Lateglacial and Holocene vegetation and climate change in lowland Colombia.
Berrio Mogollon, J.C.

Citation for published version (APA):
Berrio Mogollon, J. C. (2002). Lateglacial and Holocene vegetation and climate change in lowland Colombia. Amsterdam: UvA

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: http://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.
MULTI-INTERDISCIPLINARY EVIDENCE OF THE HOLOCENE HISTORY OF A CULTIVATED FLOODPLAIN AREA IN THE WETLANDS OF NORTHERN COLOMBIA

Juan Carlos Berrio, Arnoud Boom, Pedro Botero, Luisa Fernanda Herrera, Henry Hooghiemstra, Freddy Romero and Gustavo Sarmiento

ABSTRACT

AN ENVIRONMENTAL RECONSTRUCTION OF THE LAST 10,000 14C YEARS OF A FREQUENTLY FLOODED WETLAND ECOSYSTEM IN THE LOWER MAGDALENA VALLEY IN northern Colombia is presented on the basis of a multi-disciplinary study of the sediments of the upper 15 m the core from Boquillas (74°33'E, 9°7'N; 20 m a.s.l.). We used the following studies: pollen, lithology, organic structures, clay mineralogy, soil and sediment geochemistry, and δ13C values. The chronology is based on 13 AMS 14C dates; of 7 samples the humid acid fractions were used in the case of seven samples. Pollen from local origin (swamps, open grass-rich vegetation, and gallery forest) show the development of the wetland area. River-transported pollen from greater distance (dry forest, montane forest, Alnus) shows changes in river activity and reflects large-scale changes of climatic conditions in the Momposina basin.

From c. 10,010 to 9370 14C yr BP (zone BQS-Ia) the river system was of high energy, as inferred by the lithological changes. The landscape was dominated by open grass-rich vegetation with gallery forest along the
streams. A marked representation of *Alnus* and montane forest taxa indicate significant water transport and river dynamics. Climatic conditions were dry. From c. 9370-8430 $^{14}$C yr BP (zone BQS-Ib) wetlands were isolated from the main river system and clayey sediments with kaolinite, smectite and illite as the main minerals, accumulated in a lower-energy environment. Climatic conditions were dry and changes in the seasonal precipitation favoured the expansion of the gallery forest. From c. 8430 to 8040 $^{14}$C yr BP (zone BQS-Ic) low values of river-transported pollen indicate dry climatic conditions and open vegetation became more abundant. The flooding frequency of the Boquillas site diminished. From 8040 to 4900 $^{14}$C yr BP (zone BQS-Id) site Boquillas was dominated by open vegetation with patches of gallery forest along the streams. Supply of river-transported allochthonous pollen (from many sources) was minimal. Clay minerals from the sediments suggest variable temperature and precipitation. From c. 4900 to 1550 $^{14}$C yr BP (zone BQS-II) the site was within the reach of the main river system as is the case today. Frequent floodings, coinciding with peaks of river-transported grains of *Alnus*, and high sediment supply point to high precipitation in the composite catchment area of the Magdalena, Cauca, San Jorge, and Cesáar rivers. High values of phosphorous in the upper part of the core point to the presence of a pre-hispanic civilisation, approximately from 2000 yr $^{14}$C yr BP onward. Construction of an extensive drainage system allowed irrigation as well as drainage depending the annual cycle of precipitation. The landscape was significantly modified and allowed an extensive crop production on a system of raised fields.

6.1 INTRODUCTION

The palaeoecological history of the wetland ecosystem in northern Colombia is poorly known. This floodplain area is one of the large wetlands in the world (Van der Hammen, 1986). Paleoecological understanding is based on pollen records from the Ciénaga Morrocoy, located in the lower Magdalena river valley, providing evidence of a dry period around 720 $^{14}$C yr BP (Wijmstra, 1967). Van der Hammen and Noldus (1984) studied the pollen profile from Ciénaga Grande de Santa Marta, located at the mouth of Magdalena river near the Caribbean Sea. They showed regression-trans-
gressions during the Holocene based on migrations of the belt with mangrove vegetation. Herrera and Berrío (1998) showed in a pollen record from Caño Carate that climatic conditions were dry between 940 and 780 \(^{14}\)C yr BP, and wetter conditions around 550 \(^{14}\)C yr BP. In 9 boreholes Van der Hammen (1986) dated 25 peat-rich horizons interlaced with clay, recording Holocene fluctuations in the flooding intensity in the basin of the Magdalena-Cauca-San Jorge rivers. The inundation frequency was interpreted as reflecting changes in precipitation in the catchment area of this composite drainage system. Based on all boreholes an estimated mean sedimentation rate of 3.82 mm/yr was inferred for the last 7500 \(^{14}\)C yr BP (HIMAT, 1977).

Multi-proxy analysis of the sedimentary record is important to better understand the dynamics of an ecosystem on a regional scale (Lowe and Walker, 1997). Integration of the biotic and abiotic information obtained from sediment cores results in a more complete reconstruction of paleoenvironmental change (Patience et al., 1996; Huizer and Isarin, 1997). Depending on the environment different proxies may be used, but mostly geochemical analysis of sediments is a basis (Mackereth, 1965). In Latin America few multi-proxy studies have been published; we mention the studies in Carajás (Soubiés et al. 1991), the central Amazon basin (Irion et al., 1995), in Venezuelan lake Valencia (Curtis et al., 1999) and the study of Cauxianã in Brasil (Behling and Lima da Costa, 2000). From Colombian Amazonas we mention the study by Duivenvoorden and Lips (1995) in which proxies of the biotic and abiotic environment were integrated to show the natural processes in a lowland rainforest ecosystem.

In this paper we present the results of the new core Boquillas. We used a combination of soil geochemistry, changes in the content of \(\delta^{13}\)C of the total organic content (\(\delta^{13}\)C\(_{\text{TOC}}\)), pollen analysis and downcore changes in sediment characteristics along the core. The aim of this paper is to reconstruct environmental change of the Lower Magdalena wetland ecosystem in northern Colombia since the Lateglacial. We also try to improve the understanding of how the pre-hispanic cultures, which existed there according to the archaeological records for over 3000 years, modified the landscape to control their environment and turn it into an extensive agricultural system.
6.2 SETTING OF THE AREA

6.2.1 Geography and climate

The Core Boquillas was collected in the town of Boquillas, province of Bolivar, southeast of the village of Magangué, and southwest of the village of Mompós. The site is located 13 km from the Brazo de Loba, and 2 km from the river Chicagua, at 74°33′45″E and 9°7′25″N in the centre of the Momposina basin (Fig. 6.1). This region is known as ‘Depresión Momposina’ because it includes some 80% of the total number of ciénagas, depressions in the Cretaceous-Tertiary bedrock with stagnant, or river-dependent water bodies that accumulate sediments (Forero et al., 1997; Ballesteros, 1983).

