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THE PLIOCENE AND QUATERNARY OF THE HIGH PLAIN OF BOGOTÁ (COLOMBIA): A HISTORY OF TECTONIC UPLIFT, BASIN DEVELOPMENT AND CLIMATIC CHANGE§

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The high plain of Bogotá in the Eastern Cordillera of Colombia represents a large tectonic basin that is filled with hundreds of metres of lacustrine and fluvial sediments. In the centre of the basin, the sediment sequence attains a thickness of nearly 600 m and covers a time span of the last 3 Ma (Late Pliocene–Quaternary). Still older sediments, of mainly fluvial origin, cover the adjacent mountain slopes. The age of these sediments reaches back into the Late Miocene (to 6 Ma and older). The sediment sequence of the Bogotá area has been the subject of extensive stratigraphical and palynological studies for decades. The results of these studies have provided a unique picture of the Pliocene–Quaternary geological history of a tropical montane region. Three main factors have influenced the evolution of the landscape, sedimentation and vegetation development. These are the tectonic uplift of the Andes (between ca. 5 and 3 Ma), the development of the large tectonic–sedimentary basin of Bogotá (after ca. 3.5 Ma) and the Quaternary climatic fluctuations and glaciations (starting shortly after ca. 2.7 Ma).

INTRODUCTION

An almost continuous sequence of mostly lacustrine and fluvial sediments representing at least the last 6 Ma is present in the area of the high plain of Bogotá. The high plain of Bogotá is situated at an elevation of 2550–2600 m in the Eastern Cordillera of Colombia, in the tropical Andes of South America (lat. 4°30′–5°15′N, long. 73°45′–74°30′W). The sediments are well exposed along the margins of the high plain area and on the surrounding mountain slopes. Information on the sediment sequence underlying the central part of the high plain of Bogotá is provided by long boreholes that have been collected for palynological studies and hydrological and industrial purposes. The geological history of the Bogotá area has been reconstructed by extensive lithological, geomorphological and palynological evidence, and absolute chronological control. In the present paper we will discuss the three main events that largely defined this history, i.e. the tectonic uplift of the Andes (between ca. 5 and 3 Ma), the development of the large tectonic–sedimentary basin of Bogotá (after ca. 3.5 Ma) and the Quaternary climatic fluctuations and glaciations (starting shortly after ca. 2.7 Ma). Only a synthesis of the available evidence will be presented. For further information the reader is referred to the literature cited in the following overview of the main studies that have been conducted in the Bogotá area and the next brief outline on stratigraphy.

Early studies focused mainly on the stratigraphy of the exposed part of the Bogotá sequence (Scheibe, 1933; Stirton,

1953; Hubach, 1957; van der Hammen, 1957, 1965, 1966; de Porta, 1961; Julivert, 1961). Three lithostratigraphic units were distinguished, i.e. the Tilatá, Sabana and Mondoñedo Formations. The first long pollen record from the basin of Bogotá came from a 195-m-long core taken in the SW part of the basin below the capital city of Bogotá. This Ciudad Universitaria X–Y section showed for the first time a long sequence of glacial and interglacial cycles in tropical Andean South America (van der Hammen and Gonzalez, 1960, 1963, 1964). In van der Hammen *et al.* (1973), the results of the Ciudad Universitaria X–Y core were combined with new palynological data from older exposed peat layers, enabling the authors to establish a biostratigraphic sequence of seven biozones that reached back into the Early Pliocene. A fourth formation (the Subachoque Formation) was added to the existing lithostratigraphic framework. From the data it was concluded that the Bogotá area had been gradually uplifted by more than 2000 m during the Late Pliocene, and that near the end of the upheaval of the Cordillera the large lake of the high plain of Bogotá had formed in which, subsequently, hundreds of metres of sediments accumulated during the Pleistocene. Reference was also made to the influence of tectonics on Late Pliocene sedimentation and of glacial and ‘periglacial’ conditions upon Pleistocene sedimentation.

The second author established a mapping programme in 1980. Preliminary Quaternary geological/geomorphological maps were made for various parts of the Bogotá area, applying aerial photo interpretation and extensive field surveys (Robertson, 1981; Helmens, 1984; Bakker and van der Wiel, 1984; Bekker, 1985; Schurink, 1987). In the meantime, the palynological results were published of the 357-m-long Funza I core that had been collected in the centre of the basin of Bogotá near the village of Funza (Hooghiemstra, 1984). The Funza I pollen record also revealed a long sequence of glacial–interglacial cycles. For

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the first time a series of tephra dates provided the sequence with absolute dating control (Hooghiemstra *et al.*, 1984; Hooghiemstra, 1989). Although ample radiocarbon dating evidence was available for the uppermost part of the Bogotá sequence (e.g. van der Hammen *et al.*, 1980), the older part of the sequence had only been dated by two tephra dates (van der Hammen *et al.*, 1973, 1980). The time frame as proposed by van der Hammen *et al.* (1973) was mainly based on the interpretation of the palynological and lithological evidence, and the subsequent correlation with the European climatic stratigraphic subdivision (e.g. van der Hammen *et al.*, 1971). Shortly after the Funza I record was published, a third long pollen record, registering three full glacial–interglacial cycles, was obtained from a 13-m-long core taken in a weathering depression in sandstone in the mountains northwest of the high plain of Bogotá (Helmens and Kuhry, 1986).

In 1988, another coring project was carried out near Funza, this time reaching bedrock. The first palynological, lithological and absolute chronological results of this 586-m-long Funza II core were published in Hooghiemstra and Sarmiento (1991). The beginning of glacial–interglacial conditions is clearly recorded at a core depth of 468 m. Below this depth, the fossil flora represents slightly warmer climatic conditions. The palynological data also indicate that sedimentation in this central part of the basin of Bogotá only started after the main upheaval of the Cordillera had ceased. In recent years, extensive data have additionally been collected from the exposed sections in the marginal valleys of the high plain area and in the surrounding hills and mountains. This new evidence has been combined with the existing data, and with the descriptions of the many borings and geoelectric profiles carried out in the basin of Bogotá for hydrological and industrial purposes (Fandiño, 1967; EPAM, 1985; Lobo-Guerrero U., 1985a, b). The results of this study, together with two Neogene–Quaternary geological map sheets, were published in Helmens (1990). The extensive field and mapping data allowed the lithostratigraphic sequence to be further specified and extended, and a total of 13 formations and three members were formally described. Important palynological evidence was added to the existing biostratigraphic sequence (Kuhry and Helmens, 1990). Newly obtained fission-track dates on zircons derived both from exposed tephra layers and from a series of volcanic ashes from the Funza II core provided the Bogotá sequence with sound absolute chronological control (Helmens *et al.*, 1990; Andriessen *et al.*, *in press*). These tephra datings are, from a technical point of view, of good quality and have put in doubt many of the earlier fission-track dates on glass shards and K/Ar dates on minerals from the Funza I core. The newly obtained tephra datings have proved the validity of the original stratigraphic time frame and chronology proposed by van der Hammen *et al.* (1973). Combining this evidence with the results of a detailed study on Late Quaternary glacier fluctuations in the highest mountain ranges near Bogotá (Helmens, 1988) has resulted in a reconstruction of landscape evolution, sedimentation and vegetation development in the Bogotá area through Neogene–Quaternary times, as related to tectonics, climate and glacial history (Helmens, 1990).

