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The history of the mangrove vegetation in Bénin during the Holocene: A palynological study

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ABSTRACT

Pollen analysis of three core samples,YEV-I, GOHO.00 and DO.00, taken in the coastal area of Bénin shows the existence of mangrove during the Holocene. This mangrove underwent many physiognomic changes from the middle to the late Holocene. In the course of the middle Holocene (from 7500 to 2500 years before present (BP)), it stretched over a large area from the littoral inland. It was tightly closed and almost monospecific, dominated by *Rhizophora*. During the late Holocene, this mangrove started to regress around 3000 years BP and disappeared about 2500 years BP from the studied sites. It has been replaced by swamp meadows dominated by *Paspalum vaginatum* Sw. and a fresh water environment colonised by taxa such as *Persicaria*, *Typha*, *Ludwigia*, and *Nymphaea*.

1. Introduction

The mangrove is a halophitic vegetation, characteristic of coasts, deltas and lagoons in tropical areas, and is especially adapted to the tide. In Bénin, it occurs along the coast, where the ecological conditions are not sufficient for its optimum development (dry subequatorial climate); the height of the tide is of microtidal type. These conditions have been disrupted by a dam built on the River Mono in 1987 (Blasco, 1985; Akoègninou et al., 1997). The mangrove in Bénin currently occurs only in the central and western parts of the coastal area, while the eastern part is occupied by fresh water swamp forests, containing typical species such as *Raphia hookeri*, and swampy savannas. However, the evidence collected by Paradis (1976b), Baglo (1984) and Akoègninou et al. (1997) among others shows that the inland lakes and inland lagoon spaces of the east coast of Bénin were covered by mangrove until a few decades ago. There is mangrove forest in the deltaic area of Nigeria (east of Benin) and from Togbin (west of Cotonou) up to Grand-Popo. Curiously, however, between these blocks, swampy forests intervene. Paradis (1976b) explained that ecological mutations, characterised by a palaeo-ecological phase dated about 5500 years BP, provided for the development of the mangrove. This phase coincided with the Nouackchottian transgression, which would have enabled the extension of the mangrove all along the coast and further into the river valleys. The dynamics of the mangrove during the Quaternary have attracted many studies in West Africa, especially in Côte d'Ivoire (Assémien et al., 1971; Frédoux, 1994), Nigeria (Sowunmi, 1981a,b, 1987, 2004; Dupont et al., 2000) and Senegal (Lezine, 1986, 1996). In Bénin, many works related to the mangrove vegetation were concerned with its present structure and the factors that caused its degradation (Paradis and Adjanohoun, 1974; Paradis, 1980; Gaillard et al., 1982; Baglo, 1984; Akoègninou et al., 1997). The only study that focused on the history of the mangrove in Bénin is that of Paradis (1976b).

The present article sums up the palynological study of three cores taken in Benin's coastal strip within the framework of the "Dahomey-Gap" project. The major aim of this project is to contribute to the elucidation of the vegetational history of the dry corridor, or Dahomey-gap, during the last 10,000 years.

2. Materials and methods

2.1. Field study

2.1.1. Climate and vegetation

The sites studied are located in the coastal zone (Fig. 1) as defined by Adjanohoun (1968) and White (1983). The climate is a subequatorial type with four seasons, two dry and two rainy. The annual average temperature is around 27 °C and the mean annual rainfall is about 1400 mm.