There is a dry period from the end of November until the end of March. Most precipitation falls from May to July, and from October to November. The total annual precipitation is some 1500 mm in the localities of Magangué and Mompós; towards the south the annual precipitation increases to 2500 mm (IGAC, 1998). The mean annual temperature is 26°C. This region receives water from the Magdalena, Cauca, San Jorge, and Cesáar rivers, which transport huge amounts of sediments from the three Colombian Cordilleras into the Caribbean Sea (IGAC, 1989). The area is the most frequently flooded part in Colombia. According to Van der Hammen (1986) the uppermost 40 to 50 m of sediment in the Momposina basin is not older than of Lateglacial age, that is with a maximum age of 11,000 14C yr BP.

6.2.2 Vegetation

In the vegetation study of IGAC (1977) four main vegetation types were recognised in the study area:

(1) tropical dry forest (Bosque Seco Tropical; bs-T) with Attalea butyracea, Syagrus sancona and Acrocomia antioquiensis, Amaranthus hybridus, A. spinosus, Anacardium excelsum, Aspidosperma dugandii, Bursera tomentosa, Capparis indica, C. odorata, Casearia corymbosa as main taxa. Local vegetation is characterised by a.o. Eichornia crassipes, Eliocharis interstincta,
Figure 6.1. Map of the study area showing the location of the Momposina basin and the coring site of Boquillas, in the lower Magdalena Valley, northern Colombia.
Hydrocotyle umbellata, Ludwigia pilosa, Pistia stratiotes, Polygonum densiflorum, Salvinia sprucei, and Typha angustifolia.

(2) premontane wet forest (Bosque Húmedo Premontano; bh-PM) is located in the valley of the Magdalena river. Main taxa are a.o. Clidemia pitellata, C. octona, Miconia aeruginosa and M. stenostachya; Clusia sp., Croton sp., Cupania sp., Cordia alliodora, Didymopanax morototoni, Erythrina poepiggiana, Ficus sp., Inga densiflora, Ladenbergia magnifolia, Nectandra sp., Ochroma lagopus, Myrsine guianensis, Trichanthera gigantea and Triunfetta mollisisma.

(3) tropical wet forest (Bosque Húmedo Tropical; bh-T) mostly present as gallery forest along the rivers with Acalypha macrostachya, Alchornea sp., Cassia reticulata, C. spectabilis, Calliandra sp., Erythrina edulis, Cecropia sp., Vismia sp., Piper aduncum, Tabebuia rosea, Tecoma mollis, Trema micrantha, Warszewiczia coccinea, Spondias mombin, Ilex sp., Tapirira guianensis and Virola sebifera.

(4) savanna vegetation, present for climatic (annual precipitation less than 500 mm) as well as for edaphic reasons (subsoil characterised by floodplain soils called Entisoles or Aquents). The open herb vegetation is characterised by Poaceae (Bouteloua filiformis, Cynodon dactylon), Cyperaceae (Cyperus ferax), and Asteraceae (Aspilia tenella). Savanna trees are mainly represented by Curatella americana and Byrsonima crassifolia.

According to Rangel et al., (1995) this region has a high phytodiversity; he listed 3430 plant species for this wetland area. Families with the highest species richness are Rubiaceae (589 species), Leguminosae, including Fabaceae, Caesalpinaceae and Mimosaceae (332 species), Asteraceae (168 species), and Poaceae (136 species).

6.2.3 Abiotic setting

Analysis of the clay mineralogy including kaolinite, smectite, illite, hydromica, vermiculite and quartz can provide information about the origin of the material and its transformation under certain climatic condi-
tions (Haldorsen et al., 1989). Analysis of geochemical proxies including carbon, calcium, sodium and phosphorous is indicative of the environmental conditions of soil formation and alteration and may represent sequences of soils in the catchment area of the Momposina basin (Woodward et al., 1994).

6.2.4 Archaeological setting

Several archaeological studies have been carried out in the Momposina basin since the 1970’s. Plazas and Falchetri (1981) defined an area of more than 5000 km² of agricultural raised fields with ages varying between 2700 BP up to 750 BP (Fig. 6.2). Agricultural fields were constructed by the Zenu people in order to have vast areas dedicated to the cultivation of crops throughout the year. The main purpose of them was twofold: long (more than 1 km) perpendicular ridges and ditches to waterways were used to conduct the excess water throughout the basin and to control floods. This was important during the wet season that lasts here at least 9 months per year. Short and chess like patterns of agricultural fields of some 50 to 70 m long were constructed at the centre of the basin in order to keep the water during the dry season and assure productivity. These areas are usually located between the rivers or streams and “ciénagas” (Herrera and Berrío, 1998; Rojas and Montejo, 1999). The main agricultural products were *Zea* (maize), *Manihot* (manioc), *Capsicum* (chili peppers) and *Cucurbita* (squash). Their diet was complemented by turtle, fish and caiman from the various water bodies (Plazas et al., 1993). Together with the agricultural fields, these pre-Hispanic inhabitants created populated centres of more than 100 people per km², where house platforms were raised from the water level (Plazas et al., 1993).

6.3 METHODOLOGY

Core Boquillas was recovered during the dry season of February 1998. The site was reached by boat. A core of 50 meters long and 2.5-cm diameter was obtained using an Acker driller with a Shelby and Split Spoon sampler. The core was transported to the laboratory of the Fundación
Chapter 6

Erigaie in Bogotá for immediate sampling at 10-cm intervals. Samples of 50-100 g were collected to be sub-sampled to analyse the following proxies: sedimentology (Herrera et al., submitted), clay mineralogy, soil geochemistry, $\delta^{13}$C analysis, AMS $^{14}$C dating, and pollen analysis.