At present, detailed palynological, paleobotanical and geochemical studies of several Pliocene–Early Pleistocene peat sections are being conducted (Wijninga, *in preparation*). The palynological/paleobotanical results of an Early and of a Late Pliocene section have already been published in Wijninga and Kuhry (1990) and Wijninga and Kuhry (1993), respectively. Detailed palynological analyses have been carried out on the Funza II core (Hooghiemstra and Cleef, *submitted*; Hooghiemstra and Ran, *submitted*). A research project has just started that will study the magnetostratigraphy of the Bogotá sequence (Helmens *et al.*, *in preparation*).

STRATIGRAPHY OF THE BOGOTÁ SEQUENCE AND GEOLOGICAL MAPS

The stratigraphic framework for the Neogene–Quaternary sediment sequence of the Bogotá area is presented in Fig. 1 (Helmens, 1990). The composite and schematic lithostratigraphic column includes 13 formations and three members, and represents four main depositional environments. The principally fluvial sediments of the Marichuela and Lower Tilatá Formations are mainly found on the slopes surrounding the high plain of Bogotá, and do not show a relationship to the present-day drainage system (Miocene–Lower Pliocene). The Upper Tilatá, Subachoque, Sabana, Río Tunjuelito and Chía Formations include lacustrine and fluvial sediments deposited in the large tectonic–sedimentary basin of Bogotá (Upper Pliocene–Quaternary). The gravity flow deposits of the Chorrera Formation (Pliocene) and the fluvio-glacial deposits of the Río Siecha Formation (Pleistocene) accumulated in a footslope environment, whereas a mountain environment is represented in the slope deposits of the Balsillas, San Miguel and Mondoñedo Formations (Pliocene–Quaternary) and the glacial deposits of the Río Chisacá Formation (Pleistocene).

The surface distribution of the different lithostratigraphic units is shown in Fig. 2 (Helmens and van der Hammen, *in press*). This map is a generalized version of the two geological map sheets by Helmens (1990). The sheets cover the southern portion of the upper drainage basin of the Río Bogotá and include the main part of the high plain of Bogotá and surrounding mountains (Fig. 3). They have scales of 1:80,000 and are printed in colour. Three portions of the original map sheets are given in Figs 6–8. On the original map, grey screen symbols that accompany the Neogene–Quaternary lithostratigraphic units reflect the overall lithological character of each unit. Black line symbols depict geomorphological features like scarps, fans, glacial cirques and morainic ridges, and geological details including main synclinal axis and dipslopes. In addition to the lithostratigraphic units representing the Neogene–Quaternary sequence, bedrock units are distinguished. The bedrock geology, which mainly includes sandstones, shales and claystones of Late Cretaceous–Early Tertiary age, was adapted from the geological maps of the ‘Instituto Nacional de Investigaciones Geológico-Mineras’ (INGEOMINAS) at Bogotá. Main structural features are several wide synclines and rather narrow anticlines with a N–S to NE–SW oriented strike. On a minor scale, however, the geological structure

FIG. 1. Lithostratigraphy, biostratigraphy and chronostratigraphy of the Neogene-Quaternary sediment sequence of the area of the high plain of Bogotá (according to, among others, van der Hammen *et al.*, 1973 and Helmens, 1990; table taken from Helmens, 1990).

and the distribution of the surficial deposits might be rather complex, as different intersecting faults create irregularly outlined blocks with their own sinking and tilting movements (e.g. Bürgli, 1958; Gomez M., 1985). Schematic cross-sections through the sediment infill accompany the map fragments of Figs 2, 6 and 7 (Helmens, 1990). A detailed map of the different morainic complexes and older glacial deposits recognized in the mountains near Bogotá is presented in Fig. 10 (Helmens, 1988; Helmens and Kuhry,

in press). Figures 5–8 and 10 also include photographs of important lithological sections and geomorphological details (Helmens, 1990). The Neogene-Quaternary biostratigraphic sequence comprises the biozones I–VII (Fig. 1). The zonation as shown in the figure is mainly after van der Hammen *et al.* (1973) and was taken from Kuhry and Helmens (1990). It is principally based on the successive immigration of four important arboreal taxa into the Bogotá area (successively

FIG. 3. The high plain of Bogotá in the Eastern Cordillera, Colombia, with study area.

Hedyosmum, *Myrica*, *Alnus* and *Quercus*). These trees are all good pollen producers and have a good dispersal capacity. If they were present in the area they may be expected to be represented in the pollen-bearing horizons of the lacustrine and fluvial sediments, even if they were growing at a certain distance from the site of deposition. A second important criterion in the biostratigraphic zonation is the regional ecoclimatic zone in which the sediments were deposited. This is established on the basis of pollen assemblages found in the sediments, including indicator taxa characteristic for the different vegetation belts now present in the Eastern Cordillera. These vegetation belts are the lower tropical belt below an elevation of ca. 1000 m, the subandean and Andean forest belts between ca. 1000–2400 m and ca. 2400–3300 m, respectively, and above the upper forest line the open tropical alpine paramo belt. Above elevations of ca. 4300 m, the vegetation cover becomes sparser with elevation (superparamo belt) until perennial snow cover is reached at ca. 4800 m.

Simplified pollen diagrams of several important sections collected from exposed sediment sequences, that together represent the biostratigraphic sequence of seven biozones, are presented in Fig. 4 (van der Hammen *et al.*, 1973; Kuhry and Helmens, 1990; van der Hammen, *unpublished data* in Kuhry and Helmens, 1990; Wijninga and Kuhry, 1990, 1993). A lithological column, absolute dating control where available, a general pollen diagram and separate curves of a number of characteristic indicator taxa are given. The five ecological groups distinguished in the general diagrams reflect as clearly as possible the actual main composition of the previously mentioned altitudinal vegetation belts.

The chronostratigraphic sequence in Fig. 1 is based on fission-track dates of volcanic zircons and for the uppermost part of the sequence on extensive radiocarbon dating control. Radiocarbon dates have been obtained both from sediments and paleosols rich in organic matter, and are summarized in van der Hammen *et al.* (1980) and Helmens (1990). The fission-track datings were performed on exposed tephra layers and on a series of tephtras intercalated in the Funza II core, and these dating results are presented in Helmens *et al.* (1990) and Andriessen *et al.* (*in press*). For a discussion on the revised time frame of the Bogotá sequence, the reader is referred to Andriessen *et al.* (*in press*). The Pliocene–Pleistocene boundary in Fig. 1 corresponds to 2.4 Ma, as defined by and used among many terrestrial stratigraphers (e.g. van der Hammen *et al.*, 1971, 1973; Zagwijn, 1975, 1992; Liu, 1985; Andriessen *et al.*, *in press*).

