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Late Holocene climatic changes in west Africa, a high resolution diatom record from equatorial Cameroon

Victor François Nguetsop[a,b], Simone Servant-Vildary[b,*], Michel Servant[b]

[a] *Département de Biologie végétale, Faculté des Sciences, B.P. 67, Dschang Cameroun, USA*
[b] *Antenne IRD, UR032, Muséum National d'Histoire Naturelle Paris, 43 Rue Buffon, 75005 Paris, France*

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Abstract

Holocene climatic changes in West Africa are usually explained by increased/decreased activity of the monsoon from the Guinean Gulf toward the continent. According to a diatom record from Lake Ossa (3°50′N, 9°36′E), we suggest that, in the near coastal areas of Cameroon, phases of intensification of the monsoon were marked by reduced precipitation and reduced evaporation, conditions nowadays prevailing South of the equator (4–5°S) during the austral winter. Lake Ossa is a shallow lake located in one of the rainiest area of the African rain forest belt. During the wet season (March–November) it is fed by acid meteoric waters entailing low pH in the lacustrine waters. During the dry season (December–February) groundwater discharges allow the persistence of acid waters near the borders of the lake, but, in the inner parts, the waters tend to be alkaline, alkaliphilous diatoms are abundant in the surface sediment samples and are used as indicators of low precipitation. At that time, atmospheric dust containing reworked diatoms from Saharan Quaternary deposits is transported by the northern trade winds and reaches the Ossa area. Wind blown diatoms are considered as a signature of the northern trade winds. A diatom record from the western deep part of Lake Ossa has provided climatic data for the mid-late Holocene at a resolution of 50–60 years. A major climatic change at 2700 cal yr BP was marked by the appearance of wind blown diatoms. A millennial-scale alternation between low and high precipitation episodes is recorded during the last 5500 years. The low precipitation episodes before 2700 cal yr BP are interpreted as a consequence of a northward extension of the climatic conditions that nowadays characterize the Southern Congo during the austral winter, when the monsoon extends into West Africa and reaches the northern sub-tropical latitudes. The effects of low precipitation on the water balance and on the rain forest were obliterated by an extremely low evaporation. Between 2700 and 1300 cal yr BP, precipitation was high and the rain forest intensively disturbed in response to convective storms. A low precipitation episode between 1300 and 600 cal yr BP is explained, contrarily to the previous similar episodes, by tropical rainfalls located farther South than today during a larger part of the year. The modern climate settles at about 600 cal yr BP. The climatic oscillations on a millennial time scale were apparently coincident with temperature changes in the Northern and Southern Atlantic suggesting that the monsoon over West Africa was essentially driven by interactions between both hemispheres. This interpretation is in agreement with available data from other equatorial and sub-tropical regions of West Africa.

1. Introduction

In West Africa, the northern subtropics experienced a wet climate between 11,500 and 6500 cal yr BP and then, a trend towards dryness, which culminated after 2700 cal yr BP. These two main steps were interpreted as an intensification/weakening of the African monsoon due to Earth orbital changes (Kutzbach and Street-Perrott, 1985). Several millennial-scale oscillations were superimposed on these general trends as shown by dramatic lake-level changes in Chad and Niger (Servant and Servant, 1970). This was later confirmed by numerous studies over the whole subtropical zone, between 13°N and 23°N (see extensive references in Vernet, 1995; Jolly et al., 1998; Gasse, 2000). At the subequatorial latitudes, the only available paleohydrological record in the lowlands (lake Bosumtwi, Ghana, 6°30′N, 1°25′W) indicated that the water level remained higher than today during most of the Holocene, except falls of level around 8200, 4000 and 600 cal yr BP (Talbot and Delibrias, 1980). These short events did not apparently affect the surrounding rain forest (Maley, 1997). At higher altitude (2264 m a.s.l.), the lake Bambili

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*Corresponding author. Antenne IRD, UR032, Muséum National d'Histoire Naturelle Paris, 43 Rue Buffon, 75005 Paris, France. Tel.: +33-140793470; fax: +33-140793739.
E-mail address: mone@mnhn.fr (S. Servant-Vildary).

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record, West Cameroon (5°6’N, 10°15’E), showed that the precipitation *minus* evaporation balance (P−E) was low between 10,000 and 2700 cal yr BP, in contrast to Bosumtwi, suggesting an opposite climatic evolution at high and low altitudes (Stager and Anfang-Sutter, 1999). In the lowlands of West Cameroon and South-Congo, paleohydrological records are lacking. The only significant change throughout the Holocene was a forest clearance at 3000–2500 cal yr BP (Vincens et al., 1994, 1998; Elenga et al., 1996; Maley and Brenac, 1998). Isotopic evidences from soils located on the northern and southern forest-savannas boundaries indicate a significant forest advance over the last few centuries (Schwartz et al., 1996; Youta Happi, 2000; Guillet et al., 2001).

This study provides the first paleohydrological record for the last 5500 years in the equatorial near-coastal areas, east of the Guinean Gulf. Diatoms were analyzed in core OW4 retrieved in the Lake Ossa, West Cameroon. Numerous studies have shown that diatoms are good indicators of pH and water depth (e.g. ter Braak and van Dam, 1989; Battarbee et al., 1990; Smol and Cumming, 2000; Last and Smol, 2001; Smol et al., 2001). However, one has to take into account the morphology of the lacustrine basins and other characteristics which can modulate the response of diatoms to pH and lake level changes. Lake level changes were usually interpreted as modifications in the P-E balance. Nowadays, in the tropical zone, precipitation and evaporation are generally inversely correlated. However, in several continental areas, east of the tropical oceans, precipitation and evaporation can both be low because of a relative stability of the atmosphere at low level, a high atmospheric water vapor content and a low cloud cover. In such areas, independent determinations of P and P−E must be achieved to improve climatic reconstruction. We will show here that, in the special case of lake Ossa, the pH is linked to precipitation and is therefore a proxy for past precipitation changes. Moreover, wind-transported diatoms from Saharan Quaternary deposits (Nguetsop, 1997) will be used to infer changes in atmospheric dust which can episodically reach the sub-equatorial regions.

These new data enable us to present a revision of previous interpretations based on palynological and sedimentological data in the same record (Reynaud-Farrera et al., 1996; Wirrmann et al., 2001). In the discussion, the comparison between our data and others from the subequatorial and subtropical regions of West Africa allows to confirm an usual model which linked the past climatic variations to south/northwards shifts of the Intertropical Convergence Zone (ITCZ). These late Holocene shifts, which occurred at a millennial time-scale, appeared to be coincident with sea surface temperatures (SSTs) changes in the northern and southern Atlantic. This suggests that the previous hypothesis which linked the climatic changes in West Africa to hemispheric interactions for the Late glacial and early Holocene (Mulitza and Rühlemann, 2000) can also be applied to the late Holocene.

2. General climatic settings and studied site

In tropical Africa, the distribution of precipitation, throughout the year, is driven by the displacement of the

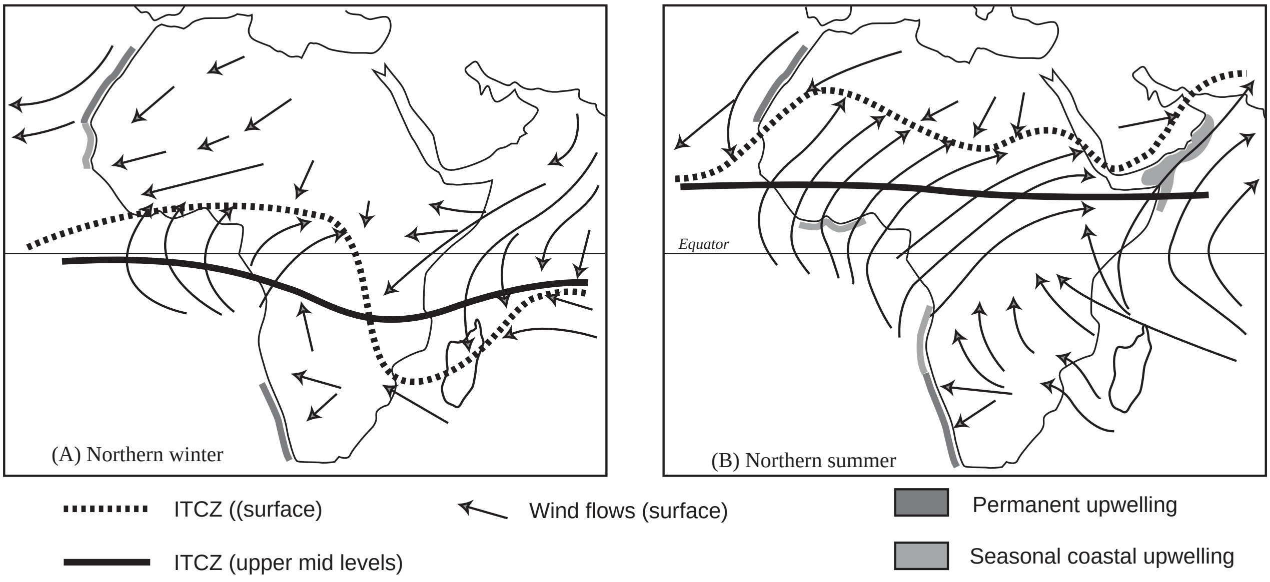

Fig. 1. General features of the atmosphere over Africa in northern winter (A) and northern summer (B). The dotted line corresponds to the surface location of the Intertropical Convergence Zone, ITCZ. The ITCZ at mid-upper levels is represented by the continuous line. It corresponds to the vertical meteorological equator, (see zone C1 in the N-S cross-section of the troposphere in Fig. 12).

intertropical convergence zone towards the warmer hemisphere. During the northern winter, the ITCZ, also referred as meteorological equator (ME, dotted line in Fig. 1) is located at the subequatorial latitudes over West-Africa. Therefore, South-Congo (e.g. Pointe Noire, Brazzaville) experiences a wet season (Fig. 2) and the regions north of the equator (Ngaoundéré, Edéa, Campo) experience a dry season (here after referred as "northern winter dry season"). The northern trade winds ("harmattan") intensify over North Africa. They transport Saharan dust that is subsequently deposited far away on the continent and the ocean (Lézine et al., 1994; Goudie and Middleton, 2001). During the northern summer, the ITCZ is located at the northern subtropical latitudes, moist wind flows from the Guinean Gulf extend over North Africa: the northern subequatorial and tropical latitudes (e.g. Ngaoundéré, Edéa) experience a wet season whereas the southern subequatorial latitudes, a dry season (e.g. Pointe Noire, Brazzaville). This dry season occasionally extends northwards entailing a more or less marked precipitation depletion in June–August near the northern border of the Guinean Gulf (e.g. Campo, Edéa).