A granulometrical analysis and soil chemistry of trace elements was determined following the standard methodology from IGAC (1990). For granulometric analysis we used a Boyoucus hydrometer after dispersion of the sediments with Na$_2$P$_2$O$_7$. The pH (H$_2$O) value was measured in a volumetric 1:1 sediment:water solution. The carbon (C) content was measured according to the Walkley-Black method (Schollemberger, 1945). The phosphorous (P) content was measured by extraction with 0.1 N HCl and 0.13 N NH$_4$F according to Bray II (Bray and Kurtz, 1945).

Exchangeable bases were measured after extraction with NH$_4$OAc 1N (pH=7) with complexed with EDTA, and the Sodium (Na) content was measured by flame photometry. Organic structures in in the undisturbed laminated sediments, such as those due to oxidation and bioturbation, were identified using a binocular microscope with magnification between 10x and 40x. Identification and quantification of minerals mainly quartz, illite (I), kaolinite (K), vermiculite (V), hydromica (Hm) and smectite (Sm) was determined with standard X-ray diffraction techniques (Whiting and Allardice 1986; Thorez 1986) using powdered bulk samples. Determinations of the organic structures and oxidation, and values for clay mineralogy and sediments geochemistry were obtained at 50-cm increments along the core. In order to characterise general conditions rather than to observe the variability within selected periods, the results are presented as smoothed curves (Fig. 6.3). Pollen curves in Figure 6.3 show changes along the core of the contribution of the different ecological groups expressed as a percentage of the pollen sum (see later).

Analysis of total organic carbon ($\delta^{13}$C$_{TOC}$) was carried out on a limited number of samples. The sediments were freeze dried, ground, treated with 2M hydrochloric acid, and allowed to react for 24 hours to remove the carbonates. The sediments were then dried in vacuo and stable carbon
FIGURE 6.2. Aerial photograph of the Momposina basin in northern Colombia, showing the complex hydrological system of 'cienagas' (lakes), man-made waterways, and raised agricultural fields. (Photograph from Instituto Geográfico Agustín Codazzi, Bogotá; with kind permission).
isotopic compositions were determined by automated online combustion (Carlo Erba CN analyser 1502 series) followed by conventional isotope ratio-mass spectrometry.

Changes of the clay mineralogy through the core were identified by observing and comparing the spacing and intensity of peaks on diffractometer traces (Fig. 6.4). We show percentages of kaolinite with good crystallinity (Kw), intermediate (Kc) and low crystallinity (Kf), and values for illite with good cristallinity (lap), regular crystallinity called “large peak” (Ilp) and low crystallinity called “open” (Io). Other clay minerals like vermiculite and smectite are shown in Fig. 6.3 together with the results from the soil geochemistry analysis for the elements C (Meq/100 g), Ca (Meq/100 g), Na (Meq/100 g) and P (ppm).

For chronology, 13 bulk samples were radiocarbon dated by accelerator mass spectrometry (AMS $^{14}$C) at the Geochron Laboratories (Krueger Enterprises, Inc.) and the Van der Graaff Laboratory of Utrecht University (Van der Borg et al., 1987). The humic acid fraction of some samples has also been dated to confirm its reliability (Bartley and Chambers 1992; Shore et al., 1995). This last method differs from the traditional AMS $^{14}$C dating by measuring two different components of the organic material, the fractions of the humic and fulvic acids, which contain different levels of $^{14}$C (see Shore et al., 1995). The humic acid fraction gives younger dates compared to the residual fraction and the traditional AMS $^{14}$C dates. Dating the humic fraction is considered more reliable in the type of sediments we are dealing with (Johnson et al., 1990) as possible contamination by older carbon residues can be eliminated (Walker and Harkness, 1990).

For pollen analysis sediment samples of 1 cm$^3$ were taken at 10-cm intervals along the core. Pollen samples were prepared using the standard treatment, including sodium pyrophosphate, acetylolysis, and heavy liquid separation by bromoform (Faegri and Iversen, 1989). Before treatment, a tablet with exotic Lycopodium spores was added to each sample for calculation of pollen concentration and pollen influx values. Pollen samples were mounted in a glycerine gelatine medium. A minimum of 300 pollen grains of terrestrial taxa was counted and forms the pollen sum; pollen of aquatics and spores of ferns, bryophytes and fungi were
**Figure 6.3.** Diagram showing the stratigraphy and downcore changes of the clay mineralogy, soil geochemistry, and δ13C of the upper 15-m of core Boquillas in relation to the pollen zones. K = kaolinite, Sm = smectite, I = illite, Hm = hydromica, V = vermiculite, Qzo = quartz, C = carbon, Ca = calcium, Na = sodium, P = phosphorous.
Figure 6.4. Downcore changes of the crystallinity of clay minerals (K and I) of the upper 15-m of the Boquillas core. Kaolinite: Kw = good crystallinity, Kc = intermediate, Kf = low crystallinity. Illite: lap = good crystallinity, lip = regular "large peak", lo = low crystallinity "open".
Figure 6.5. Depth versus age graph of the radiocarbon ages of core Boquillas. Solid circles show ages of bulk carbon fractions; open circles show ages of humic acid fractions. Five samples, placed in brackets, were rejected (see discussion in the text).
excluded from the pollen sum. For pollen and spore identification we used the pollen morphological studies by Absy (1979), Hooghiemstra (1984), Roubik and Moreno (1991), Behling (1993), Herrera and Urrego (1996) and the modern reference collections of pollen and spores of the Hugo de Vries Laboratory and the Erigai Foundation.

Identified taxa were classified into the following ecological groups: (1) open vegetation on stable soil, (2) gallery forest, (3) montane forest (excluding Alnus), (4) dry forest, (5) Alnus, (6) ferns and fungi. We consider Alnus indicative of river transport: Alnus trees mainly occur on wet soil along streams and rivers in the catchment areas of the rivers that supply water to the site. Pollen production of Alnus is high (Graban dt, 1980) and pollen is easily shed into the river systems and transported downstream by water currents (see the discussion in Van der Hammen and Hooghiemstra, 2000). For presentation of the pollen and spore data, calculations, and cluster analysis, we used the software TILIA, TILIAGRAPH, and CONISS (Grimm, 1987).

