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LATE PLIOCENE–PLEISTOCENE HIGH RESOLUTION POLLEN SEQUENCE OF COLOMBIA: AN OVERVIEW OF CLIMATIC CHANGE

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Two long continental pollen records, Funza I (357 m) and Funza II (586 m) from the high plain of Bogotá (Colombia) at 2550 m elevation, have been studied palynologically. Fission track dates on zircon from intercalated volcanic ashes provided a chronological framework and showed the pollen records, which correlate with high precision, to be continuous over the interval from ca. 3.2 Ma to ca. 27 ka. The Late Pliocene–Pleistocene history of the montane forests and open alpine paramo vegetation is documented with a temporal resolution of 6–5 ka, and for the upper 1.1 Ma with a resolution of 1.2 ka. The immigration of the northern hemisphere elements Alnus (at ca. 1 Ma) and Quercus (at ca. 0.33 Ma), which travelled along the Panamanian landbridge, caused significant changes in the composition of the Andean montane forests. The successive Pleistocene glaciations forced the Andean vegetation belts to an almost continuous altitudinal movement; the upper forest line (at present at ca. 3200 m) shifted between 1800 m (glacial) and ca. 3500 m (interglacial), corresponding to a variation in temperature between ca. 5 and 15°C at 2550 m altitude. A provisional land–sea correlation (Funza pollen–ODP Site 6778‘O) is shown for the upper 1.2 Ma (Stages 3–35). Frequency analysis of several time series showed significant periods of the eccentricity (100 ka) and precession (23 and 19 ka) bands, showing orbital forcing and a strong change in climatic variability around 800 ka. At ca. 2.7 Ma, a significant cooling of ca. 5°C is documented, reflecting the classical terrestrial Pliocene–Pleistocene boundary, which correlates to the Reuverian–Praetiglian boundary of the NW European stratigraphical climatic subdivision.

INTRODUCTION

Long continental records of climatic change are scarce but are of great importance in facilitating the comparison of land-based and ocean-based climatic histories. In the Eastern Cordillera of Colombia, the high plain of Bogotá (ca. 25 × 40 km in size) represents the bottom of a former lake that occupied a subsiding intermontane basin (Fig. 1). After the final upheaval of the northern Andes between 5 and 3 Ma (van der Hammen et al., 1973; Helmens, 1990; this volume), the development of a basin environment in the area of the present high plain of Bogotá started some 3.5 Ma (Helmens, 1990). Subsidence of the floor of the tectonic basin was more or less in equilibrium with sediment accumulation during most of the time and resulted in a sequence of almost 600 m of mainly lake sediments with an early fluviatile influx. Pollen records have been retrieved from deep boreholes in these sediments. During periods with low lake levels in the central part of the basin, sediment accumulation ceased in the outer parts. This caused the presence of hiatuses in pollen records from the outer parts of the basin (van der Hammen and González, 1960, 1964).

The objective of this paper is to present an overview of the continuous history of vegetation development and climatic change during the last ca. 3 Ma, based on several research papers which have recently been published or are in press. Data are based on the deep boreholes Funza I (357 m) and Funza II (586 m) in the centre of the sedimentary basin, where sediments reach the greatest depth. The Funza II core, recovered in 1988, reached bedrock, indicating that the complete basin infill, representing Late Pliocene to latest Pleistocene, has been recovered.

Changes in the composition of the vegetation, which reflect climatic change, are documented by the pollen rain that is conserved in slowly accumulating lake sediments. Tropical mountains especially seem to be in a favourable position because climatic change results mainly in a vertical shift of vegetation belts over the mountain slopes (Fig. 2). The different vegetation belts stay in the vicinity of the lake and are registered continuously by their intercepted pollen. The sediments in the Bogotá basin, at 2550 m elevation, accumulated at an altitude that lies halfway between the highest position of the upper forest line (during interglacial conditions ca. 3500 m) and the lowest position of the upper forest line (during glacial conditions ca. 1800 m), rendering the Bogotá sediments a sensitive recorder of palaeoclimatic change.