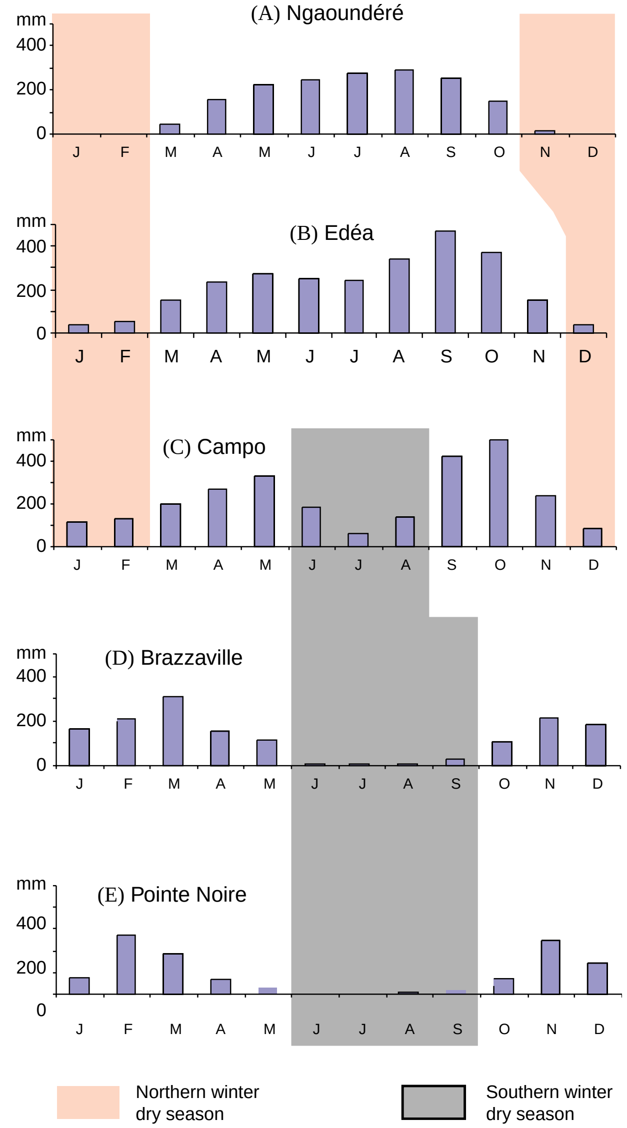

Fig. 2. Mean monthly precipitation (in mm) at some sites (location in Fig. 3) from northern Cameroon (A), western Cameroon (B and C) and southern Congo (D, E).

Lake Ossa is located at $3^{\circ}50'$N and $9^{\circ}36'$E, at an elevation of 8 m above sea level (a.s.l.) in one of the wettest area in Africa (Fig. 3, site 7), it is surrounded by the evergreen Atlantic littoral forest which is dominated by *Sacoglottis gabonensis* and *Lophira alata* (Letouzey, 1985). It is a shallow lake (maximum ~ 7 m depth during the wet season) forming along the bottom of a valley damned during the Late Pleistocene by alluvium of the Sanaga river (Wirrmann et al., 2001). The lake is subdivided into two sub-basins of $37\,\mathrm{km}^2$ (Ossa *sensu stricto*) and $7\,\mathrm{km}^2$ (Mévia) with respective catchment queen $55\,\mathrm{km}^2$ and $110\,\mathrm{km}^2$ (Fig. 4). A channel flowing from Mévia to Ossa is largely colonized by macrophytes (*Echinochloa pyramidalis*). The Lake Ossa outflows to the Sanaga River through a 3 km long outlet situated in the southeastern part of the main basin. This region experiences an oceanic sub-type of the Guinean equatorial climate. The mean annual temperature is 26.5°C. Maximum temperatures (32.5°C) occur from February to May whereas daily minima (21.6°C) occur in June. The mean annual rainfall is $2953\,\mathrm{mm}^{-1}$ with an evaporation of $700\,\mathrm{mm\,yr}^{-1}$ (Olivry, 1986). Monthly measurements performed in 1992 and 1993 (Wirrmann, personal communication) showed that the water-level decreased by 4 m between October and December, during the transitional period between wet and dry season. The lake level remained low between January and March and increased progressively from April to October during the wet season. The flat low-lying areas located at the south-eastern of the lake are flooded (2–3 m water depth) during the rainy season and dry out during the dry season.

Measurements of pH were performed during both dry and wet seasons in lake Ossa and Mévia (Table 1). They showed that the pH is low during the wet season and higher during the dry season. A similar seasonal trend was as well observed in water bodies from other forested regions of Cameroon (Seyler et al., 1993). In these regions, rainfall is acidic, pH ranges from 5.3 to 6.8 (Sigha-Nkamdjou et al., 1998) with occasional values lower than 5 (Ndam, personal communication). We may thus consider that a low pH in the lacustrine waters essentially reflects the low pH of the meteoric waters. Precise data on pH during the dry season are available thanks to 74 measurements performed in 1993, 1994 and 1995 in lakes Ossa and Mévia and several small surrounding lakes. High values of pH (>8) were recorded in lake Mévia and in the eastern part of lake

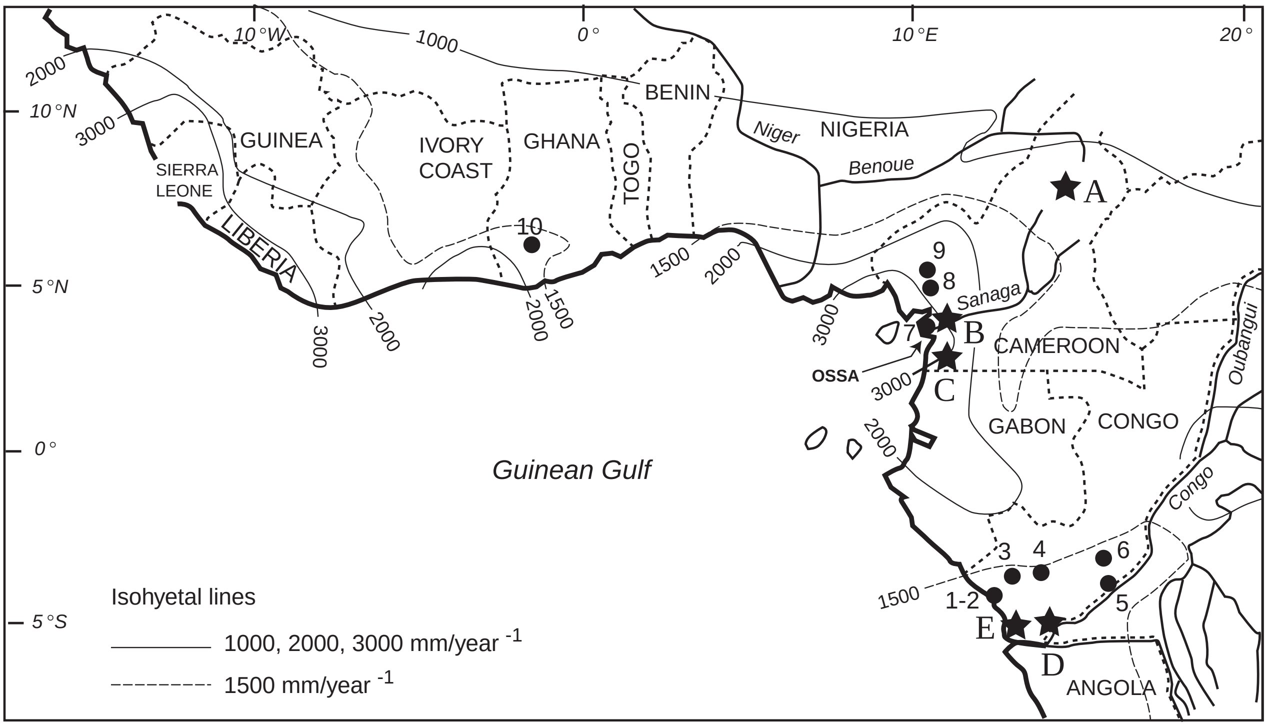

Fig. 3. Mean annual rainfall around the Gulf of Guinea and location of available Holocene records. *In South Congo*: 1—Songolo, 2—Coraf, 3—Kitina, 4—Sinnda, 5—Ngamakala, 6–Bilanko; *in West Cameroon*: 7—Ossa, 8—Barombi Mbo, 9—Bambili; *and in Ghana*: 10–Bosumtwi. Location of sites A–E mentioned in Fig. 2.

Ossa, near the outlet of lake Mévia. In the western part of lake Ossa where core OW4 was retrieved the pH is neutral or slightly alkaline (7–8). In contrast, the values of pH remained low (<7) in lake Mwembé, in the northernmost part of lakes Ossa and Mévia (essentially in shallow waters near the outlets of inflowing brooks), in the swampy areas and in the small relatively deep lake Mboli.

These data show that the pH, essentially controlled by meteoric waters, is modulated by local conditions during the dry season. Groundwater reservoirs, fed by meteoric waters during the rainy season, discharge in the small rivers and near the borders of the lakes. The pH remains low in these areas and the acidity of the waters can be reinforced when a swampy vegetation develops. In the lake Mévia, water inputs from inflowing brooks are stronger than in the lake Ossa because the watershed is twice as big. Consequently, the water balance of the lake Mévia is less affected than the lake Ossa by the dry season and the water inputs from lake Mévia strongly contribute to the feeding of lake Ossa when the precipitation is low. In the east and south-eastern part of the lake Ossa, the alkalinity is reinforced by inputs of highly alkaline waters from lake Mévia.

3. Material and chronology

The modern diatom data set includes 74 surface sediment samples with a total of 211 species (Nguetsop, 1997). A sedimentation rate of $0.1\,\mathrm{cm}^{-1}$/an obtained from ^{210}Pb measurements on several short cores retrieved in the central part of the lake Ossa indicated that the surface sediment samples represent around 10 years accumulation (Nguetsop, 1997). Even if the rate of sediment accumulation could be different in the other parts of the basin, we can assume that the diatom flora preserved in the surface samples gives a natural synthesis of the flora which lived during at least several years.

The fossil flora was studied in core OW4 (5.5 m long) retrieved during the dry season from 1.7 m water-depth, between the main central island and the western border of the lake (Fig. 4). The core is dominated by slightly organic dark-brown homogeneous clays. Previous studies on the same core provided data on pollen assemblages (Reynaud-Farrera et al., 1996) and mineral fluxes (Wirrmann et al., 2001). The time control based on 8 radiocarbon dates was discussed by Wirrmann et al., (2001), it is here complemented by 6 new dates. Amongst the available 14 dates (Table 2), 11 showed a good internal consistency as function of depth (Fig. 5) whereas 3 are inconsistent which is probably due to a slight contamination by reworked sediment. The calibration of ^{14}C yr BP into cal yr BP was performed by the Calib 4.0 program of Stuiver et al. (1998). The calendar age of each of the 77 studied samples was obtained from a linear interpolation between two adjacent consistent mean calibrated dates. The sub-samples for diatom

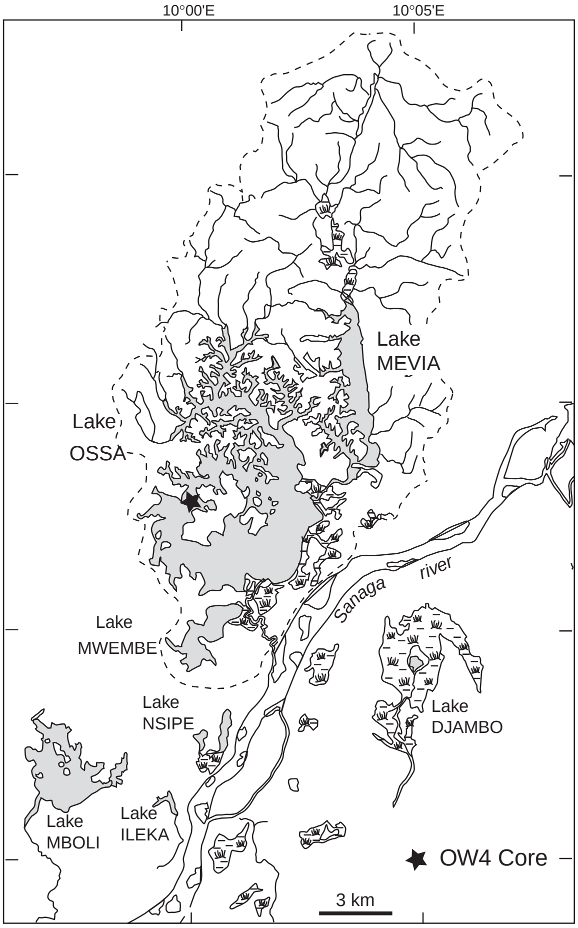

Fig. 4. The watershed of Lake Ossa. Location of core OW4 and surrounding lakes.

