A contribution of diatom analysis to Lateglacial and Holocene environmental reconstructions of Colombian lowland and montane ecosystems

Velez, M.A.

Citation for published version (APA):

General rights
It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

Disclaimer/Complaints regulations
If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: https://uba.uva.nl/en/contact, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.

UvA-DARE is a service provided by the library of the University of Amsterdam (http://dare.uva.nl)
Chapter 2

Late Holocene environmental history of southern Chocó region, Pacific Colombia; sediment, diatom and pollen analysis of core El Caimito

María Isabel Velez, Michael Wille, Henry Hooghiemstra, Sarah Metcalfe, Jef Vandenberghe and Klaas van der Borg

Abstract

We present a multi-proxy study of pollen, diatoms, sediment characteristics and major elements of a 610-cm sediment core from lake El Caimito, located in the humid rain forest of southern Chocó, Pacific Colombia. We propose an integrated reconstruction of the local basin development and of the regional vegetation which is possibly related to the tectonic activity of an unstable coastal area. Time control is based on 7 AMS $^{14}$C dates that show that the record represents the last 3850 cal yr BP. From 3850-2700 cal yr BP sandy deposits, low carbon content, absence of diatoms, and low diversity of the pollen spectra indicate that the site was under the influence of the fluvial system. Erosive event(s) removed part of the sediment record and we observed a hiatus representing 700 years. After that, the basin became more isolated from the river drainage system. From 2010-1430 cal yr BP mainly clay was deposited and repeatedly interrupted by river pulses that left sandy and silty horizons in the record. Benthic and littoral-benthic diatom species indicate a shallow water body and a stable water chemistry. Mangrove forest was close to the lake, apparently growing along the close-by inlets. Regionally, the main vegetation elements were palms, and taxa in the families of Moraceae-Urticaceae, Melastomataceae, Leguminoseae and from a number of other families and genera, characteristic of tropical lowland rain forest.

From 1430-810 cal yr BP the river impact gradually diminished. Each fluvial event that affected the local forest is shown in the pollen record by an expansion of *Cecropia* dominated pioneer forest. Decreasing intensity
of forest disturbance coincides with an increase in the diversity of fossil pollen taxa, possibly reflecting an increasing plant diversity of the forest. Mangrove pollen declined, indicating that the coastline moved seaward and suggesting tectonic uplift of the coastal area. Between 810 and 580 cal yr BP mangrove forest was closer to the lake again, reflecting an inland migration of the coastline, suggesting tectonic subsidence. From 580-300 cal yr BP the last fluvial events were recorded. Diatom associations indicate oligotrophic and acidic water. The mangrove belt moved seaward again, suggesting tectonic uplift. Palms and *Cecropia* became more abundant, suggesting increased human impact in the near shore lowland forest. During the last 300 years, stable lacustrine conditions and lowland rain forest with the highest floral diversity is registered.

1. Introduction

The strip of rain forest along the Pacific coast of Colombia, known as Chocó Biogeographic Area, is known for its high precipitation values, up to 12,000 mm/year, and high plant diversity. The geological history of this area since the Miocene has been discussed among others by Hooghiemstra and Van der Hammen (1998) and Hoorn et al. (1995). There is substantial evidence from records in the Amazonian rain forest that its present extension was reduced during dry intervals of the last glacial period, in particular during the last glacial maximum (Hooghiemstra and Van der Hammen, 1998; Van der Hammen and Absy, 1994; Van der Hammen and Hooghiemstra, 2000), but this evidence is debated by others (Bush et al., 2001; Colinvaux et al., 2000). There is insufficient understanding how high plant diversity in the neotropical rain forests was generated during the Neogene and Quaternary time (Bush and Colinvaux, 1988; Colinvaux, 1997; Colinvaux, 1998; Colinvaux et al., 2000; Schneider et al., 1999). According to Colinvaux (1997; Colinvaux et al., 2000) speciation can be understood in terms of an 'engine model' or a 'museum model'. From Amazonia there is important evidence that shows high internal dynamics in the rain forest, caused e.g. by migrating rivers or precipitation variability related e.g. to ENSO or even perhaps to orbitally induced precession changes. As the setting of Chocó rain forest differs from Amazonia, it is unclear to which degree environmental
instability is also characteristic of the rain forests in Chocó. To explore this question further, sediment cores in three lakes were collected in 1997. Previous palaeoenvironmental records from southern Chocó (Laguna Piusbi, Behling et al., 1998), and from northern Chocó (Laguna Jotaordó, Berrio et al., 2000) and the San Juan Delta (Ramirez and Urrego, 1999) documented for the first time in Chocó environmental change during the last c. 4500 years. From those data a stable forest history was inferred.

The present study presents at a multi-proxy analyses of the core from Laguna El Caimito, integrating data from pollen (analysed by M. Wille), diatoms (analysed by M. Velez) and sediments (analysed by M. Velez and J. Vandenberghe) in order to provide a maximum understanding of regional environmental change. The use of different proxies enables us to test the palaeoclimatic interpretation of a single proxy, as is the case in the studies of Lagunas Piusbi (Behling et al., 1998) and Jotaordó (Berrio et al., 2000), and provides the opportunity to validate climatic calibration data. We compare the environmental history of Chocó to palaeoclimatic changes in the Colombian savannas (Behling and Hooghiemstra, 2000; Behling et al., in prep., Berrio et al., 2002).

