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Adama Gueye, Cheikh Abdoul Kader Fofana, Insa Badiane, Matthieu Carré, Cheikh Ibrahima Youm, et al.. Sub-fossil diatoms from the Saloum Estuary, Senegal, West Africa: Floristic inventory and paleo-productivity evolution along the Ndangonkha core. *Journal of African Earth Sciences*, 2023, 199, pp.104832. <10.1016/j.jafrearsci.2023.104832>. <hal-04000565>

HAL Id: hal-04000565

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Sub-fossil diatoms from the Saloum estuary, Senegal, West Africa: floristic inventory and paleo-productivity evolution along the Ndangonkha core.

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ABSTRACT: As part of our program to reconstruct the estuaries and lagoons history in Senegal and the diatom microflora inventory in Sene-Gambia, a 400 cm long core was taken at Ndangonkha in the Saloum estuary, near Foundiougne. The dating obtained show that sedimentation began in the Nouakchottian age, around 6000 years BP, with an average rate of sedimentation higher at the base than at the top where the high hydrodynamics of the environment would have caused sediment reworking. The comparative analysis of the lithology and the microflora shows a perfect correlation between the lutite fraction, the absolute abundance of diatoms and their specific diversity. The study allowed to inventory 111 species and varieties belonging to 62 genera; the most represented genera being *Nitzschia* (10 species), *Coscinodiscus*, *Cyclotella* and *Diploneis* (5 species each). Nine species are cited for the first time in Sene-Gambia. The microflora is dominated by euryhaline forms headed by *Cyclotella striata*. This dominance would be linked to the frequent variations in salinity between the rainy and dry seasons, while the abundance of marine species is related to the dominant influence of marine waters. The rare freshwater species encountered could be brought by wind, insects or birds. The analysis of the microfloristic and lithological data shows that the primary paleo-productivity and the specific diversity are weak at the base but increasing upwards (zone A), maximum in zone B whereas in zone C they are decreasing before disappearing in the last 10cm, in relation to the hydrodynamics of the environment.

Key words: estuary, diatoms, paleo-productivity, paleo-biodiversity, hydrodynamics.

INTRODUCTION

Les zones humides constituent un maillon essentiel du fonctionnement des écosystèmes à travers le monde. Or, dans la plupart des régions du monde, ces zones subissent un déclin continu dans leur superficie et leur qualité. Au Sénégal, au titre de zones humides fragiles figure l'estuaire du Saloum. Cet estuaire (figure 1), situé au centre-ouest du Sénégal, dans la région naturelle du Sine Saloum, s'étend sur environ 500.000 ha. Il est composé de trois bras ayant un débouché direct sur la mer : le Saloum lui-même au Nord, le Diomboss au centre et le Bandiala au Sud (Diouf, 1996). Ces distributaires principaux sont interconnectés par des chenaux, en général peu profonds. Le climat de la zone est de type tropical semi-aride et caractérisé par deux saisons : une saison des pluies de juillet à octobre et une saison sèche de novembre à juin.

Wetlands are an essential link in the functioning of ecosystems around the world. However, in most parts of the world, these areas are in continuous decline in area and quality. In Senegal, fragile wetlands include the Saloum estuary. This estuary (figure 1), located in the center-west of Senegal, in the natural region of Sine Saloum, extends over approximately 500,000 ha. It is composed of three distributaries having a direct outlet on the sea: the Saloum itself in the North, the Diomboss in the center and the Bandiala in the South (Diouf, 1996). These main distributaries are interconnected by generally shallow channels. The climate of the area is of the semi-arid tropical type and characterized by two seasons: a rainy season from July to October and a dry season from November to June.

The Saloum estuary comply with the classic functions of the wetland. Indeed, the various studies undertaken have highlighted (i) a mangrove ecosystem with its mudflats rich in organic matter, (ii) the presence of a multitudes tidal channels serving as a buffer between the river and the ocean and ensuring the interaction with the hydrographic network, (iii) specific diversity both animal and plant, (iv) the presence of marine, amphibian and continental complexes (Dia, 2003). Given the importance of the area ecologically and economically and the menaces it faces, the Saloum estuary is a protected site and is part of the UNESCO Man And Biodiversity (MAB) program network. The later made it a Saloum Delta Biosphere Reserve (RBDS) in 1981 and a World Heritage Site in June 2011 (Dièye et al., 2013).

