PALYNOLOGY

VOLUME 27

2003

Published by the American Association of Stratigraphic Palynologists Foundation
Dallas, Texas, U.S.A.

PALEOGENE PALYNOSTRATIGRAPHY OF THE EASTERN MIDDLE MAGDALENA VALLEY, COLOMBIA

ANDRES PARDO-TRUJILLO
Universidad de Caldas, Facultad de Ciencias
Departamento de Ciencias Geológicas
Calle 65 No. 26-10
Manizales, Colombia
apardo66@hotmail.com and apardo66@yahoo.com

CARLOS A. JARAMILLO
Biostratigraphy Team
Instituto Colombiano del Petroleo
AA 4185
Bucaramanga, Colombia
carlos.jaramillo@ecopetrol.com.co

FRANCISCA E. OBOH-IKUENOBE
Department of Geology and Geophysics
University of Missouri-Rolla
Rolla, Missouri 65409-0410, U.S.A.
ikuenobe@umr.edu

Abstract

This work presents a detailed study of the pollen and spore distribution in the Paleocene–Eocene Lisama and La Paz Formations on the eastern border of the Middle Magdalena Valley, Colombia. One hundred and forty-seven samples obtained from cores and outcrops were prepared for palynological research, fifty-nine of which were rich in pollen and spores. Three hundred spore and pollen taxa were identified. The studied stratigraphic interval is a 2000 m thick coastal and fluvial deposit formed in a variable subsiding tectonic setting. The Lisama Formation is characterized by the dominance of the *Proxapertites* group. Some typical Paleocene forms start to disappear toward the upper part of the Lisama Formation (e.g. *Bombacacidites annae, Ephedripites vanegensis, Retidiporites magdalenensis*), and are followed by a barren interval probably linked to intense oxidation during paleosol development (the uppermost 266 m of the Lisama Formation). In the La Paz Formation there is a progressive appearance of early and middle Eocene species (e.g. *Cyclusphaera scabrata, Foveotriporites hammenii, Monoporopollenites annulatus, Perfotricolpites digitatus, Spirosyncolpites spiralis, Striatopollis catatumbus, Bombacacidites gonzalezii*). This biostratigraphic evidence indicates that an early–middle Eocene hiatus in the eastern area of the Middle Magdalena Valley basin is not present, as many authors have previously suggested. One new pollen genus, *Foveomonoporites*, and two new pollen species, *Foveomonoporites variabilis* and *Psilamonocolpites operculatus* are described and illustrated.

INTRODUCTION

Colombia is comprised mainly of Cretaceous and Tertiary sedimentary rocks that accumulated in structurally complex areas (Etayo-Serna et al., 1983). For the last 60 years, intensive geological work, mainly related to oil exploration, has been conducted on the Tertiary rocks, most of which accumulated in continental environments. Unfortunately, only a small fraction of this information has been published. This is most evident for the Middle Magdalena Valley, an area noted for pioneering Colombian oil exploration. In spite of limited published palynological information, palynomorphs (mainly pollen and spores) are the most important, and very often the only biostratigraphic tool for Tertiary sediments in the area.

Many of the important hydrocarbon reservoirs in the Middle Magdalena Valley occur in Paleocene and Eocene continental rocks (Lisama and La Paz Formations). These reservoirs are usually located in zones with structural and stratigraphic complexity where an excellent biostratigraphic framework is crucial for understanding the stratigraphy, defining successful oil-bearing structures, and planning new exploration targets. Nevertheless, this time interval remains poorly understood and will benefit from more detailed biostratigraphic studies.

During Paleocene–Eocene time a sedimentary basin existed in the northeastern region of Colombia and western Venezuela, where clastic sediments accumulated in fluvial or coastal environments. The sedimentation was controlled by, among other factors, the uplift of the Colombian Andes (Gomez, 2001), and the thrusting of the Lesser Antilles island arc in northwestern Venezuela (Pindell and Barret, 1990; Lugo and Mann, 1995). This tectonic activity pro-

Palynology, 27 (2003): 155–178

ISSN 0191-6122

duced major changes in the sedimentation rates and subsidence throughout the Middle Magdalena Valley, which is now manifest as complex lateral and vertical lithofacies variations.

This work presents palynological data from two sections located in the eastern part of the Middle Magdalena Valley (MMV), the thickest section of Paleocene–Eocene rocks in Colombia. Palynological results are compared with several sections in Colombia and Venezuela (Germeraad et al., 1968; Rull, 1997; Jaramillo, 1999; Rull, 1999). Graphic correlation was used to analyze the data, and results were then compared with the traditional biozonal schemes (Germeraad et al., 1968; Muller et al., 1987).

MATERIALS AND METHODS

Two stratigraphic sections were analyzed in this study (Text-Figure 1). The first section is located along the Rio Sucio, near the town of Uribe-Uribe (Department of Santander, Middle Magdalena Valley; 7° 13' 19" N–73° 21' 18" W). Jaramillo and Dilcher (2001) previously studied a segment of this section. In the present study the density of sampling and analysis was increased, especially in the lower part of the sequence (Lisama Formation) and the lower part of the La Paz Formation. The second section, 16 km south of the town of Uribe-Uribe (7° 5' 48.38" N–73° 23' 59.33" W), is a composite log of nine cores of the "Sogamoso River Hydroelectric Project" near the Bucaramanga–Barrancabermeja road, available in the Colombian core library of the Instituto Colombiano de Petroleo, Bucaramanga, Colombia. One hundred and forty seven samples (68 in the Uribe section and 79 in the Sogamoso sections) were prepared for palynological analysis. Fifty-nine of those recovered enough material for biostratigraphic analysis (Text-Figure 2).

Samples were prepared with the standard technique of the Liege University palynological laboratory (Belgium) as follows: Twenty-five grams of rock were broken down into 1–2 mm equidimensional pieces; followed by disintegration of mineral matrices with HCL for carbonates and HF for silicates (24 hours). Samples were then cleaned with hot HCL and sieved using a 12 μm mesh. Samples were oxidated with HNO_3 and slides were mounted using Hydroxylethyl Cellulose (HEC) to homogenize the organic particles on the glass slides and Euparal to permanently fix the coverslip. At least one slide per stratigraphic level was scanned using an optical microscope.

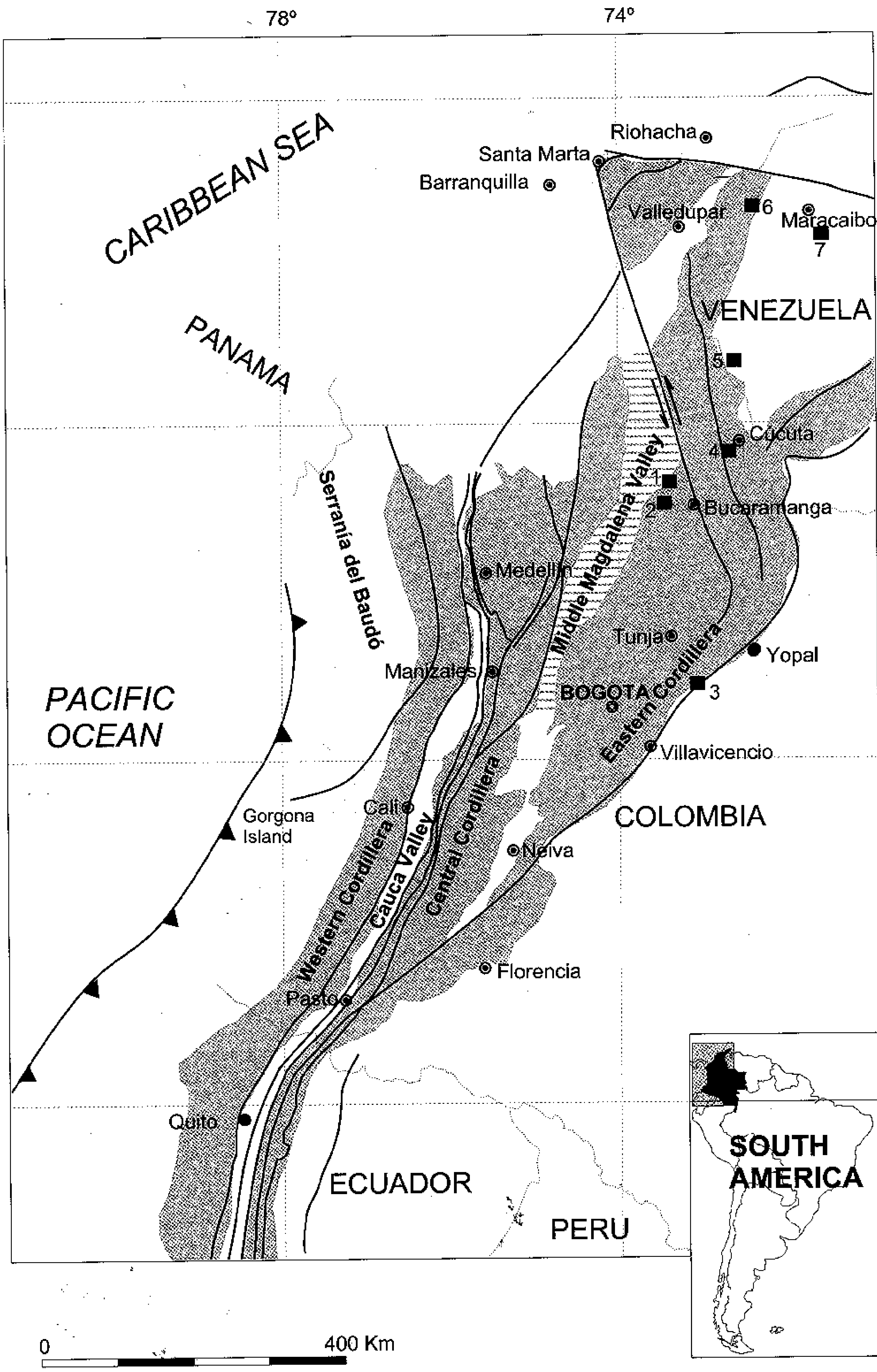
The best palynomorph specimens were photographed. They were located in the slide using the England Finder (EF) system. Specimen morphological characteristics were compared with the descriptions, pictures and diagrams of most of the available publications for the tropical Paleogene palynology (Van der Hammen, 1954; 1956a; 1956b; 1957a; 1957b; 1958; Van der Hammen and Wymstra, 1964; Van Hoeken-Klinkenberg, 1964; Elsik, 1966; Leidelmeyer, 1966; Van der Hammen and García, 1966; Van Hoeken-Klinkenberg, 1966; Gonzalez, 1967; Germeraad et al., 1968; Elsik, 1968a; 1968b; Venkatachala and Kar, 1969; Srivastava, 1972; Doubinger, 1973; Tschudy, 1973; Elsik, 1974; Elsik and Dilcher, 1974; Doubinger, 1976; Jansonius and Hills, 1976; Elsik, 1978; Jan du Chêne and Salami, 1978; Salard-Cheboldaeff, 1978; Jan du Chêne et al., 1978a; Jan du Chêne et al., 1978b; Salard-Cheboldaeff, 1979; Frederiksen, 1980; Salami, 1984; Frederiksen, 1985; Salami, 1985; Frederiksen, 1988; Venkatachala et al., 1988; Salard-Cheboldaeff, 1990; Oloto, 1992; Sarmiento, 1992; Coetzee, 1993; Guerrero and Sarmiento, 1996; Pocknall and Nichols, 1996; Samant and Phadtare, 1997; Frederiksen, 1998; Jaramillo and Dilcher, 2001). Major nomenclatural changes follow those in Jaramillo and Dilcher (2001). After identification of the species, each slide was re-scanned in order to count up to 200 specimens. The slides are stored at the National Core Library, Colombian Petroleum Institute, Bucaramanga (Colombia).

The biostratigraphic analyses were done using graphic correlation (Shaw, 1964; Edwards, 1984; Edwards, 1989; Mann and Lane, 1995). This is a method of correlating fossil occurrences based on interpretation of graphic plots of first and last appearances of taxa. It is a powerful method because it does not assume *a priori* that first and last appearances of chosen taxa are synchronous. Graphic correlation is a useful tool for producing high-resolution chronostratigraphic frameworks (Pasley and Hazel, 1995).