2. Environmental setting

2.1 Geography

The Pacific coast of Colombia, where the Chocó biogeographic area is located, is a tectonically active area. Earthquakes are relatively frequent and have caused subsidence of portions of the Pacific coastline (Herd et al., 1981). Oceanic Cretaceous limestones are overlain by Tertiary sediments represented by fluvial terraces, and which are covered by Quaternary pyroclastic and alluvial deposits (Galvis et al., 1993).

Lake El Caimito (2°32' N, 77°36' W) is located at 50 m elevation in the southwestern part of the Department of Cauca, southwest Colombia (Fig. 1). It lies between the towns of Buenaventura in the north and Tumaco in the south. The lake has a maximum depth of c. 4 m, a diameter of about 200 m, and covers an area of c. 0.5 km². The lake has steep slopes which are breached by the outlet creek. The main inlets to the lake come from the east and northeast. In the western part the El Caimito creek forms the
outlet which flows from southeast to northwest. After about 6 km this
creek meets the Rio Guapi which reaches the Pacific Ocean near the town
of Guapi. The Pacific coast, made up by many relatively small islands
separated by smaller and larger inlets, is located c. 40 km to the northwest
of the lake. About 30 km to the east of the lake the Western Cordillera
(Serranía de San Juan) rises up to a maximum altitude of some 1500 m.

2.2 Vegetation

The vegetation around Laguna El Caimito consists of tropical evergreen
rain forest. The steep slopes prevent growth of a shore vegetation. For the
vegetation around Laguna Piusbi (Fig. 1; Behling et al., 1998) Moraceae,
Melastomataceae, Lauraceae, Fabaceae, Caesalpiniaeae, Mimosaceae,
Rubiaceae, Myrtaceae and Arecaceae were identified as the most
important families representing rain forest vegetation. Along the coast
there is a c. 10-20 km wide belt with mangrove forest. The forest in the
hinterland of Guapi is named 'guandal' (del Valle, 1996), a floristically
diverse forest in which the following taxa are important for the pollen
record: Campnosperma panamensis, Socratea exorrhiza, Otoba
gracilipes and Ocotea oblingifolia.

2.3 Climate

The Pacific coast of Colombia receives some of the highest precipitation
amounts in the world. Mean annual precipitation ranges from 2000 mm in
the south to 12,700 mm in the north. Seasonality in precipitation is related
to the latitudinal movement of the Intertropical Convergence Zone
(ITCZ). Maximum precipitation occurs from April to June, when the
ITCZ shifts north, and from September to November, when the ITCZ
shifts to the south. Periods of marked decrease in precipitation are rare
and short (one week) and may occur during El Niño events (West, 1957).
In 1983, a strong El Niño year, the weather station in Guapi recorded the
following reductions in precipitation relative to the same period in 1982:
January -37%, February -50% and March -43% (IDEAM, pers. comm.).
Mean annual precipitation between 1981 and 1999 is c. 6500 mm, and
mean annual temperature 26°C (IDEAM, pers. comm.). The diurnal
temperature range in Tumaco and Buenaventura is less than 5°C (Del
Valle, 1994).
Figure 1. Map showing the location of Laguna El Caimito in the Chocó Biogeographic area

2.4 Human occupation of Chocó

The Pacific coast of Colombia and the area of Guapi have been affected by human settlements since the second century AD. According to Patiño (1988) early populations lived in the coastal area and did not reach further inland. However, the pollen record of Laguna Piusbi recorded human impact since about 3460 $^{14}$C yr BP based on an increase of palms and grassy vegetation (Behling et al., 1998). Agricultural activities in the area of Laguna Piusbi, shown by the presence of Zea mais, were recorded since about 1700 $^{14}$C yr BP.

3. Methods

3.1. Core recovery, pollen and diatom analysis

The 610-cm long core was drilled in 100-cm increments by H. Behling and H. Hooghiemstra in the centre of the lake with a modified Livingston
corer. Presence of sand prevented further sediment recovery. The 100 cm sediment intervals, collected in aluminium tubes, were transported to the laboratory in Amsterdam and stored under cold (4°C) conditions. Following lengthwise opening of the tubes in the laboratory separate samples of 1 cm³ were taken for diatom and pollen analysis at 5 cm intervals along the core.

Diatoms were prepared according to Van der Werff and Huls (1963). The following literature was used for diatom identification and ecology: De Oliveira and Steinitz-Kannan (1992), Fürstenberger (1997), Germain (1981), Hickel and Hakansson (1991), Hustedt (1930, 1959, 1961-66), Krammer and Lange-Bertalot (1986, 1991, 1997), Moro (1998), Patrick and Reimer (1966), and Steinitz-Kannan et al. (1982, 1986). In each sample a minimum of 400 valves were counted; only the interval from 504 to 475 cm contained insufficient diatoms to reach that sum. Diatoms are grouped into the following habitat preferences, 1) planktonic, 2) benthic, 3) littoral and 4) aerophylyous.

Pollen samples were prepared using standard treatment, including sodium pyrophosphate, acetolysis and heavy liquid separation by bromoform (Faegri and Iversen, 1989). Before treatment, tablets with exotic *Lycopodium* spores were added to each sample for calculation of pollen concentration and pollen influx values. Pollen samples were mounted in a glycerin gelatin medium. A minimum of 300 pollen grains was counted.