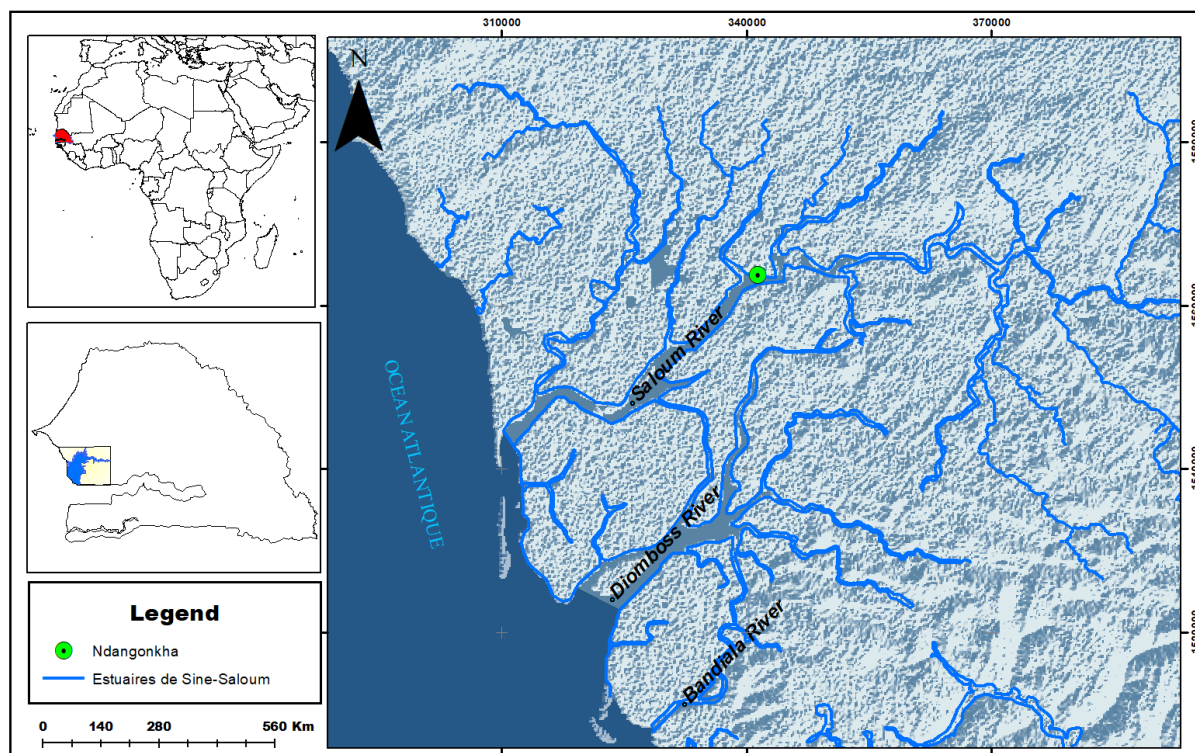


Figure 1 : Location map of the Saloum estuary.

The Saloum estuary began to form in the Tchadian age (13 000 to 8 000 BP); however, the most important phase of its formation is located in the Nouakchottian (6800 to 4200 BP) (Diouf, 1996). The oldest ages obtained by previous authors on the sedimentary bedrock revolve around 6130 and 6070 BP obtained at Bandiala by Kalck (1978). During this period, the region was occupied by a vast marine gulf going up to the upstream of Kaolack (more than 110 km from the mouth)

The Saloum estuary has been the subject of several studies. They are based on the mangrove, its evolution and its deterioration (JICA, 2005; Dièye et al., 2013); sedimentology (Ausseil-Badie et al., 1991; Barusseau et al., 1985); geomorphology, grain size, exoscopy and mineralogy (Diop, 1978 & 1986); microfauna and macrofauna (Ausseil-Badie & Monteillet, 1985); salinity, rainfall and precipitation-evaporation (Pagès & Citeau, 1990; Descroix et al., 2020; Azzoug et al., 2012) and the biology of fish populations (Sow, 2005).

Our study is a continuation of this work and aim to reconstitute, using diatoms, the paleo-environment and the paleo-climate of the Saloum estuary. These biological indicators have provided useful informations on the paleo-environnement and paleo-climate along the Casamance estuary (Sow & Diène, 2002; Sow et al., 2002 and 2005). This work is also the continuation of our inventory program of the diatom microflora of Sene-Gambia (Senegal and Gambia) which we have been working on for two decades.

2. MATERIALS AND METHODS

2.1 Sample collection and processing

The core studied was taken from the north shore of the Saloum estuary near Foundiougne in February 2015. Its geographical coordinates are: 14° 08' 27.72" N / 16° 28' 12.52" W. The core is taken using a Russian manual auger fitted with a locking system to avoid contaminations. The bottom of the mud was reached at a depth of 400 cm. On this core 2 batches of samples were made up: one intended for the study of diatom, the other for the determination of the sand and lutite fractions.

For diatom study a quantity of 0,1g of dry sediment was taken every 10 cm. Each sample was cleaned using HCl prior to H₂O₂, then rinsed three times after a settling period of three hours and decantation. The residue was suspended in 20 ml of water and after stirring, 2 ml of the suspension was mounted on a slide in Canada balsam. Some samples, sent to the Botanical Garden of Belgium for taking photos, were mounted in naphrax. On each sample, two slides were prepared.

On the second batch, the determination of the particle size fractions was carried out. To obtain a representative quantity of material, we proceeded, for each sample, to the accumulation of the sediments over 5 cm. Each sample after drying is weighed and then disaggregated following the same procedure as the first batch. Three superimposed sieves were used for washing: 1000 µm, 500 µm and 63 µm in diameter. The 1000 µm sieve is used as a protective sieve; the 500 µm sieve retains the shell debris while the 63 µm sieve retains sand fraction. After drying and weighting each fraction recovered, the total deducted from the initial weight represents the lutite fraction. The determination of these three fractions allows to specify the lithology.

2.2 Observation and identification of diatoms

Diatom identification and enumeration were done using a Leica DM 2500 optical microscope at 1 000× magnification. On each sample, a minimum of 300 valves were counted on two different slides. The counts make it possible to calculate the number of diatom valves per g of dry sediment (absolute abundance) and the relative frequency of species and ecological groups for each sample. We have distinguished two main ecological groups: marine and freshwater. At the same time, we grouped together the species belonging to these two groups that tolerate significant variations in salinity under the name euryhalines. As for marine

species, their abundance allowed us to classify them according to planktonic, benthic and epiphytic **lifeforms**. Photographs were taken using a Leica D-Lux3 digital camera mounted on the Leica microscope.

Taxonomic identification and ecological classification were based mainly on the work of: Krammer & Lange-Bertalot (1986, 1988 & 1991), Foged (1986), Gasse (1986), Compère (1991), Vyverman (1991), Cocquyt (1998), Bey & Ector (2013) and Taylor & Cocquyt (2016). Salinity was based on a compilation of salinity classes by Van der Werff et al. (in Denys 1991).

1.3 Analyse statistique

To know the distribution of diatom associations along the core, the Hierarchical Cluster Analysis (HCA) was carried out using PAST Version 3.12 software. The evolution, along the core, of each parameter was translated into a graph in Excel and finalized in Paint.

2- RESULTS

2.1. Lithologic description. The section shows from bottom to top (Figure 2a):

- 0-10 cm: black sandy mud;
- 10-35 cm: sandy mud with shell and plant debris;
- 35-150 cm: blackish mud with plant debris;
- 150-290 cm: sandy mud with little plant debris;
- 290-400 cm: sandy levels

The lutite fraction, low at the base, increases irregularly to reach a maximum of 79.2% at 100 cm. Above 100 cm, it decreases irregularly to the top (figure 2b). The two datings obtained gives ages of 3860 ± 30 B.P. between 255 and 250 cm and 1970 ± 30 B.P. between 15 and 20 cm; which gives an average sedimentary rate of 127.10^{-3} cm/year between 255 and 15 cm and $3.76.10^{-3}$ cm/year for the last 15 cm.