Table 1
Conductivity and pH measured during the dry and the rainy seasons in Lake Ossa and Lake Mévia.

Samples	Dry season			Rainy season		
	pH	Cond ($\mu S\,cm^{-1}$)	Date	pH	Cond ($\mu S\,cm^{-1}$)	Date
SO47	8.99	11.00	01.27.95	6.45	15.50	10.21.98
SO48	9.34	11.00	01.27.95	6.54	16.20	10.21.98
FO10	6.03	15.00	05.21.94	6.85	17.10	10.21.98
MV2	6.91	20.00	01.28.95	6.42	14.90	10.21.98
MV7	9.36	14.00	01.28.95	6.40	15.20	10.21.98
MV8	6.29	26.00	03.18.95	6.35	14.90	10.21.98
MV13	7.63	18.00	03.18.95	6.20	15.30	10.21.98

analyses were collected at different thickness intervals (15 cm before 3560 cal yr BP and 6 cm after) in order to obtain equivalent time resolution throughout the core (50–60 yr), each sub-sample represents between 6.5 and 16 years accumulation.

The diatom slides were prepared from ~ 0.5 g of dry sediment. At least 600 diatom valves were counted per sample when the diatom content was high and 200–300 valves when it was low. The frustules are well preserved throughout the core, however, fragmented valves are more abundant after 2700 cal yr BP. The diatom identification was based on Krammer and Lange-Bertalot (1986–1991), Schoeman (1973), Servant-Vildary (1978), Gasse (1980, 1986), Germain (1981), Simonsen (1987).

Table 2
Radiocarbon dates from core OW4

Depth (cm)	Lab number	Measured ^{14}C age (^{14}C yr BP)	Calibrated ^{14}C ages (min–median–max, 1 sigma)
6.9–9,0	Beta-73082	90 ± 60	0–140–280
62.7–64.9	Beta-86769	740 ± 50	642–685–729
122.9–125.5	Beta-73083	1890 ± 60	1950–1825–1700
174–175	UtC-3911	2442 ± 43	2355–2530–2706
176.9–179.1	GrN-4266	2000 ± 70	1808–1966–2124[a]
179.2–181.4	GrN-4273	2470 ± 60	2347–2546–2745[a]
185.9–188.1	GrN-6853	2520 ± 50	2360–2555–2751
196–198.2	GrN 5560	2830 ± 50	2780–2925–3071
202.7–204.9	GrN 6851	2600 ± 50	2506–2641–2777[a]
209.5–211.7	GrN-5559	2840 ± 50	2796–2935–3075
243–245.2	Beta-73084	3330 ± 50	3449–3564–3679
358.8–361	Beta-73085	3880 ± 60	4099–4264–4429
523.6–525.8	Beta-73086	4580 ± 50	5389–5419–5449
548.3–550.5	Beta-73087	4770 ± 60	5319–5469–5619

[a] Not used in sedimentation rate.

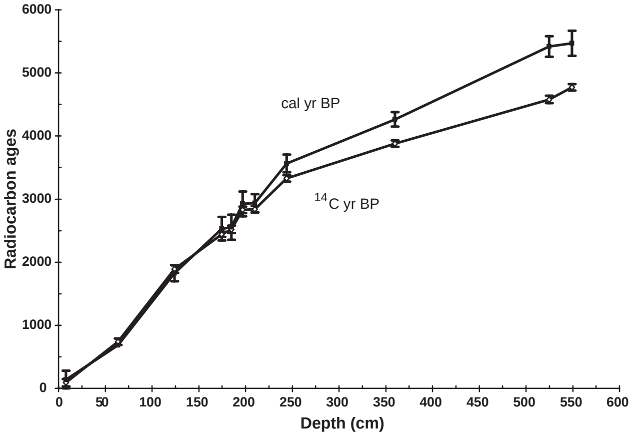

Fig. 5. Measured ^{14}C yr BP and calibrated ages BP (1950) Versus depth in core OW4.

4. Results

4.1. The modern diatom flora

Most of the species are in excellent state of preservation, but a few of them are fragmented. They belong to species colonizing large deep lakes (*Aulacoseira granulata* var. *valida*, *A. granulata* var. *tubulosa* and

Stephanodiscus neoastrea). They are also present in litter samples collected under forest, at 80 m above the present level of the lake (Nguetsop et al., 1998) and are therefore attributed to wind transport from the diatomites which outcrop in the arid areas of the Sahara, particularly in northern Chad (Servant-Vildary, 1978). It is unlikely that the species found in the surface sediments of the lake were reworked from the catchment because the frustules are more dissolved in the litter than in the lacustrine samples. Some similar wind transported diatoms (*Aulacoseira* spp.) have also been found in Atlantic deep-sea sediments and their presence has been interpreted in terms of climate variability (Pokras and Mix, 1985).

In lake Ossa, *Fragilaria leptostauron* var. *dubia* and *F. construens* are the most abundant alkaliphilous species, their optimum pH is around 8 according to the literature (Cholnoky, 1968). Acidophilous diatoms (Jones et al., 1990; Round, 1990) are mainly represented by *E. paludosa* var. *paludosa*, *E. pectinalis* var. *ventralis*, *Navicula heimansii*, *E. praerupta*, *Frustulia rhomboides* and *Eunotia incisa*. Other diatoms (*Pinnularia* spp.) are sometimes considered as indifferent to pH but they are widespread in acidic swampy environments (Krammer, 1992), they will be referred here as preferentially acidophilous. We will see later that this is in agreement with data from lake Ossa and surrounding lakes, particularly lake Mboli. Amongst the neutral or indifferent species *A. italica* and *A. muzzanensis* are the most abundant.

According to the different types of habitats, diatoms are usually classified into 5 life-form groups: planktonic, tychoplanktonic (facultative planktonic), benthic and epiphytic. Another group is also mentioned, it is composed of benthic or epiphytic species that are able to survive in shallow habitats that episodically dry up (aerophilic habitats). In lake Ossa, the planktonic are mainly represented by *A. italica* and *A. muzzanensis*, already mentioned as neutral or indifferent to pH. *A. italica* is a littoral species of the deep African lakes (Gasse, 1980), it is said to be planktonic by Cholnoky (1968). *A. muzzanensis* is planktonic (Schoeman, 1973; Gasse, 1980), sometimes present in shallow turbid waters. Tychoplanktonic species are represented by the alkaliphilous species *F. leptostauron* var. *dubia* and *F. construens*. They grow on littoral and benthic habitats or in very shallow water (Hustedt, 1930; Hustedt, 1957; Patrick and Reimer, 1966–1975; Gasse, 1980). Benthic species are represented by *Pinnularia viridiformis*, *P. subgibba* and *P. stomatophora*. Ecological data showed that these benthic taxa live in the periphyton of shallow lakes (Hustedt, 1930), rivers and bogs (Gasse, 1980), ponds and small lakes (Mölder und Tynii, 1968–1973) and bottom mud and mosses (Krammer and Lange-Bertalot, 1986–1991). The most abundant epiphytic taxa are *Achnanthes exigua* var. *exigua, A. lanceolata* and *Cymbella silesia*ca. *C. silesiaca* was encountered in epipelic or epiphytic habitats of numerous East African lakes (Gasse, 1986). The species, referred here as aerophilous are mainly represented by the acidophilous species *E. incisa*, *E. pectinalis var. ventralis* and *E.* spp. According to Hustedt (1930), the two first ones preferentially live in swampy areas, springs and ponds; according to Gasse (1980), *E. pectinalis* can grow as epiphytic, epipelic or aerophilous in peat-bogs, swamps, lakes and rivers.

The main species preserved in the surface sediments of the lake Ossa show ecological affinities in agreement with the data of the literature. Aerophilous diatoms are more abundant in samples (Fig. 6) where the water-depth ranges from 0 to 100 cm and planktonic diatoms in water-depth ranging from 100 to 290 cm (depths of the dry season). Tychoplanktonics are mainly represented, as planktonics, in the deepest areas, showing that they both live in similar habitats. We thus assume that the highest values of tychoplanktonics + planktonics characterize the deepest zones of the lake. Epiphytics and benthics are present everywhere, their abundance is highly variable, they do not show clear relationships with the water-depth (Fig. 6). Aerophilous and tychoplanktonic diatoms present in lake Ossa are acidophilous and alkaliphilous, respectively. The first group shows their maximum abundance in the samples collected in acidic waters ($\mathrm{pH} < 6.7$). In contrast, the second group (alkaliphilous tychoplanktonics) is essentially present in waters where the pH is alkaline during the dry season (Fig. 7).

In order to precise the spatial variations of the diatom assemblages, we present the abundance of the different ecological groups in 24 samples (Figs. 8 and 9). On the left side of the figures, 12 of the studied samples located near the western shore of lake Ossa are displayed from the north to the south; on the right side, 12 samples located in lake Mévia and in the south-eastern part of lake Ossa, also displayed from the north to the south. The highest abundance of planktonics (e.g. MV7, SO34) and tychoplanktonics (e.g. FOW8, FOW1) occurs in the inner parts of the lakes where the water-depth does not drop below 130 cm, even during the dry season. The alkaliphilous tychoplanktonics are more abundant in the areas where the pH is high (e.g. MV3) than in the areas where the pH is close to neutral (e.g. FOW3, FO11, MV13). This shows that in the inner part of the lake, the respective abundance of planktonics and tychoplanktonics is better explained by the values of pH in the dry season than by the water-depth.