The pollen sum consists of taxa representing the regional forest; aquatic taxa, fern spores, fungal spores and algae colonies are excluded from the pollen sum. For pollen and spore identification we used publications by Behling (1993), Graf (1992), Herrera and Urrego (1996), Hooghiemstra (1984), Murillo and Bless (1974, 1978), Roubik and Moreno (1991), and the reference collection of modern pollen and spores of the Hugo de Vries-Laboratory. The software EXCEL, TILIA, TILIAGRAPH and CONISS was used for calculations, graphing the diagrams, and cluster analysis of the diatom and pollen diagrams.
Table 1. Stratigraphy of the core El Caimito

3.2 Time control of the sediments

Seven bulk samples of 1 cm³ were collected for AMS $^{14}$C dating at depths where significant changes in the pollen record occurred. The sample at 546 cm had a volume of 4 cm³ due to low organic content. Samples were cleaned of roots and dated at the Van der Graaff-Laboratory of the University of Utrecht (Van der Borg et al., 1987). The $^{14}$C ages were calibrated with the Cal20 software (Van der Plicht, 1993). The calibrated ages were determined after visual inspection of the probability distributions (2s) along the dendro-calibration curve. We tried to fix the calibrated dates relatively in the middle of the probability distribution curves and there at highest probability values. Due to this procedure we give no standard deviation or time intervals for the calibrated ages.
Table 2. Radiocarbon ages of samples from core El Caimito

3.3 Sediment analysis

Samples for grain size analysis were taken every 5 cm at depths adjacent to those used for pollen and diatoms samples; from 500 to 610 cm core depth we sampled at 10 cm increments. Samples were prepared for sedimentological analysis according to Konert and Vandenberghhe (1997) and analysed by a FRITSCH A22 'Laser Particle Sizer'. Sand is >63μm, clay is <5.5 μm, and silt represents the range from 5.5 to 63 μm. The sediments were described with a Munsell colour chart. To analyse the total organic content of the sediments, samples for loss on ignition (LOI) were taken every 10 cm and processed after Speranza et al. (2000). Major element analysis was carried out using atomic emission spectrometry for samples taken at 20 cm increments along the core.

4. Results

4.1 Stratigraphy and time control

Table 1 shows the major sedimentological units of the core. Fig. 2 shows sediment characteristics including grain size, LOI and major elements. This diagram includes 57 samples for LOI, 106 samples for grain size and 35 samples for major elements.

The seven AMS $^{14}$C ages (Table 2) of core El Caimito show that the sediment core represents the last c. 3850 calendar years before present (cal yr BP). The depth versus age graph (Fig. 3) shows a sedimentary gap between 546 and 498 cm. In the sedimentary record there is a distinct
change at 504 cm; this core depth has a calculated age ranging from 2700 to 2010 cal yr BP. We conclude that during that period sediments were eroded and sedimentation started again around 2010 cal yr BP; as a consequence, there is a hiatus in the record of almost 700 years. From 498 cm to the top sedimentation rate continuously decrease. We suggest that this decrease is related to the gradually decreasing availability of sediment in the small catchment area after the lake came into existence. This interpretation is supported by the decrease in sand content in the upper part of the sediment column (Fig. 2).

Downcore changes in the diatom content are shown in Fig. 4 based on 99 samples. A total of 68 diatom species were identified. Species with less than 1% representation were not graphed and not used for the interpretation; most represented benthic and periphytic taxa. Planktonic diatoms were limited to only a few species.

Downcore changes in the pollen spectra are shown in Fig. 5 including 119 samples. Below 605 cm no pollen was preserved; between 605 and 540 cm pollen was absent or the pollen content was too low to reach a meaningful sum. In total 168 different fossil pollen and spore types were identified. Additional 25 pollen and spore types remained unknown. Pollen grains represent mainly arboreal taxa (about 90%). Between 605 and 500 cm herbaceous taxa reach about 20% of the total pollen sum. Aquatic pollen was almost absent.
Figure 2. Downcore changes of grain size and major elements of the core El Caimito. Major elements are in percentages of total sample weight.
Figure 3. Depth vs age graph and sand content of the core El Caimito

4.2 Description of the zonation of the pollen and diatom records

Fig. 6 shows a selection of the most important pollen and diatom taxa. The zonation is based on combining results from cluster analysis of the pollen and diatom diagrams, the grain size analysis, and visual inspection of the CONISS dendrogram. Six different zones, CAI-1 to CAI-6, can be recognised.

In zone CAI-1 (605-504 cm) sediments are mainly composed of sandy silts (25% sand and 44% silt) and a smaller proportion of clay (30-35%). The colour of the sediments (2.5Y 4/4) and the low LOI values (5-10%) indicate a low organic matter content. The percentages of the major elements are low; only SiO2 is abundant (64%). No diatoms are preserved in this core interval. It is likely that the high porosity of the sandy deposits prevented preservation. Also pollen grains are badly preserved.
Especially in the lower part of this zone (605-540 cm) pollen content is low and mainly grains of Fabaceae (32%-50%), Moraceae/Urticaceae (40%), and Melastomataceae (15%-30%) are found. Between 540 and 504 cm the representation of Leguminosae decreases to 35-10%, whereas the percentages of Moraceae/Urticaceae and Melastomataceae increase slightly. Selaginella (15%), Cyatheaceae and other fern spores and Asteraceae (30%) reach maximum values. This interval includes the radiocarbon age of 3492±35 14C yr BP (3760 cal yr BP) at 598 cm, and 3003±34 14C yr BP (3175 cal yr BP) at 545 cm.