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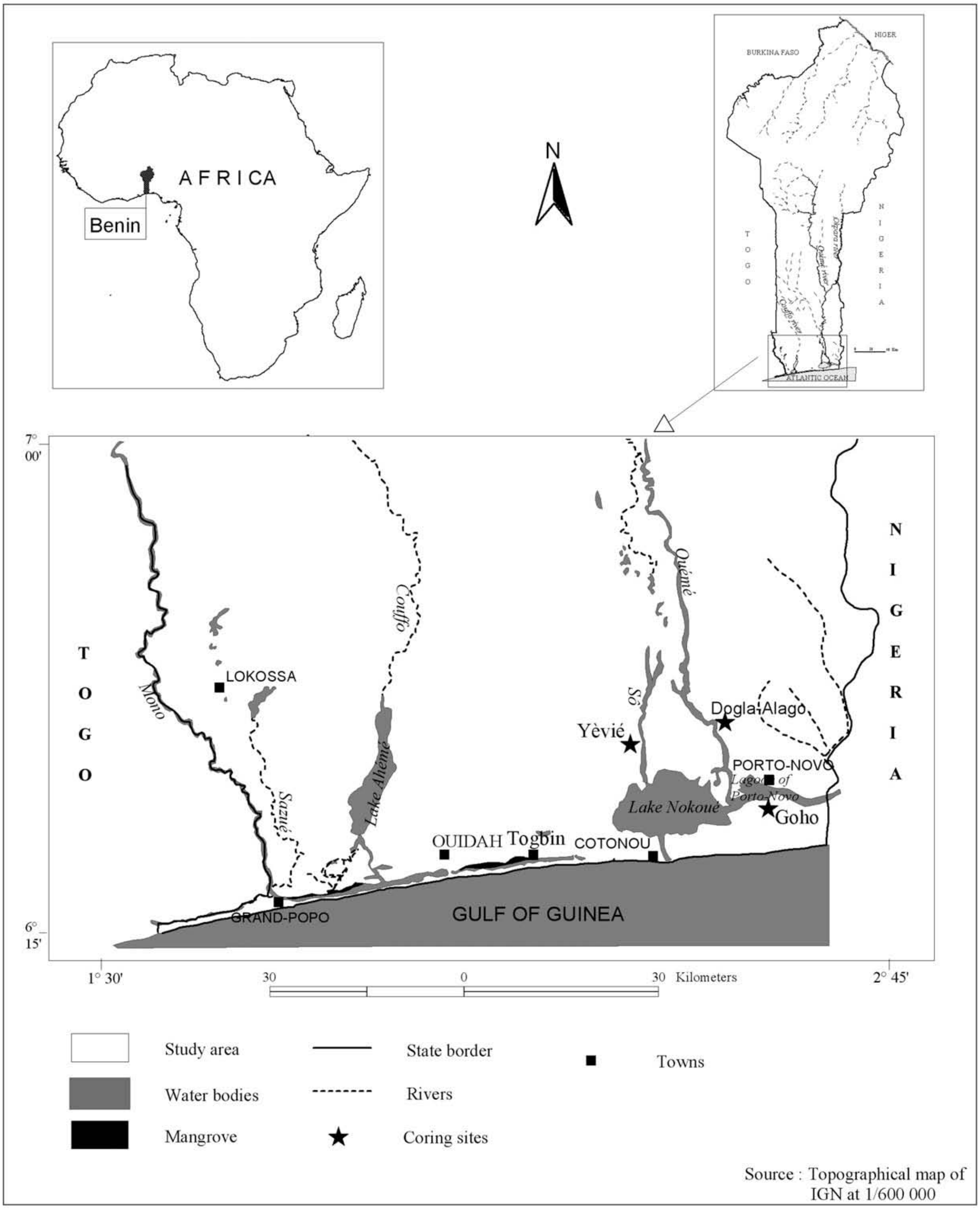

Source : Topographical map of IGN at 1/600 000

Fig. 1. Situation of coring sites.

The vegetation consists of grasses and coastal thickets, meadows, mangrove, fresh water swamp forests, dense semi-deciduous forests and Guinean savannas (Paradis, 1975, 1976a, 1977; Adjanohoun, 1968; Adjakidjè, 1984; Akoègninou, 1984). Bénin mangrove is very poor in species (Akoègninou et al., 1997; Akoègninou, 2004; De Foucault et al., 1999). The characteristic species are *Rhizophora racemosa* G. Mey. and *Avicennia germinans* (L.) L. We have added *Acrostichum aureum* L., *Phoenix reclinata* Jacq., *Laguncularia racemosa* (L.) Gaertn.f., *Conocarpus erectus* L. and *Machaerium lunatum* (L.f.) Ducke.

2.1.2. Sampling

The samples were collected, using a Livingstone modified piston corer, at sites located in Dogla-Alago in the lower valley of the Ouémé river and Yevié areas, north lake Nokoué and Goho, alongside the lagoon of Porto-Novo. They measured, respectively, 730, 455 and 990 cm. The geographic coordinates of the sites are, respectively, 6°36’25’’N, 2°35’43’’E; 6°32’06’’N, 2° 22’42’’E and 6°26’35’’N, 2°34’45’’E (Fig. 1).

Colour determination was performed using the Munsell soil colour chart. Dating control was provided by nine (09) radiocarbon dates (AMS) from peat.

2.2. Laboratory analysis

In total, 212 sub-samples were analysed. For each sub-sample, 0.3 g of sediment taken at intervals of 10 cm along the whole length of each core was treated. The analysis was carried out at the Palynology laboratory of the University of Frankfurt in Germany using the method of Faegri and Iversen (1989) method. The pollen count was performed using an Olympus® optical microscope at 200×, 400×, and 1000× magnifications. The counting was based on a full sweeping of the entire slide surface. Total counts ranged from approximately 1–6880 pollen grains per sample. Identifications were made by comparison with reference collections of the Palynology units of the University of Abomey-Calavi (Bénin), Ibadan (Nigeria), Angers (France) and Frankfurt (Germany) and the published literature (Sowunmi, 1973, 1995; Caratini and Guinet, 1974; Ybert, 1979; Thanikaimoni, 1987; Punt et al., 1994) Pollen percentages were based on the sum of arboreal and non-arboreal pollen taxa. For the calculation of percentages of pollen from mangrove trees (*Rhizophora*, *Acrostichum* and *Avicennia*) and aquatic taxa such as *Cyperaceae*, or *Nymphaea*, pollen from forest and non-aquatic herbaceous taxa was excluded.