The diatoms referred as aerophilous are dominant in the areas that dry up during the dry season especially in the shallowest acid zones at the northern part of lakes Ossa and Mévia (e.g. SO51, SO29 and MV8) and in the southern flat areas of lake Ossa (e.g. SO63, MB1). They are occasionally relatively abundant (e.g. SO20) in

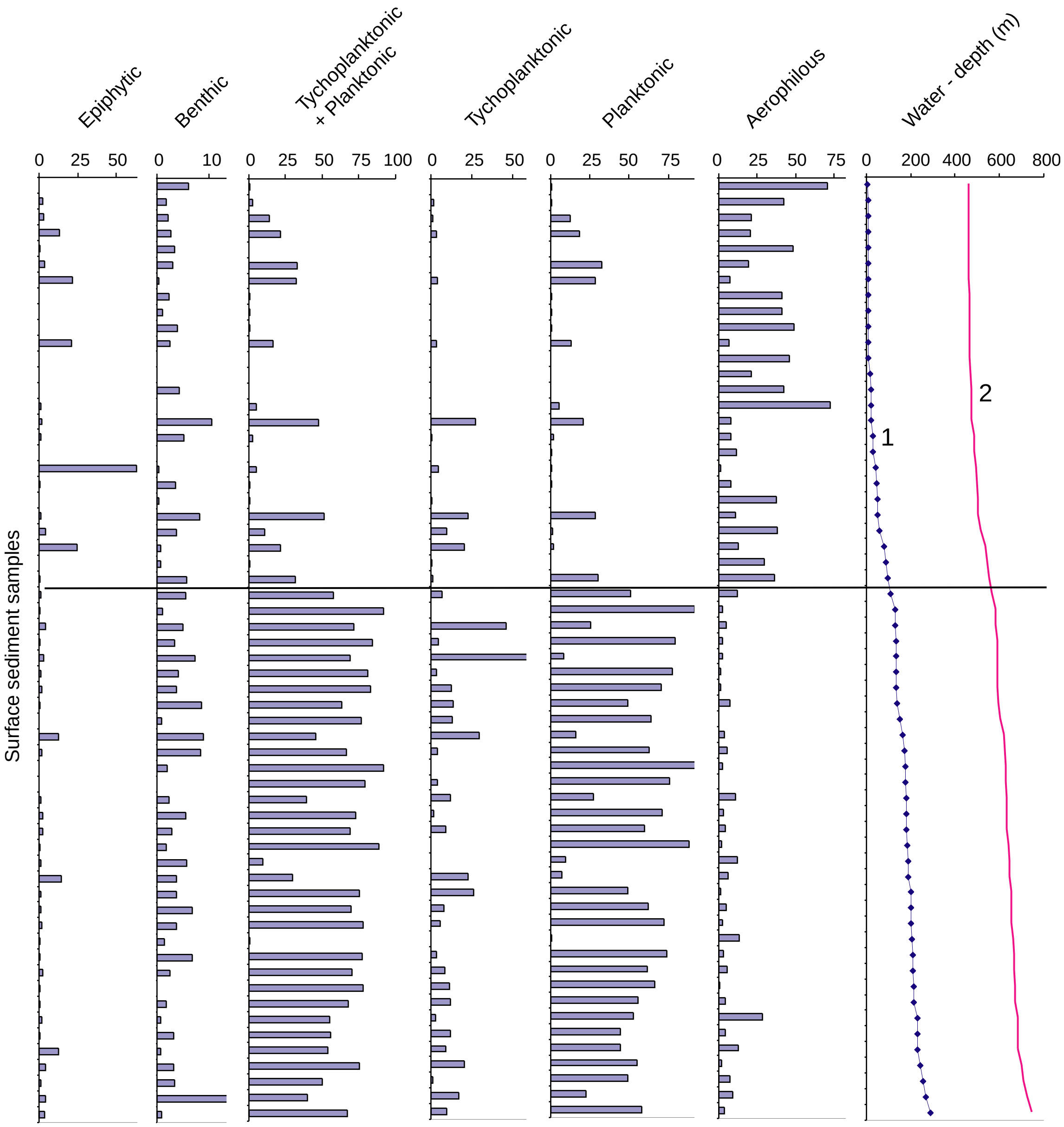

Fig. 6. Comparison between the abundance of diatom life-form groups and water-depth (1: during the dry season and 2: during the rainy season) in lakes Ossa and Mévia. Main aerophilous species: *Frustulia rhomboïdes*, *Eunotia incisa*, *E. pectinalis*, *E. praerupta*, *Navicula heimansii*. Main planktonic species: *Aulacoseira muzzanensis*, *A. italica*. Main tychoplanktonic species: *Fragilaria leptostauron* var. *dubia*, *F. construens* and *F. construens* var. *exigua*. Main benthic species: *P. stomatophora*, *P. viridiformis*, *P. subgibba*. Main epiphytic species: *Gomphonema lingulatiforme*, *Cymbella silesiaca*, *Achnanthes lanceolata*, *A. exigua*.

samples where the water-depth is high and the pH acid during the dry season. This confirms, in agreement with some data of the literature, that they are able to live as benthic or epiphytic both in permanent water bodies and in sub-aerial habitats. Epiphytic diatoms are present (<10%) in most of the samples of lake Ossa. They are more abundant in the swampy areas of the northern part of the lakes Ossa and Mévia (SO51, MV3) and can reach 30% in the southern flat areas (SO63).

The benthics are rare (e.g. MB1) or relatively abundant (e.g. MV8, SO55) both in shallow and relatively deep areas in a large range of pH in the dry season. Most of the benthics belong to the genus *Pinnularia*, referred above as indifferent or acidophilous. In the acidic relatively deep lake Mboli, diatom assemblages (not mentioned in Figs. 8 and 9) are characterized by very abundant *Pinnularia* spp. (60%). We therefore suggest that they can preferentially be acidophilous in the studied areas. If this is true, they likely developed in lakes Ossa and Mévia essentially during the rainy seasons when the waters tended to be acidic. They were mixed in the surface sediments with

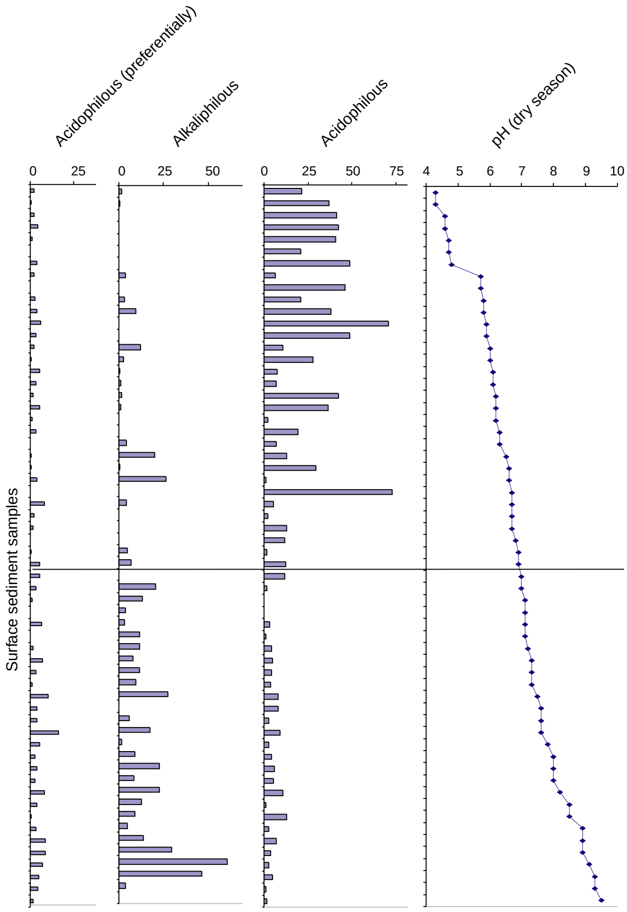

Fig. 7. Distribution of acidophilous, alkaliphilous diatom groups and *Pinnularia* spp (referred here as preferentially acidophilous) in the surface sediment samples of lakes Ossa and Mévia along a pH gradient (measured during the dry season). Acidophilous: *Frustulia rhomboïdes*, *Eunotia incisa*, *E. pectinalis*, *E. praerupta*, *Navicula heimansii*. Main alkaliphilous species: *Fragilaria leptostauron* var. *dubia*, *F. construens* and *F. construens* var. *exigua*. Main species of *Pinnularia* spp: *P. stomatophora*, *P. viridiformis*, *P. subgibba.*

alkaliphilous diatoms which developed under alkaline pH during the dry seasons.

Most of the modern samples are characterized by a dominant life-form group. We thus assume that this group reflects the environmental conditions that dominated during the period represented by a surface sample (at least several years). In some other samples, none of the groups is clearly dominant suggesting stronger environmental changes on seasonal to pluriannual time scales. This is observed for example in the flat areas of the southern border of the lake Ossa. This can be explained by seasonal desiccation and flooding.

In order to better illustrate the above observations, a Correspondence Analysis ordination (CA) was applied to the entire modern diatom data set including samples from the lakes Ossa, Mévia, Mboli, Nsipé and Ileka. In Fig. 10, the 24 samples of Figs. 8 and 9 are underlined. The species in the 74 samples were classified into pH and water-depth groups. Along axis 1 (36.8% of the total inertia) the samples collected in the shallowest and acid parts of the lake are located in the negative part of axis 1 (e.g. SO55, SO51), whereas samples collected in deeper water-depth are located in the positive part (e.g. FOW8). Axis 2 (28.1% of the total inertia) separates these samples into a group of neutral planktonic diatoms and a group of alkaliphilous tychoplanktonic species. The samples characterized by benthics and epiphytics are located close to the origin of the axes and close to the samples characterized by tychoplanktonic and alkaliphilous species, respectively. This analysis confirms that the diatom assemblages clearly separate the samples collected near the borders of the lakes (acidic waters all year around) from the samples located in the inner part (more or less alkaline in the dry season).

4.2. Fossil diatoms in core 0W4

Diatom assemblages of OW4 core are particularly significant because this core has been retrieved in a wind-sheltered zone which minimizes possibilities of sediment reworking. The fossil set is composed of 76 samples and 166 fossil taxa, 70% belong to the modern flora among which can be found all the dominant fossil species. It is thus possible to use the spatial distribution and the ecology of the modern flora to reconstruct past changes (Nguetsop et al., 2000). The sum of planktonic + tychoplanktonic species is nowadays at a maximum in the deepest parts of the lakes. In the past, its highest values can be interpreted as reflecting high water levels. Decreased percentage in planktonics + tychoplanktonics could indicate lower water level, but it must be interpreted with caution because it is due to increasing percentage of epiphytics and benthics that are found both in shallow and deep water depths (Fig. 6). The highest abundance of alkaliphilous species in the modern samples occurs in the areas where the pH is high during the dry season. At the coring site, the water is now neutral to slightly alkaline in the dry season, indifferent or circumneutral diatoms are dominant. We thus assume that in the past, dominant alkaliphilous species reflected higher pH than presently during most of the year, particularly when they reached abundances that are nowhere found in the modern assemblages.