SETTING OF PRESENT VEGETATION AND CLIMATE

The present-day altitudinal zonation of the vegetation in the Eastern Cordillera of Colombia (Fig. 2) is summarized in order to understand the changes documented by the pollen record. More complete accounts of the modern montane forest and paramo vegetation of the Colombian Andes are given in e.g. Cleef (1981), Cleef et al. (1983) and Cleef and Hooghiemstra (1984). The following vegetation zones can be recognized:

- tropical lowland rain forest from 0 to 1000 m: main taxa are Byrsonima, Iriartea and Mauritia
- subandean forest belt (lower montane forest) from 1000 to 2300 m: main taxa are Acalypha, Alchornea and Cecropia
FIG. 1. Map of Colombia and the area of the high plain of Bogotá in the Eastern Cordillera, indicating the topography of the surrounding mountains. (Redrawn after Andriessen et al., 1993.)

— Andean forest belt (upper montane forest) from 2300 to 3200–3500 m: main taxa are Podocarpus, Hedyosmum, Weinmannia, Quercus, Alnus, Vallea, Myrsine (formerly Rapanea), Symphlocos, Ilex, Juglans, Miconia, Eugenia and Myrica

— subparamo belt from 3200–3500 m to 3400–3600 m: main taxa are Ericaceae, Hypericum, Compositae and Polylepis-Acaena

— grassparamo belt from 3400–3600 m to 4000–4200 m: main taxa are Gramineae, Valeriana, Caryophyllaceae, Gentianaceae, Plantago, Aragoa, Geranium, Ranunculus and Lycopodium (species with foveolate spores)

— superparamo belt extending from 4000–4200 m upward: main taxa are Draba, mosses and blue algae

— nival zone proper, practically devoid of vegetation, extending from 4500–4800 m upward.

The highest areas of the Eastern Cordillera in the Sierra Nevada de Cocuy, some 200 km north of Bogotá, extending up to 5500 m, may be permanently covered by snow.

During glacial periods, lower temperatures caused a depression of the Andean vegetation belts, and a lowering of the position of the upper forest line of ca. 1200–1500 m has been seen (van der Hammen, 1974). The modern upper forest line in the area of Bogotá at ca. 3200 m altitude corresponds with the ca. 9.5°C annual isotherm. Thus, temperature changes at the level of the high plain of Bogotá (2550 m; present-day average annual temperature 13–14°C) can be calculated when changes of the altitudinal position of the upper forest line are estimated on the basis of the pollen record, using a lapse rate of 0.66°C per 100 m displacement of the upper forest line.

ABSOLUTE TIME CONTROL OF THE SEDIMENTS OF THE BOGOTA BASIN

A revised geochronological framework for the sequence of unconsolidated sediments present in the Bogotá area was published recently (Andriessen et al., 1993) to replace the original time frame of the Funza I pollen record (Hooghiemstra, 1984, 1989). This is based on 11 fission track datings on zircons that were obtained both from exposed ash layers and from a series of ashes from the Funza II core. The data 5.33 ± 1.02 Ma, 3.67 ± 0.50 Ma and 2.77 ± 0.50 Ma (Andriessen et al., 1993) for sediments that are considered to have been deposited before, at the beginning
and shortly after the final major upheaval of the Eastern Cordillera provide absolute chronological control for the older part of the sequence (6–2.5 Ma). Fission track data on zircon from the Funza II core (Fig. 3 and listed below) provide geochronological control for the younger part of the sequence (3–0 Ma) and these are coherent with the fission track dates of the older part of the sediment sequence: 67.7 m: 0.20 ± 0.12 Ma; 298–307 m: 1.02 ± 0.23 Ma; 317 m: 1.44 ± 0.33 Ma; 322 m: 1.01 ± 0.21 Ma; 506 m: 2.74 ± 0.63 Ma. Nevertheless, three fission track dates on zircon, at 239 m
(0.26 ± 0.18 Ma), 250 m (0.27 ± 0.11 Ma) and 270–277 m (0.53 ± 0.15 Ma), are considered as too young (Fig. 3; see the discussion in Andriessen et al., 1993).