6.4 RESULTS

6.4.1 Stratigraphy

The upper 15 m of the core Boquillas mainly consist of clay, silt and sand indicative of significant changes in river-supplied sediments to the floodplain area. As far as relevant for this paper a general description of the stratigraphy is given in Table 6.1; the most remarkable features like type of sediment, colour, presence of plant macroremains, and the location of hiatuses in core recovery are presented. Grain size analysis of the total 50-m long core showed that 84% consist of clayey sediments, indicative of a floodplain environment receiving clay (22%) and silty clay (54%) in suspension.
MULTI-INTERDISCIPLINARY EVIDENCE OF THE HOLOCENE HISTORY OF A CULTIVATED FLOODPLAIN AREA IN THE WETLANDS OF NORTHERN COLOMBIA

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Lithological description</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-80</td>
<td>fine sand with some plant macroremains. Color 2.5Y4/4.</td>
</tr>
<tr>
<td>80-140</td>
<td>silty clay, well compacted, irregularly laminated with some fine macroremains. Color 10YR5/2.</td>
</tr>
<tr>
<td>140-210</td>
<td>fine dark sand with macroremains.</td>
</tr>
<tr>
<td>380-420</td>
<td>fine gray clay.</td>
</tr>
<tr>
<td>420-480</td>
<td>hiatus.</td>
</tr>
<tr>
<td>480-510</td>
<td>muddy sediment, well compacted with few macroremains.</td>
</tr>
<tr>
<td>510-610</td>
<td>silty clay, well compacted, without macroremains. Colour 10YR5/2.</td>
</tr>
<tr>
<td>610-630</td>
<td>fine dark gray clay, well compacted.</td>
</tr>
<tr>
<td>630-680</td>
<td>fine clay, slightly laminated.</td>
</tr>
<tr>
<td>680-690</td>
<td>silty clay, well laminated.</td>
</tr>
<tr>
<td>690-780</td>
<td>mud, slightly compacted, not laminated. Colour 10YR5/2.</td>
</tr>
<tr>
<td>780-880</td>
<td>silty clay, not compacted, with few macroreains. Colour 10YR5/4.</td>
</tr>
<tr>
<td>880-905</td>
<td>sandy silt.</td>
</tr>
<tr>
<td>905-910</td>
<td>fine sand, no macroremains. Colour 2.5Y4/5.</td>
</tr>
<tr>
<td>910-930</td>
<td>fine dark clay.</td>
</tr>
<tr>
<td>930-990</td>
<td>hiatus.</td>
</tr>
<tr>
<td>990-1010</td>
<td>mud, slightly compacted, not laminated. Colour 10YR5/2.</td>
</tr>
<tr>
<td>1010-1400</td>
<td>fine dark compact clay.</td>
</tr>
<tr>
<td>1400-1405</td>
<td>compact mud.</td>
</tr>
<tr>
<td>1405-1460</td>
<td>hiatus.</td>
</tr>
<tr>
<td>1460-1500</td>
<td>fine sand.</td>
</tr>
</tbody>
</table>

Table 6.1. Lithological description of the upper 15-m of the sediment core of Boquillas.

6.4.2 Chronology

The 13 AMS radiocarbon ages on bulk samples are listed in Table 6.2 and provide the chronological time control of the sediments. The dating in a depth versus age graph is given in fig. 6.5. All dates between 1530 cm and 330 cm shows ages between 6570±60 14C yr BP and 12,990±80 14C yr BP, suggesting that these sediments accumulated in a period of some 6000
years. Near the top of the core, at 60 cm an age of $1860\pm40 \text{ yr BP}$ was obtained. Sediments in an annually flooded wetland area accumulate carbon produced by the local vegetation, but even more from river-supplied organic material which may have a wide variety of source areas.

<table>
<thead>
<tr>
<th>Lab. Number</th>
<th>Depth (cm)</th>
<th>Dated material</th>
<th>$^{14}$C yr B.P. (cal yr B.P.)</th>
<th>Calendar age</th>
<th>$^{13}$C/$^{12}$C</th>
</tr>
</thead>
<tbody>
<tr>
<td>GX-25444*</td>
<td>60</td>
<td>bulk sediment</td>
<td>1.860$\pm$40</td>
<td>1819</td>
<td>-27.4</td>
</tr>
<tr>
<td>GX-24336</td>
<td>345</td>
<td>bulk sediment</td>
<td>8750$\pm$50</td>
<td>9.704</td>
<td>-22.2</td>
</tr>
<tr>
<td>GX-24339</td>
<td>418</td>
<td>bulk sediment</td>
<td>11,900$\pm$70</td>
<td>14.007, 13.962, 13.843</td>
<td>-25.7</td>
</tr>
<tr>
<td>GX-24338</td>
<td>582</td>
<td>bulk sediment</td>
<td>9130$\pm$50</td>
<td>10.239</td>
<td>-23.4</td>
</tr>
<tr>
<td>GX-24337</td>
<td>628</td>
<td>bulk sediment</td>
<td>12,990$\pm$80</td>
<td>15.619</td>
<td>-24.7</td>
</tr>
<tr>
<td>UtC-10461*</td>
<td>1100</td>
<td>bulk sediment</td>
<td>8040$\pm$60</td>
<td>9024-8980, 8913-8900, 8879-8868, 8828-8806, 8828-8806, 8801-8784</td>
<td>-26.6</td>
</tr>
<tr>
<td>UtC-10462*</td>
<td>1220</td>
<td>bulk sediment</td>
<td>6570$\pm$60</td>
<td>7559-7537, 7508-7426</td>
<td>-27.1</td>
</tr>
<tr>
<td>GX-24477*</td>
<td>1240</td>
<td>bulk sediment</td>
<td>8710$\pm$60</td>
<td>9.682, 9640, 9.632</td>
<td>-23.2</td>
</tr>
<tr>
<td>GX-24169</td>
<td>1250</td>
<td>bulk sediment</td>
<td>7430$\pm$50</td>
<td></td>
<td>-19.7</td>
</tr>
<tr>
<td>UtC-10463*</td>
<td>1350</td>
<td>bulk sediment</td>
<td>9270$\pm$60</td>
<td>10555-10379, 10369-10362, 10340-10330, 10319-10330, 10300-10287</td>
<td>-20.4</td>
</tr>
<tr>
<td>GX-24335</td>
<td>1510</td>
<td>bulk sediment</td>
<td>8160$\pm$60</td>
<td>9.124, 9.119, 9.086, 9.048, 9.032</td>
<td>-23.6</td>
</tr>
<tr>
<td>GX-26589*</td>
<td>1530</td>
<td>bulk sediment</td>
<td>10,010$\pm$50</td>
<td>11.547, 11.509, 11.405, 11.390, 11342</td>
<td>-23.8</td>
</tr>
</tbody>
</table>

* $^{14}$C AMS analysis based on humic acid fraction.