2.2. Diatom abundance in the sediment

Diatoms are very rare at the base (400-340 cm) and almost absent in the last 10 cm. They are only representative between 330 and 10 cm from the surface. The number of valves/g of dry sediment is very low at the base then increases irregularly to reach its maximum at 50 cm ($35.9.10^6$ valves/g) (figure 2c). Above 50 cm, the number of valves/g drops rapidly to zero at 10 cm.

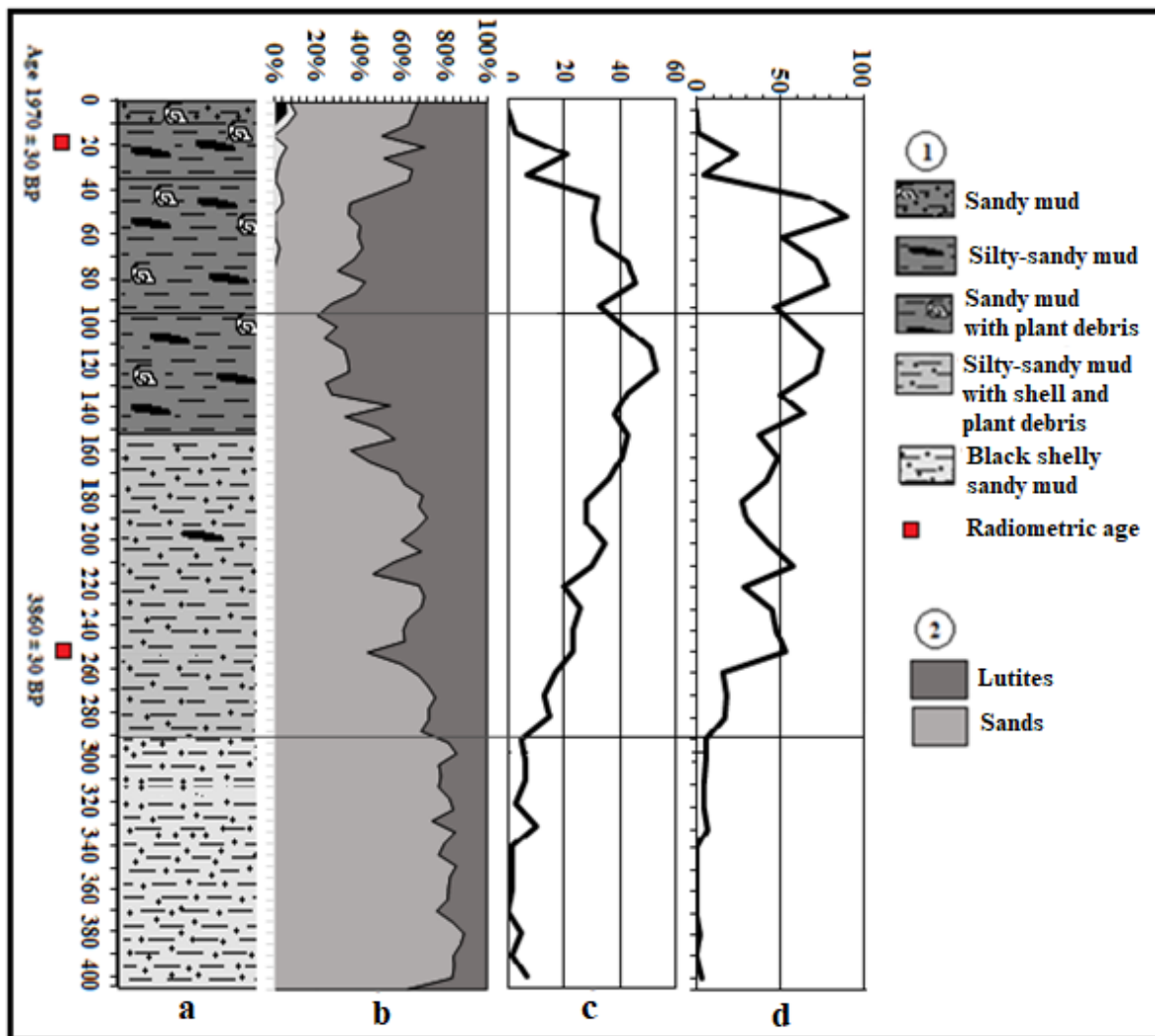


Figure 2 : Lithology (a), evolution of the sands/silt-clay percentage (b), valves number/g of dry sediment x 10⁻⁶ (c), specific diversity (d) of diatoms along Ndangonkha core.

2.3. Analysis of the specific diversity of diatoms

A total of 111 species and varieties belonging to 62 genera were inventoried (Table 1). The most represented genera are: *Nitzschia* (10 species), *Coscinodiscus*, *Cyclotella* and *Diploneis* (5 species each). Nine species are cited for the first time in Sene-Gambia. The specific diversity is unevenly distributed along the core (figure 2d). It broadly follows the evolution of the lutite fraction and that of the absolute abundance with a maximum of 53 species at 120 cm. The microflora is essentially composed of euryhaline and marine planktonic species (figure 3). It is largely dominated by *Cyclotella striata*. The few freshwater species encountered are mainly represented by the genera *Aulacoseira* and *Cyclotella*.

Table 1 : List of inventoried diatom species along the Ndangonkha core, classified by ecological group.

MARINE SPECIES

Marine planktonics

Actinocyclus normanii (Gregory ex Greville) Hustedt, 1957

A. octonarius Ehrenberg, 1837*

Actinoptychus senarius (Ehrenberg) Ehrenberg 1843

A. splendens (Schadbolt) Ralfs 1861

A. vulgaris Schumann, 1867

Asteromphalus variabilis (Greville) Rattray 1890*

Auliscus sculptus (W. Smith) Brightwell 1860

Cerataulus smithii Ralfs ex Pritchard, 1861

Chaetoceros amanita Cleve-Euler 1915

Coscinodiscus asteromphalus Ehrenberg 1844

C. excentricus Ehrenberg, 1840

C. marginatus Ehrenberg 1843

C. oculus-iridis Ehrenberg 1840

C. radiatus Ehrenberg 1841

Cosmioneis pusilla (W. Smith) D.G. Mann & Stickle, 1990

Cyclotella striata (Kützing) Grunow 1880

Hyalodiscus scoticus (Kützing) Grunow 1879

Surirella fastuosa (Ehrenberg) Kützing 1844

S. striatula Turpin 1828

Thalassionema nitzschioides (Grunow)

