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PALEOCENE-EOCENE PALYNOLOGY AND PALYNOFACIES FROM NORTHEASTERN COLOMBIA AND WESTERN VENEZUELA

By

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A mis padres Norman y Ofelia.

A la memoria de Jorge DORADO GALINDO (1954-1985), quien me transmitió su pasión por el estudio de la Paleontología y la Estratigrafía.

ABSTRACT

A palynologic and palynofacies study of the Paleocene-Eocene interval was performed in four sectors of NW South America: 1: the Paz de Río region (Eastern Cordillera, Colombia); 2: the eastern flank of the Nuevo Mundo syncline (Middle Magdalena Valley Basin, Colombia); 3: the western flank of Manuelote syncline (Maracaibo Basin, Venezuela) and 4: the Cesar-Ranchería Basin (Colombia). More than 300 pollen and spore morphospecies were identified, showing the great diversity of the Paleogene South American tropical palynoflora and its biostratigraphic potential. A detailed chart with the stratigraphic distribution of pollen and spores is presented for each locality. Based in these data and in the lithologic characteristics the Paleocene and the Eocene deposits can be differentiated.

The Paleocene deposits (Lisama, Socha, Cerrejón and Paso Diablo Formations) are dominated by shales, coal beds and minor sandstone levels accumulated in fluvial and coastal environments. In the southern Colombian sections the shales became mottled and barren in palynomorphs towards the top of the sequences. In northernmost Colombia and NW Venezuela, the coal beds become frequent and thicker and overlay calcareous shallow marine deposits. In all of these Paleocene deposits several regionally distributed species have their last appearances: *Bombacacidites annae*, *Foveotricolpites perforatus*, *Colombipollis tropicalis*, *Proxapertites cursus*, *Ephedripites vanegensis*, *Retidiporites magdalenensis* and *Diporopollis assamica*. In some levels of the Colombian sections *Proxapertites operculatus* (Arecaceae?; Araceae?) can surpass 80 % of the association. The presence of high percentages of this species in coastal and fluvial deposits in the entire basin discards a mangrove habitat as have been proposed by some authors. The microscopic organic matter associated with the palynomorphs is mainly of terrestrial origin (e.g; wood, cuticles, spores and pollen). At the Riecito Maché and the El Cerrejón sections the abundance of charcoal (fusain) in most of the coal beds is remarkable and can represent episodic droughts during the peat formation. Some of these deposits are also characterized by high percentages of *Mauritiidites fanciscoii* which suggest that the peats were formed in fresh water sedimentary conditions.

In the Eocene deposits (Picacho, La Paz and Misoa Formations) the coarse clastics sediments increase. They are characterized by the first occurrence of many new pollen and spore species. Most of them are present in very low quantities which difficult their use in biostratigraphy. Some traditional markers recognized in several sections from northwestern South America have their FAD in this interval: *Striatopollis catatumbus, Spirosyncolpites spiralis, Foveotriporites hammenii*, *Monoporopollenites annulatus, Cricotriporites guianensis, Cyclusphaera scabrata, Tetracolporopollenites transversalis, Retitescolpites*? *irregularis*. At the Picacho and the upper part of the La Paz Formations sandstone-rich fluvial deposits are dominant with some lake deposits rich on *Pediastrum*. At the Paz de Río area the paleocurrent data show a N-NW main tendency of paleoflow. The microscopic organic matter is characterized by terrestrial particles; the relative percentage of fungal remains (spores and hyphae) with respect to the Palaeocene sequences increases. At the Middle Magdalena the increase of coarse clastic deposits linked to the arrival of late Cretaceous reworked palynomorphs can be related to tectonic activity.

The palynological results of this study, together with new available sections (e.g. Jaramillo & Dilcher, 2001) were compared with the traditional biozones of Germeraad et al. (1968) and Muller et al. (1987). The general Paleocene Eocene zones of Germeraad et al. (1968) could be

identified in the Colombian sections. Nevertheless, the regional extension of the barren interval previously mentioned justifies the creation of a sterile interzone in this area. Graphic Correlation method was applied for the comparison between the sections. The line of correlation allows observing similar depositional rates between the Paz de Rio and the Llanos border sections. In contrast, the correlation line obtained between these sections with the Middle Magdalena Valley suggests a high relative sedimentation rates in the last locality. This phenomenon could be associated to differential subsidence in a foreland basin formed during the collision between the Caribbean Plate against the South American Plate.

Finally, it is necessary to emphasize that, although we have now more quantitative data that allow appreciating the lateral and vertical changes in the palynological Paleogene associations of northwestern South America, independent elements for an accurate calibration of this information on the geologic time scale do not exist yet. For this reason, it is still necessary to study new sections with marine microfossils, vertebrate remains or to use other dating techniques, such as the delta ^{13}C.

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CHAPTER 1 - INTRODUCTION

During the Paleocene-Eocene, thick clastic deposits as well as large peat-bogs were accumulated in fluvial to coastal environments in the northeastern region of Colombia and western Venezuela. The sedimentation was controlled, among other factors, by the tectonic activity from the Andes uplift (Gómez, 2001; Van der Hammen, 1958) in Colombia and the arrival of the Lara Nappes in NW Venezuela (Lugo and Mann, 1995; Pindell, 1993). This tectonic activity occurred simultaneous with the sedimentation; therefore the north western border of South America Tertiary stratigraphy is relatively complex in facial distribution and geology. There are big changes in the lateral thickness and vertical or lateral facial changes of the sequences are frequent. Additionally, there are poor marine fossiliferous localities to tie the stratigraphy to geological time; consequently, accurate time-controlled paleofacial maps of these rocks are not available.

To improve the knowledge of Colombian Paleogene rocks, it is necessary to develop a high-resolution stratigraphic tool. Biostratigraphical studies made in the past 40 years (Germeraad et al., 1968; Gonzalez, 1967; Jaramillo, 1999; Jaramillo and Dilcher, 2001; Muller et al., 1987; Sarmiento, 1992b; Van der Hammen, 1954a, 1954b, 1956a, 1956b, 1957b, 1958; Van der Hammen and Garcia, 1966; Van der Hammen and Wymstra, 1964; Van der Kaars, 1983) have shown that palynology is a good tool to correlate terrestrial and coastal units and to identify stratigraphic hiatuses in NW South America. Nevertheless, the published biozones, in some cases, are difficult to identify and their boundaries can rarely be sharply defined, and may not be exactly isochronous over longer distances (Germeraad et al., 1968). As these rocks have important organic-rich economic deposits (coal, oil and gas) there are many internal palynological reports made by oil companies which have never been published. Thus, much of the information from their research is not available or dispersed; additionally, the palynological works performed for the oil industry show only the most abundant marker taxa. Because tropical tertiary pollen floras are very rich in species, detailed taxonomic work is time-consuming work, thus, many potentially useful species for local or basin scale correlations have not been described yet and their morphologic descriptions and occurrence profiles still to be made and published.

Jaramillo & Dilcher (2001) recently described the detailed pollen distribution of three sequences of northeastern Colombia and proposed a biostratigraphic framework for the late Paleocene-middle Eocene interval; they showed the great morphologic diversity of Paleogene pollen and pointed out its great potential use in biostratigraphy. However, they also suggest important new elements (e.g. magnetostratigraphy, carbon geochemistry and the study of other groups of microfossils) to aid in the calibration of their palynological data. The work presented here will contribute to the detailed palynologic and palynofacial information of three new Paleocene-Eocene sections in the Middle Magdalena Valley Basin, Cordillera Oriental of Colombia and northwestern Venezuela and complete the information of Middle Magdalena Valley section of Jaramillo & Dilcher (2001), with the purpose of giving a detailed stratigraphic distribution of most of the species and test their correlation value. Graphic correlation technique is used and compared with traditional zonations. In one sequence (Paz del Rio area), facies and paleocurrent analysis were performed to have additional elements to interpret depositional sedimentary environments and paleogeography. Additionally, quantitative and qualitative data of the palynomorphs and microscopic organic matter assemblages (palynofacies) were recorded to interpret the evolution of the flora in the area and its possible relationship with palaeoenvironmental changes. In the Middle Magdalena Valley section, the most terrestrial sequence, there is a big quantity of *Bombacacidites* morphospecies. Thus, a detailed description and stratigraphic distribution of this genus is presented, in order to test its stratigraphic value at a basin scale. Finally, with all the regional information available some Paleogene geologic evolution models of the basin are presented and discussed.

1.1. LOCALIZATION OF THE SECTORS STUDIED

The first area studied is located to the west of Bucaramanga (Department of Santander, Colombia), in the eastern border of middle Magdalena Valley Basin (Figure 1.1). Two stratigraphic sections were studied in this sector: the first one, the "Uribe section", is located along the Sucio River near Uribe (eastern Middle Magdalena Valley, 7° 14'N - 73° 21'W). It was measured by Carlos Jaramillo using a Jacob's staff and tape and compass method. The lithology and major physical and biogenic sedimentary structures were described in detail (scale 1:100). The palynology of part of this section (La Paz Formation) was published by Jaramillo & Dilcher (2001); here new samples of Lisama and La Paz Formations of this section were studied in order to complete the Paleocene-Eocene interval. The second section, named here the "Sogamoso section", is located 17 kilometers to the south of the Uribe section (7° 5' 48.38" N- 73° 23' 59.33" W). It is a composite log of nine wells of the Río Sogamoso hydroelectric project (IC-PE-2; IC-FA-3; IC-TD-1; IC-CC7; IC-CC-12; IC-CC-2; IC-FA-4; IC-FP-1; SD-D-8D), located in the La Paz hill, near Sogamoso River and the Bucaramanga-Barrancabermeja road. These wells are available at the Colombian Core Library (Instituto Colombiano del Petróleo, Bucaramanga). The partial cores were measured and described by Pardo (1997) and further revised and sampled as presented in Appendix 2.1.

The second section is located in the Paz de Río region (Cordillera Oriental, Colombia), 200 km to the north east of Bogotá (Figure 1.1). In this area, 560 m of Paleocene-Middle Eocene rocks were described in outcrops with Christian Dupuis (Mons University), Hector Fonseca (Universidad Pedagógica y Tecnológica de Colombia, UPTC, Sogamoso) and Juan Pablo Salazar in January 2002. It comprises the upper part of the Guaduas Formation (Upper Cretaceous- Paleocene), the Areniscas de Socha Formation (Lower Paleocene), Arcillas de Socha Formation (Upper Paleocene-Eocene?) and Picacho Formation (Eocene; Figure 1.2.).

The third studied area is located in the northernmost region of Colombia and north-western Venezuela (Cesar-Ranchería and Maracaibo basins respectively), nowadays separated by the Sierra de Perijá (figure 1.1). At the Cesar Ranchería basin, a 360 m core-log (WRV04774) from the "El Cerrejón" coal mine was studied in detail. The sampling was carried each ± 4 m (87 samples) and includes the upper part of the Cerrejón Formation (late Paleocene). At the Maracaibo Basin, an outcrop section located in the Riecito Maché creek a tributary of Socuy River, was studied (80 km NW of Maracaibo, State of Zulia, Venezuela; 10 ° 48' N- 72° 20' W; Figure 1.1). The samples consist mainly of coals and organic shales and were obtained by Martin J. Bless, Dutch geologist of the "Proyecto Carbonífero del Zulia" in 1975. They include the Guasare (Paleocene), Paso Diablo (Paleocene-lower Eocene?) and Misoa Formations (lower to middle Eocene) (Figure 1.2.).

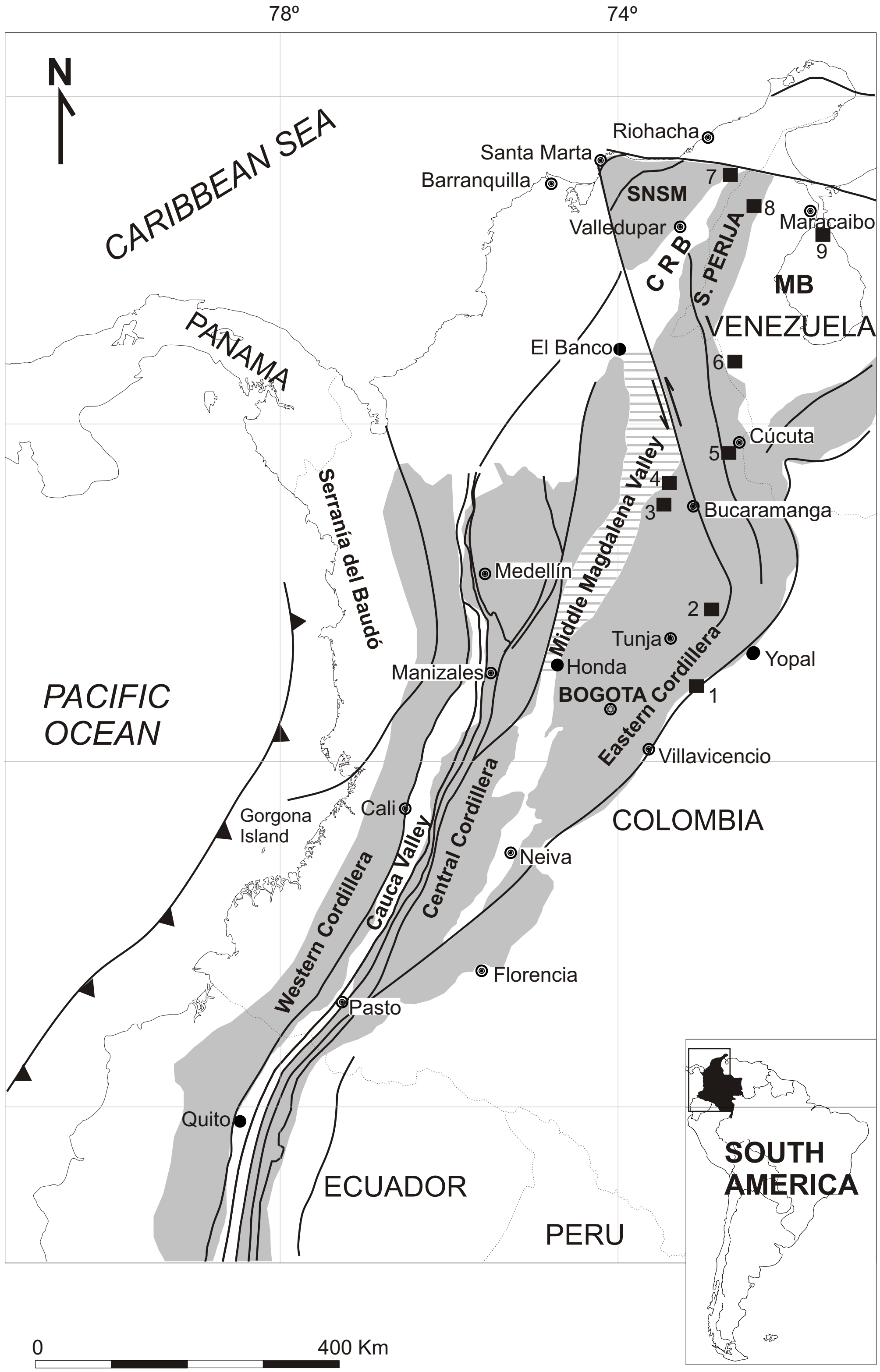


Figure 1.1. Geographic map of Colombia and Venezuela with the location of the sections studied and some Paleocene-Eocene localities discussed in this work. 1. Piñalerita section (Jaramillo and Dilcher, 2001); 2. Paz de Río section (this work); 3. Sogamoso section (this work); 4. Uribe section (Jaramillo and Dilcher, 2001 and this work); 5 Regadera section (Jaramillo and Dilcher, 2002), Tibu logs (Gonzalez, 1967) and Eleuterio- 4 log (Sarmiento, 1995; unpublished); 6. Tarra 1 log (Rull, 1997); 7. El Cerrejón section (Van der Kaars, 1983 and this work); 8. Riecito Maché section (Rull, 1999 and this work); 9. Icotea log (Germeraad et al., 1968). CRB: Cesar-Ranchería Basin; MB: Maracaibo Basin; S. Perijá: Sierra de Perijá; SNSM: Sierra Nevada de Santa Marta; In gray: Andean mountain ranges; black lines: major faults.

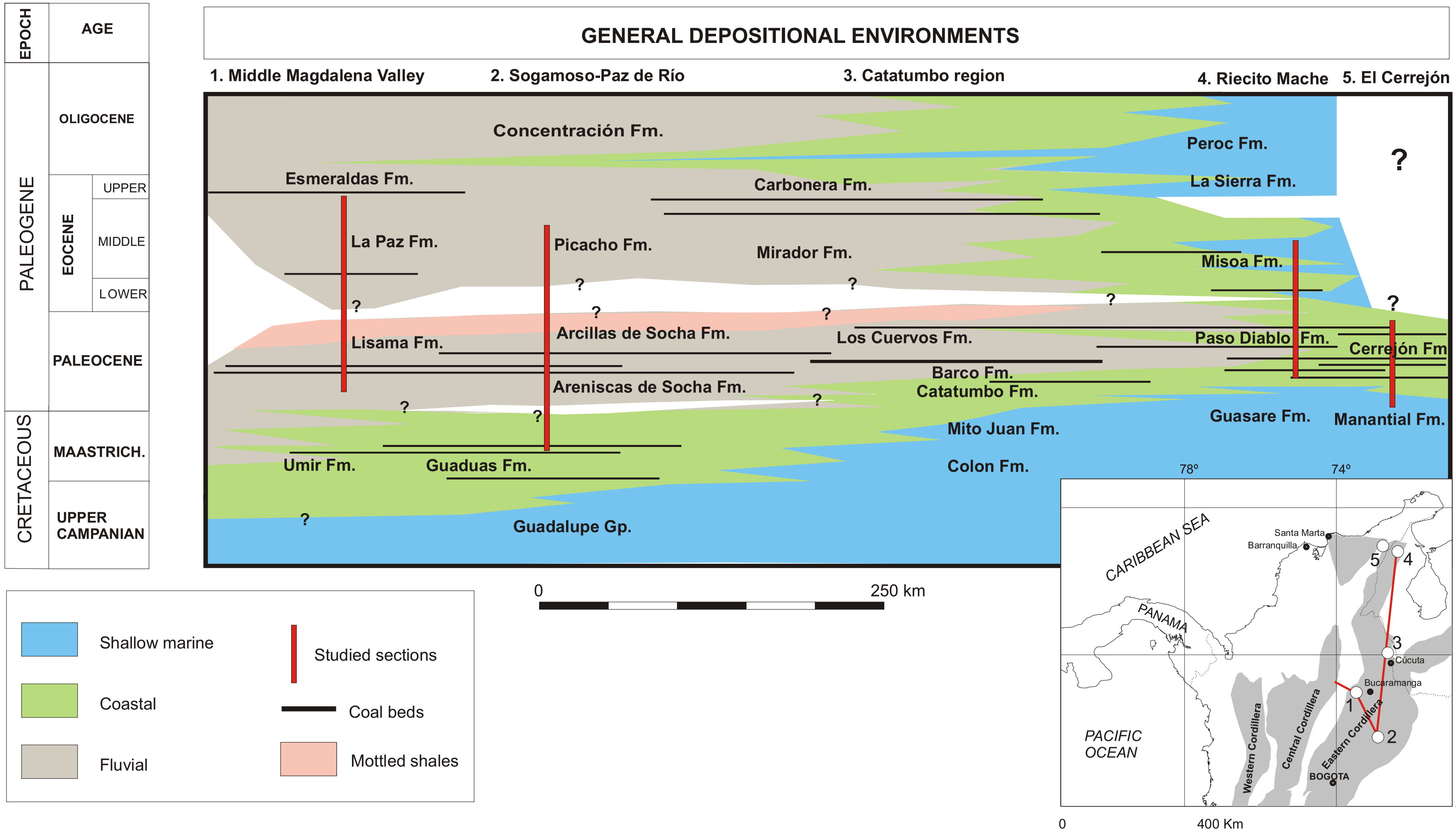


Figure 1. 2. A. Stratigraphic nomenclature and general depositional environments of upper Cretaceous-Paleogene rocks from northeastern Colombia and western Venezuela. Compiled from several sources and data obtained in the present work.

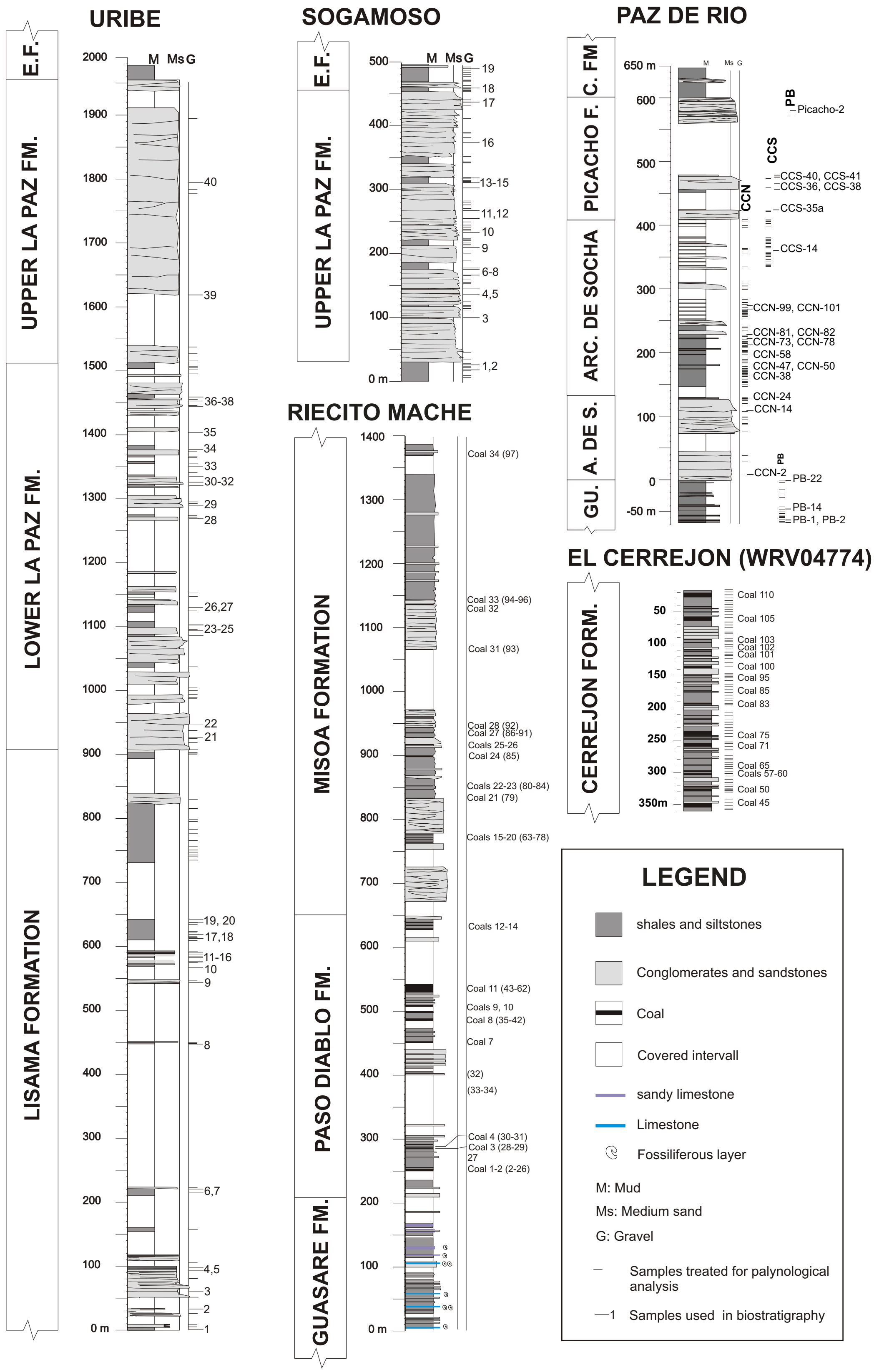


Figure 1.2.B. General stratigraphic logs, lithostratigraphic nomenclature and location of the samples studied in this work. For geographic location, see the Figure 1.1. E.F: Esmeraldas Formation; GU: Guaduas Formation; A. DE S: Areniscas de Socha Formation; ARC. DE SOCHA: Arcillas de Socha Formation; C. FM: Concentración Formation. Numbers into brackets correspond to the coal samples studied at the Riecito Maché section (see also the table 4.1). Lines in the WRV04774 log correspond to the studied samples.

1.2. REGIONAL GEOLOGICAL BACKGROUND

The geography of Colombia and Venezuela underwent many changes during Cenozoic time due to the Andes uplift. There are some paleogeographic models available of Paleogene rocks of Colombia and western Venezuela, but the limited chronological data about the placement in time and the lateral equivalences of lithologic units (e.g. Porta, 1962, 1974; Van der Hammen, 1958; Villamil, 1999) are contradictory. A general paleogeologic model of eastern Colombia will be presented here for the late Cretaceous-Tertiary for the lithologic units studied. This model is only a general outline now and should be improved with future work.

In the Santonian, a passive marine basin existed over eastern Colombia and northeastern Venezuela; shallow marine organic rich deposits were very widespread (e.g. La Luna Formation. Erlich et al., 1999). During the Campanian-Maastrichtian the level dropped as a consequence of eustatic and tectonic events, (e.g. the oblique collision between the Caribbean Plate against the western border of Colombia; Pindell, 1993). Some rocks of the present Central Cordillera, specially the cuarcitic rich early Cretaceous sedimentary cover, were redeposited to the east of the basin (Cimarrona and La Tabla Formations). During the early Paleocene the Caribbean plate continued its displacement to the north, dextral transpressive stress was very important; new areas were uplifted which controlled the deposition of the basin (Pindell, 1993). In the Late Paleocene-Early Eocene the Caribbean Plate changed its movement to the east; some oceanic rocks start to be accreted to the western border of Colombia. This phenomena produced a rising phase of the Central Cordillera that originated a displacement of the depocenter of the sedimentary basin and a decrease in accommodation space (Villamil, 1999). Some parts of the basin were uplifted (e.g. the Santander massif) (Fabre, 1983) and erosion and reworking was dominant in some areas while the sedimentation was continuous in other places (Julivert, 1961). It was under these conditions that the La Paz Formation probably started to accumulate. It is also possible that some faults of the present llanos border exercised tectonic control on the sedimentation (Cooper et al., 1995a). In the Maracaibo lake area a foreland basin begin to be formed in front of an overthrust portion of the Caribbean Plate (Lugo and Mann, 1995).

During the Upper Eocene-Oligocene, the subsidence allowed several thousands of meters of terrestrial and coastal clastic sediments to accumulate in eastern Colombian and western Venezuela (e.g. Esmeraldas and Mugrosa Formations, Gualanday Group). This was the result of the development of thrust fronts to the west of the Magdalena's Valley (Butler and Schamel, 1988) and the Santander-Floresta massif due to increase in the Caribbean Plate movement rate (Pindell, 1993). During the Oligocene and the lower Miocene, the Tablazo-Magdalena subsidence allowed thousands of meters of terrestrial and coastal clastic sediments to accumulate (Emeraldas, Mugrosa and Colorado Formations) (Fabre, 1983).

During the Late Miocene-Pliocene, the collision of a volcanic arc, the "Chocó block", with the north western border of South America produced the emersion of the Panama Isthmus and the Colombian Serranía del Baudo (Duque, 1990). This tectonic event also generated the biggest rise in the Oriental, Central and Occidental Colombian Cordilleras, which still has stayed below 3000 m up to now (Kroonenberg et al., 1990; Van der Hammen et al., 1973). During this period the current Cauca and Magdalena valleys were formed and their isolation from the

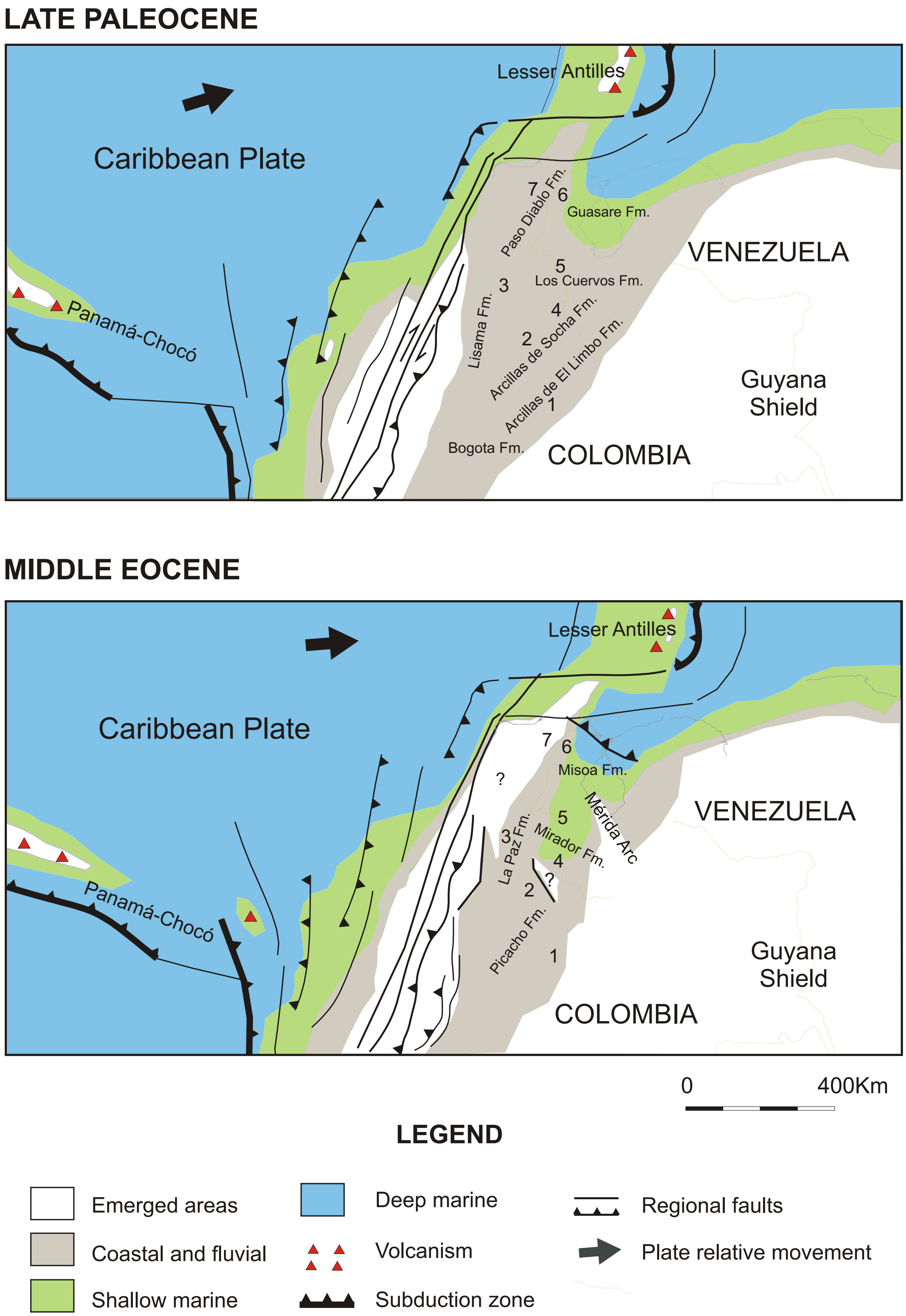


Figure 1.3. Paleogeographic maps of Colombia and western Venezuela during the late Paleocene-middle Eocene; not pallinspatically restored (modified from Moreno and Pardo, 2004). 1. Piñalerita section (Jaramillo and Dilcher, 2001); 2: Paz de Rio section (this work); 3: Sogamoso and Uribe sections (this work); 4: Regadera section (Jaramillo and Dilcher, 2001); 5: Tarra 1 log (Rull, 1997); 6: Riecito Maché section (this work); 7: El Cerrejón log (this work).

Amazons basin took place (Hoorn et al., 1995).

1.3. METHODOLOGY

In the Middle Magdalena Valley, 147 (68+79) samples were used for palynological analysis. Dark color fine shaly sandstones, siltstones and shales were selected because they are usually the most organic rich rocks. For the upper part of La Paz Formation, the sedimentological information, such as lithology and sedimentary structures were based on Pardo (1997), but these data have been revised and new samples prepared for this study. The macroscopic characteristics of the samples were described in detail (appendix 2.1). The real thickness of the logs was geometrically calculated, redrawn and located in a topographic profile using a detailed map scale 1:2000 (level curves each 5 m) with the purpose to present an elaborate composite section of the complete upper part of La Paz Formation. The whole procedure and the final column were accomplished using AutoCad for PC (figure 2.4). The Uribe section stratigraphic data are based on Jaramillo (1999) and unpublished data.

In the Eastern Cordillera, three sectors were studied in detail in the field, which permitted the construction of an upper Paleocene-Eocene composed stratigraphic log (Chapter 3, figure 3.4). 560 m of the upper part of Guaduas Formation, the Areniscas and Arcillas de Socha Formations and the first 70 m of the Picacho Formation were described layer-to-layer and located in a stratigraphic section made with a tape measure and a compass in order to construct a general stratigraphic log. Lithofacial characteristics such as, geometry of the beds, lithology, sedimentary structures were systematically registered in the field (Miall, 1984). Special attention was paid to the physical sedimentary structures in order to obtain the principal paleocurrent vectors (Potter and Pettijohn, 1963). 200 shaley levels were sampled for palynological analysis (Appendix 3.1). Macroscopic texture and color of each sample were described in detail using the Wentworth grain size scale of and the rock color chart of the Geological Society of America (1995).

All the clastic fine grained palynological samples were prepared with a standard technique (see the appendix 1.2 for detailed procedure): breaking down 25 gr. of the rock into fine equidimensional pieces (1-2 mm); disintegration of mineral matrices with HCI for carbonates and HF for silicates (24 hours); clean with HCl hot; sieving using a 12 µm mesh; oxidation with HNO_3 of organic fraction and mounting of permanent preparation slides using hydroxylethyl cellulose (HEC) to homogenize the organic particles on the glass slide and euparal to permanently fix the coverslip. To know the concentration of palynomorphs and organic particles in the samples, a known quantity of exotic spores *(Lycopodium)* was added as a standard to be compared with the autochthonous material (see Stockmarr, 1971, for the detailed technique). For each sample, three slides were made: one before to HNO_3 oxidation for the palynofacies analysis and two after the HNO_3 treatment for the biostratigraphic study. Here the term palynofacies is employed in the sense of Combaz (1964), as the global microscopic image of the organic constituents of a rock after its maceration, concentration and montage in standard conditions of preparation. This technique gives an optical method to determine maturation levels and to recognize hydrocarbon source facies. Additionally, the type of microscopic organic matter can give clues to the identification of sedimentary environments (e.g. Batten, 1982; Batten, 1996).