LAND-SEA CORRELATION OF RECORDS OF CLIMATIC CHANGE

A challenging similarity between the climatic change, registered in Andean Colombian pollen records (Fig. 4), and the climate records in marine sediments is apparent. Graphical correlation of the Funza I Arboreal Pollen record with the δ18O record of ODP Site 677 from the Eastern Pacific, by Shackleton and Hooghiemstra, is shown in Fig. 5. A set of 36 control points was established (Fig. 5; Hooghiemstra et al., 1993). At present this 36-point model is considered the best estimate for a geochronological framework for the upper part of the Funza sediment sequence. These control points, as well as the estimated ages of the pollen zone boundaries, based on provisional land–sea correlation, are graphed in Fig. 3. The intervals represented by Stages 3–25 show the best correlation between climatic oscillations.

The correlation procedure will be repeated when the temporal resolution of the Funza II core (at present ca. 5–6 ka; already for several intervals ca. 1 ka) is as high as that of the Funza I core (ca. 1 ka).

VARIABILITY OF QUATERNARY CLIMATIC CHANGE AND ORBITAL FORCING

The evolution of climatic variability has been studied in the interval of the Funza I pollen record that represents

![Graph of Funza I Arboreal Pollen percentages (Alnus included) versus time based on the revised time frame. Note the development of a distinct 100 ka climatic cycle (classical glacial–interglacial cycles) in the last ca. 0.8 Ma of the Quaternary. (After Hooghiemstra et al., 1993.)](image-url)

![Graphical correlation of the Funza I Arboreal Pollen record (pollen data based on Hooghiemstra, 1984, 1989; time control based on Andriessen et al., 1993) and δ18O record ODP Site 677 (Shackleton et al., 1996). Using the absolute time control of the Funza sediments and the ODP Site 677 δ18O record, the intervals representing Stage 22 in both records and the core tops were correlated. Subsequently, the pollen record was minimally stretched and squeezed over 35 short intervals between 36 control points (indicated as triangles). The parallel records show the provisional correlation for δ18O Stages 3–25. (After Hooghiemstra et al., 1993; see also Hooghiemstra and Sarmiento, 1991.)](image-url)
Arboreal pollen (Funza I pollen record)

FIG. 6. Frequency analysis (Maximum Entropy Spectrum Analysis) using the ‘Arboreal Pollen’ data set (Alnus included) of the Funza I core interval 2-340 m (period 30-1450 ka) by a 400-ka-wide window moving in 20 ka steps. This pollen data set represents the altitudinally shifting upper forest fine, mainly as a response to temperature change. The first spectrum covers the interval 30-430 ka. Every fifth spectrum is shown bold, with spectral peaks identified by their corresponding period in ka. Some peaks are truncated for readability. Note the presence in the upper 29 spectra of the record periods of the eccentricity band (ca. 100 ka, representing the classical Quaternary glacial-interglacial cycles). A band which is related to the precession is continuously present in the record with periods centered at 21-24 and 17-19 ka. (After Melice in Hooghiemstra et al., 1993.)

Using the revised time frame (Andriessen et al., 1993) the period from 30 to 1450 ka (Hooghiemstra and Melice, 1991, 1993; Hooghiemstra et al., 1993). The 1178 analysed pollen samples between 2.90 and 340.00 m core depth generate five time series with an average time resolution of ca. 1200 years. For this purpose a time frame is used, based on absolute datings (fission track datings on zircon; Andriessen et al., 1993) in combination with correlation of the pollen record with the ODP Site 677 δ¹⁸O record of the Eastern Pacific (Hooghiemstra et al., 1993). This last procedure resulted in small downcore adjustments of the pollen record; in fact, the best possible corrections to compensate for changes in sediment accumulation rates. A set of 36 control points was generated (Hooghiemstra and Sarmiento, 1991; Hooghiemstra et al., 1993).