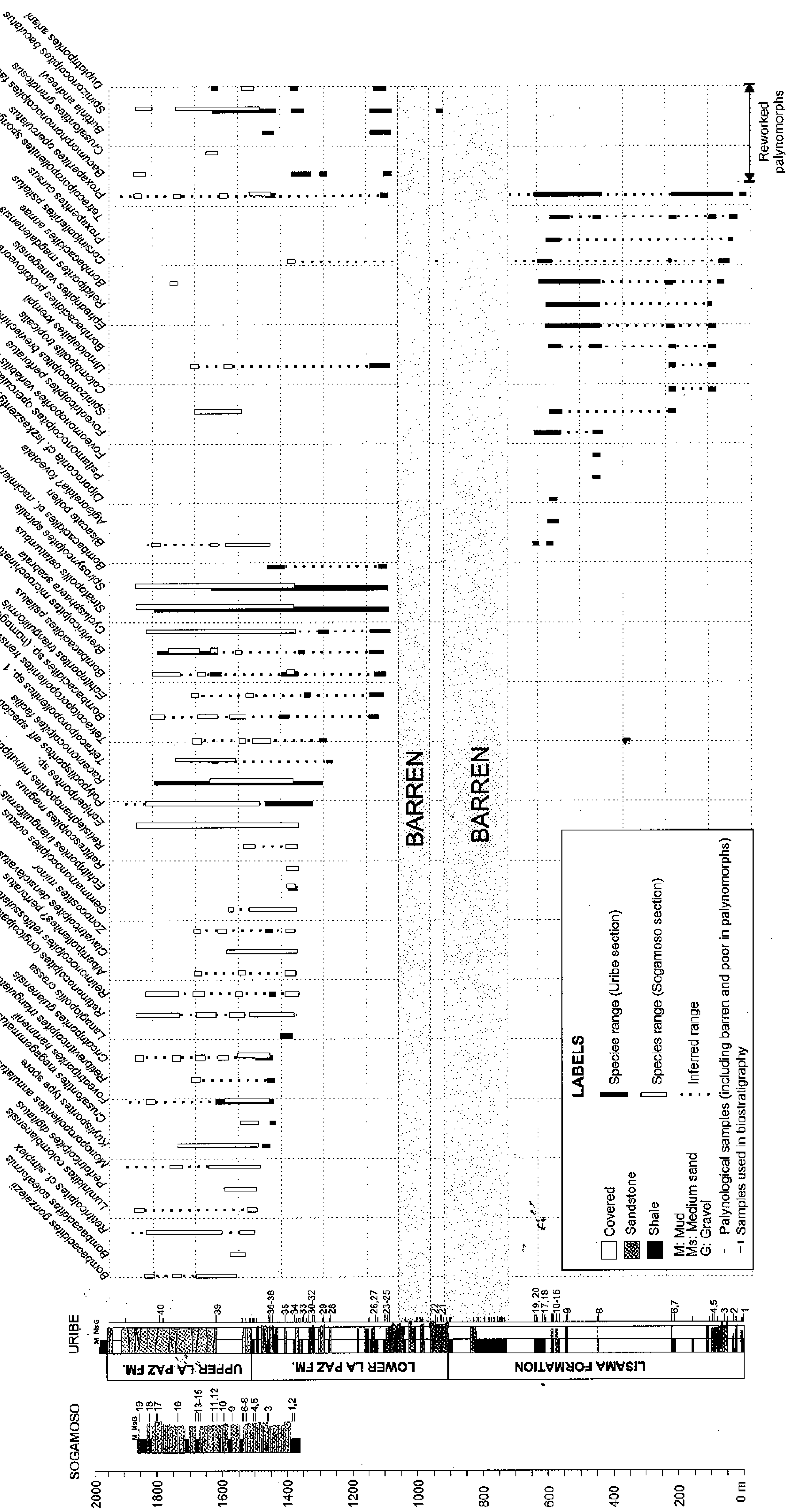
Palynological data were compared with five available sections (Text-Figure 1): The Piñalerita and Regadera sections (Jaramillo and Dilcher, 2001), the Tarra-1 well (Rull, 1997), the Riecito Mache section (Rull, 1999), and the Icotea well (Germeraad et al., 1968).

REGIONAL GEOLOGICAL SETTING

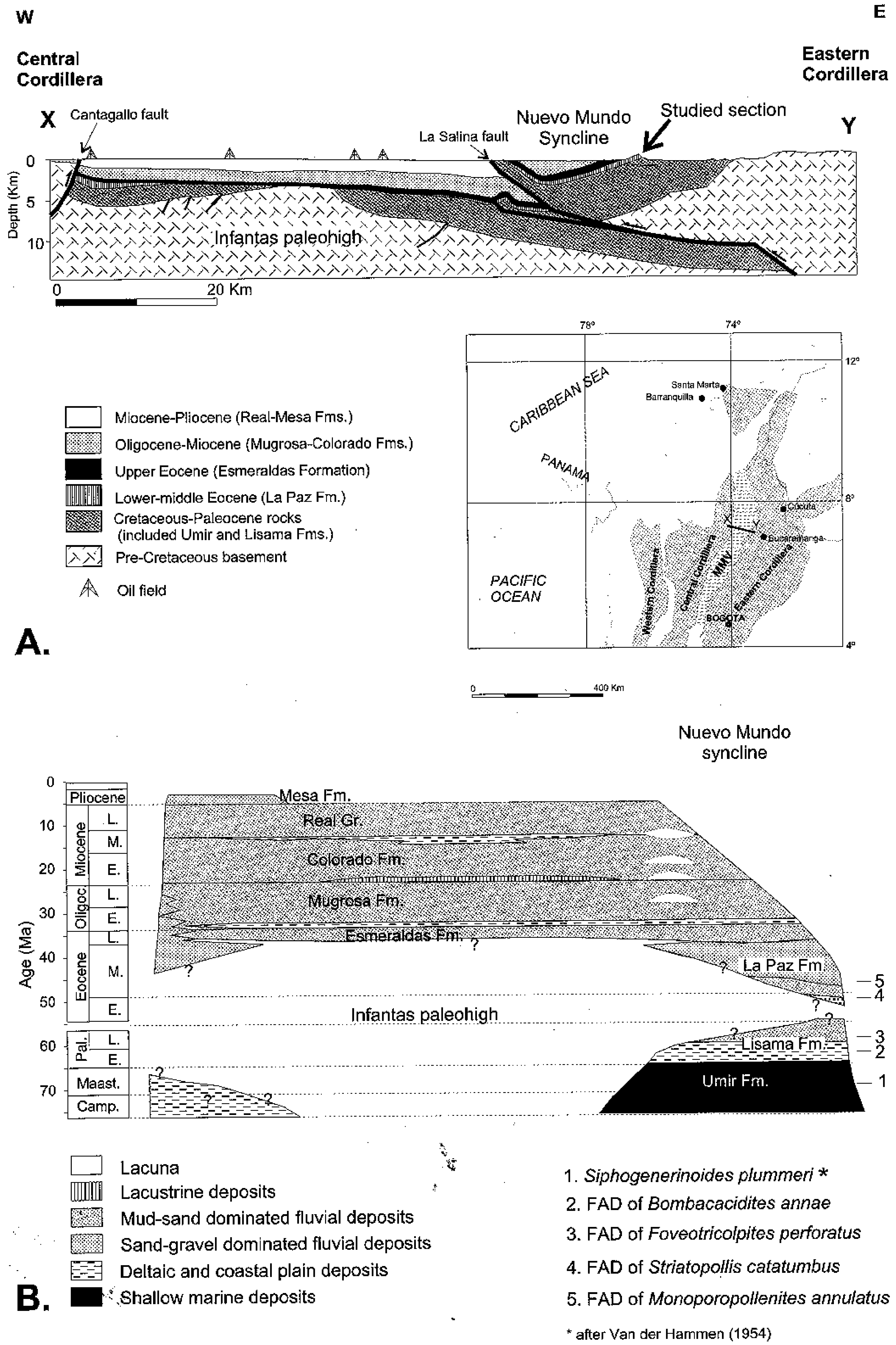
The Middle Magdalena Valley (MMV) is a sedimentary basin that has a general structural trend of N–NE. The Cretaceous to Recent sedimentary fill forms an asymmetric wedge that thickens to the east (Text-Figure 3A). The dominant structural styles flanking the eastern border of the MMV basin are large-scale paired asymmetric synclines and broad, arched, basement-cored anticlines related to westward-vergent thrust faults (e.g. Salinas and Infantas thrust systems) (Schamel, 1991). To the west, Cenozoic sedimentary deposits onlaped the basement of the Central Cordillera. North–east trending thrust and dextral slip faults are interpreted below this deposits.



Text-Figure 1. Map of northwestern South America showing the location of sections and the Middle Magdalena Valley and surrounding basins (gray: Andes Mountains; black lines: major faults).: 1. Uribe (Jaramillo and Dilcher, 2001 and this work); 2. Sogamoso (this work); 3. Piñalerita (Jaramillo and Dilcher, 2001); 4. Regadera (Jaramillo and Dilcher, 2001); 5. Tarra-1 well (Rull, 1997); 6. Riecito Maché (Rull, 1999); 7. Icotea well (Germeraad et al., 1968).



Text-Figure 2. Stratigraphic distribution of biostratigraphic useful taxa in Sogamoso and Uribe sections. White bars: biostratigraphic distribution in Sogamoso section. Black bars: biostratigraphic distribution in Uribe section.



Text-Figure 3. Regional geology of Middle Magdalena Valley A. Geological profile. Note the lateral time variation in the La Paz/Lisama unconformity (modified from Gomez, 2001). B. Chronostratigraphic chart, lithostratigraphic nomenclature and location of some stratigraphically useful pollen species (modified from Gomez, 2001).

Several researchers have studied the Middle Magdalena Valley stratigraphy during petroleum exploration (Pilsbry and Olsson, 1935; Wheeler, 1935; Morales, 1958; Hopping, 1967; Suarez, 1997a; Suarez, 1997b; Gomez, 1998; 2001). The Upper Cretaceous rocks of this area are characterized by shallow marine and coastal deposits that comprise a generally regressive sequence (Text-Figure 3B). Most of the Tertiary rocks were formed in coastal and fluvial environments and the sedimentation was dominated by terrigenous components. Different stratigraphic nomenclature have been used by the oil companies in this area (Porta, 1974). Here, we apply the terminology of Morales (1958), Van der Hammen (1958), and Gomez (2001) (Text-Figure 3B).

Three units are recognized for the Paleocene–Eocene interval, from oldest to youngest: 1) Lisama Formation. It is composed of vari-colored, red-brown, light-gray to gray, mottled shales, with medium to fine-grained sandstone interbeds; some coal layers are present in the middle part; the sandstones become coarse-grained towards the top. The thickness of this unit ranges up to 1300 meters; its lower contact is conformable and transitional with the Umir Formation and is usually placed at the lowermost, well-developed sandstone layer (Morales, 1958). 2) La Paz Formation. It is composed of gray massive to cross-bedded, sometimes conglomeratic, sandstones with minor mudstone and shale intercalations mainly in the lower and middle part; the shaley levels have poorly preserved plant remains. Towards the base is a level of gray colored shales called the Toro Formation by Waring (1931, in Porta, 1974. p. 483). Nevertheless this term has been applied to levels in different stratigraphic positions and, for this reason, Gomez (2001) proposed that it must be abandoned. The type section of the La Paz Formation is approximately 1000 m thick, although it is extremely variable across the MMV (Morales, 1958). Its lower contact with the Lisama Forma-

PLATE 1

Pollen from the Middle Magdalena Valley basin. The scale bar represent 10 μm. EF: England Finder reference.

1 *Aglaoreidia? foveolata* Jaramillo & Dilcher 2001. Sample 12 (Uribe section), slide 57155, EF: Q36/1.

2 *Albertipollenites? perforatus* (Gonzalez, 1967) Jaramillo & Dilcher 2001. Sample 2 (Sogamoso section), slide 55711, EF: D44/2.

3 Bisacate pollen. Sample 5 (Sogamoso section), slide 55771(2), EF: L45/3.

4 *Bombacacidites annae* (Van der Hammen 1954) Germeraad et al. 1968. Sample 10 (Uribe section), slide 57112, EF: W37/2.

5 *Bombacacidites* sp. (homogenous reticulum). Sample 27 (Uribe section), slide 57839, EF: G53/3.

6 *Bombacacidites gonzalezii* Jaramillo & Dilcher 2000. Sample 13 (Sogamoso section), slide 55979(2), EF: T 35/2.

7 *Bombacacidites* cf. *nacimientoensis* (Anderson 1960) Elsik 1968. Sample 36 (Uribe section), slide 57387, EF: G49/1.

8 *Bombacacidites protofoveoreticulatus* Jaramillo & Dilcher 2001. Sample 7 (Uribe section), slide 57850, EF: P56/3.

9 *Bombacacidites psilatus* Jaramillo & Dilcher 2001. Sample 2 (Sogamoso section), slide 55711(1), EF: P37/1.

10 *Bombacacidites soleaformis* Muller et al. 1987. Sample 9 (Sogamoso section), slide 55926(2), EF: D56/1.

11 *Brevitricolpites microechinatus* Jaramillo & Dilcher 2001. Sample 14 (Sogamoso section), slide 55996(2), EF: N45/3.

12 *Clavatricolpites densiclavatus* Jaramillo & Dilcher 2001. Sample 2 (Sogamoso section), slide 56058, EF: G41.

13 *Clavatricolpites densiclavatus* Jaramillo & Dilcher 2001. Sample 3 (Sogamoso section), slide 55764(1), EF: E54.

14 *Colombipollis tropicalis* Sarmiento 1992. Sample 7 (Uribe section), slide 57850, EF : D63/3–4

15 *Corsinipollenites psilatus* Jaramillo & Dilcher 2001. Sample 1 (Sogamoso section), slide 56686, EF: H50.

16 *Cricotriporites guianensis* Leidelmeyer 1966. Sample 10 (Sogamoso section), slide 55939(1), EF: Q34/1.

17 *Crusafontiites megagemmatus* Jaramillo & Dilcher 2001. Sample 4 (Sogamoso section), slide 55817, EF: M42/1.

18 *Cyclusphaera scabrata* Jaramillo & Dilcher 2001. Sample 17 (Sogamoso section), slide 56024, EF: X38/3.