THE TECTONIC UPLIFT OF THE ANDES

In the Early Pliocene, the Bogotá area lay mainly in the lower tropical belt. Folding and faulting of the Cretaceous and Early Tertiary sedimentary rocks had been largely completed and a broad and complex N–S to NE–SW striking synclinorium characterized the area. Although the major uplift of this part of the Colombian Eastern Cordillera had not yet begun, ridges and low mountains were present, at the foot of which coarse debris flow and gravity flow material had been deposited during orogenic movements in the

Miocene (Marichuela Formation). The Early Pliocene lowlands were drained and inundated by a river system depositing gravels and sands, and in local lakes and marshes (organic) clays and peat accumulated (Tequendama Member of the Lower Tilatá Formation; Fig. 5). A lower tropical paleo-flora is registered in the pollen diagram obtained from the organic-rich sediment intercalations in the sands and gravels of the Salto de Tequendama section (van der Hammen *et al.*, 1973; Fig. 4). The palm *Mauritia* formed a dominant element in the tropical lowland forest. Minor extensions of savanna vegetation types, with *Byrsonima* and Gramineae, occurred during short intervals favoured by slightly drier climatic conditions. The complete dominance of lower tropical elements and the absence (or almost absence) of *Hedyosmum* assigns the pollen record to biozone I, and indicates an altitude of deposition that presumably did not exceed 500 m. Absolute chronological control for this time interval in the geological history of the Bogotá area is provided by a fission-track date on zircon of 5.33 ± 1.02 Ma. The zircons were derived from a tephra found interlayered in the gravels of section 17 (Helmens *et al.*, 1990; Fig. 5). The tephra is underlain by organic clays containing fossil pollen and fruits of several lower tropical taxa (Wijninga, V.M., *pers. commun.*, 1993).

The earlier stages in the tectonic uplift of the Bogotá area are recorded in the fluvial sediments of the Tibagota Member of the Lower Tilatá Formation. This member includes gravels and sands deposited in large alluvial fans and clays and peaty sediments that accumulated further away from the hills/mountains. In the (sub-) tropical environment, the coarse-grained sediments were deeply brownish and reddish coloured/mottled, whereas in the fine-grained sequences iron was concentrated to form thick iron pans. Pollen diagrams obtained from the peaty intercalations in the Tibagota Member indicate altitudes of deposition ranging from ca. 1000 to 1500 m, near the boundary lower tropical zone–subandean zone (Subachoque 39 section) and in the subandean zone (Facativá 13 section). The Subachoque 39 section (Wijninga and Kuhry, 1990; Fig. 4) still shows significant percentages of pollen of lower tropical taxa, in addition to pollen of subandean and Andean forest taxa. The peaty layer also contains abundant fossil fruits and seeds including those of the lower tropical element cf. *Humiriastrum* (Fig. 6, photos 3 and 4). Characteristic lower tropical elements are absent in the pollen record of the Facativá 13 section (van der Hammen *et al.*, 1973; Fig. 4), and a significant representation of a number of lower subandean taxa, especially Apocynaceae, indicates that this peat deposit only accumulated after the area had been uplifted some 1000 m into the lower subandean forest belt. This latter stage in the upheaval of the Cordillera was reached at 3.67 ± 0.50 Ma, corresponding to a fission-track date on zircon derived from a tephra intercalation in the peat deposit of the Facativá 13 section (Helmens *et al.*, 1990). Both pollen records register *Hedyosmum* and represent biozone II.

During the next ca. 1 Ma, the area was uplifted another 1000 m to its present elevation at ca. 2500 m. These later stages in the upheaval of the Cordillera are recorded in the sediments of the Upper Tilatá Formation. Contrary to the

FIG. 4. Simplified pollen diagrams of several Pliocene-Quaternary sections exposed in the Bogotá area. Original section names, biostratigraphic units (biozones), lithostratigraphic units, absolute dating control where available and lithology are indicated. The approximate time scale is according to van der Hammen *et al.* (1973), Helmens *et al.* (1990) and Andriessen *et al.* (in press). All sites are at present located in the Andean forest belt at elevations between ca. 2600 and 2850 m. Sections are after van der Hammen *et al.* (1973; sections Salto de Tequendama and Facatativa 13), Kuhry and Helmens (1990; sections Mufia 320 and Usme 314), van der Hammen (unpublished data in Kuhry and Helmens, 1990; sections Tunjuelito 1 and 3), Wijninga and Kuhry (1990; section Subachoque 39) and Wijninga and Kuhry (1993; section Guasca 103). The tephra date in section Facatativa 13 is from Helmens *et al.* (1990).

FIG. 5. Sections 15 (photo 1) and 17 (photo 2) of the Tequendama Member of the Lower Tilatá Formation (after Helmens, 1990). The arrow in photo 2 indicates the silty ash bed that occurs intercalated between dark-coloured organic sandy clays and light-coloured diatom clays.

fluvial sediments of the Lower Tilatá Formation, which had been mainly deposited in the areas surrounding the present high plain of Bogotá, the fluvial–lacustrine sediments of the Upper Tilatá Formation represent the basal infill of the tectonic basin of Bogotá (Figs 1 and 2). Pollen-bearing horizons in the lower, Guasca Member of the Upper Tilatá Formation (Guasca 103 section of Wijninga and Kuhry, 1993; Fig. 4) register a paleo-flora characteristic for the upper part of the present subandean forest belt, and imply an altitude of deposition of ca. 2200 m. At this time *Myrica* had also arrived in the Bogotá area (biozone III). The unnamed Upper Member of the formation was deposited when the Cordillera had reached its present elevation and the area of sedimentation was located within the Andean forest belt (lower part of biozone IV). This is registered in the basal part of the Funza II pollen record (Hooghiemstra and Sarmiento, 1991). A fission-track date on zircon from tephra intercalated in the Funza II core indicates that the main upheaval of the Eastern Cordillera had ceased in the Late Pliocene sometime before 2.74 ± 0.63 Ma (Andriessen *et al.*, *in press*).

The tectonic uplift was associated with regional tectonic instability. It appears that large fault systems were reactivated, along which rather coarse material was produced. The large sandstone blocks were, mainly under the influence of gravity, transported over distances of several kilometres away from the mountains (van der Hammen *et al.*, 1973). These gravity flow deposits, which form large coalescing fan systems in areas bordering the basin of Bogotá, are defined as the Chorrera Formation. Intercalated in the gravity flow material are some gravels and several paleosols, indicating that the phases of tectonic instability alternated with phases of fluvial sedimentation and soil formation.