The five different data sets (Arboreal Pollen, Arboreal Pollen excluding Alnus, Alnus, marsh elements and Quercus) represent different variables of the palaeoclimatic (Hooghiemstra et al., 1993). These time series were then analyzed by Melice in the frequency domain with the help of Maximum Entropy Spectrum Analysis and Thomson Multi-Taper Spectrum Analysis using a moving 400 ka window with steps of 20 ka. Frequencies closely related to the Milankovitch theory were detected in the five data sets. The presence of ca. 100,000 year periods (eccentricity band) was found in time series with Arboreal Pollen and appeared to be restricted to the last ca. 800 ka (Fig. 6). Periodicities close to 23 ka (precession band) are present throughout the pollen record and are strongest in the data set of subparamo elements (Fig. 7). The five selected data sets reveal an evolution of orbital frequencies in the Middle and Upper Quaternary which is in general agreement with other marine (e.g. Imbrie et al., 1984) and continental (e.g. Kukla et al., 1990) records.

DEVELOPMENT OF FLORA AND VEGETATION OF ANDEAN MONTANE FORESTS AND PARAMO

Around 4–3 Ma, the principal upheaval of the area had ceased (van der Hammen et al., 1973; Helmens, 1990; Andriessen et al., 1993). The high plain of Bogotá was by then an extensive lake at approximately 2500 m altitude. In this lake basin, ca. 600 m of fluvial lacustrine and later pure lacustrine sediments were formed (Fig. 8), providing a long and continuous pollen record of the development of the montane vegetation belts and climatic change in northern South America during the Late Pliocene and Pleistocene time (Figs 9 and 10). Figure 9 shows the 357-m-long Funza I pollen record with a temporal resolution of ca. 1200 years (based on Hooghiemstra, 1984, 1989) representing the
Several phases in the development of montane forests and paramo vegetation of the Colombian Eastern Cordillera and distinct phases in the climate history can be recognized. In the next part, a concise account, based on the Funza II pollen record (depth intervals) and corroborated by the Funza I record, is given. Summary diagrams, upper forest line oscillations (temperature change) and provisional correlation with the marine δ18O record is given in Fig. 11 for the interval 2–158 m (based on Hooghiemstra and Ran, submitted) and for the interval 205–540 m (based on Hooghiemstra and Cleef, submitted).

The interval 540–465 m core depth (3.2–2.7 Ma) shows that warm climatic conditions and pollen spectra have no Upper Quaternary analogues. The basin had just started to accumulate lacustrine and river sediments, after a period in which sediment only accumulated in the perifere valleys. The upper limit of the subandean forest belt was situated at some 500 m lower elevation than today. In the Andean forest belt Podocarpus-rich forest, Hedysosum–Weinmannia forest (a precursor of the modern Weinmannietum) and Vallea–Miconia forest, respectively, were the main constituents with increasing elevation. Hypericum and Myrica played an important part in the timberline dwarf forests, which possibly constituted a substantial transitional zone from the early Andean forest belt (upper montane forest belt) to the open grassparamo belt. The contribution of herbs to the paramo vegetation, dominated by Gramineae and Compositae, seems less diverse than during the Upper Quaternary. The Late Pliocene (upper) Andean forests were more open than during the Middle and Upper Quaternary, as heliophytic elements, such as Borreiria, were abundant. The composition of forests on the high plain was subject to considerable change: arboreal taxa with pioneer qualities (Dodonaea, Eugenia) and other taxa (Sympliosai, Ilex) constituted, seemingly at irregular intervals, azonal forests in the basin. The upper forest line oscillated most of the time from 2800 to 3600 m elevation. The average annual temperature on the high plain was 11.5–16.5°C.

The interval 470–460 m, dated around 2.7 Ma, shows a significant decrease in the contribution of Arbororeal Pollen, suggesting that the average temperature level was lowered by some 4–5°C (provisional estimation). This episode of rapid cooling is followed by a period of gradually lowering temperatures, i.e. from 2.7 to 2.2 Ma (460–405 m core...
FIG. 8. Lithology of the sediments from the Funza II bore hole (2–586 m core interval) in the basin of Bogotá. Descriptions are made by S.R. Arevalo-Gamboa and I.D. Pinzon-Villazon. (After Sarmiento-Perez, G., Ingeominas, Bogotá; internal document.)
interval). This drop in temperature falls within the global period of transition; from the average warm Pliocene climates to the cold climatic conditions during the Lower Pleistocene. Indeed, the classical terrestrial Pliocene–Pleistocene boundary (Zagwijn, 1975, 1985, 1992) falls within the period which is characterized in the Funza record by cooling.