**Table 6.2.** List of radiocarbon dates of the samples from core Boquillas, Momposina basin.

This river-supplied carbon could well include redeposited material. As a consequence, we should consider traditional radiocarbon ages as maximum ages. However, the humic acid fraction is expected to provide more
reliable ages than the residual fraction as possible contamination by older carbon residues is potentially eliminated. Indeed, the 7 dates of humic acid fractions show a more coherent depth versus age relationship; nevertheless samples at 330 and 1220 cm deviate from this linear relationship. Of the conventional radiocarbon dates the ages at 1250 and 1510 cm are relatively close to the indicated linear relationship, whereas the ages at 330, 345, 418, 582 and 628 cm are considered as outliers. As explained before, the presence of allochthonous carbon is extremely likely and rejection of 5 dates out of the 13 is acceptable in such conditions. We conclude that the depth versus age relationship in Fig. 6.5 is most acceptable and ages of the recognised zones have been calculated by linear interpolation and extrapolation based on this curve.

6.4.3 Pollen record

Records of the most important pollen and spore taxa are shown in a pollen percentage diagram (Fig. 6.6). The sums of the ecological groups, the records of the pollen concentration and pollen influx values, and the cluster analysis dendrogram are shown in Fig.6.7. The following 5 zones were recognised: BQS-Ia, BQS-Ib, BQS-Ic, BQS-Id, and BQS-II, based on the CONISS analysis and supported by visual inspection of the pollen diagram, and changes in the clay mineralogy and sediment geochemistry,

Zone BQS-I shows a cyclic alternation between pollen grains from open vegetation and forest (gallery forest, montane forest, and dry forest, Alnus) and has the best pollen recovery and lowest oxidation rate of the sediments. The upper part of zone BQS-I and zone BQS-II contains oxidised sediments and, as a consequence, pollen preservation is poorer resulting in several gaps in the pollen record.

Pollen subzone BQS-Ia (interval 1510-1365 cm; 7 samples) is characterised by abundant pollen from open vegetation (90%), mainly represented by Poaceae (60%) and Asteraceae (30%). Gallery forest (15%, after the hiatus 25%) is represented by Acalypha, Alchornea, Cecropia, Didymopanax, Anacardiaceae, and Bignoniaceae (3%). Montane forest (5-8%) is represented by Apocynaceae (3%), Urticaceae, and Croton (2%). Dry forest taxa show a maximum of 11%, including Malvaceae (5-3%), and
Mimosaceae-I (2%). Swamp and aquatic vegetation (3-6%) is represented by *Ludwigia*, *Cuphea* and *Polygonum* (2%). *Alnus* reaches 6%. Algae were not recorded in this zone. Fern spores (20%) are represented by *Lycopodium cernum* (7%), *Lophosoria*, *Ceratopteris* (2%), *Cyathea* (2%), and Monolet episilatespores (11%). Pollen concentration and pollen influx values are low.

Pollen subzone BQS-Ib (interval 1365-1200 cm; 14 samples) is characterised by changes in the proportion of gallery forest: 25% at the bottom, 4% in the middle part and 37% in the top of the zone. The main gallery forest taxa are *Alchornea* (3%), *Anacardiacea* (5%), *Bignoniaceae*, *Fabaceae* (6%), and *Melastomataceae/Combretaceae* (5%). The proportion of taxa from open vegetation is negatively correlated with the representation of forest with values between 60% and 95%. Poaceae (20-58%) are well represented in the lower part, *Cyperacea* (3-27%) are abundant in the upper part of the zone, *Asteracea* show mostly values between 10% and 30%, *Borreria* shows 2% as a mean, whereas *Amaranthaceae/ Chenopodiaceae* (1%) are poorly represented. Montane forest elements also show significant changes (5-35%): *Apocynaceae* and *Podocarpus* (both 2%), *Myrica*, *Quercus* and *Juglans* (all 3%); *Ilex* (4%), *Ericaceae* (6%) and *Hedyosmum* (19%). Changes with depth in the record of *Alnus* (2-20%) match changes in the record of montane forest and dry forest (2-9%). Dry forest elements are *Capparidacea* and *Connaraceae* (both 2%), *Crotalaria* (3%), *Desmodium* (3%), *Mimosaceae-I*, and *Verbenaceae* (2%). Swamp and aquatic vegetation is represented by *Ludwigia*, *Utricularia*, *Cuphea*, *Polygonum* and *Sagittaria*, each with some 2%. Fern spores reach their highest values (25-80%) at the end of the zone. Also fungal spores (55%) are best represented in the uppermost part of this zone. Pollen concentration and pollen influx values are low, although higher compared to the previous zone.

The sediments are characterised by compact, fine and dark clay. Clay mineralogy presents the same composition and features as in the previous zone; with kaolinite (Kw-type) and an alternation of illites (lo-type to Ilp-type), vermiculite and hydromica. An increase of illite (15%) at the top of the zone is obvious. Quartz has higher values (30%) at the beginning of this zone, decreasing up to 12% in the upper part. The pH changes markedly from 8.5 in subzone BQS-Ia to acid conditions of pH 4.8 at the top.
Figure 6.6. Percentage pollen diagram of the upper 15-m of core Boquillas settlement, Province of Bolivar, northern Colombia. Records of the most important taxa, arranged into ecological groups are shown.
Figure 6.7. Summary pollen diagram of the upper 15-m of core Boquillas showing sums of ecological groups, pollen concentration, and pollen influx records.
Carbon (C) reach maximum values (1.8) and this trend matches with the record of the pH. The elements Ca, Na, and P that show similar values as in the previous subzone BQS-Ia. Values of $\delta^{13}\text{C}_{\text{TOC}}$ reach maximum values of -19.7% at 12.5 m.