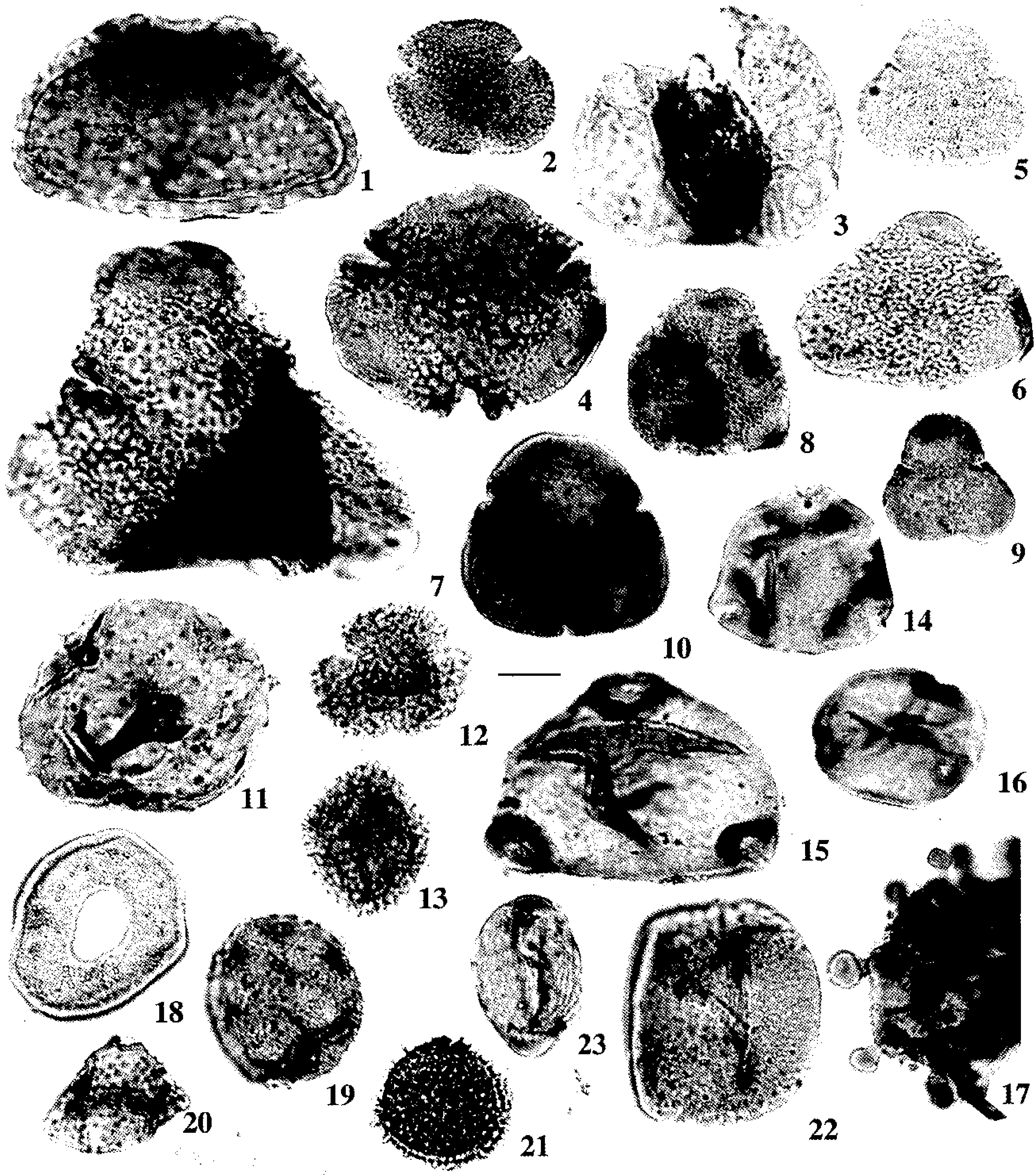
19 *Echiperiporites* sp. Sample 4 (Sogamoso section), slide 55817, EF: K53/1.

20 *Echitriporites trianguliformis* Van Hoeken-Klinkenberg 1964. Sample 32 (Uribe section), slide 57852, EF: E50/3.

21 *Echitriporites trianguliformis var. orbicularis* Jaramillo & Dilcher 2001. Taken from Jaramillo and Dilcher (2001, Pl. 10, fig. 2).

22 *Foveotricolpites perforatus* Van der Hammen & García 1966. Sample 18 (Uribe section), slide 57245, EF: K41.

23 *Ephedripites vanegensis* Van der Hammen & García 1966. Sample 12 (Uribe section), slide 57155, EF: Q53/1.


1
2
3
5
4
8
6
7
10
9
14
12
11
15
16
13
18
23
19
20
21
22
17

tion is a paraconformity, but in other places of the MMV this unit lies over Cretaceous units in angular unconformity (Text-Figure 3A). Its upper boundary is transitional with the Esmeraldas Formation. 3) Esmeraldas Formation. It consists of thinly bedded sandstones and gray mudstones interbedded with gray shales that are occasionally red, purple, or brown and mottled. Some isolated coal beds are present. The upper part of this formation contains the fossiliferous El Chorro horizon. The formation is about 1200 m thick, and thickens to the north (Porta, 1974). The upper boundary is unconformable with the Mugrosa Formation (Porta, 1974), although Morales (1958) noted that the nature of contact is not well established.

RESULTS

More than 300 pollen and spore species were identified (Pardo-Trujillo et al., 2003). Text-Figure 2 shows the stratigraphic distribution of biostratigraphically useful taxa in both sections. The palynological association of the Lisama Formation is characterized by the abundance of different types of *Proxapertites* (e.g. *P. operculatus, P. cursus*), several species of *Bombacacidites* (e.g. *B. annae*), *Retidiporites magdalenensis* and different monocolpate species (e.g. *Mauritiidites franciscoi*). Similar associations have been described in Los Cuervos Formation in the Catatumbo region, SW Venezuela and NE Colombia (Colmenares and Terán, 1993), and in the Arcillas del Limbo Formation in the Llanos foothills, on the eastern border of the Cordillera Oriental of Colombia (Jaramillo and Dilcher, 2001). The last 266 m of the Lisama Formation and the base of the La Paz Formation are characterized by mottled shales barren in palynomorphs, probably due to oxidation of well-drained soils. In the La Paz Formation several species appear, whose first appearance datums (FAD) have been considered indicative of the early–middle Eocene (*Cyclusphaera scabrata, Foveotriporites hammenii, Monoporopollenites annulatus, Perfotricolpites digitatus, Spirosyncolpites spiralis, Striatopollis catatumbus, Bombacacidites soleaformis* among others).

The Sogamoso section is equivalent to the upper part of the La Paz Formation at Uribe, 26 km to the north (Text-Figure 2). This observation can be supported by the first appearance of *Foveotriporites hammenii, Cricotriporites guianensis, Retimonocolpites retifossulatus, Kuylisporites* type spore and *Echitriporites trianguliformis* var. *orbicularis* in both sections. In the Eocene deposits of the La Paz Formation an appreciable percentage of reworked upper Cretaceous species were found (e.g. *Dinogymnium acuminatum, Buttinia andreevi, Bacumorphomonocolpites tausae, Duplotriporites ariani* and *Spinizonocolpites baculatus*).

The study sections also were compared with other published sections (Text-Figure 4) using mainly the regional palynological zonation of Germeraad et al. (1968). The stratigraphic position of the Germeraad zones for each section is shown in Text-Figure 4. Germeraad et al. (1968) divided the upper Paleocene and lower to middle

PLATE 2

Pollen and spores from the Middle Magdalena Valley basin. The scale bar represent 10 µm. EF: England Finder reference; DIC: differential interference contrast.

1–2 *Foveomonoporites variabilis* sp. nov. Paratype; Sample 8 (Uribe section), slide 57099, EF: J34/4. Fig. 2 in DIC.

3–4 *Foveomonoporites variabilis* sp. nov. Holotype; Sample 8 (Uribe section), slide 57109, L50/4. Fig. 4 in DIC.

5 *Foveomonoporites variabilis* sp. nov. Sample 8 (Uribe section), slide 57109, EF: H55.

6 *Foveomonoporites variabilis* sp. nov. Sample 8 (Uribe section), slide 57109, EF: S50/2.

7 *Foveomonoporites variabilis* sp. nov. Sample 8 (Uribe section), slide 57109, EF: Q47/1–3.

8 *Foveotriporites hammenii* Gonzalez 1967. Sample 18 (Sogamoso section), slide 56254(1), EF: V51/2.

9 *Gemmamonocolpites ovatus* Gonzalez 1967. Sample 3 (Sogamoso section), slide 55764(2), EF: O55.

10 *Kuylisporites* type spore Potonié 1956. 8: Sample 4 (Sogamoso section), 55817, L37/1.

11–12 *Kuylisporites* type spore. Sample 14 (Sogamoso section), slide 55980(1), EF: N47.

13 *Lanagiopollis crassa* (Van der Hammen & Wymstra 1964) Frederiksen 1988. Sample 36 (Uribe section), slide 57365, EF: V48.

14–15 *Luminidites colombianensis* Jaramillo & Dilcher 2001. Sample 19 (Sogamoso section), slide 56265(1), EF: L36/2–4.

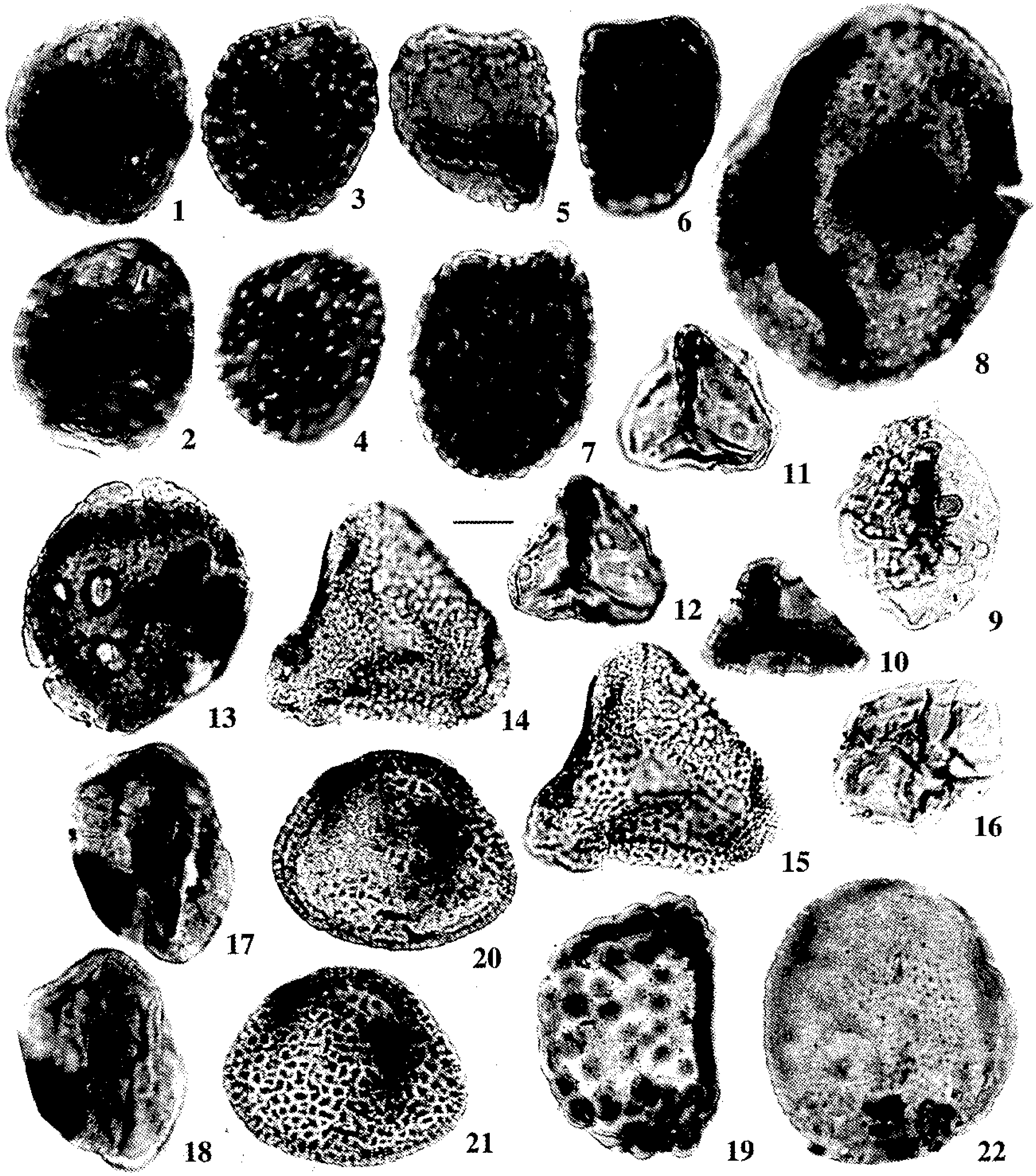
16 *Monoporopollenites annulatus* (Van der Hammen 1954) Jaramillo & Dilcher 2001. Sample 11 (Sogamoso section), slide 55963(1), EF: M40/2.

17–18 *Perfotricolpites digitatus* Gonzalez 1967. Sample 5 (Sogamoso section), 55771(1), EF: S41/4.

19 *Polypodiisporites* aff. *specious* Sah 1967. Sample 8 (Sogamoso section), 55847(1), EF: N44.

20–21 *Proxapertites cursus* Van Hoeken-Klinkenberg 1966. Sample 13 (Uribe section), slide 55847(1), EF: N44.