The interval 465–415 m core depth (2.7–2.2 Ma) shows colder climatic conditions. The upper forest line oscillated most of the time from 2600 to 2800 m in the first half of this period, and from 2400 to 2800 m in the second half. Average annual temperatures were 10.5–11.5 and 8.8–11.5°C, respectively. The Podocarpus-rich forest type occurred until the end of this period. Weinmannia was almost absent and Hedyosmum completely dominated, for the first time, the Hedyosmum–Weinmannia forest type. Miconia dominated in the Vallea–Miconia forest type, in which Hex, Myrsine and Daphnopsis were probably associated elements. For the first time in the Pleistocene, paramo vegetation became widespread in the Eastern Cordillera near Bogota. Caryophyllaceae and Valeriana were the most dominant paramo herbs at that time, whereas the contribution of Plantago and Aragoa increased. During intervals with low water levels, marsh vegetation, including Cyperaceae, Polygonum, Hydrocotyle, Ludwigia, Myriophyllum, Sphagnum and Azolla, was abundant on the high plain.

The interval 415–337 m core depth (2.2–1.42 Ma) shows, for the first time in the record, a rather persistent cold climate. The upper forest line oscillated most of the time from 1900 to 2500 m, corresponding to an average annual temperature of 5.5–9.5°C on the high plain. Podocarpus had lost its dominant part in the (lower) Andean forest belt. Hedyosmum–Weinmannia forest and Miconia–Vallea forest were most important. Daphnopsis had almost disappeared from the Andean forest belt and Borreria became less common during this period, suggesting that forests became denser. Hypericum was, for the first time in the record, the most important element in the dwarf forest, but at the end of this period Polylepis dwarf forest started to increase near the upper forest line and lower paramo. Juglans appeared for the first time regularly with low frequency and Styloceras also became a more regular component of the Andean forest belt. On a local scale, Plantago became very abundant in the basin and probably replaced a great part of the local grassparamo.

The interval 337–257 m core depth (1.42–1.0 Ma) shows a long period with mainly cold climatic conditions. The upper forest line oscillated most of the time from 2200 to 2600 m, at the end of this period slightly increasing to 2400–2800 m. This corresponds to average annual temperatures on the high plain of 7.5–10 and 9–11.5°C, respectively. Weinmannia was almost absent in the Andean forest belt and a Hedyosmum forest, possibly with important contribution of Eugenia, Myrsine and Eriaceae, constituted a precursor of the present-day Weinmannia forest. Vallea contributed, for the first time in the record, of the same order as Miconia to the Vallea–Miconia forest type. Borreria occurred at low frequency and disappeared almost at the end of this period, indicating that the forest structure was more dense and unsuitable for heliophytic elements. Polylepis dwarf forest was important at the upper forest line, and in the (lower) paramo Myrica (M. pubescens) probably contributed substantially to the upper part of the Andean forest belt. The upper limit of subandean forest during this period reached higher elevations than during the lower part of the record (but only reached modern conditions after the immigration of Quercus, later on in the record). The lake on the high plain was shallow and extensive marsh prevailed during the first half of this period. Possibly due to tectonic adjustments of the basin, the lake became deeper from ca. 300 m core depth onward, and Isoetes vegetation and algae became abundant in short time.

The interval 257–205 m core depth (1.0–0.85 Ma) shows the first major glacial–interglacial cycles, characteristic of the Middle and Upper Quaternary. Comparison with the δ18O record of the deep sea indicates that climatic change in the interval 240–205 m correlates with Stages 25–21. The interglacial (Stage 25) to glacial (Stage 22) lowering of the upper forest line is ca. 800 m (from 3000 to 1800 m, maximally), corresponding to a temperature decrease of

![FIG. 8. cont.](image-url)
FIG. 8. cont.
FIG. 8. cont.
LEGEND:

- Clay, plastic near the surface and compact at greater depth, mostly dark grey, varying depending on the organic matter content. Mica and vivianite present with maximal 1%.
- Lenses of medium sized sand.
- Volcanic ash horizons, white to grey of colour.
- Lignite horizons with variable percentages of organic matter.
- Sandy clay and clayey sand.
- Not determined sediment (most possibly sands including different minerals).
- Sand of fine to medium grain size (often difficult to recover).
- Clay, olive to grey-olive and very compact with occasionally surfaces indicative of friction and bioturbation (occurs below 410 m core depth).
- Dark mud with some lamination affected by bioturbation. Local presence of vivianite.
- Very fine sand with biogenetic structures, undulating fragments of organic material and occasionally presence of gravel up to 5 mm diameter.
FIG. 9. Summary diagram of pollen record Funza I showing the altitudinally shifting vegetational belts in response to climatic change during the last ca. 1.5 Ma with an average time resolution of ca. 1200 years. Core depth (m) and age (ka) are indicated at the left hand side of the diagram. Indicated ages correspond to the control points of the correlation between Funza I Arboreal Pollen record and ODP Site 677 δ^18O record (see Fig. 5). For convenience, δ^18O Stage numbers 3–23 are indicated in the diagram based on a provisional correlation. Downcore oscillations in the representation of vegetation belts are shown for subandean forest belt, Andean forest belt, subparamo belt and grassparamo belt. The graph of downcore changes of the percentage of total Arboreal Pollen (AP; Alnus included) shows oscillations that, in fact, represent vertical shifts of the upper forest line over the mountain slopes as a response to mainly temperature change. Three percentage levels of AP are indicated that correspond to altitudinal positions of the upper forest line at 2000, 2550 and 3000 m. These levels, on which the boundary between interglacial and glacial periods is based, change to other percentages when new immigrants from the northern hemisphere, after crossing the Panamanian landbridge, changed the composition of the Andean montane forests. This happened at 257 m core depth (ca. 1 Ma), when Alnus immigrated into the area of Bogotá, and between 77 and 45 m when the contribution of zonal Quercus forest increased rapidly as a part of the Andean forest belt (Quercus immigrated into the area of Bogotá around 340 ka and appeared at ca. 94 m core depth in the Funza records). These changes in percentage levels are approximations to account for distinct changes in the composition of the Andean montane forests (percentage levels are not indicated in a short interval around 255 m core depth, which is characterized by a hiatus). Estimations are based on improved understanding of the Bogotá pollen records (Hooghiemstra, Ran, Van’t Veer and Mommersteeg, unpublished data). The inferred changes in mean annual temperature, at the elevation of Bogotá, are from about 6 to 15°C. The former lake of Bogotá drained ca. 27 ka and this last part of the Quaternary is missing in the Funza records. The top samples are of Holocene age (Pollen data after Hooghiemstra, 1984, 1989; time control after Andriessen et al., 1993.)
1 subandean forest
2 Andean forest
3 subparamo
4 grassparamo

FIG. 9. Cont.
4.8°C. After the immigration of *Alnus*, a characteristic northern hemisphere genus, large areas of carr (swamp forest vegetation) developed on the wet flats around the lake, but *Alnus* probably also occurred incidentally as an element of the zonal forests. The contribution of *Myrica* was reduced considerably, indicating that *Myrica* contributed before to the azonal vegetation (*M. parvifolia*) as well as to the zonal forests (*M. pubescens*). The large altitudinal shifts of all montane vegetation belts, in response to the main glacial–interglacial climatic cycles, in the remaining part of the record places the high plain alternately in the Andean forest belt and in the grassparamo belt.
FIG. 11. Correlation of the pollen records Funza I (Hooghiemstra, 1984, 1989) and Funza II (Hooghiemstra and Ran, submitted) and inferred climatic change for the interval of ca. 24–735 ka. Correlating pollen zones in both records have the same numbers, with a prefix F1 (Funza I) or F2 (Funza II). Depth and age of pollen zone boundaries are indicated. A provisional correlation with the marine δ¹⁸O stratigraphy is indicated. Ages of δ¹⁸O stages after Imbrie et al. (1984). (After Hooghiemstra and Ran, submitted.)
The interval 205–158 m is not recovered in Funza II due to technical problems (Fig. 10). This interval of the sediment sequence, however, is well documented in the Funza I core (Fig. 9). It corresponds to the interval of ca. 170–207 m of the Funza I core (Funza I pollen zones 27, 26 and 25A), representing the period of ca. 735–845 ka. This interval represents two distinct interglacial periods with a marked glacial in between and corresponds to the δ¹⁸O Stages 21, 20 and 19 (Fig. 9). More precise fitting of this Funza II hiatus in the Funza I record is deferred until high temporal resolution pollen data are available. The upper forest line oscillated in this period, mainly from 3000 to 1900 m, for most of the time. The corresponding average annual temperature on the high plain is 13.6°C.