The coal samples were treated using the Institut Scientifique de Service Public (ISSeP, Belgium) technique (Somers, unpublished) as follows: crushing the sample with a mortar, sieving the sample with 65 µm-1.65 mm mesh, homogenization of the sample on a paper sheet; weigh 1 gr. of coal and 2 gr. of $KclO_3$ (pulverized), mixing of these components in an Erlenmeyer; add of 25 ml of fuming HNO_3, mechanically stir the mixture (10 minutes), add 2 liters of distilled water and rinse out of the Erlenmeyer with a washing bottle, sieving with 200 µm mesh (the residue was stocked for the megaspore study), sieving with 12 µm mesh until the water becomes clear, centrifugation of the sample, mounting of slides using hydroxylethyl cellulose (HEC) to homogenize the organic particles on the glass slide and euparal to permanently fix the coverslip.

The first approach to the palynofacies and palynologic study consisted in the identification of the different kinds of components present in the samples and the selection of the richer levels in pollen and spores for biostratigraphical purposes. Each sample was analyzed with a 40 X oil immersion objective with a transmitted-reflected light microscopy (Polyvar); general visual estimations in different parts of the slide were performed to obtain a semi-quantitative scale of organic components. The following five levels of abundance were used: 0. Absent; 1. Present; 2. Common; 3. Abundant; 4. Very abundant; 5. Exceptionally abundant. This general division allows knowing the general relative variation of different kinds of organic components in order to recognize major tendencies. After the first observation and qualitative estimation of the microscopic organic matter in the different stratigraphic sections, some apparent tendencies were studied in terms of abundance and relative proportions. After, pollen, spores, fungal remains and exotic *Lycopodium* spores were counted in order to known their relative percentages and their absolute number per gram of rock ("concentration"). More than 300 palynomorphs were counted for each sample, in addition to the *Lycopodium* markers. The concentration was calculated with a 95 % of confidence intervals using the methodology of Maher (1981). This information was then compared with some recent tropical environments where the factors that control the distribution of these components have been studied (e.g. Gastaldo et al., 1994; Gastaldo and Staub, 1997; Hardy, 2000; Hofmann, 2002; Lorente, 1986; Lorente, 1990; Muller, 1959). Nevertheless, the interpretation of palynofacies comparing similar fossil assemblages is complex and requires a careful consideration of all the evidence (Rull, 1995). The information is presented using bar plots performed in Well Plot for Macintosh and Corel Draw for PC. The classification of the microscopic organic matter used here is based in Tyson (1995) as follows:

Wood. The principal component of microscopic organic matter found in the samples is black-brown to orange blocky and angular wood debris with different degrees of degradation (plate 1.1, photos 1-7). In some cases, they are infested by fungal hyphae (plate 1.1, photo 5). Framboidal and cubic pyrite are frequent and irregularly dispersed (plate 1.1, photos 5-6).

Highly gelified woody tissues. Dark brown to orange, blocky, internally structureless debris (plate 1.1, photos 8-11). They correspond to the vitrinite maceral of the organic petrologists. Gelification is produced during complex process of decay and degradation of plant tissues that, in some cases, result in the homogenization of the structure (Batten, 1996).

Pseudo-Amorphous phytoclasts. Particles without internal structure and diffuse outline. They are associated with spore, woody and cuticle remains, and probably represent highly degraded plant debris (plate 1.1, photo 12) (cf. "Biodegraded Terrestrial Organic Matter" of Venkatachala, 1981).

Cuticles. Leaf cuticles are frequent in the samples studied, they show well preserved cellular patterns but, in some cases, they can be totally or partially destroyed by degradation (plate 1.1, photos 14, 15). Batten (1996), associates relative abundances of cuticles are associated with low energy fluvial-deltaic and lacustrine environments. In contrast, Boulter and Riddick (1986) suggest that leaf cuticles are the most abundant in the high energy systems of deposition. Gastaldo (1994) suggests that the utility of dispersed cuticles for facies discrimination is just now being tested. Cuticles are also described from submarine fan facies (Riddick, 1986; Habib, 1982; in Batten, 1996)

Other non-cuticular tissues. They include brown clear thin debris and membranes. In general, internal structure is not visible. They probably represent different degradation levels of material derived from plants containing little or no lignin (herbaceous taxa: plate 1.1, photos 13, 16; plate 1.2, photo 1), or in some cases, they could be degraded cuticles (plate 1.1, photo 15). These kinds of debris are intimately associated with the cuticles and wood debris.

Charcoal and other black phytoclasts Internally structured or structureless opaque particles; generally with higher reflectivity that the brown-black debris (Plate 1.2, photos 2-7). Some of them represent the product of wildfires; others possibly are formed in oxygenated, variably dry and wet environments, such as soils and at or near the surface of peats (Batten, 1996). Charcoal consists of almost pure carbon, thus is very resistant to biological and chemical degradation during transport, deposition and diagenesis (Mantell, 1968).

Resin fragments: They represent internal or extra-cellular secretions of higher plants. Spherical, irregular and “rod” resin fragments are frequent in almost all the samples (Plate 1.2, photos 8-11). They have a variable color between pale yellow to orange. These kinds of particles can be a common component of fluvial and nearshore facies (Gastaldo, 1994).

Fungal remains. In this category were included the fungal hyphae, sclerotia, spores and other reproductive parts. They are abundant in the samples (Plate 1.2, photos 12-17). The hyphae are usually isolated fragments or infesting the plant debris (plate 1.1, photos 5, 13).

Spore-pollen grains. A dominance of angiosperm pollen and spores characterize the studied material. They are usually well preserved and have relatively low thermal alteration index (TAI) (plate 1.2, photos 18-20).

Fresh water algae. In some stratigraphic horizons, algae similar to the recent *Pediastrum* (plate 1.2, photo 21) and *Spirogyra* (cf. Van Geel and Van der Hammen, 1978) were identified (plate 1.2, photo 22). The *Pediastrum* is often degraded.

Algal filaments and Sphaeromorphs. In some levels of the Sogamoso section, there are filamentous algal (?) remains similar to the Heterotrichales (Chrysophyta) illustrated by Lorente (1986, p.213) (plate 1.2, photo 24). In this section, some levels with smooth sphaeromorphs, which may also represent some kind of algae (?) (plate 1.2, photo 23) were recorded.

Dinoflagellate cysts, acritarchs and foraminiferal linings. Some dinoflagellate cysts (plate 1.2, photo 25), acritarchs remains and foraminiferal linings (plate 1.2, photo 26) were found in some samples, but in very low percentages. Sometimes, they are poorly preserved or dark and probably represent reworked palynomorphs.

Zooclasts. Some hairs of animal origin were observed in very low percentages (Plate 1.2, photo 27).

Each slide was scanned using a 40 X and 100 X oil immersion objectives in order to record all kinds of organic microfossils. The specimens were drawn and located with an England Finder (EF) to proceed to their identification; as morphological guide, a preliminary photographic collection of the spores and pollen was performed with a Zeiss Axiocam color (412-312) digital camera. All the specimens were compared with descriptions and pictures of most of the available Paleogene palynology publications. Once the main species were identified, each slide was re-scanned and counts of at least 200 specimens were made for each stratigraphic level. The description of the diagnostic characteristics of some pollen and spore species was organized alphabetically (appendix 1.1) and follows the nomenclature of Punt *et al.* (1994). The specimens are presented in the plates as morphological groups based on the class level subdivisions of Iversen and Troels-Smith (1950). The holotypes described in this research are available in the Geologic Museum of Caldas University (Manizales, Colombia) and at the Instituto Colombiano de Petróleo (Bucaramanga, Colombia).

The pollen distribution of marker taxa was compared with the regional biozonations available for NW South America (e.g. Germeraad et al., 1968; Muller et al., 1987). The correlations between the sections studied were done with the graphic correlation technique (Shaw, 1964). Basically, it consists of comparing the common characteristics (e.g. fossil distributions, radiometric data) of two total or partial time equivalent stratigraphic sections; they are put into a Cartesian coordinate system and the information is extrapolated in the field of the graph to obtain points of correlation. All the points obtained allow to create a line of correlation (LOC). Edwards (1984) described this method in the follow steps:

1. Compilation of raw data. In this case, it consisted of the first appearance datum (FAD's) and the last appearance datum (LAD's) of pollen and spores.

2. Selection of the order in which all the sections studied will be treated: a. reference section (good sampling, rich in species, without stratigraphic gaps or faults), b. using the most complete section.

3. Plotting on two-axis graph the reference section against the second section. For the paleontological data, the range tops and bases (first and last occurrences) of the fossils are projected horizontally from the Y-axis and vertically from the X-axis to obtain a point.

4. Positioning the line of correlation (LOC). It can be a line or line segments. Knowledge of the fossils and their environmental restrictions, sequence of fossil occurrences and stratigraphic relations must be included in the interpretation.

5. Creation of a Composite Section (CS). The LOC expresses position of the data in one section in terms of position in the other section. This information then becomes the composite section (CS).

6. A third section may be plotted against the maximum ranges from the CS, and so on…

7. After all available sections have been plotted and all data projected onto the composite ("first round of correlation"), the procedure must be repeated several times until the LOC stabilizes.

In order to obtain a general idea about the floristic changes in the studied sections, we made a synthetic graph with the relative percentage of selected pollen groups, similar to the Palms-Angiosperms-Ferns (PAF) diagram used by Van der Hammen (1954a; 1957b) (see section 1.4). With this diagram we intend to test cyclic vegetation patterns (e.g. Poumot, 1989), which can be integrated to the stratigraphic distribution of pollen and spore species and could be useful to understand vegetation variations over spatial and temporal scales. Eight groups were selected in our diagram; two of them include pollen grains with similar morphologic characteristics to some modern tropical plants (e.g. *Mauritia* palms, Bombacaceae). Three groups were defined by their abundance in particular statigraphic intervals (e.g. *Proxapertites operculatus*, reworked pollen and dinoflagellate cysts). Three groups represent general categories: 1. Other angiosperms 2. Pteridophyte spores and 3. Palm pollen excluding *Mauritia*, which is mainly equivalent to the "*Psilamonocolpites* group" of Van der Hammen (1954a).

1.4. REVIEW OF PALEOGENE PALYNOLOGICAL RESEARCHES IN NW OF SOUTH AMERICA

Palynology has been the most used technique for the correlation of the Paleogene rocks of Colombia and Venezuela (e.g. Kuyl et al., 1955; Van der Hammen, 1954a, 1957a). Van der Hammen (1954a; 1957a) made a subdivision of the Colombian Tertiary palynological associations based on the study of coal layers of several regions of the country (mainly the Valle del Cauca, Santander, Antioquia and Cundinamarca departments). He used a diagram of the relative percentage distribution of certain pollen and spore groups which, seem to represent general regional floral changes (diagram "PAF", Palms- Angiosperms-Ferns; Figure 1.4). These groups include: 1) Palm pollen group (*Monocolpites medius* group, *Monocolpites franciscoi* group and *Proxapertites operculatus* group; 2) Spore group (*Psilatriletes* group, *Striatriletes susannae* group, *Verrumonoletes usmensis*, group, *Psilamonoletes tibui* group); and 3) Angiosperm group. He proposed that the occurrence of peaks of *Monocolpites medius* coincides with an epoch or age limit and can represent 6 Ma global periodic climatic oscillations (Van der Hammen, 1961). Unfortunately, the hypothesis proposed by Van der Hammen has not had independent chronometric data to validate these periodic cycles. Based in this information, Van der Hammen subdivided the Tertiary epochs into zones (A, B, C etc…) and sub-zones. This diagram has been the chronostratigraphic base used in the geological work in Colombia for the last 40 years! See Porta & Solé de Porta (1962) for further discussion about this diagram.

Solé de Porta (1961a; 1961b; 1963; 1970; 1971; 1972) (Kedves and Solé de Porta, 1963)

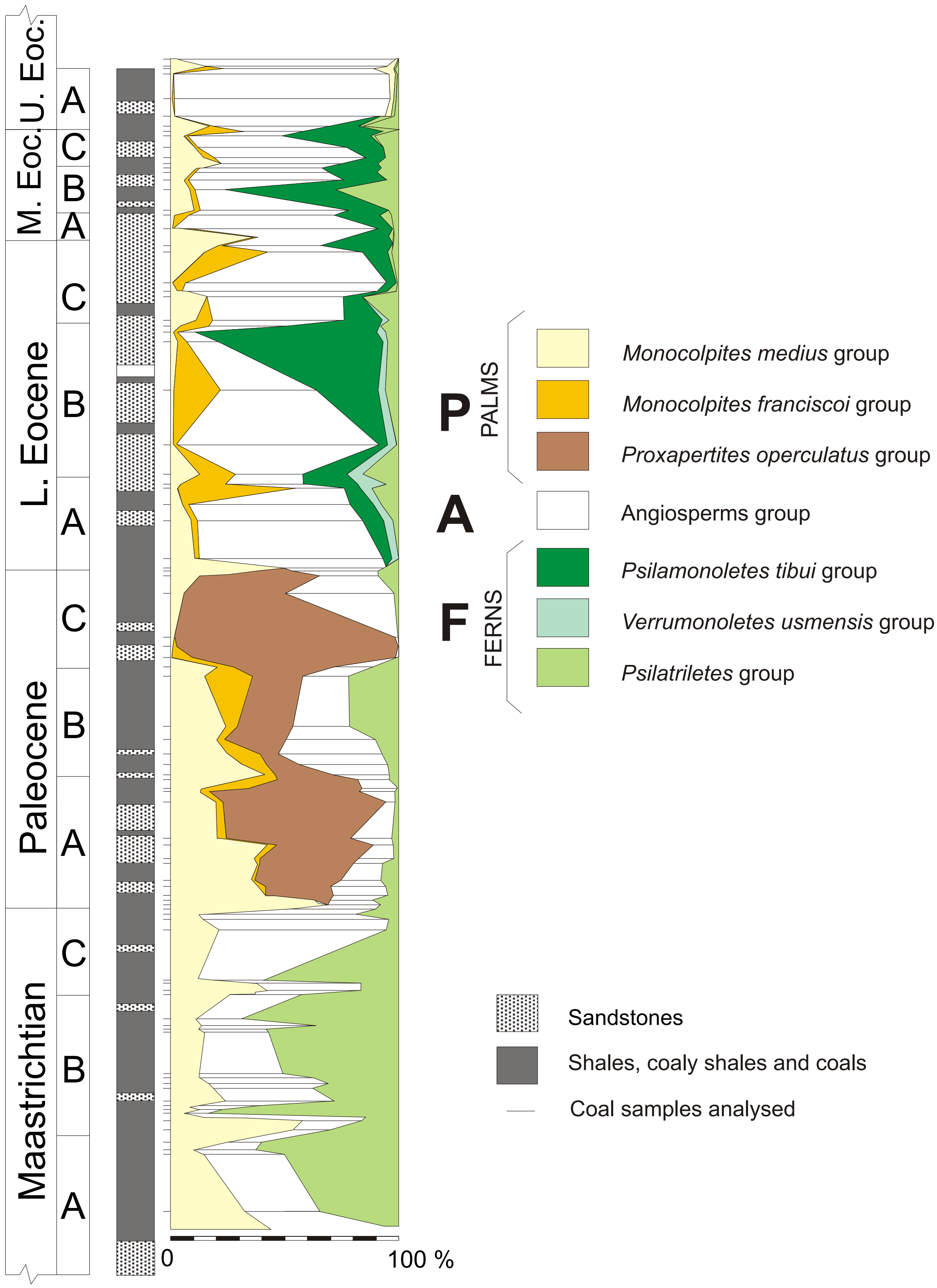


Figure 1.4. PAF (Palms-Angiosperms-Ferns) diagram of Van der Hammen (1954a, 1957a) showing the relative percentages of selected groups of palynomorphs of the upper Cretaceous-Eocene coal deposits of Colombia. Letters represent the palynological zones proposed by this author.

described and illustrated numerous late Cretaceous and Tertiary pollen and spores from the Eastern Cordillera, the Magdalena Valley (La Cira, Guaduas and Cimarrona Formations and the "Nivel de Lutitas y Arenas") and the Caribbean region of Colombia. She defined some new genera and species and suggested the botanical affinity of several forms. Porta, also made important contributions to the invertebrate paleontology and stratigraphy of the Tertiary of Colombia (Porta, 1962, 1974; Porta and Solé de Porta, 1962).

Gonzalez (1967) made a palynological study of the coal beds of the Los Cuervos and Mirador Formations (upper Paleocene-Eocene) of the Catatumbo region. Based on a great number of species (148 species, most of them being new forms), he proposed a detailed palynologic zonation and attempted to reconstruct the vegetation changes of this area, comparing the palynological variations of his diagram with South American Quaternary palynomorph assemblages where the environment is known. He proposed that the rhythmic change of the palynologic associations in his pollen distribution diagram could be associated to sea level changes in a coastal region. Gonzalez (1967) suggested that the extinct palynologic group *Brevitricolpites* represents mangrove vegetation. Thus, he considered that abundance of this pollen can be linked to marine oscillations in the basin. Because in this area there are no other types of fossils that will allow an independent assignment of the age, the dating of these units was based on the Van der Hammen (1954a; 1957a) schema.

Van der Hammen & Wymstra (1964) studied the palynology of the upper Cretaceous-Quaternary coastal sedimentary sequence of British Guiana. They used the Shelter Belt 3 borehole, located near Georgetown, to elaborate a reference pollen diagram and establish a pollen zonation for the area. This log includes 590 m (1935 feet) in total, extending from the Maastrichtian to the Quaternary. The palynological zones were defined with the vertical distribution of some "guide-associations" of pollen and the FAD (first appearance datum) of some species. They named the biozones from older to younger: A, B1, B2, C, D, E, F G1 and G2. The geologic age of these zones was established based on comparisons with the "dated Colombian and partly Venezuelan pollen associations" (not mentioned). The uppermost Maastrichtian-Eocene interval (zones B1 to D) has 128 m approximately (between 820' to 1240' below the top of the log) and is composed of shales and lignites with minor sandstone layers. In this interval, Leidelmeyer (1966) described and illustrated the pollen flora and elaborated a "Palm Angiosperms Ferns" diagram following Van der Hammen's (1954a; 1957a; 1957b) methodology. Based on this diagram, and especially on the presence of peaks in the relative percentages of *Psilamonocolpites medius*, Van der Hammen & Wymstra (1964) performed a "detailed" correlation between the zones recognized for British Guiana with the palynological zones defined by Van der Hammen in Colombia.

Germeraad, Hopping & Muller (1968) made an upper Cretaceous-Quaternary palynologic zonation for the tropical regions using data from South America, West Africa and Borneo. They defined three types of zones according to their lateral extent: pantropical, transatlantic and intra-continental zones. They divided the upper Paleocene and lower to middle Eocene into four palynologic zones for the Caribbean area: two Paleocene zones, *Ctenolophonidites lisamae* and *Foveotricolpites perforatus*, a lower Eocene zone *Retibrevitricolpites triangulatus*, and a middle Eocene zone, *Monoporites annulatus*, that is subdivided into three subzones *Psilatricolporites crassus*, *Psilatricolporites operculatus* and *Retitricolporites guianensis* (figure 1.5). The biozones were correlated with foraminifera and mollusca which,

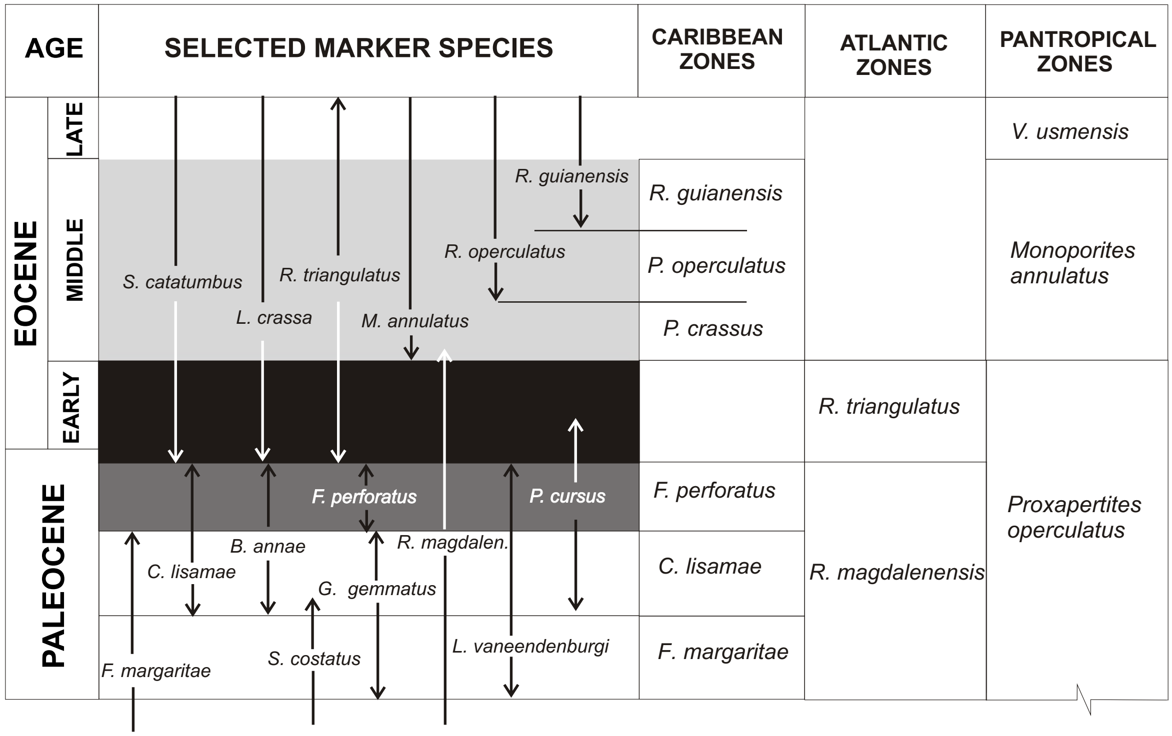


Figure 1.5. Pollen and spores biozonation of tropical areas and Caribbean range of some selected marker species (Germeraad et al., 1968).

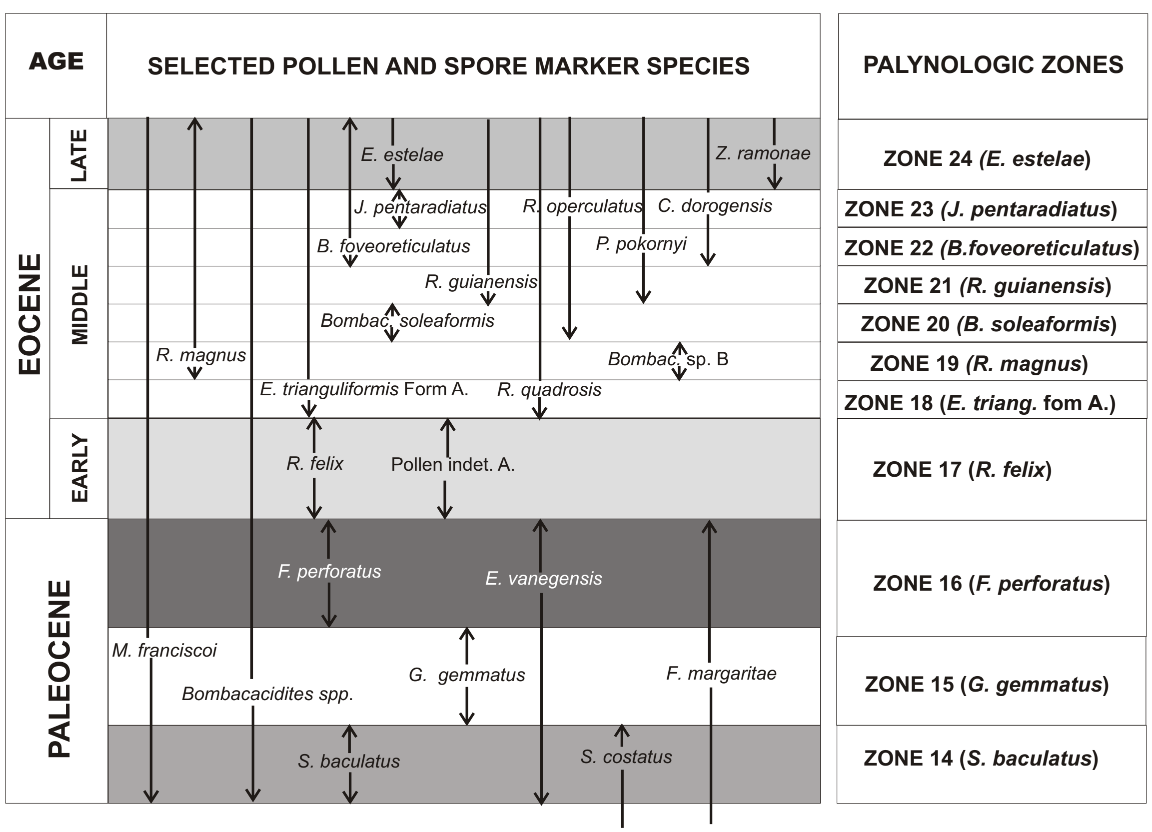


Figure 1.6. Pollen and spores biozonation of northern South America and range of some selected marker species (Muller et al., 1987).

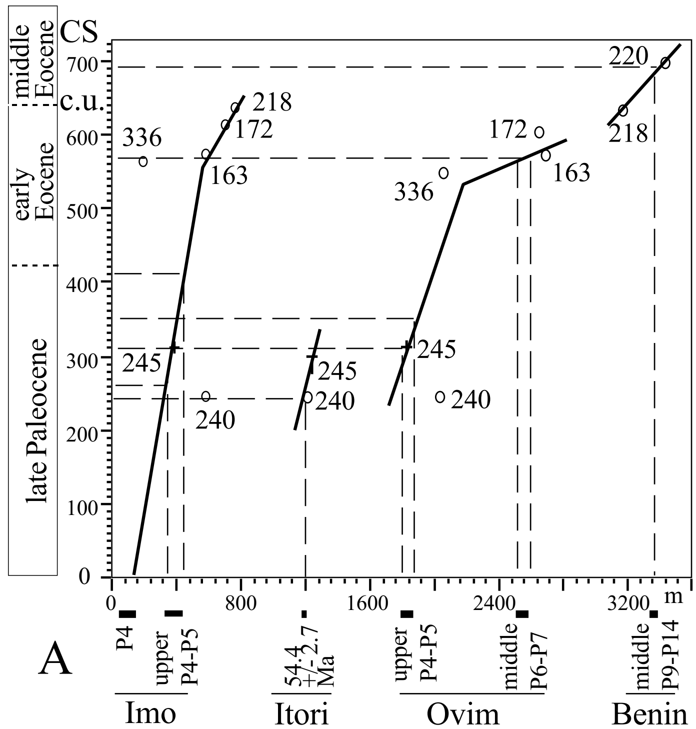
according to the authors, show that "the floral zones recognized are not markedly diachronous over the areas in which they are considered valid"; they pointed out also that "the boundaries between the zones can only rarely be sharply defined" (Germeraad *et al.*, 1968, p. 242). Unfortunately, the precise stratigraphic positions and /or geographic locality of the South American foraminifera mentioned by these authors were not published.

Schuler and Doubinger (1970) studied 3 samples of the Amagá region, in the Central Cordillera of Colombia. They determined the presence of 16 species of pollen and spores and proposed an Eocene-Oligocene age. Nevertheless, a detailed study of this area is not available.

Regali et al. (1974) made a palynological study of Mesozoic and Cenozoic rocks of the continental plattform of Brasil. For the Paleocene-Eocene interval they defined two superzones: the *Proxapertites operculatus* (PT-10) and *Cicatricosisporites dorogensis* (PT-20) superzones (P: palynomorphs; T: Tertiary) and 5 zones (PP-10 *Hystrichosphaeridium caiobensis*, PE-10 *Hystrichosphaera sergipensis*, PE-20 *Proxapertites cursus*, PE-30 *Cordosphaeridium diktyoplokus* and PE-40 *Clavatriletes disparilis*) (P: Paleocene, E: Eocene). They used planktonic foraminifera and nanoplancton to calibrate their biozones (unpublished data). When comparing this information with Germeraad et al. (1968), it becomes apparent that there are important differences in the distribution of some of these fossils (figure 1.8). For instance, the first appearance datum of *Monoporopollenites annulatus* of Regali et al. (1974) is located in the upper Paleocene in Brazil in co-occurrence with *Foveotriletes margaritae*, *Proxapertites cursus*, *Foveotricolpites perforatus*. The FAD of this species was used by Germeraad et al. (1968) as the base of the early-middle Eocene *Monoporites annulatus* pan-tropical zone and its co-occurrence with the former fossils never has been mentioned. Nevertheless, Jardiné and Magloire (1965) reported the presence of *Graminidites* sp. in the lower Maastrichtian of Senegal and Ivory Coast.

Based on Germeraad et al. (1968) zonation, Muller et al. (1987) divided the Paleocene-Eocene of northwestern South America into 2 palynological superzones (VII and VIII) and 10 zones (Figure 1.6). Zone 14, *Spinizonocolpites baculatus* (Paleocene); zone 15, *Gemmastephanocolpites gemmatus* (Paleocene); zone 16, *Foveotricolpites perforatus* (Paleocene); zone 17 *Rugotricolporites felix* (early Eocene); zone 18, *Echitriporites trianguliformis* forma A (middle Eocene); zone 19, *Retitricolpites magnus* (middle Eocene); zone 20, *Bombacacidites soleaformis* (middle Eocene); zone 21 *Retitricolporites guianensis* (middle Eocene) ; zone 22, *Bombacacidites foveoreticulatus* (middle Eocene); zone 23, *Janmulleripollis pentaradiatus* (middle Eocene) ; zone 24 *Echiperiporites estelae* (late Eocene). Some of the fossils used to define these zones correspond to those of Germeraad et al. (1968), others are new species. Unfortunately, Muller et al. (1987) do not give independent calibration arguments to justify the chronostratigraphic position of these biozones. Thus, the coincidence between some zones and their age limits is probably arbitrary. In the table IV Muller et al. (1987) made a correlation of the palynological zones with the pelagic foraminiferal zones of Blow (1969), but they pointed out "the age-correlation of the zones, as well as the correlation of pelagic foram zones is subject to revision".

Jaramillo & Dilcher (2001) made a study of distribution of pollen and spores of three Paleocene-Eocene sections of northeastern Colombia using the graphic correlation method. Using new data and two sections previously studied (Gonzalez, 1967; Rull, 1997b), they



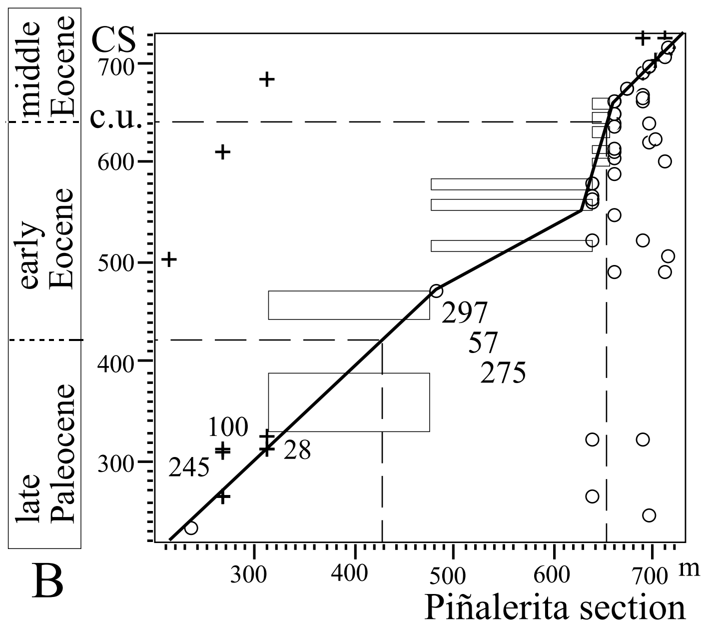


Figure 1.7. A. Summary of dating elements used by Jaramillo and Dilcher (2000) to calibrate their composite section. Imo, Itori, Ovim and Benin correspond to four sites in Nigeria: Itori well the pollen and bentonite radiometric data come from Adegoke et al., (1970); Jan du Chêne et al., (1978), and the Imo, Ovim, and Benin sections (foraminifers and pollen data from Germeraad et al., 1968). **B:** Line of correlation of composite section (CS) versus Piñalerita section used by Jaramillo and Dilcher (2000) as the reference section to construct the CS. Boxes indicate strata down to next lower sample for first appearance data and up to next higher sample for last appearance data to take into account large gaps in sample interval. P planktonic foraminifera zones of Berggren et al. (1995); c.u. composite units; O: first occurrence data. +: last occurrence data. Pollen species: *Striatopollis catatumbus* (336), *Siltaria mariposa* (297), *Tricolpites clarensis* (275), *Retidiporites magdalenensis* (245), *Retibrevitricolpites triangulatus* (240), *Ranunculacidites operculatus* (220), *Lanagiopollis crassa* (218),*Perisyncolporites pokornyi* (172), *Monoporopollenites annulatus* (163), *Foveotricolpites perforatus* (100), *Cricotriporites guianensis* (57), *Bombacacidites annae* (28). Imo and Ovim sections contain *Planorotalites* (Globorotalia) *pseudomenardii* zone of Germeraad et al. (1968) that is equivalent to P4 zone, and *Morozovella velascoensis*-*Morozovella acuta* zone that is equivalent to upper P4-P5 zone. *Morozovella formosa* zone of Germeraad et al. (1968) is equivalent to the range of *M. formosa formosa*, (middle P6-P7). *Truncorotaloides rohri* zone of Germeraad et al. (1968) is equivalent to the range of *T. rohri* (middle P9-P14).

created a composite section and located the first appearance datum (FAD) and last appearance datum (LAD) of 85 selected species. Because there are no Paleogene magnetostatigraphic, radiometric or biostratigraphic data (e.g. planktonic foraminifers) published in northern South America, they used the foraminiferal distribution of three sections of Nigeria of Germeraad et al. (1968). In this area some pollen and spore species are identical with those of northern South America (e.g. *Striatopollis catatumbus, Tricolpites clarensis, Siltaria mariposa, Retidiporites magdalenensis, Retibrevitricolpites triangulatus, Ranunculacidites operculatus, Lanagiopollis crassa, Perisyncolporites pokornyi, Monoporopollenites annulatus, Foveotricolpites perforatus, Cricotriporites guianensis, Bombacacidites annae*). Jaramillo and Dilcher (2001) showed that this method has a better resolution than the traditional biozones because many more pollen species are compared simultaneously between two sections than the few selected taxa used to define the biozone; in this way, the noise of local environmental or selective preservation controls decrease.