22 *Proxapertites operculatus* Van der Hammen 1956b. Sample 8 (Uribe section), slide 57160, EF: O37.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22

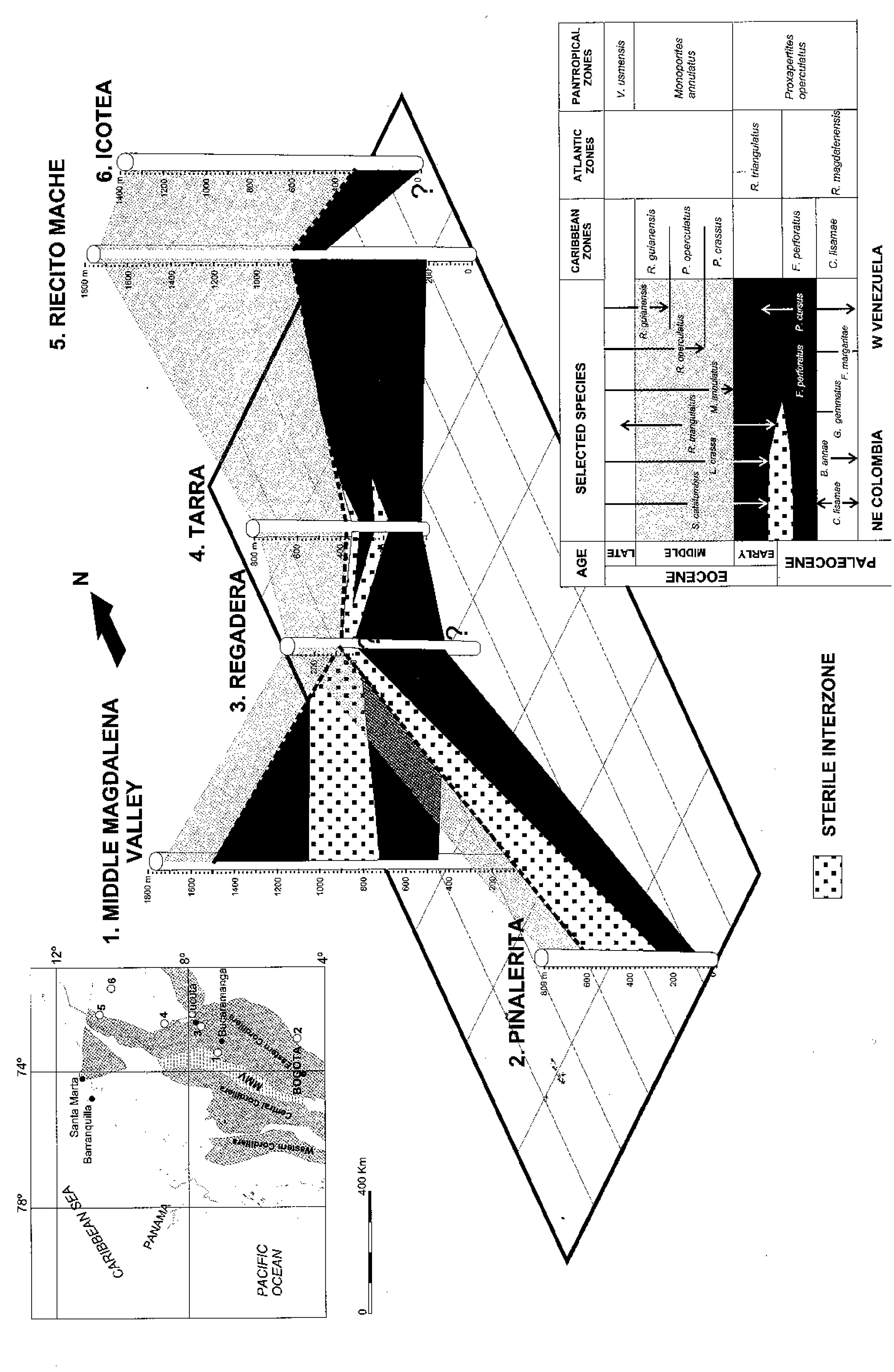
Eocene into four palynologic zones for the Caribbean area: two Paleocene zones, *Ctenolophonidites lisamae* and *Foveotricolpites perforatus*, a lower Eocene zone *Retibrevitricolpites triangulatus*, and a middle Eocene zone, *Monoporites annulatus*, that is subdivided into three subzones *Psilatricolporites crassus*, *Psilatricolporites operculatus* and *Retitricolporites guianensis* (Text-Figure 4). The Eocene palynological zones of Germeraad et al. (1968) have greater correlation and identification problems in our study area. The *Retibrevitricolpites triangulatus* zone was defined by the first appearance of the species *Retibrevitricolpites triangulatus*, *Striatopollis catatumbus*, and *Lanagiopollis crassa*. This zone was recorded in western Venezuela and Nigeria (Germeraad et al., 1968). The new information obtained in Colombia shows that there is a barren regional stratigraphic interval between the *F. perforatus* and *R. triangulatus* zones (Text-Figures 4, 5). *Striatopollis catatumbus* is the only species occurring in all the studied sections; consequently, it was used as indicative of the lower limit of the zone. There are difficulties in recognizing the subzones of the *Monoporites annulatus* zone in the Colombian sections. For example, in the Piñalerita section (Jaramillo and Dilcher, 2001) *Monoporopollenites annulatus* appears earlier than *L. crassa* and *Rhoipites guianensis* appears earlier than *Ranunculacidites operculatus*. *R. guianensis* and *R. operculatus* were not found in the sections discussed in this paper.

Germeraad et al. (1968, p. 249) included in their study a sequence of the Middle Magdalena Valley, located 13 Km to the northeast of the Uribe section (their "Rio Lebrija" section). In this section they noted the presence of the *F. margaritae* and *C. lisamae* in the lower half of the Lisama Formation, the *F. perforatus* zone in the upper part of the Lisama Formation and the base of the La Paz Formation, and the *R. triangulatus* zone that extends to the top of the La Paz Formation. This formation is disconformable with the Esmeraldas Formation where the *R. guianensis* zone was identified. Unfortunately, the stratigraphic location of the samples and pollen species was not published. Some of our data differ from those of Germeraad et al. (1968) as follows: a) the *F. margaritae* zone was not identified at the base of our section, but it could be present at the base of the Lisama Formation which was not sampled in the studied area; b) the *F. perforatus* and *R. triangulatus* zones are separated by a palynologically barren interval; and c) they noted the presence of the *R. guianensis* zone toward the contact of La Paz-Esmeraldas Formations, which has not been identified in our detailed study of this interval in the Sogamoso section.

Another zonation commonly used in this area is that of Muller et al. (1987), which was based on Germeraad's zonation. The Muller et al. scheme subdivided the Paleocene–Eocene of northwest South America in 10 palynological zones. Some of the fossils used to define the zones correspond to those of Germeraad et al. (1968), but others are new species. This scheme is difficult to apply in the Middle Magdalena Valley and in the Colombian sections described by Jaramillo and Dilcher (2001). Multiple difficulties arise: a) the species *Rugutricolporites felix*, which is used as indicator of the lower part of lower Eocene (zone 17), is rare in the Colombian sections; b) *Echitriporites trianguliformis* form A of Muller et al. (1987) (formally named *Echitriporites trianguliformis* var. *orbicularis* by Jaramillo and Dilcher, 2001) is abundant in the Piñalerita section but it appears only in one sampling level in the Middle Magdalena Valley; c) *Bombacacidites* sp. B is not recorded in the Colombian sections, d) *Retitrescolpites magnus* is found only in one sampling level in the Middle Magdalena Valley; while *Bombacacidites soleaformis*, an indicator of zone 20, is found in only two levels; and e) *Bombacacidites foveoreticulatus*, *Janmulleripollis pentaradiatus*, and *Echiperiporites estelae* are not found in the studied interval. Thus, biozones 21–24 could not be identified. The rarity or absence of these species within the studied interval hinders the establishment of the Eocene zonal boundaries described by Muller et al. (1987). Furthermore, Colmenares and Teran (1993) showed in three sections in southwest Venezuela that did not have any major hiatuses, that only five of the ten late Paleocene to middle Eocene palynologic zones proposed by Muller et al. (1987) could be identified.

In order to find ways around these problems, Jaramillo and Dilcher (2001) applied the graphic correlation technique to five geologic sections of northeastern Colombia. They also identified new species that proved to be useful in the correlation of the Colombian sections (e.g. *Cyclusphaera scabrata, Luminidites colombiaensis, Bombacacidites gonzalezii, Brevitricolpites macroexinatus, Clavatricolpites densiclavatus, Aglaoreidia? foveolata*). Other species that have proven to be regionally extensive were not used either in the Muller or Germeraad zonations (e.g. *Spirosyncolpites spiralis, Foveotriporites hammenii*). The Piñalerita section has the most complete palynological record of the sections studied by Jaramillo and Dilcher (2001). Consequently, these authors used it to create a composite section (CS) together with five sections in northeast of Colombia. The palynological information obtained in this study, was graphically correlated with this reference section in order to identify unconformities and/or differences in the relative sedimentation rate.

Text-Figure 5 shows the correlation line obtained between the Uribe and Piñalerita sections. Several breaks in the line segments allow the subdivision of the sequence into



Text-Figure 4. Correlation of palynological biozones of Germeraad et al. (1968) for the Paleocene–Eocene. The distances among sections is not to scale. For location of each section see Text-Figure 1. Here, the base of the Tarra-1 log (Rull, 1997) is taken at the First Appearance Datum of *Bombacacidites annae*.

five intervals. Each one of them will be described starting from the base of the section of Uribe:

Interval 1 (31–567 m). The correlation line presents a low slope; nevertheless, several covered intervals diminish the reliability in the location of the FAD and LAD of the taxa.

Interval 2 (567 to 642 m). It is characterized by the progressive disappearance of several Paleocene taxa (e.g. *E. vanegensis, B. annae, P. cursus, B. protofoveoreticulatus*). The correlation line increases its slope abruptly; this change can be attributed to a sudden decrease in the sedimentation rate of the Middle Magdalena Valley area with regard to the Piñalerita section.

Interval 3 (642 – 1086 m). In this sector most of the samples are barren in palynomorphs; both sections have similar facies: bioturbated mottled shales at the base and coarse clastic deposits to the top. Therefore, the position of the correlation line is uncertain.

Interval 4 (1086–1500m). Several Eocene marker taxa appear in this sector (e.g. *Spirosyncolpites spiralis, Cyclusphaera scabrata*). Some of these species occur in the first productive level, consequently their true FAD cannot be observed. However, two productive samples obtained in both sections ± 150 m below this level do not contain any of these species, and therefore constrain these first appearances. The correlation line possesses a very low slope in this sector indicating that Piñalerita is a condensed section.

Interval 5 (starting from 1500 m). The correlation line increases its slope showing that condensation ceased in Piñalerita.

DISCUSSION

The zonation of Germeraad et al. (1968) is the only one for northern South America that offers independent elements for its calibration with the geological time scale. These authors used planktonic foraminifera in several sections of South America and western Africa. However, the foraminifera data presented for the Paleogene of South America were scarce and their stratigraphic and geographic positions were not reported. Without this information, the use of pollen and spores for chronological dating must be carefully considered in the region. Additionally, one difficulty in the Colombian sections is the presence of an interval barren of pollen in the last meters of the Arcillas del Limbo and Lisama Formations and the base of the Areniscas del Limbo and La Paz Formations, which seems related to intense oxidation of well-drained alluvial soils (Jaramillo, 2002). This phenomenon has also been observed in several sections in Colombia and it could be linked to the effect that the abrupt global heating at the Paleocene–Eocene boundary had on the tropical climate (Jaramillo, 2002). Due to

PLATE 3

Pollen and spores from the Middle Magdalena Valley basin. The scale bar represent 10 μm. EF: England Finder reference; DIC: differential interference contrast.

1–2 *Psilamonocolpites operculatus* n. sp. Holotype. Sample 8 (Uribe section), slide 57109, EF: L34/2–4. Fig. 2 in DIC.

3 *Psilamonocolpites operculatus* n. sp. Paratype. Sample 8 (Uribe section), slide 57099, EF: L35.

4 *Psilamonocolpites operculatus* n. sp. without opercule. Sample 8 (Uribe section), slide 57109, EF: L42/1.

5–6 *Diporoconia* cf. *Diporoconia iszkaszentgyoergyi* (Kedves 1965) Frederiksen et al. 1985. Sample 12 (Uribe section), slide 57155, EF: E37. Fig. 6 in DIC.

7 *Diporoconia* cf. *Diporoconia iszkaszentgyoergyi* (Kedves 1965) Frederiksen et al. 1985. Sample 11, slide 57113, EF: F48/3.

8 *Racemonocolpites facilis* González 1967. Sample 6 (Sogamoso section), slide 55803, EF : T41.

9–10 *Retibrevitricolpites triangulatus* Van Hoeken-Klinkenberg 1966. Sample 15 (Sogamoso section), slide 55996(2), EF: Q47/3. Fig. 10 in DIC.

11 *Retidiporites magdalenensis* Van der Hammen & García 1966. Sample 8 (Uribe section), slide 57109, EF: S52/1.

12–13 *Retimonocolpites longicolpatus* Lorente 1986. Sample 5 (Sogamoso section), slide 55771(2), EF: Q53/4. Fig. 13 in DIC.

14–15 *Retimonocolpites retifossulatus* Lorente 1986. Sample 1 (Sogamoso section), slide 55708, EF: H49/4. Fig. 15 in DIC.

16–17 *Retistephanoporites minutiporus*. Sample 2 (Sogamoso section), slide 55711, EF: J35/3.