The interval 158–131 m core depth (estimated age 735–569 ka) shows warm climatic conditions most of the time and is tentatively correlated with the δ¹⁸O Stages 19.1–15.1. The pollen spectra have no direct modern analogues because of the absence of Quercus and related conditions. The upper forest line oscillated mainly from 2100 to 2700 m for most of the time. The corresponding average annual temperature on the high plain is 6.5–11°C. The high plain was situated in the Andean forest belt most of the time. The upper limit of the subandean forest belt (Acalypha, Alchornea) was situated some hundreds of metres below the modern elevation. Podocarpus was most important in the lower part of the Andean forest belt. Weinmannia forest, the precursor of the modern Weinmannietum, included a substantial contribution of Hedyosmum, with lower frequency Myrsine and Eugenia. A type of Vallea–Miconia forest, including low presence of ilex and Myrsine, could have occurred on the drier parts of the high plain. The lake was shallow most of the time, with local marsh vegetation of cyperaceous reed swamp and Hydrocotyle. Myrica thickets (M. parvifolia) and Alnus carr covered the wet flats around the lake. Myrica (M. pubescens) and Alnus possibly also contributed with low frequency to the zonal Andean forest belt. Dwarf forest of Polylepis, Myrica and Compositae scrub occurred at the upper forest line.

The interval 131–100 m core depth (estimated age 569–350 ka) shows cold climatic conditions most of the time and is tentatively correlated with the δ¹⁸O Stages 14.4–11.1. The upper forest line oscillated mainly from 1800 to 2500 m. The corresponding average temperature on the high plain is 5–9.5°C. The high plain was situated in the grassparamo belt most of the time. Apart from Gramineae (e.g. Calamagrostis, Chasquen) and woody stem rosettes of Espeletia (Compositae), a variety of paramo herbs (Valeriana, Caryophyllaceae, Geranium, Aragao, Lycopodium fot.) were present with substantial frequencies, and abundant cushion bogs of Plantago (P. rigida) were present. The water level in the lake was high and marsh vegetation limited. Polylepis dwarf forest occurred in the subparamo belt, along with shrub of Compositae, Hypericum and Ericaceae. In the Andean forest belt, Vallea–Miconia forest and Weinmannia–Hedyosmum forest were most important.

The interval 100–57 m core depth (estimated age 350–186 ka) shows warm climatic conditions most of the time and is tentatively correlated with the δ¹⁸O Stages 10.2–7.1. The upper forest line oscillated from 2000 to 2600 m in the first part and from 2600 to 2900 m in the last part of this interval. The corresponding average annual temperatures are 6–10 and 10–12°C, respectively. The high plain was, in the first part of this interval, mostly situated in the paramo and in the last part of this interval in the Andean forest belt. During this interval Quercus immigrated into the area of the high plain. Quercus forest occurred in a wide altitudinal range (1000–2800 m) and initially constituted local patches of forest, but at the end of this interval, zonal Quercus forests were a major part of the Andean forest belt. Acalypha and Alchornea reached higher elevations in the Quercus forests, and the upper limit of subandean forest rose to modern elevations. Weinmannia dominated in the Weinmannia–Hedyosmum forest type. At the end of this interval, the contribution of Vallea–Miconia forest increased markedly and replaced Weinmannia forest. Podocarpus-rich forest occurred in the lower part of the Andean forest belt. Alnus carr and vegetation of Myrica thickets were abundant around the lake, which was of a shallow type. Algae (Botryococcus) became very abundant from the beginning of this interval to the top of the record.