The botanic identification of pollen and spores was made either at family level only, or at genus or species level. The nomenclature is that of Akoègninou et al. (2006) and Lebrun and Stork (1991–1997), and the African Pollen Database (APD). Pollen diagrams were plotted using the software TILIA and TILIA-GRAPH (Grimm, 1991).

3. Results

3.1. Lithology

Sand became struck on the base of YEV-I and GOHO-cores, at which point coring became impossible. This was not the case for the DO.OO core, where we noted the presence of resistant clay that made coring impossible. Among the three cores, two (YEV-I and DO.OO) were richer in peat while the other one, GOHO.OO, was richer in clay. Eight informal lithological units were recognised on the basis of colour (Tables 1–3).

3.2. Radiocarbon dating

Nine AMS-generated radiocarbon dates were obtained from the three cores (Table 4). The estimated average sediment accumulation rates of the three cores were as follows:

- DO.00: 0.2 cm/year for 970–404 cm and 0.07 cm/year for 404–159 cm.
- YEV-I: 0.21 cm/year for 425–235 cm and 0.05 cm/year between 235 and 45 cm.
- GOHO-00: 0.7 cm/year for 728–257 and 0.031 cm/year between 257 and 99 cm.

Two observations can be noted:

- The estimated average sediment accumulation rates of every core appeared higher at their base but lower at their top. According to Agassounon (2002) and Sowunmi (2004), this suggests a probable hiatus in accumulation.
- The estimated average sediment accumulation rate at the base was similar for the YEV-I and DO.OO cores, which were situated at higher latitude (respectively 6°32’N and 6°36’N). However, this rate was lower than that of the GOHO.OO core, which is situated below the river.

3.3. Pollen diagram/phytoecological groups

3.3.1. YEV-I core

For the core YEV-I, 42 samples were analysed. The number of pollen grains counted varied between 1 and 1275. The pollen diagram of the core shows two pollen zones: YVI and YVII (Fig. 3).

The pollen zone YVI (455–75 cm) is constantly characterised by the predominance of pollen of *R. racemosa* type and of *A. aureum*, at percentages that reach a maximum of 90% for the first and 20–40% for the second. Poaceae pollen is observed at rates that fluctuate between 10% and 30%. Dinoflagellate cysts are relatively well represented (at between 5% and 30%).

The second pollen zone, YVII, (75–455 cm) is characterised by the disappearance of *R. racemosa*–type. At the upper levels of the diagram, the dominating taxa are Poaceae and spores. The taxa of fresh water species from swampy areas, such as *Nymphaea, Persicaria pulchra*-type, and *Ludwigia*-type, become dominant.

3.3.2. GOHO-00. core

In total, 75 samples were analysed. Pollen of tree taxa, spores, dinoflagellate cysts and foraminifera were identified. The 100 and 110 cm levels appeared poor in pollen. The total number of pollen grains counted varied from 1 to 6880.

The pollen diagram of this core shows two pollen zones, GOI and GOII (Fig. 4). The zone GOI (730–140 cm) is characterised by high rates, up to 95%, of pollen of *R. racemosa*–type. Other mangrove taxa such as *Avicennia* (2–5%) and *A. aureum* (5–30%) are also present. The Poaceae taxa and spores also show high rates (10–20%). The foraminifera are relatively large at that level of the diagram (10–15%).

In the pollen zone GOII (140–0 cm), the Poaceae (30–65%) and the spores (80–40%) are the most dominant. A sudden drastic reduction in the pollen of *R. racemosa*-type occurred; its appearance on the surface is negligible (1%). Among the mangrove taxa, only *A. aureum* (1%) persists. The fresh water elements, such as *Persicaria pulchra*-type, *Typha* and the Cyperaceae, appear at 5%, 1% and 60%, respectively.

3.3.3. DO-00. core

Ninety-five (95) samples were analysed. Taxa of the mangrove and open areas, spores, dinoflagellate cysts and foraminifera were observed. Some taxa remained undetermined. The total number of pollen grains counted varied from 1 to 3929.

The diagram of taxa percentages shows three pollen zones: DOI, DOII and DOIII (Fig. 5).