Diatom assemblages showed a major abrupt change at 2700 cal yr BP allowing the definition of two main zones (Fig. 11). During zone II (5500–2700 cal yr BP), wind-transported diatoms are rare. Apparently, Saharan dust did not reach the Ossa region (Fig. 11C). High planktonic + tychoplanktonic percentages (60–90%) suggest that the water depth remained high throughout zone II (Fig. 11A). Changes in alkaliphilous species indicate 4 sub-zones corresponding to four successional stages in the pH at the sampling site (Fig. 11B). As at the

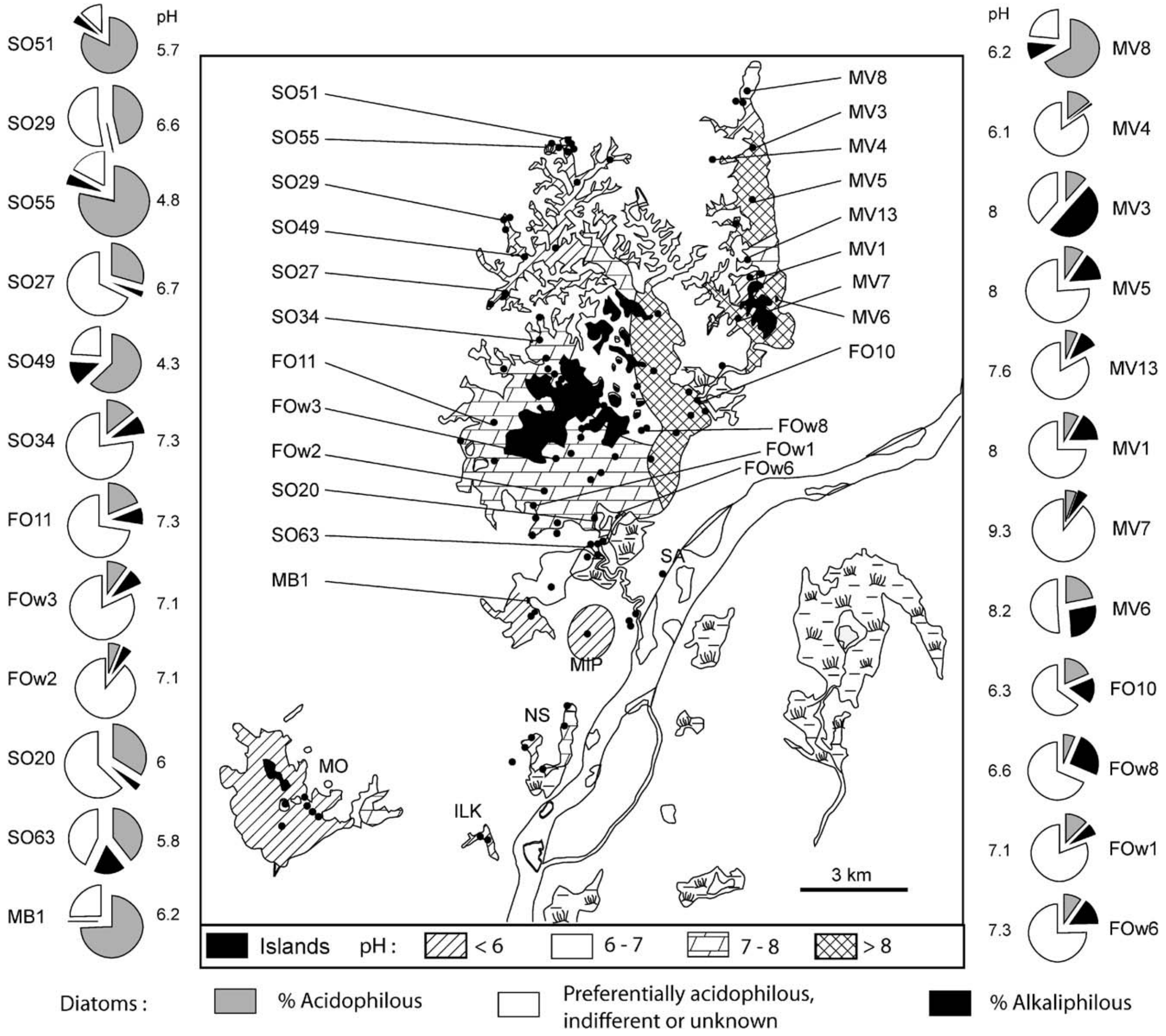

Fig. 8. Relative abundance of acidophilous, alkaliphilous and indifferent (or unknown affinity to pH) species in 12 samples listed from the northern to the southern border of lake Ossa (on the left) and in 12 samples from northern Mévia and south-eastern part of lake Ossa on the right. The spatial general features of the pH are suggested by the 74 measurements (dark points) during the dry season.

present time the pH was slightly alkaline or acid between 5500 and 5000 cal yr BP (IId). It increased between 5000 and 4500 cal yr BP (IIc). During sub-zone IIb (4500–3600 cal yr BP), the conditions prevailing in IId reappeared. In sub-zone IIa (3600–2700 cal yr BP), alkaliphilous species increased again from 20% to 72% and the pH reached its highest value of the all mid-late Holocene at the end of this sub-zone.

In zone I (2700 cal yr BP to present), wind-transported diatoms are continuously present. It is subdivided into four sub-zones. The sub-zone Id (2700–2100 cal yr BP) is characterized at the beginning (2700–2600 cal yr BP) by a sharp decrease in alkaliphilous species (from 72% to 14%) and then by rapid changes in the diatom assemblages. Benthic species peaked at 2650 cal yr BP, epiphytics at 2600 cal yr BP, planktonics at 2500 cal yr BP, epiphytics again at 2300 cal yr BP. Finally benthics peaked simultaneously with allochthonous diatoms between 2200 and 2100 cal yr BP. These changes suggest that the variability of the lacustrine environments on a secular time scale was stronger between 2700 and 2100 cal yr BP than before. Between 2100 and 1300 cal yr BP (subzone Ic), allochthonous diatoms were rare and for the first time epiphytic mixed with planktonic species reached more than 10%. In sub-zone Ib (1300–600 cal yr BP), the pH progressively increased toward values similar to those in IIc. At the beginning of Ia, by 600 cal yr BP, planktonics + tychoplanktonics were again dominant and slightly decreased between 500 and 250 cal yr BP. At that time, the abundance (15%) of

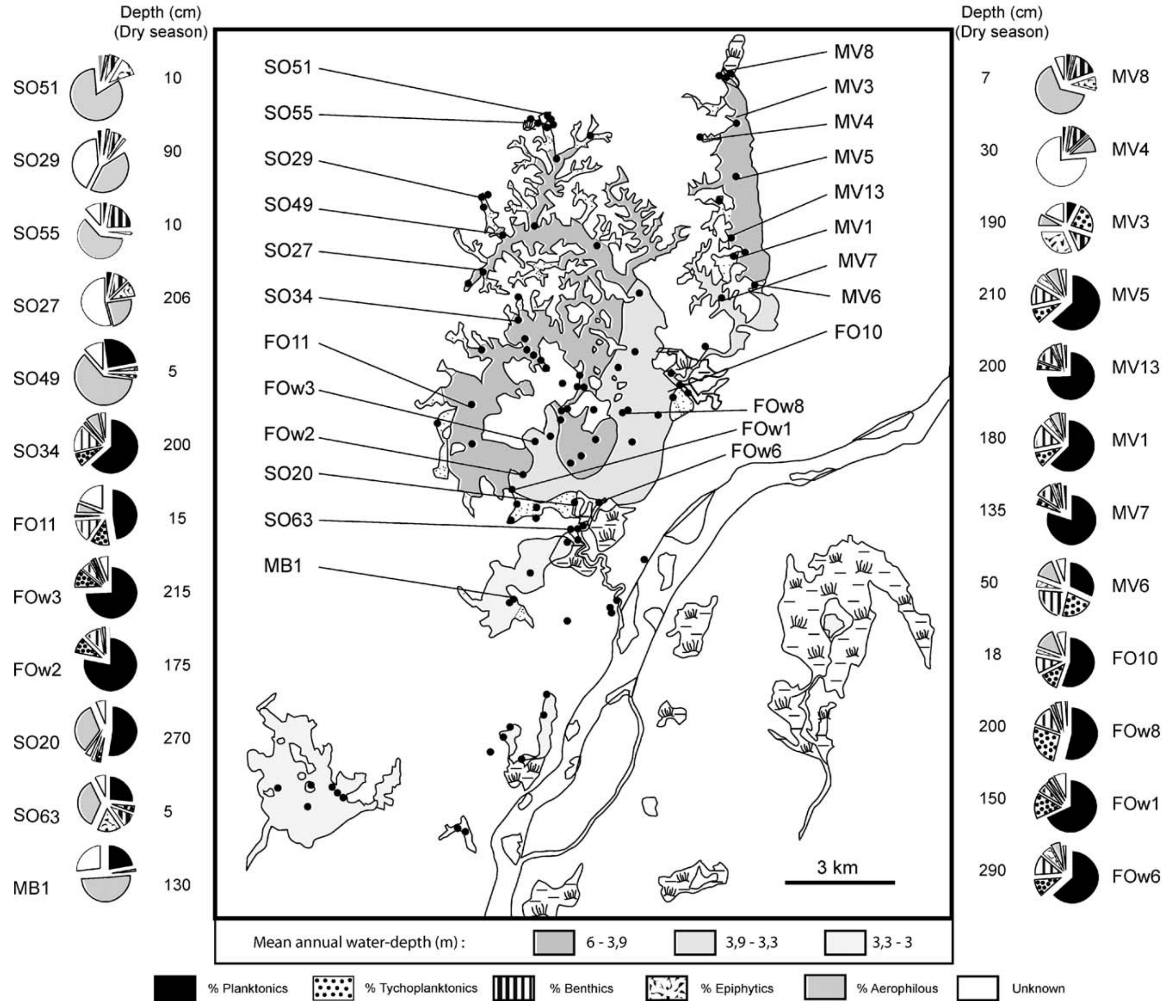

Fig. 9. Relative abundance of planktonics, tychoplanktonics (facultative planktonic), benthics, epiphytics, aerophilous and unknown preference to water-depth in 12 sites from the western part of Lake Ossa and 12 sites from Lake Mévia and the south-eastern part of lake Ossa. Spatial general features of mean annual water-depth are suggested by the 74 measurements (dark points) during the dry season and by monthly lake level measurements between September 92 and August 1993 (courtesy D. Wirrmann).

aerophilous species is the highest in the core suggesting significant environmental change. From 250 cal yr BP onwards, the hydrological conditions characterizing the base of the core (IId) reappeared, the water level was high and the pH low. Allochthonous diatoms were still present but less abundant than previously.

5. Interpretation

5.1. Paleoclimatic significance of diatoms

Saharan dust containing diatom remains from Quaternary deposits is transported by the northern trade winds essentially during the northern winter dry season between December and March, when the ITCZ is further south and the northern trade winds intensify (Suchel, 1988). Wind blown diatoms are therefore a good indicator both of a dry season centered around the boreal winter in the lake Ossa area and of an intensification of the northern trade winds over West Africa. Their appearance in core OW4 at 2700 cal yr BP and their persistence up to now (Fig. 11C) indicate more intense northern trade winds after 2700 years than before.