Sarmiento (1992b) made a palynologic research of the Guaduas Formation, one of the most studied units by Van der Hammen (1954, 1957a). He studied the thickest known section (1090 m) of this unit, located in the "Boquerón de Sutatausa area", 70 km north of Bogota. He divided this formation in two palynologic zones: the Zone I (*Buttinia andreevi* Zone) which corresponds to the "Maastrichtian zone A" of Van der Hammen (1957); the Zone II subdivided in the *Zonotricolpites variabilis* Subzone and the *Syncolporites lisamae* Subzone. Based upon physical and palynological criteria, Sarmiento suggested the position of the Cretaceous-Tertiary boundary with in the limit of these two zones. Nevertheless, there are no independent biostratigraphic or radiometric data. The upper limit of the Zone II cannot be established because the last 220 m of the Guaduas Formation are composed by green-red mottled mudstones with some sandstone levels barren of palynomorphs. However, the absence of the *Bombacacidites* genus in this palynological association suggests an older interval than the sections studied in the present work.

Ruiz and Pons (1996) studied the palynology of some deposits of the Llanos border, near Yopal (Casanare department, Colombia). They identified a variety of species such as *Cicatricosisporites dorogensis*, *Spirosyncolpites spiralis*, *Lanagiopollis crassa*, *Spinizonocolpites baculatus*, *Spinizonocolpites echinatus*, *Echinatisporis* sp. *Polypodiisporites usmensis* and several forms of angiosperms. They suggest an Eocene-Oligocene age based in the biozones of Germeraad et al. (1968) and Muller et al. (1987). Oscar Ruiz made a PhD at the Pierre et Marie Curie University (France) about the palynofacies of the Late Cretaceous-Paleogene rocks of this area, but this information is not published.

Pocknall et al. (2001) studied the palynology of the Cretaceous-Paleocene transition in NW Venezuela (The "Rio Lora" section). They described a well preserved association of dinoflagellate cysts and pollen which allows the calibration of previous zonations based only on terrestrial palynomorphs (e.g. Germeraad et al., 1968; Muller et al., 1987). With this information, Pocknall et al. (2001) suggest that some of the pollen species that have been used to define the late Cretaceous in NW South America appear to range into the Paleocene (e.g. *Proteacidites dehaani, Crusafontites grandiosus, Periretisyncolpites gigantescus, Araucariacites australis*) and some taxa whose FAD are considered as early Paleocene have been recorded in the upper Cretaceous. On the other hand, these authors show that the FAD of *Proxapertites operculatus,* a species used by Van der Hammen (see also Sarmiento, 1994) to

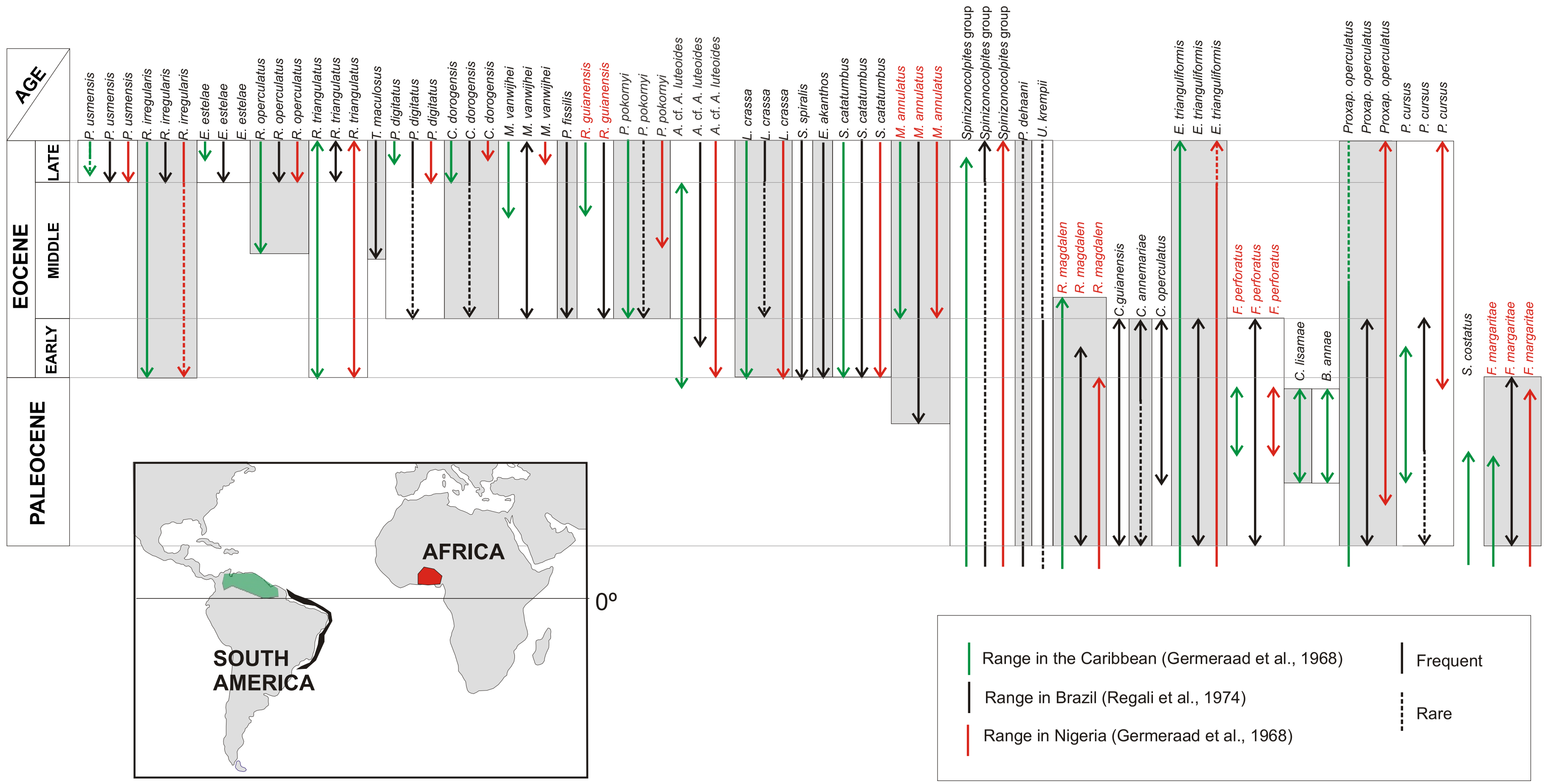


Figure 1.8. Comparison between the extension of some pollen and spore species in western Africa, Brazil and north western South America (based on data of Germeraad et al., 1969 and Regalli et al., 1974). From left to right: *Polypodiisporites usmensis, Retitrescolpites*? *irregularis, Echiperiporites estelae, Ranunculacidites operculatus, Retibrevitricolpites triangulatus, Tetracolporopollenites maculosus, Perfotricolpites digitatus, Cicatricosisporites dorogensis, Margocolporites vanwijhei, Psilastephanocolporites fissilis, Rhoipites guianensis, Perisyncolporites pokornyi, Anacolosidites* cf. *A. luteoides, Lanagiopollis crassa, Spirosyncolpites spiralis, Echiperiporites akanthos, Striatopollis catatumbus, Monoporopollenites annulatus, Proteacidites dehaani, Ulmoideipites krempii, Retidiporites magdalenensis, Cricotriporites guianensis, Crototricolpites annemariae, Cricotriporites operculatus, Echitriporites trianguliformis, Foveotricolpites perforatus, Ctenolophonidites lisamae, Bombacacidites annae, Proxapertites operculatus, Proxapertites cursus* and *Foveotriletes margaritae.*

locate the Cretaceous-tertiary limit in Colombia, is found in the Maastrichtian strata of Western Venezuela. All of these data illustrate the importance of independent data to calibrate pollen associations.

Yepes (2001) performed a palynostratigraphic study in two sections from north-eastern Colombia (the Río Molino section) and western Venezuela (the Río Loro section; studied also by Pocknall et al. 2001). With these data, he located the K-T boundary in an 11,5 m interval, which is above the lowest occurrence of *Glaphyrocysta perforata* and below the lowest occurrence of *Damassadinium californicum*. Recently, Rueda & Jaramillo (unpublished), performed a detailed study of pollen and spore distributions of this section including the Yepes samples and the Upper Paleocene-Lower Eocene interval. These data are important because they improve the time positioning of the Upper Cretaceous-Lower Tertiary pollen and spore associations described by Sarmiento (1992b) in eastern Colombia, and permit a link with the Late Paleocene-Eocene studied in the present research.

Rull (2000; 2002) applied ecostratigraphic methods (palynocycles and ecologs), to analyze cyclic patterns in the Paleogene rocks of western Venezuela, specially the Riecito Maché section, the same section studied in this work (see the chapter 4). Nevertheless, Rull (2000; 2002) employed the chronostratigraphic framework of Muller et al (1987), which does not use independent elements to calibrate the pollen and spore distribution. Additionally, Rull (2002, fig. 5) showed that Muller's biozones correlated with the Foraminiferal biozones of Berggen et al. (1995) and the nannoplankton biozones of Martini (1971), but these equivalences have never been demonstrated. Consequently, although the methods and results shown by Rull can improve the correlations on a local scale, the lack of a precise chronostratigraphic framework made regional correlations risky (e.g. the global eustatic cycles of Haq et al., 1988).

The Paleogene of the Bogotá area

The Paleogene sequences located near Bogotá are the most inerland and thickest of the sections described in the literature (Porta, 1974). It is thus important to take them in account in order to understand the lateral evolution of the basin during this period. Scheibe (1934) defined the "Bogotá Formation" to include a thick clastic sedimentary sequence that overlays the Guaduas Formation in the region nearby of Bogotá. Nevertheless, the upper contact was not well defined (see Porta, 1974). Julivert (1963b) proposed the type section of this formation in the western flank of the Usme Syncline (Tunjuelo Valley, south of Bogotá city). He describes this unit as a 2000 m thick assemblage of mottled claystones, mainly red in color, with some sandstone interbeds. Its lower limit is put in the occurrence of 100 m thick sandstones named the Cacho Sandstone. Its upper limit is located with the appearance of a thick sequence (until 400 m) of sandstone, named "Arenisca de La Regadera".

Hoorn (1988), made a sedimentologic and palynologic study of the Cacho and Bogotá Formations in two sections: the Mochuelo creek and the Bogota-Villavicencio road, in the eastern and western flank of the Usme Syncline respectively (south of Bogotá). At the Mochuelo she mades the following lithological description: The Cacho Formation, at the lower part (130 m), is composed by yellow-brownish very coarse to middle-grained sandstones and green silty claystones. The upper part (250 m) consists of various fining-upward sequences with yellow-brownish fine-grained sandstones followed by purple-grey claystones. The Bogotá Formation consist of fining-upward sequences of middle to very fine grained grey and/or green sandstones, mottled red-purple silty claystones, and purple-greyish claystones. In some cases gravel lags are present to the base of the sandstones. Cross bedding and parallel laminations are frequent in the sandstone layers. Hoorn (1988) pointed out that the Cacho Formation has about 350 m thick in this area and the Bogotá Formation varies from 250 m at the eastern flank of the Usme syncline to a minimum of 900 m in the western flank. These data are in contradiction with the 2000 m of the Bogotá Formation and the 50-100 m of the Cacho Formation mentioned by Julivert (1963) for the same area. Hoorn (1988) considers that the Cacho and Bogotá Formation were accumulated in a braided and meandering fluvial system respectively. Petrographic analysis shows a sedimentary-metamorphic source for both formations. At the Mochuelo creek all the samples treated (35) for palynology, were sterile in pollen and spores; to the top (1075-1215 m interval above the base) were found turtleshields and the jaw of a mammal specimen *Etayoa bacatensis* (Villaroel, in Hoorn, 1988). Two samples of the Bogotá-Villavicencio road section contain pollen and spores. The sample WF, located at the upper part of the Cacho formation contains *Psilamonocolpites medius*, *Psilatricolporites normalis*, *Mauritiidites franciscoi*, *Psilatricolpites minutus*, *Spirosyncolpites*, *Verrustephanoporites simplex* (*Ulmoideipites krempii*) and *Proxapertites operculatus*. The sample WD, located 75 m above the base of Bogotá Formation, gives *Proxapertites operculatus, Proxapertites tertiaria*, *Longapertites proxaperturoides* var. *proxaperturoides*, *Foveotricolpites perforatus* and *Foveotriletes margaritae*. This association can be placed in the *Foveotricolpites perforatus* Caribbean zone of Germeraad et al. (1968).

CHAPTER 2 - PALEOCENE-EOCENE PALYNOLOGY AND PALYNOFACIES FROM THE MIDDLE MAGDALENA VALLEY BASIN.

ABSTRACT

This chapter presents a detailed palynological study of two sections located in the eastern flank of the Nuevo Mundo syncline (Middle Magdalena Valley Basin, Colombia). One hundred and forty seven samples including the Paleocene-Eocene Lisama and La Paz Formations were prepared for this research, fifty nine of which are rich in pollen and spores. More than 300 pollen and spore morphospecies were identified. The palynological distribution diagram can be clearly separated in two different associations limited by a 300 m thick barren interval. The lower association (Lisama Formation) is characterized by the abundance of different types of *Proxapertites* (e.g. *P. operculatus*, *P. cursus*), some species of *Bombacacidites* (e.g. *B. annae*, *B. protofoveoreticulatus*), *Retidiporites magdalenensis* and different monocolpate species (e.g. *Psilamonocolpites medius*, *Mauritiidites franciscoi*). The upper half of this unit is characterized by the highest concentrations of pollen and spores and a dominance of *Proxapertites operculatus,* which can amount 95 %. The upper association (La Paz Formation) in general has very low concentrations of pollen and spores but is very rich in new species, some of which have regional distribution (e.g. *Striatopollis catatumbus*, *Foveotriporites hammenii*, *Monoporopollenites annulatus*, *Spirosyncolpites spiralis, Bombacacidites soleaformis*, *Cricotriporites guianensis, Cyclusphaera scabrata*).

The biostratigraphical information was compared with the regional biozones of NW South America. The *Foveotricolpites perforatus* Caribbean zone of Germeraad et al (1968) and Muller et al (1987) is recognized in the upper half of the Lisama Formation. The lower part of this formation is included in the *Ctenolophonidites lisamae* zone of Germeraad et al (1968) or in the *Gemmastephanocolpites gemmatus* of Muller et al (1987). Nevertheless, some bostratigraphic markers used for these authors were not recorded (e.g. *Gemmastephanocolpites gemmatus*, *Foveotriletes margaritae*, *Stephanocolpites costatus*) or are very scant (e.g. *Ctenolophonidites lisamae*). In the upper La Paz Formation the base of the *Monoporites annulatus* biozone of Germeraad et al (1968) was identified. Nevertheless, in the underlying *Retibrevitricolpites triangulatus* zone only one (*Striatopollis catatumbus*) of the three species that define this biozone was identified. Thus, two of these species (*Retibrevitricolpites triangulatus* and *Lanagiopollis crassa*), which are abundant in the Venezuelan sections seems to be environmentally controlled. The geologic age of these units has been controversial, and it should be said that there are not enough useful dating elements to calibrate the palynologic zones to known geologic time intervals in this area. Our data give detailed quantitative information about pollen and spore distribution, which, until present, was not available. On the other hand, some new species described in this area (e.g. *Psilamonocolpites operculatus, Diporoconia* cf. *Diporoconia iszkaszentgyoergyi* and *Diporopollis assamica*) are now recognized in other sections of the basin which could improve the available biozonations. Once more calibration elements become available, the palynologic associations can be compared more accurately with biological or geological events of other basins in the world.

Taking into account the chronological data of Germeraad et al (1968), the Paleocene-Eocene boundary seems to be located in the barren interval, which includes the top of the Lisama Formation and the base of the La Paz Formation. Until now there are neither geologic nor paleontologic evidence that allows a precise location for this boundary. On the other hand, the seismic profiles available in this area show that the contact surface between the Lisama-La Paz Formations is a paraconformity that becomes an angular unconformity to the west. The palynological data obtained in this study show the occurrence of a high percentage of late Cretaceous-Paleocene reworked pollen in the La Paz Formation. This is linked to a strong facies change in the La Paz-Lisama Formations which seems to indicate a discontinuity in the geologic record; nevertheless, the duration of this event can not be estimated with the current palynostratigraphical resolution.

Based in sedimentary and facies studies, some authors have proposed different paleoenvironmental interpretations for these units. One of the most controversial points is the hypothesis of marine influence in the sedimentation. The palynological data obtained in this work, such as abundant wood, cuticles, pollen, spores, fungi and in some cases levels rich in *Pediastrum* linked to the absence of marine and/or brackish water macro and/or microfossils favor a terrestrial environment.

2.1. STRATIGRAPHIC AND PALYNOLOGIC ANTECEDENTS

The Middle Magdalena Valley Basin (MMVB) of Colombia is a physiographic expression, used to designate the depressed area that is limited with the Eastern Cordillera to the East; the Central Cordillera to the West; the town of El Banco to the north and the town of Honda to the south (Figure 1.1), this area embraces approximately 32000 Km^2 (Morales et al. 1958). It is conformed by rocks which age ranges from Paleozoic to recent and formed in different tectonic settings; a great part of the recent configuration of this valley is due to the late Tertiary Andes uplift. In the Paleogene this area accumulated more than 2000 m of clastic rocks; some of them are very rich in microscopic organic matter. In this chapter we will discuss how palynology can provide new elements to interpret the Paleogene geologic evolution and its correlation with other places of the basin. The MMVB has a general N-NE structural trend. The Cretaceous to recent sedimentary fill comprise a general asymmetric wedge that thickens to the east (figure 2.1). The dominant style of the structures flanking the eastern borders of MMV consist of large-scale paired asymmetric synclines and broad, arched, basement-cored anticlines (Schamel, 1991) related to westward-verging thrust faults (e.g. Salinas and Infantas thrust systems). To the west progressively more recent Cenozoic sedimentary fill onlaps the basement of the Central Cordillera (figure 2.2). NW trending normal faults are conspicuous in this area probably linked to the dextral-slip movement of the Palestina fault.

The Middle Magdalena Valley Basin stratigraphy has been studied by several authors specially linked to the oil and gas exploration and production (Anderson, 1927; Anderson, 1945; Gómez, 2001; Hopping, 1967; Morales et al., 1958; Pilsbry and Olsson, 1935; Suárez, 1996; Suárez, 1997a; Wheeler, 1935). The upper Cretaceous rocks of this area are characterized by shallow marine and coastal deposits that, in general, comprise a regressive sequence. Most of the Tertiary rocks were formed in coastal and fluvial environments and

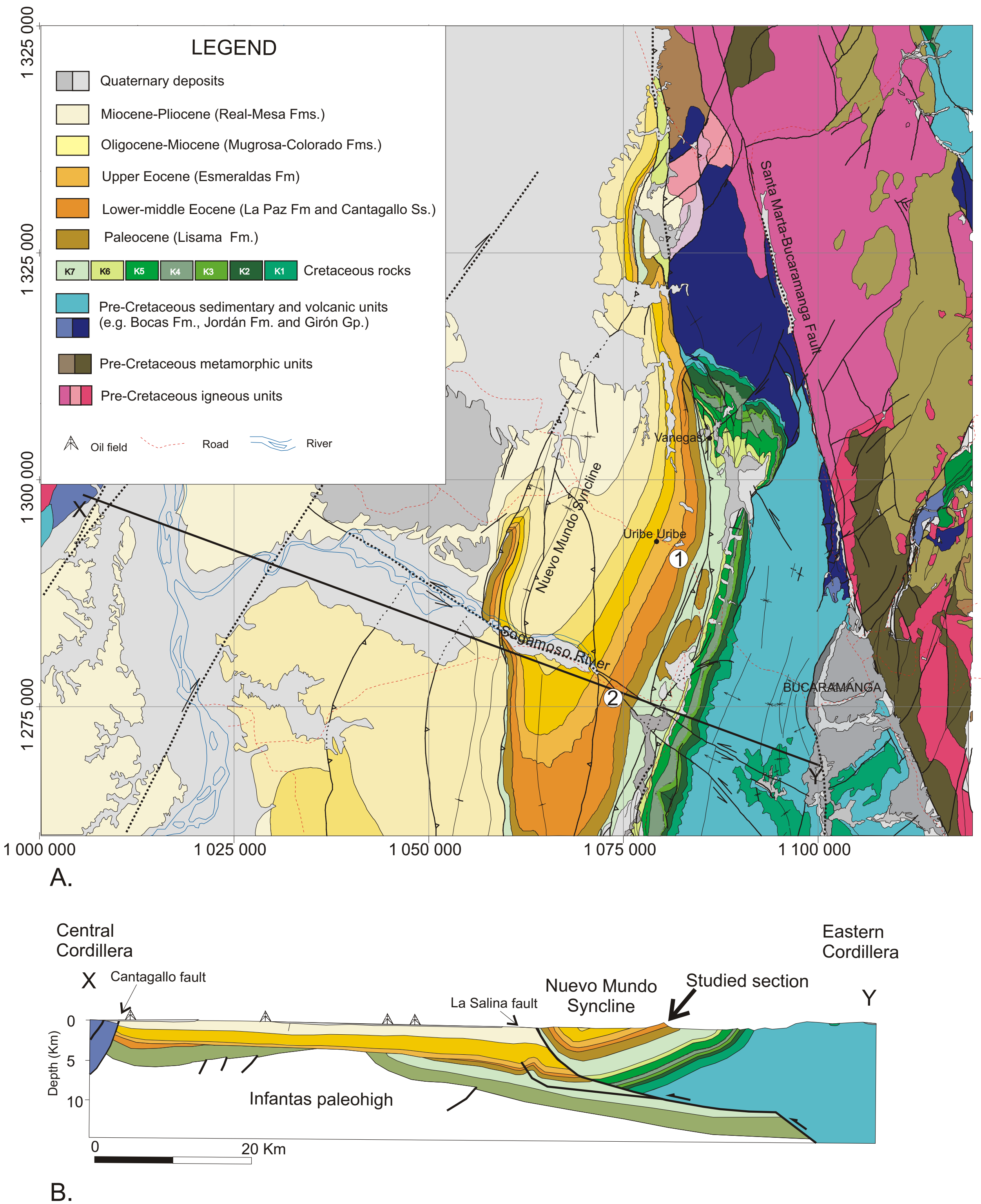


Figure 2.1. A. Geologic map of the northern Middle Magdalena Valley Basin and location of the studied sections. 1: Uribe section; 2: Sogamoso section. K: Cretaceous units. K1: Los Santos Fm.; K2: Rosablanca Fm.; K3 : Paja Fm.; K4: Tablazo Fm.; K5: Simiti Fm.; K6: La Luna Fm.; K7: Umir Fm. (modified from Ingeominas, 1969). **B.** Structural cross section of the Middle Magdalena Valley Basin. In white: pre-Cretaceous basement. Post-Eocene rocks are not diferentiated (after Gómez, 2001).

terrigenous sediments dominated. Different stratigraphic nomenclatures have been used by the oil companies in this area (see Porta, 1974 for detailed historical account). Here, we applied the terminology of Morales et al. (1958); Van der Hammen (1958) and Gomez (2001); for the Paleocene-Eocene interval for which 3 units have been recognized from the base to the top (Figure 2.1):

The Lisama Formation

Theo A. Link defined this unit in 1.925 in an unpublished report (Morales et al., 1958). The type locality is located in the Lisama Creek, a tributary of the Sogamoso River; nevertheless, there is not a published detailed description of this section. Later on, Wheeler (1935) published a synthesis of the Tertiary stratigraphy of the Middle Magdalena Valley Basin. He described the Lisama Formation as "a 3500 foot series of beds containing much more coarse sediments were laid down. These consisted of beds of mottled shales, alternating with minor amounts of dull-colored carbonaceous shales, intercalated with occasional coal beds of much less notable development than those of the Umir, and brown, fine and medium-grained well-bedded sandstones up to 25 or 30 feet in thickness". Morales et al. (1958) based upon many unpublished reports, especially those of the oil industry, a proposed standard nomenclature for the Middle Magdalena Valley Basin. In this paper they describe the Lisama Formation as composed "principally of vari-colored, red, brown, light-grey to grey, mottled shales, with interbeds of medium to fine grained, grey to greenish-grey and brown, occasionally cross-bedded sandstone. The sandstones become coarse grained towards the top, and occasional coal seams less well developed that those of the Umir are present". The thickness of this unit ranges up to 1225 meters; its lower contact is conformable and gradual with the Umir Formation and usually is placed at the "lowermost well-developed sandstone layer" (Morales *et al*., 1958). Typical exposures can be also seen along the Puerto Wilches-Bucaramanga railroad, near Vanegas (Morales et al., 1958).

Van der Hammen (1954a) analyzed some coal samples from Agua Blanca (Bucaramanga-San Vicente road, Santander) and Vanegas (Lebrija River, 13 km to the north-east of the Uribe Uribe town; figure 2.1) that occurs in the Umir Formation located under the Lisama Formation; 7 samples came from Agua Blanca (20 km to the south of Vanegas) section collected by the paleontologist H. Bürgl (From base to top: HB 288, HB 365, HB 286, HB 385, HB 383); they are located approximately along the Formation. Near to the sample HB 385, 210 m below the contact Lisama-Umir Formations was founded the foraminifer *Siphogenerinoides plumeri* of Maastrichtian age. This sample is included in the limit of the palynological sub-zones B_3-C_1 defined by Van der Hammen (1954b) in the Guaduas Formation to the south (near Bogotá). Van der Hammen (1954b, p. 76) mentioned also a complete "renovation" of the palynoflora in the lower Lisama Formation with respect to the undreliying Umir Formation; he used this phenomenon as criteria to establish the Cretaceous-Tertiary limit in this area. In a further work, Van der Hammen (1957b, p. 196) pointed out also that the presence of a peak of *Monocolpites medius* and the first appearance of *Proxapertites operculatus* in the Upper Guaduas Formation and in several regions of Colombia (Catatumbo, Río Lebrija and El Cerrejón) can represent the Cretaceous-Paleocene boundary. However, a recent palynological research in the Rio Loro section in western Venezuela (Pocknall *et al*., 2001) shows that this species is present also in the Maastrichtian deposits of this area (see the section 1.4 of this work).

The La Paz Formation

The La Paz Formation was defined by Tropical Oil Company geologists in 1923, and published by Wheeler (1935) and Morales et al. (1958). The type section is localized near Vanegas town in the site named "angostura del Rio Lebrija", in the railroad of Puerto Wilches (Van der Hammen, 1958). It is conformed by grey massive to cross-bedded sandstones, sometimes conglomeratic, with minor intercalations of mudstones and shales mainly in the lower and middle part; the shaley levels have bad preserved plant remains. Towards the base it presents a level of shales of grey color that were denominated Toro Formation by Waring (1931, in Porta, 1974. p. 483) nevertheless this term has been used to designate different units separated by an unconformity and, for this reason, Gomez (2001) proposed that it must be abandoned (see also Bueno, 1968, for a revision about the origin and stratigraphic position of this "unit"). In the type section this formation has 1000 m approximately although it is variable across the Middle Magdalena Valley (Morales et al., 1958); its lower contact with the Lisama Formation is an unconformity and in other places of the MMV this unit rest over Cretaceous units in angular unconformity. The upper boundary is transitional with Esmeraldas Formation.

The La Paz Formation dating has been based mainly on stratigraphic relationships and sedimentary characteristics. Van der Hammen suggests that the lithologic change between Lisama and La Paz Formations could be an unconformity. Based on its stratigraphic position above the Umir Formation and the probable Paleocene age of the Lisama Formation, Van der Hammen considers a Lower-Middle Eocene age for the La Paz Formation (Van der Hammen, 1954b, p. 58, 59). Gemeraad et al. (1968) put this unit in the upper part of *Foveotricolpites perforatus* and the *Retibrevitricolpites triangulatus* and lower *Retitricolporites guianensis* Upper Paleocene-Lower Eocene Caribbean palynological zones; unfortunately, the pollen distribution used to recognize these biozones was never published. Later work based only on stratigraphic and structural relationships consider a Late Eocene age for all the Formation (e.g. Suárez, 1996). According to Van der Hammen (1958) this unit can be correlated with the Mirador Formation, and its underlying "Toro Shale" Formation is probably equivalent to the upper part (Eocene) of Los Cuervos Formation in the Catatumbo area (Figure 1.2.).

The Esmeraldas Formation

The Esmeraldas Formation was defined by geologists of the Gulf Oil Company (in Wheeler, 1935). The type locality is near the town of Esmeraldas, close to the Sogamoso River, 35 km south of the Uribe section. It consists of thinly bedded sandstones and grey mudstones interbedded with grey shales that are occasionally red, purple or brown and mottled. Some isolated coal beds are present. The upper part of the formation contains the fossiliferous "Los Corros" (see below). The formation is about 1200 m thick and thickens to the north (Porta, 1974). The lower contact is gradual with La Paz Formation, whereas the upper boundary is unconformable with the Mugrosa Formation (Porta, 1974), although Morales et al. (1958) noted that the nature of contact is not well established. The Esmeraldas and La Paz Formations are included by Morales et al. (1958) in the Chorro Group (see Porta, 1974 for a historical account of this term).

Pilsbry and Olsson (1935) dated the Los Corros fossiliferous horizon in the Esmeraldas

Formation as Upper Eocene, based on the freshwater to slightly brackish-water molluscan assemblage of *Hemisinus* (s. str.) *corrosensis* Pilsbry and Olsson, *Potamides* (s. lat.) *macgilli* Pilsbry and Olsson, *Diplocyma wheeleri* Pilsbry and Olsson, *D. sucionis* Pilsbry and Olsson, and *Sogamosa cyrenoi*des Pilsbry and Olsson. The name of the species is according to the revised determinations of Olsson material by Nuttall (1990). After an extensive analysis of molluscan faunas of northern South America, Nuttall (1990) concluded that there was no molluscan paleontological evidence for the age of the Los Corros fauna that could be more precise than "probably Paleogene." Pilsbry and Olsson (1935) based the late Eocene age determination on the inclusion of *Tympanotonus lagunitensis* Woods from the Saman Eocene of western Peru in their new genus *Diplocyma*, but these species are barely similar and the inclusion was unwarranted (Nuttall, 1990). Meanwhile, this Eocene age has been assigned to the formation by palynologists working in the area. Van der Hammen (1958) dated the formation as upper Eocene based on palynological correlation of his "climatic cycles," while Germeraad et al. (1968) dated the base of the formation as middle to upper Eocene (*Retitricolpites guianensis* Caribbean pollen zone and *Verrucatosporites usmensis* Pantropical pollen zone).

One of the most remarkable unconformities recognized in seismic profiles in the MMVB can be observed in the lower contact of La Paz Formation. Seismic data obtained in the Nuevo Mundo syncline (Gómez, 2001) show a very low angle onlap between La Paz-Lisama Formations; however, this surface separates progressively older units to the west (Figure 2.2). Thus, deformation should start earlier in the west and be deformed progressively towards the basin deposits to the east where sedimentation continued. Consequently, the deposition-erosion time interval that is involved in this unconformity changes along the MMVB (see Villamil, et al., 1995). As the Paleogene rocks of this area do not have marine fossils that permit us to know the time of deposition, there are controversies about the duration of this unconformity in various places in the basin. Moreover similar facies characteristics in Paleocene and Eocene units linked to frequent facial lateral variations makes interpretations complex. There are some evidences that suggest that this unconformity surface started in the Late Cretaceous: the first presence of quartzitic rich coarse clastic deposits in the south western border of MMVB (Cimarrona Formation) and in the Upper Magdalena Valley (La Tabla and Monserrate Formations) which have been interpreted as fragments of the metamorphic basement of the Central Cordillera (Gómez and Pedraza, 1994) or its Lower Cretaceous sedimentary cover (Moreno-Sanchez and Pardo-Trujillo, 2003), indicates that tectonic activity in the Central Cordillera starts in the Maastrichtian in these areas.

In the Nuevo Mundo Syncline area there are not upper Cretaceous coarse-grained deposits, but a change in mature quartz-rich typical of the upper Cretaceous deposits to metamorphic-rich sandstones is recognized in the Paleocene Lisama Formation, which suggests the unroofing age of the Central Cordillera basement for this sector (Hathon and Espejo, 1997). Gomez (2001) named this surface “Late Cretaceous Cenozoic Unconformity” (LKCU) and pointed out that Late Cretaceous to Early Eocene time-transgresive eastward and northward migration of Central Cordillera deformation constituted the first stage in the formation of this unconformity. Additionally, the presence of growing strata and synsedimentary faults in all the Tertiary sedimentary pile of the MMV suggest that the deformation started in the Maastrichtian but continued during all the tertiary with different intensity (Gómez, 2001). In this tectonic setting, reworking of old units could be frequent. Thus, the analysis of reworked palynomorphs could give supplementary information in fine-grained rocks about the erosion timing and its relative intensity; data that can be confronted with the classical provenance studies in sandstones and conglomerates.