Mereschkowsky 1902

Thalassiosira decipiens (Grunow) Jørgensen 1905

T. eccentrica (Ehrenberg) Cleve 1904

T. oestrupii (Ostenfeld) Hasle 1972

Marine epiphytics

Achnanthes brevipes Agardh 1824

A. citronella (A.Mann) Hustedt, 1937*

A. longipes Agardh, 1824

Amphora crassa Gregory 1857

Ardissonia crystallina (Agardh) Grunow, 1880

Cocconeis debesii var. *rufisquiana* Amossé, 1970

C. disculus (Schumann) Cleve 1895

C. placentula Ehrenberg 1838

C. scutellum Ehrenberg 1836

Cyclotella stylorum Brightwell 1860

Nitzschia punctata (W. Smith) Grunow 1880

Plagiogramma appendiculatum Giffen 1975

Rhaphoneis castracanei Grunow 1881*

Marine benthics

Amphora ovalis (Kützing) Kützing 1844

A. proteus Gregory 1857

A. ventricosa Gregory 1857

Biddulphia aurita (Lyngbye) Brébisson 1838

B. pulchella Gray 1821

B. tuomeyi (Bailey) Roper 1859

Brachisira hamulifera (Grunow) Kuntze 1891

Dimeregramma minus (Gregory) Ralfs 1861

Opephora schwartzii (Grunow) Petit ex Pelletan 1889

Paralia sulcata (Ehrenberg) Cleve 1873

Petroneis granulata (Bailey) D.G. Mann 1990

P. monilifera (Cleve) A.J. Stickle & D.G.Mann 1990

P. xi (Cleve) Witkowski, Lange-Bertalot & Metzeltin 2000

Pinnunavis yarrensensis (Grunow) H. Okuno 1975

Plagiogramma rhombicum Hustedt 1955

P. tenuistriatum Cleve 1881

Pleurosigma intermedium W. Smith 1853

Pseudostaurosira brevistriata (Grunow)

Williams & Round 1988

Pyxilla prolungata Brun 1893*

Rhopalodia gibberula (Ehrenberg) O. Müller 1899

Terpsinoe americana (Bailey) Ralfs 1861

Trachyneis aspera (Ehrenberg) Cleve 1894

Triceratium favus Ehrenberg 1839

Trigonium alternans (Bailey) A.Mann 1907

FRESHWATER SPECIES

Achnanthes delicatula (Kützing) Grunow 1880

Aulacoseira ambigua (Grunow) Simonsen

A. distans (Ehrenberg) Simonsen 1979

A. granulata (Ehrenberg) Simonsen 1979

Caloneis africana (M.H. Giffen) Stidolph 1995*

Campylodiscus clypeus Ehrenberg 1840

Craticula cuspidata (Kützing) D.G. Mann 1990

Cyclotella atomus Hustedt 1937

C. caspia Grunow 1878

C. meneghiniana Kützing 1844

Diatoma vulgare Bory 1824*

Epithemia turgida (Ehrenberg) Kützing 1844

Eunotia curvata (Kützing) Lagerstedt 1884

E. intermedia (Krasske ex Hustedt) Nörpel & Lange-Bertalot 1993

Frustulia rhomboides (Ehrenberg) De Toni 1891

Luticola mutica (Kützing) D.G. Mann 1990

Melosira varians C. Agardh 1827

Navicula cryptocephala Kützing 1844

N. punctulata W.Smith, 1853*

Neidium affine (Ehrenberg) Pfitzer 1871

Nitzschia amphibia Grunow 1862

N. dissipata (Kützing) Rabenhorst 1860

N. lorenziana Grunow in Cleve & Möller 1879

N. sigma (Kützing) W. Smith 1853

Pinnularia viridis (Nitzsch) Ehrenberg 1843

Staurosira construens Ehrenberg 1843

Staurosirella pinnata (Ehrenberg) William & Round 1987

Stephanodiscus niagarae Ehrenberg 1845

Tabellaria fasciculata (Agardh) D.M. William & Round, 1986

<p><i>Diploneis bombus</i> Ehrenberg 1853</p> <p><i>D. chersonensis</i> (Grunow) Cleve 1894</p> <p><i>D. didyma</i> Ehrenberg, 1894</p> <p><i>D. ovalis</i> (Hilse) Cleve 1891</p> <p><i>D. smithii</i> (Brébisson) Cleve, 1894</p> <p><i>Entomoneis paludosa</i> (W.Smith) Reimer 1975*</p> <p><i>Eunotogramma laeve</i> Grunow 1883</p> <p><i>Fragilaria hyalina</i> (Kützing) Grunow 1862</p> <p><i>Grammatophora hamulifera</i> Kützing 1844</p> <p><i>G. marina</i> (Lyngbye) Kützing 1844</p> <p><i>G. oceanica</i> Ehrenberg 1840</p> <p><i>Gyrosigma balticum</i> (Ehrenberg) Cleve 1894</p> <p><i>Hemidiscus weissflogi</i> (Grunow) Kuntze 1898</p> <p><i>Halamphora coffeaeformis</i> (Agardh) Levkov 2009</p> <p><i>Lyrella lyra</i> (Ehrenberg) Karaeva 1978</p> <p><i>Martyana martyi</i> (Héribaud) Round 1990</p> <p><i>Nitzschia granulata</i> Grunow, 1880</p> <p><i>N. lanceola</i> Grunow, 1880</p> <p><i>N. penduriformis</i> Gregory, 1857</p> <p><i>N. tryblionella</i> Hantzsch 1860</p> <p><i>N. vidovichii</i> Grunow 1862</p>	<p><i>Ulnaria ulna</i> (Nitzsch) Compère 2001</p> <p>EURYHALINE SPECIES</p> <p><i>Actinocyclus normanii</i></p> <p><i>Amphora ovalis</i></p> <p><i>A. ventricosa</i></p> <p><i>Campylodiscus clypeus</i></p> <p><i>Cosmioneis pusilla</i></p> <p><i>Cyclotella meneghiniana</i></p> <p><i>C. striata</i> (Kützing)</p> <p><i>Diploneis didyma</i></p> <p><i>D. ovalis</i></p> <p><i>D. smithii</i></p> <p><i>Halamphora coffeaeformis</i></p> <p><i>Lyrella lyra</i></p> <p><i>Martyana martyi</i></p> <p><i>Navicula punctulata</i></p> <p><i>Nitzschia sigma</i></p> <p><i>N. tryblionella</i></p> <p><i>Opephora schwartzii</i></p> <p><i>Pseudostaurosira brevistriata</i></p> <p><i>Rhopalodia gibberula</i></p>
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* Species cited for the first time in Sene-Gambia.