The pollen zone DOI (990 cm to 400 cm) shows a high incidence of pollen of *R. racemosa*–type (95%), which, remarkably, remains constant throughout the sequence. This species is followed by other taxa of the mangrove such as *A. aureum* (10–75%) and *Avicennia* (5%). The presence of Foraminifera, dinoflagellate cysts, Poaceae taxa, and spores was noticed; they occur in low quantities (10–40%).

In the pollen zone DOII (400–225 cm), the pollen percentage of *R. racemosa*-type gradually decreases from 95% to 20%, then to 10%. The pollen of *Nymphaea* and monoletes spores reach high values (60%).

The last zone, DOIII, (from 225 cm to the surface) is characterised by a low incidence of the pollen of *R. racemosa*–type; this pollen subsequently disappears completely. Herbaceous taxa such as

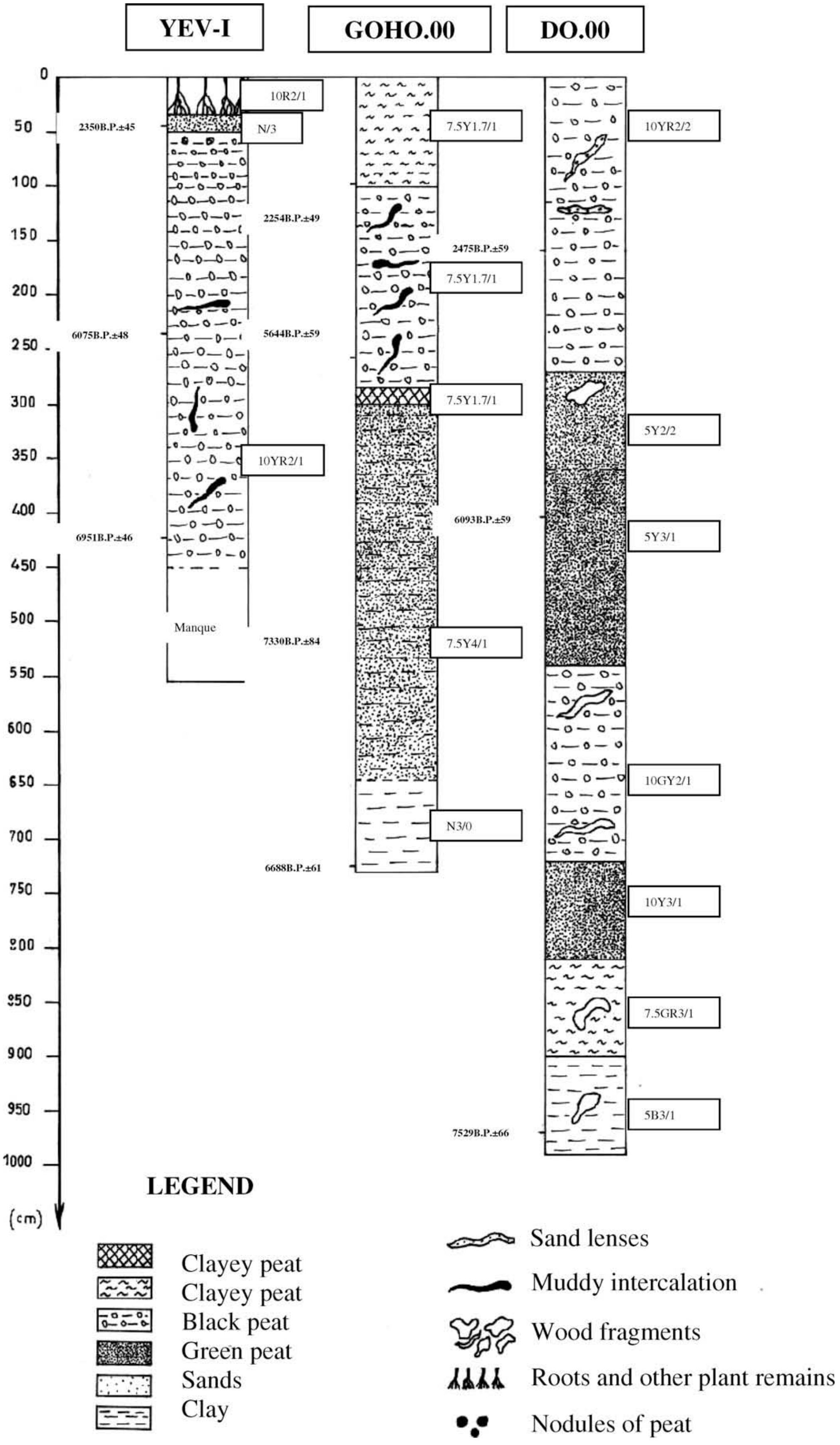

Fig. 2. Lithology of YEV- I – GOHO.00. –DO.00.