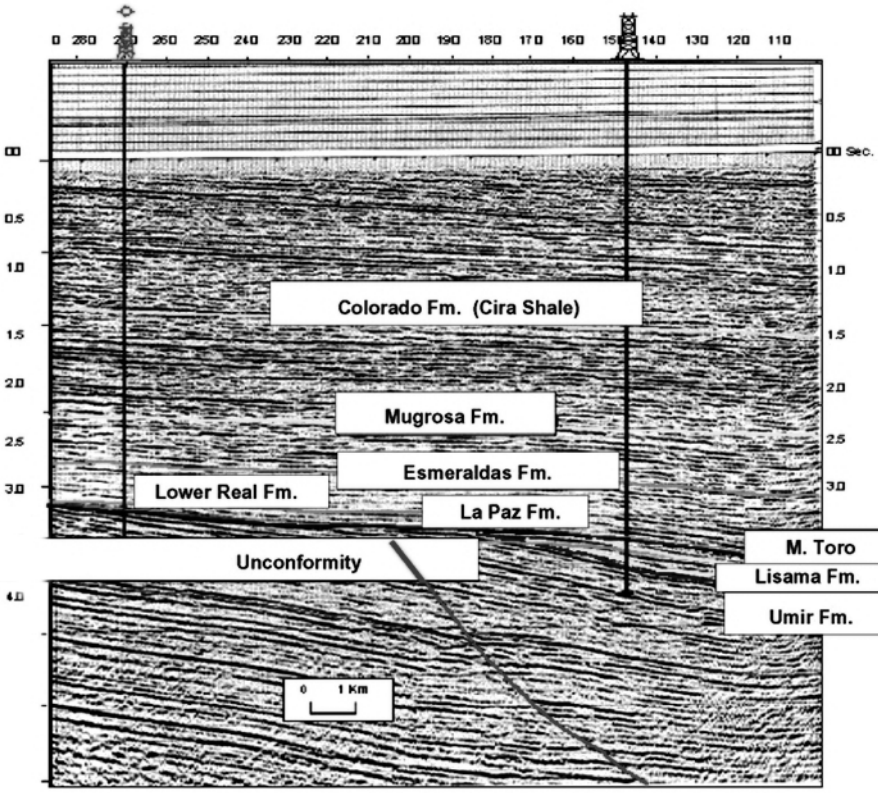


Figure 2.2. Seismic section across the Middle Magdalena Valley Basin which shows the progressive onlapp of Eocene rocks over the Late Cretaceous Cenozoic Unconformity (LKCU). The duration of unconformity increases to the W indicating tectonic activity simultaneously with the sedimentation (from ECOPETROL, Colombia).

2.2. DESCRIPTION OF THE STUDIED SECTIONS

The sections studied are located in the western flank of the Nuevo Mundo Syncline (Figure 2.1). They are the “Uribe” and the “Sogamoso” sections (Figure 2.3; see also the figure 1.1. for regional location). The Uribe section was studied in the field by Carlos Jaramillo along the Sucio river, near the Uribe-Uribe town (7° 14’N - 73° 21’W; figure 2.1). The Sogamoso section, 17 km to the south of the Uribe section, is located in the La Paz hill near the Sogamoso River (7° 5' 48.38" N- 73° 23' 59.33" W; figure 2.1). It is a composite log of nine wells of the “Río Sogamoso hydroelectric project” (wells IC-PE-2; IC-FA-3; IC-TD-1; IC-CC-7; IC-CC-12; IC-CC-2; IC-FA-4; IC-FP-1; SD-D-8D), in storage at the Colombian Core Library (Instituto Colombiano del Petróleo, Bucaramanga). The partial cores were measured and described by Pardo (1997), but revised and sampled by the author (Figures 2.4 and 2.5).

2.2.1. The Uribe section

It includes the Lisama, La Paz and the base of the Esmeraldas Formation. The lower contact between the Lisama and the Umir Formation is not visible in this area. In the Lisama Formation 906 m can be measured; nevertheless, there are many covered intervals (Figure 2.3). Based in the lithological characteristics the section is separated in several segments:

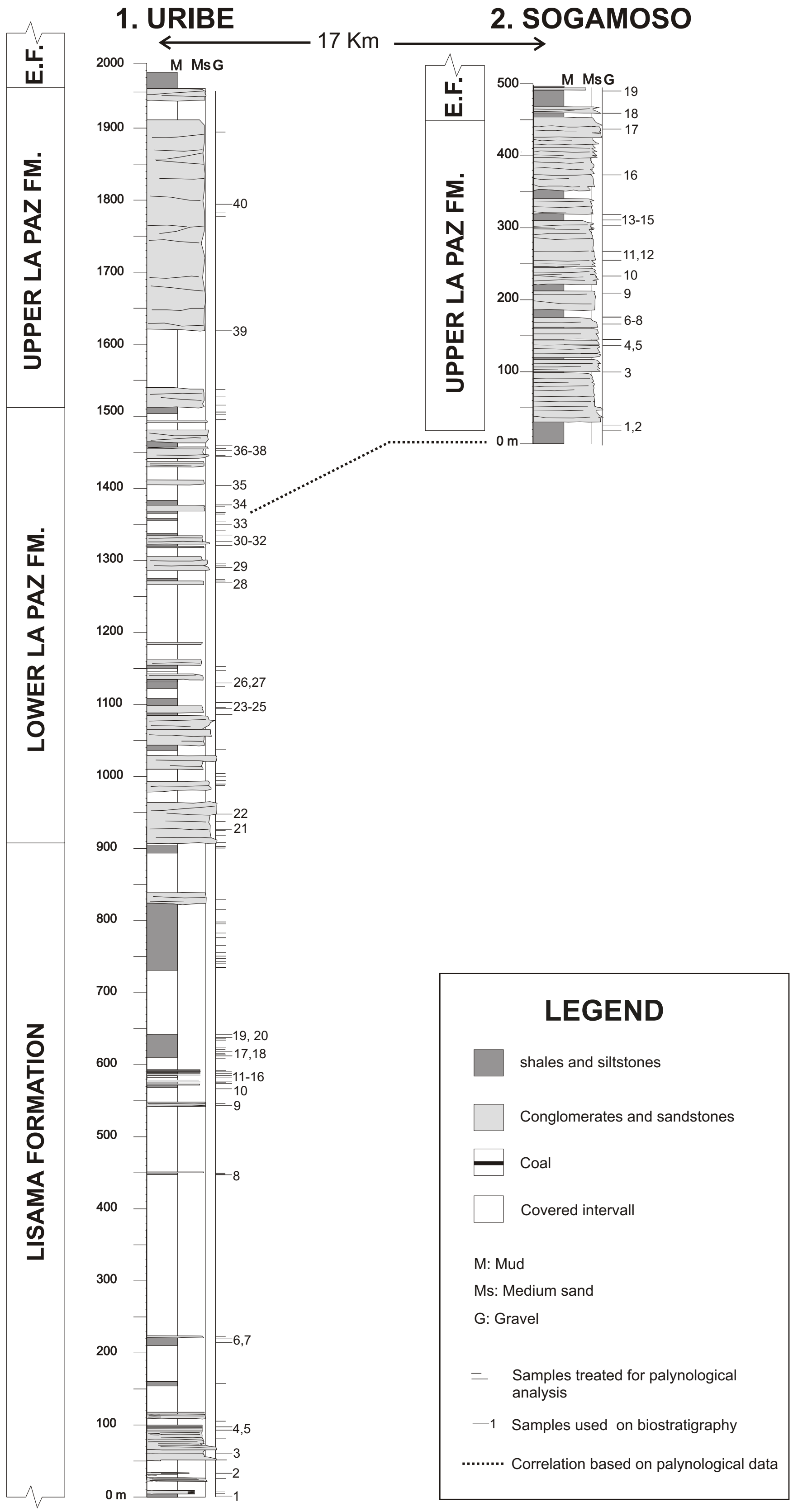


Figure 2.3. Stratigraphic sections of the Middle Magdalena Valley Basin and location of the samples studied in this work. (see the figure 2.1 for location). E.F: Esmeraldas Formation.

0-223.5 m. Composed by coarse to very fine lithic sandstones with shale interbeds. The sandstones are disposed in amalgamated sets with planar and trough cross-bedding; shale intraclast are common in some levels. In the fine sand-mud intervals flasser and lenticular bedding are frequent. The shales are micaceous, dark- medium grey to greenish grey in color.

223.5-542 m. Mainly a covered interval. Between 447.5-450.5 m some levels of dark to medium grey shales, and fine micaceous sandstones can be observed.

542-592 m. Conformed by sandstone shale interbeds. The sandstones are lithic medium to fine in size, rhytmically intebedded with the shales, some coal layers are present; flasser, lenticular and ripple bedding are conspicuous. The shales are organic rich dark to medium grey in color.

592-642 m. Shale-dominated interval with some sandstone interbeds. The shales are greenish, brownish and bluish grey in color; some of them are mottled and varicolored.

642-734 m. Covered interval.

734-902. Fine-grained interval dominated by grey and red-purple varicolored shales with different degrees of burrowing and root bioturbation. Some amalgamated tough cross-bedded sandstones are present to the top of this interval.

Interval 906-1086 m, lowermost La Paz Formation: This is characterized by clast-supported polimictic conglomerates, massive coarse-grained lithic arenites. Thick bedded and large scale planar and trough cross-bedding are common.

Interval 1086-1491 m, lower La Paz Formation: This interval is divided into three units, 1086-1161 m, 1161-1372 m, and 1372-1491 m. The first unit is dominated by thin-bedded, fine to medium-grained lithic arenites, with plane-parallel lamination interbedded with red claystones, and thin coal beds. The second unit is characterized by trough cross-bedded, medium-grained lithic arenites interbedded with black shales and thin-bedded, very fine-grained lithic arenites, as well as several covered intervals that probably are fine-grained because they produced valleys in the topography. Toward the top, this second unit has thin to medium-bedded, medium to coarse-grained lithic arenites with planar cross-bedding, and isolated lenticular arenite bodies in dark shales. The third unit is dominated by red to brown claystones in the lower part. The upper part consists of thin-bedded and amalgamated, fine-grained lenticular quartz arenites interbedded with fine-grained quartz arenites with lenticular lamination and upward-fining channel-fills. These channel-fills have gravel lags, trough cross-bedding, and planar cross-bedding.

Interval 1491-1895 m, upper La Paz Formation: Most of this interval is either not exposed or is poorly exposed. The first 134 m (1491-1625 m) is poorly exposed and dominated by light grey claystones interbedded with thin-bedded, medium-grained lithic arenites. The upper 270 m (1625-1895 m) is dominated by medium- to coarse-grained quartz arenites, with large-scale trough and planar cross bedding, and conglomeratic beds; fine sediments are scarce.

Interval 1895-1952 m, uppermost La Paz Formation: The lower part of this interval is covered and is probably fine-grained sediment because it occurs as a topographic low. Toward the top, the outcrop is a massive, medium-grained quartz arenite in amalgamated lenticular bodies.

Interval 1952-1972 m, lowermost Esmeraldas Formation: This interval is dominated by purple, mottled, light grey claystones.

2.2.2. The Sogamoso section

The Sogamoso section has 493 m approximately and includes the upper part of Lower La Paz Formation, the Upper La Paz Formation and the lower 50 m of Esmeraldas Formation (Figures 2.3, 2.4 and 2.5). From base to top the following characteristics are recognized:

0-25.6 m. (Upper part of Lower La Paz Formation). Conformed by light olive grey siltstones, frequently red mottled, some plant remains and siderite nodules. These deposits can be interpreted as strong oxidized paleosoils accumulated in alluvial plains with relatively high subsidence.

25.6-170 m. Mainly composed by metric layers of brown-grey medium to fine sandstones, with thin (less than 50 cm thick) shaly interlayers. The sandstones have planar and through cross bedding at different scales (Plate 2.1; photo 5), convolute lamination and muddy intraclast are very frequent, locally bioturbation is conspicuous. The shales are dark medium grey to olive-grey in color, micaceous; some of them are rich in plant debris. Several fining upward amalgamated sequences can be observed with ripple cross lamination to the upper part (Plate 2.1; photo 6).

170-313.3 m. Similar to the former interval but with some shaly levels of more than 5 m thick (Plate 2.1; photo 8), some polimictic conglomerates are present to the top. The sandstones are disposed in metric to decimetric amalgamated strata, medium to fine in size with abundant muddy intraclasts, frequently bioturbated. Different sizes of cross bedding are the most common internal sedimentary structure, convolute bedding is also present, plant debris are very frequent and stand out the stratification. Fining upward sequences are also frequent. The shales are dark grey to greenish grey, micaceous, some of them with abundant plant debris; red mottled is rare. The conglomerates are located at the base of several fining upward sequences in gradational contact with sandstones; they have milky quartz, shale intraclasts, black chert and other sedimentary fragments (Plate 2.1; photo 3). The shale intraclasts can reach 12 cm in diameter (Pardo, 1997).

313.3-449 m. Composed by metric layers of sandstones, conglomeratic sandstones and conglomerates, forming fining upward sequences; shales are scarce (Plate 2.1; photo 7). In this interval conglomeratic levels are more frequent; they are composed by lutitic intraclasts, milky quartz, chert and other fine-grained sedimentary rock fragments (Plate 2.1; photos 1 & 2). The sandstones have cross bedding (Plate 2.1; photo 4), convolute bedding, locally bioturbated. The shales are grey to green-grey, micaceous, sometimes with abundant plant debris.

449-493 m (Lower part of the Esmeraldas Formation). It is mainly a fine grained interval. To the base it has medium grey shales followed by fining upward metric successions of cross-bedded grey sandstones and conglomerates, amalgamated; plant debris and biotubation is

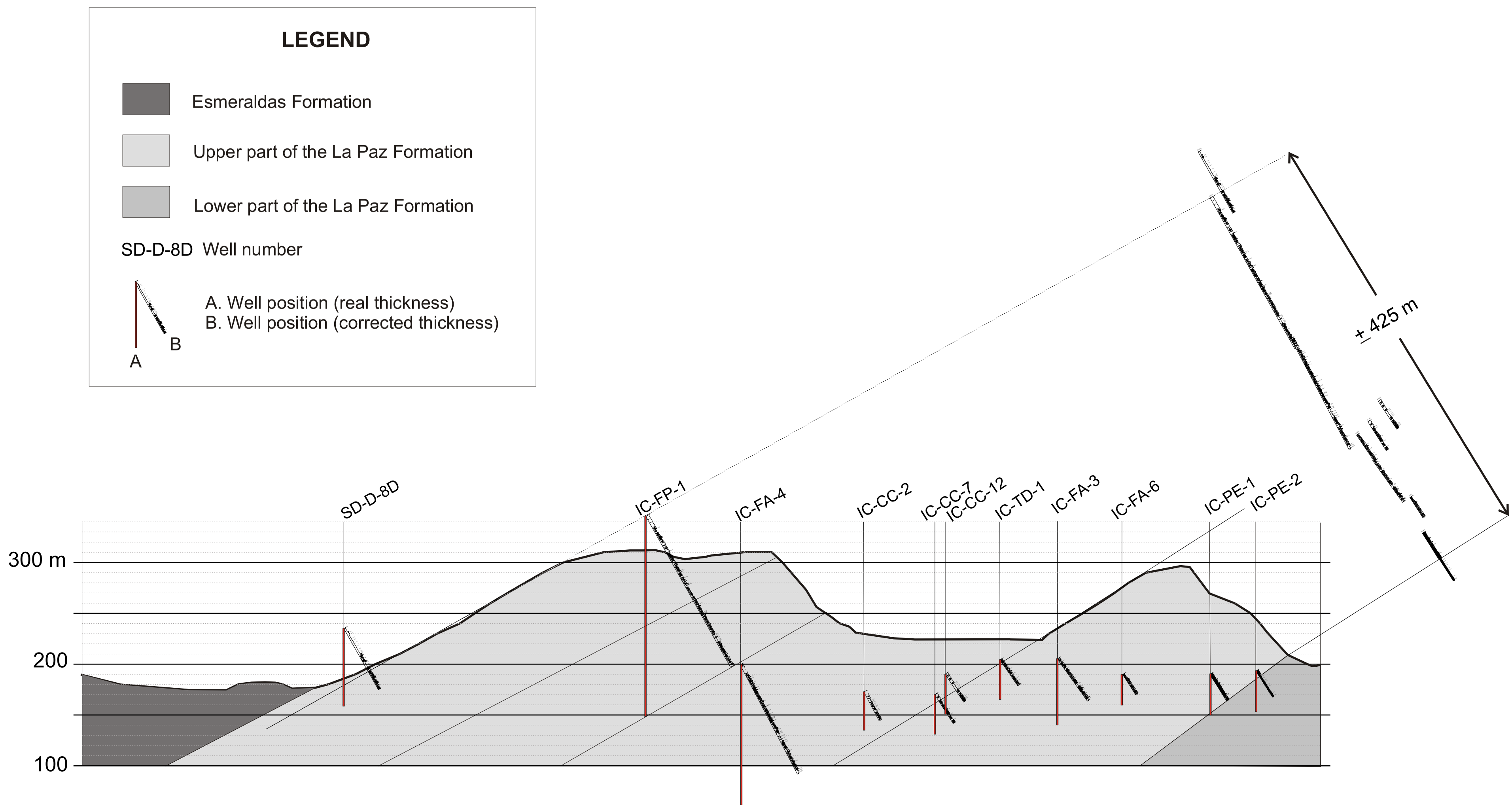


Figure 2.4. Cross section of the La Paz hill and location of the well cores used to construct the Sogamoso section (topography based on the map of the appendix 2.5).

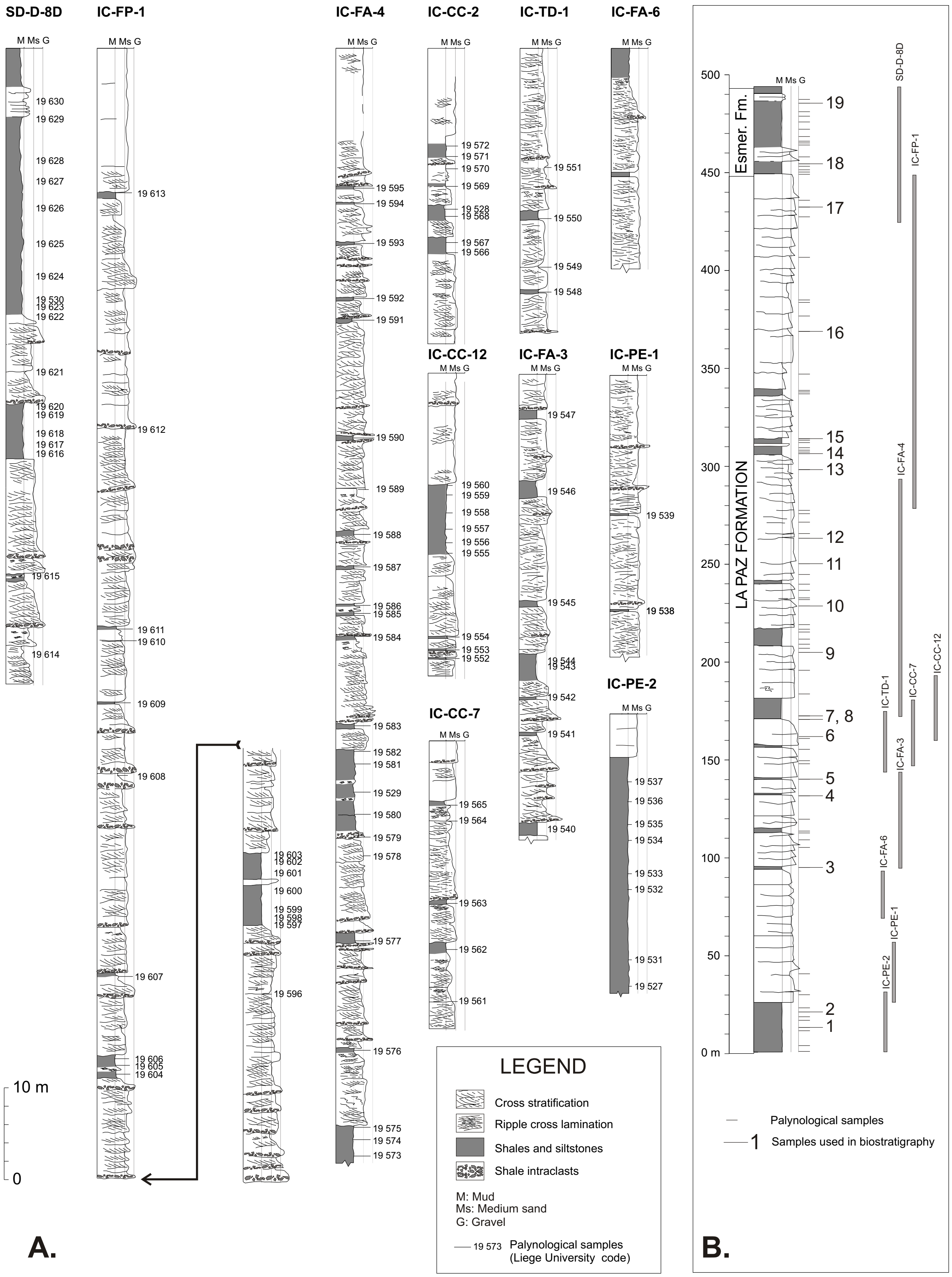


Figure 2.5. A. Sedimentologic characteristics of selected well cores of the "Rio Sogamoso hydroelectric Project" (upper La Paz and Esmeraldas Formations, Middle Magdalena Valley). Here the apparent thickness was corrected geometrically (modified from Pardo, 1997). See the appendix 2.5 for location . **B.** Composite log and relqtive position of the studied samples.

locally abundant. The studied interval finished with 25 meters of red mottled greenish-grey silty shales, strongly bioturbated (Plate 2.1; photo 9).

2.3. BIOSTRATIGRAPHY

2.3.1. General description

The Paleogene of the MMVB is very rich in pollen and spore species. In this study more than 300 pollen and spore species are recorded (appendix 2.2). The figures 2.6 and 2.7 show the general distribution of pollen, spores and dinoflagelates founded in the studied sections. The Uribe section (figure 2.6) can be separated in four sectors with different lithological and palynological characteristics limited by a 340 m thick interval barren of organic microfossils.

Lower part of the Lisama Formation (samples 1 to 7; figure 2.6): it is characterized by the occurrence of *Bombacacidites annae*, *Bombacacidites* sp. 2, *Bombacacidites protofoveoreticulatus*, *Corsinipollenites psilatus*, *Ephedripites vanegensis*, *Longapertites microfoveolatus*, *Mauritiidites franciscoi*, *Proxapertites operculatus*, *Proxapertites cursus*, *Proxapertites magnus, Psilamonocolpites medius, Retidiporites magdalenensis*, *Tetracolporopollenites spongiosus*, *Ulmoideipites krempii* as the most abundant species. Nevertheless, some of these taxa have a long stratigraphic range. *Corsinipollenites psilatus* similar to the pollen of the Onagraceae family is relatively frequent in this interval. The last appearance of *Colombipollis tropicalis* species seems to be located in this sector; this species have been found in several sections of NW South America (e.g. Guerrero and Sarmiento, 1996; Pocknall et al., 2001; Sarmiento, 1992b) and consequently could be a stratigraphic marker. *Longapertites microfoveolatus* and *Proxapertites magnus* are relatively frequent. *Ulmoideipites krempii* are present in several successive levels in this interval, disappears towards the upper part of the Lisama Formation and reappears in the La Paz Formation. *Bombacacidites annae* and *Bombacacidites* sp. 2 are common in this sector and probably represent the first appearance of this genera in the area since Van der Hammen (1954a) did not found them in the underlying Umir Formation at the Vanegas section, 14 kilometers to the north-east of our section. In the same way, the *Proxapertites operculatus* species, which is not present in the Umir Formation (Van der Hammen, 1954a) is already important in this sector (e.g. 71 % relative in the sample 1); *Psilamonocolpites medius* records a high relative percentage. Additionally, the occurrence of some dinoflagellate species and the high morphologic “diversity” of the trilete spores (many of them have not been formally described in this work) are characteristic in this sector of the diagram.

Upper part of the Lisama Formation (samples 8 to 20; figure 2.6): Following a 200 m covered interval, some species are observed from the base (e.g. *Foveotricolpites perforatus*, *Foveomonoporites variabilis* and *Psilamonocolpites operculatus*). *Aglaoreidia*? *Foveolata*, *Diporoconia* cf. *Diporoconia iszkaszentgyoergyi* and *Diporopollis assamica* are some of the few species that apparently have their first appearance in this interval. Additionally, some bisacate pollen begins to be recorded in this sector. *Ephedripites vanegensis*, *Retidiporites magdalenensis*, *Bombacacidites annae*, *Foveotricolpites perforatus*, *Proxapertites cursus* have their LAD in this part of the diagram (figura 2.5). An important characteristic of this interval is the dominance of the *Proxapertites operculatus* species: in 11 of the 13 studied samples it surpasses the 40 % and amounts at 94 % in the sample 19. Similar pollen and spore

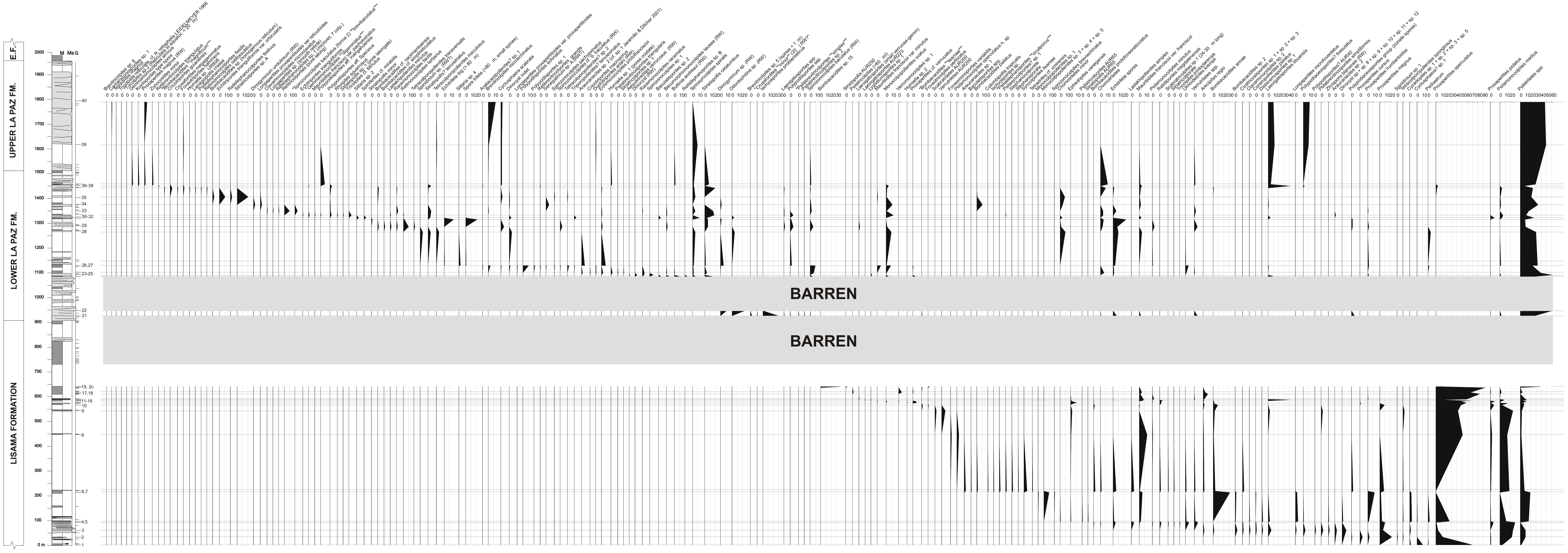


Figure 2.6. Stratigraphic distribution of relative percentages of pollen and spores (Uribe section).

associations have been described in the Los Cuervos Formation in the Catatumbo region in the southwest of Venezuela (e.g. Colmenares and Terán, 1993) or in the Arcillas del Limbo and Socha Formation in the central part and eastern border of the Cordillera Oriental of Colombia (Jaramillo and Dilcher, 2001) and in the Paso Diablo Formation to the north-west of Venezuela (Rull, 1999a).

Lower part of the La Paz Formation. In the lowermost part of the La Paz Formation, which is included in the barren interval, two samples (21 and 22; figure 2.6) give some pollen and spore associations. The sample 21 is conformed mainly by spores. Between them the abundance of *Ischyosporites problematicus* and *Psilatriletes* ssp. can be remarked. Following the barren interval, which corresponds a the last 170 m of the Lisama Formation and the first 170 m above the base of the La Paz Formation, an important change in the palynoflora can be appreciated. Some species such as *Cyclusphaera scabrata*, *Spirosyncolpites spiralis*, *Striatopollis catatumbus*, *Brevitricolpites microechinatus* and *Tetracolporopollenites transversalis* appear in the lower La Paz Formation. Nevertheless, it is necessary to stand out that most of the samples of this sector are poor in pollen and spores: in 12 of the 20 studied samples less than 100 palynomorphs were recorded. Additionally, in this sector Late Cretaceous-Early Paleocene reworked species are recorded in appreciable percentage (e.g. *Dinogymnium acuminatum*, *Buttinia andrevi*, *Bacumorphomonocolpites tausae*, *Duplotriporites ariani* and *Spinizonocolpites baculatus*). They were considered “reworked” because this association is reported only in the Late Cretaceous- lower Paleocene strata of some sections of NE Colombia (Guerrero and Sarmiento, 1996; Sarmiento, 1992b; Solé de Porta, 1971) and western Venezuela (Jaramillo, C. pers. com, Pocknall et al., 2001); and in some cases they are bad preserved in our samples. On the other hand, the relative percentage of spores in some samples is higher than 50 % and contrast with the low percentage recorded in the Lisama Formation.

Upper part of the La Paz Formation. This sector could be sampled in detail from the core logs of the Sogamoso section. Eighty shale samples distributed along this interval dominated by sandstones were treated for palynological analysis; between them 21 samples were selected for the biostratigraphical study, 15 of which provided more than 100 grains of pollen and spores. 43 slides distributed in 19 stratigraphic levels were studied by the author at Liege University (Belgium) and 2 slides in two stratigraphic levels were studied by C. Jaramillo at the Instituto Colombiano de Petróleo (ICP). In this section more than 200 morphospecies were identified (figure 2.7; appendix 2.2). This information allowed completing the pollen distribution in the upper part of the diagram. In contrast, the Uribe section has a low sampling resolution in this sector (two samples), because the thin shale interbeds are usually altered or covered at the Sucio River outcrops. Some of the pollen species recorded in this section have been recognized in different regions from NW of South America: *Striatopollis catatumbus*, *Spirosyncolpites spiralis*, *Bombacacidites* cf. *soleaformis*, *Foveotriporites hammenii*, *Monoporopollenites annulatus*, *Perfotricolpites* cf. *digitatus*, *Cricotriporites guianensis*, *Tetracolporopollenites maculosus*, *Gemmamonocolpites ovatus*, *Retitricolpites* cf. *simplex*, *Luminidites colombianensis*, *Kuylisporites* type spore, *Retimonocolpites retifossulatus*, *Echiperiporites* sp. *Racemonocolpites facilis*. Aditionally, in the upper La Paz Formation the *Polypodiaceoisporites* zonate spores and *Polypodiisporites* ssp. (not formally decribed) become frequent. The former spores have a lower verrucation that *Polypodiisporites usmensis* used by Germeraad et al. (1968) as a stratigraphic marker. On the other hand

Figure 2.7. Stratigraphic distribution of relative percentages of pollen and spores (Sogamoso section).

Albertipollenites? *perforatus*, some forms of *Brevitricolpites* (e.g. *Brevitricolpites* "densiechinatus"), *Horniella* sp., *Rugumonocolpites* "pacificus" and several species of *Bombacacidites* occurs in this interval in low percentage. Nevertheless, as they have clear diagnostic morphological characteristics, their stratigraphic potential should be tested as new sections become available.

The palynological information was also grouped in a composite distribution diagram (Figure 2.8). The Sogamoso section is equivalent to the upper part of lower La Paz-upper La Paz and Lower Esmeraldas Formations at Uribe section, 26 km to the north. This is supported by the first appearance of *Foveotriporites hammenii*, *Cricotriporites guianensis* and *Echitriporites trianguliformis* var. *orbicularis*; *Kuylisporites* type spore and *Retimonocolpites retifossulatus*. 50 potential biostratigraphic useful taxa are presented here. They were selected based on their occurrence in other sections described in the literature, their narrow stratigraphic range, their apparent FAD or LAD in the studied interval, and/or their use in previous stratigraphic studies.

2.3.2. Comparison with some biozonal schemas of NW South America

Different authors have proposed palynological zonations to subdivide the Paleogene of the northwestern South America (e.g. Germeraad et al., 1968; Gonzalez, 1967; Muller et al., 1987; Van der Hammen, 1957b) (see the chapter 1). The most employed are those from Germeraad *et al*. (1968) and Muller *et al*. (1987). Germeraad *et al*. (1968) included in their study of the Tertiary palynology of tropical regions a sequence from the Middle Magdalena Valley Basin. It is located 13 Km to the northeast of the Uribe section (the "Río Lebrija" section). In this section they mentioned the presence of the *Foveotriletes margaritae* and *Ctenolophonidites lisamae* in the lower half of the Lisama Formation; the *Foveotricolpites perforatus* zone in the upper part of the Lisama Formation and the base of the La Paz Formation and the *Retibrevitricolpites triangulatus* zone that reaches the last meters of the La Paz Formation were is in paraconformity with the *Retitricolpites guianensis* zone. Unfortunately, the location of the samples and the stratigraphic distribution of the pollen species were not published.