The map fragment and cross-sections in Fig. 6 show the

alluvial fan deposits of the Tibagota Member of the Lower Tilatá Formation on the western slopes of the Subachoque valley, along the northwestern border of the Bogotá area (Fig. 2). The central valley, which forms an extension of the high plain of Bogotá, includes the fluvial–lacustrine sediments of the Guasca Member of the Upper Tilatá Formation, that are exposed under the Early Pleistocene Subachoque Formation. At the foot of the eastern valley side there are remnants of a large fan system that is composed of gravity flow deposits of the Chorrera Formation. Sites of photographs accompanying the figure are indicated on the map fragment. The present distribution of the alluvial fan deposits of the Lower Tilatá Formation is striking. The gravel dominated sequences (photo 1) are situated near the central valley, whereas the fine-grained sandy, clayey and peaty sequences (photos 2 and 3) are found in the vicinity of the main water divide (photo 5). Sediment supply came from the southeast, i.e. from the area of the present high plain of Bogotá. The alluvial fan deposits were subsequently tilted in the direction of the central high plain area and planated (photo 5), most probably during the later phases in the upheaval of the Cordillera, when the high plain of Bogotá area underwent large-scale subsidence and the fluvial–lacustrine sediments of the Upper Tilatá Formation were deposited in the central Subachoque valley. Photo 6 gives a view of one of the fans of the Chorrera Formation and photo 7 shows the composing coarse, unsorted and rather angular gravity flow deposits.

It is concluded that in the Bogotá area the main upheaval of the Eastern Cordillera took place between ca. 5 and 3 Ma (van der Hammen *et al.*, 1973; Helmens *et al.*, 1990; Andriessen *et al.*, *in press*). During this time interval sediments with lower tropical floras were uplifted some 2000 m, averaging ca. 1 mm/year. The sediment record, however, seems to indicate that the uplift took place in various phases.

Phases of high tectonic activity, with coarse gravity flow deposition, alternated with phases of fluvial (lacustrine) sedimentation and soil formation. The phases of uplift were accompanied by some very important reorganizations in relief, which eventually resulted in the development of a large central sedimentary basin.

THE DEVELOPMENT OF THE TECTONIC-SEDIMENTARY BASIN OF BOGOTÁ

In the Late Pliocene, the initial phases in the development of the basin of Bogotá were characterized by highly variable sedimentary environments. Rivers deposited sands and gravels and there were extensive lakes and marshes in which clays, organic clays, diatom clays and peat could accumulate. Fluvial and lacustrine sedimentation was at intervals interrupted by important phases of colluviation, producing thick layers of silts. The resulting sediment sequence, with its large lateral and temporal variation in lithology, is defined as the Upper Tilatá Formation. Basin sedimentation initiated in the outer valleys of the present high plain of Bogotá. Sedimentation of the Guasca Member of the Upper Tilatá Formation started in these marginal basins near the end of the tectonic uplift of the Cordillera when the Bogotá area was situated in the upper part of the subandean forest belt (biozone III), at ca. 3.5 Ma (Helmens *et al.*, 1990; Andriessen *et al.*, *in press*). At about 3 Ma, when the main upheaval of the Cordillera had ceased and the area was located at its present elevation of ca. 2500 m in the Andean forest belt (lower part of biozone IV), the first sediments of the unnamed Upper Member of the formation were deposited in the central part of the high plain area (Helmens *et al.*, 1990; Andriessen *et al.*, *in press*). The pollen records obtained from the Guasca Member (Guasca 103 section of Wijninga and Kuhry, 1993; Fig. 4) and the unnamed Upper Member (Funza II core in Hooghiemstra and Sarmiento, 1991), although reflecting different ecoclimatic zones and therefore representing different biozones, show a similar pattern of chaotic changes in the floristic composition of the subandean and Andean forests, with several arboreal taxa alternating as dominant elements. Many of the important arboreal elements, including *Alchornea*, *Rapanea*, *Ilex*, *Myrica* and *Eugenia*, have certain pioneer qualities and the rapid changes in the composition of the forests might be related to the dynamic local conditions of rapidly changing sedimentation patterns, frequently fluctuating water levels and large-scale colluviation that accompanied the initial stages of formation of the basin of Bogotá (Kuhry and Helmens, 1990; Wijninga and Kuhry, 1993).

After sedimentation had started in the central part of the high plain of Bogotá, during the next ca. 1.5 Ma there was a gradual development of a large tectonic basin in which sediments were spread out over increasing areas. The sedimentary environment in the basin gradually obtained a more lacustrine character, that would prevail during the remaining part of the basin's history (van der Hammen *et al.*, 1973). Within the expanding basin a distinct change in sedimentation patterns is recorded shortly after ca. 2.7 Ma, induced by climatic cooling. Changing conditions of the

Quaternary period resulted during the Early Pleistocene in the subsequent deposition of a regular sequence of clays, peat, sands and some gravels in the basin (Subachoque Formation). The basin had reached its full extension, and a lacustrine environment predominated all over the present high plain of Bogotá, when the first sediments of the Subachoque Formation are recorded in the southeastern part of the high plain area (start of the Ciudad Universitaria X-Y record; van der Hammen and Gonzalez, 1960, 1963). The rapid changes in representation of Andean pollen taxa, and also of the non-arboreal elements *Borreria* and *Polygonum* that characterize pollen diagrams in biozones III and IV (lower part), then came mostly to an end (provisional base of biozone V).

Shortly after the basin had reached its maximum extension, reinforced tectonic movements caused another distinct change in the extension of the basin environment and in basin sedimentation. A deeper central lacustrine environment was created in which mainly clays started to accumulate. The overall general rise in lake level is well expressed in the Funza I (Hooghiemstra, 1984) and Funza II cores (Hooghiemstra and Sarmiento, 1991) and the Ciudad Universitaria X-Y core (van der Hammen and Gonzalez, 1963), and corresponds to a strong increase in the representation of the alga *Botryococcus* and the aquatic taxon *Isoëtes* in the pollen diagrams of these cores. Three fission-track datings in the Funza II core indicate that the rise in lake level in the central basin occurred at about 1 Ma (Andriessen *et al.*, *in press*). During the later part of the Early Pleistocene and the Middle and Late Pleistocene, the changing conditions of the Quaternary period only affected sedimentation in the outer zones of the lake, where peat, sands and some gravels became locally intercalated in the mainly clayey sequence (Sabana Formation). Deposition of the Subachoque Formation continued in the marginal valleys of the high plain of Bogotá during the later part of the Early Pleistocene, after which basin sedimentation in these regions came mostly to an end (Figs 1 and 2).