Table 1
Lithological units defined in the YEV-I core (Fig. 2)

Depth (cm)	Types of sediments	Colour
0–34	Clay	Black grey (roots and other plants remains)
50–455	Peat	Black/brown(presence of partly charred wood fragments at 235 cm)

Table 2
Lithological units defined in the GOHO-00 core (Fig. 2)

Depth (cm)	Types of sediments	Colour
0–55	Clayey peat	Black
55–100	Clay	Black
100–285	Peat	Black (separated by Blacksand lenses)
285–300	Clayey peat	Black
300–645	Clay	Grey
645–730	Clay	Black

Table 3
Lithological units defined in the DO-00 core (Fig. 2)

Depth (cm)	Types of sediments	Colour
0–270	Peat	Brown/black sand lenses at 62 cm
270–360	Peat	Black olive
360–540	Peat	Black
540–720	Peat	Black/green
720–810	Clayey peat/peat	Black/green/black-olive
810–900	Peat/clayey peat	Black greenish black
900–990	Clay	Black greenish

Table 4
Radiocarbon dates (AMS) from YEV-I, GOHO-OO and DO-OO cores

Sites	Sample depth (cm)	Lab. code	Age ^{14}C year BP	δ^{13}C (‰)	Analysed fraction
YEV-I	45	Erl4059	2350 ± 45	−27.77	Peat
	235	UtC8503	6075 ± 48	−29.4	Peat
	421–425	UtC8504	6951 ± 46	−28.2	Peat
	99	Erl4363	920 ± 44	−21.95	Peat
GOHO.00	257	Erl4364	6004 ± 61	−28.30	Peat
	728	Erl4365	6688 ± 61	−28.37	Peat
	159	Erl4366	2475 ± 59	−30.28	Peat
DO.00	404	Erl4367	6093 ± 59	−29.14	Peat
	970	Erl4061	7529 ± 66	−29.39	Peat

Persicaria, *Ludwigia* and *Typha* appear. Poaceae and monolete spores reach the highest values (60–95%).

4. Discussion

4.2. The middle and upper Holocene mangrove in coastal Bénin deposits

4.2.1. Palaeo-vegetation

According to Hutchings and Saenger (1997), the development and floral composition of mangroves depend on many factors, such as the nature of the land, salinity, the duration and frequency of floods, mud deposits and the energy of tides and waves.

The pollen diagrams from the three cores show that mangrove existed around Lake Nokoué, the lagoon of Porto-Novo and in the lower valley of the Ouémé river in the middle Holocene (7500–2500 years BP). Its abundance is clear from all of these diagrams, and *Rhizophora* pollen reached values of 90–95% during that period. It was well developed, very dense and almost monospecific/generic because the other taxa of the mangrove such as *Avicennia* and *Acrostichum* rarely appear. The low incidence of these latter two does not indicate whether they occupied low areas behind the *Rhizophora* population. According to Dupont and Weinelt, 1996; van Campo and Bengo, 2004; Scourse et al., 2005, in central west equatorial Africa, where the mangrove typically consists of the genera *Rhizophora* and *Avicennia, Avicennia* produces pollen in low quantities and has low representation in marine sediments. On the other hand, *Rhizophora* pollen is produced in very large quantities and is often preserved in abundance in sediments. The results of pollen analysis reveal an important geographical extension of mangrove, with *Rhizophora* extending over the whole of the coast of Bénin during the middle Holocene. That episode is consistent with the later mangrove extension in west Africa. This took place during the Nouackchottian transgression, which reached its maximum towards 5500 years BP (Sowunmi, 1981a,b; Lezine, 1986).

In the late Holocene (towards 2500 years BP) this mangrove disappeared totally, but the reduction could have started even earlier, from 3000 years BP, as Sowunmi (1986) noted.

4.2.2. Palaeo-geography

The coastal sediments, the development of lake deposits and the cores in the mangrove peat generally indicate the relative changes of sea level (Lézine, 1996; Taylor et al., 2001). According to Faure et al. (1982), mangrove development takes place especially in the intertidal zones, which provide a good indication of the upper limit of the sea level. The extension of the mangrove during the Nouackchottian transgression (towards 5500 years BP) shows that the marine influence on the sites was very great. According to Diop and Sall (1986) and Lézine and Casanova (1989), during the middle Holocene, the sea level rose by 1 or 2 m compared with the present level and penetrated inland, so that deltas, estuaries and streams opened to the ocean. According to Diop and Sall (1986), this rise in sea level resulted in an extension of the mangrove. The marine influence is indicated by the presence of marine palynomorphs such as foraminifera and dinoflagellate cysts (Tossou, 2002), which are sensitive indicators of sea level variation.