Some of our data differ from those of Germeraad *et al*. (1968): among the species used to define the upper Paleocene biozones only three of them, *Bombacacidites annae*, *Foveotricolpites perforatus* and *Proxapertites cursus* are well recorded in our studied section (Figures 2.6). In contrast, *Ctenolophonidites lisamae*, *Gemmastephanocolpites gemmatus* and *Foveotriletes margaritae* are absent or rarely present. Consequently, the *Foveotriletes margaritae* and *Ctenolophonidites lisamae* zones cannot be well identified at the base of our section. Nevertheless, they may be present in the covered part of the Lisama Formation in our studied area (Figure 2.3). The limit of the *Foveotricolpites perforatus* and *Retibrevitricolpites triangulatus* zones was located by Germeraad *et al*. (1968, p. 249) near to the base of La Paz Formation in the Río Lebrija section. The new information obtained here shows that there is a barren stratigraphic interval that encompasses the upper Lisama-lowermost La Paz Formations (Figures 2.6 and 2.8). This phenomenon has been reported by Jaramillo & Dilcher (2001) in other Colombian sections several hundred kilometers apart, a criterion to include a sterile biostratigraphic interzone (sensu Hedberg, 1976) in this region. The "Late Paleocene-Early Eocene" zone *Retibrevitricolpites triangulatus* was defined by Germeraad *et al*. (1968) by the first appearance of *Retibrevitricolpites triangulatus*, *Striatopollis catatumbus* and *Lanagiopollis crassa* species; this zone was specially observed in western Venezuela and

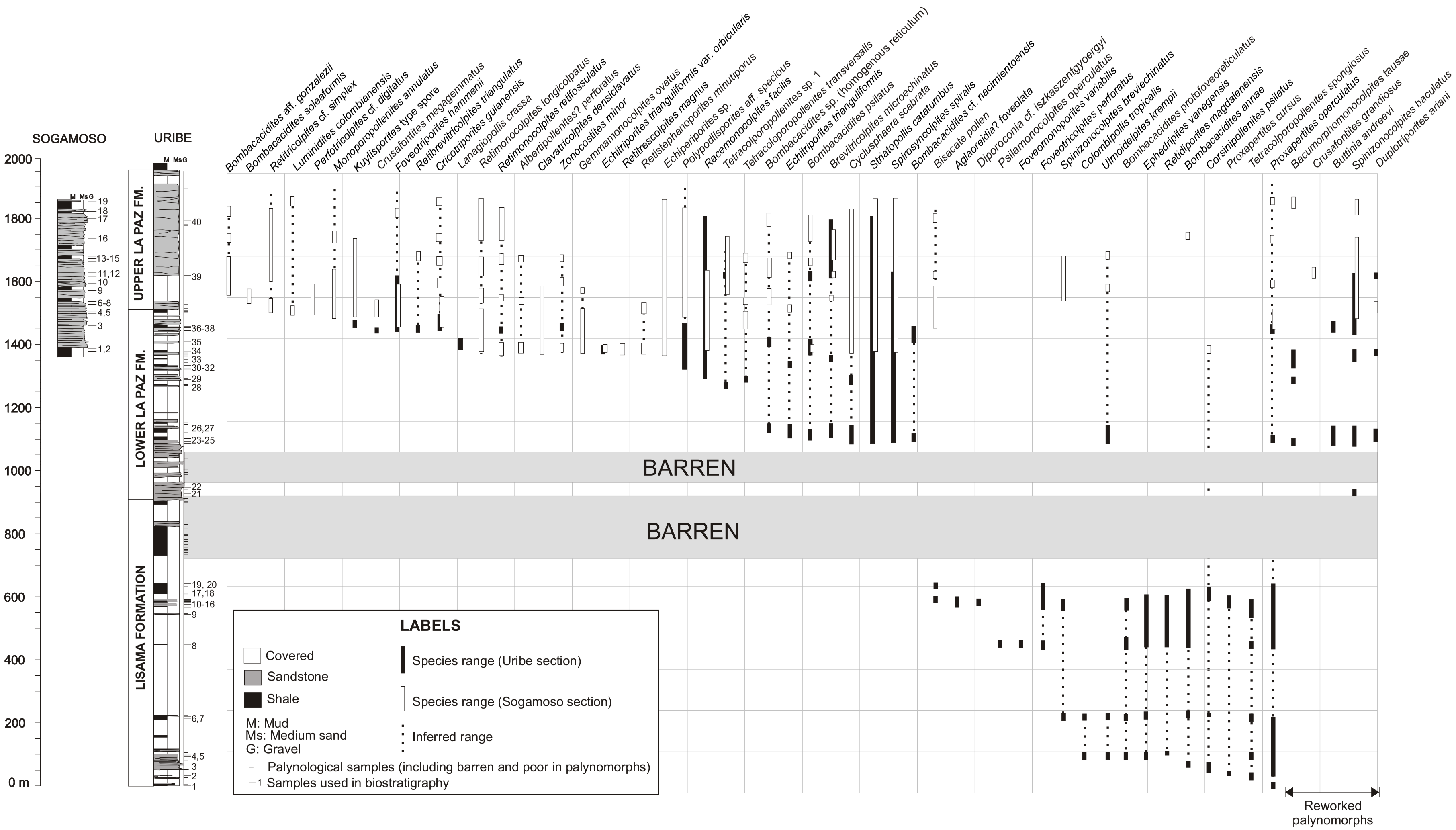


Figure 2.8. Stratigraphic distribution of biostratigraphic usefull taxa in the Sogamoso and Uribe sections

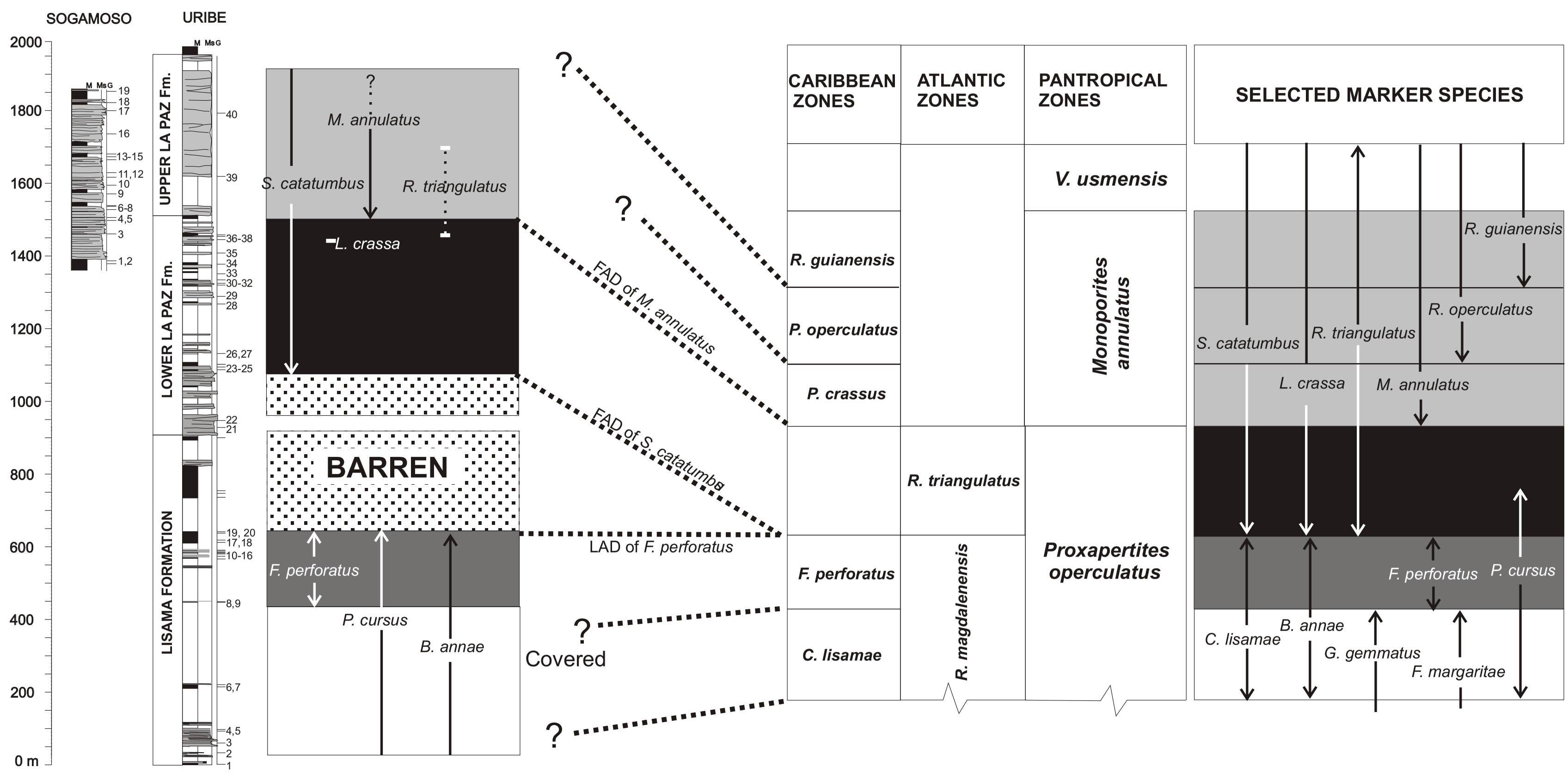


Figure 2.9. Correlation between the Paleocene-middle Eocene palynologic zones of Germeraad et al. (1968) and the Middle Magdalena Valley sections. FAD: First appearance datum; LAD: last appearance datum.

Nigeria (Germeraad et al., 1968). In our section, this zone was recognized with the FAD of *Striatopollis catatumbus*, which is the only species that has continuous stratigraphic distribution. In contrast, *Retibrevitricolpites triangulatus* and *Lanagiopollis crassa* were found only in two and one stratigraphic levels respectively (Figure 2.9). The FAD of *Monoporopollenites annulatus* zone can be recognized at the base of the upper La Paz Formation. Nevertheless difficulties occur when trying to recognize the sub-zones defined by Germeraad *et al*. (1968) in the studied section; *Ranunculacidites operculatus* indicator of one of these sub-zones is not recorded. The species *Rhoipites guianensis* is common in the Esmeraldas Formation but it is not recorded in La Paz Formation; it indicates that the *R. guianensis* sub-zone is not present at the top of La Paz Formation in the Nuevo Mundo syncline area as was previously proposed by Germeraad *et al*. (1968).

Muller *et al*. (1987) subdivided the Paleocene-Eocene of NW South America in 10 palynological zones (zones 15 to 24), some of the species used to define them correspond to those of Germeraad *et al*. (1968) others are new (Figure 2.10). When we try to apply this schema to our section multiple difficulties arise: *Gemmastephanocolpites gemmatus* used as indicator of the zone 15 is not recorded; the species *Rugutricolporites felix* indicator of the zone 17 is not found in the studied area; *Echitriporites trianguliformis* Form. A. (formally named *Echitriporites trianguliformis* var. *orbicularis* by Jaramillo and Dilcher, 2001a), appears only in one stratigraphic level (Figure 2.10); *Bombacacidites* sp. B is not recorded; *Retitrescolpites magnus* is present in a single stratigraphic level; *Bombacacidites soleaformis* indicator of the zone 20 is found only in two levels of the MMVB (2 specimens); *Bombacacidites foveoreticulatus*, *Janmulleripollis pentaradiatus* and *Echiperiporites estelae* are not found in the studied interval. The biozones 21-24 of Muller *et al*. (1987) could thus not be identified. In the schema of Muller *et al*. (1987), some zones that were originally defined in Venezuela are difficult to identify in the studied area, specially the "Eocene" (zones 17-24). The *Rugutricolporites felix* zone was not observed in the MMVB. A possible explanation is that taphonomical factors related to the oxidation of the organic matter to the base of the La Paz-Top of the Lisama Formations precluded its preservation. Nevertheless, in NW Venezuela in the Riecito Maché section where this sterile interval apparently does not exist the FAD of this species is about 1000 m over the *Foveotricolpites perforatus* zone (Rull, 1999a). This fact is incoherent with the scheme of Muller *et al*. (1987). As mentioned above, the species *Retitricolpites magnus* is restricted to a single stratigraphic level in the studied section. In contrast, this species is abundant in the Piñalerita section of Jaramillo & Dilcher (2001), 250 km to the south in the eastern border of the Eastern Cordillera of Colombia. It could suggest a hiatus in the MMVB. However, under the FAD of *R. magnus*, in the lower La Paz Formation still rest a 150 m thick interval that could not be including in the zones proposed by Muller *et al*. (1987); this could suggest an environmental control on the distribution of this species, and consequently a lowering in its stratigraphic value. Additionally, Colmenares & Teran (1993), have shown that in several Paleogene sections of southwestern Venezuela (the Delicias, Quebrada La Capacha and Río Guarumito sections), where accordingly to the author "apparently no important stratigraphic hiatuses occurs", only 5 out of the 10 Late Paleocene-Middle Eocene palynologic zones proposed by Muller *et al*. (1987) can be identified.

Gonzalez (1967) performed a detailed palynostratigraphical analysis of the upper Los Cuervos and Mirador Formation in the Tibú area (NE Colombia). The samples came from three bore-holes drilled by the Colombian Petroleum Company on the Tibú anticline. Some pollen

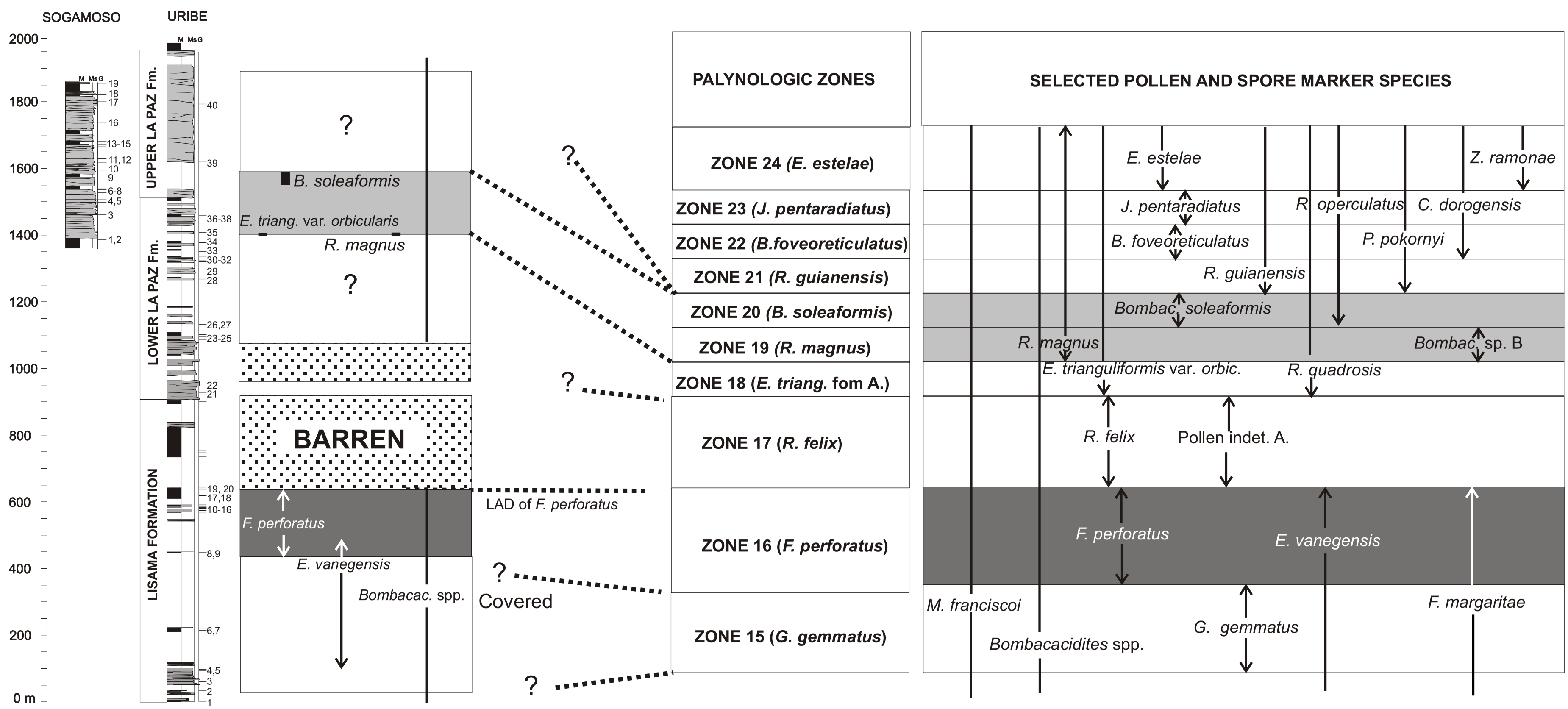


Figure 2 .10. Correlation between the Paleocene-middle Eocene palynologic zones of Muller et al. (1987) and the Middle Magdalena Valley sections.

species described by this author have been also found in the Middle Magdalena Valley (e.g. *Striatopollis catatumbus, Monoporopollenites annulatus, Foveotriporites hamenii*, *Racemonocolpites facilis*, *Retitricolpites* cf. *simplex*, *Spirosyncolpites spiralis*, *Tricolpites clarensis*, *Perforotricolpites digitatus*, *Gemmamonocolpites ovatus*, *Racemonocolpites racematus*, *Ladakhipollenites simplex*). Nevertheless, some marker species recorded by Gonzalez (1967) are not found (e.g. *Ranunculacidites operculatus*, *Cicatricosisporites dorogensis*, *Rugutricolporites felix*) or are less frequent that in the MMVB sections (e.g., *Retitrescolpites irregularis*). On the other hand, the absence of *Bombacacidites* genus in almost all the Gonzalez (1967) section is outstanding. Additionally, the order of apparition of some marker species used by Germeraad et al (1968) in their Caribbean zonation is different in the Gonzalez section. For instance the *Monoporopollenites annulatus* appears 80 m bellow *Striatopollis catatumbus*; and *Ranunculacidites operculatus* appears simultaneously with *Monoporopollenites annulatus*. Based in our data and in the new available information of the Catatumbo area, some inconsistencies in the Gonzalez-Guzman schema can be detected: as have been noted by Notestein (1944) in his pioneering work of the Catatumbo region, red yellow and purple mottled claystones characterized the upper part of the Cuervos Formation at the Rio de Oro anticline section, ± 55 km NW of the logs studied by Gonzalez (1967). These facies in general are unfavourable for palynological studies. Nevertheless, Gonzalez (1967) mentioned the presence of several coal seams at the upper part of this formation which have a rich palynoflora described in his study. Recent researches performed by Jaramillo & Dilcher (2001) and Sarmiento (1995) in the same area described a sterile interval to the upper part of the Los Cuervos Formation. These data question the reliability of the precise stratigraphic location of the samples studied by Gonzalez. Unfortunately, this author does not precise the type of samples used in his study (e.g. core logs or cuttings?), and the slides are not available to be re-studied.

Jaramillo and Dilcher (2001) applied the graphic correlation technique in five geologic sections of northeastern Colombia and also identified new species that proved to be useful in the correlation of the Colombian sections (e.g. *Cyclusphaera scabrata*, *Luminidites colombianensis*, *Bombacacidites gonzalezii*, *Brevitricolpites macroexinatus*, *Clavatricolpites densiclavatus*). Others, although have proven to be regionally extended, do not were used in the Muller et al. (1987) or Germeraad et al (1968) zonations (e.g. *Spirosyncolpites spiralis*, *Foveotriporites hammenii*). The Piñalerita has the more complete palynological record of the sections studied by Jaramillo and Dilcher (2001), and consequently, it was used by these authors like reference to create a composite section (CS) together with five sections of the northeast of Colombia. The palynologic information obtained here, was graphically correlated with this reference section in order to identify unconformities and/or differences in the relative sedimentation rate. The figure 2.11 shows the correlation line obtained between the Uribe and Piñalerita sections; several breaks in the line segments allows to sub-divide the sequence in 5 intervals; each one of them will be described starting from the base of the section of Uribe:

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

Interval 2 (567 to 642 m). It is characterized by the progressive disappearance of several Paleocene taxa (*Ephedripites vanegensis*, *Bombacacidites annae*, *Proxapertites cursus*, *Bombacacidites protofoveoreticulatus*). The correlation line increases its slope abruptly; this

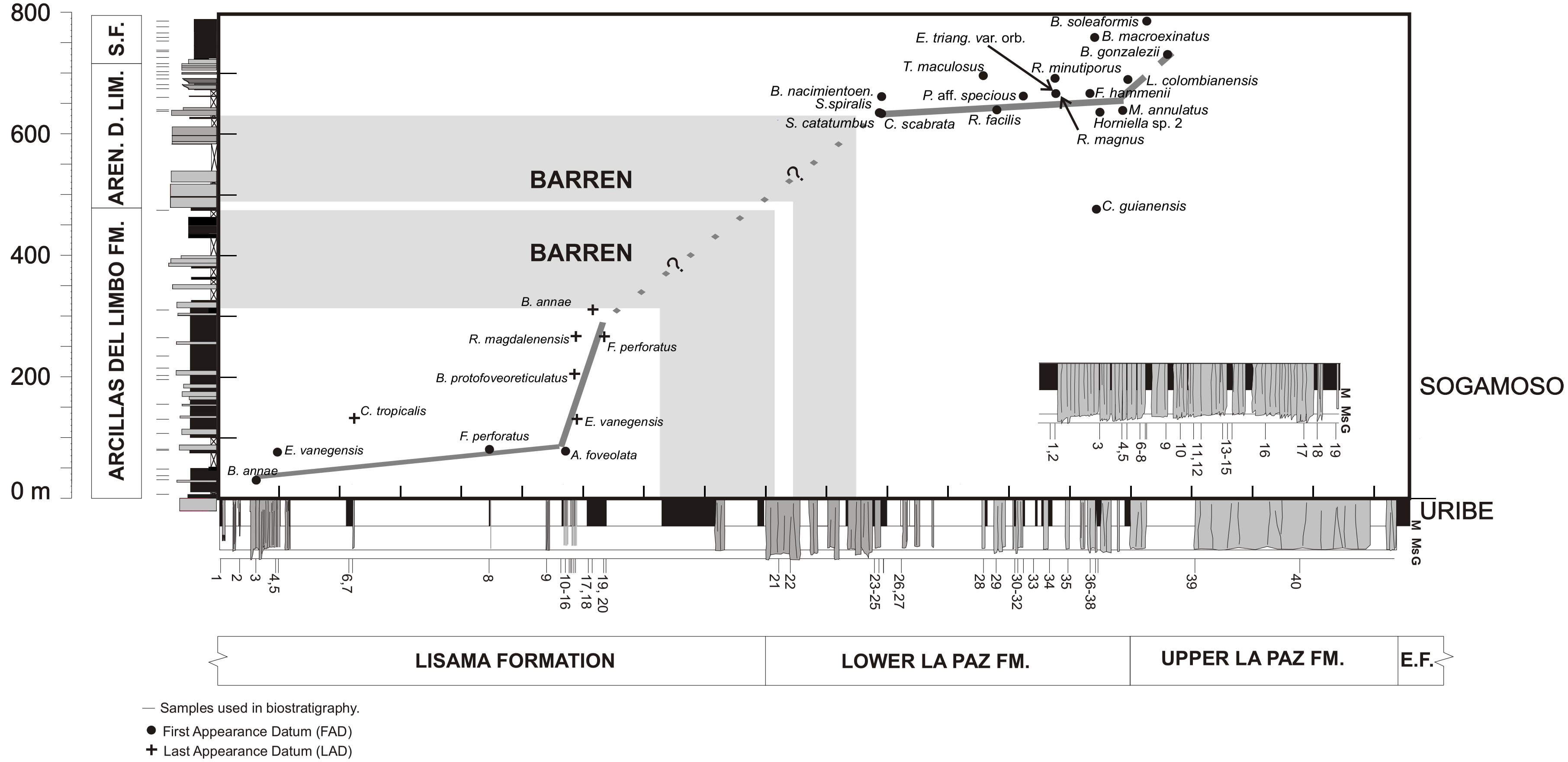


Figure 2.11. Graphic corelation between the Uribe-Sogamoso composite section and Piñalerita section of Jaramillo & Dilcher (2001). E.F: Esmeraldas Formation; AREN. D. LIM: Areniscas del Limbo Formation; S.F: San Fernando Formation.

change can be attributed to a sudden decrease in the sedimentation rate of the Middle Magdalena area with regard to Piñalerita. Nevertheless, as this line is based in LADs located near to the barren interval, these data must be carefully considered and require new sections to be tested.

Interval 3 (650 - 1086 m). In this sector most of the samples are barren in palynomorphs; both sections have similar facies characteristics: bioturbated mottled shales at the base and coarse clastic deposits to the top; therefore, the position of the correlation line is uncertain.

Interval 4 (1086-1500m). In this sector several Eocene marker taxa appear (e.g. *Spirosyncolpites spiralis*, *Cyclusphaera scabrata*). It is necessary to stand out that some of these species occur immediately in the first productive level, consequently their true FAD cannot be observed; however, two productive samples obtained in both sections $\pm$ 150 m below this level does not possess any of these species and, therefore seem to constrain these first appearances. The correlation line possesses a very low slope in this sector indicating a condensation in the Piñalerita section.

Interval 5 (Starting from 1500 m). The line increases its slope, but it cannot be traced until the top of the section due to the absence of correlation points.

2.3.3. Discussion

The palynostratigraphical information presented here gives new quantitative data about the occurrence and abundance of some species used to establish correlation in NW South America. Nevertheless, it is necessary to pointed out that the zonation of Germeraad et al. (1968) is the only one that offers independent elements for its calibration with the geological time scale. These authors used planktonic foraminifera in several sections of South America and western Africa. However, the foraminifera data presented for the Paleogene of South America were scarce and their stratigraphic and geographic positions were not reported. Without this information, the use of pollen and spores for chronological dating must be carefully considered in the region. Additionally, other dating techniques (e.g. C isotopes, vertebrate biostratigraphy?) never have been performed in this area and could contribute to increase the available information. The figure 2.12 show a chronostratigraphic chart proposed in this work for the upper Cretaceous-Tertiary units of the MMVB. It is based in our data integrated with the Germeraad et al. (1968) and Gomez (2001) data. Nevertheless, for the reasons exposed above, this schema must be continuously tested, as new information became available.

The only known record of marine microfossils is located 210 m below the limit between the Lisama-Umir Formations at the Vanegas section, 15 m to the north of the Uribe section. In this level Van der Hammen (1954a), recorded *Siphogenerinoides plummeri* of Maastrichtian age. The occurrence of the genus *Bombacacidites* from the base of the studied section indicate a post-Danian age (*Ctenolophonidites lisamae* zone of Germeraad et al 1968). At the upper part of the Lisama Formation the occurrence of *Foveotricolpites perforatus* species indicates a late Paleocene age (*Foveotricolpites perforatus* zone of Germeraad et al. 1968). Following this zone, a barren interval can not permit to locate the Paleocene-Eocene boundary; consequently, the traditional location of this limit at the upper part of the Lisama Formation is only

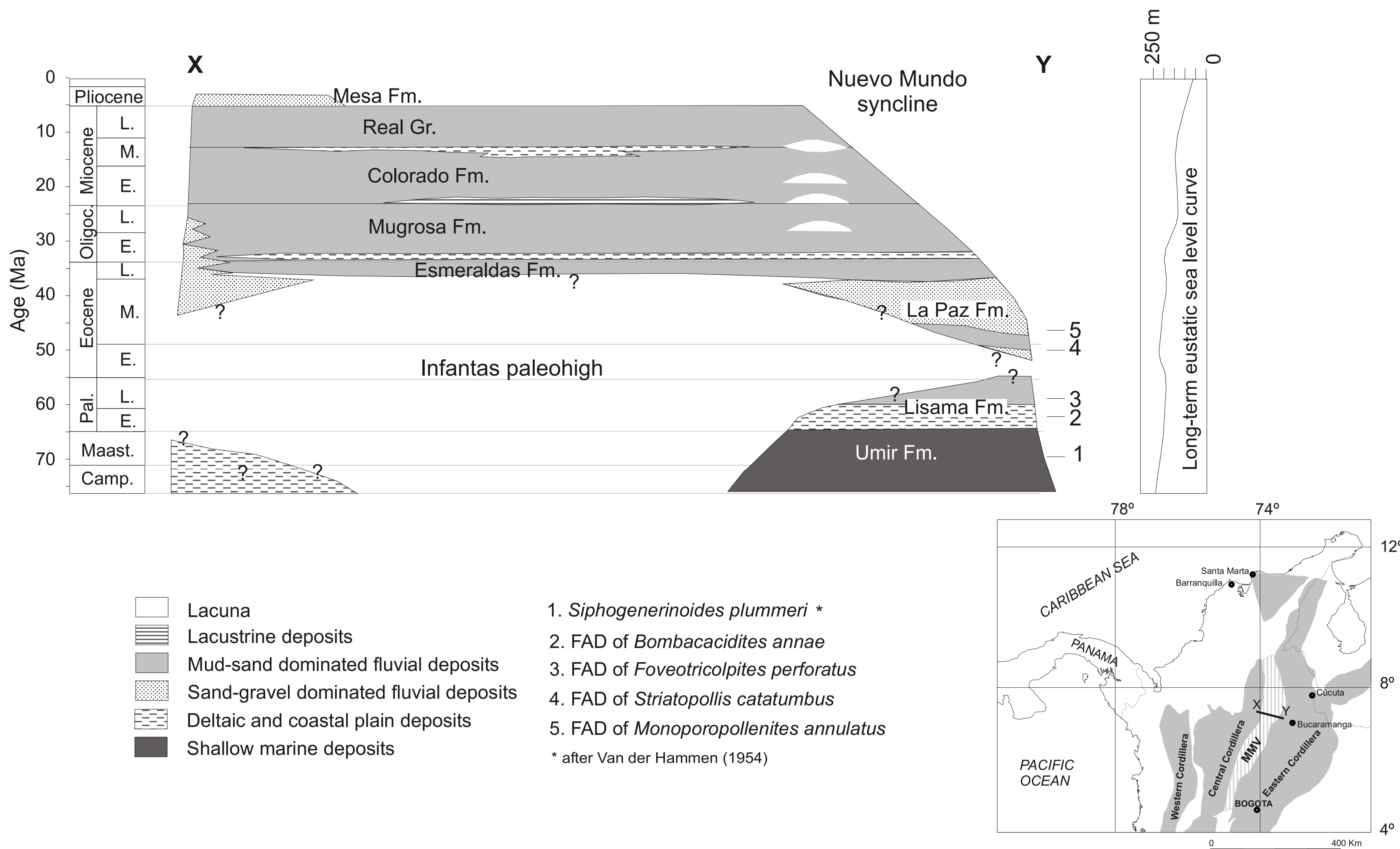


Figure 2.12. Chronostratigraphic chart proposed for the Middle Magdalena Valley Basin, lithostratigraphic nomenclature, general environments and location of some stratigraphically useful pollen species (based on Gomez, 2001, Germeraad et al., 1968 and personal data).

speculative (e.g. Van der Hammen, 1957). It is also possible that the rocks formed during this period of time had not been preserved in this area or that it is located at the base of the La Paz Formation. After the barren interval, the current palynologic information shows that the lower limit of the *Retibrevitricolpites triangulatus* biozone of Germeraad *et al*. (1968) can be placed 200 m above the base of the La Paz Formation with the first regular appearance of *Striatopollis catatumbus*. This species is very similar to the pollen of the genus *Crudia* (Fabaceae) (Germeraad et al., 1968), nowadays common in alluvial plains. On the contrary, *Retibrevitricolpites triangulatus* and *Lanagiopollis crassa*, the other species that define the biozone, were only identified in a single stratigraphic level in the Middle Magdalena Valley Basin but they are abundant in Venezuela (see chapter 5). This difference could be explained by environmental factors that controlled the lateral distribution of these taxa. The great similarity among *Lanagiopollis crassa* with the mangrove pollen *Pelliciera rhizophorae* (Germeraad et al., 1968; Graham and Jarzen, 1969) seems to support this hypothesis. Accordingly, their distribution would be more important in Venezuela where marine influence in the sedimentation is stronger (Figure 1.2). This hypothesis would also explain the absence of the *Psilatricolporites crassus* zone in the Middle Magdalena Valley Basin. It could be due to environmental controls and not as a consequence of a hiatus, as was originally proposed by Germeraad *et al*. (1968). This information shows that the lower Eocene *Psilabrevitricolpites triangulatus* zone is, at least in the eastern flank of the Nuevo Mundo Syncline, the thickest of all the studied Colombian sections. This dating is important since some models of geologic evolution of NW South America (Cooper et al., 1995a; Villamil, 1999) consider, without biostratigraphic evidence, that during the early-middle Eocene, the entire Middle Magdalena Valley Basin experienced an erosion or no deposition (see chapter 5). The new information suggests sediment accumulation in this area at least in the eastern Middle Magdalena Valley. The upper limit of the *Retibrevitricolpites triangulatus* biozone is based on the first regular appearance of *Monoporopollenites annulatus*, a species of regional distribution in the basin. This type of pollen is associated with the Poaceae family (Gramineae), that are mostly wind pollinated plants with widespread distribution and preservation potential, good reasons to consider it as a stratigraphic marker. In spite of these reasons and without discussion, Muller et al. (1987) did not use this taxon in their biozonation.

The palynological assemblage found in the last productive sample of the Lisama Formation records the LAD of several taxa. The lithofacies characteristics of the upper Lisama Formation reflex a drastically change in the sedimentary conditions: of waterlogged organic rich deposits to well drained oxidized soils. This phenomenon could be produced by multiple factors (climatic, tectonic and/or eustatic changes). It is remarkable that the sudden mud-dominated to coarse grain dominated facial change between the Lisama and La Paz Formations contact follows several samples with reworked palynomorphs (see above). In the conglomeratic layers of the lowermost La Paz Formation have been also reported coal fragments (Colmenares et al., 1995). This evidence suggests an increase in the erosion rate of old units during the sedimentation of the La Paz Formation. In this situation, taxa with their first appearance data (FADs) are more confident to correlation.