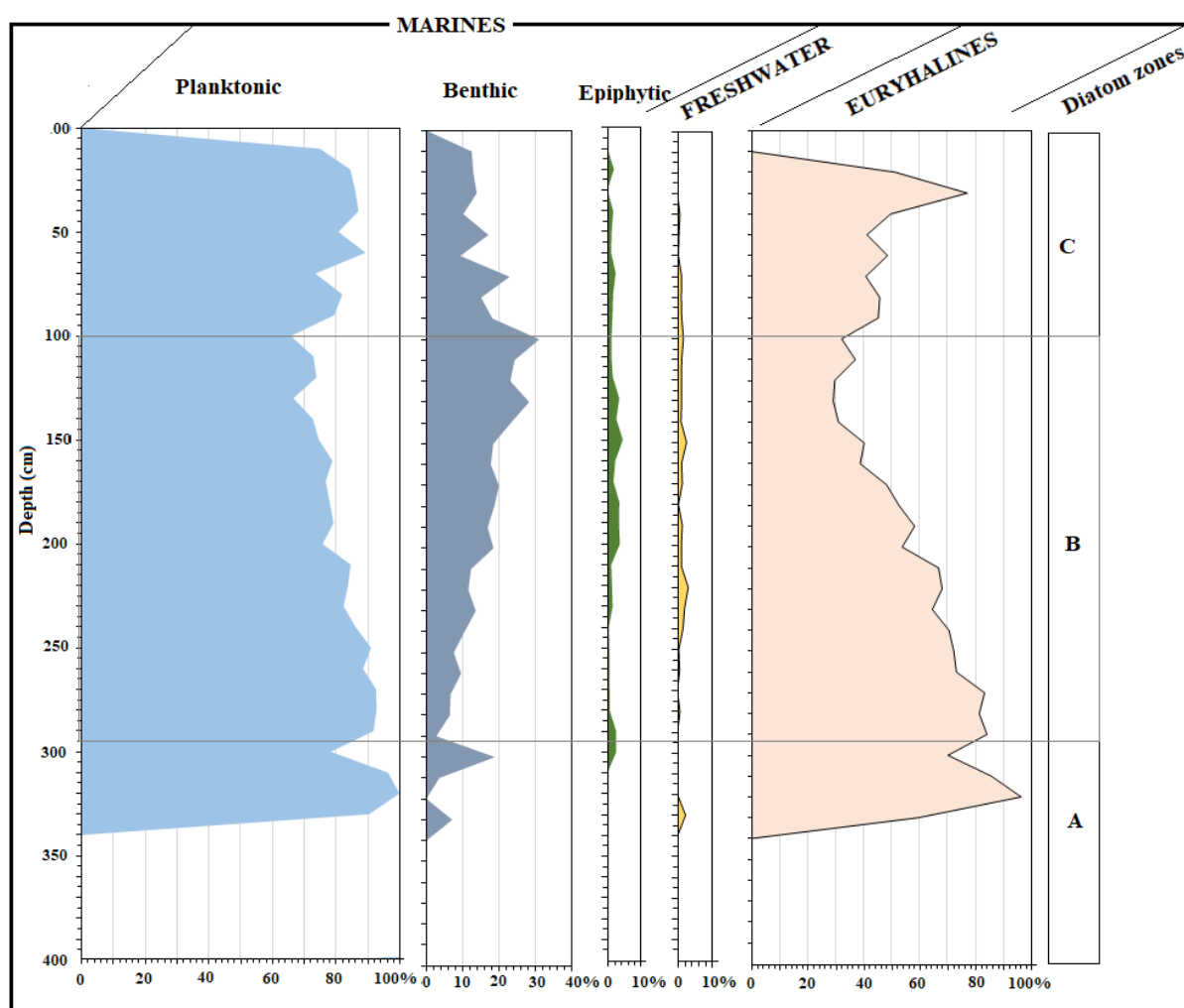


Figure 3 : Evolution of the relative abundance of ecological groups of diatoms along the Ndangonkha core

2.4. Distribution of diatoms

The dendrogram of Bray-Curtis similarity index of the Ndangonkha core shows a cleavage of the species into three groups (Figure 4) corresponding to three zones defined along the core (figures 3, 5 and 6).

