THE PALYNOLOGY OF THE CERREJÓN FORMATION (UPPER PALEOCENE) OF NORTHERN COLOMBIA

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Abstract

A palynological study of the Cerrejon Formation was conducted in order to date the formation and understand the floristic composition and diversity of a Paleocene tropical site. The Cerrejon Formation outcrops in the Cerrejon Coal Mine, the largest open cast coal mine in the world. Two cores (725 m) were provided by Carbones del Cerrejon LLC for study. Two hundred samples were prepared for palynology, and at least 150 palynomorphs were counted per sample where possible. Several statistical techniques including rarefaction, species accumulation curves, detrended correspondence analysis, and Anosim were used to analyze the floristic composition and diversity of the palynofloras. Palynomorph assemblages indicate that the age of the Cerrejon Formation and the overlying Tabaco Formation is Middle to Late Paleocene (ca. 60–58 Ma). Major structural repetitions were not found in the Cerrejon Formation in the Cerrejon coal mine, and there is little floral variation throughout. The floral composition, diversity, and lithofacies do not change significantly. Lithofacies associations and floral composition indicate deposition fluctuating from an estuarine-influenced coastal plain at the base to a fluvial-influenced coastal plain at the top. There are, however, significant differences in the composition and diversity of coal and siliciclastic samples. Coal palynofloras have fewer morphospecies, and a distinct and more homogeneous floral assemblage compared to assemblages from the intervening sisliciclastic strata, suggesting that tropical swampy environments supported fewer plant species and had a distinct vegetation adapted to permanently wet environments.

Key words: Paleocene; tropics; pollen; diversity; coal; paleoecology; South America.

INTRODUCTION

The Neotropics during the Paleocene were characterized by a warm and wet climate. This is indicated by the widespread accumulation of coal, mostly in coastal to upper fluvial plain environments from Colombia, to Venezuela and Guyana (Leidelmeyer, 1966; Wijmstra, 1969; Villamil, 1999; Montes et al., 2005; Jaramillo et al., 2006). The coals are heavily exploited, representing a large portion of the economies of these regions. In Colombia alone, coal reserves represent 6556 million tons of high-quality, low-ash, low-sulphur, non-caking, high-volatile bituminous B coal (Ingeominas, 2004). This extensive coal deposition formed several million years after the biotic mass extinction across the Cretaceous–Paleogene boundary, although its effect has not been studied in the tropics. How-

Palynology, 31 (2007): 153–189

ISSN 0191-6122

ever, the extinction of several biostratigraphic markers suggests a major floral change, and recent analysis seems to confirm this (Jaramillo and de la Parra, 2006). The Neotropical Paleocene flora contains many modern elements (Romero, 1993; Wing et al., 2004), such as Araceae and Palmae. The tropical Paleocene flora has been called the 'Palmae Province' due to the dominance of the Palmae and Araceae (Herngreen and Chlonova, 1981; Romero, 1993; Jaramillo and Dilcher, 2001). During the Late Cretaceous and Early Paleogene the Neotropical flora was isolated, with limited connections to North America (0.7% of pollen similarities), Africa (11.5% of pollen similarities, see Jaramillo and Dilcher, 2001), and southern South America. Pollen with tropical affinity has been found in the floral assemblage of southern South America and is termed the Mixed Flora (Romero, 1993). The two cores studied here from the Cerrejon coal mine represent most of the Cerrejon Formation, and represent 725 m. The distribution of the palynoflora found is presented here, with an analysis of age, diversity and floral composition.

REGIONAL SETTING

The Cerrejon coal mine is located in the Rancheria River Valley, Colombia (11° 3'N, 72° 41'W). It is bounded to the north by the Oca Fault, to the west by the eastern foothills of the Sierra Nevada de Santa Marta (SNSM), and to the east by the northwest-verging thrust belt system of the Perijá Range (Text-Figure 1). The strata in the Cerrejon coal mine have a regional dip to the southeast, and are locally folded and faulted (Text-Figure 1). Northwest-verging basement-involved uplift of the SNSM and Perijá Range has been dated as Pliocene–Pleistocene (Kellogg and Bonini, 1982). However, the SNSM has been considered to be the northernmost elevation of the ancestral Central Cordillera since the latest Maastrichtian–Early Paleocene (Villamil, 1999) or Late Paleocene (Montes et al., 2005). The depositional systems migrated toward Lake Maracaibo to the east (Van Andel, 1958; Villamil, 1999). The SNSM includes sedimentary and metamorphic rocks of Precambrian, Paleozoic, Triassic and Jurassic ages (Tschanz et al., 1974), and has a structural relief of 12 km (Kellogg and Bonini, 1982). By contrast, the Perijá range exposes sedimentary and low-grade metamorphic rocks of Paleozoic age, as well as Mesozoic volcanic and sedimentary rocks (Kellogg, 1984; Ujueta and Llinás, 1990).

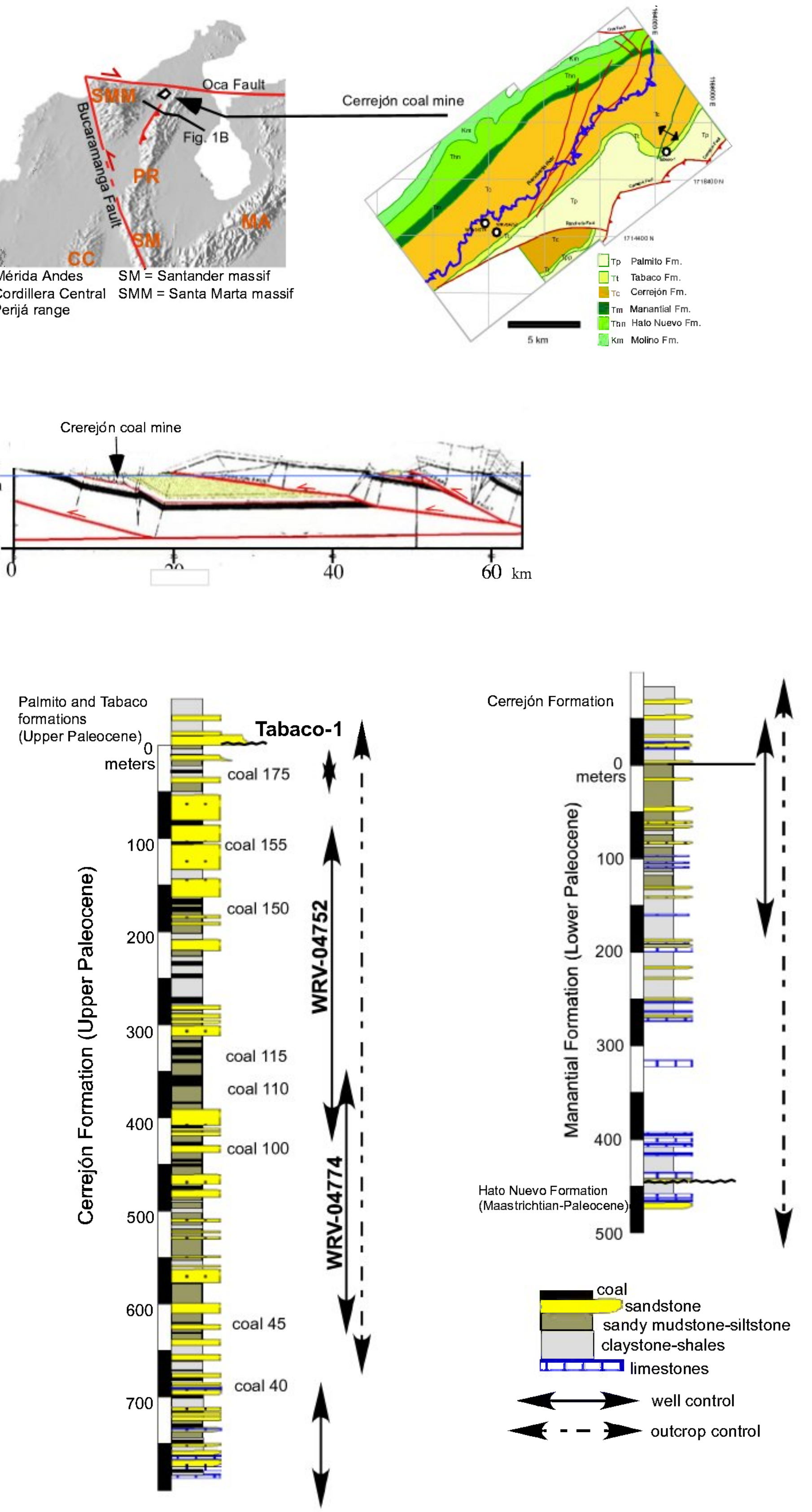
The Cerrejon Formation, which is 1 km thick, conformably overlies the 170 to 440 m thick Manantial Formation with a gradational contact. The formation is separated from the overlying 0–75 m thick Tabaco and 300 m thick Palmito formations by a disconformity (Haught et al., 1944; Ramos, 1990) (Text-Figure 1). The Manantial and Cerrejon formations have been dated as Paleocene using mollusks (Etayo-Serna, 1979) and pollen (Van der Kaars, 1983). The age of the Tabaco and Palmito formations has been considered to be Eocene on the basis of their stratigraphic positions (Caceres et al., 1980). The nomenclature of coal seams used in this paper is taken from Carbones del Cerrejón LLC.

METHODS

Two cores were studied, WRV04752 and WRV04774, drilled by Carbones del Cerrejon LLC through the Cerrejon Formation. These include coal seams 45 to 155; the seams are numbered from old to young. Core WRV04774 was drilled to 357.59 m and includes coal seams 45 to 110. It is located at 11° 3' 57.011"N, 72° 41' 34.12"W at 108.95 m elevation. Core WRV04752 was drilled to 367.74 m and includes coal seams 103–155. It is located at 11° 3' 23.106"N, 72° 41' 3.673"W at 111.12 m elevation. The cores were drilled 1.3 km apart. Other cores and outcrops in the mine were also used to assess the stratigraphy and lithofacies of the upper Manantial, Cerrejon and Tabaco formations, although extensive palynological analyses were not undertaken.

One sample approximately every 3.5 m was collected and processed for palynology from the two cores; two hundred samples were processed. The samples were prepared by digesting 30 g of sample in HCl and HF, then oxidizing if necessary (Traverse, 1988). The fuming HNO_3 technique was used to prepare the coals. Light microscopy was used for routine palynological analyses, and at least 150 palynomorphs per sample were counted where possible. The relatively low number of 150 grains, as opposed to the standard 200–300 grains, was used because the main aim was to obtain an overall view of the palynofloras of the Cerrejon formation. Resources were not available to count to 200–300 grains. The relatively low count level will not help to reject the Null hypotheses. These are that there are no differences among samples, a statistical error type II, and the error of failing to observe a difference when there is one. Low counts would be a problem if they led to a statistical error type I, i.e. observing a difference when there is none.

Twenty-five samples from the coal seams and eighty-eight samples from the inter-coal sediments from core WRV04752 were processed. Seventeen samples from coal seams and seventy samples from the inter-coal sediments from core WRV04774 were processed. Samples from the two cores were combined into a single range chart using coals 110, 105 and 103 as correlation guides, in order to obtain a composite succession of the Cerrejon Formation, from coal seams 45 to 155.



Text-Figure 1. **A)** Regional geologic setting and map of the region studied (after Cerrejón, 1956a, **B)** Geological cross section across the Cerrejón Basin, Perija Sierra, and northwestern Maracaibo Basin. **C)** Generalized stratigraphic section of Paleocene strata of the Cerrejón Basin (after Haught et al., 1944; Ramos, 1990; Cerrejón, 2003b).

Morphologic characteristics of the specimens were compared with illustrations from the literature on tropical Paleogene palynology (Van der Hammen, 1954; 1956a, b; 1957a, b; 1958; Van der Hammen and Wymstra, 1964; Van Hoeken-Klinkenberg, 1964; Van der Hammen and García, 1966; Van Hoeken-Klinkenberg, 1966; Gonzalez, 1967; Germeraad et al., 1968; Doubinger, 1973; 1976; Van der Kaars, 1983; Guerrero and Sarmiento, 1996; Jaramillo and Dilcher, 2000; 2001; Jaramillo, 2002; Pardo-Casas et al., 2003) and an electronic database (Jaramillo and Rueda, 2006). Major nomenclatural usages follow those in Jaramillo and Dilcher (2001). Informal species are those between quotation marks; the most important taxa are illustrated in Plates 1 to 7. The taxa encountered are listed in Appendix 1. Other key information pertaining to this contribution is presented in Appendices 2–6; these are available electronically at http://www.palydisks.palynology.org/ (Jaramillo et al., 2007).

A number of techniques were used to analyze the patterns of pollen and spore diversity, and floral composition. Diversity is used here to denote the number of species (Rosenzweig, 1995). Diversity within a sample was estimated using rarefaction, an interpolation technique that estimates how many species may have been found if the sample had been smaller (Raup, 1975). The rarefaction was calculated with the fungal spores removed, because they represent a large proportion and can mask possible vegetation patterns. Bootstrapped species accumulation curves were used to calculate the total sample diversity (Gilinsky, 1991). Fungal spores were excluded from the diversity analyses, because little taxonomic work has been undertaken on tropical Paleocene fungi.

The overall variation in floral composition was analyzed using detrended correspondence analysis (DCA) (Hill and Gauch, 1980). This summarizes variation in assemblage composition in a small number of dimensions, and it is an appropriate ordination for nonlinear data (Pielou, 1984; Wing, 1998). The ordination was performed on the abundance data, both with and without the fungal spore counts. The Anosim technique was used to assess floral differences between the coal and non-coal samples. This non-parametric technique tests the null hypothesis that there are no differences in composition between two or more groups of samples (Clarke, 1993). It measures the dissimilarities among groups and between groups. If groups are different, intergroup dissimilarity must be smaller than intragroup dissimilarity. The Anosim statistic (R) is based on the difference of mean ranks between groups (rB) and within groups (rW), giving the equation $R = (rB - rW)/(N(N-1)/4)$. The R statistical significance was found by bootstrapping (Clarke, 1993); 1000 permutations were done and the Sorensen similarity index was used as a metric of comparison (Magurran, 2004).

Rarefaction has been performed on palynological data from the BHP core, from the Paleocene of North Dakota (Harrington et al., 2005). Rarefaction was also performed on palynological data from two Holocene cores, Monica and Piusbi, from lowland neotropical rainforests (Berrio, 2002), and four Holocene cores, Woodwort, Pickerel, Medicine, and Devil from the Dakotas (McAndrews, 2000a, b; Radle, 2000; Watts, 2000). Comparison of the Cerrejon rarefied diversity with other sites was done using non-coal samples. Coal samples were not used in order to decrease the lithological bias in the comparison.

Carbon 13-isotopes values, determined for the whole section, were determined. Bulk-sediment samples were air-dried, powdered, and acidified with 1 molar HCl at room temperature for 48 hours to remove carbonates. The insoluble residue was neutralized with distilled/de-ionized water and freeze-dried. The carbon isotopic composition of the decalcified, dried residues was determined in duplicate by combusting the residue in a Costech Elemental Analyzer fitted to a Finnigan Delta Plus XL mass-spectrometer. Results are reported in per mil (‰) relative to the Vienna Pee Dee belemnite standard (VPDB).

All analyses were done using *R for Statistical Computing* (R-Development-Core-Team, 2005), and the packages Vegan (Oksanen et al., 2005) and Labdsv (Roberts, 2005). All R codes used here are presented in Appendix 4 (Jaramillo et al., 2007). Samples that had less than 50 grains (excluding fungi) were excluded from the analyses. This was chosen as a minimum because rarefaction analysis shows that the differences between coal and non-coal samples become statistically insignificant when the sampling level is less than 50 grains (see Results).

The cores and slides are stored at 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 center of information and research in geological sciences officially responsible for managing and preserving the rock and microfossil collections of Colombia.

RESULTS

Stratigraphic Framework

The upper Manantial, Cerrejón and Tabaco formations exhibit an upward decrease of calcareous beds, an increase of terrigenous influx, and a general upward-coarsening in grain size of sandstone beds in the uppermost Cerrejón and Tabaco formations. The upper Manantial Formation includes fossiliferous packstones and wackestones interbedded with calcareous sandstones and mudstones in thin to medium tabular beds. Internal sedimentary structures are dominantly lenticular, wavy and ripple laminations, and moderate bioturbation at some levels. Cross beds are identified in sandstones near the top. Mollusk fragments are broken and concentrated in thick to medium beds. These deposits accumulated in a mixed shallow platform to fine-grained subtidal environments (lagoons), crossed by subtidal channels at the top.

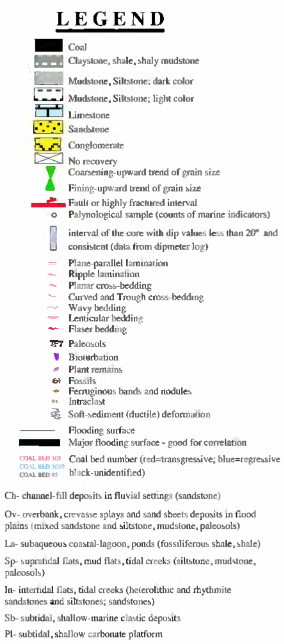
The Cerrejón Formation is approximately 1000 m thick (Ramos, 1990; Bayona et al., 2004) and consists dominantly of argillaceous sandstones, dark-colored siltstones, black shales, and coal seams. Three complete depositional sequences bounded by major flooding surfaces were identified in the two cores (Text-Figure 2); each sequence may be divided into three parts. The lower part consists either of fossiliferous black shales and laminated black mudstones with thin lenticular laminae of sandstones (anoxic lagoonal, flooded coastal-plains environments), and/or flaser-laminated sandstones (subtidal). These beds overlie or underlie thick coal seams. The middle part is dominated by poorly bioturbated mudstones and sandstones with flaser and heterolithic lamination and dispersed plant remains (subtidal and tidal flats). Both coarsening- and fining-upward grain size trends are common. Coal seams have variable thickness in this part of the succession, and few occurrences of dinoflagellate cysts and foraminifer linings are present. The upper part is dominated by fine-grained, massive to lenticularly-laminated, bioturbated mudstones and siltstones with abundant plant remains, which are cut by thick, massive to cross-bedded sandstones (coastal plains crossed by channels). Medium to thin coal seams are common at the top of this succession (Text-Figure 2). Flaser and heterolithic laminations in sandstone beds are more common in the lower Cerrejón Formation. Massive and cross-bedded sandstones filling channel structures are more common in the middle and upper Cerrejon Formation. The top of the Cerrejón Formation and the Tabaco Formation include fining-upward successions from conglomeratic coarse-grained sandstones to massive light-colored mudstones and siltstones. These deposits are interpreted as the filling of channel structures cutting alluvial plains.

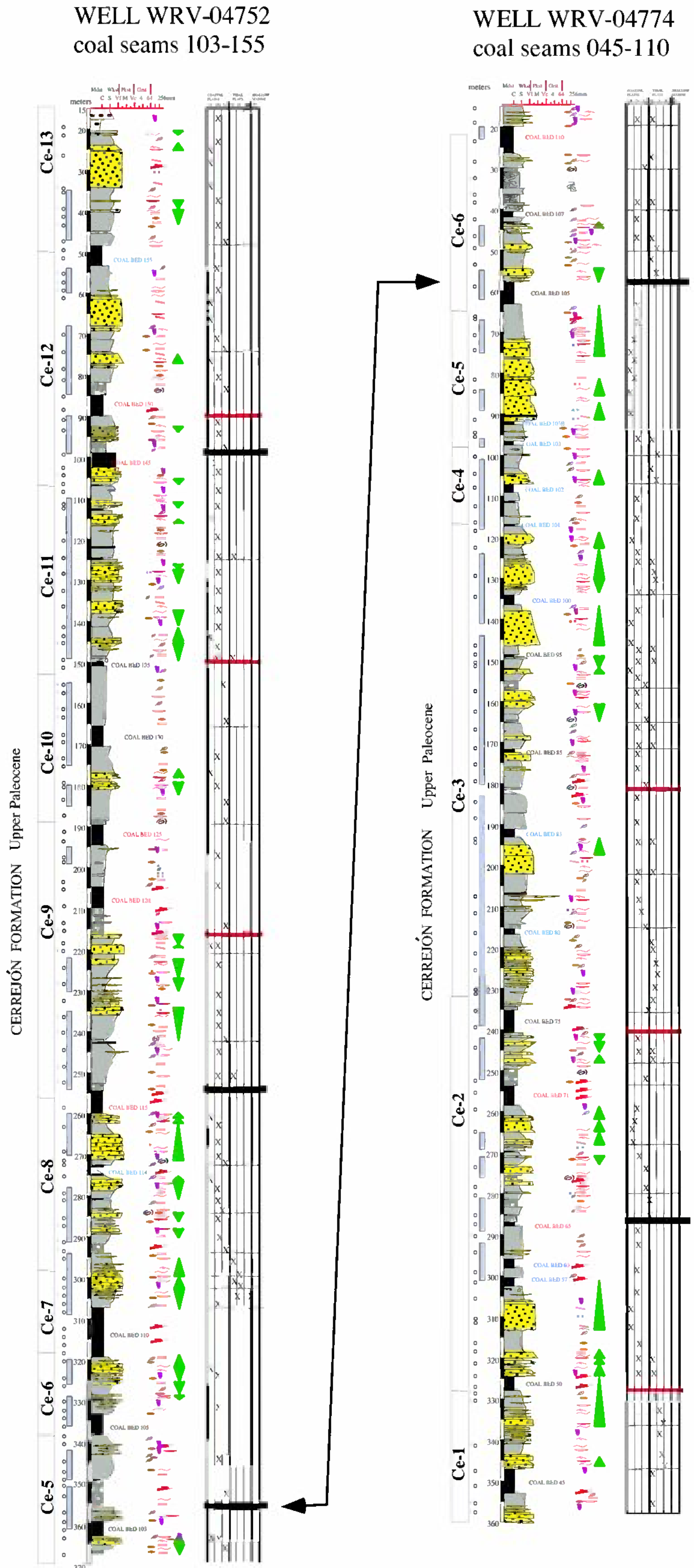
Sandstone composition changes from sublitharenites in the Manantial Formation, to feldspathic litharenites and lithic arkoses in the Cerrejón Formation, and to subarkoses in the Tabaco Formation (Lamus, 2006). Major changes in petrofacies coincide with major flooding surfaces. Flooding events and sandstone composition have been interpreted as the record of uplift of the Sierra Nevada de Santa Marta since the Late Paleocene, and of the Perija range since the latest Paleocene (Montes et al., 2005; Lamus, 2006).