Seismic studies show that to the west of Nuevo Mundo Syncline the Lisama Formation or older deposits are in an angular unconformity below the sedimentary deposits of La Paz or the Esmeraldas Formations (See above, discussion about the Paleogene unconformity of the MMV), and in general La Paz Formation and its lateral equivalents are onlapping the unconformity surface; this suggest a tectonic perturbation immediately after or during the Lisama deposition. The cause of this phenomenon has been attributed to the diagonal collision between a volcanic arc and some portions of the Caribbean Plate against the western border of Colombia during the Paleogene (Gómez, 2001; Pindell, 1993; Pindell and Drake, 1998) and the change of movement of the Caribbean to the east (Pindell, 1998). This kind of perturbation was also recorded in the Paleocene-Eocene deposits of the Lower Magdalena Valley (e.g. Arroyo Seco Formation, Porta, 1974. p. 15). On the other hand, some researches (e.g. Lugo and Mann, 1995) show that during the late Paleocene-early Eocene the thrust of some portions of the Caribbean Plate ("Lara Nappes") produced a foreland basin in NW Venezuela which changed the sedimentation dynamics in the Maracaibo basin, at this time in connection with the Middle Magdalena Valley Basin. All of these evidences suggest an important tectonic control in the sedimentation. The regressive tendency of the long term late Paleocene-Eocene eustatic sea level curve (Haq et al., 1988) probably had some influence in the sedimentation. Additionally, the global climatic curve indicates a warming period at the late Paleocene-Lower Eocene interval (e.g. Zachos et al., 1993). A cycle of lateritization recognized on the Guiana Shield during this interval (e.g. Théveniaut and Freyssinet, 2002) could be related to this event. These phenomena on the whole could amplify the sedimentological changes in the NW South America basin; nevertheless, the separation between the effects of each phenomenon from the geological record seems to be difficult.

The correlation line can be a supplementary tool to compare different sections in the basin and to estimate the relative differences in the sedimentation rates. The breaks observed in the line of correlation suggest changes in the subsidence between the MMVB and the Llanos basin. Nevertheless, the presence of covered and barren intervals, especially in the Lisama Formation, compels to analyze carefully this information.

2.3.4. Stratigraphical distribution of the *Bombacacidites* genus in the Middle Magdalena Valley Basin:

The studied sections have one of the most varied associations of *Bombacacidites* in northwestern South America (more than 25 morphospecies), some of them, seems to correspond to new species. For this reason we intend to do a morphological differentiation of this genus, in order to test its biostratigraphic potential and to start a morphologic database which could be useful to interpret evolutional trends. This schema was elaborated in the MMVB section, because is one of the thickest sections in the Paleogene of Colombia, which indicates relatively high sedimentation rates (e.g. Jaramillo and Dilcher, 2001). Nevertheless, this information must be tested and completed with new stratigraphic sections.

The *Bombacacidites* Couper 1960 genus, includes « isopolar, tricolporate, colpi short, plan-aperturate (apertures midway in sides of the grain in polar view); peroblate, triangular amb, clearly sculptured » pollen grains very similar to the type found in the family Bombacaceae (Jansonius and Hills, 1976). The first occurrence of pollen of this family has been recorded by Wolfe (1975, 1976, in Muller, 1981), which is similar to the *Cavanillesia* genus. This occurrence made that Muller (1981) suggest an eastern North American origin for the Bombacaceae family. Nevertheless, Askin (1990) recorded *Bombacacidites* in the Maastrichtian deposits of the Seymour island (Antarctica) (see the figure 5.6.B for a revision of the upper Cretaceous-Paleogene world distribution of this genus). In north western South

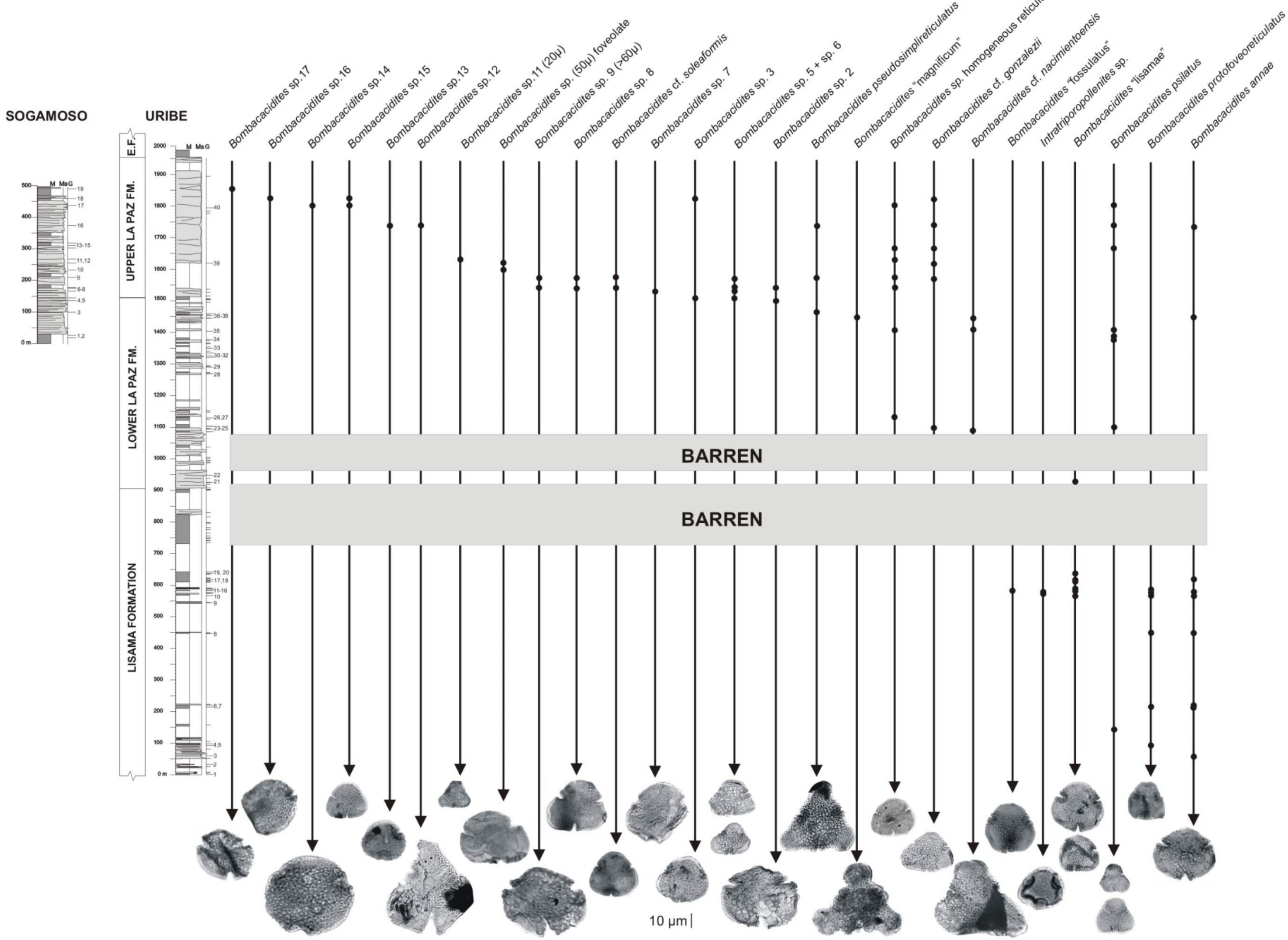


Figure 2.13. Stratigraphic distribution of *Bombacacidites* species in the Middle Magdalena Valley Basin. For conventions, see figure 2.3.

America this kind of pollen was firstly described by Van der Hammen (1954a) as *Tricolp(or)ites annae*, a species founded in a coal layer of the the Paleogene Lisama Formation near Vanegas town (Santander department, Colombia). He pointed out that this species belongs to the Bombacaceae family and probably can be use as biostratigraphical marker because it represents a “more advanced” form with respect to the Maastrichtian flora of the region. New data obtained from the Rio Loro section, in western Venezuela (C. Jaramillo written communication) show that *Bombacacidites* species appears 200 m above the Cretaceous-Tertiary boundary, which probably corresponds to the upper part of the Early Paleocene (*Ctenolophonidites lisamae* zone of Germeraad et al., 1968). Muller et al. (1987) had used different species of *Bombacacidites* to propose some Paleogene and Neogene zones of northwestern South America (e.g; *Bombacacidites soleaformis* and *Bombacacidites baculatus* zones). Bombacaceae is currently restricted to tropical regions but during the Eocene occupied middle and high latitudes (e.g. Paris basin, north of Alaska and Tasmania; see the chapter 5), due to a global increase of temperature.

The figure 2.13 show a synthesis of the stratigraphic distribution of the main *Bombacacidites* forms found in the Middle Magdalena Valley Basin (see also the appendix 2.2). In general this genus represents less than 6 % of the total pollen and spore association but in some cases can surpass 10 % (e.g. 36, 14 and 11 % for the samples 6, 10 and 34 respectively). In the Lisama Formation the *Bombacacidites annae* and *B protofoveoreticulatus* species have the longest stratigraphical extension in this unit. *Bombacacidites annae* a traditional Paleocene marker has sporadic occurrences in the La Paz Formation (due to reworking?). To the upper part of the Lisama Formation new forms appear: *Intratriporopollenites* and other rounded forms with a homogeneous reticule. In the upper part of the diagram (La Paz Formation) many new forms appear, but usually they are in very low quantities (sometimes only 1 or 2 specimens). In this case there are practical problems for defining formally new species because we do not have enough specimens to study their morphological variability. An outstanding characteristic is the big size of several species whose first appearance datum are located in the La Paz Formation (e.g. *Bombacacidites magnificum* n. sp., *Bombacacidites* sp. 14, *Bombacacidites* sp. 12, *Bombacacidites* sp. 9, *Bombacacidites* sp. (50 μ) and *Bombacacidites pseudosimplireticulatus*) .

2.3.5. General palynofloral changes in the Middle Magdalena Valley Basin:

The figure 2.14 shows the vertical variation in relative percentages of general groups of palynomorphs at the Uribe section. This graphic can be divided in 4 segments which correspond to those employed in the biostratigraphy section:

1. Lower Lisama (samples 1-6): In this part of the section we have only 6 samples, consequently only general tendencies will be mentioned. In the sample 1 (analyzed by C. Jaramillo) *Proxapertites operculatus* is dominant (87 %), in the following samples the percentage relative of this species is variable but always less than 30 %. An increasing followed by a decreasing tendency characterizes the Other angiosperms, Palm and spore groups. *Bombacacidites* and *Mauritiidites* are in low relative percentages (< 3%), with exception of the uppermost sample were they can amount to 36 and 7 % respectively.

2. Upper Lisama (samples 8-19): This interval is characterized by the dominance of

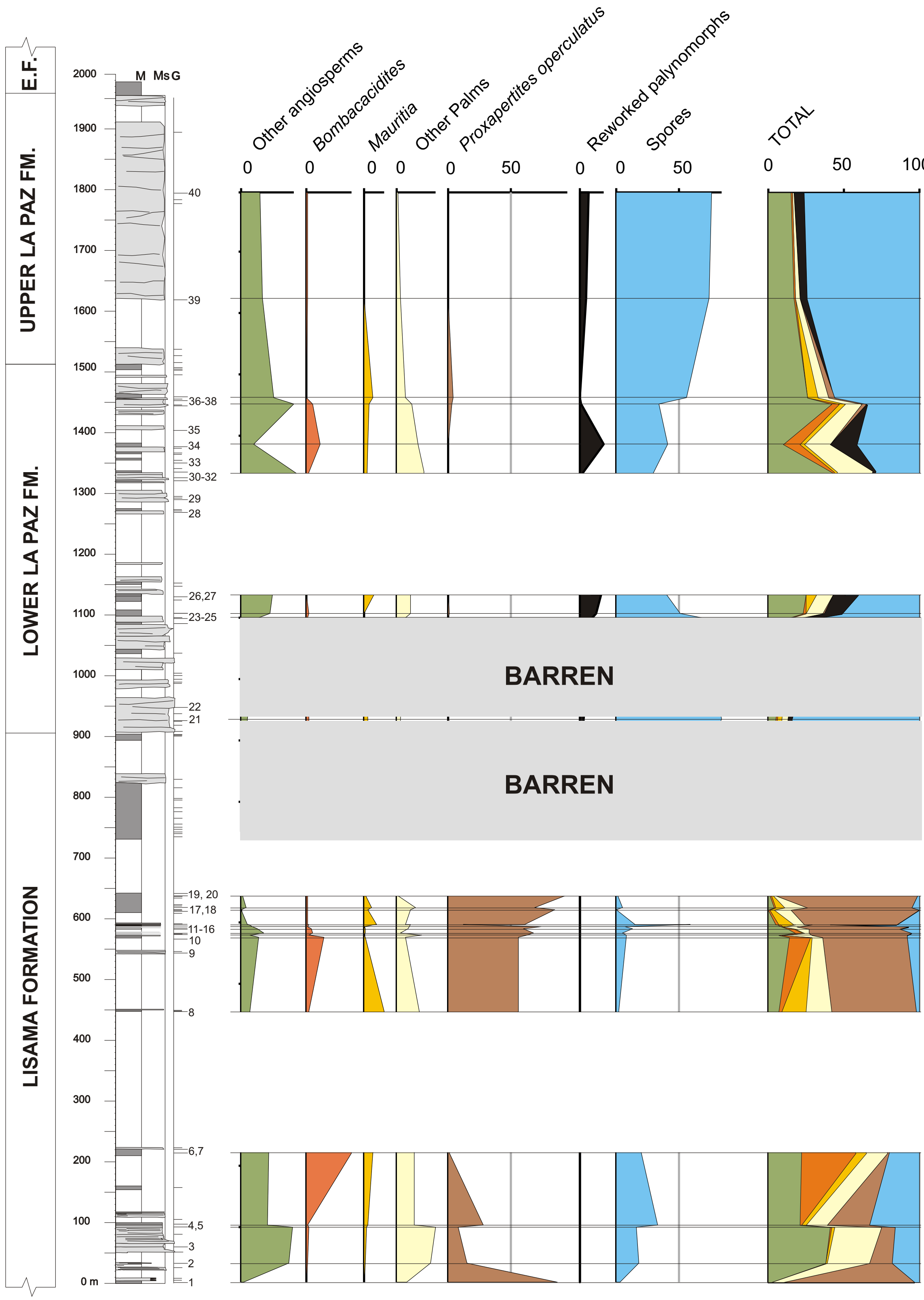


Figure 2.14. Stratigraphic distribution of general groups of palynomorphs at the Uribe section. E.F: Esmeraldas Formation.

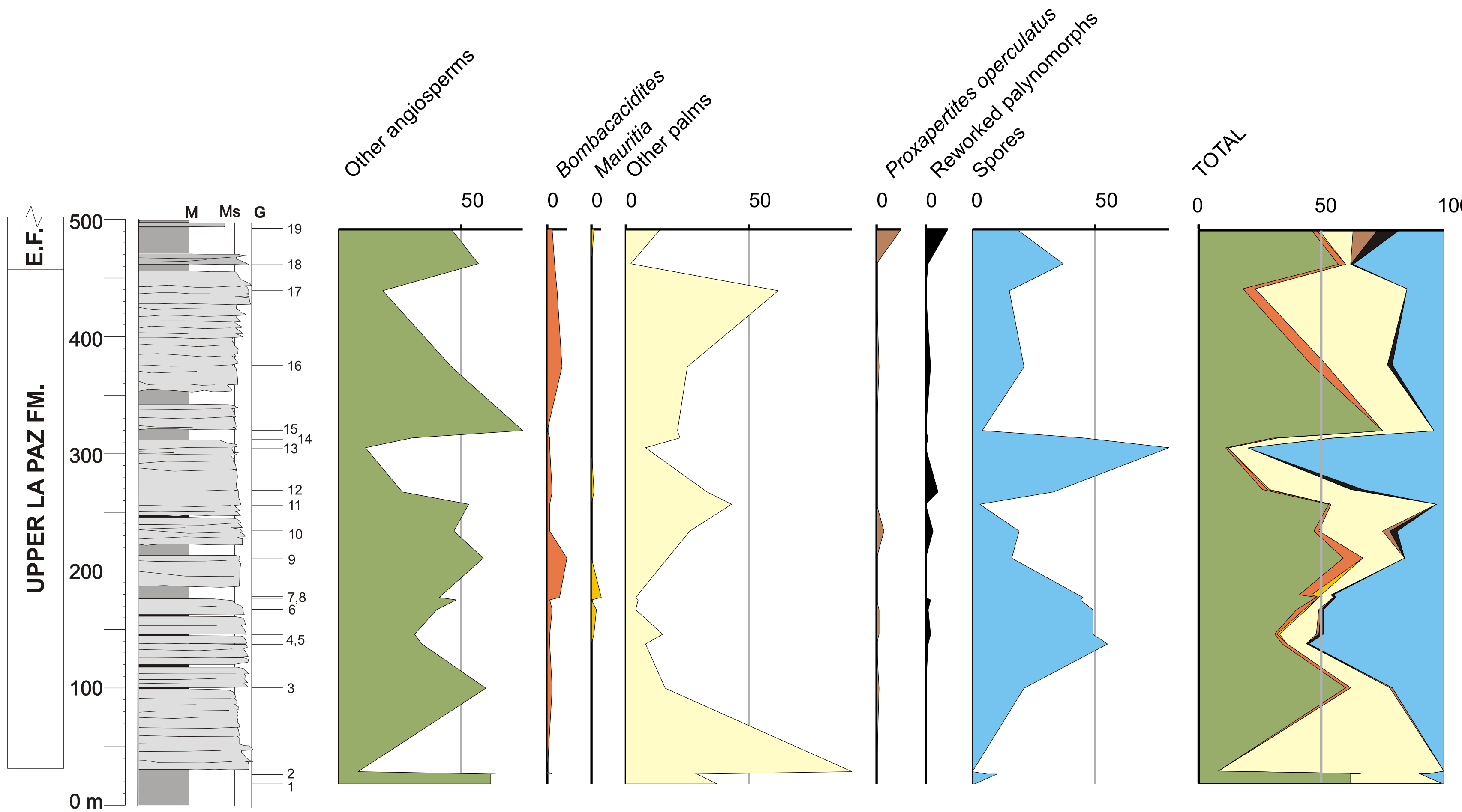


Figure 2.15. Stratigraphic distribution of general groups of palynomorphs at the Sogamoso section. E.F: Esmeraldas Formation.

Proxapertites operculatus, which has a general increasing tendency and can amount 95 % (sample 19). Excluding the sample 8, the Other angiosperms and *Bombacacidites* groups decrease to the top. *Mauritia* and the Palms group percentages are variable with maximal values of 16 y 20 % respectively. In this sector the spores has the lowest relative percentage values of all the studied section (< 15%), with exception of the sample 15, which surpass 50 %.

3. Lower La Paz (samples 21-36): As was mentioned, this interval is poor in pollen and spores. It is characterized by the spore abundance and the occurrence of reworked palynomorphs. The spores reach 84 % to the lower part of this interval and decrease to the upper part until 34 %.

4. Upper La Paz (samples 37-40): In this segment only 4 samples are available. To the top the Other angiosperms, *Mauritia* and Palms groups decrease and the spores and reworked palynomorphs increase. *Bombacacidites* and *Proxapertites* are always in very low percentages (< 4 %).

The Upper La Paz Formation was studied in more detail at the Sogamoso section (figure 2.15). Comparing the diagrams of the Upper La Paz Formation at the two localities, we can see the great influence in the density of sampling to recognize the oscillations in the general palynomorph groups. In the Sogamoso section at least three peaks with more than 25 % in the palms and spore groups can be recognized. The distance between these peaks is 150-200 m. Two palynologic successions with peaks of Other angiosperms-Palms and Spores can be differentiated at the upper ¾ of the section. At the lower part this pattern can not be recognized. These patterns can be controlled by multiple factors; which can related to regional (e.g. eustatic, climatic) or local scale (e.g. channel migrations).

2.4. PALYNOFACIES

2.4.1. General remarks

In general the samples have variable quantities in microscopic organic matter. The measures of color performed along the entire studied interval indicate a thermal alteration index (TAI) between 2 to 3 (color scale of Traverse, 1988). No important differences in coloration between the Lisama and La Paz Formations are observed. Gomez (2001) performed a vitrinite reflectance analysis of some rocks of the Lisama and La Paz Formation near to the Sogamoso River, few meters apart from the section studied in this work. He found a Ro value of 0,48 % for the Lisama Formation and between 0,5 and 0,6% for the La Paz and Esmeraldas Formation, which indicates that the organic matter reached temperatures of 70° C (mature). Rangel et al. (2002) studied the organic matter geochemistry (biomarkers) of the Umir Formation in the same area, which underlay the Lisama Formation. Based in some biomarkers they suggest a mixed source of algae and upper plants for the origin of the microscopic organic matter of this unit. In contrast, the SOM found in the Lisama and La Paz Formation has almost exclusively a plant origin. The figures 2.16 and 2.17 show the semi-quantitative distribution of the different kinds of microscopic organic matter found in the studied samples. The SOM characteristics of Lisama and Lower La Paz Formation were studied in the Uribe section (figure 2.16). The uppermost lower La Paz Formation, the upper La Paz Fm and the

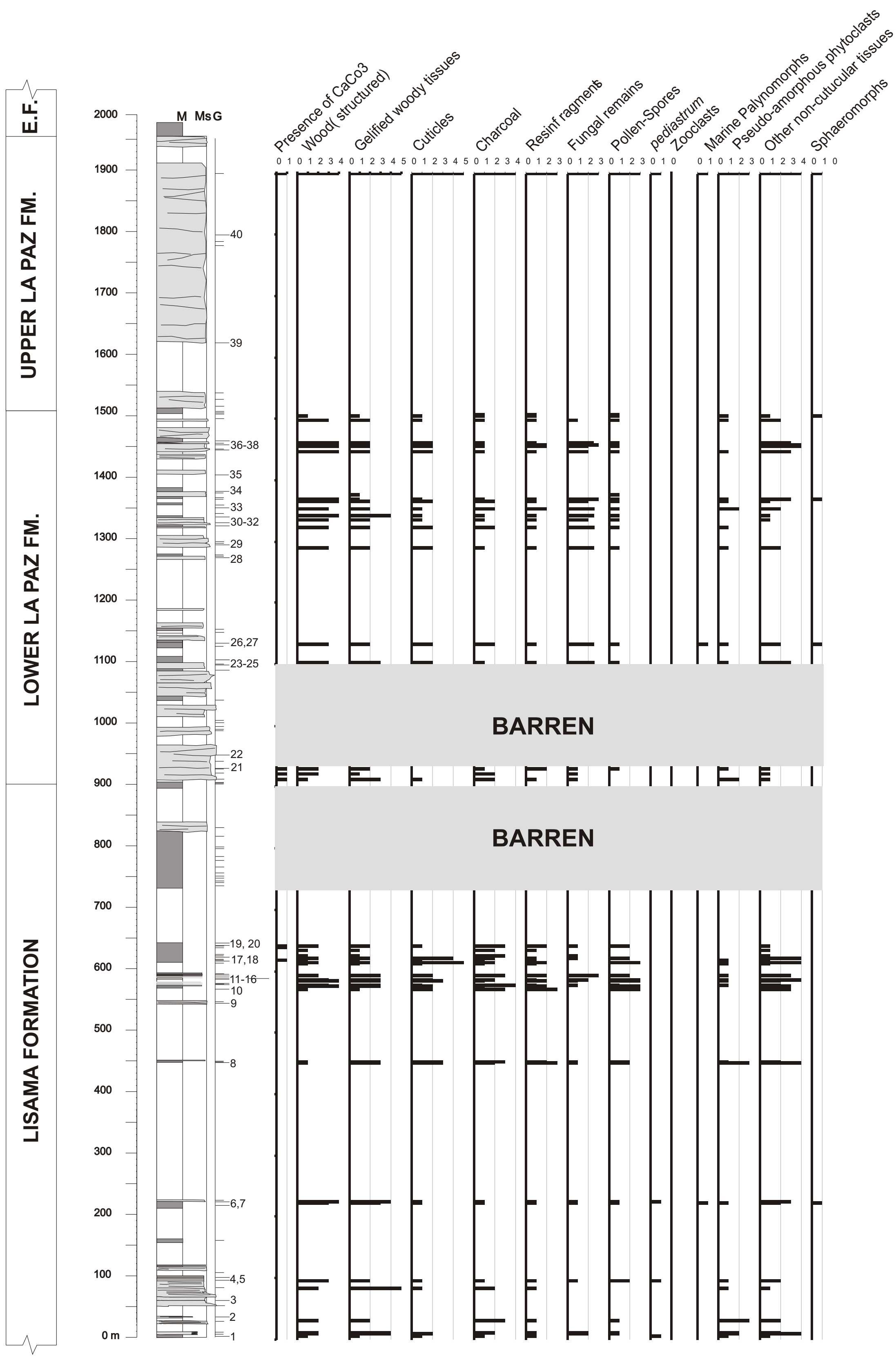


Figure 2.16. Semi-quantitative stratigraphic distribution of sedimentary organic matter (Uribe section). 1: present; 2: common; 3: abundant; 4: very abundant; 5: exceptionally abundant.

lowermost Esmeraldas Formation were studied at the Sogamoso section (figure 2.17). Some general trends can be mentioned:

1. Dominance of plant debris in the entire studied interval. In general the woody debris are more abundant that the cuticles in almost all the samples. In recent environments the cuticles are less common than woody material in sediments, and more restricted in its distribution, even though leaf litter production exceeds woody litter production (Tyson, 1995). The tracheid material is about ten times more abundant than cuticle debris, this is apparently because of relative ‘buoyancy’, but may also reflect differential preservation (Tyson, 1995). Its buoyancy allows floating greater distances. The distribution patterns could be also influenced by the nature of the leaves (Fisher, 1980).

2. The other non-cuticular tissues are abundant in several samples and intimately associated with the woody fragments. They can correspond to high degraded cuticles may result in bleaching and loss of the cuticular flanges (Maclennan & Trewin, 1989, p. 107; in Tyson, 1995, p. 236) or low lignified debris of herbaceous taxa.

3. The charcoal and resin fragments seem to be more abundant at the upper part of the Lisama Formation.

4. The fungal remains (spores and hyphae) are relatively abundant in the La Paz Formation (see below). They are intimately related to the woody debris, which, in some cases are infested by hyphae. Fungal spores probably show similar hydrodynamic behavior to other palynomorphs (Tyson, 1995), they have a density higher than 1 and therefore sink in still water. In the present tropical deltas, (e.g. the Mahakam delta in Indonesia and the Niger delta in Africa), fungal spores may represent 35-80 % relative of the total palynomorphs (Hardy, 2000).

5. At the upper part of the Lisama Formation pollen and spores are relatively abundant. In contrast, the La Paz Formation, samples are in general poor or barren in palynomorphs. This variation seems to be related to paleoenvironmental (e.g. taphonomic) factors. On the other hand, the concentration variations suggest a paleoenvironmental control: the organic rich samples of the shale and coal dominated upper Lisama Formation or different depositional environments and/or post-depositional preservation conditions.

6. At the upper part of the Lisama Formation-lower La Paz the samples are barren in microfossils and very poor in microscopic organic matter. It is characterized by barren mottled shales; this phenomenon probably results from the oxidation of the organic matter in well-drained alluvial soils. The presence of calcareous cement (not calcretes) in several samples of this interval can suggest also a change in the geochemical characteristics of the soils.

7. The organic matter of the La Paz Formation does not show important indicators of marine influence. On the contrary, some *Pediastrum* rich shaley sequences record fresh water lake development in the area (cf. Del Papa and Quattrocchio, 2002; Mahmoud, 2003). *Pediastrum* alga is typically planktonic; most often appears associated with “hyper-eutrophic” lakes with unstable water columns. Fossil *Pediastrum* occurrences have been associated with permanent low salinity lakes with a dysoxic-anoxic conditions (Tyson, 1995).

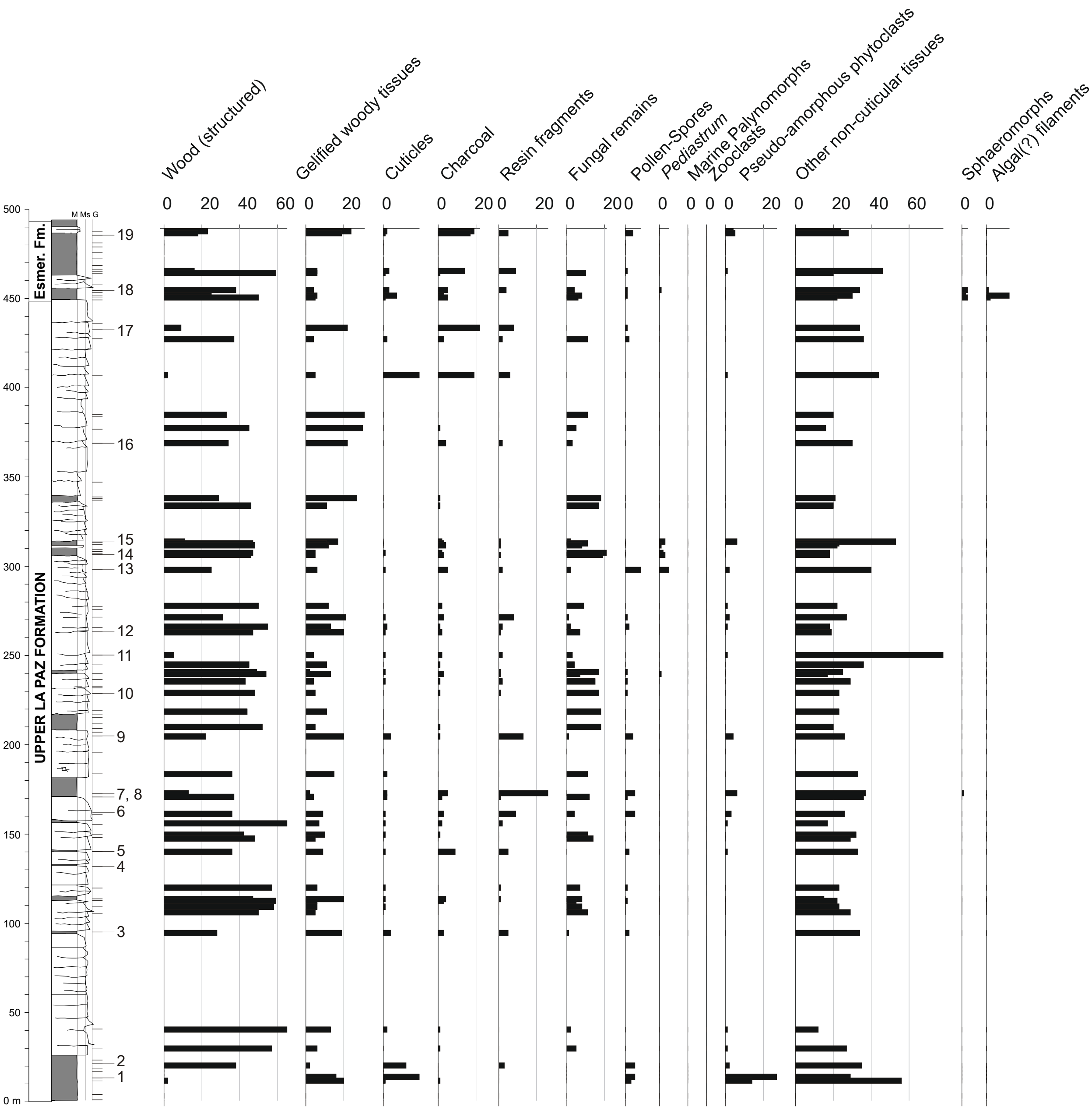


Figure 2.17. Stratigraphic distribution of percentages of sedimentary organic matter (Sogamoso section). Esmer. Fm: Esmeraldas Formation.

8. One of the most conspicuous characteristics of the La Paz Formation is the presence of reworked palynomorphs which can amount 19 % of the total of organic microfossils (figure 2.14). This phenomenon, together with a sudden increase in coarse clastic facies in the La Paz Formation reflects the existence of base level changes in the source area (e.g. Streel and Bless, 1980) which increase the erosion rates during the La Paz Formation deposition. This could be related to tectonic activity, changes in the sedimentary budget and/or eustatic variations which allow the exposition of sedimentary rocks already deposited in the basin. The presence of an unconformity that separates the Fm La Paz is well-known from seismic profiles (figure 2.2); this unconformity in some cases is angular with the underlying units (e.g. with the Lisama Formation, and/or Cretaceous rocks). This evidence suggests that tectonic activity had a great importance during the deposition of the La Paz Formation. In this situation, reworked pollen became abundant. Additionally, the long term eustatic regressive pattern in this period (e.g. Haq et al., 1988) increased the exposed areas and probably amplified the erosion phenomena. In the recent Orinoco delta, Muller (1959) records Tertiary reworked pollen which are rather abundant in the levee deposits of the delta plain (>17%).

2.4.2. Quantitative distribution of pollen, spores and fungal remains in the Middle Magdalena Valley Basin

In order to know the quantitative variations of pollen, spores and fungal remains, some of the samples used in biostratigraphy were studied in detail. The lower part of the Lisama Formation (samples 4-7) comes from an alternating sandstone-shale sequence and, in general, it is poor in pollen and spores. The upper part of the Lisama Formation is characterized by dominance in the relative percentage of pollen (figure 2.18). This phenomenon is reversed in the lower La Paz Formation where the fungal remains are dominant. In the upper La Paz Fm., 6 of the 10 samples analyzed have more than 50 % of fungal remains. On the other hand, the upper Lisama Formation has an average concentration of pollen that oscillates between 8000 and 300000 specimens by gram of rock. The sample 19 the uppermost productive is an exception, which is included in an interval of grey and red mottled shales barren in palynomorphs and microscopic organic matter (see above). In this part of the sequence, all of the samples treated (22 samples) are barren in palynomorphs (appendix 2.3). Most of the samples pertaining to the La Paz Formation have an average concentration of pollen that oscillates between 200 and 2000 grains by gram of rock. The concentration of fungal remains oscillates enormously in the upper Lisama Fm., but in general it rests below the values of pollen concentration. On the contrary, in several samples of the La Paz Formation the average values of concentration of fungal remains (between 1000 and 10000 specimens by gram of rock) surpass in several orders of magnitude the values of pollen. The average values of concentration of spores are below the values of concentration of pollen (except the sample 13 of the Sogamoso section). In the upper Lisama Fm. the values of fungal remains are variable and can reach up to 100 000 specimens by gram of rock. In the La Paz Formation, in general the concentration of spores oscillates between 10 and 1000 specimens by gram with a decreasing tendency towards the top.