The onset of zone CAI-2 (504-402 cm) is defined by a change from non-organic silty sediments in CAI-1 to a humic clay (10YR 4/2). The stratigraphic contact between both types of sediments is sharp. This abrupt change is also recorded by the LOI which rises suddenly from 8.3% to 29%. The sharp contact and the shift in the depth vs. age graph (Fig. 3) points to a hiatus at 504 cm. In the lower part of zone CAI-2 the sand fraction is high (15%) but it gradually decreases towards the top of the zone (< 4%). The contribution of clay varies between 30% to 74%, whereas the silt fraction is relatively stable around 30%. Most of the elements show a marked increase at the bottom of the zone, except for SiO2 (average 64%-35%), TiO2 (average 0,9%-0,7%) and the MgO/Al2O3 ratio (average 0,09%-0,055%) which decrease. From this depth to the upper part of the core, the percentages of Fe2O3, Al2O3, TiO2 are relatively constant (Fig. 2).
Figure 4. Diatom percentage diagram of the core El Caimito. Zones based on CONISS cluster analysis
Figure 5. Pollen percentage diagram of the core El Caimito showing the most important taxa. Pollen sum values and CONISS cluster analysis is shown at the right.
Diatoms are scarce and badly preserved at the bottom of zone CAI-2; they appear at 475 cm. Initially, the assemblage is dominated by *Frustulia rhomboides* (55%), *Pinnularia* spp. (50% in the bottom to 15% in the middle part) (bad preservation prevented further identification), *Cymbella gracilis* (15%) and *C. spicula* (15%). The middle and upper part of the zone is dominated by *Frustulia rhomboides* (30%-45%), *Aulacoseira cf. herzogii* (c.30%), *Anomoeoneis brachysira* (20%-30%). *Cymbella* and *Pinnularia* species are reduced to about 5% or less. Species of *Eunotia, Navicula, Achanthes subatomoides* and *Actinella guianensis*, appear for the first time (Fig. 4).

The pollen record shows at the bottom of CAI-2 a sharp increase of *Rhizophora* (5%-10%) and *Cecropia* (5%-15%). Towards the upper part of this zone representation of *Rhizophora* is increasing from 10% to 25%. *Selaginella* disappears, and representation of Asteraceae and Fabaceae drop to low values (5%). The contribution of Moraceae/Urticaceae is stable in the whole pollen zone (50%), whereas percentages of Melastomataceae decrease from 30% to 15%. This interval includes the radiocarbon age of 2040±60 $^{14}$C yr BP (1975 cal yr BP) at 498 cm.

In zone CAI-3 (402-274 cm) sediments are dominated by clay (around 70%). The silt fraction is relatively stable (around 28%) and the sand fraction is low (<2%). At 294 cm and 341 cm there are marked increases in sand (15% and 5%, respectively). LOI values are relatively constant between 25% and 30%. P$_2$O$_5$ is relatively high (0.65%) but decreases to the top of the zone to 0.51%. The CaO/Al$_2$O$_3$ ratio is low (average 0.0144%) with maxima at the bottom (0.0071%) and in the upper part of the zone (0.0061%). At 340 cm most of the major elements have a sharp increase (Fig. 3) except for phosphorous.

The diatom assemblage is dominated by *Anomoeoneis brachysira* (55%-60%) and *Frustulia rhomboides* (25%). Other main taxa are *Eunotia intermedia, Cymbella gracilis, C. spicula, Aulacoseira cf. herzogii* and *Pinnularia* spp. In this zone *Eunotia* species become more common and *Pinnularia* spp. are less common than in the previous zone (Figs. 4 and 5).

In the pollen record Moraceae/Urticaceae and Melastomataceae (both around 20%) are most abundant. *Rhizophora* decreases from 30% at the bottom of the zone to 20% at the top. *Cecropia* values increase from 5%
at the bottom to 15% at the top. This interval includes the radiocarbon age of 1516±31 $^{14}$C yr BP (1405 cal yr BP) at 398 cm.

In zone CAI-4 (274–174 cm) sediments continue to be dominated by clay (around 70%). The content of silt and sand is similar to the previous zone. The proportion of sand increases sharply at 273 cm (up to 10%) and 219 cm (up to 7%), and at these horizons the contribution of clay decreases to 45% and 49%, respectively. LOI values decline from 27% at the bottom to 18% at the top of the zone, probably related to the increasing sand content. P$_2$O$_5$ values decrease from 0.47% to 34%, values of other elements are stable during this interval.

The diatom assemblage is dominated by *Anomoeoneis brachysira* (45%-55%) and *Frustulia rhomboides* (c. 40%). Important taxa, in decreasing order of abundance, are: *Aulacoseira* cf. *herzogii*, *Eunotia intermedia*, *Cymbella gracilis*, *C. spicula*, *Eunotia aff. glacialis* and *Pinnularia* spp. *A. brachysira* tends to decrease towards the top, whereas *F. rhomboides* and *A. cf. herzogii* tend to increase. Common elements are *Anomoeoneis serians* and *Actinella guianensis*. *Eunotia septentrionalis* disappears from the record.

The pollen assemblages continue with *Moraceae/Urticaceae* (20-30%) and *Melastomataceae* (15%). The contribution of *Cecropia* increases to 15% at the middle of the zone, falls to 3% around 200 cm, and increases to 13% at the top of CAI-4. The values of *Rhizophora* range between 10% and 30% and representation is contrary to the representation of *Cecropia*. This interval includes a radiocarbon age of 879±31 $^{14}$C yr BP (775 cal yr BP) at 266 cm core depth.