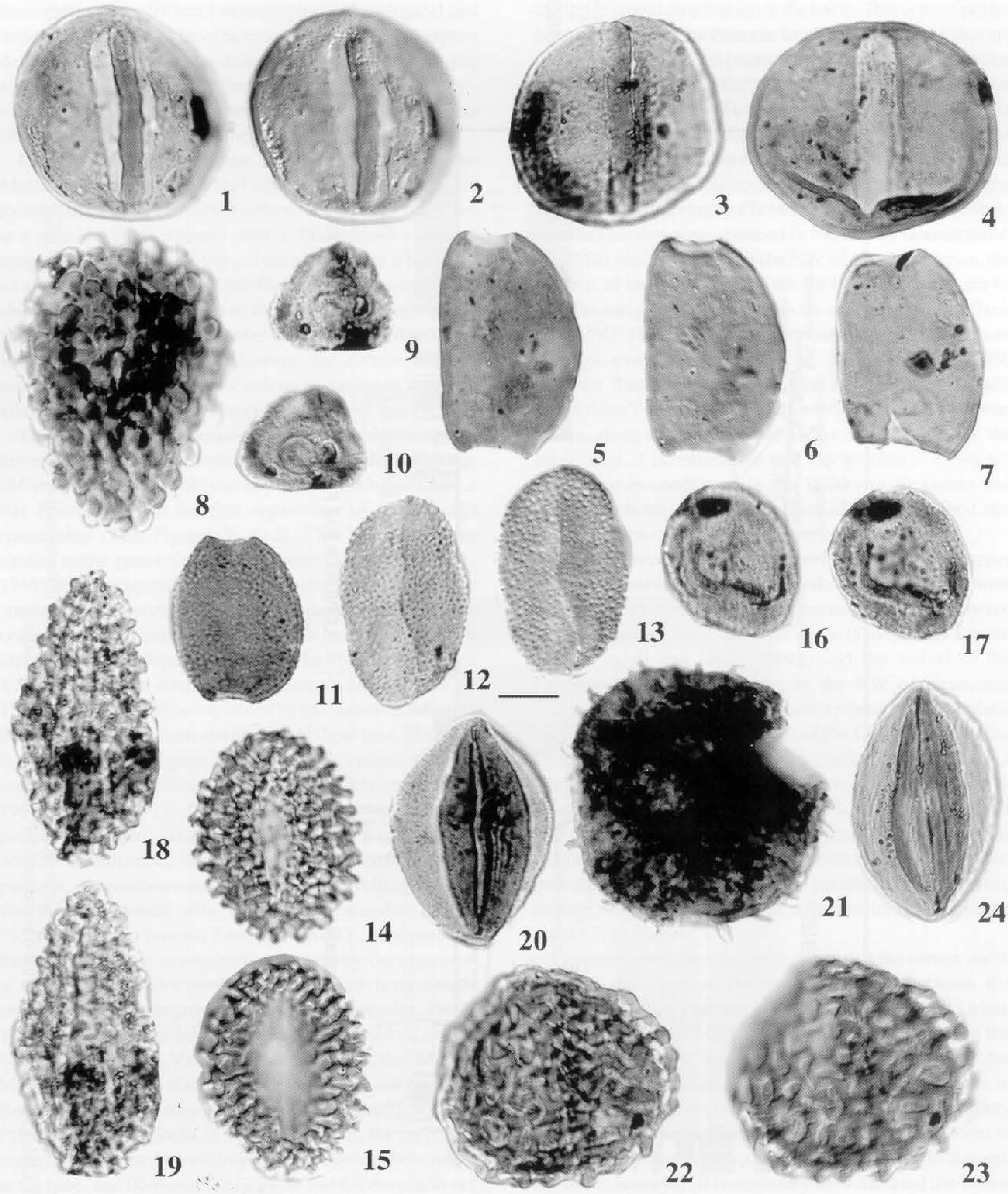
18–19 *Retitrescolpites magnus* (González 1967) Jaramillo & Dilcher 2001. Sample 2 (Sogamoso section), slide 55711(1), EF: V56/2.

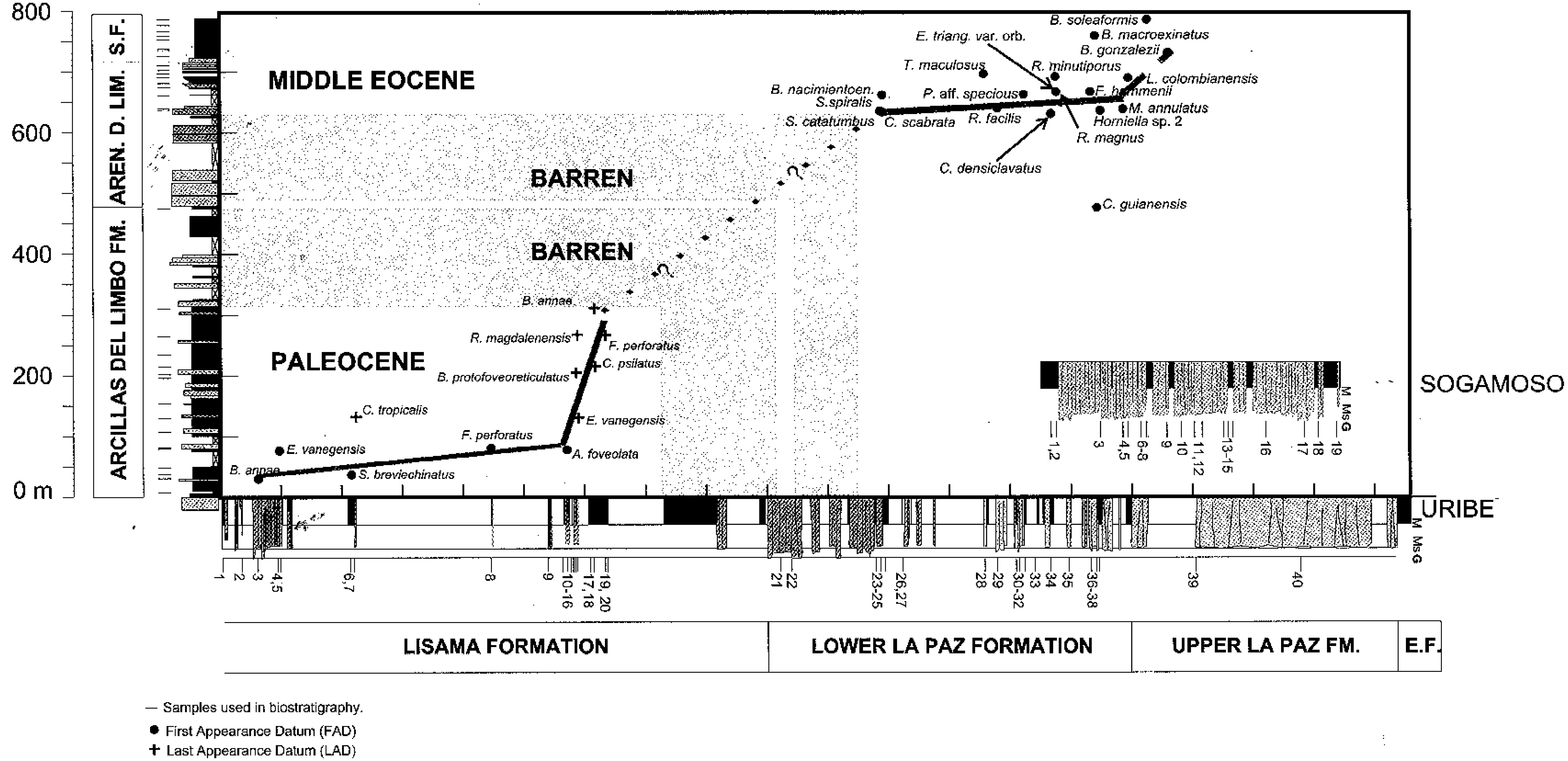
20 *Retitricolpites* cf. *simplex* Gonzalez 1967. Sample 16 (Sogamoso section), slide 56035(1), EF: J47.

21 *Spinizonocolpites breviechinatus* Jaramillo & Dilcher 2001. Sample 13 (Uribe section), slide 57158, EF: F38/1.

22–23 *Spirosyncolpites spiralis* González 1967. Sample 6 (Sogamoso section), slide 55803(1), EF: M59/3. Fig. 23 in DIC.

24 *Striatopollis catatumbus* (González 1967) Takahashi & Jux 1989. Sample 2 (Sogamoso section), slide 56058, EF: R53/3–4.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24



Text-Figure 5. Graphic correlation between the Uribe–Sogamoso composite section and Piñalerita section of Jaramillo and Dilcher (2001). E.F.: Esmeraldas Formation; AREN. D. LIM. FM.: Areniscas del Limbo Formation; S.F.: San Fernando Formation.

these difficulties, different stratigraphic, palynological and structural approaches have been used to date the Paleogene deposits of the Middle Magdalena Valley. For example, the age of La Paz Formation has been suggested as early–middle Eocene (Van der Hammen, 1954); middle Eocene (Ramirez, 1988); and late Eocene (Suarez, 1996).

In the Nuevo Mundo syncline, on the eastern border of the Middle Magdalena Valley and where the study sections are located, the La Paz formation onlaps the Lisama Formation at a very low angle (Gomez, 2001). This contact separates progressively older units toward the west, where it becomes an angular unconformity (Text-Figure 3A). These relationships show that the duration of the La Paz–Lisama hiatus is shorter toward the eastern border of the Middle Magdalena Valley (Text-Figure 3B). However, the current state of resolution of the pollen associations in the basin does not allow determination of the precise duration of this event.

The palynological information in this paper shows that the lower limit of the *Retibrevitricolpites triangulatus* biozone of Germeraad et al. (1968) can be placed at the base of the La Paz Formation with the first appearance of *Striatopollis catatumbus* (Text-Figures 2, 4, 5). This species is very similar to the genus *Crudia* (Fabaceae) (Germeraad et al., 1968) that is common in alluvial plain deposits. On the contrary, *Retibrevitricolpites triangulatus* and *Lanagiopollis crassa*, the other species that define this biozone, were only identified in a single sampling level in the Middle Magdalena Valley but they are abundant in Venezuela (Text-Figure 6). This difference could be explained by environmental factors that controlled the lateral distribution of these taxa. This idea is supported by the great similarity of *L. crassa* with the mangrove pollen *Pelliciera rhizophorae* (Germeraad et al., 1968; Graham, 1977). Therefore, *L. crassa* would be expected to be more abundant in Venezuela where marine conditions influenced the sedimentation patterns. This hypothesis of environmental conditions controlling species distributions would also explain the absence of the *Psilatricolporites crassus* Zone in the MMV, as opposed to there being a hiatus as originally proposed by Germeraad et al. (1968). *Retibrevitricolpites triangulatus* has been considered indicative of mangrove environments (Gonzalez, 1967). This species has a similar abundance distribution to *L. crassa* being abundant in Venezuela and rare in the Middle Magdalena Valley (Gonzalez, 1967; Rull, 1999). The *Retibrevitricolpites triangulatus* zone was dated as latest Paleocene–early Eocene in Nigeria based on the co-occurrence of *Globorotalia velascoensis* and *Globorotalia acuta* at the base, and *Globorotalia formosa* and *Globorotalia rex* in the upper part of the zone.

The upper limit of the *Retibrevitricolpites triangulatus* biozone is based on the first regular consecutive appearance of *Monoporopollenites annulatus*, which is a species having regional distribution in the basin. This type of pollen is associated with the Poaceae family (Gramineae), that are mostly wind pollinated plants with widespread distribution and preservation potential, and could be considered a good stratigraphic marker (Text-Figures 4, 5). In spite of the barren interval that exists in the lower part of La Paz Formation, the thickness of this biozone in the MMV is the thickest of all the sections in Colombia, and includes the Upper La Paz Formation (Text-Figures 4, 5). If the calibration data for this zone obtained in Nigeria by Germeraad et al (1968) can be applied in the NW of South America, the interval of sedimentation of the La Paz Formation can be dated as early–middle Eocene in the studied area (east flank of MMV). This dating is important since some models of geologic evolution (Cooper et al., 1995; Villamil, 1999) consider that within this time interval, the entire Middle Magdalena Valley experienced an erosion or non-depositon hiatus, along with many other basins in Colombia. On the other hand, it is remarkable that this biozone is either not present or is condensed in the Piñalerita–Regadera and Tarra-1 sections, and it is very thick in the Maracaibo Lake sector (Icotea section, Text-Figure 4).

Regional tectonic models suggest that during the upper Paleocene–middle Eocene interval, tectonic activity took place in Colombia due to an increase in the westward displacement of the Caribbean Plate (Pindell and Barret, 1990; Pindell and Drake, 1998) and the arrival of the Leward Antilles volcanic arc to the NW of Venezuela (Lugo and Mann, 1995). These events produced two foreland basins, one formed by the uplift of the Colombian Central Cordillera and the other by the thrusting of portions of a Caribbean volcanic arch in Venezuela ("Lara nappes"). The Middle Magdalena Valley and Icotea sections show two of the most subsiding areas in these basins, while the Piñalerita, Regadera and Tarra-1 sections were condensed probably as a consequence of the peripheral bulge formed during isostatic readjustment adjacent to the subsiding areas (Text-Figures 4, 5).

Graphic correlation results indicate that the abrupt variations in the slope of the correlation line between the Piñalerita section (eastern border of the Cordillera Oriental) and the Middle Magdalena Valley (western side of the Cordillera Oriental, see Text-Figure 1) are very useful for identifying condensed sections and relative variations in accommodation rates among these areas. The great variety of pollen and spores found in the studied sections seem to have a great potential to make accurate correlations through the basin; however, it is necessary to understand the lateral distribution of certain taxa. Some of the new species described in the Colombian sections (e.g. Jaramillo and Dilcher 2001) have not been observed in Venezuela. Is this apparent absence linked to taphonomical and/or environmental changes? Is it due to the number of specimens counted by sample, or a result of differences in the research goals (e.g. priority in the identification of the traditional markers in the Venezuelan sections)? In order to respond to these questions it is necessary to continue a detailed study of all the sections using the same approaches and working methods.

Jaramillo and Dilcher (2001) used the Piñalerita section to build a Standard Composite of the upper Paleocene–Middle Eocene interval of northwestern South America. The information shown here indicates that the 630–660 m interval is condensed (Text-Figure 5). These data together with the barren interval found in the Colombian sequences, compel us to search for new areas in order to build a solid Standard Composite for the Paleogene of northwestern South America. One of the most promising areas to investigate the barren interval of Colombia is located in the Maracaibo Basin (northwest Venezuela) where there are thick sequences with abundant pollen and spores interbedded with marine deposits (e.g. Paso Diablo Formation for the upper Paleocene–Lower Eocene and Misoa for the Eocene).