The great contrast between relative percentages and concentrations of fungal remains, pollen and spores between the Lisama and La Paz Formations is outstanding. The difference in concentration of pollen can be related, among other factors, to environmental conditions: the

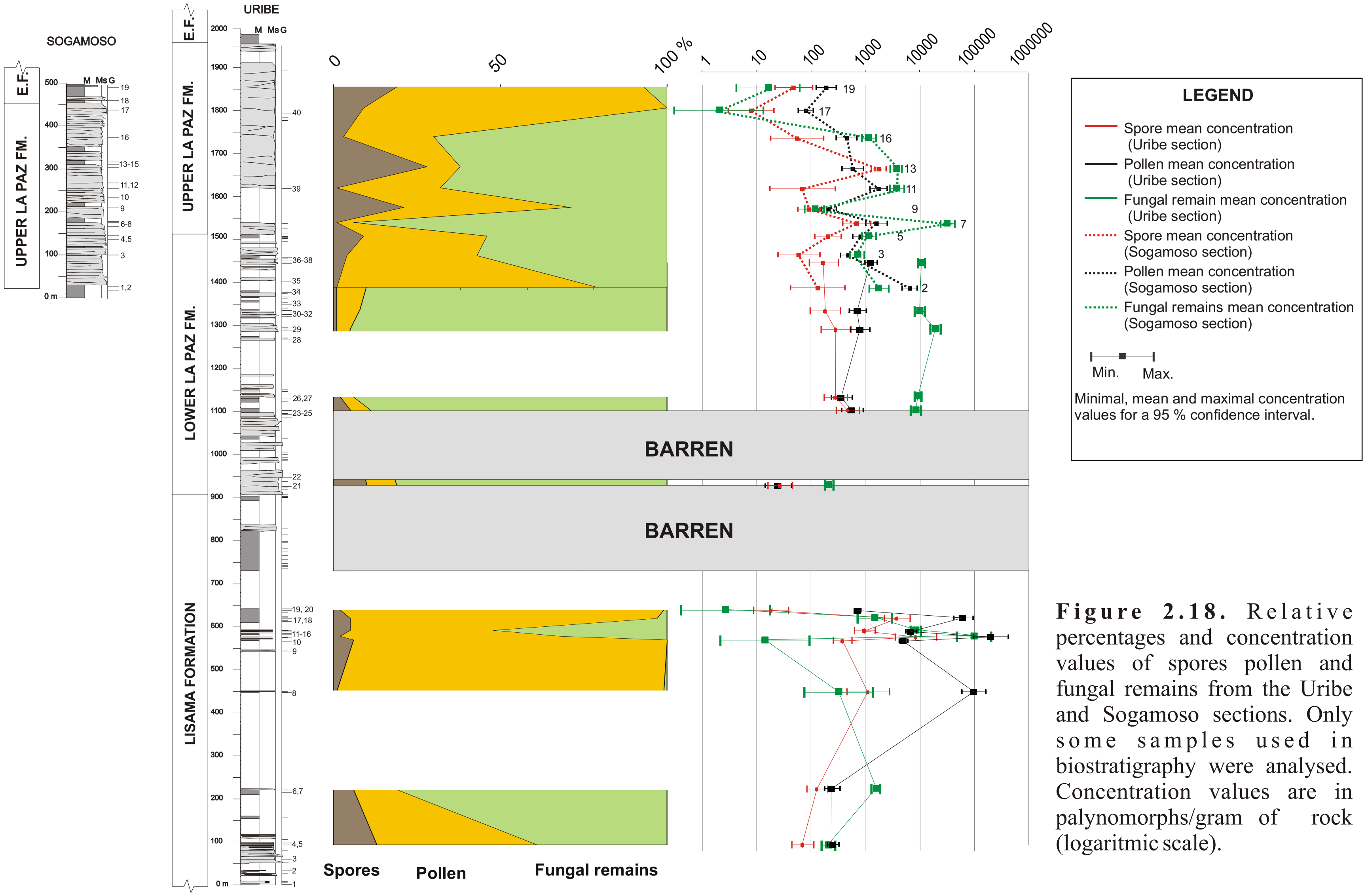


Figure 2.18. Relative percentages and concentration values of spores pollen and fungal remains from the Uribe and Sogamoso sections. Only some samples used in biostratigraphy were analysed. Concentration values are in palynomorphs/gram of rock (logaritmic scale).

upper Lisama Formation is dominantly composed by grey shales with some coal banks. This kind of facies is usually founded in marshy, poorly drained areas (Collinson, 1996). These environments are relatively closed sedimentary systems; thus, the production of pollen and organic matter is intimately related to the local production of the surrounded vegetation of the flooded zones. On the other hand, this type of environment in general have less clastic input of the external sources and has relatively reducing conditions that allow the preservation of the vegetal material. The chemistry of peats may have discouraged extensive fungal activity (Taylor & Taylor, 1993). The small relative percentage and concentration of fungal remains (especially hyphae) in these deposits could be reflecting permanence of the sediment under the water table (cf. Middeldorp, 1982).

The samples obtained in the La Paz Formation are fine-grained rocks interpreted as flood plain, lake, and crevasse splay deposits associated with bed load and suspended load rivers (e.g. Gómez, 2001; Jaramillo, 1999). The high concentration of fungal remains together with the low concentration of pollen in the La Paz Formation can be explained by several factors: 1. High availability of exposed vegetal material in aerobic conditions and high humidity which promotes the decomposition of the sedimentary organic matter (including pollen grains) by fungi and bacteria. According to Rayner and Boddy, (1988, in Tyson, 1995, p. 154), fungal degradation is the highest where wood is at least periodically exposed to the atmosphere and thus alternating wet-dry cycles. 2. High detritic influx during states of underflow of the river channel, which dilutes the palynomorphs and microscopic organic matter. In this situation the contribution of regional palynomorphs and organic matter increases but the preservation chance decrease during transport. On the other hand, most of the samples of the La Paz Formation have small quantities of pollen and spores (not included in this study; appendix 2.3); this variation could be related to differences in their position with respect to the main fluvial channel. Jarzen & Elsik (1986) studied the variability in abundance of fungal palynomorphs in three samples from the Luangwa River, which represent three water levels: lowest dry season level, high flood level and the flood plain. Their results shown an abundant and diversified assemblage in fungal remains and plant pollen and spores in the lower and high river water level samples; in contrast, the flood plain sample was barren, probably linked to oxidation processes. On the other hand, Muller (1959) mentioned a high range of variation of pollen concentration in the recent deltaic deposits of the Orinoco river linked to facial (e.g. high clastic input) and vegetation controls (e.g. prolific pollen producers). The lowest values (1.000 grains/gram) are found on the natural levees and the maximum (100.000 grains/gram) in the back-swamp deposits.

Ediger (1981), made a quantitative study of fungal palynomorphs in marine, deltaic lagoonal to lacustrine and palustrine rocks from the late Eocene- Oligocene from Turkey. He show that the fungal remains are more abundant in lacustrine and palustrine (shaly dominated) environments with respect to deltaic clastic deposits but the relative % of fungal remains out of total palynomorphs increases in the deltaic deposits. He interprets this tendency as a differential preservation effect, because fungi are more resistant than other microfossils in such environments.

2.5. INTEGRATION OF PALYNOFACIES DATA TO PALEOENVIRONMENTAL INTERPRETATIONS

There are some paleoenvironmental interpretations about the Paleogene of the MMVB (e.g. Colmenares et al., 1995; Gómez, 2001; Gómez and Jordan, 1997; Suárez, 1996; Suárez et al., 1997), some of them are contradictory. Here, we will intend to integrate our palynologic and palynofacies data in order to contribute with new elements to these interpretations.

Lisama Formation:

There are not published works about detailed paleoenvironmental analysis of this unit. Porta (1974) and Morales et al.(1958) consider this formation as the passage of marine to continental conditions in the MMVB. Thus, these authors suggest a lacustrine and deltaic depositional environment for this unit, based in its general lithological characteristics. Colmenares et al. (1995) suggest that all the Lisama Formation was accumulated in inter and supra-tidal environments and in meandering fluvial environments with "estuarine influence". This hypothesis is based mainly in lithology (e.g. "glauconite" < 1% to the lower part of the unit), paleocurrents (bimodal pattern) and ichnofossils (e.g. *Thalassinoides, Ophiomorpha* sp., *Skolitos*). Nevertheless, marine or brackish water macrofossils are not reported. The upper 569 m of this unit was also studied by Gomez (2001) in the Bucaramanga-Barrancabermeja road few meters apart of the Sogamoso section. He mentioned bioturbated (not specified) varicolored mudstones, and cross-laminated sets of fine-grained sandstones. Thin to medium beds of coal or carbonaceous dark grey claystones are also common. This facies were interpreted as meandering channels, overbank deposits, paleosoils and poorly drained swampy areas in fluvial environments (Gómez, 2001). In our palynological study some dinoflagellate species were founded in the lower part of the Lisama Formation, which can suggest marine influence in the sedimentation; nevertheless, the palynofacies characteristics of the upper part of this unit suggest an exclusively terrestrial source which seems coherent with the Gómez (2001) interpretation.

La Paz Formation:

Jaramillo (1999) made a sequence stratigraphic analysis of the La Paz Formation at the Uribe Section using palynofacies, paleoecological and lithological data. His palynofacies data show that there are no indicators of marine influence in this part of the unit. Based in the coarse-fine clastic facies relationships, Jaramillo (1999) interpreted the lowermost La Paz Formation (906-1086 m interval of the figure 2.3) and the lower La Paz Formation (1086-1491 m interval of the figure 2.3) as "bed-load" and "mixed-load" fluvial deposits respectively.

The Sogamoso section covers principally the upper La Paz Formation. Nevertheless, as this study was based only in core samples, they can not allow recording the medium scale geometry and lateral variations observed in outcrops which are very important in paleoenvironmental reconstructions (e.g. Miall, 1985; Miall, 1988). Gómez (2001) made a field description of La Paz Formation over the Bucaramanga-Barrancabermeja road few meters apart of the logs studied in this work; thus, this information can be used to know the medium scale geometry of the sedimentary bodies. He described the sandstone as lens-shaped or elongate, decimeter to meter thick, which are characterized by highly irregular lower contacts; most of them show inclined sigmoid surfaces of discontinuity. This author suggests that the sandstones were deposited in sinuous channels based in the relationship between the orientation of inclined surfaces of accretion of these sandstones and paleoflow orientation indicates lateral and oblique accretion of fluvial bars. Our data show many cyclic regular fining upward sequences, which could suggest point bar deposits (figure 2.5). The paleocurrent data presented by Gomez (2001), show a N-NE principal direction of paleoflow. In contrast, Suárez et al. (1997) performed a facies analysis of the La Paz Formation in the Provincia field, few kilometers north of the Uribe section. Based in cores and well logs, core petrophysical data, they recognized four facies associations which represent deposition in braided trunk channel, minor channel (distributary or crevasse), crevasse splay and floodplain sub-environments. Colmenares et al.(1995) suggested that La Paz Formation was formed in a fluvial environment with tidal influence. They support this interpretation mainly by the ichnofossils (e.g. *Skolithos*, *Arenicolites*, *Ophiomorpha*, *Diplocraterion*, *Thalassinoides*, *Teredolites* and *Macaronichnus*) and a paleocurrent bimodality pattern (not recognized by Gomez 2001). Nevertheless, they did not record marine or brackish-water macrofossils.

Our palynofacies study shows few evidences of marine influence in both Lisama and La Paz Formations. All the samples analyzed are composed mainly by wood debris, cuticles, fungal remains, and variable amounts of pollen and spores (figure 2.16). Dinoflagellate cysts are also present in some levels of this formation but in very low percentages (< 2 %); some of them are bad preserved and could thus indicate reworking. These data linked to the presence of *Pediastrum* algae and *Chomotriletes* in some levels of the upper La Paz Formation (figure 2.17) suggest fresh water sedimentary conditions and a dominant terrestrial source. Nevertheless, well preserved specimens of *Spinizonocolpites echinatus*, pollen similar to the Nypa palm, which lives nowadays in back-mangrove regions of the Indo-Malesian area (Morley, 2000), are found in low percentage (< 3%) in the upper La Paz Formation (appendix 2.2). This could indicate local near-shore environments (e.g. Caratini and Tissot, 1988). Additionally, *Lanagiopollis crassa* and *Zonocostites minor*, pollen associated with recent mangrove vegetation, are recorded in the upper La Paz Formation in very low percentages (< 1 %) and thus could indicate proximity to coastal areas.

Esmeraldas Formation:

The thick deposits of green reddish mottled, silty mudstones of this unit record well drained, oxidizing soils over flood plain deposits; the high mud/sand ratio indicate higher accommodation that the upper La Paz Formation. In the Sogamoso section 12 samples of the lower 44 m of this unit were analyzed palynologically. Five of them, which are composed by red mottled greenish-grey silty shales are barren in pollen, spores and microscopic organic matter. The lowest samples, mainly grey shales, are composed mainly by woody particles and fine debris. Pollen and spores are scant but algal (?) filaments and sphaeromorphs are relatively abundant. The lithological and palynofacial characteristics of this unit suggest a fluvial environment with a relatively high accommodation rate. Colmenares et al. (1995) suggest a fluvial and coastal environments ("inter-tidal") for this formation. Jaramillo (1999) suggest for the lowermost Esmeraldas Formation a "floodplain deposits in suspended-load dominated channels of the upper-coastal plain environment". In our study there is not palynological evidence to suggest a marine influence for this part of the unit.

CHAPTER 3 - STRATIGRAPHY, PALYNOLOGY AND PALYNOFACIES OF THE LOWER TERTIARY ROCKS FROM THE PAZ DE RIO REGION (CHICAMOCHA RIVER VALLEY, EASTERN CORDILLERA, COLOMBIA).

ABSTRACT

A study of the palynostratigraphy and palynofacies on the Paleogene of the Paz de Río region (Eastern Cordillera of Colombia) is presented. It includes the upper part of the Guaduas Formation (early Paleocene?), The Areniscas and Arcillas de Socha Formations (late Paleocene?) and the Picacho Formation (Eocene). A total of 197 samples were treated for palynological analysis, from which 24 were suitable for biostratigraphy. The pollen associations can be divided in 5 assemblages: assemblage 1 characterized the upper part of the Guaduas Formation, and included the species *Spinizonocolpites sutae*, *Spinizonocolpites baculatus*, *Psilabrevitricolporites annulatus*, *Psilabrevitricolpites marginatus*, *Proxapertites verrucatus*, *Foveotriletes margaritae*, *Buttinia andreevi*, *Echitriporites trianguliformis*, *Retitricolpites microreticulatus*, *Collombipollis tropicalis* and *Ulmoideipites krempii* as the most characteristic species; assemblage 2 occurs in the Areniscas de Socha Formation, and included *Bombacacidites* sp., *Colombipollis tropicalis*, *Longapertites vaneendenburgi*, *Proxapertites magnus, Retidiporites magdalenensis*, *Psilamonocolpites medius*, *Psilamonocolpites operculatus* and different types of spores such as *Cicatricososporites* (two forms), *Echitriletes* (several forms), *Polypodiaceoisporites* group, *Cicatricosisporites*, *Verrutriletes* spp. and *Retitriletes* (*Zlivisporis blanensis* ?). Assemblage 3 occurs in the lower part of the Arcillas de Socha Formation, which is very rich in pollen and microscopic organic matter. It includes *Proxapertites operculatus*, *Proxapertites cursus*, *Bombacacidites annae*, *Psilamonocolpites medius, Longapertites vaneendenburgi, Foveotricolpites perforatus*, *Mauritiidites franciscoi*, *Aglaoreidia*? *foveolata*, *Corsinipollenites psilatus*, *Retidiporites magdalenensis*, *Clavatricolporites leticiae* and *Ephedripites vanegensis*. In some levels *Proxapertites operculatus* reaches more than 50 %. Assemblage 4 characterized the upper part of the Arcillas de Socha Formation, a formation poor in pollen spores and microscopic organic matter. The dominant facies in this interval are mottled shales indicating oxidation processes in well drained soils; conditions which were unfavorable for palynomorph preservation. This barren interval has been also recognized in the Llanos Border (Jaramillo & Dilcher, 2001a) and in the Middle Magdalena Valley regions (this work). Only three samples included some pollen and spores species such as *Brevitricolpites microechinatus, Tricolpites clarensis* and *Bombacacidites* sp. (sp 2 of Jaramillo & Dilcher 2001). *Spinizonocolpites pachyexinatus* have their first occurrence datum in this interval. On the other hand, *Bombacacidites annae, Retidiporites magdalenensis, Proxapertites magnus, Foveotricolpites perforatus*, *Clavatricolporites leticiae* have their last occurrence datum. It is important to remark the high percentage of *Retistephanocolporites* "boyacensis" and low percentages of reworked palynomorphs (e.g. *Bacumorphomonocolpites tausae, Dinogymnium* sp., and *Spinizonocolpites baculatus*). Assemblage 5 occurs in the lower part of Picacho Formation. It is characterized by the FAD of several species: *Striatopollis catatumbus*, *Spirosyncolpites spiralis*, *Foveotriporites hamenii*, *Albertipollenites*? *perforatus*, *Retimonocolpites*

retifossulatus, *Cyclusphaera scabrata*, *Retitrescolpites? irregularis*, *Retitricolpites* cf. *simplex*, *Retistephanoporites angelicus*, *Margocolporites vanwijhei*, *Monoporopollenites annulatus*, *Rugutricolporites* cf. *felix*, *Cricotriporites guianensis*, *Echiperiporites* sp., *Racemonocolpites microgemmatus*, *Rhoipites guianensis*, *Polypodiisporites* aff. *inangahuensis*, *Psilastephanocolporites fissilis* and several forms of *Bombacacidites* (e.g. *Bombacacidites* aff. *gonzalezii*, *Bombacacidites psilatus*, *Bombacacidites pseudosimplireticulatus*, *Bombacacidites* cf. *nacimientoensis*, *Bombacacidites baumfalki* and *Bombacacidites soleaformis*). The comparison of these data with the biozonal schemes of Germeraad et al. (1968) and Muller et al. (1987) is difficult, possibly due to the presence of barren or pollen-poor intervals in our studied section and to differences in the stratigraphic range of some marker taxa.

The graphic correlation performed between the Paz de Río and Llanos border section (Jaramillo & Dilcher 2001; Guerrero & Sarmiento, 1996), presents similarities in the stratigraphic range of the pollen and spore species and thus in their correlation line. In contrast, the high slope of the correlation line obtained with the Middle Magdalena Valley section shows a high difference in sedimentation rate. The palynofacies, sedimentologic and paleocurrent data of these units suggest fluvial environments with different accommodation rates. The Areniscas de Socha Formation was accumulated by bed-load dominated fluvial environment. In contrast the Arcillas de Socha Formation was formed by mixed-load rivers with abundant swamp and crevasse splay deposits. The upward change from grey-green to mottled dominated shaly deposits indicates a change from poorly to well drained conditions in the alluvial plain. The Picacho Formation evidences the return of bed-load fluvial environments with episodic fresh water lakes rich in *Pediastrum*. Preliminary paleocurrent data suggest an N-NW main direction of paleoflow during the entire studied interval.

3.1. STRATIGRAPHICAL AND PALYNOLOGICAL ANTECEDENTS

The Paz de Río area (Boyacá department, Colombia) is located 200 km north east of Bogotá in the Eastern Cordillera of Colombia (Figure 1.1). It is a region rich in sedimentary mineral resources (e.g. coal, limestone, iron, phosphate), therefore, it has one of the most important mining activities in Colombia. The geological exploration in this area began in the 1920's, followed by the work of Alvarado and Sarmiento (1944), who started systematic stratigraphical studies for the Colombian iron and steel plan (Reyes, 1984); unfortunately, this work was not published and the original report was missing at Ingeominas (Guzman, G., written communication). Alvarado and Sarmiento (1944) proposed the terms "Socha Inferior", "Socha Superior" and "Picacho Formations" for the lower Tertiary rocks that outcrop at the Rio Chicamocha area. Although this nomenclature was not officially published, it was used in other regions of the Boyacá department (e.g. Renzoni, 1967). Afterwards, Reyes (1984) made a geologic map and a general description of the stratigraphic units in the area including the units studied in this work; nevertheless, this information was also unpublished. Recently, Ulloa et al (2001) proposed the terms "Areniscas de Socha" and "Arcillas de Socha" Formations to replace the "Socha Inferior" and "Socha Superior" of Alvarado and Sarmiento (1944). These terms were proposed because the International stratigraphic guide (Hedberg, 1976), suggested that the terms "Upper" (Superior), "Middle" (Medio) and "Lower" (Inferior) cannot be used to nominate formal lithostratigraphic units. This nomenclature was also used by Rodriguez and Solano (2000) in the recent explicative memoir of the digital geological map of Boyacá department. For our work, we followed this latest proposal, combining the nomenclature of Alvarado and Sarmiento (1944) with the modifications of Ulloa et al. (2001). It includes from base to top: the Guaduas, Areniscas de Socha, Arcillas de Socha and Picacho Formations (figure 3.1). Based on the North American Stratigraphic Code nomenclature (NACSN, 1983), Guerrero and Sarmiento (1996) proposed the terms "Socha Allogroup" limited by regional unconformities, which included the Socha Inferior Alloformation (equivalent to the Areniscas de Socha Formation) and Socha Superior Alloformation (equivalent to the Arcillas de Socha Formation).

Palynology has been the only technique used for dating these rocks and for correlation with other areas of Colombia and Venezuela. Nevertheless, previous studies only present a brief palynologic information of the Paz de Río area (e.g. Germeraad et al., 1968; Van der Hammen, 1957a) or are not published (e.g. Van der Hammen and García, 1955). Additionally, the samples and slides used in these researches are not available for future revisions. Moreover in this area, there are neither marine fossils, nor other dating techniques applicable. Therefore, the age proposed for the palynologic associations is not well supported.

The Guaduas Formation

The term "Guaduas" was originally employed by Hettner (1892) and re-defined by Hubach (in Kehrer, 1933.) and Hubach (1957) (see Porta 1974, for detailed historical account). Near Bogotá, this unit is limited by the Arenisca Tierna Formation to the base and the Arenisca de Cacho Formation to the top, this latter formation being probably equivalent to the Areniscas de Socha Formation in our study area. Solé de Porta (1970) studied this unit in the Guatavita region, 35 km NE of Bogotá. In this sector, it is composed mainly by shales with minor sandstone layers. Coal beds are frequent. Two sandstone-dominated intervals (the "Arenisca Guía" and "Arenisca Lajosa") have been regionally recognized in the Sabana de Bogotá area and used as stratigraphic guides. The thickness of the Guaduas Formation is variable along the Eastern Cordillera; the thickest section is located in the Checua-Lenguazaque syncline (1100 m. Sarmiento, 1992a); in contrast, only 410-450 meters have been measured at the Paz de Río area (Osorno, 1994; Reyes, 1984). Based on the study of several sections of this formation (e.g. Salto del Tequendama, Suesca, Santa Rosita, Lenguazaque, Tunja, Paz de Río, Rondon and Molagavita) Van der Hammen (1954a) proposed four palynological zones for the Guaduas Formation. Their limits correspond to the maximal abundance peaks of *Monocolpites medius* (see chapter 1). Sarmiento (1992a) performed a detailed stratigraphic and palynologic analysis of this formation in the Checua-Lenguazaque syncline, 35 km N of Guatavita. Based on the facies characteristics, he divided this unit in nine segments and proposed lagoon, coastal swamps, lakes, channels and alluvial plains as the main depositional environments. At the Sutatausa area, the lower part of this formation has been dated as Maastrichtian using foraminifera and dinoflagellate cysts (Sarmiento, 1992b). The upper part cannot be dated because its red-green mottled shales and sandstones are barren in fossils.

Van der Hammen & García (1955) made a palynological study of the coal beds present in the Guaduas Formation in the "La Chapa" coal mine, near Paz de Río. A total of 150 samples in 14 coal beds were studied. Their results are presented graphically in a PAF (Palm-Angiosperms- Ferns) diagram and a qualitative (in some cases quantitative) distribution of the pollen and spore species. Based on these data the authors suggest that most of the coal beds can be included in the C late Maastrichtian palynologic zone of Van der Hammen (1957)

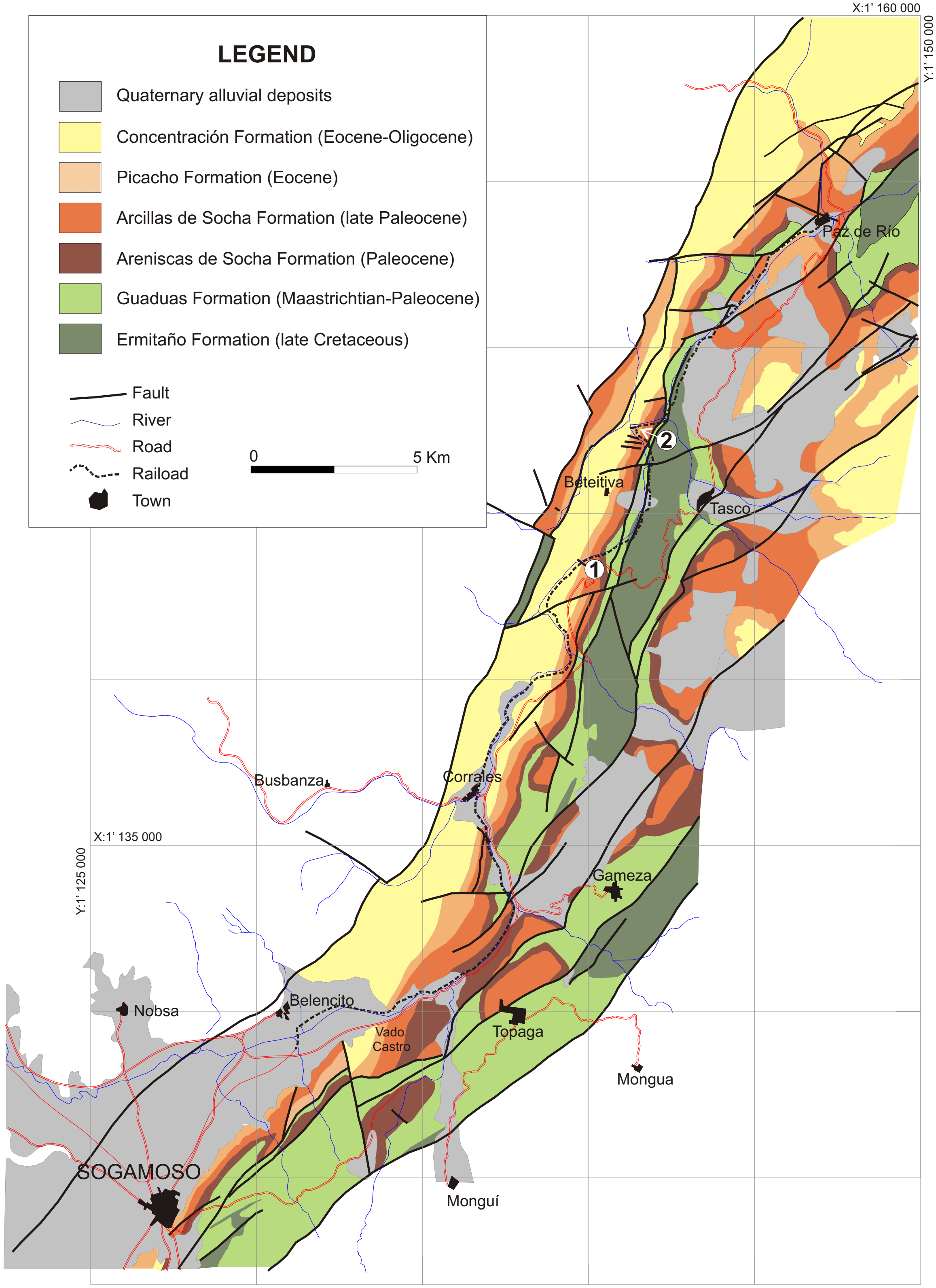


Figure 3.1. Geologic map of the Sogamoso-Paz de Río area (central Eastern Cordillera, Colombia) with the location of the stratigraphic sections studied in this work (after Reyes, 1984). 1: Peña Blanca section; 2: Curva de Cosgua section. Stratigraphic nomenclature follows the modifications of Ulloa et al. (2001). See explanation in the text.

(figure 1.4).

The Areniscas de Socha Formation:

As previously mentioned, the Areniscas de Socha Formation is equivalent to the Socha Inferior Formation of Alvarado and Sarmiento (1944) (see Ulloa et al., 2001). Alvarado and Sarmiento (1944) proposed the type locality of this unit near to Socha Viejo locality 7 km north of Paz de Río town. Nevertheless, a detailed stratigraphic section of this area is not available. The formation includes compact cross-bedded coarse quartz sandstones in its lower part, locally very coarse to conglomeratic (rounded quartz pebbles of 0.5 to 2 cm in diameter), and white medium sandstones in its upper part (Alvarado & Sarmiento, in Porta, 1974). The thickness of this unit ranges between 100 and 150 m. Its lower contact is sharp with the Guaduas Formation and its upper contact is concordant with the Arcillas de Socha Formation (Porta, 1974). Ulloa et al. (2001) described this unit in a section of 156 m thick, located over the Corrales-Paz de Río road (figure 3.1). In this sector it is composed of a succession of fine to medium quartz-sandstones, of variable thickness, interlayed with sporadic grey and red shales. Its upper contact is “concordant and transitional” with the Arcillas de Socha Formation (Ulloa et al., 2001). Van der Hammen (*in* Hubach, 1957, p. 83) found in this unit the pollen species *Proxapertites operculatus*. He suggested an early Paleocene age and correlated this unit with the upper part of the Guaduas Formation of the Sabana of the Bogotá area, the Lisama Formation of the Middle Magdalena Valley Basin and the Barco Formation of the Catatumbo region. Germeraad et al. (1968) recorded the species *Bombacacidites annae* and located this unit (named “Arenisca de Cacho” in their work) in their *Ctenolophonidites lisamae* palynogical Caribbean zone.

The Arcillas de Socha Formation:

The Arcillas de Socha Formation is equivalent to the Socha Superior Formation of Alvarado and Sarmiento (1944; see above). The type locality is located south of the Sochaviejo town, near Chicamocha river valley (Alvarado & Sarmiento 1944, in Reyes, 1984). The Formation has sharp lower and upper contacts with the Areniscas de Socha and Picacho Formations. In the type locality, the lower part of this unit comprises dark green sandy shales with some sandstone beds; the middle part contains green shales with some coal beds; and the upper part, sandstone layers interbedded with shales (Porta, 1974). Gypsum is common at the upper part of the formation. According to Reyes (1984), the thickness of this unit varies between 250 and 270 m. In contrast Porta (1974) mentioned 380 m of thickness in the Leona’s creek, 400 m in the Socha Viejo section, 300 m in the Cerro Fraile section and 180 m in the Chicuasá creek. Due to these large variations, Alvarado and Sarmiento (1944), and Vargas et al. (1981) suggested an unconformity between this unit and the overlaying Picacho Formation.

Germeraad et al. (1968) recorded the species *Longapertites vaneendenburgi*, *Retidiporites magdalenensis*, *Proxapertites operculatus*, *Proxapertites cursus*, *Ctenolophonidites lisamae* and *Foveotricolpites perforatus* in this unit (named Bogotá Formation in their work). These authors located the limit between the *Foveotricolpites perforatus* and the *Psilabrevitricolpites triangulatus* palynologic zones at the upper part of this Formation. Van der Hammen (in Hubach, 1957b, p. 82) mentioned the dominance of *Proxapertites operculatus* in this unit; he also mentioned *Bombacacidites annae* and *Ephedripites vanegensis*. Based on these data a late

Paleocene age was suggested. Van der Hammen (1957) correlated this unit with the Lisama and Los Cuervos Formations in the Middle Magdalena Valley and the Catatumbo region respectively.

The Picacho Formation:

Alvarado & Sarmiento (1944) used the name "Picacho Formation" for a group of sandstones that occurs in sharp contact over the Arcillas de Socha Formation. The type locality of this unit is located north of Betéivita, near to the « El Fraile » and « Picacho » hills (west of Paz de Río). In this area conglomeratic sandstones in the lower part, underlie medium grained sandstones. The upper part includes levels of quartz-conglomeratic sandstones and sandstones (Porta, 1974). The thickness of this unit varies between 90 and 115 m. Germeraad et al. (1968) recorded the pollen species *Striatopollis catatumbus*, and included this unit in their *Retibrevitricolpites triangulatus* (?) Atlantic zone. Based on unpublished palynological data, Van der Hammen (1958) correlated the Picacho Fm. with the La Paz Formation in the Middle Magdalena Valley area.

3.2. DESCRIPTION OF THE STUDIED SECTIONS

The previous researches performed in this area include only general stratigraphic logs of the Paleocene -Eocene units (e.g. Reyes, 1984; Rodriguez and Solano, 2000). In the present work, 560 m of the upper part of Guaduas Formation, Areniscas and Arcillas de Socha Formations and the lower part of the Picacho Formation were carefully described and measured, permitting the reconstruction of a detailed stratigraphic section (figure 3.2). Two sectors were studied in this work (figures 3.3 and 3.4). The last 65 m of the Guaduas Formation and the lowermost Areniscas de Socha Formations were studied and sampled few meters to the north of the "Peña Blanca" rail station (Figure 3.1). The Areniscas de Socha, Arcillas de Socha and Picacho Formations were studied four Km to the north of this locality, in the "Curva de Cosgua" sector over the Belencito-Paz de Río railroad (figure 3.1; plate 3.1, photo 1). The Curva de Cosgua is divided in two sections: The Curva de Cosgua Norte (CCN) and the Curva de Cosgua Sur (CCS) (Figure 3.2 and 3.3.A).