In zone CAI-5 (174–91 cm) sediments are composed mainly of clay (around 80%). At 119, 124, 167, 173 cm core depth, there is a marked increase in sand content (12%, 6%, 20%, and 4% respectively) and a concomitant decrease in clay. At 119 cm there is a marked increase in the grain size as there are sand particles of 500 µm diameter. Values of LOI have a minimum of 13% at 165 cm, and maxima of 30% (125 cm) and 32% (115 cm); during the remaining part of this interval values are low (17-18%). At 120 cm depth all major elements show a marked decrease: P$_2$O$_5$ from 0.35% to 0.24%, TiO$_2$, from 0.9% to 0.7%, Fe$_2$O$_3$/Al$_2$O$_3$ ratio from 0.4% to 0.3%, and SiO$_2$ from 46.5% to 39%. Only the ratio
CaO/Al₂O₃ increases from 0.01% to 0.004%. In the remaining upper part of the core average values of the previous zone are reached again.

The diatom assemblages are dominated by *Anomoeoneis brachysira* (20%-45%), *Frustulia rhomboides* (c. 35%-40%) and *Aulacoseira* cf. *herzogii* (10%-30%). Common species are *Anomoeoneis serians*, *Eunotia intermedia*, *Cymbella gracilis*, *C. spicula*, *Eunotia aff. glacialis*, *E. subarctuatoide*, *E. minor*, *E. trigibba*, *Actinella guianensis*. *Pinnularia* spp. are rare and tend to disappear.

The pollen assemblages show average values of Melastomataceae of 15-20% with two maxima at 150 cm and 110 cm; at the top of the zone only 10% is noted. The percentages of Moraceae/Urticaceae decrease to 10%. *Rhizophora* values decrease to 3% in the middle of the zone, but increase to 10% at the top. The representation of *Cecropia* increases from 7% to 10%. The representation of *Arecaceae*, mostly with values of 3-4% in the core, reach in the middle of the zone relatively high values of 10%. This interval includes a radiocarbon age of 522±30 ¹⁴C yr BP (535 cal yr BP) at 151 cm.

In zone CAI-6 (91-0 cm) sediments are dominated by clay (around 75%). At 73 cm the clay content decreases from 70% to 44% coinciding with an increase in silt of 28% to 55%. LOI values are stable around 17%. The contribution of most elements are stable, except for the increase in the ratios of MgO/Al₂O₃ (average 0.068%-0.078%) and Fe₂O₃/Al₂O₃ (average 0.3%-0.47%).

The diatom assemblages are dominated by *Anomoeoneis brachysira* (c. 40%), *Frustulia rhomboides* (25%) and *Aulacoseira* cf. *herzogii* (10-20%). This zone shows high representation of *Eunotia intermedia* (increase from 5% to 10%), *E. praerupta* (c. 5%), *Cymbella gracilis* (c. 5%), and *Eunotia subarctuatoide*. *Pinnularia braunii* appeared again in this interval.
Figure 6. Percentage diagram of dominant pollen and spore taxa (left) and diatom taxa (right) of the core El Caimito. Radiocarbon ages, extrapolated time frame (in cal yr), depth scale, lithological column, zones and CONISS cluster analysis are shown.

The pollen assemblages are characterised by increasing values of Moraceae/Urticaceae from 14% to 25% and decreasing percentages of Melastomataceae from 15% to 10% minimum. *Rhizophora* values show
an average around 10% with two spikes of 15%. *Cecropia* percentages increase from 10% to 15% at the top of the zone. This interval includes a radiocarbon age of $-1621 \pm 28$ $^{14}$C yr BP (modern) at 11 cm.

5. **Reconstruction of environmental change in the study area**

Zone CAI-1 (estimated period from 3840–2700 cal BP; 605–504 cm). The high proportions of sand and silt, and the low organic matter content of the sediments indicate that during this period the site was a depression influenced by fluvially transported material. Abundant coarse sediments are indicative of a high-energy environmental setting. Reducing conditions in the sediments might be indicated by relatively low values of Fe$_2$O$_3$. The coarse deposits provided unfavourable conditions for preservation of diatoms and pollen grains and, as a consequence, the pollen and diatom association may be biased. The presence of *Selaginella* ferns (common in active drainage systems) is indicative of a high energy environment, as well as abandoned parts of a drainage system. Presence of Fabaceae, Asteraceae and Melastomataceae may be indicative of an arboreal vegetation that occurs in coastal areas out of the reach of brackish water input (del Valle, 1996). Mangrove forest (*Rhizophora*) is absent in the catchment area of the basin. Arboreal taxa, such as *Piper*, *Acalypha*, *Alchornea*, *Solanaceae*, *Hedyosmum* and *Cyatheaceae* reflect inland lowland forest.

The transition from zone CAI-1 to CAI-2 coincides with a gap in the sedimentary record of about 700 years. Our study area is well known for its tectonic activity and episodes of subsidence. In the coastal area near the town of Guapi an earthquake in 1979 caused a subsidence event of about 1.4 m (Herd et al., 1981). Gonzalez (2001) also recorded for the period of about 500 years ago subsidence of the coastal area near the delta of the San Juan river of about 1.3 m. It is possible that a tectonic event caused a change in the river system allowing the formation of El Caimito lake.