Pollen subzone BQS-Ic (interval 1200-1100 cm; 9 samples) is characterised by maximum values of Poaceae (41%), Cyperaceae (14%), and Asteraceae (55%). Gallery forest taxa show high percentages, but are lower (40-5%) in the middle part of the zone. Important gallery forest taxa are Alchornea (3%), Acalypha and Anacardiaceae (both 2%), Bignoniaceae (6%), Malpighiaceae and Fabaceae (both 7%), in addition in the lower part of this zone Rubiaceae (5%) and in the upper part of this zone Spondias (9%). Montane forest taxa (5-24%) show the same trend as the gallery forest elements and are mainly represented by Urticaceae (3%), Ericaceae (10%) and Ilex (5%). Podocarpus, Quercus and Juglans are poorly represented (less than 2%). Also Alnus (3-18%) follows this trend. Local swamp elements and aquatics show 3% as a mean and consist mainly of Ludwigia (2%) and Polygonum (3%). Dry forest (4-10%) is represented by Capparidaceae, Connaraceae and Convolvulaceae (all around 3%), and Crotalaria, Desmodium and Malvaceae (all around 2%). Representation of fern spores decrease from 50% to 5%. Fungal spores show 5%. Pollen concentration and pollen influx values increase in the upper part of this pollen zone.

As in the previous zone, clayey sediments including kaolinite (59%) with constant crystallinity (kw) dominate in this interval. Smectite (3%) appears again in this zone. Illite and vermiculite increase to 15% and 10%, respectively. Quartz rises to 19%. There is a rapid change to basic conditions (pH 8.2). Compared to the previous zone carbon (C) diminishes markedly to 0.4, whereas the content of Na and P does not change. At 12-m core depth significant input of C$_3$ plant debris (for example from gallery forest) is obvious.

In pollen subzone BQS-Id (interval 1100-670 cm; 5 samples) many of the samples show a poor pollen recovery due to the high oxidation rate of the sediments. This zone starts with a decrease to 60% of taxa from open vegetation, followed by an increase to 80%. This interval shows lowest
representation in the core of Poaceae (15-41%) and Cyperaceae (2%). Asteraceae (35-65%) reach high representation in this zone; Borressia and Amaranthaceae/Chenopodiaceae are poorly represented for the first time. Taxa of gallery forest decrease from 35% to 20%, with Anacardiaceae and Bignoniaceae (both 5% as a mean) as main taxa; Spondias (8%) shows highest values along the pollen record. Other gallery forest taxa, like Alchornea and Cecropia are minimally represented. Taxa of montane forest (2-6%), and Alnus also, show lowest values in this zone. Taxa from dry forest (5%) have low values and mainly include Capparidaceae, Connaraceae, Crotalaria and Desmodium. Swamp and aquatic taxa (3%) are represented by Utricularia (1%) and Polygonum (3%). Fern spores show low representation (10%). Pollen concentration and pollen influx values decrease from highest to lowest values in the record.

In the lower part of this subzone the lithology is complex with different layers of clay, silty clay and sand, and some hiatuses (see also Herrera et al., submitted). Kaolinite show high values (52-56%), but values are lower compared to the previous zone. Smectite becomes more abundant (up to 12%). Illite shows a continuous presence of 15%. At the end of this interval crystallisation of kaolinite is low cristalised (Kf); illite varies in this subzone showing Ilp, Iap and Io. The content of quartz is variable but shows 15% as a mean. Sediments continue to be basic (pH 8). Carbon (C) shows low values with 0.3 as a mean. The contribution of the elements like Ca and Na remains constant compared to the previous zones; P shows in the middle part of the zone a marked increase to 241 ppm in the middle part of the zone, but the concentration diminish to 38 ppm in the upper part. Values of δ13C are fluctuate between -28.6 and -26%.

Pollen zone BQS-II (interval 670-50 cm; 14 samples) show oxidised sediments hampering pollen recovery. Taxa characteristic of open vegetation are dominant (maximum of 99% in the middle part of the zone). Asteraceae (67%) are most important; Poaceae averages 30% as a mean, and Cyperaceae 5%. Gallery forest taxa vary (up to 30%), mainly consisting of Bignoniaceae and Lecythidaceae (both 5%), Fabaceae and Melastomataceae/Combretaceae (both 6%), Alchornea (3%), Protium and Sapindaceae (both 4%). Montane forest taxa show mean values of 5%; main
taxa are *Podocarpus* (3%) and *Myrica* (2%), *Urticaceae* (4%), and *Apocynaceae* (2%). *Alnus* shows highest values of the record (maximally 25%). Swamp and aquatic taxa mainly include *Ludwigia* (4%) and *Polygonum* (5%). Dry forest taxa (3-15%) mainly include *Capparidaceae*, *Connaraceae* and *Desmodium* (all 3%), *Crotalaria* (4%), and *Mimosaceae* (3%), are best represented in the middle part of the zone. Algae (3-10%) show highest values, as is the case in zone BQS-I, and are mainly represented by *Botryococcus* (5%). Fern spores show values of 20-100%. Fungal spores are up to 38% (apart from an outlier value of 99%). Pollen concentration and pollen influx values are low.

6.5 PALAEOENVIRONMENTAL RECONSTRUCTION BASED ON MULTI-PROXY RECORDS

From ca. 10,010 to 9370 ¹⁴C yr BP (subzone BQS-Ia, 1510-1365 cm) clay mineralogy with higher values of quartz and the intercalation of minerals like kaolinite, smectite, hydromica and vermiculite in combination with the presence of coarse sands show a high-energy river system. This period coincides with the second part of the transitional period from Lateglacial to Holocene conditions. According to Van 't Veer *et al.*, (2000) the period of ca. 10,500- ca. 9000 ¹⁴C yr BP reflects relatively dry conditions in the Eastern Cordillera. We infer that our site was close to a main part of the drainage system allowing supply and accumulation of coarse sediments by the Chicaguá River. A poor crystallisation of kaolinite and the presence of open illite together with high oxidation of the organic matter suggest warm and dry climatic conditions. Under this environmental setting pollen preservation may be poor explaining the low pollen concentration and influx values. The landscape was dominated by open grass-rich vegetation with gallery forest along the streams. At places where the energy of river system was lower aquatics were common. Lack of stagnant waters near the site explains the absence of algae. Significant representation of *Alnus* suggests that the drainage system of our study area was still connected with the main river system supplying this allochtonous pollen taxon. Likewise pollen from montane forest was transported to the site. The abundance of
dry forest and grass-rich vegetation are in agreement with the abiotic data pointing also to dry climatic conditions. Evidence for dry climatic conditions was also registered in lake Valencia, Venezuela, at that time a shallow saline lake (Bradbury et al., 1981; Curtis et al., 1999; Leyden, 1985; Martin et al., 1997). Lake La Yeguada in Panama also showed dry conditions suggesting reduced stream flow (Bush et al., 1992). Also east of the Andes, in the savannas of the Llanos Orientales, dry climatic conditions prevailed after ca. 10,000 \(^{14}\)C yr BP (Behling and Hooghiemstra, 1998) and provide supporting evidence for a dry climate in northernmost South America during this period.