In the marginal valleys of the high plain of Bogotá, the maximum thicknesses of the Upper Tilatá Formation and the Subachoque Formation are about 15 and 20 m, respectively (Fig. 1). In the centre of the tectonic basin of Bogotá, the Subachoque Formation attains a thickness of ca. 150 m, and is underlain by some 110 m of sediments of the Upper Tilatá Formation and overlain by a 320-m-thick sediment sequence of the Sabana Formation (Figs 1 and 2). From the absolute chronological data of the Funza II core (Andriessen *et al.*, *in press*), it can be concluded that in the central basin the sediments of the Subachoque Formation were deposited at an average of ca. 0.1 mm/year, whereas the sediments of the Sabana Formation accumulated at ca. 0.3 mm/year. In the marginal valleys, the surface of the Subachoque Formation has been cut off by erosion, the erosion surface gently dipping into the direction of the central high plain area, and is deeply incised by the tributaries of the Río Bogotá. In the valley of Subachoque (see map fragment and cross-section B-B' in Fig. 6), the erosion surface in the Subachoque Formation is bounded to the west by the slightly more inclined and highly dissected planation surface cut into the

FIG. 6. Fragment of the northern Neogene–Quaternary geological map sheet of the Bogotá area, in the surroundings of the village of Subachoque (Fig. 2), cross-sections through the Subachoque valley and several photographs of important lithological sections and geomorphological details in the area (after Helmens, 1990). The location of the photographs is indicated on the map. Photo 1 shows section 22 and photos 2 and 3 show section 27 of the Tibagota Member of the Lower Tilatá Formation. A pollen diagram of the peaty clay layer of section 27 (photo 3) is presented in Fig. 4 (Subachoque 39 section of Wijninga and Kuhry, 1990). The peaty layer contained many fossil fruits of the lower tropical element cf. *Humiriastrum* (photo 4; Wijninga and Kuhry, 1990). Photo 5 shows the planation surface cut into the sediments of the Tibagota Member. Photo 6 shows a fan of the Chorrera Formation and photo 7 the composing gravity flow deposits (section 176). Photos 8, 9 and 10 show sections in the Subachoque Formation (sections 48, 43 and 55, respectively).

FIG. 6. Cont.

alluvial fan deposits of the Early Pliocene Lower Tilatá Formation, whereas to the southeast it passes into the more or less flat and only weakly incised surface of the Sabana Formation. In the Late Pliocene, it appears that the outer regions of the Bogotá area, including the sediments of the Lower Tilatá Formation, were slightly tilted and their surfaces planated when large-scale subsidence started to affect the area of the present high plain of Bogotá. This pattern seems to have repeated itself during the renewed tectonic movements in the later part of the Early Pleistocene. Now the marginal valleys of the high plain of Bogotá, and the sediments of the Subachoque Formation, were tilted and their surfaces subsequently planated while the central high plain area underwent faster subsidence. In this way the area of sedimentation was gradually transposed from the margins to the centre of the Bogotá area.

During the upper part of the Last Glacial period, a marked lowering in the water level of the large Bogotá lake took place, which eventually led to its disappearance. Radiocarbon dates indicate that the lake level dropped below the margins of the basin somewhere between ca. 40,000 and 30,000 BP, whereas the lake disappeared from the central basin at ca. 28,000 BP (van der Hammen *et al.*, 1980). The sudden lowering in water level may have had its origin in tectonic movements near the outlet of the lake in the southwest (Fig. 3), or by strong erosion of this outlet during the very high lake levels of the middle part of the Last Glacial period. The former lake bottom was subsequently incised by the Río Bogotá and its main affluents. The fine-grained fluvial sediments that border these rivers have a mostly Holocene age (Chía Formation).

QUATERNARY CLIMATIC FLUCTUATIONS AND GLACIATIONS

During the Quaternary period (i.e. the last 2.4 Ma), the Bogotá area experienced important climatic fluctuations that had a major impact on vegetation cover in the area. The climatic oscillations resulted in impressive altitudinal shifts in the zonal vegetation belts along the slopes of the Eastern Cordillera. The slopes surrounding the tectonic-sedimentary basin of Bogotá were, as a result, alternately covered with Andean forest and open paramo vegetation types. The changes in climatic/vegetational conditions were accompanied by fluctuations in water level in the basin. Low lake levels or relatively dry local conditions were common during the warmer interglacial (interstadial) periods when the area lay within the Andean forest belt. Relatively high lake levels, on the other hand, generally prevailed during the colder glacial periods when the surrounding slopes were covered with paramo vegetation dominated by Gramineae. The fluctuations in lake level are explained by differences in evaporation under warm and cold climatic conditions (Hooghiemstra, 1984; van der Hammen, 1988), and by differences in interception, evapotranspiration and water storage of forest and open vegetation types (Kuhry and Helmens, 1990; Kuhry, 1991). In addition to the influence upon vegetation cover and lake level, the phases of climatic cooling caused glaciers to form and expand in the highest mountain ranges around Bogotá.

The lake level fluctuations and glaciations had an important impact on the sedimentation in the basin of Bogotá. During the colder periods of the Early Pleistocene, there was generally a large lake that extended all the way into the marginal valleys of the present high plain of Bogotá. Clays were deposited in the lake and peaty sediments accumulated in marshes along its shores. It appears that the area occupied by the lake became more restricted to the central high plain area, however, during the coldest intervals. During these intervals glaciers must have formed and expanded on the highest watersheds, causing a sudden large supply of coarse-grained sediment in the basin. As a result, the central parts of the marginal valleys were now occupied by broad sandy floodplains with gravel deposition in minor stream channels, and especially along the main river courses. Some sand was deposited into the central lake. Major climatic warming and the replacement of open paramo vegetation by Andean forest was accompanied by an important drop in lake level to well below the level of the marginal valleys, where fluvial incision now dominated. In the central basin, these low water levels of the warm interglacial periods often resulted in the development of marshes in which peat could accumulate. The resulting Early Pleistocene sediment sequence of clays, peat, sands and some gravels is defined as the Subachoque Formation. The concentrations of gravels along the rivers entering the basin of Bogotá are defined as the lower part of the Río Tunjuelito Formation (Subachoque Member).

Tectonic adjustments in the basin some 1 Ma ago resulted in the development of a deeper central lacustrine environment in which, during the later part of the Early Pleistocene and the Middle and Late Pleistocene, mainly clays were deposited. The fluctuations in lake level and the glaciations, however, continued to affect sedimentation in the basin to some extent. The relatively low water levels of the warm interglacial periods allowed peat accumulation in marshy shore vegetation, whereas during the coldest periods with glaciers on the highest mountain tops, sands and gravels were locally deposited into the outer zones of the lake. The resulting sediment sequence of mainly clays with local intercalations of peat, sands and some gravels along the margins of the sedimentary basin is defined as the Sabana Formation. Thick sequences of glacially derived gravels continued to be built up in the centre of a large delta that extended for kilometres into the southeastern part of the lake, and to a minor extent in the marginal valleys (Sabana Member of the Río Tunjuelito Formation). The central parts of the marginal valleys were, during the Middle and Late Pleistocene, mainly effected by erosion (Fig. 1).