Zone CAI-2 (estimated period from 2010–1430 cal yr BP; 504–402 cm). The increase in clay and total carbon content of the sediments suggest that sedimentation occurred under quiet lacustrine conditions where
organic material from the surrounding vegetation could accumulate. The amount of silt and sand at the beginning of the period indicates that the sedimentary basin was not fully isolated from the regional drainage system and at least periodically experienced input of coarse sediment under higher energy conditions. However, the coarse sediment fraction diminished rapidly and indicates that the basin became isolated within about 200 years. Shallow conditions are indicated by the abundance of benthic and littoral-benthic diatom species, such as Frustulia rhomboides, Anomoeoneis brachysira, Pinnularia spp. Cymbella spicula, C. pseudogracilis and species of Eunotia. This diatom association suggests the lake was acidic (pH range between c. 4 and 6), oligotrophic, and the water had low conductivity. Riverine influence during the second half of this period is supported by the presence of Aulacoseira cf. herzogii which requires turbulence (Van Landingham, 1964) and some turbidity (Jewson et al., 1993). The diatom association, grain size characteristics, LOI values, and major elements indicate that sedimentation in a proper lacustrine environment started in this period.

Most conspicuous in the pollen record is the presence of mangrove forest. Marine palynological studies (Muller, 1959; Hooghiemstra and Agwu, 1986) have shown that significant representation of mangrove pollen is only found at a short distance from the source area and there is no evidence that wind transport is an important factor in the distribution of Rhizophora pollen. We therefore assume that the mangrove forest was close to the lake. At present day brackish water and mangrove forest penetrate several kilometres inland. Given the mangrove forest proportions, we infer that the coastline was closer to the lake. This situation is very plausible as tectonic uplift and/or fluvial deposition of material from the Western Cordillera might have caused shifts of the coastline. In the regional forest Moraceae/Urticaceae, Melastomataceae, Arecaceae (palms), Fabaceae, Piper, Acalypha, Solanaceae, Alchornea, Sapotaceae and Sapindaceae were important taxa. Significant representation of Weinmannia may be related to regional forest at higher elevation, but Gentry (1986) noted presence of 'montane trees' in the lowland forests of Chocó under extreme precipitation values (see the discussion in Van der Hammen and Hooghiemstra, 2000). Cecropia is a typical pioneer tree which occupies barren land after disturbance. Highest representation of Cecropia coincides with peaks of silt and sand fractions, suggesting that expansion of Cecropia forest follows
disturbance of local forest by river action. In between these events of forest disturbance mature forest, dominated by Melastomataceae, Fabaceae and Arecaceae, was common.

Zone CAI-3 (estimated period from 1430-810 cal yr BP; 402-274 cm). Sediments consist almost entirely of clay and silt. Apparently, the fluvial input decreased. Events with increased sand content, and changes in major elements, indicate that there were two main pulses of increased riverine energy. The first one occurred between 1160 and 1130 cal yr BP (340-346 cm). The marked change in major elements, in particular the increase in TiO2 and Fe2O3, indicates more soil erosion followed by an increased input of heavy minerals and detrital material into the lake. The second pulse occurred around 900 cal yr BP (295 cm). Cecropia responds to these events and pioneer forest expanded. Also the high representation of 'indeterminate pollen grains' (Fig. 5) may be related to riverine supply of a wider variety of pollen taxa from the watershed area to the basin. Benthic species dominate the diatom assemblages; it is plausible that the lake reached its present setting during this period with a water depth of 4 m. The Rhizophora record reaches highest values in the beginning of this zone (around 1430 cal yr BP) and mangrove forest, possibly representing a narrow zone along the river system, must have been close to the lake. During this period the proportion of Rhizophora decreased; apparently the belt with mangrove forest shifted seaward between 1430 and 810 cal yr BP. We infer a westward migration of the coastline, possibly related to regional tectonic uplift. Compared to the previous zone, the regional forest hardly changed in floral composition. Moraceae/Urticaceae, Melastomataceae, Arecaceae (palms), Fabaceae, Acalypha, Solanaceae, Alchornea, Sapotaceae and Sapindaceae were important taxa, but Piper and Acalypha became less common. The proportion of Weinmannia remained unchanged compared to the previous zone.

Zone CAI-4 (estimated period from 810-580 cal yr BP; 274-174 cm). This period shows alternating peaks of clay and silt, pointing to a stable lacustrine setting. Three spikes of the coarse fraction (sand and silt) at 275 cm, 225 cm and 174 cm document occasional riverine input of sediments. The first two events are, as in the previous events, followed
by expansion of *Cecropia* dominated pioneer forest. Also the increase of *Aulacoseira cf. herzogii* might indicate an increase of depositional energy, as this diatom species requires turbulence and turbidity to float (Van Landingham, 1964; Jewson et al., 1993).

The representation of *Rhizophora* first increased (until about 720 cal yr BP), but diminished between about 640 and 580 cal yr BP and remained at a low level up to recent time. We interpret the second major expansion of mangrove forest in this record either as an inland migration of the coastline (in the direction to lake El Caimito) related to tectonic activity, or a significant re-organisation of the system of water ways in the coastal area near Guapi. The latter may also be related to tectonic activity. The pollen record shows little evidence for changes in the floral composition of the regional lowland forest, compared to the previous zone. Palms (*Iriartea* in particular), Sapotaceae and *Protium* became more common in the forest, whereas the gradually increasing values of 'indeterminate pollen grains' (not occurring as spikes as previously; Fig. 5) is considered to reflect a floristically more diverse forest.