The interval 57–2 m core depth (estimated age 186–24 ka) shows, for the first time in the record, abundant presence of zonal Quercus forests. The composition of the Andean forest belt had changed dramatically. Based on Arboreal Percentages, climatic conditions seem warm most of the time, but the high frequency of Quercus, a wind-pollinated tree that produces large amounts of pollen, exaggerates natural conditions. This interval is provisionally correlated with the δ¹⁸O Stages 6–3.0. The upper forest line oscillated from 2000 to 3000 m most of the time. The corresponding average annual temperature is 6–12.5°C. Quercus forests, resembling the modern Saurauia–Quercus humboldti forest, and Weinmannia–Hedyosmum forest, resembling the modern Weinmannietum, dominated in the Andean forest belt. Vallea–Miconia forest probably resembled the modern Xylosma–Duranta–Vallea forest, but the latter is palynologically difficult to recognize. Eugenia, Ilex and Myrsine contributed substantially to this rather dry forest type of low stature. Polylepis dwarf forest was frequent at the forest line and possibly also in the paramo belt up to 4000 m. Alnus carr completely dominated the flat parts of the high plain. Myrica thickets and marsh vegetation were reduced in the last part of this period. Sediment accumulation was very high (up to 60 cm per 1000 years). Supposedly, erosion of the Tequendama Falls in the Rio Bogotá, the only outlet of the high plain, led to the final drainage of the lake, depending on the location between ca. 28 and 22 ka.

The Andean biozones IV–VII (van der Hammen et al., 1973) are represented in the Funza records. Biozone IV (540–415 m core interval; estimated age 3.2–2.2 Ma) is mainly characterized by high percentages of Borreria. Alnus and Quercus are absent. In biozone V (415–257 m core interval; 2.2–1.0 Ma), Polylepis replaced Hypericum as the major element in the dwarf forest zone. Weinmannia replaced Hedyosmum as the most important element in the Weinmannia–Hedyosmum forests (precursor of the modern Weinmannietum), and the upper limit of the subandean forest
FIG. 12. Correlation of the pollen records Funza I (Hooghiemstra, 1984, 1989) and Funza II (Hooghiemstra and Cleef, *submitted*) and inferred climatic change for the interval 0.8 to ca. 3.2 Ma. Correlating pollen zones in both records have the same numbers, with a prefix F1 (Funza I) or F2 (Funza II). Depth and age of pollen zone boundaries are indicated. A provisional correlation with the marine δ¹⁸O stratigraphy is indicated. Ages of δ¹⁸O stages after Imbrie *et al.* (1984) up to Stage 22 and after time control of ODP Site 677 (Shackleton *et al.*, 1990) for the lower part of the pollen record. (After Hooghiemstra and Cleef, *submitted*.)

CONCLUSIONS

The extremely thick sediment sequence of the high plain of Bogotá, which accumulated continuously during the last 3 Ma, forms a unique and important source of data for belt had increased several hundreds of metres. *Alnus* and *Quercus* are still absent. Biozone VI (257–94 m core interval; estimated age 1.0–0.33 Ma) is characterized by the immigration of *Alnus* (first appearance date for the study area 1.0 Ma). Biozone VII (94–0 m core interval; estimated age 0.33 Ma to recent) is characterized by the immigration of *Quercus* (first appearance date for the study area 0.33 Ma, but present as an element that formed relevant zonal forests since 0.2 Ma). The upper limit of the subandean forest belt increased and reached modern elevations.
palaeoclimatological, palaeoecological and biogeographical studies with high temporal resolution. The first studies were initiated by van der Hammen and the present research is characterized by interdisciplinary studies. Several research projects concerning different aspects of the Quaternary history of the high plain of Bogotá are in progress. They are carried out within the research tasks of the PAGES Project of IGBP (International Geosphere–Biosphere Programme); see IGBP Global Change Reports 12 (1990) and 16 (1991).

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