Palynology of Core WRV04774 (Coal Seams 45 to 110)

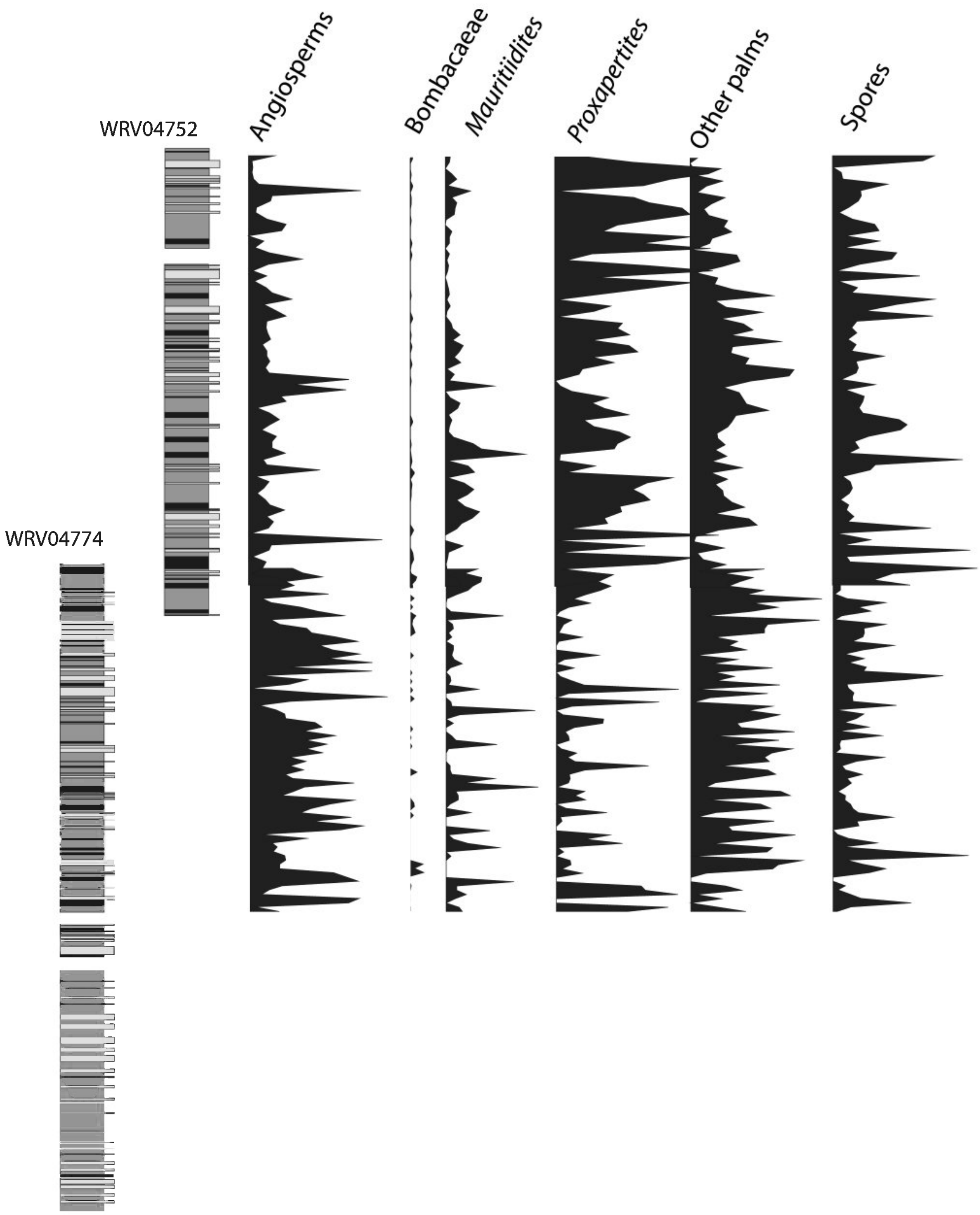
A range chart is given for this core in Appendix 5 (Jaramillo et al., 2007), and the counts are provided in Appendix 2 (Jaramillo et al., 2007). Seventy percent of the samples were palynologically productive. The palynomorph taxa are listed in Appendix 1 and illustrated in Plates 1–7. Fungal spores are abundant in virtually all the samples. Excluding the fungal spores, angiosperms are dominant in over 80 % of the samples (Text-Figure 3). *Mauritiidites franciscoi*, the *Proxapertites* group (*Proxapertites cursus*, *Proxapertites operculatus*, and *Proxapertites psilatus*), the *Psilamonocolpites* group (psilate, micropitted monocolpate pollen), and the small tricolporate pollen group (< 15 μm) are the most frequent palynomorphs (Text-Figure 3).

The interval between 357.59 m and 328.60 m is characterized by good recovery of palynomorphs, characterized by high frequencies of *Proxapertites operculatus, Proxapertites psilatus,* and *Psilamonocolpites medius*, with moderate frequencies of *Retidiporites magdalenensis*. Some dinoflagellate cysts and fungal spores were also recovered. Coal seam 45 yielded moderate numbers of *Brevitricolporites* sp. and *Psilatriletes* sp. (>50 um); *Proxapertites operculatus* was not observed. Coal seam 50 yielded assemblages dominated by *Mauritiidites franciscoi* var. *pachyexinatus* and *Siltaria cerrejonensis*. Poor recovery of sporomorphs was obtained between 321.66 m and 311.28 m. High frequencies of *Psilamonocolpites medius* are common from 310.30 m to 280.47 m, accompanied by moderate numbers of *Mauritiidites franciscoi* var. *pachyexinatus* and *Proxapertites operculatus*. High frequencies of *Camarozonosporite*s sp. and *Psilastephanocolpites globulus* were recovered at 310.30 m (coal seam 57) and 285.08 m respectively. Coal seams 60 and 65 yielded poor to fair palynomorph assemblages with some specimens of *Aglaoreidia*? *foveolata* and *Ctenolophonidites lisamae*. Poor to fair recovery of palynomorphs was obtained from between 278.12 m and 259.81 m. A high frequency of *Gemmastephanocolpites gemmatus* was recovered at 255.35 m. from coal seam 71 and moderate frequencies of *Ericipites fossulatus, Mauritiidites franciscoi* var. *pachyexinatus,* and *Psilastephanocolpites globulus* were obtained from the coal seam 75, at 239.29 m. High frequencies of *Psilamonocolpites medius* are common between these coal seams. The section from 231.16 m to 207.50 m is characterized by poor to fair recovery of palynomorphs, with some high frequencies of *Psilamonocolpites medius*





Text-Figure 2. Sedimentary structures, depositional environment interpretations, and identification of flooding surfaces for wells WRV04774 and WRV04752. The thick black lines in the right hand columns are major flooding surfaces that are interpreted as the boundaries of depositional sequences. The location of palynology samples and codes of coal seams are also indicated.



Text-Figure 3. The relative abundances of the most abundant palynomorph groups in wells WRV04774 and WRV04752.

toward the base. The first local stratigraphic record of *Verrutriletes virueloides* occurs at 216.9 m. Fair to good recovery of palynomorphs was obtained between 194.97 m and 151.82 m, with assemblages dominated by *Psilamonocolpites medius*. Moderate frequencies of *Brevitricolporites* sp., *Echistephanoporites inciertus*, *Laevigatosporites tibuensis*, *Mauritiidites franciscoi*, *Proxapertites cursus*, *Siltaria cerrejonensis*, and *Spathiphyllum vanegensis* were also recognized within this interval, which includes coal seams 83 and 95. A high frequency of *Proxapertites operculatus* was identified at 150.45 m. This is followed by a poor to fair recovery of palynomorphs to 134.60 m, where another high frequency of *Proxapertites operculatus* was identified within coal seam 100, accompanied by common *Diporipollis assamica*. The interval between 129.52 m and 96.65 m includes coal seams 101 to 103, and is characterized by poor to fair recovery of palynomorphs, with moderate frequencies of *Psilamonocolpites medius* and the *Psilatriletes* 25–50 micron group. The first local stratigraphic record of *Ischyosporites problematicus* occurs at 118.25 m. The section above 96.65 m yielded palynofloras similar those from the lower interval in the well WRV 04752

Palynology of Core WRV04752 (Coal Seams 103 to 155)

A range chart and abundance data are given for this core in Appendices 6 and 3 respectively of Jaramillo et al. (2007). Angiosperm pollen grains, mainly *Mauritiidites franciscoi*, the *Proxapertites* group, and the *Psilamonocolpites* group are dominant in almost all the samples. Fungal spores are abundant in the upper section, and several samples contain dinoflagellate cysts or colonies of *Pediastrum* sp.

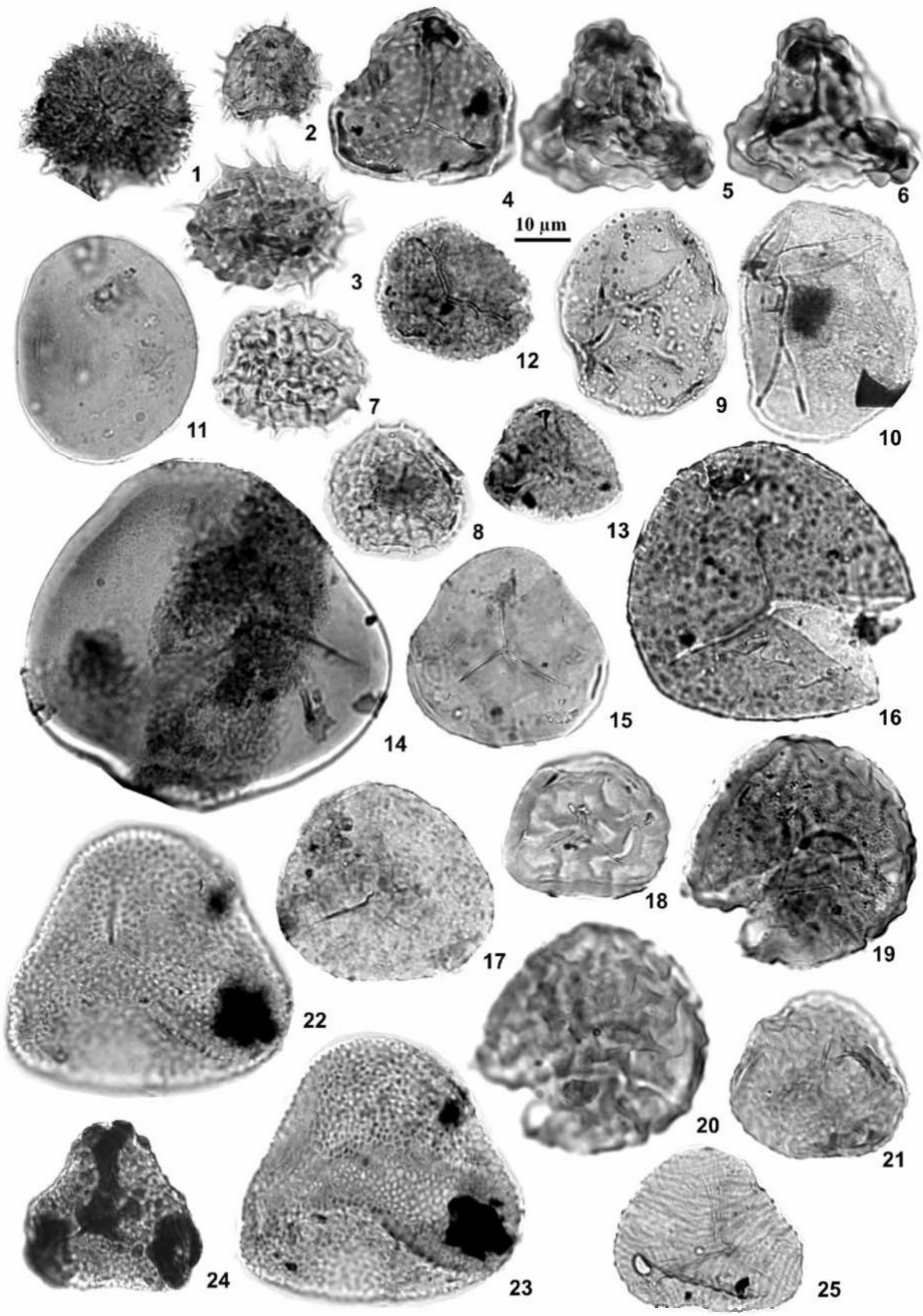
The interval between 367 m and 334.44 m, including coal seams 103 and 105, is characterized by both assemblages dominated by fern spores (*Ischyosporites problematicus* and the *Psilatriletes* group), and rich in *Mauritiidites franciscoi*, *Proxapertites*, and *Psilamonocolpites medius*. High frequencies of *Psilastephanocolpites globulus* and *Psilabrevitricolporites simpliformis* were also recorded. Poor to fair recovery was obtained between 332.3 m and 308.43 m, with increasing levels of *Syncolporitae lisamae* at 324.42 m. Coal seam 110 yielded an assemblage characterized by *Momipites* sp. and *Psilatricolporites pachyexinatus*. *Mauritiidites franciscoi, Proxapertites cursus*, *Proxapertites operculatus,* and *Psilamonocolpites medius* are abundant between 306.34 and 279.18 m. Some dinoflagellate cysts were recovered at 291.54 m.

The interval from 271.36 m to 263.12 m yielded assemblages dominated by fern spores, including *Echinatisporis minutus, Ischyosporites problematicus, Laevigatosporites tibuensis Polypodiaceoisporites*? *fossulatus*, and the *Psilatriletes* group. High numbers of *Mauritiidites franciscoi* var. *pachyexinatus,* together with *Retidiporites botulus* characterizes coal seam 115. Assemblages from 252.66 m to 213.44 m are dominated by *Mauritiidites franciscoi, Proxapertites cursus, Proxapertites operculatus, Psilamonocolpites medius,* and the *Psilatriletes* group.

PLATE 1

All sample numbers are prefixed 'Cerrejón'. The sample number (e.g. WRV 04774, 94.41) is followed by the England Finder (EF) coordinate.

1	*Echitriletes* sp., WRV 04774, 94.41, EF L15/1,2.
2	*Echitriletes* sp., WRV 04774, 175.75, EF S22/4.
3	*Echitriletes* sp., WRV 04774, 221.09, EF E30/2.
4	*Foveotriletes concavoides* sp. nov., holotype, WRV 04774, 264.94, EF J30/1.
5, 6	*Ischyosporites problematicus* Jaramillo & Dilcher 2001, WRV 04774, 118.25, EF J16.
7	*Retitriletes cristatus* sp. nov., holotype, WRV 04774, 81.08, EF L18/3.
8	*Retitriletes cristatus* sp. nov., paratype, WRV 04774, 70.08, EF V32/1.
9	*Laevigatosporites granulatus* sp. nov., holotype, WRV 04774, 330.65, EF Q22/4.
10	*Laevigatosporites tibuensis* (folded), WRV 04774, 301.88, EF E26/4.
11	*Laevigatosporites tibuensis*, WRV 04774, 151.82, EF K37/2.
12	*Baculatisporites* sp., WRV 04774, 301.88, EF O28/2.
13	*Baculatisporites* sp., WRV 04774, 310.3, EF R37/3.
14	*Psilatriletes* sp. (>50 μm), WRV 04774, 116.82, EF J36/4.
15	*Psilatriletes* sp. (25–50 μm), WRV 04774, 122.47, EF L15.
16	*Verrutriletes virueloides* sp. nov., holotype, WRV 04774, 46.75, EF P29/1.
17	Trilete spore (scabrate–verrucate), WRV 04774, 148.50, EF Q30.
18	*Camarozonosporites* sp., WRV 04774, 91.38, EF F20.
19, 20	*Camarozonosporites* sp., WRV 04774, 310.3, EF V34/4.
21	*Rugutriletes sp.*, WRV 04774, 150.45, EF W32/1.
22, 23	*Retitriletes* sp., WRV 04774, 310.3, EF X48/3.
24	*Trilobosporites* sp., WRV 04774, 46.75, EF E24/2.
25	*Striatriletes* sp., WRV 04774, 104.56, EF D26/1.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High frequencies of *Scabratriporites annellus* were recorded between 203.3 m and 197.08 m, and coal seam 125 is characterized by dominant *Ctenolophonidites lisamae*. The section between 187.22 m and 173.44 m yielded high frequencies of *Psilamonocolpites medius* at the base, which are gradually replaced by high frequencies of *Proxapertites operculatus* at the top, accompanied by *Mauritiidites franciscoi*, *Proxapertites cursus*, *Psilatriletes* gr., and fungal spores.

Assemblages dominated by *Proxapertites operculatus* and/or *Psilamonocolpites medius* with some dinoflagellate cysts were recovered from 163.18 m to 151.1 m. Alternation of assemblages dominated by fern spores and assemblages rich in *Proxapertites operculatus* and *Psilamonocolpites medius* characterizes the interval from 149.14 m to 136.37 m. Coal seam 145 is dominated by *Proxapertites operculatus*. The last stratigraphic occurrence of *Retitriletes cristatus* is at 104.74 m. and some reworked dinoflagellate cysts (*Dinogymnium* sp.) occur between 132.43 and 93.53 m. The interval between 81.02 m and 55.38 m is characterized by high frequencies of *Proxapertites cursus* and *Proxapertites operculatus*. The uppermost section, between 47.44 m and 19.66 m, yielded assemblages dominated by *Proxapertites operculatus* and high frequencies of *Curvimonocolpites inornatus* and *Spathiphyllum vanegensis* at 39.22 m, *Proxapertites cursus* at 35.12 m, *Diporipollis assamica* at 34.00 m and *Chomotriletes minor* at 19.66 m.

Overall Diversity and Floral Composition

One hundred and ninety six samples were analyzed, these comprise 50 and 146 from coal and non-coal lithotypes respectively. A total of 222 morphotypes were observed; 38,251 palynomorphs were counted including 18,593 pollen/spore grains, 19,655 fungal spores, and minor occurrences of dinoflagellate cysts and foram linings. The difference in the number of palynomorphs counted per sample from coal and non-coal samples does not differ (t-test, mean 213 versus 190; p-value < 0.5).