At the foot of the highest mountain ridges, where local conditions were favourable for the accumulation of sediment, thick sequences of coarse-grained fluvio-glacial deposits built up. The gravels and rounded boulders formed, in places, large coalescing fan systems that extend for kilometres away from the mountain fronts. During phases of maximum glaciation, some till was deposited into the upper fan areas. The fan deposits, in which intercalated paleosols indicate that the phases of sedimentation were alternated with phases of soil formation, are defined as the Río Siecha Formation. Although glaciers at intervals descended into the

apical zones of the fluvio-glacial fans, the major part of glacial deposition, however, occurred in the mountains themselves. Here ablation till was piled up in often huge, lateral-frontal morainic ridges (Río Chisacá Formation). Depending on the general climatic conditions, glacial deposition and erosion took place by valley glaciers or smaller cirque glaciers, or by ice caps that descended the mountains only weakly influenced by underlying topography (Helmens, 1988).

The Quaternary climatic oscillations are well expressed in the long pollen records from the Bogotá area. The start of the first cold period is recorded at a depth of 468 m in the Funza II core (Hooghiemstra and Sarmiento, 1991), and occurred according to a fission-track date on volcanic zircon at a core depth of ca. 506 m shortly after 2.74 ± 0.63 Ma (Andriessen *et al.*, *in press*) and, according to land-sea correlation, at 2.4 Ma (Hooghiemstra and Sarmiento, 1991). The generally high percentages of Andean forest elements in the lowermost part of the core are suddenly replaced by high percentages of Gramineae. The high percentages of Gramineae, together with the registration of characteristic paramo elements, indicate that the upper Andean forest limit had descended to below the altitudinal level of the basin of Bogotá and open paramo vegetation covered the slopes surrounding the basin. What follows in the Funza II pollen record, and what is also registered in the other long pollen records from cores collected in the basin of Bogotá (van der Hammen and Gonzalez, 1960, 1963, 1964; Hooghiemstra, 1984, 1988) and the mountains west of the high plain area (Helmens and Kuhry, 1986), are fluctuations in the percentages of Andean forest elements versus paramo elements representing a long sequence of relatively warm interglacial (interstadial) and cold glacial periods. A series of pollen diagrams that register the Quaternary climatic fluctuations were also obtained from the exposed sediment sequences in the marginal valleys and the southeastern part of the basin of Bogotá. Pollen diagrams from fine-grained intercalations in the gravels of the Río Tunjuelito Formation in the basin's southeastern part are presented in Fig. 4 (Usme 314 section of Kuhry and Helmens, 1990; Tunjuelito 3 and 1 sections of van der Hammen, *unpublished data* in Kuhry and Helmens, 1990). The alternation of Andean forest and paramo vegetation in the Bogotá area during the Quaternary period is represented in biozones IV (upper part)–VII. *Alnus* immigrated into the Bogotá area at the beginning of biozone VI and *Quercus* appeared at the beginning of biozone VII. From the pollen-analytical evidence, mean annual temperatures are estimated to have lowered of the order of up to ca. 6–11°C (van der Hammen and Gonzalez, 1960, 1963; Hooghiemstra, 1984; Helmens and Kuhry, 1986).

The sediments of the Early Pleistocene Subachoque Formation are well exposed at the surface in the valleys of Subachoque and Guasca (Fig. 2). In the middle part of the central Subachoque valley (Fig. 6), the Subachoque Formation includes thick layers of fluvial sands with lenses and pockets of gravels that cut off series of lake clays and peaty sediments (photo 9). Going upvalley, there is an increase in gravels at the expense of the clayey and peaty sediments (photos 8 and 9), whereas going downvalley, and

away from the main river crossing the valley, exposures show sands and clays (photo 10). Gravels are concentrated in thick sequences along the main river (Río Tunjuelito Formation in map fragment and cross-sections). The sands and gravels are interpreted to have a glacial origin (van der Hammen *et al.*, 1973), derived from former glaciers in the northernmost part of the Subachoque valley. The glacial origin of the coarse-grained sediments of the Subachoque and Río Tunjuelito Formations in the tectonic basin of Bogotá becomes especially clear in the valley of Guasca. In this valley (Fig. 7), the basin of Bogotá is situated close to the formerly glaciated mountains, and a nice lithological transition is observed from the morainic deposits (Río Chisacá Formation) in the high mountain range to the east, via fluvio-glacial gravels and boulders of the Río Siecha Formation that form a large coalescing fan system directly at the foot of the mountain front (photos 1 and 3), to the gravels of the Río Tunjuelito Formation (photos 2 and 3) and the sands and clays of the Subachoque Formation (photo 4) in the central valley. In addition, radiocarbon dating evidence for the uppermost part of the Río Tunjuelito Formation and the Río Chisacá Formation suggests a close match between the deposition of gravels in the basin of Bogotá and the glacial events as recorded in the surrounding mountains (van der Hammen *et al.*, 1980/1981; van der Hammen, 1986). The boundary between the Subachoque Formation and the mainly clayey sequence of the Late Pliocene Upper Tilatá Formation is shown in photo 5.

The presence of certain characteristic paleosols and some radiocarbon dates indicate that the fluvio-glacial deposits of the Río Siecha Formation in some areas correspond to Middle Pleistocene glaciations, whereas in other areas only the glaciations of the Last Glacial period are represented in the formation. Radiocarbon dating control for the Río Chisacá Formation indicates a mostly Last Glacial age for the glacial deposits in the mountains near Bogotá. The palynological, lithological and absolute chronological evidence from the basin of Bogotá, however, indicates that glacial periods comparable with the last one have occurred in the Bogotá area since 2.4 Ma. The fact that no older morainic systems from the earlier glacial periods have been found, and the incomplete fluvio-glacial record, are ascribed to erosion/denudation in the high relief areas outside the tectonic basin of Bogotá, and the many subsequent glaciations (van der Hammen *et al.*, 1973).