Increased/decreased diatom-inferred pH in the core can be considered as an indicator of low/high rainfall respectively, if one assumes that rainfall had similar

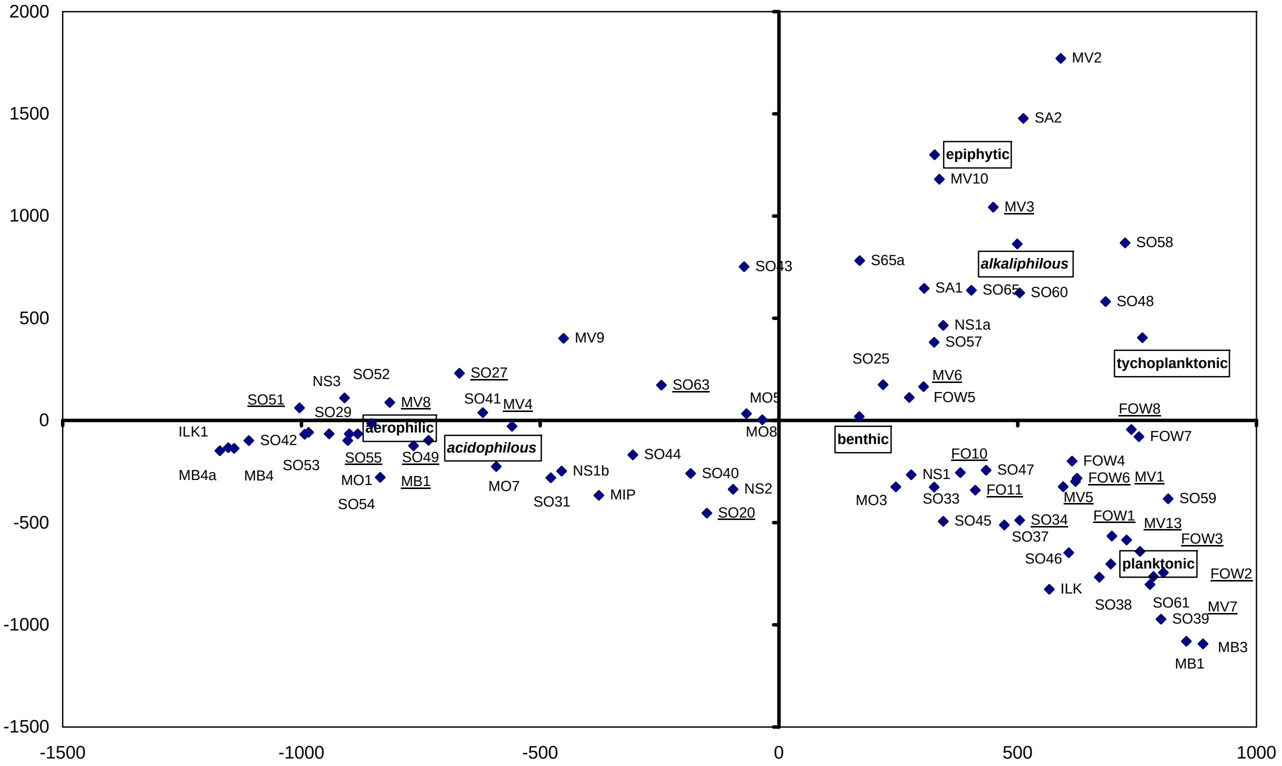

Fig. 10. Correspondence Analysis (CA) of 74 modern samples from Lake Ossa and other surrounding lakes. The 24 selected samples of Figs. 8 and 9 (underlined) are located along axes 1 and 2 within the whole modern data set.

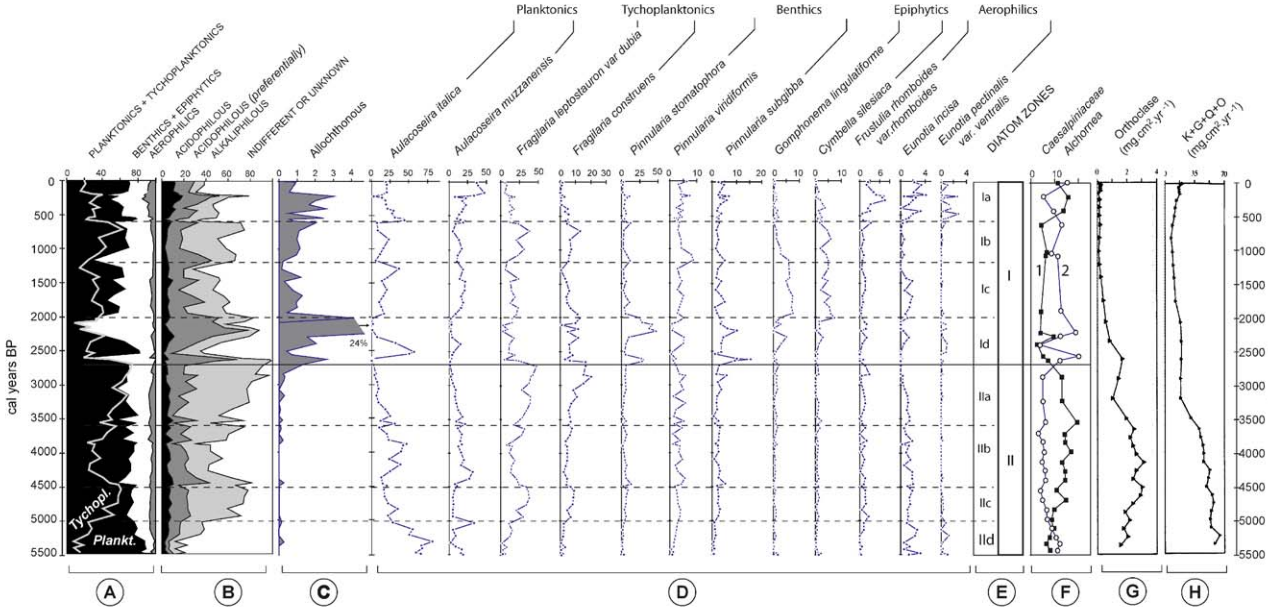

Fig. 11. Comparisons between diatom, pollen and sedimentological data in core OW4 presented Versus calendar ages. (A) planktonics + tychoplanktonics, benthics + epiphytics and aerophilics, (B) acidophilous, preferentially acidophilous, alkaliphilous, indifferent or unknown to pH, (C) allochthonous diatoms from Sahara, (D) relative variations of the 12 most abundant species, (E) diatom zones. (F) relative abundance of (1) Caesalpiniaceae (mature rain forest) and (2) *Alchornea* (heliophilous taxon linked to disturbed rain forest) according to Reynaud-Farrera et al. (1996). (G) and (H): orthoclase feldspath and total mineral fluxes, Kaolinite + Gibbsite + Quartz + Orthoclase (mg cm^{-2} yr^{-1}) according to Wirrmann et al. (2001).

acidity in the past as it is today. The periods 5000–4500 and 3600–2700 cal yr BP, where alkaliphilous (Fig. 11B) and planktonic species (11A) are abundant, were characterized by low precipitation (P), continuously high water levels (high P−E balance) and consequently low evaporation. This evokes the modern climatic conditions observed in South Congo during the southern winter when a relative stability of the atmosphere at low level causes low precipitation and low evaporation. The paleoclimatic significance of these specific conditions will be specified in the discussion. The period 1300–600 cal yr BP, also characterized by low precipitation (high abundance of alkaliphilous), shows significant percentage of wind blown diatoms, contrarily to periods 5000–4500, 3600–2700 cal yr BP. We thus suggest that reduced precipitation cannot be explained here by a northward shift of the climatic conditions now prevailing in South Congo during the southern winter. It was probably due to a longer than today dry season, centered around the northern winter.

We have shown in Section 2 that nowadays the effects of reduced precipitation on the water balance are weaker in lake Mévia than in lake Ossa. During the dry season, lake Ossa is essentially fed by alkaline waters from lake Mévia. Therefore, in the past and during the periods of low precipitation, lake Ossa was fed most by lake Mévia than by its own watershed. Consequently, the alkalinity at the coring site was intensified and the abundance of alkaliphilous species reached values nowhere found in the modern samples.

The periods 5500–5000, 4500–3600, 2700–1300 and 600–0 cal yr BP corresponded to phases of high precipitation. The P-E balance was globally high during these periods. However, several short spells (at around 2650, 2200–2100, 1300 and 250 cal yr BP) were marked by decreased percentages of planktonic + tychoplanktonic species due to peaks of benthics. This life-form group reaches here abundance very much higher than everywhere now in lakes Mévia and Ossa (Fig. 6). A modern analogue was found in one of the surrounding lakes, the lake Mboli, where the pH is acid and the water depth relatively high.

5.2. Comparisons with palynological data

Pollen analyses in the OW4 core (Reynaud-Farrera et al., 1996) showed that the rain forest persisted over the last 5500 years. However, if we take into account the respective abundance of Caesalpiniaceae (characteristic of mature rain forest) and heliophilous taxa as *Alchornea* (characteristic of openings in the canopy), the forest ecosystem has been modified (Fig. 11F). The strong abundance of *Alchornea* after 2600 cal yr BP were interpreted as due to a drier climate than before 2600 cal yr BP. But this does not fit with diatom data which show high long-lasting precipitation after 2700 cal yr BP. An alternative explanation can be deduced from the modern dynamics of the ecosystems. In the rain forest, canopy openings due to tree falls are usually observed just after a storm which causes stresses due to wind, water load on the foliage and reduced strength of the saturated soils. Thus, they are more frequent under climatic conditions characterized by an alternation of wet and dry episodes (Riéra and Alexandre, 1988). Moreover, large blowdowns due to convectional storms are likely to persist as areas of forest structure and composition for decades to centuries (Nelson et al., 1994). We thus assume that in the past, maximum disturbances in the forest can be explained by strong precipitation, convective storms and/or short time scale climatic changes. *Alchornea* was as abundant as Caesalpiniaceae between 5500 and 5200 cal yr BP, when P-E balance and P were high. After 2700 cal yr BP it became more abundant, under conditions of high precipitation. In contrast, the rain forest was less disturbed between 5200 and 2700 cal yr BP during a period characterized by a general trend of decreasing precipitation. The rain forest survived thanks to high atmospheric moisture, a cloud cover of stratiform type and subsequently relatively low temperature.

Because the Iron Age extended over the whole of forested equatorial Africa around 3000–2500 cal yr BP (Oslisly and Fontugne, 1993), forest disturbances after 2700 cal yr BP may be also linked to human activities. However, openings in the rain forest were observed in several regions without apparent relationships with human activities. In South Congo, heliophilous taxa reached their maximum abundance before the beginning of the Iron Age (Vincens et al.,1998), in French Guyana, Holocene forest disturbances occurred without any indication of the presence of human beings (Charles-Dominique et al., 1998). We believe that at Ossa, the forest disturbances reflected heavy rainfall and/or short term climatic variations. In other sites of West Cameroon, as the Barombi Mbo crater, the presence of Gramineae by 2500 cal yr BP, interpreted as due to a dry spell (Maley and Brenac, 1998), can also be explained by larger openings in the canopy due to highly unstable soils on deep slopes. In the marginal forested zones of South Congo, modern precipitation is close to the threshold ($\sim 1500\,\mathrm{mm\,yr^{-1}}$) which allows the forest to survive. In the past, major transformations of the ecosystems, attested by the appearance of included savannas (Vincens et al., 1999) could occur in response to small rainfall variations.

5.3. Comparisons with sedimentological data

Sedimentological analyses showed significant changes in the mineral fluxes along core OW4 (Wirrmann et al., 2001). Detrital minerals are essentially composed of Kaolinite (K), Gibbsite (G), Quartz (Q) and Orthoclase Feldspath (O), also present in the surface sediments. Orthoclase presents a peculiar interest because it is reworked from a rocky outcrop located near the northern border of lake Mévia. It is nowadays present solely in lake Mévia and near its outlet in the eastern and south-eastern part of lake Ossa. We think that this mineral can be a good indicator of water input from lake Mévia into lake Ossa.