The sites of Yévié, Goho and Dogla-Alago were probably large estuaries covered by the sea, resulting in the encroachment of high tides far inland (Fig. 6). Schematically, we could visualise a very large estuary located between the plateau of Allada and that of Sakété. This estuary, under the influence of the sea as well as of fresh water from the rivers Ouémé and Sô, encouraged the expansion of the mangrove because of the increase in both salinity and sedimentary area.

The mangrove that existed between 7500 years BP and 2500 years BP generally disappeared, at the upper levels of the diagrams, up to 2500 years BP. That of core GOHO.00, however, persisted until around 920 ± 44 years BP. This can be explained by the fact that this site is the nearest to the mouth of the Porto-Novo Lagoon (Fig. 1). The disappearance of the mangrove is linked to the low level of the sea (and therefore the reduction of salinity) during the regression that followed the Nouackchottian transgression, as Hesp et al. (1998) and Nonn (1974) have noted. Nonn (1974) attributed the disappearance of the mangrove to desalinisation and modification of the soil structure, which resulted in aerobic conditions. According to Faure and Hebrard (1977) and Diop and Sall (1986), the sea level was lowered by 2–3 m during the post-Nouakchottian period, which was characterised by a semi-dry to dry climate around 4000 years BP. At that time the coastlines were raised in all of the Nouackchottian Gulfs of the west African coast, among them the gulf of Bénin. According to Oyédé (1983), the hydrodynamic causes responsible for the disappearance of the mangrove in Bénin provided for the establishment of coastal lines, the closure of the lagoons and the genesis of muddy areas.