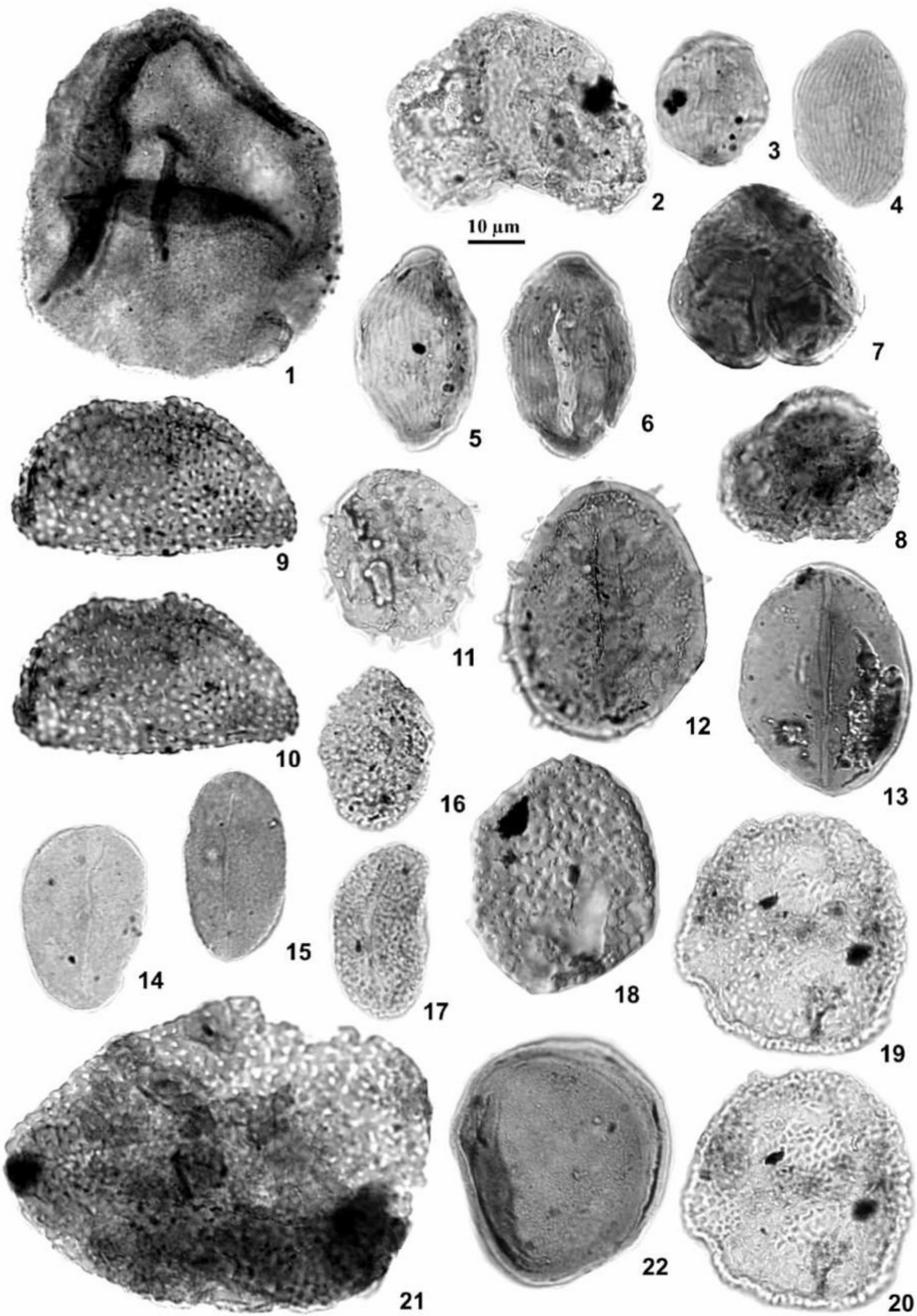
The first axis of the detrended correspondence analysis (DCA) explains 30.02% of the variation (Text-Figure 4). The first axis has a variance of values that seems related to lithology, i.e. coal versus non-coal samples. The DCA first axis scores were compared with sample lithology, coal or non-coal (Text-Figure 4). There is a significant difference in DCA scores across lithologies (t-test, average coal samples = -0.4375670; average non-coal samples = 0.2257021; p-value $< 4.842 \times 10^{-13}$).

The DCA analysis was repeated excluding fungi, which are significantly more abundant in coals than in non-coal samples (t-test, mean fungi abundance coal samples = 221.3; mean fungi abundance non-coal samples = 94.2; p-value <0.0002918). The first DCA axis explains 38% of the variation and shows a significant difference in coal versus non-coal samples. This is similar to the results when the fungi are included in the analysis (t-test, average coal

PLATE 2

All sample numbers are prefixed 'Cerrejón'. The sample number is followed by the England Finder (EF) coordinate.

1 *Araucariacites* sp., WRV 04774, 150.45, EF G17/3,4.
2 *Podocarpites* sp., WRV 04774, 278.12, EF H18/2.
3 *Spathiphyllum vanegensis* (Van der Hammen & Garcia 1966) Hesse & Zetter 2007, WRV 04774, 273.50, EF R16.
4 *Spathiphyllum vanegensis* (Van der Hammen & Garcia 1966) Hesse & Zetter 2007, WRV 04774, 151.82, EF F36/4.
5 *Spathiphyllum vanegensis* (Van der Hammen & Garcia 1966) Hesse & Zetter 2007, WRV 04774, 166.80, EF D28/3,4.
6 *Spathiphyllum vanegensis* (Van der Hammen & Garcia 1966) Hesse & Zetter 2007, WRV 04774, 150.45, EF G35/1,2.
7 *Tetradrites psilatus*, WRV 04774, 239.29, EF H30.
8 *Ericipites fossulatus* sp. nov., holotype, WRV 04774, 96.65, EF X27.
9, 10 *Aglaoreidia? foveolata* Jaramillo & Dilcher 2001, WRV 04774, 328.6, EF J18/2.
11 *Mauritiidites franciscoi* var. *franciscoi* Van der Hammen 1956, WRV 04774, 184.55, EF K22.
12 *Mauritiidites franciscoi* var. *pachyexinatus* Van der Hammen & Garcia 1966, WRV 04774, 171.57, EF F21/2.
13 *Psilamonocolpites marginatus* sp. nov., holotype, WRV 04774, 36.55, EF T52/1.
14 *Psilamonocolpites medius*, WRV 04774, 112.90, EF X29/2.
15 *Psilamonocolpites medius*, WRV 04774, 252.66, EF P33.
16 *Racemonocolpites racematus* (Van der Hammen 1954) Gonzalez 1967, WRV 04774, 225.91, EF D15/2.
17 *Retimonocolpites* sp., WRV 04774, 118.25, EF F33/1.
18 *Proxapertites cursus* Van Hoeken Klinkenberg 1966, WRV 04774, 38.63, EF R24.
19, 20 *Proxapertites cursus* Van Hoeken Klinkenberg 1966, WRV 04774, 216.9, EF K16/2.
21 *Proxapertites magnus* Muller et al. 1987, WRV 04774, 301.88, EF T37/2.
22 *Proxapertites operculatus* (Van der Hammen 1956) Germeraad et al. 1968, WRV 04774, 36.55, EF P62/2.



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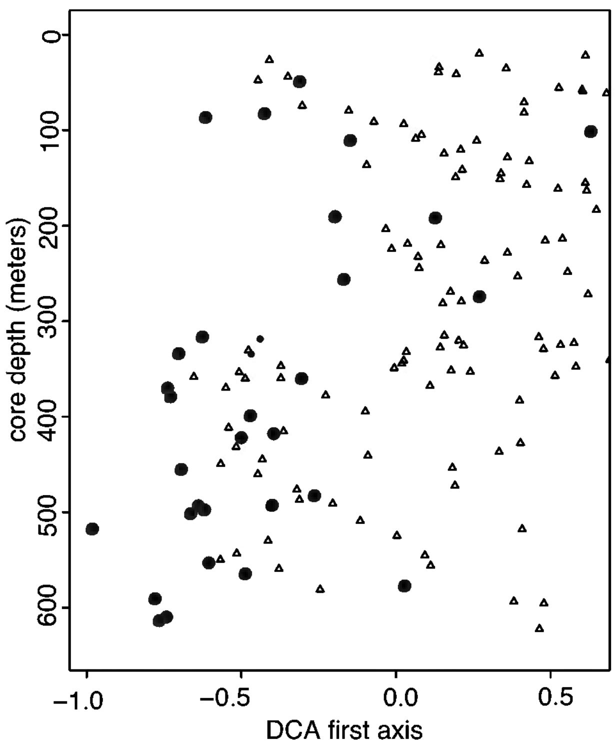


Text-Figure 4. First axis of the detrended correspondence analysis versus the stratigraphic positions within the Cerrejón Formation; it explains 30% of the variation. The triangles indicate non-coal samples, and the filled circles indicate coal samples. The coal samples have, on average, lower DCA values than the non-coal samples.

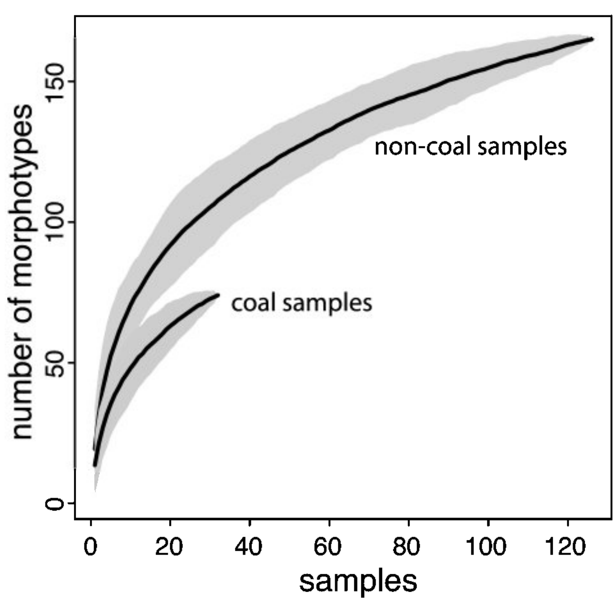
sample = -0.1493991; average non-coal sample = 0.915288; p-value < 6.512×10^{-10}).

Several additional analyses were done to establish the differences between coal and non-coal samples. The species accumulation curve indicates that within-sample diversity in coal-samples on average is lower than in non-coal samples (Text-Figure 5). For example, when 23 samples are pooled, coal samples have an average of 68 morphospecies versus 101 morphospecies (standard deviation 6.8) for non-coal samples.

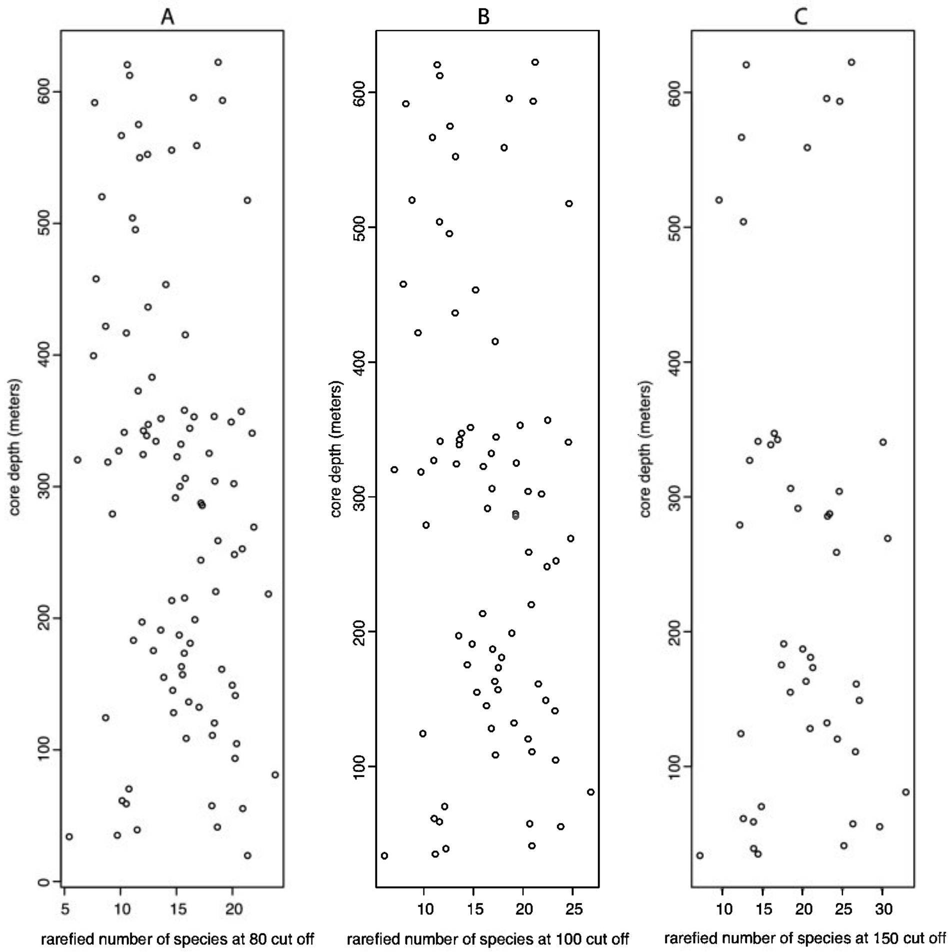
Rarefaction analysis of different numbers of specimens shows that there is no significant variation in within-sample diversity along the stratigraphic profile, regardless of sample counting intensity, or the number of samples analyzed (Text-Figure 6). Rarefaction analysis was also undertaken comparing coal versus non-coal samples. The results indicate that coal samples have, on average, a significantly lower number of morphospecies than non-coal samples, regardless of the count size (Text-Figure 7). For example, at a 100 grain cut off, mean morphospecies diversity is 11.6, (standard deviation 3.43) for coal samples, while it is 17.2, (standard deviation 4.4) for non-coal samples; this difference is significant (t-test, p.value < 1.263093×10^{-05}).

The Anosim analysis indicates that there are significant differences between the coal and non-coal assemblages (statistic R: 0.4541; p.value < 0.001; Text-Figure 8). Coal samples are dominated by *Brevitricolporites* sp. (unknown angiosperm), *Ctenolophonidites lisamae* (Ctenolophonaceae), *Diporopollis assamica* (fungi), *Gemmastephanocolpites gemmatus* (unknown angiosperm), *Mauritiidites franciscoi* var. *franciscoi*, *Mauritiidites franciscoi var pachyexinatus* (palms), *Proxapertites operculatus* (Araceae), *Psilamonocolpites medius* (palm), *Psilastephanocolpites globulus*, *Psilatricolporites pachyexinatus* (unknown angiosperms), *Psilatriletes* sp. 25–50 µm, *Psilatriletes* >50 µm (ferns), *Siltaria cerrejonensis*, and small *Tricolporites* (unknown angiosperms) (Text-Figure 9). *Ctenolophonidites* is a genus now extinct in South America, but has relatives living in the tropical freshwater swamps of West Africa (Thanikaimoni et al., 1984; Rull, 1999).

The dominant taxa in non-coal samples are fungi, and fungi are significantly less abundant than in coal samples (t-test, p-value < 0.0002918). Dominant taxa are *Arecipites regio* (a palm) *Diporopollis assamica*, *Echistephanoporites inciertus*, *Laevigatosporites tibuensis* (fern), *Mauritiidites franciscoi* var. *franciscoi*, *Momipites africanus* (Moraceae), *Proxapertites cursus*, *Proxapertites operculatus*, *Proxapertites psilatus*, *Psilabrevitricolporites simpliformis*



Text-Figure 5. Morphospecies accumulation curves; the bands around the lines represent standard deviations from the mean. The non-coal samples have larger intra-sample diversities.



Text-Figure 6. Rarefied species diversities at three different cut off points. **A)** cut off of 80 grains; **B)** cut off of 100 grains; **C)** cut off of 150 grains. The cut offs represent the number of specimens counted. Note that this is not a variation in richness within the Cerrejón Formation.

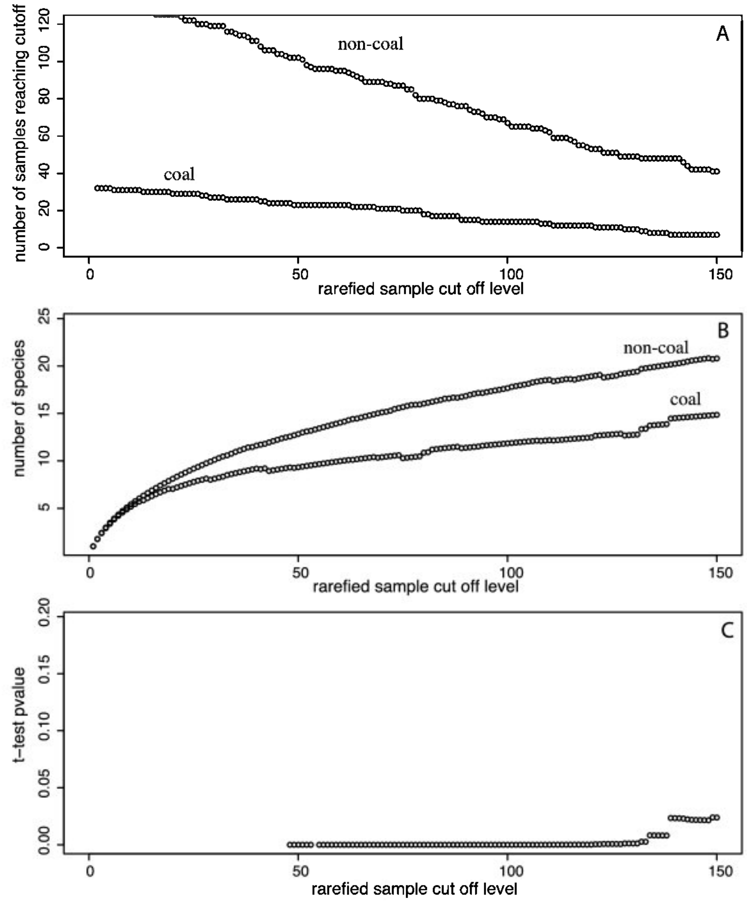
(unknown angiosperm), *Psilamonocolpites medius*, *Psilatriletes* sp. 25–50 µm, *Spathiphyllum vanegensis* (Araceae, Wilde et al., 2005; Hesse and Zetter, 2007), and small *Tricolporites* sp. (Text-Figure 9).

Comparison with Other Palynofloras

Rarefaction diversity values of the Cerrejón Formation palynofloras, at two cut off points (150 and 180 grains), were compared with Paleocene palynofloras from North Dakota, and Holocene palynofloras from the lowland Neotropics and North Dakota (Text-Figure 10). There is a significant difference between the rarefied diversities of Holocene Neotropical and Paleocene Cerrejón Formation samples (t-test, p-value $< 2.2 \times 10^{-16}$). A significant difference between Paleocene and Holocene diversities from the neotropics, and the Paleocene and Holocene diversities from Dakota was observed (t-test, p-value $< 9.922 \times 10^{-09}$ and p-value $< 2.2 \times 10^{-16}$). A significant difference between Paleocene Cerrejón Formation and Paleocene Dakota samples (t-test, p-value $< 9.922 \times 10^{-09}$) was also noted.

Carbon Isotopes

Carbon isotopes ($\delta^{13}C$) exhibit small variations throughout the Late Paleocene Cerrejón Formation, with an average of -25.200 (standard deviation 1.28) (Text-Figure 11). A comparison of Cerrejón Formation values with Late Paleocene isotopic values from northern South America (Jaramillo et al., 2006) shows that there is no significant difference between the Cerrejón Formation and 60–58 Ma isotopic values (t-test p-value < 0.81; mean for northern South America = -25.158).



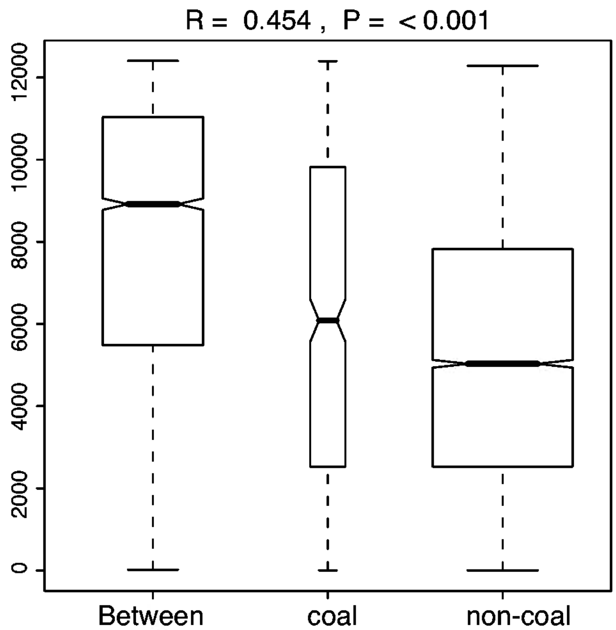
Text-Figure 7. Rarefied diversities of coal versus non-coal samples. **A)** number of samples that reached each cut off level; **B)** rarefied diversities at each cut off level; **C)** P-value of a t-test between rarefied diversities of coal versus non-coal samples at different cut off levels. Note that there is a significant diversity difference between coal and non-coal samples regardless the sample size, or sample counting.

DISCUSSION

Composition and Diversity

The conformable stratigraphic succession of the Manantial, Cerrejón, and Tabaco formations shows the onset of siliciclastic deposition over carbonate deposition, and the general progradation of continental settings over shallow-marine and tidal-dominated environments (Text-Figure 2). The palynoflora of the Cerrejón Formation suggests mostly coastal plain conditions with occasional, short, flooding events indicated by some discrete levels with dinoflagellate cysts. These are above coal 45, below coal 114, above coal 115, above and below coal 130, and below coal 155 (Text-Figures 2, 3, Annexes 2 and 3). *Mauritiidites franciscoi*, *Psilamonocolpites medius*, and *Psilatriletes* are common in wetland areas behind mangroves, near the upper limit of tidal influence (Rull, 2000a, b; 2000a, b; 1999; 2000). There is also an apparent cyclicity in the abundance of the major groups in the Cerrejón Formation flora (Text-Figure 3). This cyclicity has been shown by other studies (Rull, 2000).

Throughout the Cerrejón Formation, no obvious trends were detected in the diversity, the pollen/spore recovery, or temporal changes in palynoflora (Text-Figures 3, 4, 6). This suggests that, in general, the floral communities remained fairly stable throughout. However, this apparent stability may be an artefact of the low number of pollen/spores counted per sample, and this could potentially mask any differences. This however is unlikely, given that differences between coal and non-coal samples were easily detected, demonstrating that the counting of 150 grains per sample was sufficient to detect fine-scale differences in floral communities. Indeed, these differences are apparent in all grain counts greater than 50 (Text-Figure 5, 7, 8, 9).



Text-Figure 8. Anosym analysis of coal versus non-coal samples. The results show that intra-group similarities are significantly larger than inter-group similarities, suggesting that floras living in coal-producing environments were different from floras in other sedimentary settings.