Zone CAI-5 (estimated period from 580-300 cal yr BP; 174-91 cm). Grain size shows a continuation of the conditions in the previous zone. There are two main spikes of coarse sand and silt which represent occasional pulses of high riverine energy. The oldest peak occurred at c. 570 cal yr BP and the other at c. 420 cal yr BP. Both events relate to abrupt maxima in the total organic content of the sediments. It is plausible that this organic matter was supplied by the river and caused a more productive lake. Considering the total record, this zone reflects a low energy environment with maximum accumulation of clay, and an input of organic matter that reflects the autochthonous production in and around the lake (high energy riverine events supply coarse fraction as well as allochthonous organic matter). The diatom association, *Anomoeoneis brachysira*, *Eunotia* spp. and *Frustulia rhomboides* in particular, indicates oligotrophic and acidic water with low conductivity. The peak of *Aulacoseira cf. herzogii* and the concomitant decrease in benthic diatoms during the last high energy riverine event support a more energetic environment, a disturbed bottom lake and an increased in turbidity and water turbulence.

The pollen record from this zone onward (the last 580 years BP) shows low representation of *Rhizophora*. The belt with mangrove forest
apparently reached the greatest distance from lake El Caimito recorded in the last 2000 years. This may be indicative of further tectonic uplift of the coastal area. From this zone onward, the representation of *Cecropia* and palm trees (Arecaceae) increased markedly suggesting that more inland areas were used and disturbed by human activities. Palms are intensively used in human settlements and a response of the palm record to increased human disturbance was also noted in lake Piusbi (southern Chocó; Behling et al., 1998), Amazonia (Berrio et al., 1999), and in the savannas of the Llanos Orientales (Behling and Hooghiemstra, 1998, 1999). The proportion of 'indeterminate pollen grains' has higher values reflecting an increase of the floral composition of the coastal forest.

Zone CAI-6 (estimated period from 300 cal yr BP to present day). Sediments are dominated by clay and silt indicative of stable lacustrine conditions without riverine influence. Low LOI values indicate that the level of carbon input by the local ecosystem in and around the lake was low. The diatom assemblages indicate acidic (estimated pH 4-6) and oligotrophic water with low conductivity. The increase of *Eunotia praerupta* and *P. braunii* indicative of iron (Moro and Fürstenberger, 1997) matches the increased values of Fe$_2$O$_3$. Therefore, we infer the water was richer in iron.

The pollen record shows a regional forest type in which Moraceae/Urticaceae, Melastomataceae, Arecaceae (palms), Fabaceae, *Piper*, *Acalypha*, Sapotaceae, *Protium*, and *Ficus* are most important. The proportion of 'indeterminate pollen grains' reaches the highest values reflecting higher floral diversity of the forest. The relatively high proportion of *Cecropia* and palms are considered as (partly) a reflection of increased human disturbance. Indeed, the Spanish Conquest in Colombia, provoked migration of populations from the Andes to remote areas, including Chocó. During our visit to the forest we noted at remote places shelters for fishermen and hunters totally constructed by palm trees. The contribution of potential 'montane trees' to the pollen spectra (*Weinmannia, Hedyosmum, Ilex*) is low and may reflect the natural proportion of these taxa to super-humid lowland rain forest. We expect melastomataceous trees to be most important in the forest close to the mangrove belt (see zone CAI-1); the decrease reflects the present day environmental stability in the study area.
6. Discussion

As demonstrated in the previous section, integration of pollen, diatom, grain size, and major element proxies appears to enhance our reconstruction of the development of a dynamic environment. The record demonstrates a development from: (1) a high energy (coarse sediments) river-influenced basin, at close distance to the coastal mangrove forest, from 3850 to 2700 cal yr BP (zone CAI-1), to (2) a period of fluvial erosion in the depression, causing a hiatus in the record from 2700 to 2010 cal yr BP to (3) a lake system that is periodically affected by events of high energy by the regional drainage system (repeated abrupt input of coarse sediments in a matrix of clay and silt, followed by an expansion of *Cecropia* dominated pioneer forest in riverine disturbed areas) and at very close distance to mangrove forest along the drainage system from 2010 to 580 cal yr BP (zones CAI-2 to CAI-4), to (4) a lake isolated from regional riverine system disturbance (high content of fine grained sediments, a total carbon content of the sediment that reflect only the local input and production in the lake) surrounded by a floristically diverse forest with probable impact of human activities (during the last 580 cal yr BP, but especially during the last 300 years). The decrease in P2O5 indicate that the lake become gradually less productive and depleted of nutrients. The increasing MgO/Al2O3 ratio indicate a gradual increase in the input of manganese into the lake. CaO content is positively correlated to the increase of silt. Therefore calcium seems to be allochthophonous and probably derived from the Cretaceous limestones. Elements such as aluminium and iron have been relatively stable in the lake.