CONCLUSIONS

The Paleocene to middle Eocene biozones of Germeraad et al. (1968) are relatively operative in the new sections studied in Colombia. The palynologically barren interval between the *F. perforatus* and *R. triangulatus* zones in all the studied sections justifies creating a barren interzone for the Colombian region at this time. The Eocene subzones of Germeraad et al. (1968) and the biozones of Muller et al. (1987) do not seem to be applicable to the studied sections.

The current state of knowledge of the pollen successions of the Middle Magdalena Valley does not support a hiatus encompassing the entire lower and middle Eocene, as has been suggested by some authors. However, the stratigraphic relationships and palynological data indicate important lateral variations in the thickness of the Lisama and La Paz Formations and heterochrony in its limiting lower unconformity surface. This hiatus lasts a shorter amount of time to the east of the Middle Magdalena Valley. The graphic correlation technique together with the detailed study of new sections to the west of the basin could help to understand the true nature of this unconformity.

Palynology is potentially a useful tool for detailed stratigraphic study of the Paleogene sequences of northwestern South America and to constrain the available paleogeographic and geologic models. However, although the knowledge of the pollen associations has been improved, there are not enough independent calibration elements that allow using this information as an accurate chronostratigraphic tool. For this reason, it is necessary to look for new sections with both pollen and marine microfossils, and/or the integration of other dating methods such as $\delta^{13}C$ and paleomagnetism.

SYSTEMATIC PALEONTOLOGY

Descriptive morphological terminology closely follows that of Jaramillo and Dilcher (2001) for exine architecture and tectal sculpturing. The Rules of the International Code of Botanical Nomenclature (I.C.B.N.; Greuter et al., 2002) for species names are followed herein. All figured and type specimens are stored at the palynological collection of the National Core Library (Litoteca Nacional) Bernardo Taborda, Colombian Petroleum Institute, Km 7 via Piedecuesta, Piedecuesta, Santander, Colombia. The National Core Library of Colombia is a government institute, and a public centre of information and research in geological sciences officially responsible of managing and preserving the rock and microfossil collections of Colombia. The Library promotes its use by scientists and consultants interested in global geological process and exploration of oil, mining and energy resources. The inventory includes public and confidential collections of cores, cuttings, outcrops, petrological rock samples and micropaleontological collections. Holotypes and paratypes can be freely consulted upon written request to the Library manager.

Angiosperm pollen

Genus *Foveomonoporites* gen. nov.

Type. *Foveomonoporites variabilis* sp. nov.

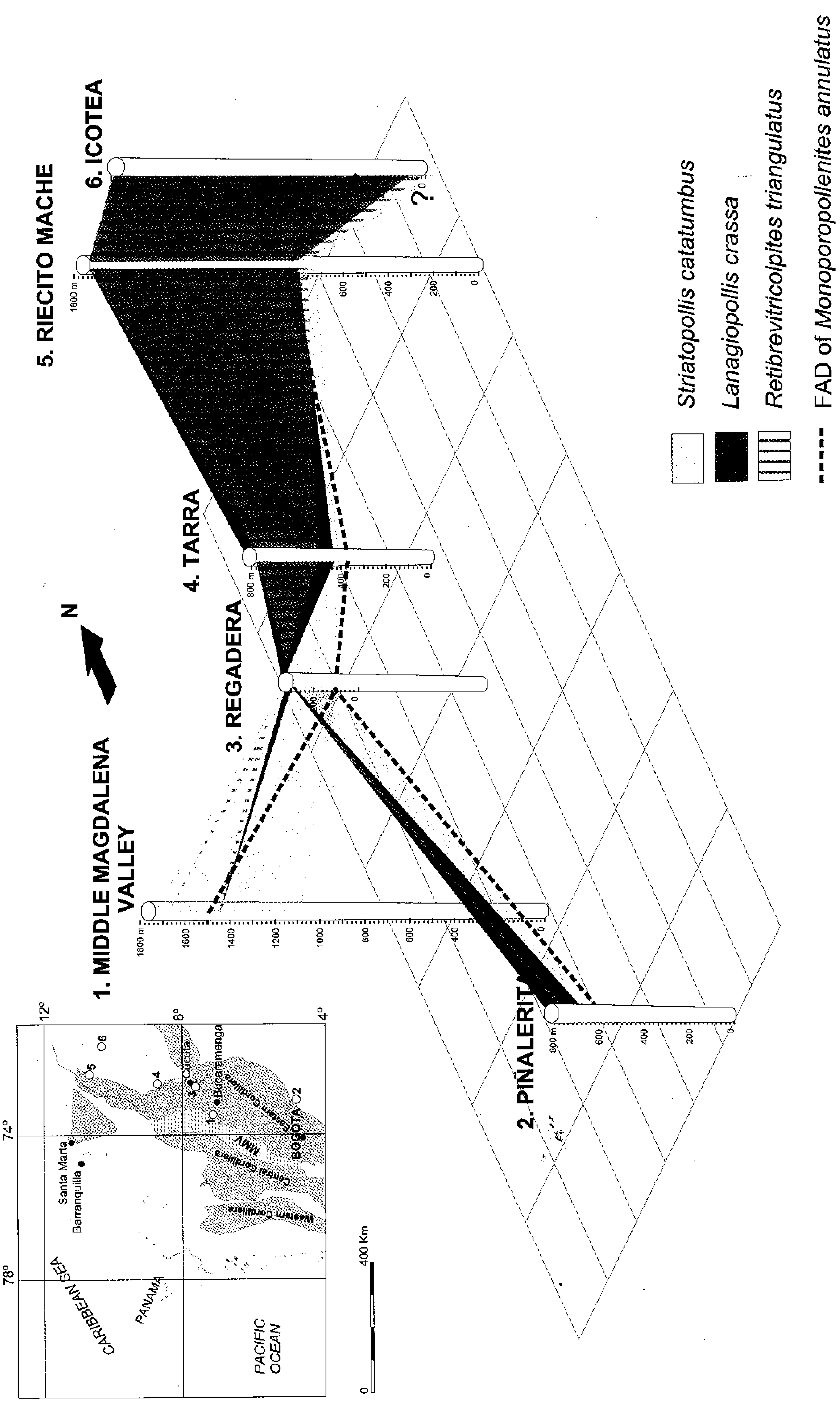
Diagnosis. Pollen grains free, anisopolar, elliptical, monoaperturate, pore simple, atectate, sculpture foveolate to fossulate.

Etymology. (*fovea*, latin: a small pit; *monis*, greek: single; *porus*, latin: small opening) The genus is named after the foveolate sculpture and the presence of single pore.

Comparisons. *Monoporopollenites* Meyer 1956 has smooth exine; *Monulcipollenites* Fairchild in Stover, Elsik & Fairchild 1966 has thinner exine, annulate ulcus and the foveola is smaller and densely distributed.

Foveomonoporites variabilis sp. nov.
Plate 2, figs 1–7

Holotype. Plate 2, figs. 3, 4; sample 8 (Uribe Section), slide 57109, England Finder reference L50/4.



Text-Figure 6. Lateral distribution of the species that define the *Retibrevitricolpites triangulatus* zone of Germeraad et al. (1968).

Paratype. Plate 2, figs. 1, 2; sample 8 (Uribe Section), slide 57099, England Finder reference J34/4.

Geographic and stratigraphic location. Rio Sucio near Uribe-Uribe, 7° 13' 19" N–73° 21' 18" W, Colombia, Lisama Formation.

Age. Upper Paleocene.

Etymology. (*variabilis*, latin: capacity of variance) Reflecting variation in the foveolate–fossulate ornamentation.

Description. Monad, radial, anisopolar, amb elliptical (egg-like), one side convex in equatorial view; monoporate, pore simple, 10 µm long, 5 µm wide; atectate, exine 2 µm, two layers visible, columella not visible; sculpture foveolate, irregularly distributed, foveolae 0.5–1 µm wide, circular or elongate, muri 0.5–5 µm apart, variable in density between the specimens, some of them are fossulate.

Dimensions. Length 31 (36) 39 µm; width 22 (29) 33 µm; 9 specimens measured.

Differential diagnosis. *Monulcipollenites confossus* Fairchild in Stover et al. 1966 has annulate pore, thinner exine (1 µm), thinner and more densely distributed foveola. *Aglaoreidia? foveolata* Jaramillo & Dilcher 2001 is trapezoidal straight–convex, has collumela, and has costate pore which is located in lateral position.

Remarks. In some specimens the exine can be folded to look like a colpus (e.g. Plate 2, fig. 6).

Botanical affinity. Unknown

Genus *Diporoconia* Frederiksen et al. 1985

Diporoconia cf. *Diporoconia iszkaszentgyoergyi* (Kedves 1965) Frederiksen et al. 1985
Plate 3, figs 5–7.

cf. 1985 *Diporoconia iszkaszentgyoergyi* (Kedves 1965) Frederiksen et al. 1985, pl. 1, fig 2.

Geographic and stratigraphic location. Rio Sucio near Uribe-Uribe, 7° 13' 19"N–73° 21' 18"W, Colombia, Lisama Formation,

Age. Upper Paleocene.

Description. Monad, bilateral, subisopolar, amb elliptic, in equatorial view the proximal side is less curved than the distal side; diporate, pores slightly costate, 2 µm wide, pores 7–10 µm long, border well defined; atectate, exine 0.5–0.8 µm thickening near pores to 1 µm; sculpture psilate.

Dimensions. Equatorial diameter width 22(23)24 µm; equatorial diameter length 34(37)39 µm; 3 specimens measured.

Remarks. *Diporoconia* Frederiksen et al. (1985), include diporate pollen grains with the "distal face" more convex than the "proximal face", exine surface smooth or perforate, collumellae indistinct under light microscope, and big pores have annuli or tumescence. In some specimens the pores appear offset toward one face. Frederiksen

PLATE 4

Pollen and reworked palynomorphs from the Middle Magdalena Valley basin. The scale bar represent 10 µm. EF: England Finder reference; DIC: differential interference contrast.

1 *Tetracoloporopollenites spongiosus* Jaramillo & Dilcher 2001. Sample 14 (Uribe section), slide 57160, EF: N51/4.

2 *Tetracolporopollenites transversalis* (Dueñas 1980) Jaramillo & Dilcher 2001. Sample 16 (Sogamoso section), slide 56035(1), EF: H40/3.

3 *Tetracolporopollenites* sp. 1. Sample 9 (Sogamoso section), slide 55926(1), EF: H50/3.

4 *Ulmoideipites krempii* (Anderson 1960) Elsik 1968. Sample 25 (Uribe section), slide 57853, EF: M52/4.

5 *Ulmoideipites krempii* (Anderson 1960) Elsik 1968. Sample 4 (Uribe section), slide 57848, EF: C45/3.

6–7 *Zonocostites minor* Jaramillo & Dilcher 2001. Sample 10 (Sogamoso section), slide 55939(2), EF: R56/3

Reworked palynomorphs:

8 *Bacumorphomonocolpites tausae* Sole De Porta 1971. Sample 25 (Uribe section), slide 57853, EF: U52/2

9–10 *Buttinia andreevi* Boltenhagen 1967. Sample 38 (Uribe section), slide 57399, EF: U41.

11 *Crusafontites grandiosus* Sole de Porta 1971. Sample 12 (Sogamoso section), slide 55974, EF: J43/2.

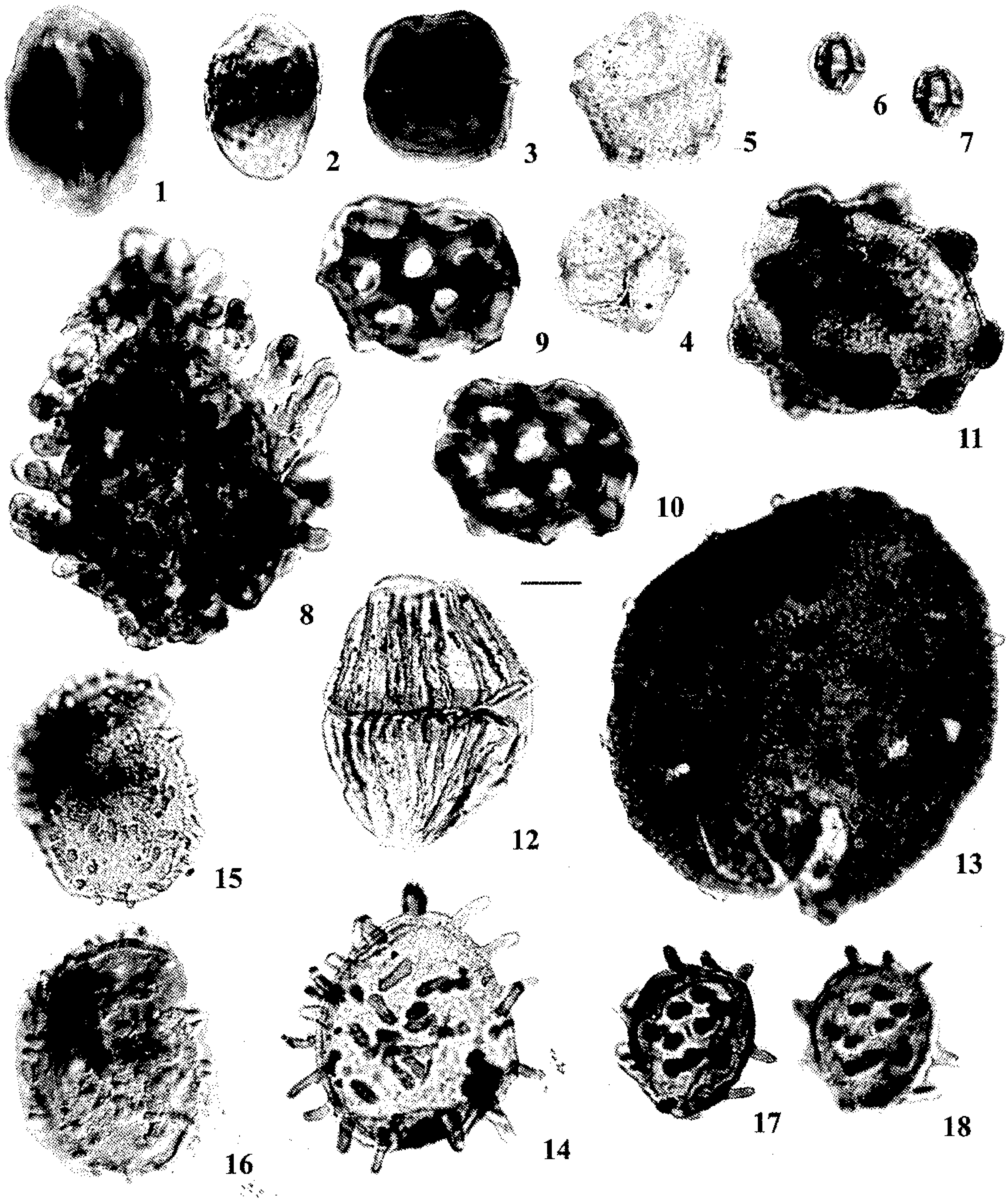
12 *Dinogymnium acuminatum* Evitt, Clarke & Verdier.1967. Sample 21 (Uribe section), slide 57304, EF: N49/3.