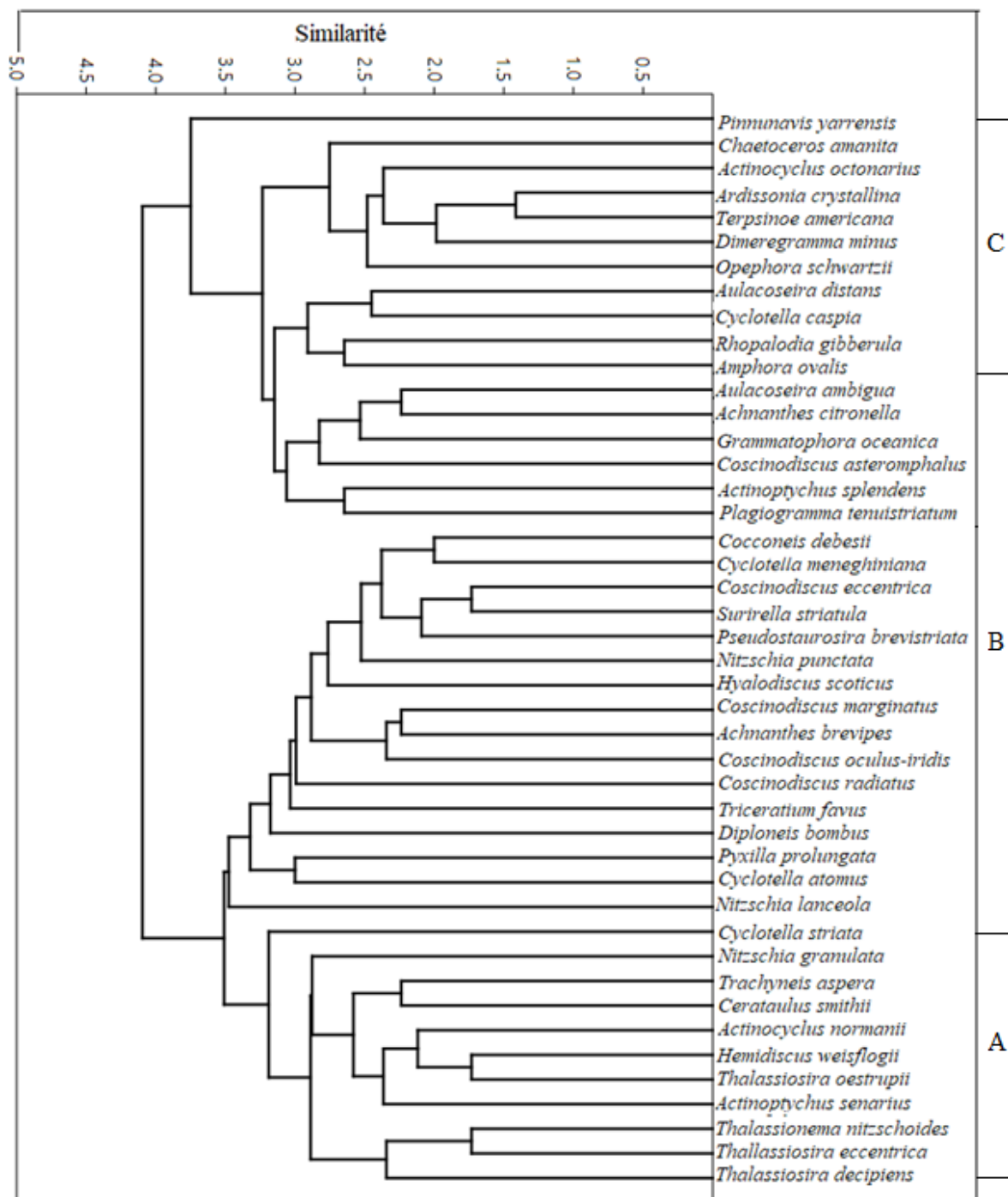


Figure 4 : Dendrogram of constant diatoms along the Ndangonkha core.

Zone A (400-290 cm): It contains the species of group A. The specific diversity, low at the base, evolves at the same time as the lutite fraction. From 400 to 340 cm, only a few diatom valves were encountered. Diatoms only become representative above 340 cm. The microflora is largely dominated by planktonic marine species headed by *Cyclotella striata* and *Actinocyclus normanii* also euryhalines (figure 6). They are followed by *Thalassiosira decipiens*, *Actinoptichus senarius* (figure 6), *Thalassionema nitzschoides*, *Thalassiosira oestrupii* and *T. eccentrica*. Then follow the benthic marine forms with *Hemidiscus weisflogii*, *Nitzschia granulata* and *Paralia sulcata* (figure 5) then the epiphytic marine forms which only appear at 300 cm with *Cocconeis debesii* (figure 6). Freshwater species are very rare (figure 3).

Zone B (290-100 cm) contains the species of Group B. In this zone, we note an increase in the lutite fraction which reaches its maximum at 100 cm, in the absolute abundance of diatoms as well as the specific diversity which reaches a maximum of 53 species at 120 cm (figure 2). In addition to the species of zone A, appear new genera such as *Amphora*, *Aulacoseira*, *Petroneis* and new species. The planktonic marine species decrease and reach 66% at 100 cm; they are enriched with new species such as *Hyalodiscus scoticus*, *Coscinodiscus marginatus*, *C. oculus iridis* and some spores of *Chaetoceros amanita*. Benthic marine forms are also increasing (31% at 100 cm) with new species such as *Pinnunavis yarrensii*, *Pyxilla prolungata*, *Nitzschia lanceola*, *Triceratium favus* and *Diploneis bombus*. The epiphytic marine forms increase slightly in percentage, specially from 260 cm; they are also enriched with a new species such as *Achnanthes brevipes* and *Nitzschia punctata*. The rare freshwater forms are dominated by *Cyclotella atomus*, *C. caspia* and *Aulacoseira ambigua*. Euryhaline species decrease to reach a minimum percentage of 29.28% at 130cm (figures 3 and 5).

In this zone, we note the presence of large intact valves of *Coscinodiscus* as well as frustules of *Paralia sulcata* and *Aulacoseira* in chain. Silicoflagellates such as *Distyocha fabula* Ehrenberg (1839) and *Mesocena elliptica* Ehrenberg (1844) are also encountered.

Zone C (100-00 cm) contains the species of Group C. The lutite fraction reaches its maximum between 90 and 100 cm (79.2%) before falling; it evolves at the same time as species diversity. The absolute abundance reaches its maximum at 50 cm ($32.81 \cdot 10^5$ valves/g) before falling and disappearing between 20 and 10 cm. The percentage of planktonic marine forms fluctuates slightly before they disappear. We note the appearance of a new species, *Cosmioneis pusilla* which is also euhyaline. The benthic marines, despite the appearance of a

new species (*Terpsinoe americana*), diminish in importance before their disappearance; as well as marine epiphytics. Although the freshwater microflora is diversifying with the appearance of two new species (*Tabelaria fasciculata* and *Ulnaria ulna*), its relative abundance decreases and disappear 30 cm from the surface.