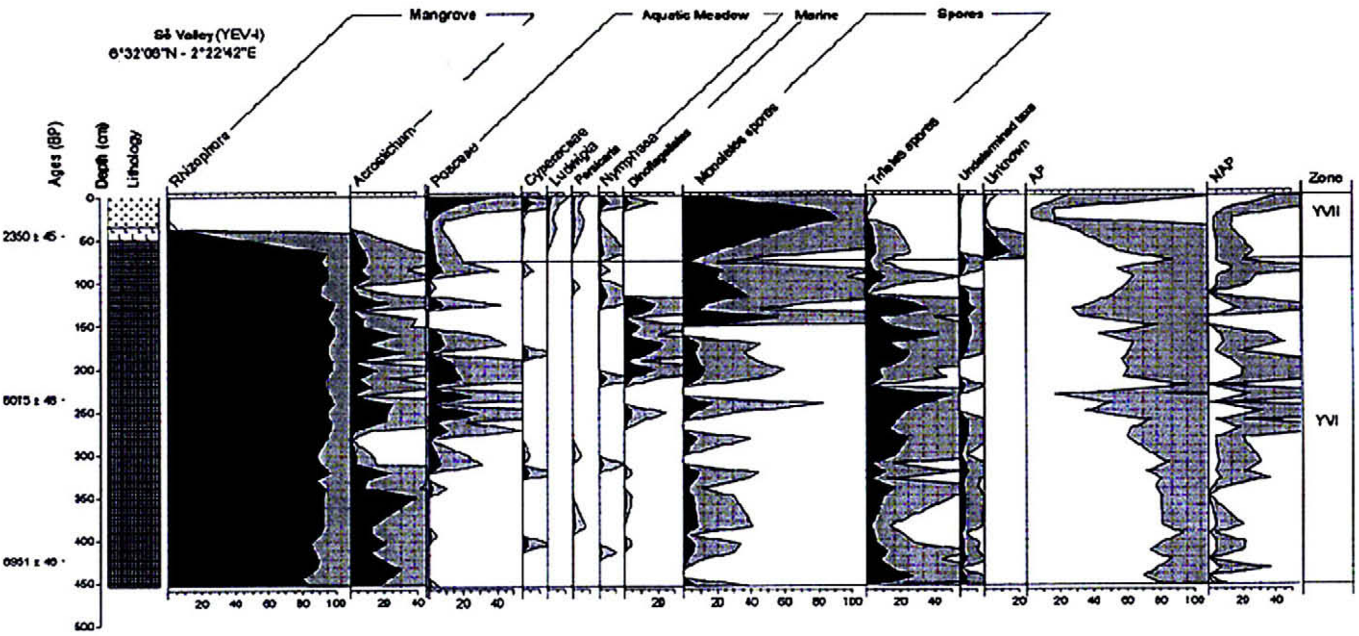

Fig. 3. Pollen diagram of YEV-I core

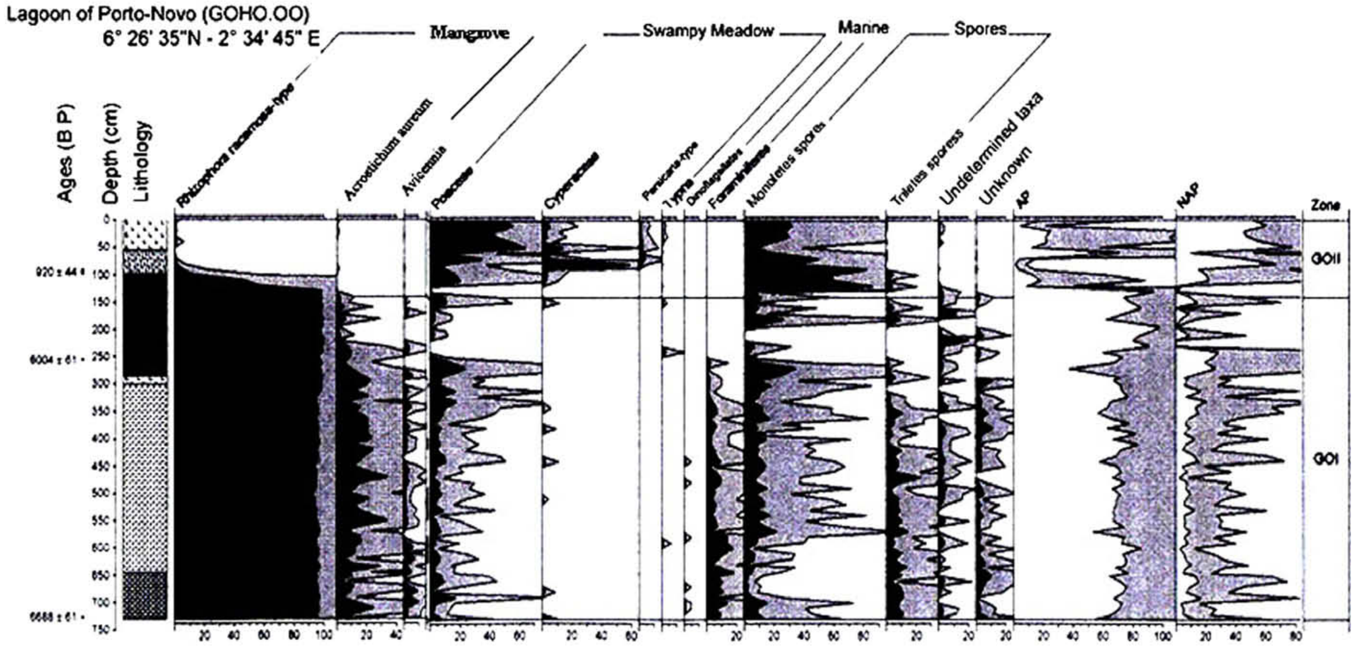

Fig. 4. Pollen diagram of GOHO.OO core.

4.3. The presence of the mangrove on the western coasts of Africa in the middle Holocene

A core of about 32 m, taken from the Niger delta in Nigeria, has been dated to 7500 years BP at 13.38 m and more than 30,000 years BP at the base. The Holocene core is dominated by *Rhizophora* pollen, underlining the position of the mangrove at that period (Sowunmi, 1981a,b). In Senegal, pollen analysis of coastal sediments depicts the development of *Rhizophora* mangrove towards a latitude of 15–16°N between 12,000 and 2000 years BP. The pollen spectra of continental sediments show that *Rhizophora* pollen was predominant in the middle Holocene along most of the coasts in the Gulf of Guinea. The important extension of the *Rhizophora* mangrove in western Africa (between 8°N and 21°N) took place during the same period, that is, around the maximum of the Nouakchottian transgression (Lézine, 1996). The mangrove in Bénin also underwent a large expansion between 7500 and 2500 years BP.

Results very strikingly similar to those of this study were obtained by Sowunmi (2004) from a palynological study of a core from the extreme part of south-western Nigeria, adjacent to the easternmost part of Bénin Republic. In essence, there was abundant mangrove, dominated by *Rhizophora*, from ca 8576 ± 48 BP to just before ca. 3109 ± 26 BP. By the later period *Rhizophora*