Based on the assumption that the abundance of derived minerals was linked to the intensity of river water flow, Wirrmann et al., reported that high mineral flux between 5500 and 3200 cal yr BP (Fig. 11H) can be explained by higher precipitation than today, in agreement with the previous interpretation of Reynaud-Farrera et al. (1996) deduced from pollen. An alternative explanation is that the minerals deposited in the core area were mostly controlled by water inputs from lake Mévia. We may thus expect, according to our hydrological model presented in Section 2, that a higher abundance of orthoclase occurred during the periods of low precipitation (the relative contribution of lake Mévia to the feeding of lake Ossa is stronger when precipitation is low). If this is true, the strong abundance of orthoclase between 5500 and 2700 cal yr BP (Fig. 11G) may indicate a stronger influence of lake Mévia on the water balance of lake Ossa and consequently lower precipitation than today in the whole area. On the contrary, low abundance of this mineral (similar to present) from 2700 cal yr BP onward could indicate high precipitation as nowadays. The second explanation fits well with the diatom data.

6. Discussion

Since the 1960s, Bernard (1962) has linked the climatic variations in West Africa with the modifications in the location of the ITCZ during the northern and southern summer. In northern summer, the ITCZ corresponds to a limit between a SW moist wind-flow from the Guinean Gulf at low level and eastern wind-flows at mid-upper levels (Fig. 12, after Leroux, 1970, 2001). This limit rises up southwards and becomes vertical at the northern subequatorial latitudes. At these latitudes, a deep atmospheric convection entails abundant precipitation. Further south, subsiding air at the mid-level and atmospheric stability at low level entail cloud cover of a stratiform type, light rain and drizzle.

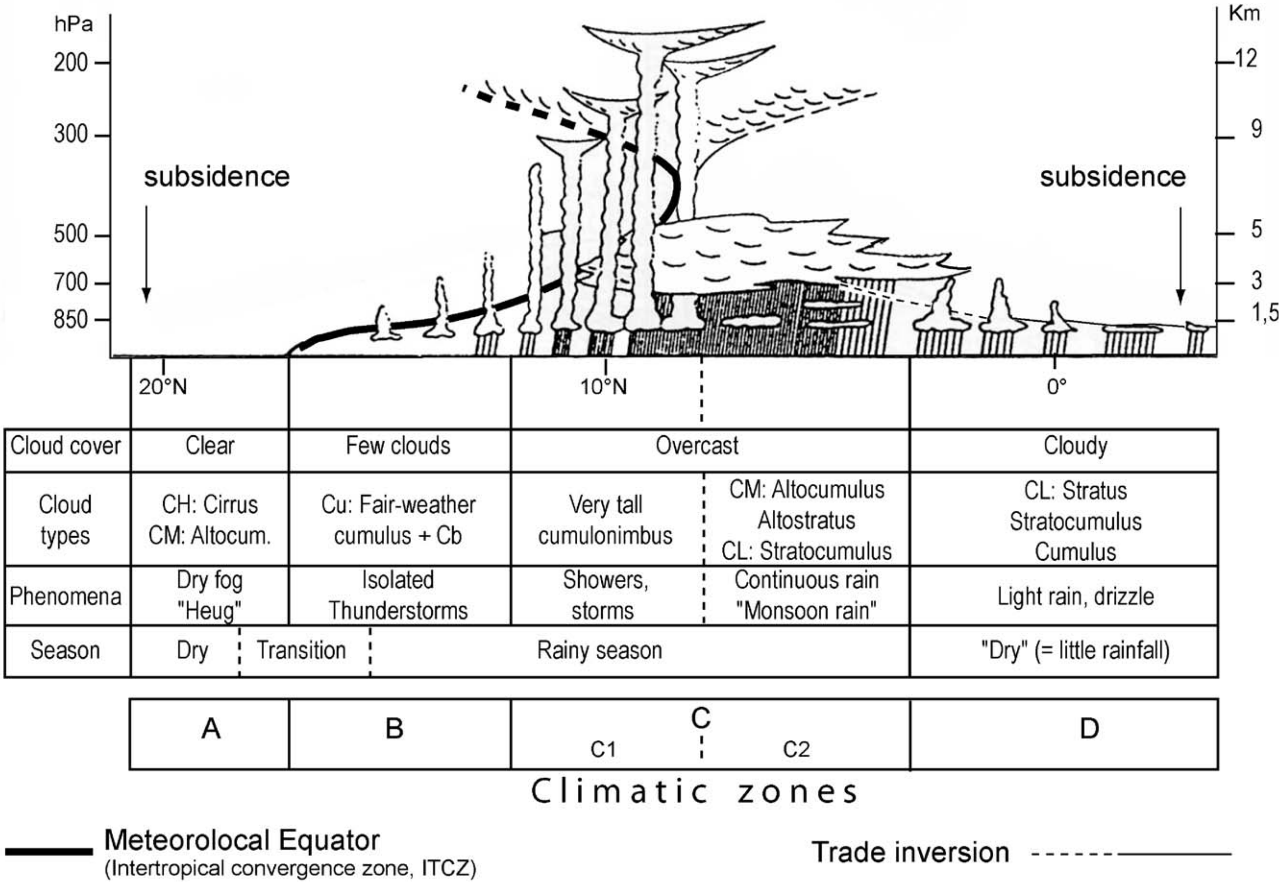

Fig. 12. North–South schematic cross-section of the troposphere over tropical Africa and general climatic pattern during the northern summer between 20°N and 5°S (after Leroux, 1970, 2001). The climatic zones A, B, C and D are defined by taking into account the seasonal variations: (A) aridity all year around. (B) alternation between a long dry and a short rainy season, centered respectively around January en July. (C) the northern winter dry season is shorter and finally (sub-zone C1) convective rainfalls occur during most of the year, only interrupted by a short dry season in the boreal winter. (D) a dry season occurs during the southern winter, it is particularly well-marked south of the equator. This dry season presents peculiar characteristics because weak precipitation is associated to a high water vapor content of the atmosphere and low cloud cover.

During the northern winter, dry wind-flow from Sahara extends towards the equator entailing a dry season, with a duration that becomes shorter southwards. At upper-mid level, the ITCZ is located at the southern subequatorial latitude (Fig. 1A). According to these general atmospheric features, we can expect that, in the past, higher and lower precipitation occurred at the northern subtropics and at the northern subequatorial zone, respectively, when the ITCZ shifted north of its present position. In contrast, when the ITCZ was close to its present position, arid conditions prevailed in the southern Sahara and high precipitation occurred in the subequatorial zone. Finally, if the ITCZ shifted further south, we can expect a well-marked dry season at the northern subequatorial latitude and a longer wet season at the southern subequatorial latitudes, during the northern winter.

6.1. *Comparison between data from ossa and data from the northern subtropics*

We will show now that the above model fits well with available data by comparing the late Holocene climatic evolution at Ossa and in the sub-Saharan zone (13°N–21°N). In eastern Niger and northern Chad, the climate was wetter than today up to 6500 cal yr BP, a dry trend began just after and the P-E balance reached its lowest value at around 4000 cal yr BP (Servant and Servant-Vildary, 1980). At that date, most of the lakes dried up in the southern Sahara but persisted in the Sahelian belt, south of 16°N–17°N (Gasse, 2000). Although poorly dated, a high resolution diatom record at Tjéri, Chad (13°44′N, 16°30′E) has shown that several short-term climatic oscillations were superimposed on this dry trend (Servant-Vildary, 1978). Such oscillations were also suggested in the Southern Sahara according to an overview of radiocarbon dates on lacustrine samples (Vernet, 1995). Paleolakes retreated at around 5800 cal yr BP, probably extended by 4700 and again by 4400 cal yr BP before the well-known dry phase at around 4000 cal yr BP. A last water-level positive oscillation began just before 3500 and lasted up to 2800 cal yr BP in several areas. Finally, at around 2800 cal yr BP, arid conditions settled in the southern Sahara and most of the lakes dried up completely in the Sahelian belt. Concerning the last 2800 years, we know little about the climatic evolution in the northern subtropics. According to historical data, Maley (1981) suggested that several severe droughts occurred in the lake Chad area (~13°N) just after 600 cal yr BP.

The high precipitation phase at Ossa between 5500 and 5000 cal yr BP coincided with the beginning of a dry trend in Southern Sahara. Decreasing precipitation at Ossa (5000–4500 cal yr BP) could correspond to wet episodes in the Southern Sahara, if one admits that the lakes extended by 4700 and 4200 cal yr BP. A positive oscillation in precipitation at Ossa between 4500 and 3900 cal yr BP is correlated with the well-known dry phase in the sub-Saharan zone at 4000 cal yr BP. Conversely, the decreasing precipitation trend between 3900 and 2700 cal yr BP at Ossa was coincident with rising water level in the Sahelian and southern Saharan zones. The desiccation of the lakes in the northern subtropics by 2800 cal yr BP was synchronous with an abrupt increase precipitation at Ossa. Finally, the last period of increasing precipitation, which began at 600 cal yr BP at Ossa, could correspond to severe droughts in the lake Chad area.

Changes in the location of the ITCZ can explain the opposite climatic changes at the subequatorial latitudes of Ossa and at the northern subtropics. When the ITCZ shifted northwards, the southern Sahara experienced high P-E balance and in the Ossa area the climatic conditions (low P and low E) were similar to the ones which now occur in South Congo during the austral winter. When the ITCZ shifted southwards, high precipitation due to the location of the subequatorial deep atmospheric convection close to its present position, occurred at Ossa and dry conditions settled in the southern Sahara.

Arid conditions in the Sahara was registered by the deposition of Saharan dust in the eastern Atlantic and in the near-coastal areas in the Gulf of Guinea. Saharan atmospheric dust abruptly increased by 5500 cal yr BP in the core 658C (20°45′N, 18°35′W) retrieved off Mauritania (deMenocal et al., 2000) and only by 2700 cal yr BP at Ossa. The first change reflected a well-known evolution toward aridity in the central and northern Sahara whereas the second one reflected a larger southward extension of arid areas when most of the lakes dried up in the Sahelian zone.