From ca. 9370-8430 \(^{14}\)C yr BP (zone BQS-Ib; 1365-1200 cm) wetlands were more isolated from the main river system and more clay accumulated in a lower energy environment. Clay minerals like mid-to-well crystallised kaolinite and illite 'large peak' intercalated with smectites point to lower energy flooding possibly due to seasonal precipitation. Higher pollen concentration and pollen influx values are explained by the low degree of oxidation and bioturbation and the quieter depositional environment. Gallery forest could expand along the streams and the more abundant vegetation in the wetland area favoured the accumulation of organic matter in swamps under low pH (acid) conditions. The \(\delta^{13}\)C record shows high values which clearly correspond to the expansion of gallery forest. During most of this period supply of pollen from dry forest, montane forest and Alnus, all mainly river-transported taxa, is low suggesting the intensity of water currents in the drainage system of the Magdalena, Cauca, San Jorge, and César rivers was relatively low. This is indicative of dry climatic conditions in a large part of Colombia. Dry climatic conditions were also reconstructed for the savannas east of the northern Andes (for example, Behling and Hooghiemstra, 1998, 1999, 2001). In contrast, lake Valencia, Venezuela, shows evidence of overflow pointing to wet climatic conditions (Curtis et al., 1999; Martin et al., 1997). Wet climate is also shown in the pollen record of lake La Yeguada (Bush et al., 1992), in the pollen record of Pantano de Mónica (Behling et al., 1999), and on the basis of \(^{18}\)O/\(^{16}\)O ratios in ostracod shell in the Caribbean area (Hodell et al., 1991). Thus, wet climatic conditions in Ecuador, Colombia Amazon and central Venezuela contrast with dry climatic conditions in Andean and northern Colombia,
this contrasting fact is clearly exposed by Martin et al., (1997), driven by the shift of the ITCZ (Intertropical Coversion Zone) between 12,400 to 8800 cal yr B.P.

During the short period from c. 8430 to 8040 uncal BP (subzone BQS-Ic; 1200-1100 cm) the supply of pollen grains from remote source areas, such as the areas of dry forest, montane forest, and Alnus decrease sharply indicating dry regional climatic conditions and/or an isolation of the local drainage system from the main river system. An increase of open vegetation with mainly Asteraceae and grasses, and a change in the compositions of the gallery forest (Alchornea, Bignoniaceae and Spondias becomes more abundant) are indicative of continuously dry regional climate, as well as a diminishing flooding frequency of the study area. More stable soils permitted an increase of soil organisms leading to an increase of bioturbation in the sediments. The pollen influx was hardly dependent on river-supply but a high local pollen production by the grass-rich vegetation explains the high pollen influx values. The same features of low water levels were recorded by Bradbury et al., (1981), Leyden (1985) and Curtis et al., (1999) with fluctuating lake levels and therefore affecting the ostracod assemblages by the salinity variations.

From 8040 to 4900 uncal BP (subzone BQS-Id; 1100-670 cm) supply of river-transported allochtonous pollen was minimal and the low water level favoured soil organisms leading to increased levels of phosphorous (P), showing that the isolation of the local drainage system from the main river system continued between ca. 8000 to 6000 uncal BP; similar features was found by Bradbury et al., (1981) showing higher salinity and a mixed forest with woodland-savanna (Leyden, 1985 and Curtis et al., 1999) by the low water level at lake Valencia, La Yeguada lake in Panama (Bush et al., 1992), laguna Sardinas (Behling and Hooghiemstra, 1998) and Laguna Linda (Behling and Hooghiemstra, 2000) in the Colombian savannas of Llanos Orientales. The local vegetation consisted mainly of open grass-rich vegetation, confirmed by low values of δ13C, with gallery forest along the drainage system. Intercalation of silt points to periodic flooding Chicaguaya River supplying coarser sediments to the site. As the clay minerals shown, a sorting between kaolinite, illite and smectite (Figs 6.3 and 6.4)
and the increasing of the oxidation level of the sediments, a variable temperature and precipitation can be inferred (warm-wet and warm-dry). After the silty horizon the river abandoned the site (after 6210 $^{14}$C yr BP) and only clays were deposited afterwards, deposited from still flood waters in the basin (also reported by Bradbury et al., 1981; Leyden, 1985; Bush et al., 1992 and Curtis et al., 1999).

From ca. 4900 to 1550 uncal BP (zone BQS-II; 670 to 50 cm) increased pollen supply by the river Chicagua from remote source areas, such as the areas with dry forest, montane forest and *Alnus* indicate that the site was again within the reach of the main drainage system, as is the case today. Increased precipitation in the catchment area of the Magdalena, Cauca, San Jorge, and Cesár rivers caused increased sediment supply to the study area leading to low values of pollen concentration and pollen influx. Increased bioturbation and a high oxidation rate indicated the soils were most of the time stable and not flooded. The $\delta^{13}$C values (−22.8) correspond to the herbaceous character of the local vegetation, dominated by Asteraceae and Poaceae. This fact suggests an expansion of open vegetation during the last 2000 yr uncal BP (see also Herrera and Berrio, 1998). The stratigraphical column shows clay with repeated intercalations of silty clay pointing to repeated floodings by the river system of intermediate energy. These events coincide with peaks of allochtonous *Alnus* grains also indicative that water from the main river system repeatedly reached the site. Abundant microorganisms caused again an increase of phosphorous values around 2700 $^{14}$C yr BP (88 cm core depth). According to the archaeological records pre-Hispanic peoples started to occupy the area around this time and the landscape started to be modified from a natural wetland ecosystem into a water-controlled agricultural system (Plazas and Falchetti, 1986; Plazas et al., 1993). In our record we cannot find significant evidence of the start of land use. The variation of kaolinite and illite crystallisation suggests climate became warmer and drier. Also the mineralogical variation of smectite and kaolinite also confirms this conclusion. Swamps and shallow water bodies started to be permanent and the river Chicagua became less dynamic than before. This favoured the C formation and a lowering of the pH due to the growth of local vegetation. High phosphorous (P) values, increase of smectite and low sodium values, in combination with less arid climatic
conditions, favour the natural soil fertility. These features suggest strong human impact as found by Plazas and Falchetti (1986). Pre-hispanic populations in the study area modified the landscape for agricultural activities; they developed an efficient drainage system to drain the land during the rainy season, and to irrigate the land during the dry season with help of a system of water reservoirs. During the last ca. 1000 year climatic conditions compare to those of today. According to Herrera and Berrio (1998) the pre-hispanic cultures of the Zenúes and Malibúes people used the raised fields in combination with a drainage system to cultivate crops like *Zea mays* (maiz; Poaceae), *Ipomoea batata* (batatas, sweet potato; Convolvulaceae) and *Cucurbita maxima* (ahuyama; Cucurbitaceae). We found no remnants of these crops. Close to the coring site we observed raised areas of 1.5 to 2 m² from the original surface, which must have been used as house platforms.