During zones CAI-2 to CAI-5 (2010 to 300 cal yr BP), six distinct horizons with a high content of sand and silt (430-420 cm, 1593-1536 cal yr BP; 310-290 cm, 990-885 cal yr BP; 275 cm, 808 cal yr BP; 223-220 cm, 685-677 cal yr BP; 173-167 cm, 580-568 cal yr BP; 120-124 cm, 432-413 cal yr BP) indicate periodic events of high energy of the river system. The increase in riverine energy led to greater erosion of the sandy fluvial terraces and lake slopes and the subsequent increase in sand deposition. The intensity of these events (based on the sand and silt record) seems to decrease and matches the decreasing content of total
organic matter. During zones CAI-2 and CAI-3 the basin received allochthonous carbon but during zones CAI-5 and CAI-6 only locally produced carbon reached the sediments. The floristic composition of the forest responds clearly to the periodic fluvial disturbance: expansion of the Cecropia dominated pioneer forest follows each event of high energy and forest rich in melastomataceous taxa prevail during the stable periods when mainly clay is deposited. Decreasing riverine also matches with the observed succession in the pollen record: periodically damaged lowland rain forest at close distance to the mangrove belt (zones CAI-2 to CAI-4) becomes gradually floristically richer (increase of unidentified pollen types) when soils are better drained and the distance from the study site to the belt with mangrove forest increases.

We observed that periods of higher riverine energy interrupted more quiet lake deposition (clay deposition and less than 0.4% sand) periodically after AD 1570. By using linear interpolation of the calibrated radiocarbon ages we calculated 57, 119, 9, 24, 21, 27, 77, 39, 19 and 210 years time between these high energy events. The occurrence of those periods could be related to the El Niño/Southern Oscillation (ENSO) frequency, in addition to the present day recurrence intervals of 3 to 7 years. According to Anderson et al., (1982) long term ENSO variability is expressed in cycles of 50, possibly 22 and between 80 to 100 years.

The diatom associations from lake El Caimito are dominated by Anomoeoneis brachysira, Frustulia rhomboides, Aulacoseira cf. herzogii and species of Eunotia, and Cymbella. This association points to acidic and oligotrophic conditions in a relatively shallow and stable water body during the last 1840 years. Decreasing abundance of A. brachysira and the P2O5 content in the sediments, might indicate that this species was favoured during the first part of the record by the relatively high nutrient content of the water. Maximum abundance of Aulacoseira cf. herzogii, indicative of increased turbidity and turbulence, coincided and followed episodes of higher energy in the ecosystem.

The diatom assemblages found in the El Caimito sediments are very similar to those found in modern lakes in Brazilian and Ecuadorian Amazonia (De Oliveira and Steinitz-Kannan, 1992; Moro and
Fürstenberger 1997; Steinitz-Kannan et al., 1982, 1988). They are characterised by being poor in planktonic, and rich in periphytic and benthic species. Such water bodies are also frequently dominated by a *Eunotia-Frustulia* assemblage (Uherkovich and Franken, 1980).

![Geographical setting today](image)

![Geographical setting (tentative)](image)

**Figure 7.** Map showing the tentative changes of the geographical position of the coastline and the mangrove belt in the Caimito area

Together with the pollen records of Laguna Piusbi (Behling et al., 1998) and Laguna Jotaordó (Berrio et al. 2000) (Fig. 1) the pollen record of El Caimito is the third document of environmental dynamics in the lowland rain forests of Chocó. All sedimentary basins originate from a dynamic and high energy fluvial system and developed into a lake system more of less isolated from the regional drainage pattern. Continuous lake sedimentation was registered from 4300 $^{14}$C yr BP in Piusbi, around 2010 $^{14}$C yr BP in El Caimito, and around 1440 $^{14}$C yr BP in Jotaordó. Lakes Piusbi and El Caimito are both located in the coastal plain and register the presence of mangrove forest. Migrations of the belt with mangrove forest near the coast were inferred from the pollen record (Fig. 7). The movement of the coastline can be explained by the tectonic instability (uplift and subsidence) (Herd et al., 1981) and/or fluvial deposition of material coming from the Western Cordillera. Shifting coastlines inferred from pollen records were earlier documented for Guyana and Surinam by Wijmstra (1971).

The floral composition of the regional forest near Piusbi and El Caimito is similar, but differs from Jotaordó. This is due to the different setting of
the Jotaordó site which has no contact to the coastal area and is located in a broad river valley with a meandering drainage system.

7. Acknowledgements

Diatom research was funded by NWO-WOTRO grant WB 75368 to H. Hooghiemstra / M.I. Velez. Pollen research was funded by NWO-GOA grant 750.197.08 to H. Hooghiemstra / M. Wille. The core was collected under exiting, but logistically and physically difficult conditions by H. Behling, A. Negret and H. Hooghiemstra during a NWO-GOA funded post-doctoral project (grant 750.195.10 to H. Hooghiemstra / H. Behling). We thank the director of the 'Corporación de Cauca' in Guapi for providing transport and the local population along the Guapi River for support with carrying our coring equipment through the rain forest. We thank the Tropenbos-Colombia office in Bogotá (J. Saldarriaga and C. Rodriguez) for logistic support during our expeditions in one of the wettest areas on the globe. We thank Jody dos Santos for invaluable support from our laboratory in Amsterdam. Nico de Wilde (Amsterdam) is acknowledged for major mineral analysis, Annemarie Philip for preparing the pollen samples, Kay Beets (Vrije Universiteit) for supporting the interpretation of mineral records. We thank Martina Hagen and Martin Konert (Vrije Universiteit) for their support in the sediment analysis. We thank Kurt Graf and an anonymous reviewer for constructive comment which improved the manuscript substantially.

8. References


Van der Hammen T. and Absy M.L, 1994. Amazonia during the last