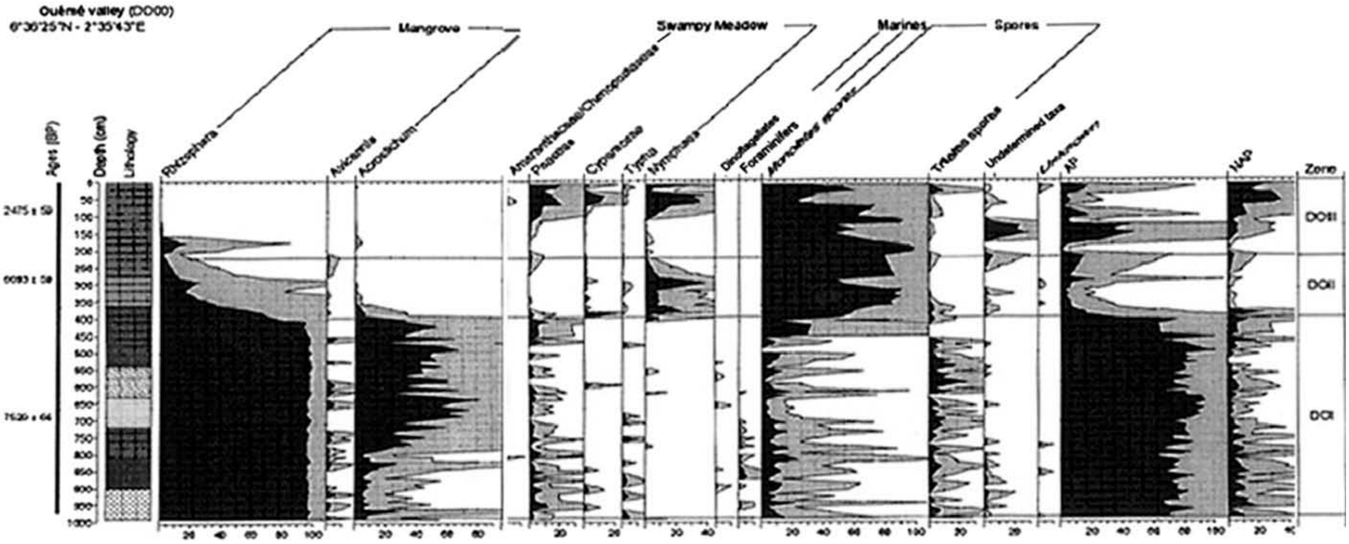

Fig. 5. Pollen diagram of DO.OO core.

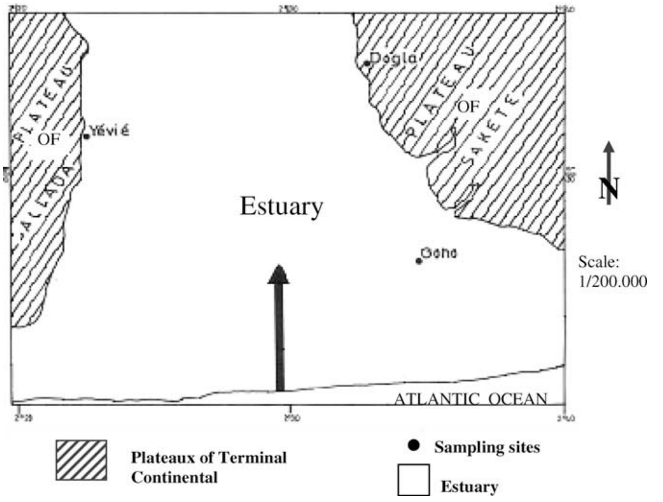

Fig. 6. Sketch showing the probable existence of a large estuary allowing the establishment of mangrove in the middle Holocene.

had declined very sharply and it disappeared completely soon after. The mangrove was replaced by fresh water swamp, an expanded fresh water forest and savanna.

Generally speaking, our results correspond with these data and confirm the general aspects of these phenomena on West African coasts.

According to Faure and Hebrard (1977), during the Nouakchottian period, the sea reached its highest level of 3 m above the current level. The sea level variations along the coasts of West Africa are revealed by the coastal peat soils (Pirazzoli, 1991). These variations are the cause of major changes in the coastal area (Barusseau et al., 1985; Taylor et al., 2001). The Nouakchottian transgression is the last episode of the mangrove extension in West Africa, as shown by the coastal sediments. The development of the mangrove along the coasts of West Africa may be an indicator of ocean upwellings in the entire area. It is also proof of an average rainfall higher than that at present, as well as the fluctuations in marine level. In the late Holocene, there was an important reduction of the mangrove in some countries of Africa, or its total disappearance, as was the case in Congo (Giresse and Lanfranchi, 1984), in Côte d'Ivoire (Frédoux, 1980), parts of south-eastern Nigeria (Sowunmi, 2004) and in Benin (this study).

In the Sherbo bay in Sierra-Leone, a regression movement created non- flood conditions and oxidation of land, causing the development of meadows in older sites of the mangrove (Anthony and Marius, 1984–1985).

5. Conclusion

The results obtained here, based on the pollen analysis of sediments from cores YEV-I, GOHO-00 and DO-00, contribute to a better knowledge of the middle and late Holocene mangrove dynamics. The vegetation was characterised by mangrove and semi-deciduous forest, with a preponderance of the former, during the middle Holocene. The mangrove was replaced in the later Holocene by very dense fresh water vegetation. The disappearance of the mangrove might have been mainly caused by marine regression, which was responsible for reduction in the salinity of the area.

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All merits of this piece of word are shared with them while all the shortcomings are entirely ours.

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