Contrary to the highest mountain ranges that show abundant geomorphological evidence of former glaciations, like numerous morainic ridges, cirques, U-shaped valleys and glacially scoured level areas with many glacial lakes (Helmens, 1988), the lower hills and mountains near Bogotá, i.e. with elevations less than ca. 3600 m, lack evidence of a former ice-cover. However, remnants of thick sequences of slope deposits are locally present in these regions that date back to the Early Pleistocene. Characteristic of the slope deposits are the high weathering grade of the clasts and the strong reddish/orange colouration of the clayey matrix (San Miguel Formation). Pollen data obtained from organic clayey intercalations in the slope deposits (Muña 320 section of Kuhry and Helmens, 1990; Fig. 4) show a cold pollen flora

LITHOSTRATIGRAPHIC UNITS

- Río Tunjuelito Formation (Qrt), locally with thin cover of Chía F.
- Sabana Formation (Qsa)
- Subachoque Formation (Qsu)
- Upper Tilitá Formation (T(Q)tgu)
- Río Siecha Formation (Qrs)
- Chorrera Formation (Tch)
- Mondoñedo Formation (Qmo)
- Río Chisacá Formation (Qrc)
- Lower Tilitá Formation (Ttte)
- local slope and lake deposits Q(dp)

- Usme Formation (Tu)
- Regadera Formation (Tr)
- Bogotá Formation (Tb)
- Guaduas Formation (TKg)
- Guadalupe Formation (Kg)
- Chipaque Formation (Kc)

GEOMORPHOLOGICAL DETAILS

- escarpment
- break of slope
- convex part of slope
- fan
- cirque

- morainic ridges
- dipslope
- main water divide
- drainage system

TOPOGRAPHICAL DETAILS

- 3500- contour line (metres)
- main roads
- village
- >3 site of photograph

FIG. 7. Fragment of the northern Neogene-Quaternary geological map sheet of the Bogotá area, in the surroundings of the village of Guasca (Fig. 2), cross-sections through the Guasca valley and several photographs of important lithological sections and geomorphological details in the area (after Helmens, 1990). The location of the photographs is indicated on the map. Photo 3 shows the coalescing fan system of the Río Siecha Formation and the central Guasca valley with the Río Tunjuelito Formation, and photos 1 and 2 the composing fluvio-glacial deposits (section 185) and fluvial deposits (section 167), respectively. Photos 4 and 5, and photos 6 and 7 show sections in the Subachoque Formation (sections 32 and 66, respectively). The arrow in photo 5 indicates the lower contact of the Subachoque Formation with the Lower Tilitá Formation.

FIG. 7. *Cont.*

corresponding to biozone (IV upper part–) V. The San Miguel Formation is found in those hilly or mountainous regions where the Late Cretaceous sandstones have been deeply weathered, leaving sandstone banks surrounded and intersected by large concentrations of reddish clays. The formation is interpreted to have its origin in the old tropical weathering product of the Late Cretaceous sandstones, that apparently was readily transported downslope during the first cold periods of the Pleistocene, most probably by 'periglacial' solifluction (van der Hammen *et al.*, 1973). Figure 8 shows the San Miguel Formation (photo 1) and the weathered sandstones (photos 2 and 3) in the hills near the village of Facatativá, along the western border of the Bogotá area (Fig. 2). The sandstone hills show a highly irregular topography with many depressions and a mostly internal drainage system. Coarse-grained, rather angular and poorly sorted solifluction material is also found locally intercalated in the marginal parts of the Early Pleistocene Subachoque Formation (Fig. 7, photos 6 and 7).

THE LAST GLACIAL–INTERGLACIAL CYCLE

The Last Glacial–Holocene sequence is known in much greater detail. The numerous pollen diagrams obtained over the last 30 years from the Bogotá area, i.e. from the tectonic basins of Bogotá and Fúquene, the weathering depressions in the surrounding sandstone hills, the many glacial lakes in the nearby high mountain ranges and endorheic lakes along the western, outer slope of the Cordillera allow a detailed reconstruction of vegetation development, lake level fluctuations and climatic change for this time interval (e.g. Schreve-Brinkman, 1978; van der Hammen *et al.*, 1980; Kuhry, 1988; Helmens and Kuhry, *in press*). The mapping and absolute dating of glacial deposits in the highest mountains give a detailed picture of Last Glacial glacier fluctuations in the region (e.g. van der Hammen *et al.*, 1980/81; Helmens, 1988; Helmens and Kuhry, *in press*). Fossil bones of *Mastodon* have been found in silty slope deposits of Late Pleniglacial and Late Glacial age (de Porta, 1961; van der Hammen, 1965, 1981), whereas the presence of early man in the Late Glacial and Holocene is, among others, recorded in findings of artefacts (van der Hammen and Correal, 1978).

Figure 9 shows the distribution of forest, dwarf forest of *Polylepis*, grass paramo and xerophytic vegetation, and glaciers in the Eastern Cordillera near Bogotá during different periods of the Last Glacial–Interglacial cycle (van der Hammen, 1981). During the cold and humid Middle Pleniglacial, between ca. 45,000 and 25,000 BP, the upper forest limit was frequently located at an elevation of around 2500 m, with a broad zone of *Polylepis/Eschallonia* dwarf forest above a zone of *Quercus* forest. Glaciers extended temporarily down to ca. 2850 m, and should have been locally in contact with forest; there was a relatively very narrow zone of wet paramo vegetation. During the upper part of the Upper Pleniglacial, between ca. 21,000 and 14,000 BP, the climate was very cold and dry. The upper forest limit may locally have been at 2000 m, the glacial advances were less extent than during the slightly warmer but more humid Middle Pleniglacial and there was a very broad zone of

relatively dry paramo. There are clear indications that on the west slope of the Cordillera towards the inter-Andean Magdalena valley, dry and partly xerophytic types of open to half-open vegetation extended upwards, to be locally in contact with paramo vegetation. Large open to half-open areas were thus in contact, permitting the megafauna (especially *Mastodon*, but also horses) to move rather freely from warm tropical levels to the paramos of the high plain of Bogotá. When temperature and rainfall increased in the Late Glacial between ca. 14,000 and 10,000 BP, montane forest extended again, closing the gaps and separating the megafauna populations. In the xerophytic western part of the high plain of Bogotá, the last *Mastodon* and horses were apparently hunted by palaeoindians. They may have given the last blow to extinction. Following the warmer Guantiva interstadial of the Late Glacial, there is the cool Late Glacial El Abra stadial (ca. 11,000–10,000 BP; approximate Younger Dryas equivalent). The tree line was then again around the altitude of the high plain, with an extensive subparamo zone with abundant game animals, like the deer *Odocoileus*, hunted by the palaeoindians of that time. When some 10,000 years ago the Holocene began, there was a considerable gradual rise of the upper forest limit, from ca. 2500 to altitudes of 3000–3500/3600 m.