There is a significant difference in the palynomorph diversity and composition of coal and non-coal samples. Coals have palynofloras that are distinct from the interbedded shales and sandstones (Text-Figures 5, 6, 8, 10). Coals have a lower intra-sample diversity (Text-Figure 7), a lower inter-sample diversity (Text-Figure 5), and significantly higher abundances of fungi. Paleocene coal samples exhibit similar variations in diversity in temperate regions, for example the Paleocene of the Powder River and Bighorn basins, Wyoming (Pocknall and Nichols, 1996; Wing and Harrington, 2001). Modern tropical coal-forming swamp forests are also relatively low in diversity compared to other tropical forests (Wittmann et al., 2006), and have a number of water-stress adaptations such as pneumatophores, adventitious (aerial) roots, or still roots (Osborne, 2000).

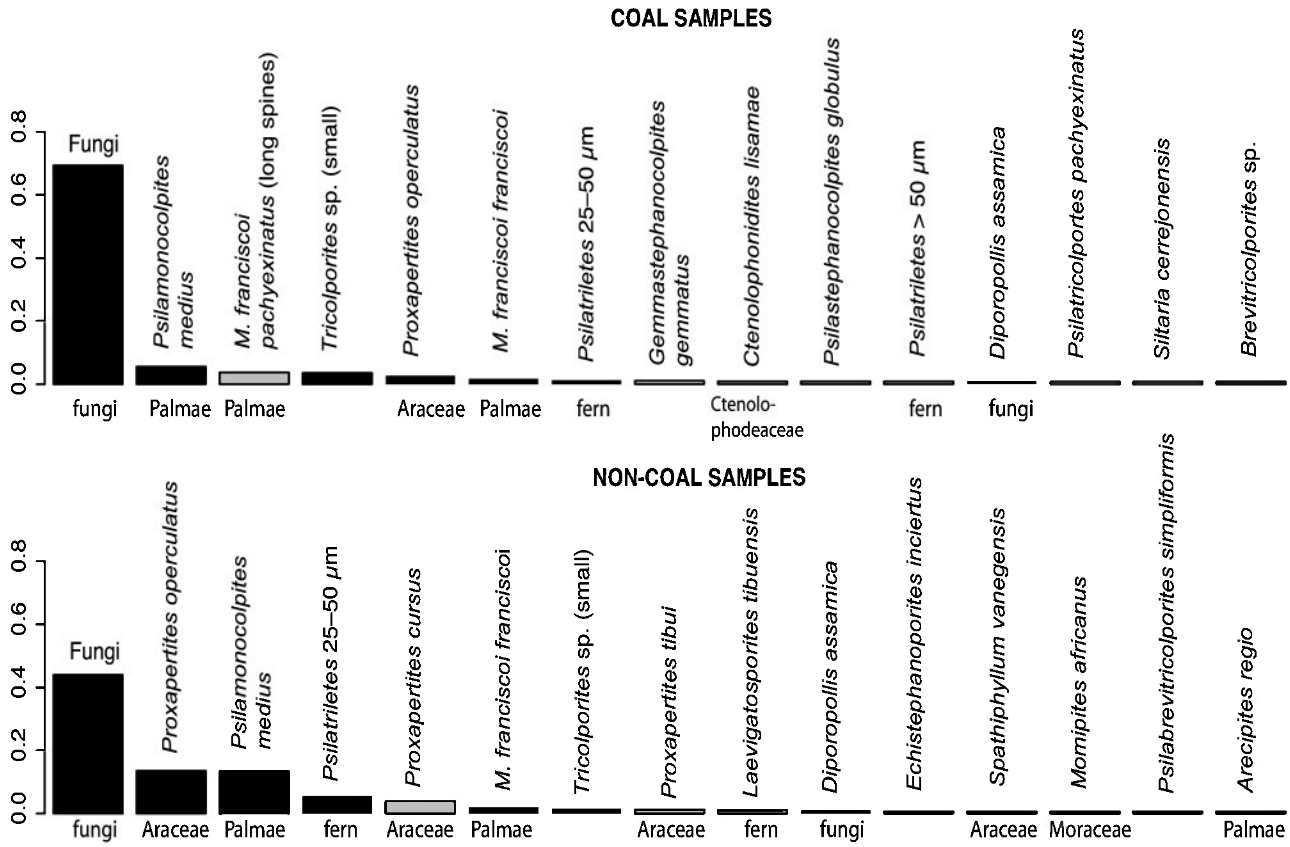
The assemblage composition is also different as shown by the Anosim (Text-Figure 8) and the DCA (Text-Figure 4) analyses, that were statistically significant (p.value < 0.001 and $< 6.512 \times 10^{-10}$ respectively). The most abundant taxa present in both sets of samples, coal and non-coal, are mainly fungi, Araceae, ferns and some palms. But there is a different set of angiosperm taxa that are more common in either the coal or the non-coal, but not in both (Text-Figure 9). Coal samples contain higher abundances of *Brevitricolporites* sp., *Ctenolophonidites lisamae* (Ctenolophodeaceae), *Gemmastephanocolpites gemmatus*, *Mauritiidites franciscoi* var. *pachyexinatus* (Palmae), *Psilastephanocolpites globulus*, *Psilatricolporites pachyexinatus*, and *Siltaria cerrejonensis*. Conversely, non-coal samples have higher abundances of *Arecipites regio* (Palmae), *Echistephanoporites inciertus*, *Laevigatosporites tibuensis* (fern), *Momipites africanus* (Moraceae), *Proxapertites cursus*, *Proxapertites psilatus* (Araceae), *Psilabrevitricolporites simpliformis*, and *Spathiphyllum vanegensis* (Araceae). These differences in pollen assemblage probably reflect differences in *in-situ* plant assemblages, as has been recognized in other coal deposits (Traverse, 1988).

The Cerrejón Formation palynoflora is different from Late Paleocene palynofloras such as those in temperate northern regions that are dominated by Cercidiphyllaceae, Juglandaceae, Nyssaceae, Taxodiaceae, and Ulmaceae (Harrington, 2004). There are few taxa common with northern temperate floras at this time, mainly *Proxapertites*, confirming the low level similarity (0.7%) found in previous studies that compared northern South American and Gulf Coast palynofloras (Jaramillo and Dilcher, 2001).

Results also suggest that the latitudinal intra-sample diversity gradient was reduced in the Paleocene compared to Holocene values (Text-Figure 10). This gradient is pervasive in modern biotas and is well documented (Willig et al., 2003). However, few authors have studied the nature of this pattern in the geological past. The inter-sample diversity gradient in North America during the late Paleocene/early Eocene was steeper than today (Harrington, 2004). However, (Harrington, 2004) analyzed inter-sample rather than intra-sample diversity, hence making a direct comparison of results unclear. A lower intra-sample diversity gradient in the Paleocene, a time of relative global warm climate (Zachos et al., 2001), could be due to a greater rate of plant extinction in the tropics across the Cretaceous–Paleogene mass extinction, as some preliminary data suggest (Jaramillo and de la Parra, 2006). However, more data points along the American continent need to be analyzed before confirming a reduced diversity gradient for the Paleocene.

The Age of the Cerrejón Formation

The palynomorph assemblages correspond to the *Foveotricolpites perforatus* Zone of Germeraad et al. (1968) and Muller et al. (1987), and the Cu-02 zone of Jaramillo et al. (2005). *Bombacacidites annae* and *Foveotricolpites perforatus* occur throughout the entire interval studied. This zone is presently dated as Late Paleocene (Muller et al. 1987), and this is confirmed by the carbon isotope values



Text-Figure 9. The most abundant taxa in non-coal and coal samples. Note that some taxa are abundant in both sample types (e.g. fungi and *Proxapertites operculatus*), but there are some that are present in either, but not both.

(Text-Figure 11); these correspond to the values of the positive carbon isotope excursion at 60–58 Ma (Zachos et al., 2001; Jaramillo et al., 2006).

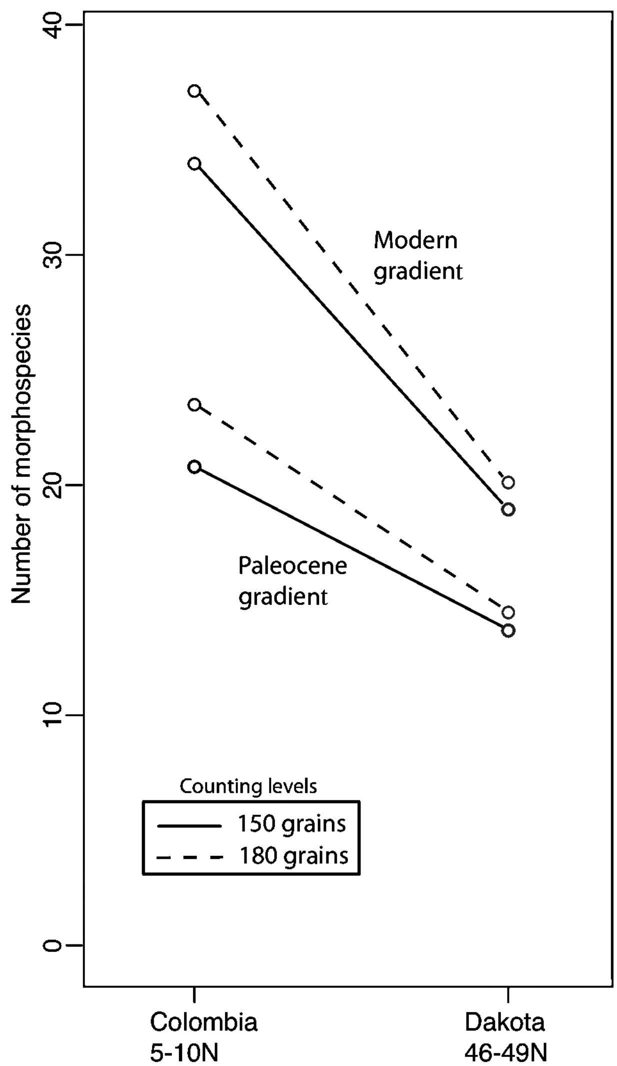
Some unpublished reports on the Cerrejón coal mine suggest that the section may be duplicated by low angle thrust faults. Tectonic models in the area suggest a style of thrust faults involving basement (Kellogg, 1984). Nevertheless, the data herein demonstrate that there are no major repetitions in the cores studied. There are important differences in the palynomorph distribution throughout the Cerrejón Formation that preclude major structural repetitions. *Aglaoreidia*? *foveolata* is restricted to between coal seams 45 to 60. *Gemmastephanocolpites gemmatus* is restricted to the interval between coal seams 45 and 100. *Ischyosporites problematicus* was found only between coal seams 101 to 155. *Horniella lunarensis* was found only between coal seams 110 and 155. *Proxapertites operculatus* is more abundant between coal seams 105 to 155, than between seams 45 to 105. *Retidiporites operculatus* was only found between coal seams 45 to 50. Finally, *Spinizonocolpites echinatus* was only found below coal seam 90.

CONCLUSIONS

There is little variation within the 725 m of the Cerrejón Formation. The floral composition, diversity, and lithofacies do not change significantly. Lithofacies associations and the floral composition indicate deposition in estuarine to fluvial coastal plain environments. There is, however, a large difference in the floral composition and diversity of coal and non-coal samples. Coal palynofloras have lower diversities, and a distinct and more homogeneous floral assemblage when compared to non-coal assemblages. The age of the Cerrejón Formation is Late Paleocene (60–58 Ma), and major structural repetitions were not found in the cores studied.

SYSTEMATIC PALEONTOLOGY

The descriptive morphologic terminology used here closely follows that of Jaramillo and Dilcher (2001) for exine architecture and tectal sculpture. The rules of the International Code of Botanical Nomenclature (I.C.B.N.;



Text-Figure 10. Paleocene versus Holocene palynofloral diversity gradients at two different cut offs of rarefied diversities. Note how the Paleocene gradient is reduced, compared to the Holocene gradient.

Greuter et al., 2002) are followed. The informal species names are written in Roman font between quotation marks. Coordinates for specimens prefixed UP are measured on the Zeiss microscope 2 of the Paleobotanical Laboratory of Florida Museum of Natural History and can be translated to any other microscope with a reference slide that has marked five coordinates, and is stored with the material studied. All other specimens are located using the England Finder system (EF). All type and figured specimens are stored in 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 center of information and research in geological sciences officially responsible for managing and preserving the rock and microfossil collections of Colombia. The Library promotes its use by scientists and consultants interested in global geological processes and the resource exploration. The inventory includes public and confidential collections of cores, cuttings, outcrops, petrological samples and micropaleontological collections. Holotypes and paratypes can be consulted upon written request to the Library manager.

All the material described in this section is from the Middle to Late Paleocene Cerrejón Formation of the Cerrejón coal mine, Colombia.

Pteridophyte and Bryophyte spores

Echitriletes "tuberosus"
Plate 7, figs. 4–5

Diagnosis. Spore grains free, echitrilete, intermediate in size (27 µm), with an interradial crassitude bearing a protuberance.

Description. Spore single, symmetry radial, amb circular; trilete, margo very thin, 0.5 µm wide, radii 10 µm long, commissure straight, curvatura imperfect; sporoderm one-layered, intexine 1 µm thick with interradial crassitude 3–5 µm wide; sculpture echinate, spines both on distal and proximal faces, spines 2 µm long, 2 µm wide at base, ends pointed, distributed unevenly, 3–4 µm apart, interradial crassitude has a protuberance resembling a spine 3 µm high at the center of the interradial area.

Dimensions. Equatorial diameter 27 m, one occurrence.

Comparison. *Psilatriletes lobatus* Hoorn 1994 is psilate.

Specimens. Sample Cerrejón WRV04752-340.85, EF M18.

Foveotriletes concavoides sp. nov.
Plate 1, fig. 4

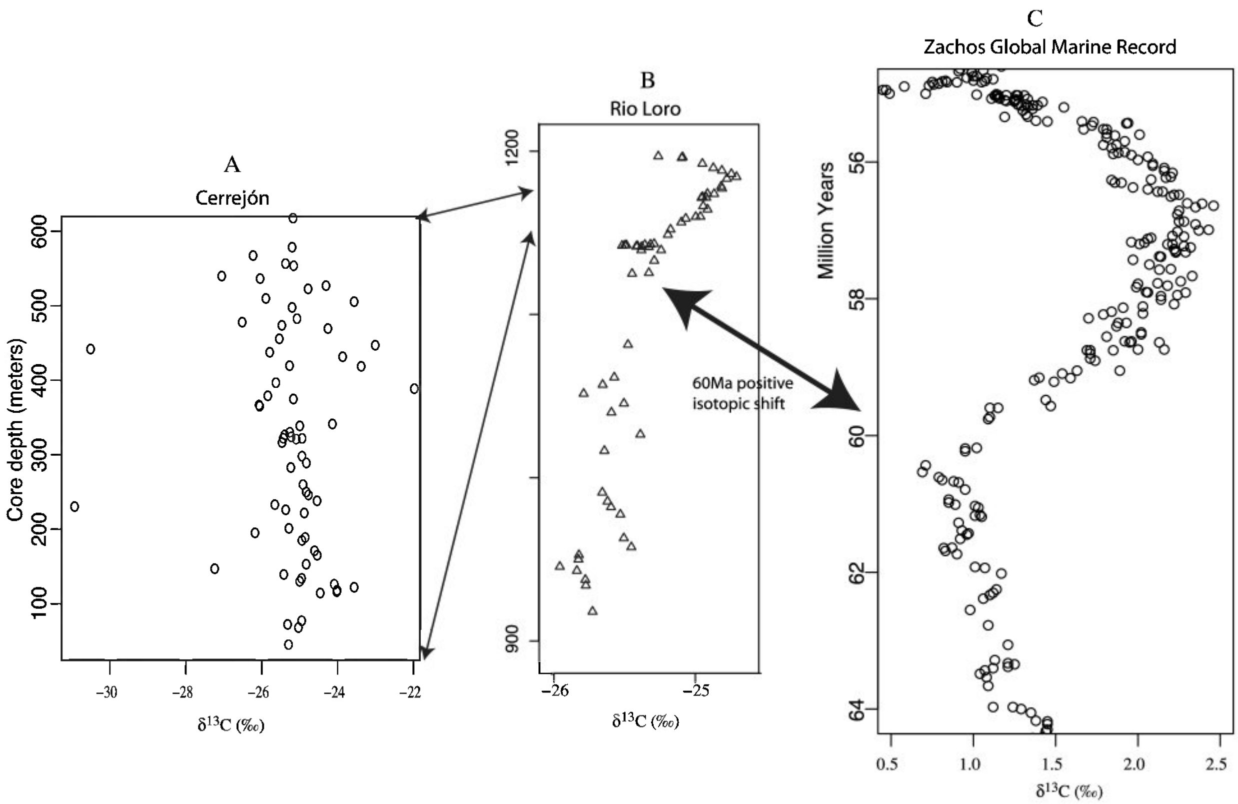
Foveotriletes sp. 1, Jaramillo and Dilcher, 2001, pl. 2, figs. 21–24.

Holotype. Plate 1, fig. 4, sample Cerrejón WRV 04774-264.94, EF J30/1.

Paratypes. Jaramillo and Dilcher, 2001, pl. 2, figs. 21–24, UFP 49, 12.2 x 111.8; UFP 43, 5 x 82.3.

Etymology. Named after the triangular–obtuse–concave amb.

Diagnosis. Foveotrilete spores, intermediate in size (30–35 µm), proximal face laevigate, distal face foveolate–fossulate.



Text-Figure 11. **A)** carbon isotope (^{13}C) values for the Cerrejón Formation. The samples have an average of 25.200, which is statistically similar to the average for the positive carbon isotope excursion in the 60–58 Ma interval found in **B)** the Rio Loro section (Jaramillo et al., 2006) that correlates with **C)** the global positive carbon isotope excursion (Zachos et al., 2001).

Description. Spores single, symmetry radial, pyramidal, amb triangular–obtuse–concave; trilete, margo 0.5 μm wide, indistinct to absent, curvatura absent, radii long, commissure straight; sporoderm single-layered, intexine 1–1.5 μm thick; sculpture foveolate–fossulate, proximal face laevigate, distal face foveolate–fossulate, lumina 2–3 μm wide, 2–5 μm long, elongated to rhomboid, angles rounded, 1–1.5 μm apart, shaped irregularly, densely distributed.

Dimensions. Equatorial diameter 29(33)35 μm, length/width ratio 1.1; measured 4, observed 10.

Comparisons. *Crassoretitriletes vanraadshooveni* Germeraad et al. 1968 has a coarse reticulum over the entire grain. *Foveotriletes margaritae* (Van der Hammen 1954) Germeraad et al. 1968 has ornamentation over the entire grain, and is larger (38–53 μm).

Foveotriletes "microfoveolatus"
Plate 7, figs. 2–3

Diagnosis. Spores free, foveotrilete, intermediate in size (33 μm), proximal face laevigate, distal face foveolate, 0.5 m wide, 0.5 m apart.

Description. Spores single, symmetry radial, amb triangular–obtuse, straight; trilete, margo 3 μm, commissure straight, radii long, almost reaching equator, curvatura absent; sporoderm single-layered, intexine 1 μm thick; sculpture foveolate on distal face, laevigate on proximal face, foveolae densely arranged, 0.5 μm wide, 0.5 μm apart.

Dimensions. Equatorial diameter 33 μm, one occurrence.

Comparisons. *Foveotriletes* sp. 1 of Jaramillo and Dilcher (2001) has larger foveolae (2 μm wide), and *Foveotriletes margaritae* (Van der Hammen 1954) Germeraad et al. 1968, *Filtrotriletes nigeriensis* Van Hoeken-Klinkenberg 1966, and *Foveotriletes ornatus* Regali et al. 1974 have foveolae on the proximal and distal faces.

Specimens. Sample Cerrejón WRV04752-141.34, EF S27/4.

Laevigatosporites granulatus sp. nov.
Plate 1, fig. 9

Laevigatosporites sp. 1, Jaramillo and Dilcher, 2001, pl. 2, figs. 32–34.

Holotype. Plate 1, fig. 9, sample Cerrejón WRV 04774-330.65, EF Q22/4.

Paratype. Jaramillo and Dilcher, 2001, pl. 2, figs. 32–34, UFP 9, 10 x 108.1.

Etymology. From the Latin *granum,* meaning grain, seed, or kernel, after the small granulate ornamentation.

Diagnosis. Monolete spores, intermediate in size (33 μm), intexine < 0.5 μm, granular, granules < 0.5 μm in diameter, distributed irregularly, forming patches.

Description. Spores single, symmetry radial, plane-convex; monolete, margo absent, curvatura absent, laesurae intermediate in size, commissures straight, slightly intruding, ends pointed; sporoderm single-layered, intexine < 0.8 μm thick, sporoderm thin; sculpture granular, granules < 0.5 μm long, < 0.5 μm wide, circular, uniform in shape, variable in density, distributed irregularly, forming patches.

Dimensions. Equatorial diameter 28(34)36 μm, polar diameter 22(24)27 μm; measured 6, observed 50.

Comparisons. *Laevigatosporites catanejensis* Muller et al. 1987 and *Laevigatosporites* sp. 2 of Jaramillo and Dilcher (2001) both have thicker sporoderm and wider granules.

Retitriletes cristatus sp. nov.
Plate 1, figs. 7–8

Holotype. Plate 1, fig. 7, sample Cerrejón WRV 04774-81.08, EF L18/3.