13 *Duplotriporites ariani* Sarmiento 1992. Sample 25 (Uribe section), slide 57276, EF: M55/4.

14 *Spinozonocolpites baculatus* Muller 1968. Sample 33 (Uribe section), slide 57859, EF: O46/3–4.

15–16 *Spinizonocolpites baculatus* ("brevibaculatus"; form 2). Sample 5 (Sogamoso section), slide 55771(1), EF: X55/1. Fig. 16 in DIC.

17–18 *Spinizonocolpites* cf. *baculatus* Muller 1968. Sample 5 (Sogamoso section), slide 55771(1), EF: G45/2. Fig. 18 in DIC.


1
2
3
5
6
7
9
4
11
8
10
12
13
15
16
14
17
18

et al. (1985) used the species *Diporites iszkaszentgyoergyi* of Kedves 1965 as the type species of this new genus. Our specimens are very similar to some pollen grains included by Frederiksen et al. (1985) in the *Diporoconia iszkaszentgyoergyi* (e.g. Kedves, 1969, pl. XXII, figs. 24, 25; Gruas-Cavagnetto, 1976, pl. 5, figs. 7, 11, 18; Emile, 1991, pl. 1, figs. 3, 4).

Botanical affinity. A monocot, probably a palm (Frederiksen et al. 1985).

Genus *Psilamonocolpites*
Van der Hammen & García 1966

Psilamonocolpites operculatus sp. nov.
Plate 3, figs. 1–4

Holotype. Plate 3, figs. 1–2; sample 8 (Uribe Section), slide 57109, England Finder reference L34/2.

Paratype. Plate 3, fig. 3, sample 8 (Uribe Section), slide 57099, England Finder reference L35.

Geographic and stratigraphic location. Rio Sucio near Uribe-Uribe, 7° 13' 19" N–73° 21' 18" W, Colombia, Lisama Formation.

Age. Upper Paleocene.

Etymology. (*operculum*, latin: a covering) The species is named after the operculum covering the sulcus.

Description. monad, bilateral, anisopolar, amb circular; monosulcate, sulcus simple, long, elliptical, never extends to the polar region, covered by an operculum; atectate, nexine 1.5 μm thick, thinning to the polar regions; sculpture psilate to scabrate.

Dimensions. Equatorial diameter width 35(39)41 μm; equatorial diameter length 36 μm (7 specimens measured).

Differential diagnosis. *Psilamonocolpites grandis* (Van der Hammen 1954) Van der Hammen and Garcia 1966 and *Psilamonocolpites ciscudae* Sarmiento 1992 each lack an operculum.

Remarks. In some specimens the operculum is totally or partially detached. When it is not present, they can be identified by the typical elliptic form of the sulcus (Plate 3, fig. 4).

Botanical affinity. Unknown.

ACKNOWLEDGMENTS

We thank V. Rull and three anonymous reviewers for their useful comments. This project was financed by the Vicerrectoría de Investigations and Postgrados of the Caldas University (Manizales, Colombia), the Petroleum Research Fund, administered by the American Chemical Society (Grant number 34676 to Francisca Oboh-Ikuenobe), the Fundación para la promoción de la investigación y la tecnología, Banco de la República, and the Corporación Geológica Ares. AP thanks the University of Caldas and its Faculty of Sciences for funding this research at the Liege University as part of his doctoral study. Thanks to all the scientific and technical personnel of the Geological Department at Liege University (Belgium) for their collaboration: to Emile Roche for his help in the morphologic and taxonomic study of the pollen and spore species; to Phillipe Steemans for his advice and logistical support; and to Marcela Giraldo for the laboratory treatment of the samples and the preparation of the slides. CJ thanks Instituto Colombiano del Petróleo for permission to sample the Sogamoso cores, and G. Bayona and J. Roncancio for their help during fieldwork. The Corporación Geológica Ares provided valuable logistic support. CJ is also grateful to all the people who helped during the field season in the town of Uribe-Uribe. Thanks to R. Barclay for improving the manuscript. Special thanks go to M. I. Barreto for her continuous support and sources of ideas.

References Cited

COETZEE, J.A.
1993 African floras since the Terminal Jurassic. *In*: Goldblatt, P. (ed.), *Biological Relationships between Africa and South America*. Yale University Press, New Haven, Connecticut, p. 37–61.

COLMENARES, O.A., and TERÁN, L.
1993 A biostratigraphic study of Paleogene sequences in southwestern Venezuela. *Palynology*, 17: 67–89.

COOPER, M.A., ADDISON, F.T., ALVAREZ, R., CORAL, M., GRAHAM, R.H., HAYWARD, A.B., HOWE, S., MARTINEZ, J., NAAR, J., PENAS, R., PULHAM, A.J., and TABORDA, A.
1995 Basin development and tectonic history of the Llanos Basin, Eastern Cordillera and Middle Magdalena Valley, Colombia. *AAPG Bulletin*, 79: 1421–1443.

DOUBINGER, J.
1973 Pollen and spores from the Paleocene coal basin of Cerrejon (Guajira Province, Colombia). *Proceedings, 96 Congres Nat.'l des Soc. Savantes (Toulouse, 1971)*, 5: 253–262.

DOUBINGER, J.
1976 Spore–pollen assemblages from the Tertiary of Colombia. *Acts, 97 Contres Nat.'l des Soc. Savantes (Nantes)*, 4: 9–18.

EDWARDS, L.E.
1984 Insights on why graphic correlation (Shaw's method) works. *Journal of Geology*, 92: 583–597.

EDWARDS, L.E.
1989 Supplemented graphic correlation: A powerful tool for paleontologists and nonpaleontologists. *Palaios*, 4: 127–143.

ELSIK, W.C.
1966 New sporomorph genera from the Upper Cretaceous of Perú. *Pollen et Spores*, 8(3): 553–564.

ELSIK, W.C.
1968a Palynology of a Paleocene rockdale lignite, Milan county, Texas. I. morphology and taxonomy. *Pollen et Spores*, 10(2): 263–314.

ELSIK, W.C.
1968b Palynology of a Paleocene rockdale lignite, Milan county, Texas. II. morphology and taxonomy (end). *Pollen et Spores*, 10(3): 599–664.

ELSIK, W.C.
1974 Characteristic Eocene palynomorphs in the Gulf Coast, U.S.A. *Palaeontographica* Abt. B, 149: 90–111.

ELSIK, W.C.
1978 Palynology of the Gulf Coast lignites: the stratigraphic framework and depositional environments. *Texas University Bureau of Economic Geology, Report of Investigations*, 90: 21–32.

ELSIK, W.C., and DILCHER, D.L.
1974 Palynology and Age of Clays Exposed in Lawrence Clay Pit, Henry County, Tennessee. *Palaeontographica* Abt. B., 146: 66–87.

EMILE, R.
1991 Sporopollinic biostratigraphy and Ypresian paleoenvironment. *In*: C. Dupuis, J. Deconinck, and E. Steurbaut (eds.), *The Ypresian stratotype. Bulletin de la Societé belge de Géologie*. Ministry of Economic affairs–Belgian geological survey, Brussels, p. 373–383.

ETAYO-SERNA, F., BARRERO, D., LOZANO, H., ESPINOSA, A., GONZÁLEZ, H., ORREGO, A., BALLESTEROS, I., FORERO, H., and RAMÍREZ, C.
1983 Mapa de Terrenos Geológicos de Colombia. Publ. Geol. Esp., 14-I. INGEOMINAS, Bogotá, 235 pgs.

FREDERIKSEN, N.O.
1980 Sporomorphs from the Jackson Group (Upper Eocene) and adjacent strata of Mississippi and western Alabama. *United States Geological Survey Professional Paper*, 1084: 1–75.

FREDERIKSEN, N.O.
1985 *Review of Early Tertiary Sporomorph Paleoecology*. AASP Contributions Series, 15. AASP Foundation, 92 pgs.

FREDERIKSEN, N.O.
1988 Sporomorph biostratigraphy, floral changes, and paleoclimatology, Eocene and earliest Oligocene of the eastern Gulf Coast. *United States Geological Survey Professional Paper*, 1448: 1–68.

FREDERIKSEN, N.O.
1998 Upper Paleocene and lowermost Eocene angiosperm pollen biostratigraphy of the eastern Gulf Coast and Virginia. *Micropaleontology*, 44: 45–68.

FREDERIKSEN, N.O., WIGGINS, V.D., FERGUSON, I.K., DRANSFIELD, J., and AGER, C.M.
1985 Distribution, paleoecology, paleoclimatology, and botanical affinity of the Eocene pollen genus *Diporoconia* n. gen. *Palynology*, 9: 37–60.

GERMERAAD, J.H., HOPPING, C.A., and MULLER, J.
1968 Palynology of Tertiary sediments from tropical areas. *Review of Palaeobotany and Palynology*, 6: 189–348.

GOMEZ, E.,
1998 *Relative timing of Cenozoic deformation of the middle Magdalena Valley basin and bounding mountain ranges, Colombia*, American Association of Petroleum Geologists 1998 annual meeting. AAPG and SEPM, Salt Lake City, UT, analytic compact disc.

GOMEZ, E.
2001 *Tectonic controls on the Late Cretaceous to Cenozoic sedimentary fill of the Middle Magdalena Valley Basin, Eastern Cordillera and Llanos Basin, Colombia*. Ph.D. Dissertation, Cornell University, 619 pgs.

GONZALEZ, A.E.
1967 *A palynologic study on the upper Los Cuervos and Mirador formations (lower and middle Eocene), Tibú Area, Colombia*. E.J. Brill, Leiden, 68 pgs.

GRAHAM, A.
1977 New records of *Pelliciera* (Theaceae/Pelliceriaceae) in the Tertiary of the Caribbean. *Biotropica*, 9: 48–52.

GREUTER, W., MCNEIL, J., BARRIE, F.R., BURDET, H.M., DEMOULIN, V., FILGUEIRAS, T.S., NICHOLSON, D.H., SILVA, P.C., SKOG, J.E., TREHANE, P., URLAND, N.J., and HAWKSWORTH, D.L.
2000 International Code of Botanical Nomenclature (Saint Louis) 2002. *Regnum vegetabile*, 138: 1–474.

GRUAS-CAVAGNETTO, C.
1976 Etude palynologique du Paléogène du sud de l'Angleterre. *Cahiers de micropaléontologie*, 1: 49.

GUERRERO, J., and SARMIENTO, G.
1996 Estratigrafía física, Palinológica, Sedimentológica y Secuencial del Cretácico Superior y Paleoceno del Piedemonte Llanero. Implicaciones en Exploración Petrolera. *Geología Colombiana*, 20: 3–66.

HOPPING, C.A.
1967 Palynology and the Oil industry. *Review of Palaeobotany and Palynology*, 2: 23–48.

JAN DU CHÊNE, R.E., ONYIKE, M.S., and SOWUNMI, M.A.
1978b Some new Eocene pollen of the Ogwashi–Asaba Formation, South-Eastern Nigeria. *Revista Española de Micropaleontología*, 10: 285–322.

JAN DU CHÊNE, R.E., PERCH-NIELSEN, K., and PETTERS, S.W.
1978a New stratigraphic data on the Paleogene Ewekoro and Akinbo Formations (Southwestern Nigeria). *Archives des Sciences*, 31(3): 205–212.

JAN DU CHÊNE, R.E., and SALAMI, M.B.
1978 Palynology and Micropaleontology of the Upper Eocene of the well Nsukwa 1 (Niger Delta, Nigeria). *Archives des Sciences*, 13(1): 5–9.

JANSONIUS, J., and HILLS, L.V.
1976 *Genera File of Fossil Spores*. Special Publication, Dept. of Geology, University of Calgary, Calgary, Canada, cards 1–3287.

JARAMILLO, C.
1999 *Middle Paleogene palynology of Colombia, South America: Biostratigraphic, sequence stratigraphic and diversity implications*. Ph.D. Thesis, University of Florida.

JARAMILLO, C.
2002 Response of tropical vegetation to Paleogene warming. *Paleobiology*, 28: 222–243.

JARAMILLO, C.A., and DILCHER, D.L.
2001 Middle Paleogene palynology of central Colombia, South America: A study of pollen and spores from tropical latitudes. *Palaeontographica,* Abt. B, 258: 87–213.

KEDVES, M.
1969 Palynological studies on Hungarian early Tertiary deposits. *Akadémiai Kiadó*, Budapest, 84 pgs.