6.2. *Comparisons with the northern and southern high latitudes*

The episodes characterized by dryness in the sub-Saharan zone and high precipitation at Ossa, which were explained above by a southwards displacement of the ITCZ, occurred at dates close to cold events (Fig. 13G) identified in the northern Atlantic (Bond et al., 1997). Similar climatic linkages between high and low latitudes were also documented in the Core 658C off Mauritania. A strengthening of the Canarian cold current or increased coastal upwelling occurred in phase with cold northern Atlantic events (DeMenocal et al., 2000) indicating an intensification in the northern trade winds along the west-African coast. We thus assume that phases of trade-wind intensification could also have entailed a southwards shift of the ITCZ and subsequently dry phases in the northern subtropics and high precipitation phases at Ossa. The two enhanced precipitation phases which began at Ossa at 4300 and

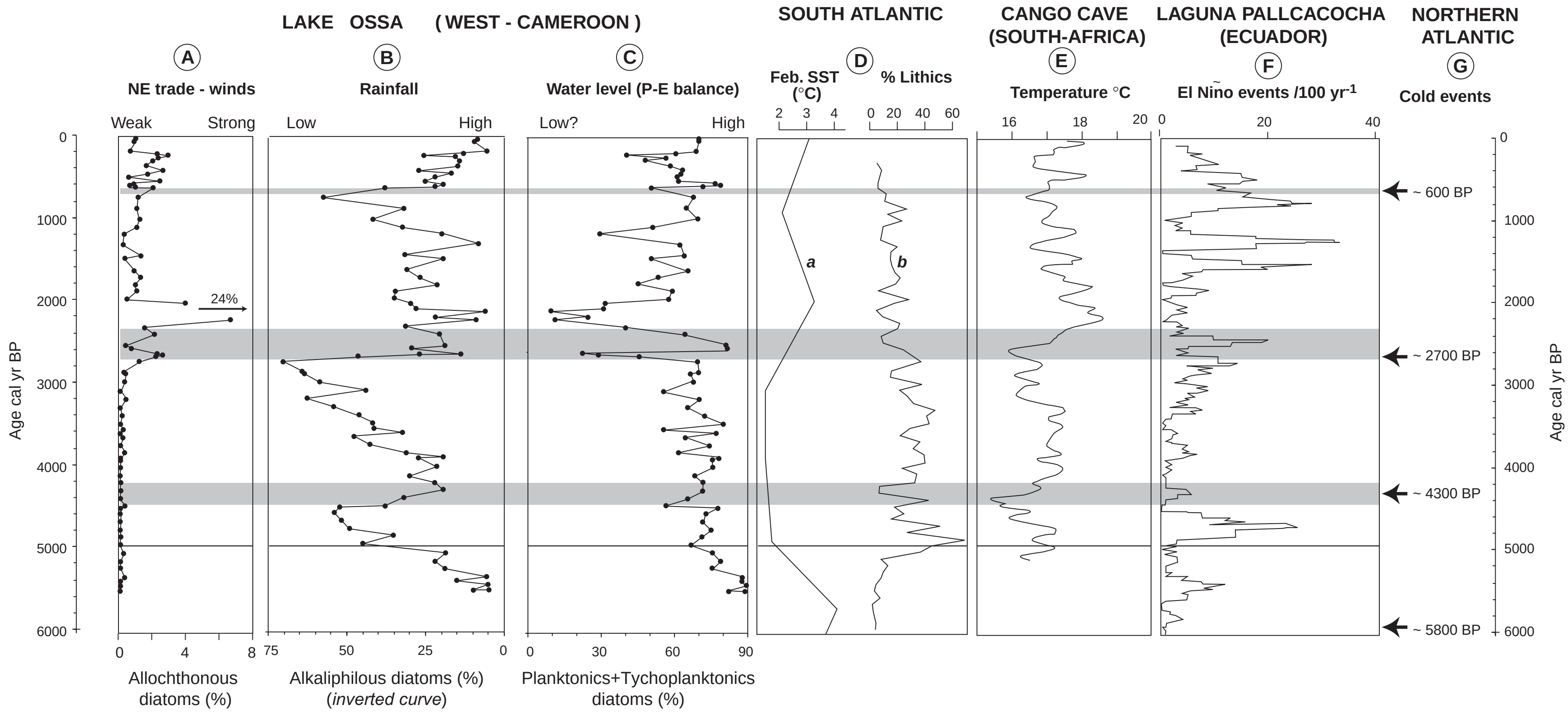

Fig. 13. Comparisons between lake Ossa (West Cameroon), South Atlantic, South Africa and Ecuador. (A) variations in NE trade winds according to allochthonous diatoms; (B) relative changes in rainfall inferred from alkaliphilous diatoms, (C) relative changes in the P-E balance inferred from planktonic + tychoplanktonic diatoms. High abundance of planktonics + tychoplanktonics indicates high water level. Low abundance can be interpreted or as low water level or low pH, (D) climate-proxies from the South-Atlantic core TTN057-13-PC4; (a) February sea surface temperature; (b) relative percent of lithics (Hodell et al., 2001), (E) temperature changes inferred from stable isotopes in speleothem of Cango caves, South Africa (Talma and Vogel, 1992), (F) variations in El Niño frequency inferred from alluviations in Laguna Pallcacocha Ecuador (Rodbell et al., 1999), (G) North-Atlantic cold events (Bond et al., 1997).

2700 cal yr BP closely match with cold events off Mauritania, although timing effects are possible within dating uncertainties. The highest value of Saharan dust input in lake Ossa occurred at 2200–2000 cal yr BP just before a cold event off Mauritania, dated 1900 cal yr BP. Low precipitation by 800–700 cal yr BP interpreted at Ossa as the result of the boreal winter southernmost position of the ITCZ, is close to another cold event dated 800 cal yr BP in Core 658C. These comparisons suggest that modifications in the intensity of the northern trade winds may have been one of the main causes of the millennial-scale changes in temperature off Mauritania and precipitation at Ossa.

Another cause can also be found in the temperature variations in the southern Atlantic: precipitation trends at Ossa look coincident with SSTs trend in the southern Atlantic (Fig. 13B and D). A sharp decrease in temperature in February and a sea ice expansion by 5000 cal yr BP, recorded in core TTN057-13-PC4 (Hodell et al., 2001), coincided closely with a precipitation decrease at Ossa, also registered in the lakes Kitina and Sinnda in South-Congo (Vincens et al., 1998; Bertaux et al., 2000). Between 5000 and 2700 cal yr BP, a cold trend in the southern Atlantic coincided with a general precipitation decrease at Ossa. A similar lowered sea surface temperature has also been observed at the early late Holocene transition in the Benguela zone (Morley and Dworetsky, 1993). Conversely enhanced temperature in the South Atlantic and increased precipitation at Ossa appeared quasi simultaneously by 3000–2700 cal yr BP. More precise correlation appears with temperatures inferred from speleothem at Cango caves, South Africa (Talma and Vogel, 1992). Increased precipitation at 4500–4300 cal yr BP and at around 2700–2600 cal yr BP at Ossa can be equated with temperature increases at Cango caves (Fig. 13B and E).

The rapid climatic change at 2700 cal yr BP was the most prominent event highlighted at Ossa. According to the above comparisons, it was linked both to a cold spell in the northern Atlantic and increased temperature in the southern Atlantic and in South Africa. Numerous evidence from Europe and other continents show that it was a worldwide event (Van Geel et al., 1996).

6.3. *Comparisons with the other sites in the subequatorial regions*

Our model that links the climatic changes at Ossa with the changes in the location of the sub equatorial deep atmospheric convection fits with the other available data in West Cameroon. The intense forest disturbances in lake Barombi Mbo by 2500 cal yr BP (Maley and Brenac, 1998) can be explained, as at Ossa, by enhanced rainfall and convective storms. At higher altitude (2264 m a.s.l.), in lake Bambili, the water level was low between 5500 and 2700 cal yr BP. At that time, in West Cameroon the atmosphere was relatively stable at low level and subsident at mid-upper levels, generating a low cloud cover, similar to the conditions which nowadays characterize South Congo during the austral winter. The Ossa area located at low altitude was thus subjected to low evaporation and the lake level remained high despite low precipitation. On the contrary, because of its higher altitude, the Bambili area was located above the cloud cover and was subjected to atmospheric subsidence. Subsequently, weaker nebulosity and higher evaporation combined with low precipitation were responsible for a lower P-E balance. At about 2700 cal yr BP, the lake Bambili water level rose and reached its highest level by 2200 cal yr BP (Stager and Anfang-Sutter, 1999), in coincidence with precipitation increase at Ossa. Both areas fell into the subequatorial deep convection zone for most of the year, as nowadays.

The settlement of a deep atmospheric convection also occurred in other subequatorial regions but at different dates. In lake Bosumtwi (Ghana), slack winds and/or weak seasonal temperature variations were replaced at 3600–3200 cal yr BP by stronger winds and/or significant seasonal variations (Talbot et al., 1984; Talbot and Johannessen, 1992). Slack winds and/or weak seasonal temperature variations were likely due to atmospheric stability at low level and the presence of a cloud cover of a stratiform type throughout the year. In contrast, from 3600 to 3200 cal yr BP onwards, the area experienced strong winds and more intense seasonal variations in temperature due to convectional storms and significant changes in precipitation and nebulosity throughout the year. Intensified convective rainfall could be linked to increased SSTs and/or weakened coastal upwelling off Ghana. This climatic transition has been punctuated by a sharp water-level drop probably due to the settlement of a well-marked northern winter dry season.

In South Congo, near the southern boundary of the rain forest, the late Holocene paleoenvironmental changes were more intense than in the lowlands of West Cameroon. In lake Kitina, palynological and sedimentological data (Vincens et al., 1998; Bertaux et al., 2000) have suggested stronger disturbances in the rain forest than at Ossa (higher abundance of heliophilous taxa) and an evolution towards a semideciduous facies between 6200 and 2700 cal yr BP. A major lowering in rainfall is recorded by the appearance of included savannas at 2700 cal yr BP at Kitina and by a desiccation of lake Sinnda after 4400 cal yr BP (Vincens et al., 1994). It has been followed by a wetter climate recorded by the filling up of lake Sinnda and a progressive reforestation in the Kitina area after 1300 cal yr BP. These data show that drier conditions than to day prevailed between 2700 and 1300 cal yr BP in South Congo when precipitation increased at Ossa. This suggests that, at that time, the deep atmospheric convection zone and associated rainfall were located at the latitude of Ossa during most of the year and only reached South Congo episodically. A possible explanation is that the Benguela current and/or the coastal upwelling east of the Guinean Gulf were still stronger than to day, entailing dryness in the near-coastal areas. From 1300 to 600 cal yr BP, wetter conditions settled in South Congo, the forest extended and lake Sinnda filled up. Because the Ossa area was subjected to lower precipitation during this time interval, we assume that the subequatorial deep atmospheric convection zone was located south of its present position during a longer part of the year than today. Subsequently, the northern winter dry season intensified at Ossa whereas South Congo was subjected to a longer rainy season. The ITCZ probably reached its southernmost position at that time.

Finally, all these data show that the climatic conditions characterized by convective rainfall for most of the year was established at 3700–3200 cal yr BP in Ghana and 2700 cal yr BP in West Cameroon. In South Congo, convective rainfall was reinforced at around 1300 cal yr BP. These time-lags strongly suggest that the coastal upwelling weakened and/or sea surface temperature increased, gradually from Ghana to South-Congo. This evolution was coincident with an increasing frequency of warm events of the El Niño/Southern oscillation (Fig. 13F) previously highlighted on the Peruvian coast (Sandweiss et al., 2001) and in Ecuador (Rodbell et al., 1999; Rowe et al., 2002).

7. Conclusion

Most of the available data in West Africa for the Holocene concern P-E balance and vegetation changes. The OW4 core of lake Ossa is the only late Holocene continental record in West Africa which provided information on the precipitation changes. Alternation between periods of increasing (5500–5000, 4500–3600, 2700–1300, 600–0 cal yr BP) and decreasing precipitation (5000–4500, 3600–2700, 1300–600 cal yr BP) are now well-documented at a millennium time scale for the last 5500 years. They are interpreted as a result of south/northward shifts of the ITCZ. A southward shift of the ITCZ, combined with strengthened northern trade winds, was marked by low and high precipitation at the northern subtropics and the subequatorial zone respectively. These events occurred in coincidence with cold spells in the northern Atlantic. The most intense event at 2700 cal yr BP (abrupt precipitation increase at Ossa) coincided with increased temperature in the southern Atlantic and in South-Africa. All these data suggest that the climatic evolution in the tropical zone of Africa was essentially driven by interactions between the northern and the southern hemispheres, however, these interhemispheric relationships were probably modulated by increasing frequency in El Niño-like events.

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