Paratype. Plate 1, fig. 8, sample Cerrejón WRV 04774-70.08, EF V32/1.

Etymology. From the Latin *crista,* meaning comb or plume, after the cristate ornamentation.

Diagnosis. Trilete spores, intermediate in size (25–26 m), cristate–echinate.

Description. Spores single, symmetry radial, amb triangular–obtuse–convex; trilete, laesurae indistinct, curvatura absent, radii long, reaching equator, margo thin, 0.5 m, commissure slightly undulating; sporoderm single-layered, intexine 0.5 μm; sculpture echinate, spines 2 m high, 2 m wide, 2 m apart, joined by a ridge, 0.5–1 m wide, forming ornamentation cristate on both proximal and distal faces, cristae produces a pseudoreticulate ornamentation, 2–4 m wide, spines sometimes isolated.

Dimensions. Equatorial diameter 23(24)26 μm; measured 3, observed 5.

Comparison. *Cicatricosisporites cristatus* Regali et al. 1974 is cicatricosate.

Rugulatisporites "maculosus"
Plate 7, fig. 1

Diagnosis. Spores free, rugulate, mid-sized (25 μm), rugae 2 μm high, densely distributed.

Description. Spore single, symmetry radial, amb circular; trilete, radii long, indistinct, commissure straight, sporoderm single-layered, intexine 1 μm thick, sculpture rugulate, rugae curved or straight, on both proximal and distal sides, 2 μm high, 2–5 μm long, 2 μm wide, densely distributed, surface inter-rugae psilate.

Dimensions. Equatorial diameter 25 μm, one occurrence.

Comparison. *Rugulatisporites polysculptilis* Herngreen 1975 has a foveolate distal surface.

Specimens. Sample Cerrejón WRV04752-19.66, EF K56.

Striatriletes elegantis sp. nov.
Plate 7, figs. 6–7

Holotype. Plate 7, figs. 6–7, sample Cerrejón WRV04752-340.58, EF R16/2.

Paratypes. Sample Cerrejón WRV04752-340.58, EF M57/1; sample Cerrejón WRV04752-326.59, EF T20/3.

Etymology. From the Latin *elegans,* meaning tasteful or fine, after the elegant striation pattern.

Diagnosis. Spores free, striatrilete, intermediate in size (27–30 μm), proximal and distal face striate.

Description. Spores single, symmetry radial, amb triangular–obtuse; trilete, radii, reaching equator, commissures straight, ends pointed, indistinct, slightly marginate, margo thin, 0.5 μm wide, curvatura absent; sporoderm single-layered, intexine 0.5 to 1 μm thick; sculpture striate, muri 0.5 μm wide, 1 μm high, grooves 3–7 μm wide, muri branching from a single striae that circles the grain from the proximal to the distal faces; 4 to 12 striae on each face.

Dimensions. Equatorial diameter 27(28)30 μm; measured 3, observed 9.

Comparisons. *Cicatricosisporites* sp. 1 of Jaramillo and Dilcher (2001) has a laevigate proximal face. *Magnastriatites grandiosus* (Kedves & Sole de Porta 1963) Duenas 1980 is larger (77–132 μm).

Verrutriletes "echinatus"
Plate 7, figs. 8–9

Diagnosis. Spores free, trilete, verrucate–scabrate–rugulate, large (52 μm).

Description. Spore single, symmetry radial, amb triangular–obtuse–convex; trilete indistinct; sporoderm single-layered, intexine 0.5 μm thick; sculpture verrucate–scabrate–rugulate, over the entire grain, 0.5 μm high, densely and randomly arranged.

Dimensions. Equatorial diameter 52 µm, 1 occurrence.

Comparison. *Verrutriletes virueloides* sp. nov. has a homogeneous sculpture.

Specimens. Sample Cerrejón WRV04752-104.74, EF P14.

Verrutriletes virueloides sp. nov.
Plate 1, fig. 16

Holotype. Plate 1, fig. 16, sample Cerrejón WRV 04774-46.75, EF P29/1.

Etymology. From the Latin *variola,* meaning spotted, after the spotted ornamentation pattern.

Diagnosis. Spores single, trilete, verrucate, large in size (34–53 µm), sparse verrucae.

Description. Spores single, symmetry radial, amb convexly subtriangular; trilete distinct, commissures straight, radii 18–22 µm long, reaching or not reaching the equator, margo absent, curvature absent; sporoderm single-layered, intexine 0.5–1 µm thick; sculpture verrucate, verrucae 0.5–1.5 µm wide, 0.5 µm high, 1–5 µm apart, sparsely to densely distributed over entire grain.

Dimensions. Equatorial diameter 34(45)53 µm; measured 3, observed 50.

Comparisons. *Osmundacidites minor* Jaramillo & Dilcher 2001 is smaller (25–30 µm).

Angiosperm pollen

Bombacacidites foveolatus sp. nov.
Plate 7, figs. 33–34

Holotype. Plate 7, figs. 33–34, sample Cerrejón WRV04752-111.0, EF R25.

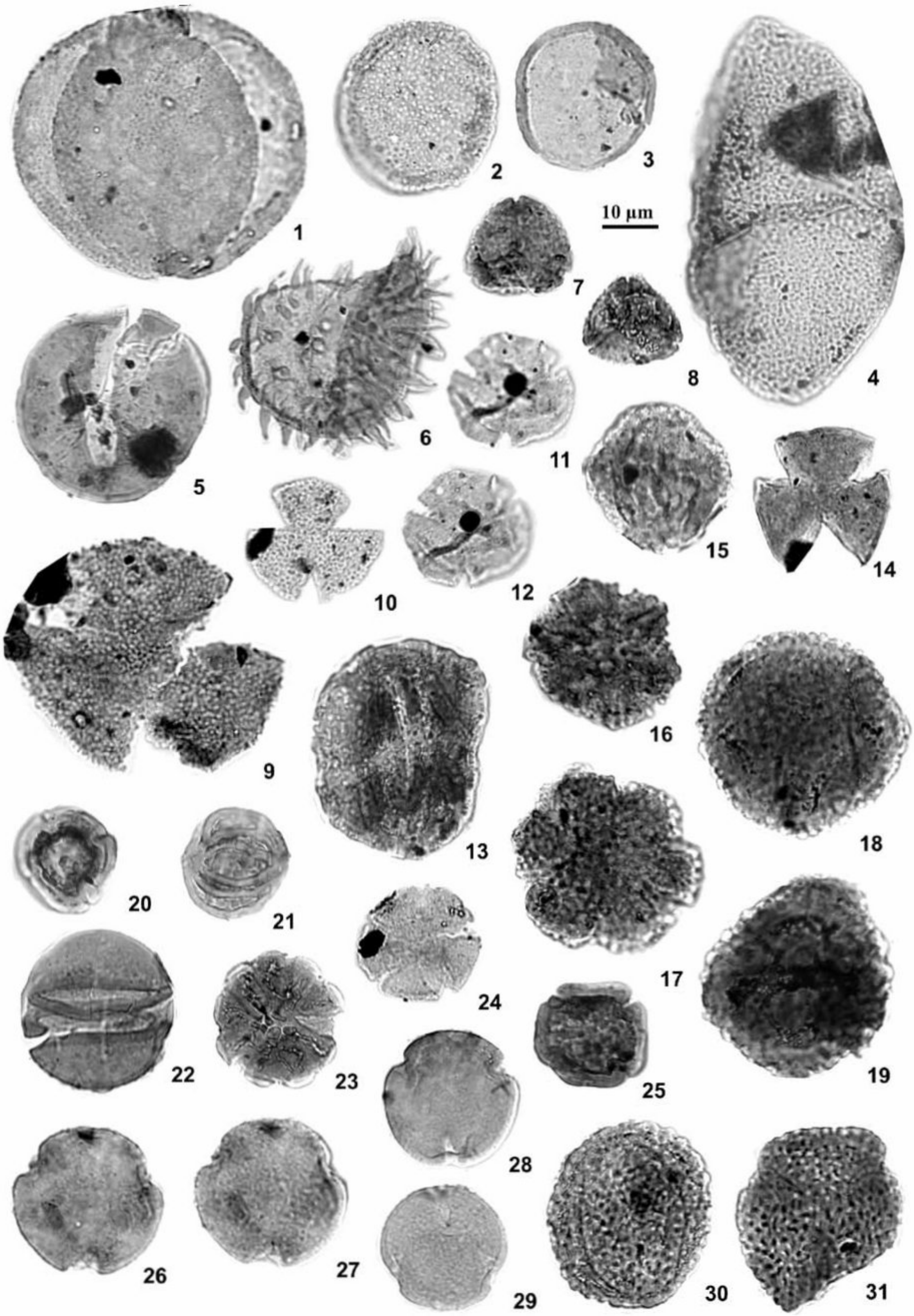
Etymology. From the Latin *fovea,* meaning pit, after the foveolate ornamentation.

Diagnosis. *Bombacacidites*-type pollen, intermediate in

PLATE 3

All sample numbers are prefixed 'Cerrejón'. The sample number is followed by the England Finder (EF) coordinate.

1 *Proxapertites operculatus* (Van der Hammen 1956) Germeraad et al. 1968, WRV 04774, 112.90, EF J30/4.
2 *Proxapertites operculatus* (Van der Hammen 1956) Germeraad et al. 1968, WRV 04774, 252.66, EF L35/1.
3 *Proxapertites psilatus* Sarmiento 1992, WRV 04774, 252.66, EF M34/2.
4 *Longapertites vanendeenburgi* Germeraad et al. 1968, WRV 04774, 94.41, EF S16/2.
5 *Psilamonocolpites operculatus* Pardo et al. 2003, WRV 04774, 19, EF T55.
6 *Spinizonocolpites echinatus* Muller 1968, WRV 04774, 184.55, EF P19/1.
7 *Syncolporites lisamae* Van der Hammen 1954, WRV 04774, 66.15, EF K28/4.
8 *Syncolporites lisamae* Van der Hammen 1954, WRV 04774, 15.05, EF E59/1.
9 *Retitricolpites grandis* sp. nov., holotype, WRV 04774, 19, EF S52/4.
10 *Retitricolpites communis* sp. nov., WRV 04774, 216.9, EF V19.
11, 12 *Bombacacidites sp.*, WRV 04774, 252.66, EF T31/2.
13 *Foveotricolpites perforatus* Van der Hammen & Garcia 1966, WRV 04774, 66.15, EF W22/3,4.
14 *Psilatricolpites* sp., WRV 04774, 216.9, EF S33/4.
15 *Ctenolophonidites lisamae* (Van der Kaars & Garcia 1966) Germeraad et al. 1968 (equatorial view), WRV 04774, 216.9, EF H28.
16 *Ctenolophonidites lisamae* (Van der Kaars & Garcia 1966) Germeraad et al. 1968 (polar view), WRV 04774, 36.55, EF G60.
17 *Gemmastephanocolpites gemmatus* Van der Kaars & Garcia 1966 (polar view), WRV 04774, 255.35, EF S28.
18 *Gemmastephanocolpites gemmatus* Van der Kaars & Garcia 1966 (equatorial view), WRV 04774, 151.82, EF K37/3.
19 *Gemmastephanocolpites gemmatus* Van der Kaars & Garcia 1966 (equatorial view), WRV 04774, 255.35, EF M34/2.
20 *Psilastephanocolpites globulus* Van der Kaars 1983 (polar view), WRV 04774, 285.08, EF O35/3.
21 *Psilastephanocolpites globulus* Van der Kaars 1983 (equatorial view), WRV 04774, 285.08, EF U27/3,4.
22 *Psilastephanocolpites globulus* Van der Kaars 1983 large (equatorial view), WRV 04774, 310.3, EF T36/2,4.
23 *Psilastephanocolpites* sp., WRV 04774, 46.75, EF J37/1.
24 *Stephanocolpites scabratus*, WRV 04774, 330.65, EF C27/4.
25 *Stephanocolpites* sp., WRV 04774, 36.55, EF E58/1.
26, 27 *Foveotricolporites brevicolpatus* sp. nov., holotype, polar view, WRV 04774, 107-108.85, EF W34/1.
28 *Foveotricolporites brevicolpatus* sp. nov., paratype, WRV 04774, 287.52, EF Q27/4.
29 *Foveotricolporites brevicolpatus* sp. nov., paratype, WRV 04774, 347.54, EF E44/3.
30 *Foveotricolporites* sp., WRV 04774, 116.82, EF X29/4.
31 *Foveotricolporites* sp. (polar view), WRV 04774, 116.82, EF H37.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size (38 µm), circular, foveolate.

Description. Monad pollen grains, radial, isopolar, elliptic to circular; tricolporate, ectocolpi short, borders straight, ends pointed; endopores costate, costae 2 µm wide, 1 µm thick, protruding, pore circular; tectate, exine 1.5–2 µm, columellae distinct, nexine 0.5 µm thick, columellae 1 m thick, tectum 0.5 µm thick; sculpture foveolate, foveolae over entire grain, densely and uniformly distributed, 0.5–1 µm wide, circular, 1–2 µm apart.

Dimensions. Equatorial diameter 35(38)40 µm; measured 3, observed 6.

Comparisons. *Bombacacidites fossureticulatus* Jaramillo & Dilcher 2001 is fossulate at the apocolpia and the colpus margins, and reticulate at the mesocolpia. *Bombacacidites foveoreticulatus* Muller et al. 1987 is foveolate–reticulate, and has a thicker exine (3 µm).

Bombacacidites "poloanularis"
Plate 7, figs. 10–12

Diagnosis. *Bombacacidites* type pollen, intermediate in size (25 µm), with a distinct thickening at apocolpia.

Description. Monad, radial, isopolar, amb triangular–obtuse–concave; tricolporate, ectocolpi costate, costae 2 µm wide at equator decreasing in width toward the polar end of colpi, colpi 7 µm long, ends pointed, endopores indistinct; semitectate, exine 1.5 µm thick, nexine 0.25 µm, columella 0.5 µm thick, tectum 0.25 µm thick, exine with a distinct thickening at apocolpia, 8 µm wide; sculpture reticulate, lumina 0.5 µm wide, equiangular, densely distributed over entire grain.

Dimensions. Equatorial diameter 25 µm, 1 occurrence.

Comparison. *Bombacacidites grahamii* Jaramillo & Dilcher 2001 has a thickening at the mesocolpia intercolpate region.

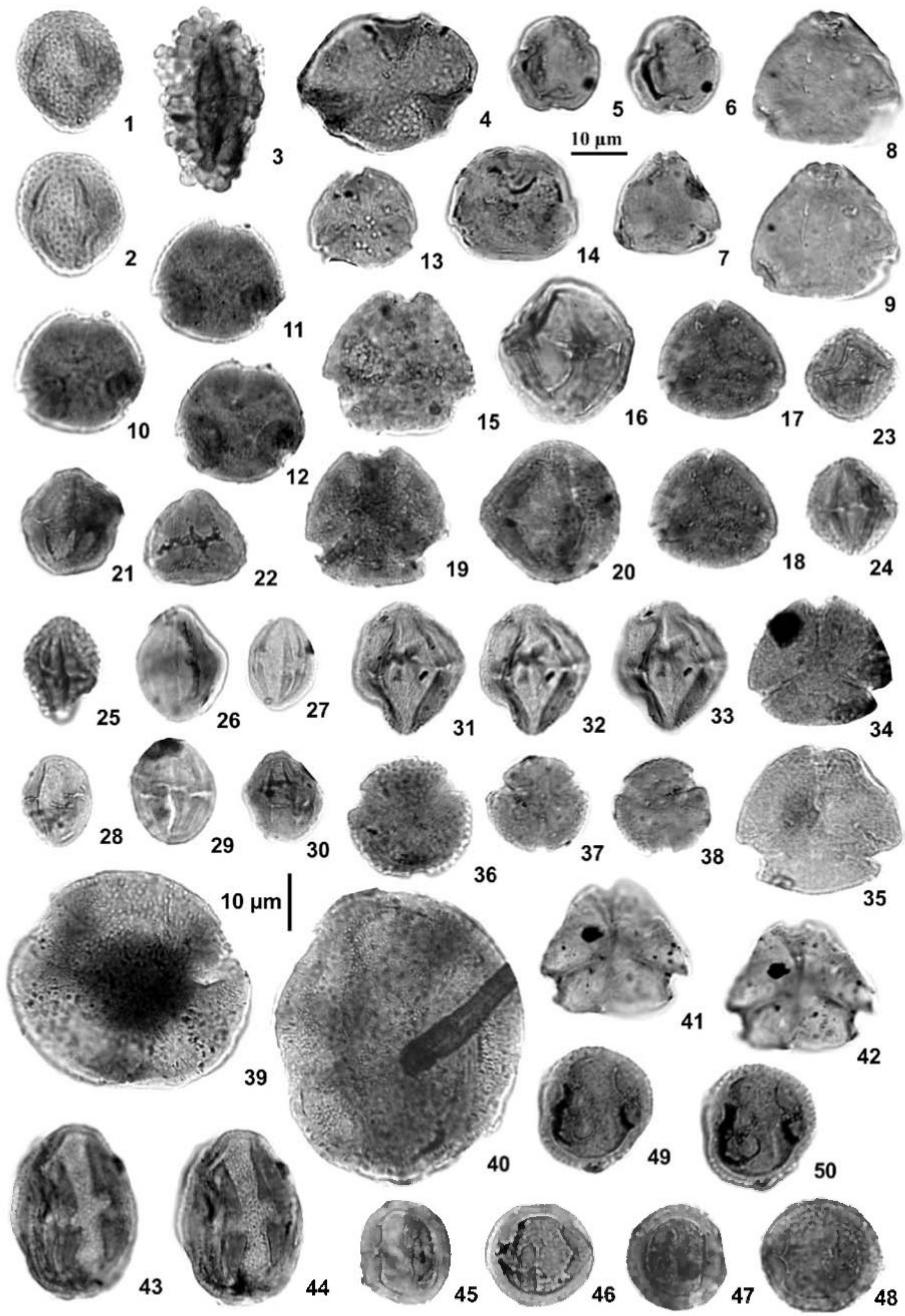
Specimens. Sample Cerrejón WRV04752-57.47, EF T28/1.

Bombacacidites "pseudoannae"
Plate 7, figs. 13–15

PLATE 4

All sample numbers are prefixed 'Cerrejón'. The sample number is followed by the England Finder (EF) coordinate.

1, 2	*Foveotricolporites* sp. 3 (Jaramillo & Dilcher 2001), WRV 04774, 301.88, EF R30.
3	*Gemmatricolporites* sp., WRV 04774, 225.91, EF X29/1,3.
4	*Margocolporites* sp., WRV 04774, 70.08, EF S24/4.
5, 6	*Psilabrevitricolpites* sp., WRV 04774, 38.63, EF G26/3.
7	*Psilabrevitricolporites simpliformis* Van der Kaars 1983 (small), WRV 04774, 38.63, EF G19/4.
8, 9	*Psilabrevitricolporites simpliformis* Van der Kaars 1983 (large), WRV 04774, 91.38, EF J16/2,4.
10–12	*Psilatricolporites marginatus* Van der Kaars 1983, WRV 04774, 326.82, EF L35/2.
13	*Psilatricolporites marginatus* Van der Kaars 1983 (small), WRV 04774, 84.35, EF Y20/2,4.
14	*Psilatricolporites marginatus* Van der Kaars 1983, WRV 04774, 294.28, EF E27/1.
15	*Psilatricolporites pachyexinatus* Van der Kaars 1983, WRV 04774, 148.50, EF Q27/2.
16	*Psilatricolporites* sp., WRV 04774, 207.50, EF T20/4.
17, 18	*Scabratricolporites* sp., WRV 04774, 326.82, EF M40.
19	*Siltaria cerrejonensis* sp. nov. holotype, WRV 04774, 171.57, EF V23/2.
20	*Siltaria cerrejonensis* sp. nov. paratype, WRV 04774, 326.82, EF P36/2.
21	*Scabratricolporites* sp., WRV 04774, 285.08, EF H28/3.
22	*Scabratricolporites* sp., WRV 04774, 184.55, EF E14/3.
23–30	*Tricolporites* sp.
23	WRV 04774, 96.65, EF J27/2.
24	WRV 04774, 22.69-24.55, EF U28/1,3.
25	WRV 04774, 235.32, EF G31/3.
26	WRV 04774, 244.20, EF M34/3.
27	WRV 04774, 252.66, EF J27.
28	WRV 04774, 188.64, EF H26/3.
29	WRV 04774, 287.52, EF G28/4.
30	WRV 04774, 171.57, EF P32/3.
31–33	*Striatopollis* sp., WRV 04774, 112.90, EF S24/3,4.
34	*Tricolporites* sp., WRV 04774, 107-108.85, EF U30/2.
35	*Tricolporites* sp., WRV 04774, 310.3, EF L29/3.
36	*Tricolporites* sp. (reticulate), WRV 04774, 112.90, EF S34.
37, 38	*Tricolporites* sp. (reticulate), WRV 04774, 100.60, EF F28/1,3.
39	*Psilatricolporites* sp. (small), WRV 04774, 112.90, EF K32/4.
40	*Psilatricolporites* sp. (small), WRV 04774, 193, EF Q44.
41, 42	*Tricolporites* sp., WRV 04774, 318.14, EF J23/1.
43, 44	*Tricolporites* sp., WRV 04774, 70.08, EF S17/4.
45	*Psilatricolporites kogiorum* sp. nov., holotype, WRV 04774, 171.57, EF Q22/4.
46	*Psilatricolporites kogiorum* sp. nov., paratype, WRV 04774, 22.69-24.55, EF T45/3.
47	*Psilatricolporites kogiorum* sp. nov., WRV 04774, 287.52, EF O32.
48	*Psilatricolporites kogiorum* sp. nov., WRV 04774, 193, EF O31/2.
49, 50	*Psilatricolporites kogiorum* sp. nov., WRV 04774, 15.05, EF G49.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Diagnosis. *Bombacacidites* type pollen, intermediate in size (25 µm), fossulate at apocolpia, micropitted at mesocolpia.