In the highest mountain ranges around Bogotá, four different morainic complexes are recognized (Helmens, 1988) that distinctly differ in morphology and degree of erosion/denudation (Fig. 10). The younger complexes 4 and 3 are most complete and characteristic. Morainic complex 4 includes a distinct system of winding ridges only a few metres high, whereas morainic complex 3 consists of an almost continuous multiple system of arcuate ridges that rises up to several tens of metres above the valley floors (photos 1 and 2). Morainic complex 2 is often closely related to complex 3, enclosing in part the moraines of this complex and reaching ca. 100–150 m further downvalley. It is made up of a few well developed, but often incomplete, ridges modified by erosional and denudational processes. The oldest moraines, indicated as morainic complex 1, are subdued and are found only locally. Downvalley from the system of moraines, remnants of still older glacial deposits have been found that no longer show a morainic topography (van der Hammen *et al.*, 1980, 1980/81). An older till is intercalated in the fan deposits of Fig. 10 (Helmens, 1990). Radiocarbon dates of peat, lake sediments and paleosols from the formerly glaciated areas, and additional chronological evidence obtained from the radiocarbon-dated volcanic ash–paleosol sequence in the Bogotá area, provide the following time frame for the corresponding glacial events (Helmens and Kuhry, *in press*): morainic complex 4 is dated between ca. 13,000 and 12,800 BP. Morainic complex 3 is dated between ca. 18,000 and 14,500 BP. Morainic complex 2 is dated as older than ca. 19,500 BP and possibly younger than ca. 23,500 BP. Morainic complex 1 is dated as older than ca. 31,000 BP and possibly younger than ca. 36,000 BP, whereas the older glacial deposits seem to represent a glacial event that antedated ca. 38,000 BP and possibly postdated ca. 43,000 BP. There seems to be a good agreement of these complexes with those described earlier from the Sierra Nevada del Cocuy area (in the Eastern Cordillera, north of

FIG. 8. Fragment of the southern Neogene–Quaternary geological map sheet of the Bogotá area, in the surroundings of the village of Facatativá (Fig. 2), and several photographs of important lithological sections in the area (after Helmens, 1990). The location of the photographs is indicated on the map. Photo 1 shows the San Miguel Formation (section 210) and photos 2 and 3 the weathering-residue of the Guadalupe sandstones (section 193).

FIG. 10. Morainic complexes 1-4 and older glacial deposits in the area of the Cuchilla Boca Grande, Páramo de Sumapaz (Fig. 2). Photographs of morainic complexes 3 and 4 are given. After Helmens (1988) and Helmens and Kuhry (*in press*).

FIG. 9. Distribution of forest, dwarf forest of *Polylepis*, grass páramo and xerophytic vegetation, and glaciers in the Eastern Cordillera near Bogotá during different periods of the Last Glacial–Interglacial cycle (from van der Hammen, 1981).

Bogotá), respectively the Upper Lagunillas moraines, the Lower Lagunillas moraines, the Río Cóncavo moraines and the Río Negro moraines (Van der Hammen *et al.*, 1980/81). The youngest morainic complexes of the much higher Cocuy massif, the Bocatoma moraines (approximately 11,000–10,000 BP) and the Corralitos moraines ('Little Ice Age') were not found in the area of Bogotá, the mountains not being high enough.

CONCLUSIONS AND DISCUSSION

The final uplift of the Bogotá area in the Eastern Cordillera of Colombia of ca. 2000 m took place between ca. 5 and 3 Ma, and was associated with major changes in landscape organization. Before and during the early stages of the uplift, fluvial sedimentation took place mainly outside of the area of the present high plain of Bogotá. With the development of the large tectonic basin of Bogotá during the later stages of the uplift, the general actual surface configuration became gradually established. The increased regional tectonic activity during the uplift was accompanied by coarse gravity flow deposition. The upheaval resulted in an impressive change from lower tropical to high-Andean environments. Similar amounts of tectonic uplift have been recorded from the northern continuation of the Eastern Cordillera in Venezuela, the Sierra de Mérida area, for the period between 5 and 2 Ma (Kohn *et al.*, 1984). A review of the upheaval of the northern Andes is presented in Kroonenberg *et al.* (1990).

Basin sedimentation in the high plain of Bogotá area proper started at ca. 3.5 Ma. First, sedimentation took place in the outer valleys, i.e. in small marginal basins. At

ca. 3 Ma, when the main upheaval of the Cordillera had ceased, sedimentation also occurred in the central high plain area. During the next ca. 1.5 Ma, there was a gradual development of a large tectonic basin in which sediments were spread out over increasing areas. In the initial basin, fluvial–lacustrine sediments were deposited, but soon after a prevailing lacustrine environment developed. At ca. 1 Ma, important tectonic adjustments in the basin resulted in a change towards a deeper central lacustrine environment. A marked lowering in water level between ca. 40,000 and 30,000 years ago eventually led to the disappearance of the lake.

Glacial–interglacial conditions influenced Pleistocene sedimentation. The changes in climatic conditions resulted in important altitudinal shifts of the zonal vegetation belts along the slopes of the Cordillera and were accompanied by fluctuations in the water level in the basin of Bogotá. Glaciations in the surrounding mountains formed another important factor influencing sedimentation during this period. Morainic sediment was deposited in the mountains, fluvio-glacial sediment formed large fan systems at the foot of the mountains, whereas coarse-grained fluvial sediment (of fluvio-glacial origin) was deposited in the marginal parts and valleys of the basin of Bogotá. Solifluction material was deposited locally under the influence of 'periglacial' conditions. The considerable cooling of the climate and the onset of glaciations took place shortly after ca. 2.7 Ma, most probably at 2.4 Ma. The maximum extension of glaciers during the Last Glacial period preceded 25 ka and was associated with high precipitation regimes.

The start of glacial–interglacial conditions in the Bogotá area shortly after ca. 2.7 Ma, and also recent data from the Bolivian Andes where the occurrence of the first glacial–interglacial oscillation has been dated at ca. 2.2 Ma (Thouveny and Servant, 1989), conform to the abundant evidence obtained from the Eurasian continent on the beginning of glacial–interglacial conditions. Pollen records from northwestern Europe (De Jong, 1988; Zagwijn, 1992) and southern Europe (Arias *et al.*, 1987) register a major change in vegetation at 2.4 Ma. The start of loess deposition in China has been dated at 2.4 Ma (Liu, 1985). Loess deposition also started at this time in central Europe (Kukla, 1987) and in Tadzekistan, former U.S.S.R. (Dodonov, 1987). The age of 2.4 Ma additionally corresponds to the initiation of moderate-sized ice sheets in the northern hemisphere as registered in the many oxygen isotope and calcium carbonate records from the deep sea (e.g. Ruddiman and Raymo, 1988). The age of 2.4 Ma is used in this paper as the lower boundary of the Quaternary period. The associated environmental change caused by important cooling/drying is well expressed both in the continental records and in the records from the oceans, and is directly marked by the palaeomagnetic reversal at the Gauss/Matuyama boundary (at 2.48 Ma).

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POSTSCRIPTUM

In a recent publication, a formal chronostratigraphic nomenclature (names of stages) is proposed for the Colombian Pliocene and Quaternary, based mainly on the continuous sequence of Funza (T. van der Hammen and H. Hooghiemstra, 1994. Cronostratigrafía y correlación del Plioceno y Cuaternario de Colombia, basada en la recuperación de Funza, Sabana de Bogotá. Análisis geográficas, Inst. Geogr. Agustín Codazzi, Bogotá). In the same publication, the 'upper unnamed member' of the Upper Tilatá formation, is formally described as 'Guali' member.

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