LEIDELMEYER, P.
1966 The Paleogene and Lower Eocene pollen flora of Guyana. *Leidse Geologische Mededelingen*, 38: 49–70.

LUGO, J., and MANN, P.
1995 Jurassic–Eocene tectonic evolution of Maracaibo basin, Venezuela. *In*: Tankard, A.J., Suarez, R., and Welsink, H.J. (eds.), *Petroleum basins of South America*. AAPG, Tulsa, Oklahoma, p. 699–725.

MANN, K.O., and LANE, H.R.
1995 Graphic Correlation: A Powerful Stratigraphic Technique Comes of Age. *In*: Mann, K.O., and Lane, H.R. (eds.), *Graphic Correlation, SEPM Special Publication* 53: 3–13.

MORALES, L.G.
1958 General Geology and Oil occurrences of Middle Magdalena Valley, Colombia. *In*: Weeks, L.G., (ed.), Habitat of Oil, American Association of Petroleum Geologists, Tulsa, Oklahoma, p. 641–695.

MULLER, J., DI GIACOMO, E., and VAN ERVE, A.
1987 A palynologic zonation for the Cretaceous, Tertiary and Quaternary of Northern South America. *American Association of Stratigraphic Palynologists, Contribution Series*, 19: 7–76.

OLOTO, I.N.
1992 Succession of palynomorphs from the Early Eocene of Gbekebo-1 well in SW Nigeria. *Journal of African Earth Sciences*, 15(3/4): 441–452.

PARDO-TRUJILLO, A., JARAMILLO, C.A., and OBOH-IKUENOBE, F.E.
2003 Appendix 1. palynomorphs in the Uribe section. Appendix 2. palynomorphs in the Sogamoso core. Appendices for "Paleogene palynostratigraphy of the eastern Middle Magdalena Valley, Colombia (Palynology volume 27, 2003)." American Association of Stratigraphic Palynologists, Data Committee, PALYDISK 23, available online at http://www.palynology.org/.

PASLEY, M.A., and HAZEL, J.E.
1995 Revised Sequence Stratigraphic interpretation of the Eocene–Oligocene Boundary interval, Mississippi and Alabama, Gulf Coast Basin, USA. *Journal of Sedimentary Research*, B 65(1): 160–169.

PILSBRY, H.A., and OLSSON, A.A.
1935 Tertiary fresh-water mollusks of the Magdalena Embayment, Colombia. *Proceedings of the Academy of Natural Sciences of Philadelphia*, 87: 7–21.

PINDELL, J.L., and BARRET, S.F.
1990 Geological evolution of the Caribbean region: a plate tectonic perspective. *In*: Dengo, G., and Case, J.E. (eds.), The Geology of North America, (A Decade of North American Geology), Vol. H, The Caribbean Region. *Geological Society of America*, Boulder, Colorado, p. 405–432.

PINDELL, J.L., and DRAKE, C.L.
1998 Paleogeographic evolution and non-glacial eustasy, Northern South America. *SEPM Special Publication* 58, 324 pgs.

POCKNALL, D.T., and NICHOLS, D.J.
1996 *Palynology of coal zones of the Tongue River Member (upper Paleocene) of the Fort Union Formation, Powder River Basin, Montana and Wyoming*. American Association of Stratigraphic Palynologists, Contributions Series 32, 58 pgs.

PORTA, J.D.
1974 *Colombie (deuxieme partie), Tertiaire et Quaternaire. Lexique Stratigraphique International, Amerique Latine, V (4b)*. Centre National de la Recherche Scientifique, Paris, 689 pgs.

RAMIREZ, R.E.
1988 *Stratigraphy of the Tertiary of the Middle Magdalena Basin (Colombia), central and northern parts*. Masters Thesis, University of Texas, Austin, 199 pgs.

RULL, V.
1997 Sequence analysis of western Venezuelan Cretaceous to Eocene sediments using palynology: chrono-paleoenvironmental and paleovegetational approaches. *Palynology*, 21: 79–90.

RULL, V.
1999 Palaeofloristic and palaeovegetational changes across the Paleocene/Eocene boundary in northern South America. *Review of Palaeobotany and Palynology*, 107: 83–95.

SALAMI, M.B.
1984 Three new sporomorph form genera from the Late Cretaceous and Paleogene of southwestern Nigeria. *Grana*, 23: 163–166.

SALAMI, M.B.
1985 Upper Senonian and Lower Tertiary pollen grains from the Southern Nigeria Sedimentary Basin. *Revista Española de Micropaleontología*, 17(1): 5–26.

SALARD-CHEBOLDAEFF, M.
1978 Sur la Palynoflore Maestrichtienne et Tertiaire du Bassin Sedimentaire Littoral du Cameroun. *Pollen et Spores*, 20(2): 215–260.

SALARD-CHEBOLDAEFF, M.
1979 Palynologie Maestrichtienne et Tertiaire du Cameroun, Etude Qualitative et Repartition Verticale

des Principales Especes. *Review of Palaeobotany and Palynology*, 28: 365–388.

SALARD-CHEBOLDAEFF, M.
1990 Intertropical African palynostratigraphy from Cretaceous to Late Quaternary times. *Journal of African Earth Sciences*, 11(1/2): 1–24.

SAMANT, B., and PHADTARE, N.R.
1997 Stratigraphic palynoflora of the Early Eocene Rajpardi lignite, Gujarat and the lower age limit of the Tarkeswar Formation of South Cambay Basin, India. *Palaeontographica* Abt. B, 245: 1–108.

SARMIENTO, G.
1992 Palinología de la Formación Guaduas—estratigrafía y sistemática. *Boletín Geológico Ingeominas*, 32: 45–126.

SCHAMEL, S.
1991 Middle and Upper Magdalena Basins, Colombia. *In*: Biddle, K.T. (ed.), *Active margin basins*. AAPG, p. 283–301.

SHAW, A.B.
1964 *Time in Stratigraphy*. McGraw-Hill, New York, 365 pgs.

SRIVASTAVA, S.K.
1972 Some spores and pollen from the Paleocene Oak Hill member of the Naheola Formation, Alabama (USA). *Review of Palaeobotany and Palynology*, 14: 217–285.

SUAREZ, M.
1996 *Facies analysis of the upper Eocene La Paz Formation, and regional evaluation of post-middle Eocene stratigraphy, northern Middle Magdalena Valley Basin*. Masters Thesis, University of Colorado, Boulder, 88 pgs.

SUAREZ, M.A.
1997a Stratigraphy and petroleum potential of the La Paz Formation, Middle Magdalena Valley Basin (northern part), Colombia. *Annual Meeting Abstracts – American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists*, 6: 112.

SUAREZ, M.A.
1997b Fluvial architecture and reservoir characterization of the upper Eocene La Paz Formation, Provincia Field, Middle MagdalenaValley Basin, Colombia. *Annual Meeting Abstracts – American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists*, 6: 112.

TSCHUDY, R.H.
1973 Stratigraphic distribution of significant Eocene palynomorphs of the Mississippi embayment. *United States Geological Survey Professional Paper*, 743-B: 1–24.

VAN DER HAMMEN, T.
1954 The development of Colombian flora throughout geologic periods: I, Maestrichtian to Lower Tertiary. *Boletín Geológico (Bogotá)*, 2: 49–106.

VAN DER HAMMEN, T.
1956a Description of some genera and species of fossil pollen and spores. *Boletín Geológico (Bogotá)*, 4: 103–109.

VAN DER HAMMEN, T.
1956b A Palynological Systematic Nomenclature. *Boletín Geológico (Bogotá)*, 4(2–3): 63–101.

VAN DER HAMMEN, T.
1957a Palynologic stratigraphy of the Sabana de Bogota (East Cordillera of Colombia). *Boletín Geológico (Bogotá)*, 5: 187–203.

VAN DER HAMMEN, T.
1957b Climatic periodicity and evolution of South American Maestrichtian and Tertiary Floras: a study based on pollen analysis in Colombia. *Boletín Geológico (Bogotá)*, 5: 49–91.

VAN DER HAMMEN, T.
1958 Estratigrafía del Terciario y Maestrichtiano continentales y Tectonogénesis de los Andes Colombianos. *Boletín Geológico (Bogotá)*, 6(1–3): 67–128.

VAN DER HAMMEN, T., and GARCÍA, C.
1966 The Paleocene pollen flora of Colombia. *Leidse Geologische Mededelingen*, 35: 105–114.

VAN DER HAMMEN, T., and WYMSTRA, T.A.
1964 A palynological study on the Tertiary and Upper Cretaceous of British Guayana. *Leidse Geologische Mededelingen*, 30: 183–241.

VAN HOEKEN-KLINKENBERG, P.M.J.
1964 A Palynological Investigation of some Upper Cretaceous sediments in Nigeria. *Pollen et Spores*, 6(1): 209–231.

VAN HOEKEN-KLINKENBERG, P.M.J.
1966 Maastrichtian Paleocene and Eocene pollen and spores from Nigeria. *Leidse Geologische Mededelingen*, 38: 37–48.

VENKATACHALA, B.S., CARATINI, C., TISSOT, C., and KAR, R.K.
1988 Paleocene–Eocene marker pollen from India and tropical Africa. *Palaeobotanist*, 37(1): 1–25.

VENKATACHALA, B.S., and KAR, R.K.
1969 Palynology of the Tertiary sediments of Kutch- 1. Spores and Pollen from bore-hole no. 14. *Palaeobotanist*, 17(2): 157–178.

VILLAMIL, T.
1999 Campanian–Miocene tectonostratigraphy, depocenter evolution and basin development of Colombia and western Venezuela. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 153: 239–275.

WHEELER, O.C.
1935 Tertiary stratigraphy of the Middle Magdalena Valley. *Proceedings of the Academy of Natural Sciences of Philadelphia*, 87: 29–31.

Appendix. List of species used in the text.

Aglaoreidia? *foveolata* Jaramillo & Dilcher 2001
Albertipollenites? *perforatus* (Gonzalez 1967) Jaramillo and Dilcher 2001
Bacumorphomonocolpites tausae Sole De Porta 1971
Bombacacidites annae (Van der Hammen 1954) Germeraad et al. 1968.
Bombacacidites gonzalezii Jaramillo & Dilcher 200
Bombacacidites nacimientoensis (Anderson 1960) Elsik 1968
Bombacacidites protofoveoreticulatus Jaramillo & Dilcher 2001
Bombacacidites psilatus Jaramillo and Dilcher 2001
Bombacacidites soleaformis Muller et al. 1987
Brevitricolpites microechinatus Jaramillo & Dilcher 2001
Buttinia andreevi Boltenhagen 1967
Clavatricolpites densiclavatus Jaramillo & Dilcher 2001
Ctenolophonidites lisamae Van der Hammen & Garcia 1966
Colombipollis tropicalis Sarmiento 1992
Corsinipollenites psilatus Jaramillo & Dilcher 2001
Cricotriporites guianensis Leidelmeyer 1966
Crusafontites grandiosus Solé de Porta 1971
Crusafontites megagemmatus Solé de Porta 1971
Cyclusphaera scabrata Jaramillo & Dilcher 2001
Dinogymnium acuminatum Evitt et al. 1967
Diporoconia cf. *Diporoconia iszkaszentgyoergyi* (Kedves 1965) Frederiksen et al. 1985
Duplotriporites ariani Sarmiento 1992
Echitriporites trianguliformis Van Hoeken-Klinkenberg 1964
Echitriporites trianguliformis var. orbicularis Jaramillo & Dilcher 2001
Ephedripites vanegensis Van der hammen & García 1966
Foveomonoporites variabilis sp. nov.
Foveotricolpites perforatus Van der hammen & García 1966
Foveotriletes margaritae (Van der Hammen 1954) Germeraad et al. 1968
Foveotriporites hammenii Gonzalez 1967
Gemmastephanocolpites gemmatus Van der Hammen & García *1966*
Kuylisporites genus Potonié 1956.
Lanagiopollis crassa (Van der Hammen & Wymstra 1964) Frederiksen 1988
Luminidites colombianensis Jaramillo & Dilcher 2001
Mauritiidites franciscoi (Van der Hammen 1956) Van Hoeken-Klinkenberg 1964
Monoporopollenites annulatus (Van der Hammen 1954) Jaramillo & Dilcher 2001
Perfotricolpites digitatus González 1967
Polypodiisporites aff. *specious* Sah 1967
Proxapertites cursus Van Hoeken-Klinkenberg 1966
Proxapertites operculatus Van der Hammen 1956b
Psilamonocolpites operculatus n. sp.
Racemonocolpites facilis González 1967
Ranunculacidites operculatus (Van der Hammen & Wymstra 1964) Jaramillo & Dilcher 2001
Retibrevitricolpites triangulatus Van Hoeken-Klinkenberg 1966
Retidiporites magdalenensis Van der Hammen & García 1966
Retimonocolpites longicolpatus Lorente 1986
Retimonocolpites retifossulatus Lorente 1986
Retistephanoporites minutiporus Jaramillo & Dilcher 2001
Retitrescolpites magnus (González 1967) Jaramillo & Dilcher 2001
Retitricolpites cf. *simplex* González 1967
Rhoiphites guianensis (Van der Hammen & Wymstra 1964) Jaramillo & Dilcher 2001
Rugutricolporites felix González 1967
Spinozonocolpites baculatus Muller 1968
Spinizonocolpites breviechinatus Jaramillo & Dilcher 2001
Spirosyncolpites spiralis González 1967
Striatopollis catatumbus (González 1967) Takahashi & Jux 1989
Tetracolporopollenites spongiosus Jaramillo & Dilcher 2001
Tetracolporopollenites transversalis Dueñas 1980
Ulmoideipites krempii (Anderson 1960) Elsik 1968
Zonocostites minor Jaramillo & Dilcher 2001