Description. Monad, radial, isopolar, amb triangular–obtuse–convex; tricolporate, ectocolpi short, 3 µm long, costate, costae 4–5 µm thick set, protruding, endopore indistinct; sculpture fossulate micropitted, fossulate in apocolpial areas and surrounding the colpi, micropitted in mesocolpial areas, the transition from fossulae to micropitted is gradual, tectate, exine 2 µm thick, columella indistinct, nexine 1.5 µm thick, tectum 0.5 µm.

Dimensions. Equatorial diameter 25 µm, 1 occurrence.

Comparisons. *Bombacacidites annae* (Van der Hammen 1954) Leidelmeyer 1966 is reticulate, *Bombacacidites protofoveoreticulatus* Jaramillo & Dilcher 2001 is fossulate–foveolate over the entire grain.

Specimens. Sample Cerrejón WRV04752-93.53, EF T45/1.

Echistephanoporites inciertus sp. nov.
Plate 6, figs. 31–35

Holotype. Plate 6, fig. 35, sample Cerrejón WRV 04774-84.35, EF X30/2.

Paratypes. Plate 6, fig. 31, sample Cerrejón WRV 04774-290.77, EF P44/2; Plate 6, figs. 32–33, sample Cerrejón WRV 04774-112.90, EF Q23/3; Plate 6, fig. 34, sample Cerrejón WRV 04774-38.63, EF H25/3.

Etymology. From the Latin *incertus,* meaning doubtful, after the cryptic character of the apertures.

Diagnosis. Stephanoporate pollen grains, echinate, intermediate in size (22–30 µm), echinate, 5–6 pores, costate.

Description. Monad pollen, radial, isopolar, amb circular; stephanoporate, pores 5–6, circular, 2 µm wide, costate, costae 1.5–2 µm thick, operculate, operculum often lost, pores may be difficult to observe due to dense arrangement of spines; tectate, exine 1–1.5 µm thick, columellae indistinct; sculpture echinate, spines 1–3 µm high, 1–1.5 µm wide, tips pointed, conical, densely arranged over entire grain, surface inter-spines psilate to slightly scabrate.

Dimensions. Equatorial diameter 23(25)29 µm; measured 7, observed 25.

Comparisons. *Echistephanoporites alfonsi* Leidelmeyer 1966 is smaller (17–19 µm).

Ericipites fossulatus sp. nov.
Plate 2, fig. 8; Plate 7, figs. 19–20

Holotype. Plate 2, fig. 8; sample Cerrejón WRV 04774-96.65, EF X27.

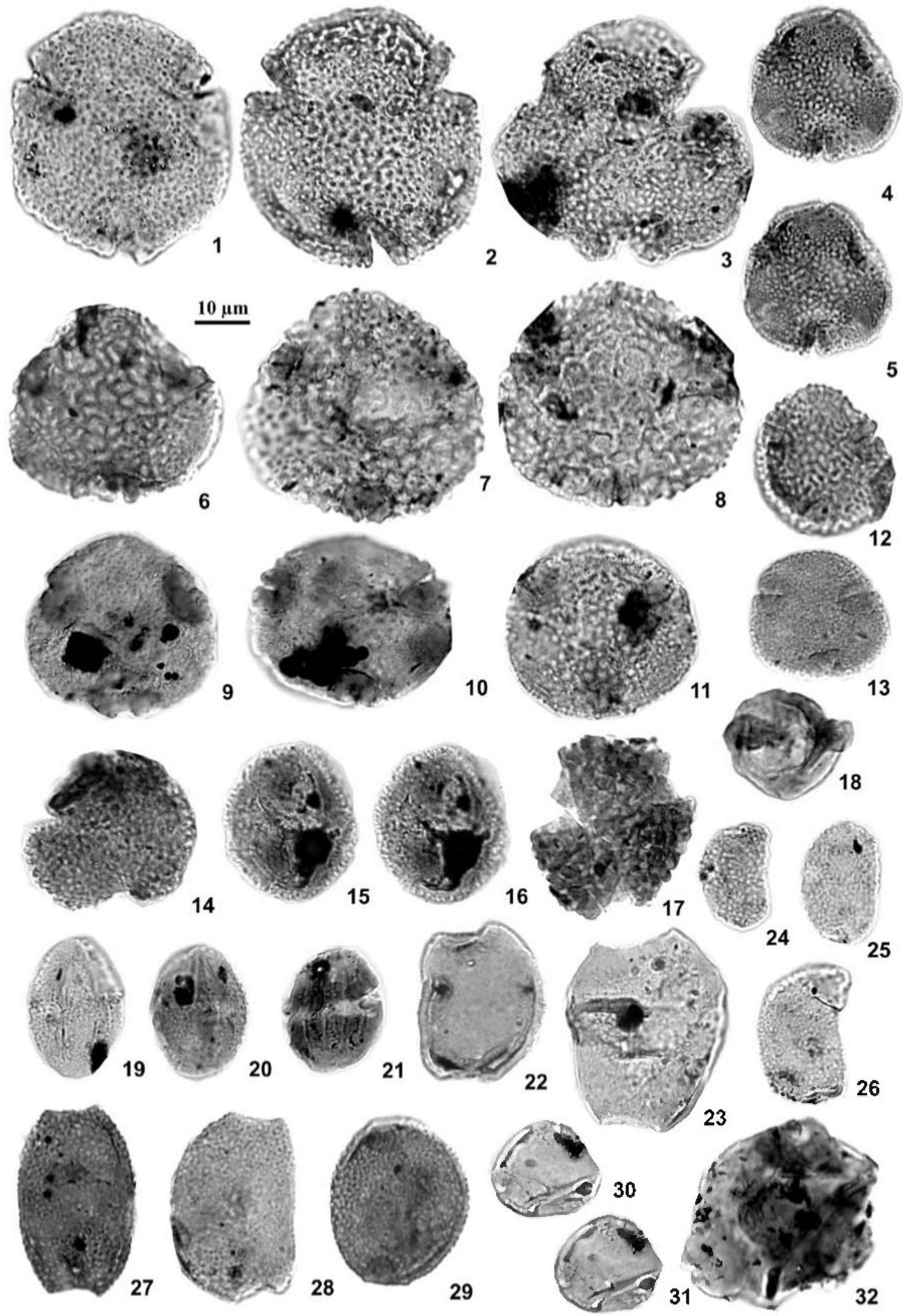
Paratypes. Plate 7, figs. 19–20, sample Cerrejón WRV 04774-59, EF O31/2; sample Cerrejón WRV04774-96.65, EF D49/1.

Etymology. From the Latin *fossa,* meaning ditch, after

PLATE 5

All sample numbers are prefixed 'Cerrejón'. The sample number is followed by the England Finder (EF) coordinate.

1 *Bombacacidites* sp., WRV 04774, 84.35, EF X29.
2 *Bombacacidites* sp., WRV 04774, 328.60, EF H33/1.
3 *Bombacacidites* sp., WRV 04774, 53.95, EF S22/4.
4, 5 *Bombacacidites* sp., WRV 04774, 118.25, EF W31/1.
6 *Bombacacidites* sp., WRV 04774, 321.66, EF P51/3.
7 *Bombacacidites* sp., WRV 04774, 150.45, EF F31.
8 *Bombacacidites* sp., WRV 04774, 321.66, EF H33/1.
9 *Bombacacidites* sp., WRV 04774, 66.15, EF P37.
10 *Bombacacidites* sp., WRV 04774, 150.45, EF U26.
11 *Bombacacidites* sp., WRV 04774, 74.30, EF W29/1.
12 *Bombacacidites* sp., WRV 04774, 328.60, EF D25/1.
13 *Bombacacidites* sp., WRV 04774, 42.71, EF N33/2, 4.
14 *Clavatricolporites* sp., WRV 04774, 15.05, EF M64.
15, 16 *Clavatricolporites* sp., WRV 04774, 330.65, EF R32/2.
17 *Verrutricolporites*, WRV 04774, 19, EF K67.
18 *Aquilapollenites?*, WRV 04774, 244.2, EF N25.
19 *Rousea* sp., WRV 04774, 74.30, EF W37/4.
20 *Rousea* sp., WRV 04774, 252.66, EF L19/1.
21 *Psilastephanocolporites fissilis* Leidelmeyer 1966, WRV 04774, 15.05, EF G51/3.
22 *Diporoconia* cf. *D. iszkaszentgyoergy*i (Kedves 1965) Frederiksen et al. 1985, WRV 04774, 188.64, EF U29.
23 *Diporoconia* cf. *D. iszkaszentgyoergyi* (Kedves 1965) Frederiksen et al. 1985, WRV 04774, 129.52, EF K19/4.
24 *Retidiporites botulus* Leidelmeyer 1966, WRV 04774, 211.13, reference unavailable.
25 *Retidiporites botulus* Leidelmeyer 1966, WRV 04774, 104.56, EF H29/3.
26 *Retidiporites botulus* Leidelmeyer 1966, WRV 04774, 203.40, EF P22/1.
27 *Retidiporites magdalenensis* Van der Hammen & Garcia 1966, WRV 04774, 252.66, EF W31.
28 *Retidiporites magdalenensis* Van der Hammen & Garcia 1966, WRV 04774, 84.35, EF S24/2.
29 *Retidiporites operculatus* Van der Kaars 1983, WRV 04774, 42.71, EF T23/2.
30, 31 *Caryapollenites* sp., WRV 04774, 278.12, EF O28/3.
32 *Corsinipollenites* sp., WRV 04774, 259.81, EF X23/1.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the fossulate ornamentation.

Diagnosis. Tetrads of pollen, tricolpate, intermediate in size (36–48 µm) fossulate, exine intectate.

Description. Tetrads of pollen, tetrahedral, individual grains radial, isopolar, spherical; tricolpate, colpi simple, long; intectate, exine 2 µm thick; sculpture fossulate, fossulae 2–3 µm long, 1 µm wide, 1 µm deep, 1 µm apart, densely and uniformly distributed over entire grain, sculpture may be almost reticulate.

Dimensions. Entire tetrad 40(45)50 µm wide, 36(40)44 µm long, equatorial diameter of a single grain 22(24)25 µm; measured 4, observed 20.

Comparisons. *Inaperturotetradites lacunosus* Van Hoeken-Klinkenberg 1964 is inaperturate. *Longapertites brasiliensis* Gonzalez 1967 is larger (70–110 µm). *Magnotetradites magnus* (Van der Hammen 1954) Van der Hammen & Garcia 1966 is inaperturate. *Tetradites umirensis* Van der Hammen 1954 is psilate.

Foveotricolporites brevicolpatus sp. nov.
Plate 3, figs. 26–29

Holotype. Plate 3, figs. 26–27, sample Cerrejón WRV 04774, 107-108.85, EF W34/1.

Paratypes. Plate 3, fig. 28, sample Cerrejón WRV 04774-287.52, EF Q27/4; Plate 3, fig. 29, sample Cerrejón WRV 04774-347.54, EF E44/3.

Etymology. After the short colpi.

Diagnosis. Tricolporate pollen, intermediate in size (23 µm), foveolate, colpi short, costate.

Description. Monad pollen, radial, isopolar, spherical, amb circular; tricolporate, colpi short, ends pointed, slightly costate, costae 1 µm wide, pore circular, simple, indistinct; intectate, exine 1 µm thick; sculpture foveolate, foveolae 0.5 µm wide, circular, 1 µm apart, densely to sparsely distributed over entire grain.

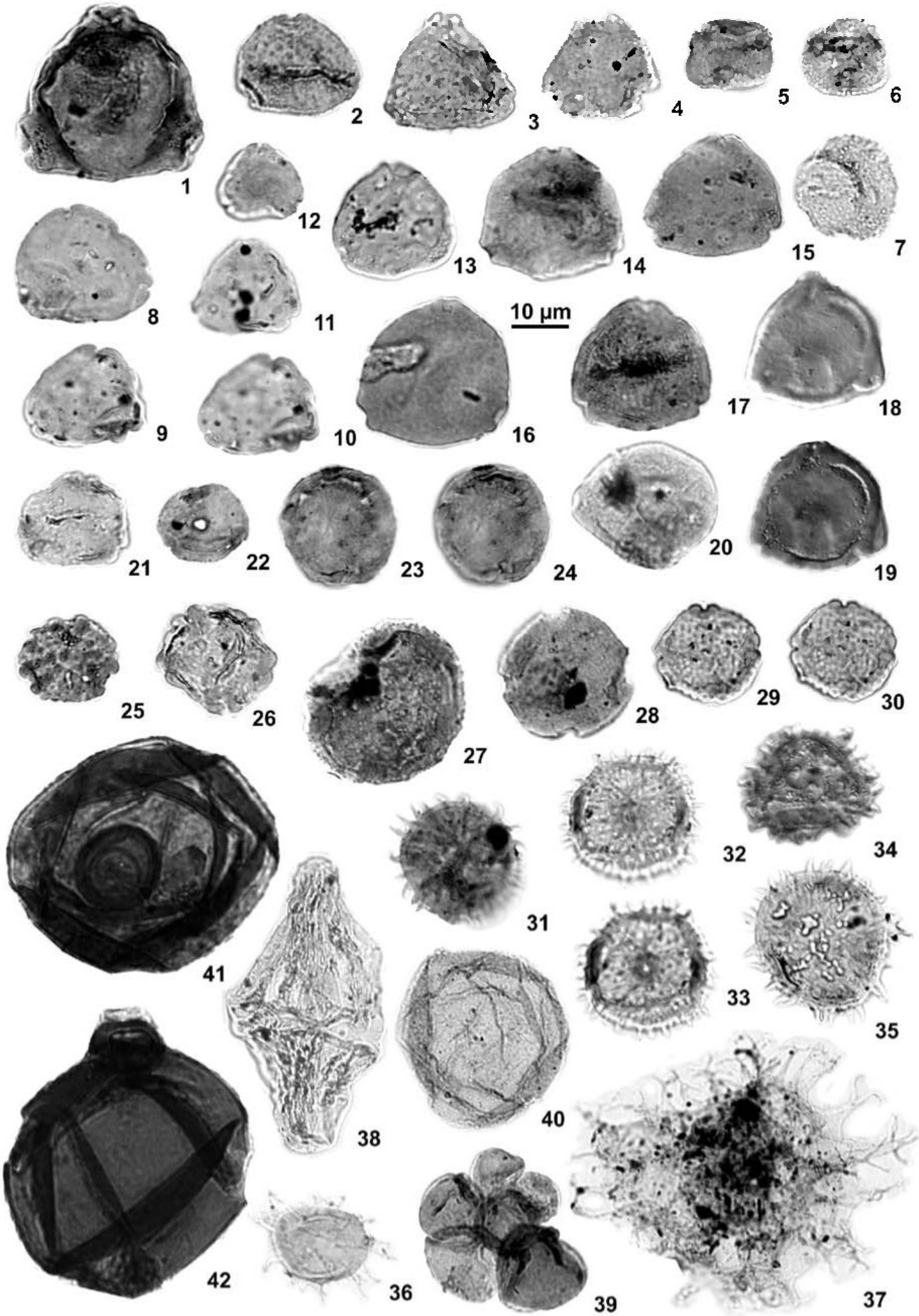
Dimensions. Equatorial diameter 22–23 µm, polar diameter 21 µm; measured 3, observed 4.

Comparisons. *Foveotricolporites* sp. 1 of Jaramillo and Dilcher (2001) has fastigiate endopores, and foveolae that diminish in width towards the equator.

PLATE 6

All sample numbers are prefixed 'Cerrejón'. The sample number is followed by the England Finder (EF) coordinate.

1 *Corsinipollenites* sp., WRV 04774, 46.75, EF R23.
2 *Echitriporites trianguliformis* Van Hoeken Klinkenberg 1964, WRV 04774, 38.63, EF P19/1,3.
3 *Echitriporites trianguliformis* Van Hoeken Klinkenberg 1964, WRV 04774, 294.28, EF M25.
4 *Proteacidites*? sp., WRV 04774, 259.81, EF R18/1,3.
5 *Retitriporites* sp. (costate pore), WRV 04774, 259.81, EF T14/3.
6 *Retitriporites* sp. (costate pore), WRV 04774, 252.66, EF M22.
7 *Retitriporites simplex* Van der Kaars 1983, WRV 04774, 221.09, EF C30/1.
8 *Momipites africanus*, WRV 04774, 259.81, EF Q31/2.
9, 10 *Momipites africanus*, WRV 04774, 316.16, EF M23/3.
11 *Momipites africanus*, WRV 04774, 146.55, EF M24.
12 *Momipites africanus*, WRV 04774, 184.55, EF S24/3.
13 *Carya* type, Cerrejon WRV 04774, 278.12, EF H35.
14 *Momipites macroexinatus* sp. nov., holotype, WRV 04774, 19, EF N56/3.
15 *Momipites macroexinatus* sp. nov., paratype, WRV 04774, 53.95, EF F20/2.
16 *Momipites macroexinatus* sp. nov., WRV 04774, 310.3, EF T34/1.
17 *Momipites macroexinatus* sp. nov., WRV 04774, 15.05, EF X53.
18, 19 *Momipites macroexinatus* sp. nov., WRV 04774, 32.6, EF S55. Specimen photographed using differential interference contrast (DIC).
20 *Momipites macroexinatus* sp. nov., WRV 04774, 96.65, EF P31/4.
21 *Triporites* sp., WRV 04774, 216.9, EF R32/2.
22 *Triporites* sp., WRV 04774, 252.66, EF R20.
23, 24 *Triporites* sp., WRV 04774, 285.08, EF E22/1.
25 *Verrutricolporites* sp., WRV 04774, 184.55, EF E21/2.
26 *Stephanoporites* sp., WRV 04774, 278.12, EF O32/1.
27 *Stephanoporites* sp., WRV 04774, 28.65, EF X49/4.
28 *Stephanoporites* sp., WRV 04774, 19, EF O58.
29, 30 *Ulmoideipites krempii* (Anderson 1960) Elsik 1968, WRV 04774, 188.64, EF C24/1.
31 *Echistephanoporites inciertus* sp. nov., paratype, WRV 04774, 290.77, EF P44/2.
32, 33 *Echistephanoporites inciertus* sp. nov., paratype, WRV 04774, 112.90, EF Q23/3.
34 *Echistephanoporites inciertus* sp. nov., paratype, WRV 04774, 38.63, EF H25/3.
35 *Echistephanoporites inciertus* sp. nov., holotype, WRV 04774, 84.35, EF X30/2.
36 Unidentified acritarch, WRV 04774, 311.28, EF P55/3,4.
37 Unidentified dinoflagellate cyst, WRV 04774, 32.6, EF E53/4.
38 *Dinogymnium* sp. (dinoflagellate cyst), WRV 04774, 46.75, EF J30/3 (reworked).
39 Foraminiferal test lining, WRV 04774, 355.64, EF R16/4.
40 *Leiospheridia* sp. (acritarch), WRV 04774, 207.50, EF M25/4.
41 *Diporopollis assamica* Dutta & Sah 1970 (equatorial view), WRV 04774, 134.6, EF L29/3.
42 *Diporopollis assamica* Dutta & Sah 1970 (polar view), WRV 04774, 157, EF O46/3.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Horniella lunarensis sp. nov.
Plate 7, figs. 22–23

Horniella sp. 3, Jaramillo and Dilcher, 2001, pl. 11, figs. 24–26.

Holotype. Plate 7, figs. 22–23, sample Niscota E1-1120/1150, EF T31/2.

Paratype. Jaramillo and Dilcher, 2001, pl. 11, figs. 24–26, UFP 21, 6.4 x 83.8.

Etymology. From the Latin *lunaris,* meaning of the moon, after the thickening of the pore that resembles a full moon.

Diagnosis. Retitricolporate pollen, intermediate in size (23–40 μm), pores conspicuously costate and fastigiate, sculpture reticulate, fine to psilate.

Description. Monad pollen, radial, isopolar, amb triangular–obtuse–convex; tricolporate, ectocolpi simple, CEi 0.7 μm, long, borders straight, ends pointed, polar area small, 13 μm wide, endopore costate fastigiate, lalongate, 4 μm wide, 1 μm long, pores indistinct, costae conspicuous, 5 μm wide, fastigia 4 μm long, 6–10 μm wide; tectate, exine 1 μm thick, nexine separated from sexine in equatorial zone around pores, columellae distinct, < 1.0 μm wide, < 1.0 μm apart; sculpture reticulate to psilate, lumina < 1.0 μm wide, rounded, uniform, distributed densely, muri < 1.0 μm wide, some grains psilate or micropitted.

Dimensions. Equatorial diameter 22(33)41 μm; measured 10, observed 40.

