension which was associated with the spreading of the Bantou in the rain forest (Schwartz, 1992; Oslisly and Peyrot,1992; Oslisly and Fontugne, 1993) it is possible that the nuts of the oil Palm could have been cultivated by Man and so progressively domesticated. However, more precise conclusions concerning the important problem of oil palm domestication, particularly the methods used and the period of controlled cultivation, can only be attained by new research involving palynologists, archaeologists, botanists and geneticists.

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