### 6.6 DISCUSSIONS

Our site represents a setting where direct river impact at a high energy level and impact of flooding at an intermediate energy level prevents a continuous accumulation of sediments from occurring. Also, the periods of oxidation and bioturbation of exposed sediments lead to poor preservation of the fossil assemblages in some parts of the core. Although we demonstrated in Fig. 6.5 that the accumulation rate of sediments over the last 10,000 years is generally not far from linear, sediment accumulation on shorter time scales is clearly very irregular, which causes changes in pollen concentration values. The changes between direct pollen supply from the nearby main river system to a setting that our site is located far from the active river system, cause irregular pollen deposition at our site. Paleoecological analysis of a site under such conditions requires the use of a number of different research methods in order to have more sources of information available to piece together the local environmental history. The present study shows how information from the biotic and abiotic parts of the environmental system contributes to an environmental reconstruction of the very dynamic wetlands of the lower Magdalena during the Holocene.
Pollen supply by the local vegetation (aquatic vegetation, local swamps, wet open grasslands, wet shrub-land, gallery forest) and the regional vegetation at distances of more than 30-80 km (dry forest, montane forest, wet *Alnus*-dominated forest along rivers and streams) made it possible to differentiate between the local development of the wetland ecosystem and changes in climatic conditions in the total catchment area of the Magdalena, Cauca, San Jorge, and Cesár rivers, an area that covers a significant part of central and northern Colombia. *Alnus* hardly occurs (if at all) in the wetlands of the Lower Magdalena (Wijmstra, 1967). Therefore there is little risk of misinterpreting the *Alnus* record as a evidence of river action supplying pollen and sediments from large distance to the study area (see also the discussion in Van der Hammen and Hooghiemstra, 2000). Moreover, the record of *Alnus* peaks together with the records of dry forest and montane forest taxa, and the pollen grains of both groups were without doubt transported there from a great distance. In a similar way Chmura and Liu (1990) in the lower Mississippi River delta used the pollen record of *Quercus* (oak) as an indicator of river action.

Martin *et al.*, (1997) suggested that long-term changes in precipitation in southern and central America are controlled by precession-forced movements of the ITZC. He showed a clear antiphase between the water levels of lake Titicaca (Bolivia) and lake Valencia (Venezuela) between 12,400 and 8800 cal yr BP. Based on this mechanism we expect that our composite catchment area in Colombia will behave as lake Valencia. The decrease in precipitation between about 9500 and 8500 \(^{14}C\) yr BP is consistent with the record of lake Valencia. It is also in agreement with the change to drier conditions in the Llanos Orientales, a large savanna area that stretches from Colombia into Venezuela (Behling and Hooghiemstra, 1998, 1999; Berrío *et al.*, 2002). The Colombian wide synthesis of pollen data based on the biomisation technique also showed a change to drier climate between the time-slices of 9000 \(^{14}C\) yr BP and 6000 \(^{14}C\) yr BP (Marchant *et al.*, 2001). Although the flooding frequency and energy-level of the sedimentary environment depends also on the distance from site Boquillas to the main river system, apparently the distinct decrease in precipitation in northernmost South America between 9500 and 8500 \(^{14}C\) yr BP is clearly reflected in the sedimentary record. Based on the occurrence of peat horizons in sequences of lacustrine sediments
Van der Hammen (1986) identified in northern Colombia six relatively dry periods, around 7000, 5500, 4700, 4000, 2500 and 2300 uncal BP. Although our chronology does not allow the precise identification of the core depths with these ages, all these depths coincide with low *Alnus* percentages when a linear accumulation rate is accepted in between the zone boundaries. We conclude that the Boquillas record does not contradict the dry periods reported by Van der Hammen (1986).

There is no doubt that pre-hispanic civilisations in the surroundings of Boquillas had a strong impact on the landscape. There is much archaeological evidence that the Zenú and Malibú groups brought a significant part of this annually flooded area under their control using a complex system of canals, water reservoirs, raised fields and elevated house platforms in combination with gallery forest as a tool to protect small-scale hydrological structures and to control the inundation (Plazas *et al.*, 1993; Herrera and Berrío, 1998; Rojas and Montejo, 1999). Although no pollen grains from crop plants were found in the sediments of Boquillas, geochemical evidence (high phosphorous values in zone II) and geomorphological features in the region point to the occupation history of this area (Herrera *et al.*, submitted). The main features that lead us to this interpretation is the presence of long agricultural raised fields next to the Chicagua River and Brazo de Mompos, together with the presence of house platforms and burial mounds.

6.7 ACKNOWLEDGEMENTS

We thank to the Colombian Science Foundation for financial support (COLCIENCIAS project number 6212-13-537-96 to Erigaie Foundation). We are grateful to the local people of Boquillas for their assistance during the drilling. We thank Willian Barbosa for his assistance with the lithological analysis. We acknowledge Annemarie Philip (Amsterdam) for the preparation of the pollen samples, and Thomas van der Hammen (Chía) for his valuable discussions of the data. We thank the Netherlands Foundation for Scientific Research in the Tropics (WOTRO-DGIS grant WB 84-461 to H. Hooghiemstra / J.C. Berrío) for financial support during the preparation of this paper.
6.8 REFERENCES


Herrera, L.F., Sarmiento, G., Romero, F., Botero, P.J. and Berrío, J.C., Submitted. Evolución ambiental de la Depresión Momposina, Colombia, desde el Pleistoceno tardío a los paisajes actuales. Geología Colombiana.


Thorez, J. 1986. *The bases of clay geology (or arcillogenesis)*. Liege State University. Faculty of Science. Liege, Belgium.