Comparisons. *Psilatricolporites marginatus* Van der Kaars 1983 has marginate colpi, is smaller (19–27 μm), and lacks vestibula. *Retitricolporites costatus* Leidelmeyer 1966 is smaller (25 μm), and has a uniform and fine reticulum.

Ladakhipollenites "felipei"
Plate 7, figs. 27–29

Diagnosis. Psilatricolpate, mid sized (35 μm), prolate, atectate.

Description. Monad, radial, isopolar, prolate; tricolpate, colpi simple, long, almost reaching apocolpia; atectate, exine 2 μm thick; sculpture psilate.

Dimensions. Equatorial diameter 22 μm, polar diameter 35 μm, polar/equatorial diameter 1.6 μm, one specimen measured.

Comparison. *Eucommiidites* has unequal colpi length.

Specimens. Sample Cerrejón WRV04752-93.53, EF M17.

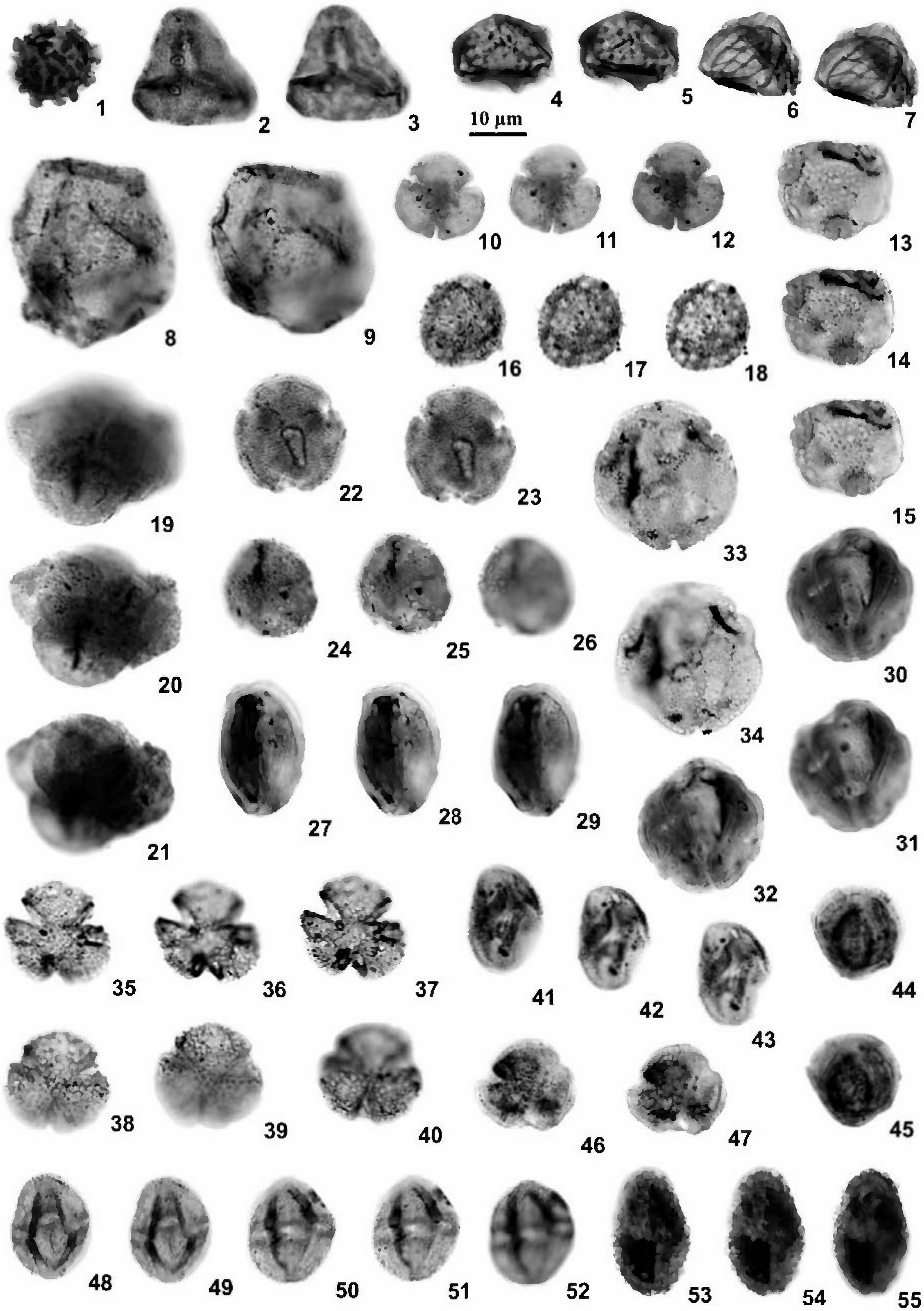
Margocolporites "reticulatus"
Plate 7, figs. 24–26

Diagnosis. *Margocolpororites* type, intermediate in

PLATE 7

All sample numbers are prefixed 'Cerrejón', except figures 22, 23. The sample number is followed by the England Finder (EF) coordinate.

1	*Rugulatisporites* "maculosus" WRV 04752, 19.66, EF K56.
2, 3	*Foveotriletes* "microfoveolatus", WRV 04752, 141.34, EF S27/4.
4, 5	*Echitriletes* "tuberosus", WRV 04752, 340.85, EF M18.
6, 7	*Striatriletes elegantis* sp. nov., holotype, WRV 04752, 340.58, EF R16/2.
8, 9	*Verrutriletes* "echinatus", WRV 04752, 104.74, EF P14.
10–12	*Bombacacidites* "poloanularis", WRV 04752, 57.47, EF T28/1.
13–15	*Bombacacidites* "pseudoannae", WRV 04752, 93.53, EF T45/1.
16–18	*Echistephanoporites inciertus* sp. nov., WRV 04774, 316.16, EF M23/3.
19–21	*Ericipites fossulatus* sp. nov. paratype, WRV 04774, 59, EF O31/2.
22, 23	*Horniella lunarensis* sp. nov. holotype, Niscota E1, 1120/1150, EF T31/2.
24–26	*Margocolporites* "reticulatus", WRV 04752, 41.34, EF D18/1.
27–29	*Ladakhipollenites* "felipei", WRV 04752, 93.53, EF M17.
30–32	*Tetracolporopollenites* "binocularis", WRV 04752, 41.34, EF K24.
33–34	*Bombacacidites foveolatus* sp. nov., holotype, WRV 04752, 111.0, EF R25.
35–37	*Retitrescolpites definidus* sp. nov., holotype, WRV 04752, 70.28, EF K47/4.
38–40	*Retitrescolpites definidus* sp. nov., paratype, WRV 04752, 78.97, EF B34/1.
41–43	*Rousea*? "polopsilatus", WRV 04752, 57.47, EF S24.
44, 45	*Tetracolporopollenites*? *semispongiosus* sp. nov., holotype, WRV 04752, 81.02, EF O19/2.
46, 47	*Tetracolporopollenites*? *semispongiosus* sp. nov., paratype, WRV 04752, 81.02, EF V10/2.
48, 49	*Striatricolporites guajiraensis* sp. nov, holotype, WRV 04752, 124.42, EF V25/4.
50–52	*Striatricolporites guajiraensis* sp. nov, paratype, WRV 04752, 124.42, EF O19/2.
53–55	*Verrutricolpites* "gemmatus", WRV 04752, 252.66, EF K43/2.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size (26 μm), fossureticulate.

Description. Monad, radial, isopolar, amb circular; tricolporate, *Margocolporites* type, ectocolpi 10 μm long, marginate, margo 4 μm wide by thinning of exine, endopore indistinct, simple; tectate, exine 2 μm thick at mesocolpia decreasing to 1 μm near ectocolpi, columella indistinct; sculpture fossulate–reticulate, lumina at apocolpia 1 μm wide increasing toward mesocolpia to 2 μm wide, nexine psilate around colpi.

Dimensions. Equatorial diameter 26 μm, one specimen measured.

Comparisons. *Margocolporites vanwijhei* Germeraad et al. 1968 is reticulate.

Specimens. Sample Cerrejón WRV04752-41.34, EF D18/1.

Momipites macroexinatus sp. nov.
Plate 6, figs. 14–20

Holotype. Plate 6, fig. 14, sample Cerrejón WRV 04774-19, EF N56/3.

Paratype. Plate 6, fig. 15, sample Cerrejón WRV 04774-53.95, EF F20/2.

Etymology. After the thick exine.

Diagnosis. Psilatriporate pollen, intermediate in size (24–26 μm), triangular–obtuse–convex, atectate 2 μm thick, pores slightly protruding, atria slightly developed.

Description. Monad pollen, radial, isopolar, amb triangular–obtuse–convex; triporate, pores atriate, slightly elongate, 3 μm wide, 2 μm long, slightly protruding, atrium slightly developed, atectate, nexine 1 μm thick; sculpture psilate.

Dimensions. Equatorial diameter 22(24)25; measured 5, observed 10.

Comparisons. *Momipites africanus* Van Hoeken Klinkenberg 1966 has thinner exine (1 μm), and *Momipites* sp. 1 of Jaramillo and Dilcher (2001) has highly irregular pore borders.

Retitrescolpites definidus sp. nov.
Plate 7, figs. 35–40

Holotype. Plate 7, figs. 35–37, sample Cerrejón WRV04752-70.28, EF K47/4.

Paratype. Plate 7, figs. 38–40, sample Cerrejón WRV04752-78.97, EF B34/1.

Etymology. From the Latin *definitus,* meaning distinct, after the well-defined costa–colpi.

Diagnosis. Tricolpate pollen, intermediate in size (27–28 μm), reticulate, colpi costate, costae well defined.

Description. Monad pollen, isopolar, prolate, circular; tricolpate, ectocolpi costate, colpi 20 μm long, ends pointed, costae well defined, 2 μm wide, protruding, 1 μm thick; semitectate, exine 2 μm thick, columellae distinct, nexine 0.5 μm thick, columellae 1 μm thick, tectum 0.5 μm thick; sculpture reticulate, lumina polygonal, 1.5–2 μm wide, variable in width, densely distributed over entire grain, muri 1 μm wide, thin, undulating, simplicolumellate.

Dimensions. Equatorial diameter 27(28)28 μm; measured 2, observed 5.

Comparisons. *Retitrescolpites*? *irregularis* (Van der Hammen & Wymstra 1964) Jaramillo & Dilcher 2001 has costate pores. *Retitrescolpites saturum* (Gonzalez 1967) Jaramillo & Dilcher 2001 is larger (40–47 μm).

Rousea? "polopsilatus"
Plate 7, figs. 41–43

Diagnosis. Tricolporate, intermediate in size (27 μm), reticulate at mesocolpia, psilate at apocolpia.

Description. Monad, isopolar, prolate, circular; tricolporate, ectocolpi simple, long, ends pointed, endopore circular, costate, costae 2 μm long; semitectate at mesocolpia, tectate at apocolpia, exine 1 μm thick, columellae distinct, nexine 0.25 μm thick, columellae 0.5 μm thick, tectum 0.25 μm thick; sculpture reticulate, muri 1 μm thick, luminae 1 μm wide, polygonal, lumina decreasing gradually toward apocolpia where sculpture is psilate.

Dimensions. Equatorial diameter 19 μm; polar diameter 27 μm; polar/equatorial diameter 1:4, one specimen measured.

Specimens. Sample Cerrejón WRV04752-57.47, EF S24.

Siltaria cerrejonensis sp. nov.
Plate 4, figs. 19–20

Siltaria sp. 4, Jaramillo and Dilcher, 2001, pl. 19, figs 19–20.

Holotype. Plate 4, fig. 19, sample Cerrejón WRV 04774-171.57, EF V23/2.

Paratype. Plate 4, fig. 20, sample Cerrejón WRV 04774-326.82, EF P36/2.

Etymology. After the Cerrejón Coal Mine and the Cerrejón Formation.

Diagnosis. Tricolporate pollen, small to intermediate in size (21–31 μm), subprolate, columellae indistinct, ectocolpi costate, pore simple, micropittted.

Description. Monad pollen, radial, isopolar, subprolate, amb triangular–obtuse–convex; tricolporate, ectocolpi costate, CPi 0.7, borders straight, ends pointed, costae 1.5 μm wide at equator, 1 μm at colpi ends, 1 μm thick, polar area small, 6 μm wide, endopores simple, circular, 3 μm wide, 3 μm long, pores distinct; tectate, exine 1 μm thick, nexine thickening around colpi to 1.5 μm, columellae barely distinct; sculpture micropitted, lumina 0.5 μm wide, rounded, uniform, distributed densely, muri < 0.5 μm wide.

Dimensions. Equatorial diameter 11(18)24 μm, polar diameter 21(25)31 μm, polar/equatorial ratio 1:4; measured 5, observed 12.

Comparisons. *Rhoipites squarrosus* (Van der Hammen & Wymstra 1964) Jaramillo and Dilcher 2001 has thicker exine (2 μm), distinct columellae, and wider lumina (>0.5 μm). *Siltaria media* (Gonzalez 1967) Jaramillo and Dilcher 2001 has simple colpi.

Striatricolporites guajiraensis sp. nov.
Plate 7, figs. 48–52

Holotype. Plate 7, figs. 48–49, sample Cerrejón WRV04752-124.42, EF V25/4.

Paratypes. Plate 7, figs. 50–52, sample Cerrejón WRV04752-124.42, EF O19/2.

Etymology. After Guajira state, where the Cerrejón coal mines are located.

Diagnosis. Tricolporate pollen, striate, prolate, intermediate in size (28 μm), muri parallel to colpi, exine reticulate within striae, colpi and pores costate.

Description. Monad pollen, radial, isopolar, prolate; tricolporate, ectocolpi costate, long, almost reaching apocolpia, costae 0.5 μm wide, pores costate, elongate, 6 μm long, 3 μm wide, costae 2 μm wide, 2 μm thick; intectate, exine 1 μm thick; sculpture striate, striae 1–3 μm wide, muri 0.5 μm wide, parallel to colpi, exine within striae reticulate, lumina 1–3 μm wide, muri 0. 5 μm wide, elongate, striae may be tenuous.

Dimensions. Equatorial diameter 22–23 μm, polar diameter 27–28 μm, polar/equatorial ratio 1:3; measured 2, observed 8.

Comparisons. *Striatopollis*? *tenuistriatus* Jaramillo & Dilcher 2001 is tricolpate. *Striatricolpites saramacensis* Wijmstra 1971 has thicker exine (2–3 μm), and distinct columellae. *Striatricolpites semistriatus* Gonzalez 1967 has striae that bifurcate at the poles. *Striatricolporites agustinus* Gonzalez 1967 is smaller (19–23 μm). *Striatricolporites tenuissimus* Dueñas 1980 has simple, lolongate pores. *Striatricolporites* sp. 1 of Jaramillo & Dilcher (2001) has simple pores.

Tetracolporopollenites "binocularis"
Plate 7, figs. 30–32

Diagnosis. Tricolporate, intermediate in size (35 μm), atectate, tectum thick, psilate, pore strongly costate.

Description. Monad, radial, isopolar, circular, subprolate; tricolporate, ectocolpi simple, ends pointed, long, almost reaching apocolpia, endopores costate, costae well developed, 4 μm wide at mesocolpia, extending toward the end of the colpi, where it reduces to 1 μm, pore lalongate 7 μm long, 2 μm wide; atectate, exine 1.5 μm thick, sculpure psilate, sometimes slightly micropitted.

Dimensions. Equatorial diameter 33 μm, polar diameter 35 μm, polar/equatorial diameter 1:1, one specimen measured.

Comparisons. Other species of *Tetracolporopollenites* have a spongy exine, and are prolate.

Specimens. Sample Cerrejón WRV04752-41.34, EF K24.

Tetracolporopollenites kogiorum sp. nov.
Plate 4, figs. 45–50

Holotype. Plate 4, fig. 45, sample Cerrejón WRV 04774-171.57, EF Q22/4.

Paratype. Plate 4, fig. 46; sample Cerrejón WRV 04774-22.69-24.55, EF T45/3.

Etymology. After the Kogi Tribe that inhabit the Sierra Nevada de Santa Marta, Colombia.

Diagnosis. Tricolporate pollen, small in size (19–23 μm), thick tectate exine, colpi costate.

Description. Monad pollen, radial, subprolate, amb circular; tricolporate, ectocolpi costate, costae 2 μm wide, 1.5–2 μm thick, ends pointed, short to intermediate in size, endopores elongate, 4 μm long, 2 μm wide, simple; tectate, exine 2 μm thick, nexine 1 μm thick, columellae 0.5 μm, tectum 0.5 μm, columellae distinct, sculpture psilate to foveolate, foveolae 0.5 μm wide, 1 μm apart, 0.5 μm deep, distributed over entire grain.

Dimensions. Equatorial diameter 16(18)21 μm, polar diameter 19(20)23 μm, polar/equatorial ratio 1:2; measured 4, observed 10.

Comparison. *Psilatricolporites devriesi* Lorente 1986 has irregular poles, is larger, and the colpi are simple.

Tetracolporopollenites? *semispongiosus* sp. nov.
Plate 7, figs. 44–47

Holotype. Plate 7, figs. 44–45, sample Cerrejón WRV04752-81.02, EF O19/2.

Paratype. Plate 7, figs. 46–47, sample Cerrejón WRV04752-81.02, EF V10/2.

Etymology. From the Latin *sponge,* meaning spongy substance, after the semi-spongy character of the exine.

Diagnosis. Tricolporate pollen, psilate, intermediate in size (25 μm), colpi marginate, exine partially spongy, thick.

Description. Monad pollen, isopolar, circular;

tricolporate, ectocolpi marginate, long, ends pointed, almost reaching apocolpia, polar area small, margo 2 μm wide, by thinning of the exine, endopore simple, circular, distinct; tectate, 2.5 μm thick, columellae distinct, nexine 1 μm, columellae 0.5 μm, tectum 1 μm, exine gradually decreasing near colpi to 1 μm; sculpture psilate, easily degraded.

Dimensions. Equatorial diameter 23(24)25 μm; measured 3, observed 3.

Comparisons. These specimens have long colpi that are strongly marginate, and cannot be placed satisfactorily in any existing genus. It is placed provisionally in *Tetracolporopollenites* Pflug & Thomson *in* Thomson & Pflug 1953 because of its psilate sculpture and thick exine. *Ladakhipollenites simplex* (Gonzalez 1967) Jaramillo & Dilcher 2001 is tricolpate, and slightly marginate (0.5 μm wide). *Psilatricolporites marginatus* Van der Kaars 1983 has a margo produced by a thickening of the exine. *Tetracolporopollenites spongiosus* Jaramillo & Dilcher 2001 has simple colpi.

Verrutricolpites "gemmatus"
Plate 7, figs. 53–55

Diagnosis. Tricolpate, intermediate in size (35 μm), verrucate/gemmate, intectate, thick exine.

Description. Monad, radial, isopolar, prolate; tricolpate, colpae indistinct, long, simple; intectate, exine thick, 2 μm thick, 1–1.5 μm high; sculpture verrucate–gemmate, verrucae 1 μm wide, near mesocolpia larger verrucae, 3 μm wide, 2 μm high, gemmae 1–3 μm wide, 1–2 μm high, both verrucae and gemmae interspersed and densely arranged over entire grain.

Dimensions. Equatorial diameter 22 μm, polar diameter 35 μm, polar/equatorial diameter 1:6, one occurrence.

Comparison. *Gemmatricolpites pulcher* Gonzalez 1967 has thin (1 μm) exine.

Specimens. Sample Cerrejón WRV04752-252.66, EF K43/2.

ACKNOWLEDGMENTS

This project was supported by the Colombian Petroleum Institute, the Smithsonian Paleobiology Endowment Fund, the Fondo para la Investigacion de Ciencia y Tecnología Banco de la Republica de Colombia, the Unrestricted Endowments Smithsonian Institution Grants, and Carbones del Cerrejón LLC. Thanks go to Norman Frederiksen and an anonymous reviewer for detailed reviews of the manuscript. The biostratigraphy team at the Colombian Petroleum Institute, and Camilo Montes helped with logistic support and fieldwork. Richard Condit helped with the R code. Shivani Moodley, Iann Sanchez, and Aaron Odea commented on the manuscript. Juan Carlos Berrio is thanked for pollen raw data. Special thanks go to M. I. Barreto for her continuous support, and ideas.

References Cited

BAYONA, G., JARAMILLO, C.A., RUEDA, M., PARDO, A., and HERNANDEZ, G.
2004 Important paleotectonic and chronostratigraphic considerations of the Late Paleocene in the northernmost Andes as constrained by Paleocene rocks in the Cerrejón Coal Mine, Guajira, Colombia. *III Conven-cion Tecnica ACGGP. Bogota,* CD ROM (abstract).

BERRIO, J.C.
2002 *Lateglacial and Holocene vegetation and climatic change in lowland Colombia.* Unpublished PhD Thesis, University of Amsterdam, Amsterdam, 240 p.

CACERES, H., CAMACHO, R., and REYES, J.
1980 *The geology of the Rancheria Basin.* Geological Field Trips, Colombia 1980–1989. Asociación Colombiana de Geólogos y Geofísicos del Petróleo, Bogotá, 31 p.

CARBONES DE CERREJÓN
2003a Mapa geológico, Cerrejón zona Norte. Scale: 1:50000, Carbones del Cerrejon.
2003b Stratigraphic columns for the Cerrejón deposit - Patilla section. Scale 1:2000, Carbones del Cerrejon.