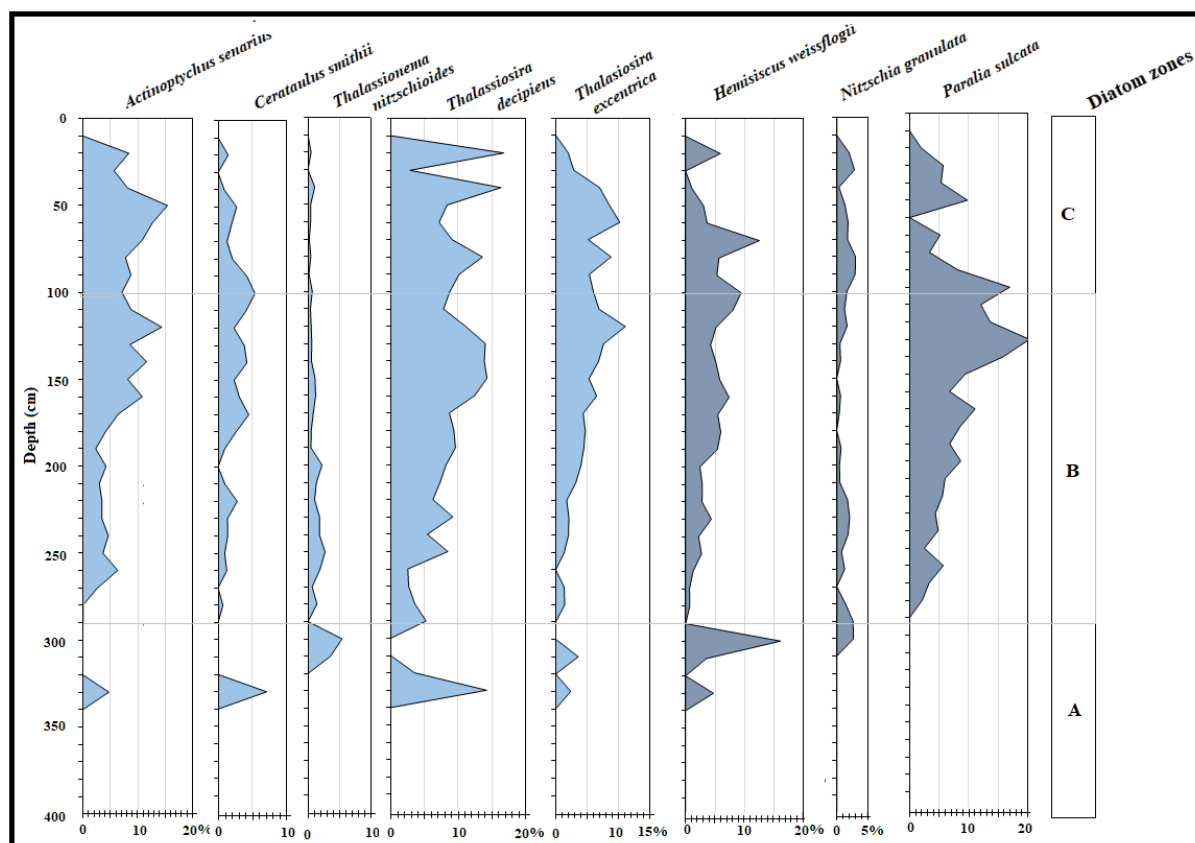


Figure 5 : Evolution of the percentage of dominant marine planktonic and benthic species of diatoms along the Ndangonkha core.

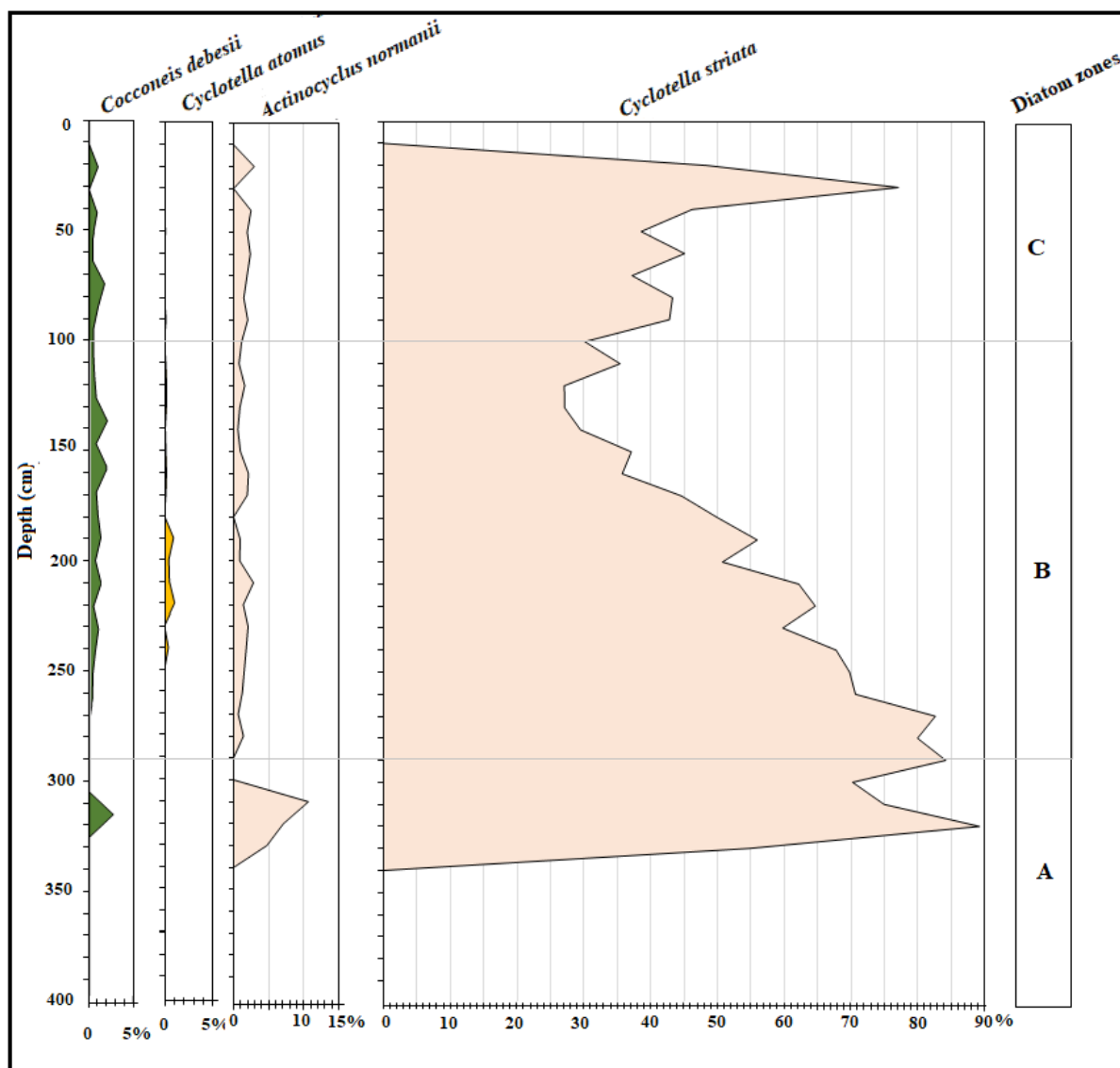


Figure 6 : Evolution of the percentage of dominant marine epiphytic, freshwater and euryhaline species of diatoms along the Ndangonkha core.