CLARKE, K.R.
1993 Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology*, 18: 117–143.

DOUBINGER, J.
1973 Pollen and spores from the Paleocene coal basin of Cerrejón (Guajira Province, Colombia). *Proceedings de la 1996 Congres de National des Société Savantes, Toulouse, 1971*, 5: 253–262.
1976 Spore–pollen assemblages from the Tertiary of Colombia. *Actas 1997 Congres de National des Société Savantes, Nantes*, 4: 9–18.

ETAYO-SERNA, F.
1979 Moluscos de una capa del Paleocene de Manantial (Guajira). *Boletin de Geologia*, 13: 5–55.

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.

GILINSKY, N.L.
1991 Bootstrapping and the fossil record. *In*: Gilinsky, N.L., and Signor, P.W. (eds.). *Analytical paleobiology.* Short Courses in Paleontology. Paleonto-

logical Society, Pittsburgh, 185–206.

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 p.

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 (St Louis) 2002. *Regnum Vegetabile*, 138: 1–474.

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.

HARRINGTON, G.J.
2004 Structure of the North American vegetation gradient during the late Paleocene/early Eocene warm climate. *Evolutionary Ecology Research*, 6: 33–48.

HARRINGTON, G.J., CLECHENKO, E.R., and KELLY, D.C.
2005 Palynology and organic-carbon isotope ratios across a terrestrial Palaeocene/Eocene boundary section in the Williston Basin, North Dakota, U.S.A. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 226: 214–232.

HAUGHT, L., COLLEY, B., and BELDING, H.
1944 *Geology of the Cesar-Rancheria Valley and Commissary of Guajira*. Geological Report, Tropical Oil Company (unpublished).

HERNGREEN, G.F.W., and CHLONOVA, A.F.
1981 Cretaceous microfloral provinces. *Pollen et Spores*, 23: 441–555.

HESSE, M., and ZETTER, R.
2007 The fossil record of Araceae. *Plant Systematics and Evolution*, 263: 93–115.

HILL, M.O., and GAUCH, H.G.
1980 Detrended correspondence analysis, an improved ordination technique. *Vegetatio*, 42: 47–58.

INGEOMINAS
2004 *El carbon Colombiano, recursos, reservas y calidad*. Ministerio de Minas y Energia Ingeominas, Bogota, 470 p.

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

JARAMILLO, C.A., and DILCHER, D.L.
2000 Microfloral diversity patterns of the late Paleocene–Eocene interval in Colombia, northern South America. *Geology*, 28: 815–818.
2001 Middle Paleogene palynology of central Colombia, South America: a study of pollen and spores from tropical latitudes. *Palaeontographica Abteilung B*, 258: 87–213.

JARAMILLO, C.A, MUÑOZ, F., COGOLLO, M., and DE LA PARRA, F.
2005 Quantitative biostratigraphy for the Paleocene of the Llanos foothills, Colombia: improving palynological resolution for oil exploration. *In*: Powell, A.J., and Riding, J.B. (eds.). *Recent Developments in Applied Biostratigraphy*. The Micropalaeontological Society, Special Publication, p. 145–159.

JARAMILLO, C.A., and DE LA PARRA, F.
2006 Palynological changes across the Cretaceous–Paleocene boundary in the Neotropics, *Geological Society of America, Abstracts with Programs, Philadelphia*, p. 380 (abstract).

JARAMILLO, C.A., and RUEDA, M.
2006 A morphological electronic database of Cretaceous–Tertiary fossil pollen and spores from northern South America. Colombian Petroleum Institute and Smithsonian Tropical Research Institute, CD ROM.

JARAMILLO, C.A., RUEDA, M., and MORA, G.
2006 Cenozoic plant diversity in the neotropics. *Science*, 311: 1893–1896.

JARAMILLO, C.A., BAYONA, G., PARDO-TRUJILLO, A., RUEDA, M., TORRES, V., HARRINGTON, G.J., and MORA, G.
2007 Appendix 2 - Palynological counts, core WRV04774; Appendix 3 - Palynological counts, core WRV04752; Appendix 4 - R code used in the analyses; Appendix 5 - Biostratigraphic Range Chart, Core WRV04774 (Coal seams 45-110); Appendix 6 - Biostratigraphic Range Chart, Core WRV04752 (Coal seams 103-155). Appendices 2–6 for 'The palynology of the Cerrejón Formation (Upper Paleocene) of northern Colombia' *Palynology*, 31: 153–189. American Association of Stratigraphic Palynologists Data Committee, Palydisk 24. Available at: http://www.palydisks.palynology.org/.

KELLOGG, J.N.
1984 Cenozoic tectonic history of the Sierra de Perijá, Venezuela–Colombia, and adjacent basins. *In*: Bonini, W.E., Hargraves, R.B., and Shagam, R. (eds.). *The Caribbean–South American Plate Boundary and Regional Tectonics*. Geological Society of America Memoir, Boulder, 239–261.

KELLOGG, J.N., and BONINI, W.E.
1982 Subduction of the Caribbean Plate and basement uplifts in the overriding South American Plate. *Tectonics*, 1: 251–276.

LAMUS, F.
2006 *Análisis de la sucesión Paleocena en el sector norte de la cuenca Cesar-Ranchería: implicaciones en*

los modelos tectónicos de la Sierra Nevada de Santa Martha y Serranía de Perijá. Undergraduate dissertation, Universidad Nacional de Colombia, Bogota.

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

MAGURRAN, A.E.
2004 *Measuring biological diversity*. Blackwell Publishing, Malden, Massachusetts, U.S.A., 256 p.

McANDREWS, J.H.
2000a Devils Lake pollen record. *In*: Grimm, E.C. (ed.). *North American Pollen Database*. IGBP PAGES/World Data Center for Paleoclimatology, NOAA/NCDC Paleoclimatology Program, Boulder, Colorado, U.S.A.
2000b Woodwort pollen record. *In*: Grimm, E.C. (ed.). *North American Pollen Database*. IGBP PAGES/World Data Center for Paleoclimatology, NOAA/NCDC Paleoclimatology Program, Boulder, Colorado, U.S.A.

MONTES, C., BAYONA, G., JARAMILLO, C.A., OJEDA, G., MOLINA, M., and HERRERA, F.
2005 Uplift of the Sierra Nevada de Santa Marta and subsidence in the Cesar-Rancheria Valley: rigid-beam pivot model. *Sixth International Symposium of Andean Geodynamics*, 520–523 (abstract).

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.

OKSANEN, J., KINDT, R., and O'HARA, B.
2005 *Community Ecology Package, Package VEGAN R for Statistical Computing*.

OSBORNE, P.L.
2000 *Tropical ecosystems and ecological changes*. Cambridge University Press, Cambridge, 464 p.

PARDO-TRUJILLO, A., JARAMILLO, C.A., and OBOH-IKUENOBE, F.
2003 Paleogene palynostratigraphy of the eastern Middle Magdalena Valley, Colombia. *Palynology*, 27: 155–178.

PIELOU, E.C.
1984 *The interpretation of ecological data*. John Wiley and Sons, New York, 263 p.

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 p.

R-DEVELOPMENT-CORE-TEAM
2005 *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL: http://www.R-project.org (viewed May 24th, 2007).

RADLE, N.J.
2000 Medicine Lake pollen record. *In*: Grimm, E.C. (ed.). *North American Pollen Database*. IGBP PAGES/World Data Center for Paleoclimatology, NOAA/NCDC Paleoclimatology Program, Boulder, Colorado, U.S.A.

RAMOS, J.G.
1990 *Ambientes de deposito relacionados con los parametros de calidad de los carbones del Cerrejón Bloque B*. Undergraduate dissertation, Universidad Nacional de Colombia, Bogota.

RAUP, D.M.
1975 Axonomic diversity estimation using rarefaction. *Paleobiology*, 1: 333–342.

ROBERTS, D.
2005 *Laboratory for Dynamic Synthetic Vegephenomenology*. R for Statistical Computing, v. 1.01.

ROMERO, E.J.
1993 South American paleofloras. *In*: Goldblatt, P. (ed.). *Biological relationships between Africa and South America*. Yale University Press, New Haven, 62–85.

ROSENZWEIG, M.L.
1995 *Species diversity in space and time*. Cambridge University Press, Cambridge, 433 p.

RULL, V.
1997a Oligo-Miocene palynology of the Rio Chama sequence (Western Venezuela), with comments on fossil algae as paleoenvironmental indicators. *Palynology*, 21: 213–229.
1997b Sequence analysis of western Venezuelan Cretaceous to Eocene sediments using palynology: chrono-paleoenvironmental and paleovegetational approaches. *Palynology*, 21: 79–90.
1998a Biogeographical and evolutionary considerations of *Mauritia* (Arecaceae), based on palynological evidence. *Review of Palaeobotany and Palynology*, 100: 109–122.
1998b Middle Eocene mangroves and vegetation changes in the Maracaibo Basin, Venezuela. *Palaios*, 13: 287–296.
1999 Palaeofloristic and palaeovegetational changes across the Paleocene/Eocene boundary in northern South America. *Review of Palaeobotany and Palynology*, 107: 83–95.
2000 Ecostratigraphic study of Paleocene and Early Eocene palynological cyclicity in northern South America.

Palaios, 15: 14–24.

THANIKAIMONI, G., CARATINI, C., VENKATACHALA, B.S., RAMANUJAM, C.G.K., and KAR, R.K.
1984 Selected Tertiary Angiosperm pollens from India and their relationship with African Tertiary pollens. *Institut Français de Pondichery Travaux de la Section Scientifique*, 19: 1–92.

TRAVERSE, A.
1988 *Paleopalynology*. Academic Press, New York, 600 p.

TSCHANZ, C., MARVIN, R., CRUZ, J., MENNERT, H., and CEBULA, E.
1974 Geologic evolution of the Sierra Nevada de Santa Marta. *Geological Society of America Bulletin*, 85: 269–276.

UJUETA, G., and LLINÁS, R.D.
1990 Reconocimiento Geológico de la parte mas septentrional de la Sierra de Perijá. *Geologia Colombiana*, 17: 197–209.

VAN ANDEL, T.H.
1958 Origin and classification of Cretaceous, Paleocene, and Eocene sandstones of western Venezuela. *American Association of Petroleum Geologists Bulletin*, 42: 734–763.

VAN DER HAMMEN, T.
1954 The development of Colombian flora throughout geologic periods: I, Maestrichtian to Lower Tertiary. *Boletín Geológico (Bogotá)*, 2: 49–106.
1956a A palynological systematic nomenclature. *Boletín Geológico (Bogotá)*, 4: 63–101.
1956b Description of some genera and species of fossil pollen and spores. *Boletín Geológico (Bogotá)*, 4: 103–109.
1957a 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.
1957b Palynologic stratigraphy of the Sabana de Bogota (East Cordillera of Colombia). *Boletín Geológico (Bogotá)*, 5: 187–203.
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 WYMSTRA, T.A.
1964 A palynological study on the Tertiary and Upper Cretaceous of British Guayana. *Leidse Geologische Mededelingen*, 30: 183–241.

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

VAN DER KAARS, W.A.
1983 A palynological–paleoecological study of the lower Tertiary coal-bed sequence from El Cerrejón (Colombia). *Geología Norandina*, 8: 33–48.

VAN HOEKEN-KLINKENBERG, P.M.J.
1964 A palynological investigation of some Upper Cretaceous sediments in Nigeria. *Pollen et Spores*, 6: 209–231.
1966 Maastrichtian Paleocene and Eocene pollen and spores from Nigeria. *Leidse Geologische Mededelingen*, 38: 37–48.

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

WATTS, W.A.
2000 Pickerel Lake pollen record. *In*: Grimm, E.C. (ed.). *North American Pollen Database*. IGBP PAGES/ World Data Center for Paleoclimatology, NOAA/ NCDC Paleoclimatology Program, Boulder, Colorado, U.S.A.

WIJMSTRA, T.A.
1969 Palynology of the Alliance well. *Geologie en Mijnbouw*, 48: 125–133.

WILDE, V., KVACEK, Z., and GBOGNER, J.
2005 Fossil leaves of the Araceae from the European Eocene and notes on other Aroid fossils. *International Journal of Plant Sciences*, 166: 157–183.

WILLIG, M.R., KAUFMAN, D.M., and STEVENS, R.D.
2003 Latitudinal gradients of biodiversity: patterns, process, scale, and synthesis. *Annual Review of Ecology and Systematics*, 34: 273–309.

WING, S.L.
1998 Late Paleocene–early Eocene floral and climatic change in the Bighorn Basin, Wyoming. *In*: Berggren, W., Aubry, M.-P., and Lucas, S. (eds.). *Late Paleocene–early Eocene biotic and climatic events*. Columbia University Press, New York, p. 371–391.

WING, S.L., and HARRINGTON, G.J.
2001 Floral response to rapid warming at the Paleocene/ Eocene boundary and implications for concurrent faunal changes. *Paleobiology*, 27: 539–563.

WING, S.L., HERRERA, F., and JARAMILLO, C.A.
2004 A Paleocene flora from the Cerrejón Formation, Guajira Peninsula, northeastern Colombia. *International Organization of Paleobotany, Seventh Quatrennial Conference, Bariloche, Argentina*, p. 146–147 (abstract).

WITTMANN, F., SCHONGART, J., MONTERO, J.C., MOTZER, T., PIEDADE, M.T.F., QUEIROZ, H.L., and WORBES, M.
2006 Tree species composition and diversity gradients in white-water forests across the Amazon Basin. *Jour-*

nal of Biogeography, 33: 1334–1347.
ZACHOS, J., PAGANI, M., SLOAN, L., THOMAS, E., and BILLUPS, K.
2001 Trends, rhythms, and aberrations in global climate 65 Ma to present. *Science*, 292: 686–693.

APPENDIX 1. List of palynomorph species

This Appendix lists all valid palynomorph taxa below generic level that are mentioned in this contribution with full author citations. The palynomorphs are listed alphabetically within their constituent groups.

Pteridophyte and bryophyte spores

Apiculatasporites obscurus Jaramillo & Dilcher 2001
Chomotriletes minor (Kedves 1961) Pocock 1970
Clavatisporites mutisii (Van der Hammen 1954) Jaramillo & Dilcher 2001
Echinatisporis minutus Van der Kaars 1983
Foveotriletes margaritae (Van der Hammen 1954) Germeraad et al. 1968
Foveotriletes ornatus Regali et al. 1974
Foveotriletes concavoides sp. nov.
Ischyosporites problematicus Jaramillo & Dilcher 2001
Laevigatosporites granulatus sp. nov.
Laevigatosporites tibuensis (Van der Hammen 1956) Jaramillo & Dilcher 2001
Polypodiaceoisporites? *fossulatus* Jaramillo & Dilcher 2001
Retitriletes cristatus sp. nov.
Striatriletes elegantis sp. nov.
Verrutriletes virueloides sp. nov.

Angiosperm pollen

Aglaoreidia? *foveolata* Jaramillo & Dilcher 2001
Arecipites regio (Van der Hammen & Garcia 1966) Jaramillo & Dilcher 2001
Bombacacidites annae (Van der Hammen 1954) Leidelmeyer 1966
Bombacacidites nacimientoensis (Anderson 1960) Elsik 1968
Foveotricolporites brevicolpatus sp. nov.
Clavatricolpites densiclavatus Jaramillo & Dilcher 2001
Colombipollis tropicalis Sarmiento 1992
Ctenolophonidites lisamae (Van der Hammen & Garcia 1966) Germeraad et al. 1968
Curvimonocolpites inornatus Leidelmeyer 1966
Diporoconia cf. *D. iszkaszentgyoergyi* (Kedves 1965) Frederiksen et al. 1985
Duplotriporites ariani Sarmiento 1992
Echimonocolpites protofranciscoi Sarmiento 1992
Echistephanoporites inciertus sp. nov.
Echitriporites suescae (Van der Hammen 1954)
Echitriporites trianguliformis Van Hoeken Klinkenberg 1964
Echitriporites trianguliformis var. *orbicularis* Jaramillo & Dilcher 2001
Spathiphyllum vanegensis (Van der Hammen & Garcia 1966) Hesse & Zetter 2007
Ericipites fossulatus sp. nov.
Foveodiporites operculatus Van der Kaars 1984
Foveotricolpites perforatus Van der Hammen & Garcia 1966
Foveotricolporites cf. *fossulatus* Jaramillo & Dilcher 2001
Gemmamonocolpites aff. *ovatus* Gonzalez 1967
Gemmamonocolpites dispersus Sarmiento 1992
Gemmamonocolpites gemmatus (Van der Hammen 1954) Van der Hammen & Garcia 1966
Gemmastephanocolpites gemmatus Van der Hammen & Garcia 1966
Horniella lunarensis sp. nov.
Longapertites aff. *vaneendenburgi* Germeraad et al. 1968
Longapertites marginatus Van Hoeken Klinkenberg 1964
Longapertites microfoveolatus Adegoke & Jan du Chêne 1975
Longapertites perforatus Gonzalez 1967
Longapertites proxapertitoides var. *reticuloides* Van der Hammen & Garcia 1966
Longapertites proxapertitoides var. *proxapertitoides* Van der Hammen & Garcia 1966
Longapertites vaneendenburgii Germeraad et al. 1968
Magnotetradites magnus (Van der Hammen 1954) Van der Hammen & Garcia 1966
Mauritiidites franciscoi var. *pachyexinatus* Van der Hammen & Garcia 1966
Mauritiidites franciscoi var. *franciscoi* (Van der Hammen 1956) Van Hoeken Klinkenberg 1964
Mauritiidites franciscoi var. *minutus* Van der Hammen & Garcia 1966

Momipites aff. *africanus* Van Hoeken Klinkenberg 1966
Momipites macroexinatus sp. nov.
Monocolpopollenites ovatus Jaramillo & Dilcher 2001
Monoporopollenites annulatus (Van der Hammen 1954) Jaramillo & Dilcher 2001
Poloretitricolpites aff. *absolutus* (Gonzalez 1967) Jaramillo & Dilcher 2001
Proxapertites aff. *operculatus* (Van der Hammen 1954) Van der Hammen 1956
Proxapertites aff. *tertiaria* Van der Hammen & Garcia 1966
Proxapertites aff. *verrucatus* Sarmiento 1992
Proxapertites cursus Van Hoeken Klinkenberg 1966
Proxapertites humbertoides (Van der Hammen 1954) Sarmiento 1992
Proxapertites magnus Muller et al. 1987
Proxapertites minutus Dueñas 1980
Proxapertites operculatus (Van der Hammen 1954) Van der Hammen 1956
Proxapertites psilatus Sarmiento 1992
Proxapertites tertiaria Van der Hammen & Garcia 1966
Proxapertites verrucatus Sarmiento 1992
Psilabrevitricolporites annulatus? Sarmiento 1992
Psilabrevitricolporites simpliformis Van der Kaars 1983
Psilamonocolpites grandis (Van der Hammen 1954) Van der Hammen & Garcia 1966
Psilamonocolpites aff. *operculatus* Pardo et al. 2003
Psilamonocolpites grandis (Van der Hammen 1954) Van der Hammen & Garcia 1966
Psilamonocolpites medius (Van der Hammen 1956) Van der Hammen & Garcia 1966
Psilamonocolpites minutus Regali et al. 1974
Psilastephanocolpites globulus Van Hoeken Klinkenberg 1966
Psilastephanocolporites fissilis Leidelmeyer 1966
Psilatricolporites marginatus Van Hoeken Klinkenberg 1967
Psilatricolporites pachyexinatus Van der Kaars 1983
Racemonocolpites racematus (Van der Hammen 1954) Gonzalez 1967
Retidiporites botulus Leidelmeyer 1966
Retidiporites magdalenensis Van der Hammen & Garcia 1966
Retimonocolpites aff. *claris* Sarmiento 1992
Retimonocolpites retifossulatus Lorente 1986
Retitrescolpites definidus sp. nov.
Striatricolporites guajiraensis sp. nov.
Tricolpites antonii (Gonzalez 1967) Jaramillo & Dilcher 2001
Tricolpites clarensis (Gonzalez 1967) Jaramillo & Dilcher 2001
Tetracolporopollenites? *semispongiosus* sp. nov.
Retitriporites simplex Van der Kaars 1983
Scabratriporites annellus Van Hoeken Klinkenberg 1964
Siltaria cerrejonensis sp. nov.
Spinizonocolpites echinatus Muller 1968
Striatricolporites digitatus Jaramillo & Dilcher 2001
Syncolporites lisamae Van der Hammen 1954
Tetracolporopollenites aff. *transversalis* (Dueñas 1980) Jaramillo & Dilcher 2001
Tetracolporopollenites kogiorum sp. nov.
Tetradites aff. *umirensis* Van der Hammen 1954
Ulmoideipites krempii (Anderson 1960) Elsik 1968

Fungi

Diporipollis assamica Dutta & Sah 1970

Appendices 2–6 are available electronically at http://www.palydisks.palynology.org/ (Jaramillo et al., 2007).

Appendix 2. Palynological counts, core WRV04774.
Appendix 3. Palynological counts, core WRV04752.
Appendix 4. R code used in the analyses.
Appendix 5. Biostratigraphic Range Chart, Core WRV04774 (Coal seams 45–110).
Appendix 6. Biostratigraphic Range Chart, Core WRV04752 (Coal seams 103–155).