4- Discussion

The age of 3860 ± 30 B.P. obtained between 255 and 250 cm authorizes fixing the base of the core at around 6000 years B.P. (beginning of the Nouakchottian transgression), corresponding to the age of the base of the sedimentary series obtained by Ausseil-Badie et al. (1991). The sandy fraction, high in this lower part of the core, was reported by the same authors who indicated that between 6130 and 3500 years B.P. the deposit consists of fine sands and silty clays characterizing an intertidal environment. The sandy fraction would have a marine origin as evidenced by the subrounded character of the quartz grains (Diouf, 1996). The upper part, marked by the dominance of lutites, was deposited following the filling of the lagoons located

behind the coastal bars from 1990 years B.P. (Ausseil-Badie et al., 1991). In this part, the 35 to 10 cm interval, rich in shell debris, would come from the reworking of an older deposit. This idea of reworking is reinforced by the very low average sedimentation rate ($3.76 \cdot 10^{-3}$ cm/year) calculated in the last 15 cm. This amounts to saying that the age of 1970 ± 30 B.P. between 20 and 15 cm would correspond to the age of the deposit before reworking.

The curve of variation in the number of diatom valves/g of dry sediment, similar to a curve of primary paleoproductivity (Sow & Diène, 2002) as well as the specific diversity, are positively correlated with the richness in lutite. This productivity is low at the base and zero at the top. The dominant species (*Cyclotella striata*) is a mesohalobe species (Foged, 1986 and 1987), halophile in brackish water (Vyverman, 1991), littoral marine (Hustedt, 1930), euryhaline, marine or continental (Barde-Labayle-Bounes, 1980). It is therefore a species tolerant of a wide range of salinity ranging from marine to freshwater, common on all the coasts of the North Sea and the Tay and Clyde estuaries (Hendey, 1964). The freshwater forms are most likely allochthonous and brought by the wind, insects or birds given their very low percentage and their great irregularity.

In zone A, *Cyclotella striata* is accompanied by other planktonic forms attesting to an opening of the Saloum estuary to the ocean in fairly warm periods. However, the presence of benthic and epiphytic forms testifies to a shallow environment without significant influence of freshwater inputs given the rarity of freshwater forms.

Zone B is marked by a higher primary productivity correlated with a decrease in the sandy fraction. The planktonic species that accompany *Cyclotella striata* are generally cited in upwelling regions (Sancetta, 1979 and 1982; Sancetta et al., 1992; Schrader 1982 and 1992; Abrantes 1991) as well as the planktonic marine silicoflagellates that accompany them. More generally, the phytoplankton blooms that follow the upwelling phenomenon occur in coastal environments and can be the source of a large part of the annual production. This is probably the reason why at that time the microflora was very diverse. The dominant benthic forms encountered in this zone (*Paralia sulcata* and *Hemidiscus weisflogii*) are also frequent in saline inland waters whose concentration can be equivalent to the concentration of seawater as well as in upwelling zones. The epiphytes encountered in this zone are known in the coastal environment and in estuaries and their development would be linked to the existence of a mangrove vegetation belt. The presence of large intact valves of *Coscinodiscus* as well as frustules of *Paralia sulcata* and *Aulacoseira* in chains indicate weak hydrodynamics. During

this period the Saloum was in connection with the open sea with relatively deep and calm waters.

In zone C, primary productivity reaches its maximum before decreasing to zero at 10 cm from the surface. These two phases are positively correlated with the lutite fraction and the specific richness. Although marine influences remain largely dominant, the increase in the percentage of *Cyclotella striata* in this zone and the diversification of freshwater forms would be the sign of a slight dilution of the waters following an improvement in rainfall. This improvement is only of short duration because the latter begin to disappear from 60 cm. The planktonic marine forms that accompany them (*Paralia sulcata* and *Pinnunavis yarrensis*) characterize a confined environment, with probable periods of exposure, in a hot climate (Zong, 1997; Podzorski & Håkansson, 1987; Foged, 1986 and 1987; Sow et al., 2006).

The absence of diatoms in the last 10 cm can be attributed to two factors: (1) hyperhalinity linked to the aridification of the environment that began in this climatic zone from 1600 (Carré et al., 2018); (2) the hydrodynamics of the environment. The first factor must be excluded given the fact that Dia (1985) encountered 30 species of diatoms in the phytoplankton of the Saloum estuary in a hyperhaline regime. Hydrodynamics then remains the factor responsible for the absence of diatoms in this interval. It would have caused the deposit of coarser particles accompanied by fragments of shells. The coarser character of these sediments is reported by Barusseau et al. (1985) who indicate a superposition of a relatively coarse current layer on the fine sediments of the mudflats under the influence of climatic variations. The shell debris would come from a remobilization from old shell middens probably of anthropogenic origin.

Conclusion

The Ndangonkha core sediments would be between 6000 years B.P. (Nouakchottian) and the present. The average rate of sedimentation would be higher at the base than at the top where the high hydrodynamics of the environment would have caused sediment reworking. The comparative analysis of the lithology and the microflora shows a perfect correlation between the lutite fraction, the absolute abundance of diatoms and their specific diversity.

The study of diatoms along the core of Ndangonkha allowed to inventory 111 species and varieties belonging to 62 genera; the most represented genera being *Nitzschia* (10 species), *Coscinodiscus*, *Cyclotella* and *Diploneis* (5 species each). The diatom floristic list of Senegambia has been enriched by nine species. All along the core, the microflora is dominated by

Cyclotella striata which is a euryhaline cosmopolitan species. The dominance of euryhaline species would be linked to the frequent variations in salinity between the rainy and dry seasons, while the abundance of polyhalobe species is related to the dominant influence of marine waters. Rare freshwater species could be brought by wind, insects or birds.

The analysis of this microflora combined with the lithology made it possible to distinguish 3 zones: zone A characterized by low primary paleo-productivity and specific diversity at the base but increasing upwards; zone B with maximum paleo-productivity and species diversity; zone C where the primary paleo-productivity and the specific diversity decrease before canceling out in the last 10 cm in relation to the hydrodynamics of the environment.