The regional cartography of the area shows a faulted contact between the Areniscas de Socha and the underlay Guaduas Formation (Reyes, 1984). At the Curva de Cosgua Norte section, this fault is evidenced by a strong variation in the stratification trend between these units. In contrast, this contact can be observed at the Peña Blanca area (Figure 3.3.B). The stratigraphic information was grouped in a composite stratigraphic log, named here the Paz de Río section (figure 3.4). It can be divided into five intervals with different facies characteristics. From base to top, these intervals are the followings (see the figure 3.4 for thickness reference):

Interval 1 (66-0 m). Upper part of the Guaduas Formation. This part was described and measured at the Peña Blanca (PB) area (figures 3.1, 3.3.A and 3.3.B.1). It includes grey shales interbedded with medium to fine quartz-sandstones. Rhythmic silty-sandy sequences with wavy, flasser and lenticular structures at different scales are common. The textural changes between the sandstones and shales can be sharp or gradual. Two coal layers with 90 and 30 cm of thickness respectively are present in the lower half of this section. The sandstone layers are less than 60 cm thick, with irregular surfaces and internally wavy and/or small scale cross-

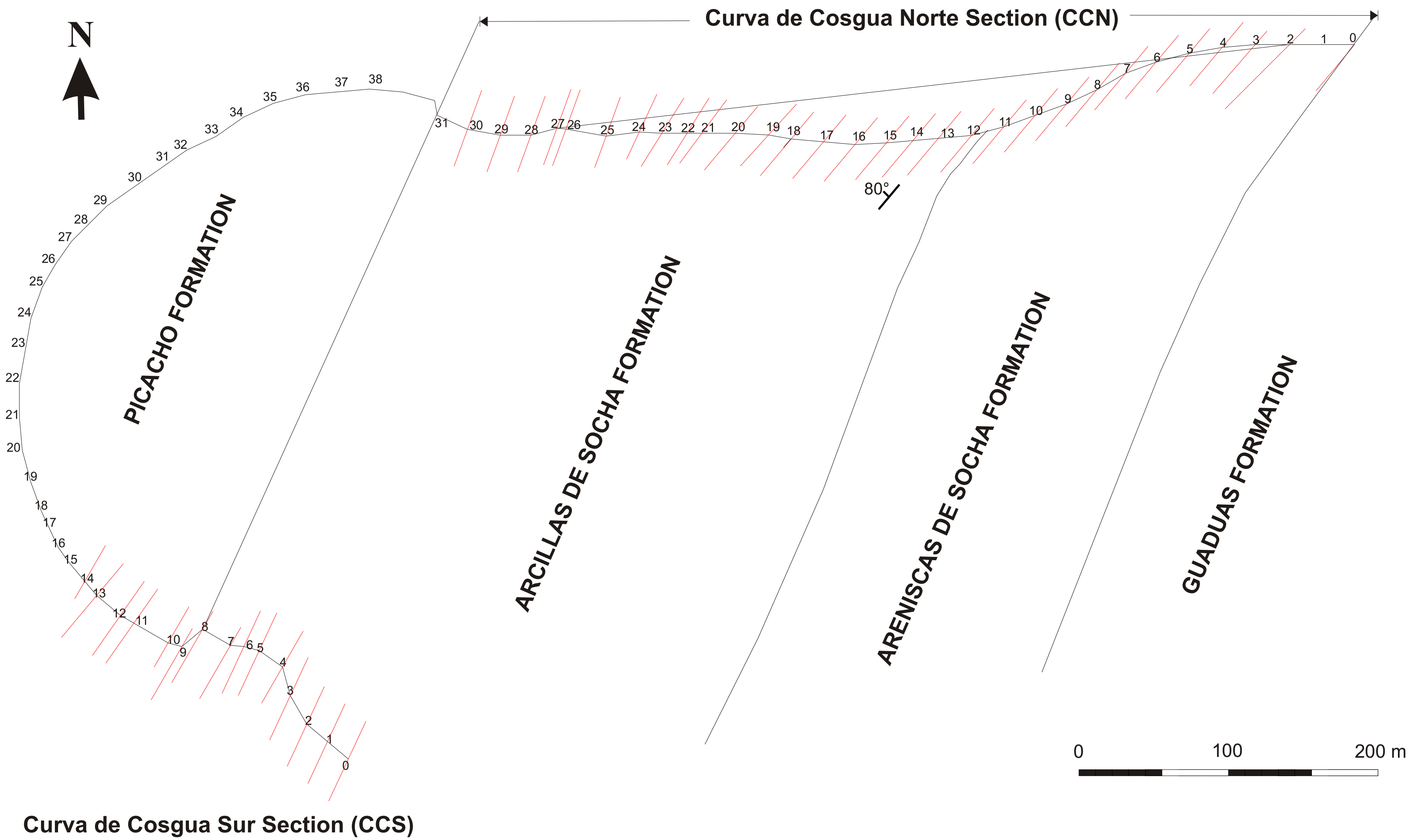


Figure 3.2. Map of the Curva de Cosgua section. Numbers represent the stations used during the field survey. They are also indicated on the detailed log of the figure 3.3. In red: strike of the beds (dip to the west). For regional location see the figure 3.1.

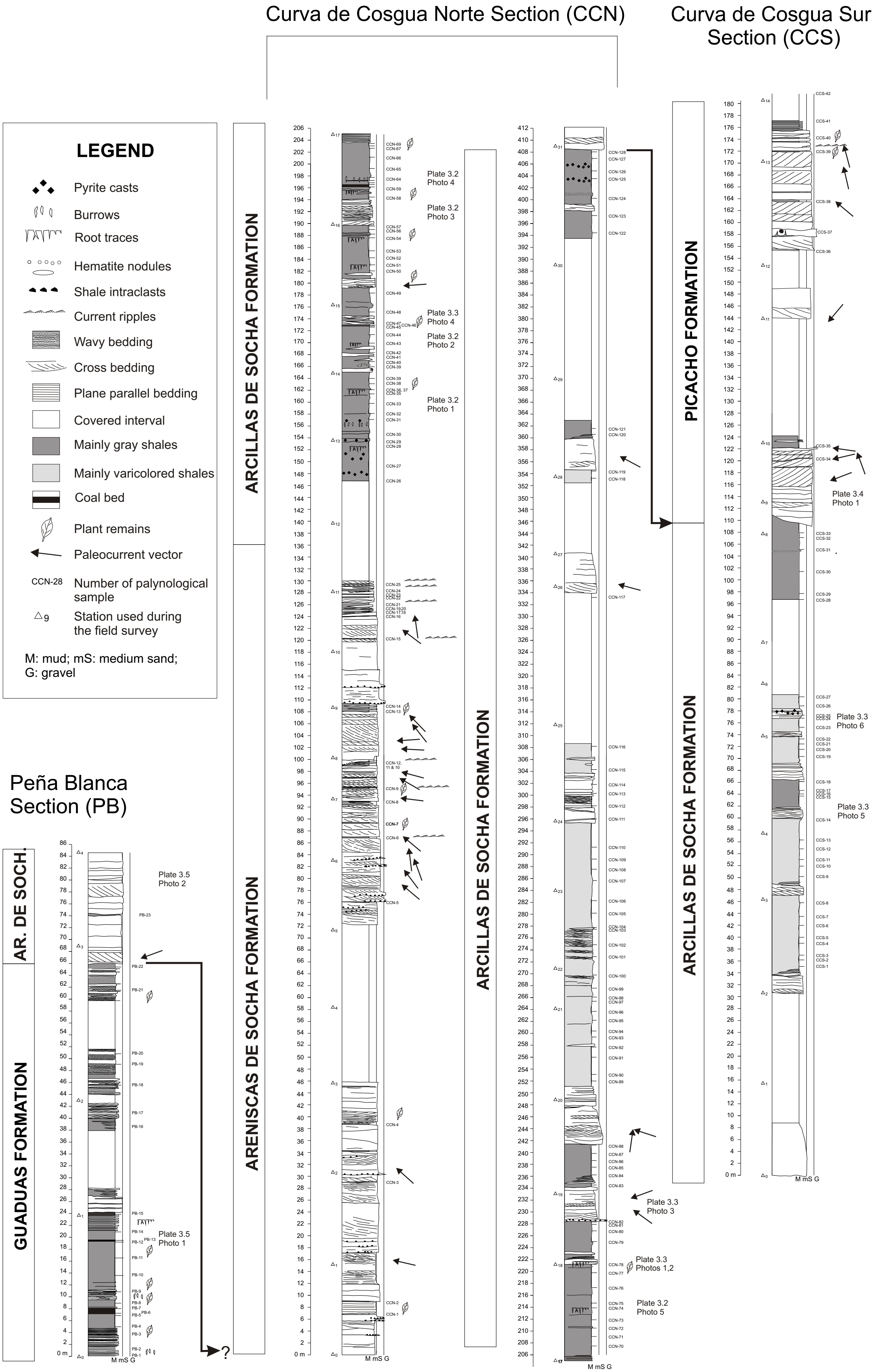


Figure 3.3. A. Sedimentologic characteristics of the studied sections and location of the palynologic samples. For location see the figures 3.1 and 3.2.

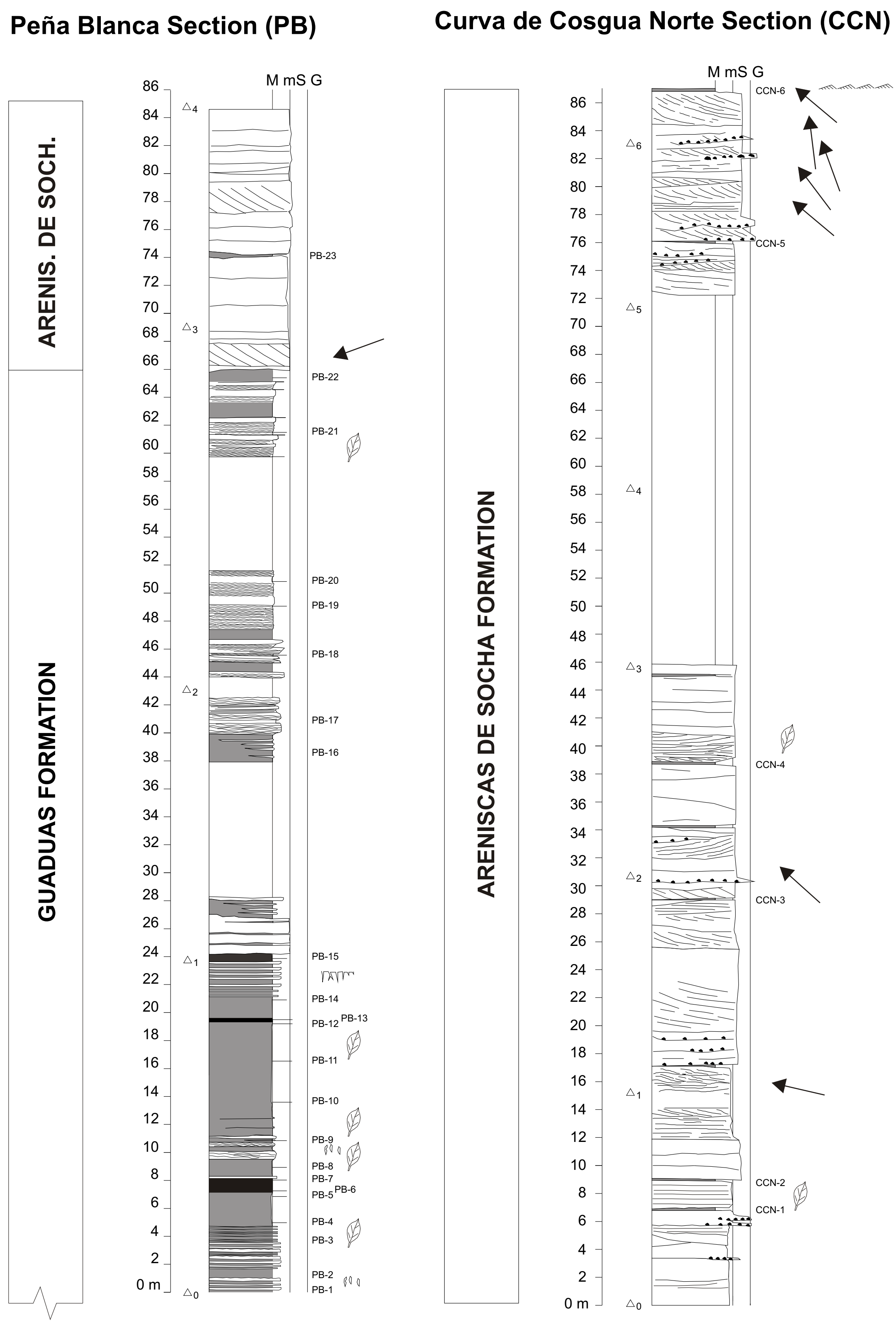


Figure 3.3. B.1. Detailed sections of the Guaduas Formation and the lower part of the Areniscas de Socha Formation. Conventions as in figure 3.3.A.

Curva de Cosgua Norte Section (CCN)

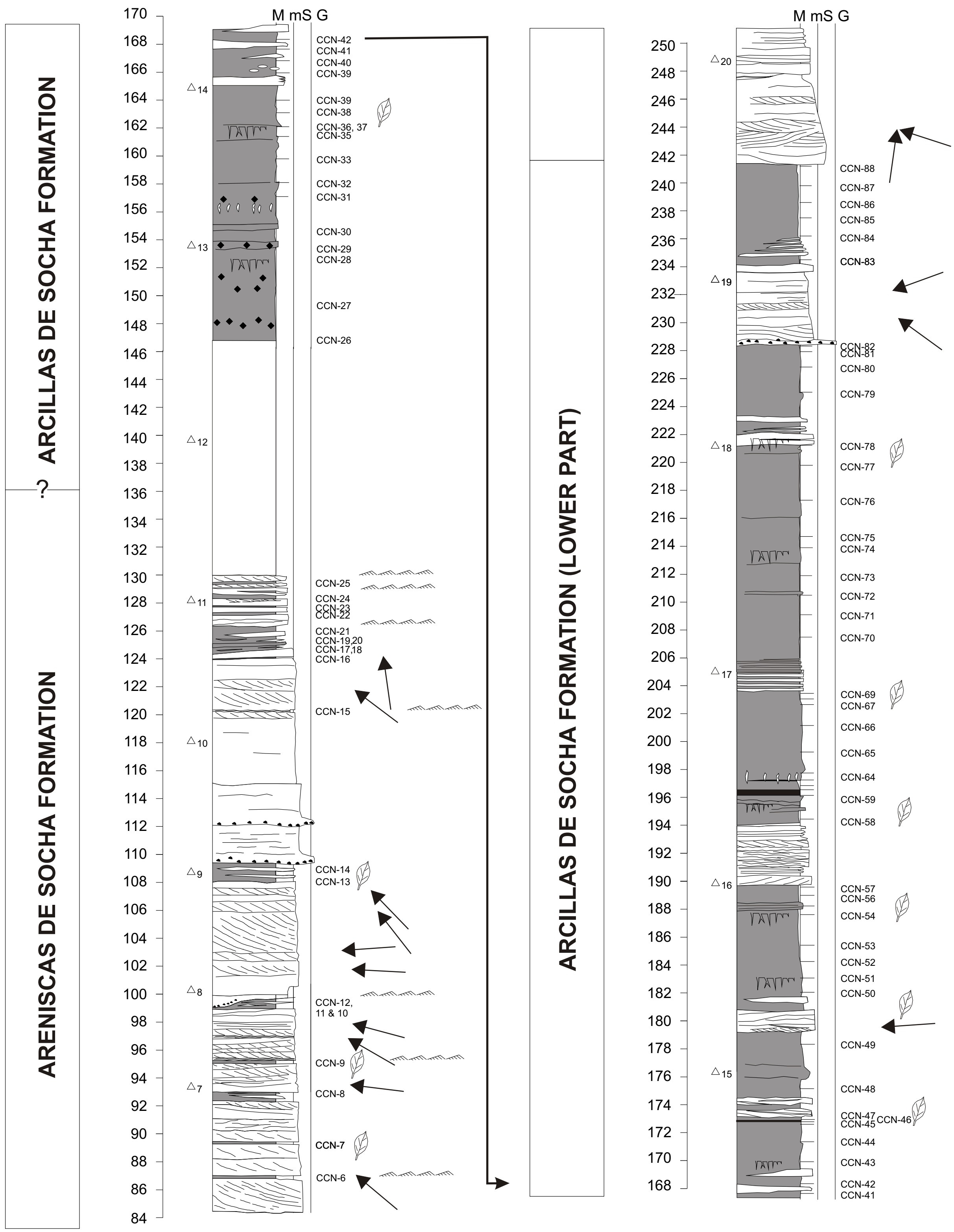


Figure 3.3. B. 2. Continuation. Detailed sections of the upper part of the Areniscas de Socha Formation and the lower part of the Arcillas de Socha Formation. Conventions as in figure 3.3.A.

Curva de Cosgua Norte Section (CCN)

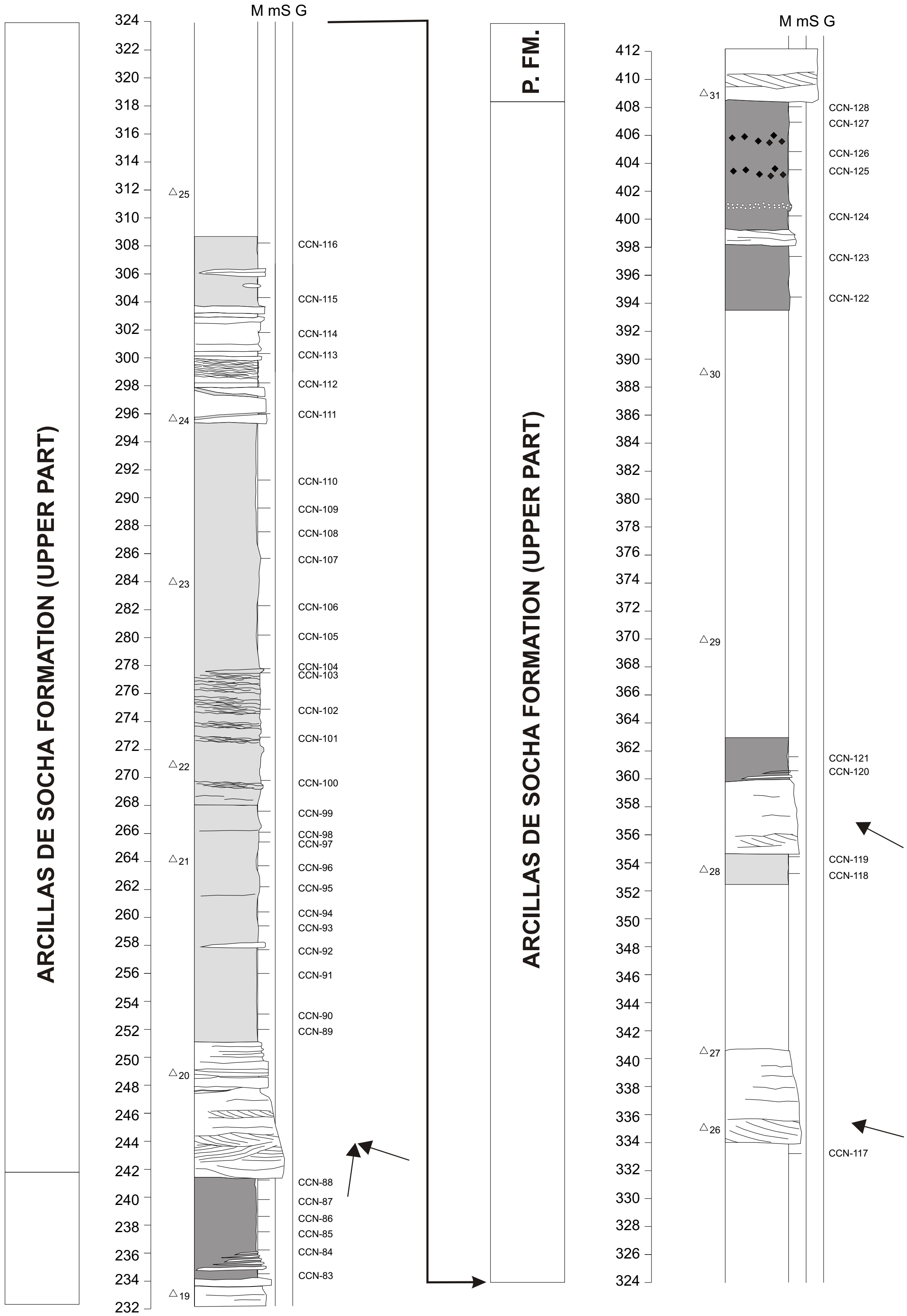


Figure 3.3. B. 3. Continuation. Detailed sections of the upper part of the Arcillas de Socha Formation and the lower part of the Picacho Formation. Conventions as in figure 3.3.A. P. FM: Picacho Formation.

Curva de Cosgua Sur section (CCS)

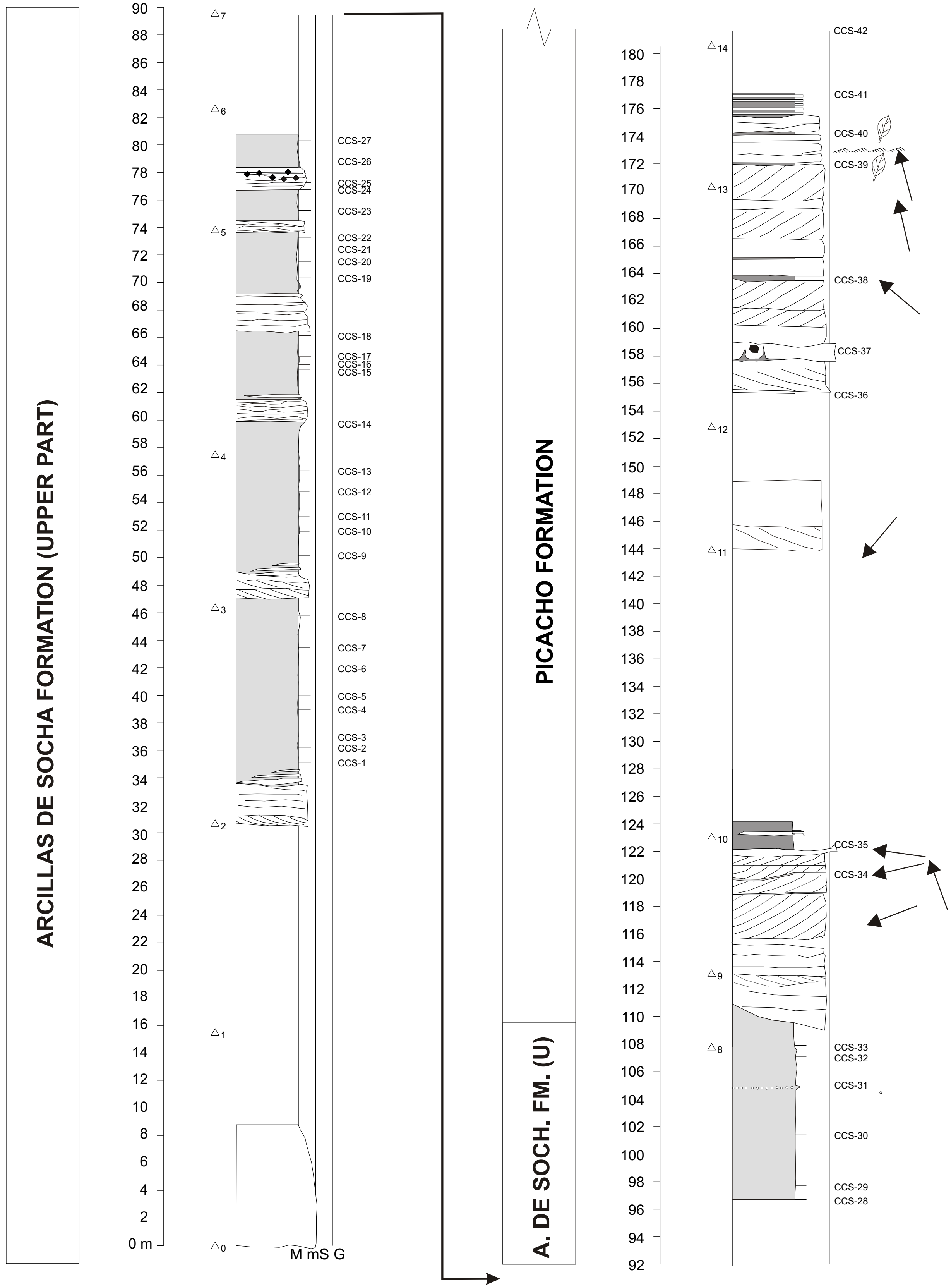


Figure 3.3. B. 4. Continuation. Detailed sections of the upper part of the Arcillas de Socha Formation and the lower part of the Picacho Formation. A. DE SOCH. FM. (U): Arcillas de Socha Formation (upper part). Conventions as in figure 3.3. A.

lamination. Ripple marks and/or groove casts are common on the bedding surfaces. The shales have plant remains and locally burrowing and root traces.

Interval 2 (0-130 m). Areniscas de Socha Formation. This formation contains medium to fine grained quartz sandstones with minor grey shaly interbeds. The sandstone layers are mainly arranged in medium to thick lens-shape sets (figure 3.3.B.1; plate 3.5; photo 2), with trough and planar cross-bedding as the main internal structure. The maximum thickness of a single set is 4 m. At the top of some sandstone sets, current-ripples can be observed especially at the upper part of the formation (figure 3.3.B.2; plate 3.1, photos 2, 3 & 4); shale intraclasts are very common at the base of the sandstone beds. The usually lens-shape shale layers are less than 50 cm thick. At the upper part of the formation, the shales occur more frequently in association with thin lenses of fine sandstones and siltstones. Plant remains are relatively common in the fine deposits. After this interval there are 16 m covered by recent colluvial deposits, preventing the observation of the contact between the Areniscas de Socha and Arcillas de Socha Formations (130-146 m interval of the figure 3.3.B.2).

Interval 3 (146-242 m). Lower part of Arcillas de Socha Formation. This formation is mainly composed of grey to black claystones and siltstones with some thin sandstone interbeds (figure 3.3.B.2); coal levels are also present (10-50 cm thick) (Plate 3.2). The shales have root traces and abundant plant debris; in some cases trunk fragments and tool casts are observed at the base of some sandstone beds. Cubic and hexagonal casts of pyrite are abundant in the lower part of this interval; some ferruginous concretions (sideritic?) are locally present. The sandstones have fine to medium grain size; cross-bedding, flaser structure and climbing ripple lamination are their main internal structure. Some of them are disposed as isolated beds in the shaley-dominated facies or as metric sequences of thin sandstone beds interlayed with siltstones. A fining upward sandstone sequence more than 4 m thick, characterizes the upper part of this interval (Plate 3.3, photos 2 & 3).

Interval 4 (242-408 m). Upper part of the Arcillas de Socha Formation. This part is mainly composed of shales with interbedded sandstones and siltstones. Due to the presence of many covered intervals at the Curva de Cosgua Norte section (CCN), the upper part of this unit was sampled and described at the Curva de Cosgua Sur section (CCS) (figures 3.3.A, 3.3.B.3 & 3.3.B.4). The shales are mainly mottled, grey-green-reddish in color. Plant remains and ferruginous concretions are locally present. Gypsum crystals and carbonate cement are common. Some sandstone beds are disposed in thick (>3m) sequences of cross-bedded sets grading upward to shales. Mud intraclast are frequent in some sandstone beds. Intervals with thin-bedded fine sandstones and siltstones with small scale cross-bedding and /or climbing ripple lamination are locally abundant (plate 3.3, photos 5 & 6).

Interval 5 (408- 478 m). Lower part of the Picacho Formation. The Picacho Formation has a sharp contact with the underlying Arcillas de Socha Formation (figure 3.3.B.4). This unit includes medium to coarse quartz-sandstones, conglomeratic sandstones, quartz conglomerates and some interbedded shales. The sandstone beds are lens-shaped and frequently amalgamated. They are disposed in sets with tangential or tabular cross-bedding, which can reach 3 m in thickness (plate 3.4., photo 1). Some of them have isolated pebbles of milky quartz and chert at the base. Current-ripples, flame structures and shale intraclasts are locally present. Thin (< 30 cm) mudstone beds are located between some sandstone sets (plate 3.4.,

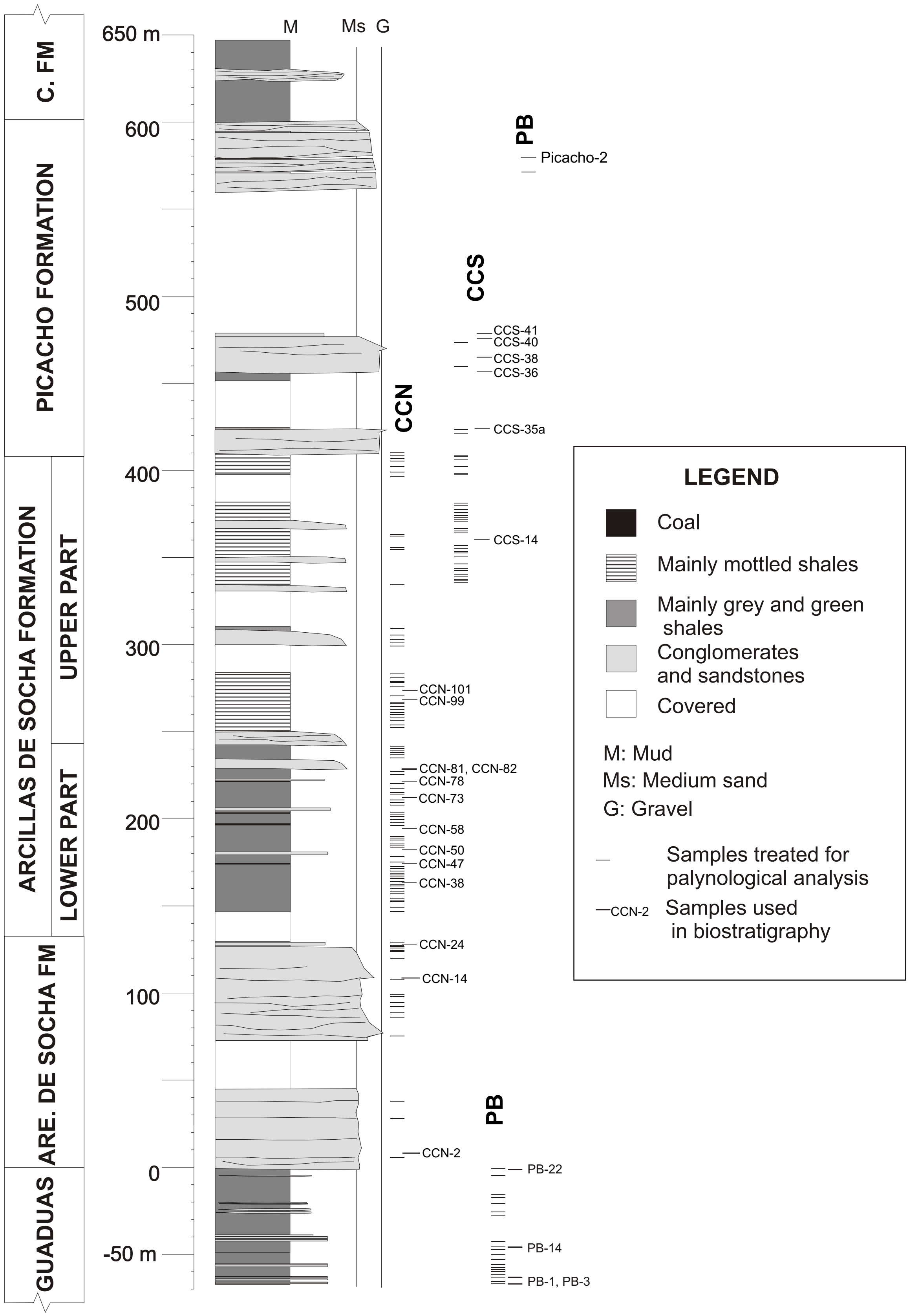


Figure 3.4. Composite stratigraphic section of the Paz de Rio area and location of the samples studied in this work. CCN: Curva de Cosgua Norte section; CCS: Curva de Cosgua Sur section; PB: Peña Blanca section; ARE. DE SOCHA FM: Areniscas de Socha Formation; C. FM: Concentración Formation. The thicknes of the Picacho Formation is based on Reyes (1984).

photo 3). The upper measured part consists on a rhythmic sequence of tabular thin beds of fine grained sandstones and shales (figure 23.3.E). Plant remains are locally abundant.

3.3. BIOSTRATIGRAPHY

3.3.1. General description

A total of 197 samples were treated for palynological analysis (128 in the CCN section, 44 in the CCS section and 25 in the Peña Blanca section); many of them are barren in pollen and spores. Thus, only 24 samples were analyzed for the biostratigraphical study (figures 3.5 and 3.6). The figure 3.5 shows the detailed distribution of palynomorphs in the studied section; the figure 3.6 shows a general stratigraphic distribution of the most important species of the composite stratigraphic section; some samples of the Guaduas Formation are included in this schema. More than 150 morphological groups can be differentiated (appendix 3.2). Most of the spores were grouped in general morphological categories (e.g. *Psilatriletes*, *Echitriletes*). The pollen distribution can be divided in the five following intervals:

Upper part of the Guaduas Formation: In this interval the samples are poor in pollen and spores. Samples from the lower part of the sequence yield the species *Spinizonocolpites sutae*, *Spinizonocolpites baculatus*, *Proxapertites humbertoides*, *Longapertites vaneendenburgi*, *Psilabrevitricolporites annulatus*, *Psilabrevitricolpites marginatus*, *Proxapertites verrucatus*, *Foveotriletes margaritae*, *Buttinia andreevi*, *Racemonocolpites racematus*, *Gemmamonocolpites dispersus*, *Echitriporites trianguliformis*, *Retitricolpites microreticulatus*., *Collombipollis tropicalis* and *Ulmoideipites krempii* (appendix 1.1, plate 2.1).

Areniscas de Socha Formation: In this unit only 3 of 25 samples analyzed are relatively rich in palynomorphs. The species *Bombacacidites* sp. (triangular), *Colombipollis tropicalis*, *Longapertites vaneendenburgi*, *Retimonocolpites* ssp., *Verrumonocolpites* sp., *Proxapertites magnus* and *Retidiporites magdalenensis* were recorded in this interval. *Psilamonocolpites medius* is present in high percentage (29-36 %), and *Psilamonocolpites operculatus* became abundant. This species was identified for the first time in the Middle Magdalena Valley Basin (Pardo-Trujillo et al., 2003). *Proxapertites operculatus* and *Proxapertites psilatus* were present in very low percentage (1 %). This interval was also characterized by different types of spores (not formally described), such as *Cicatricososporites* (two forms), *Echitriletes* (several forms), *Polypodiaceoisporites* group, *Cicatricosisporites*, *Verrutriletes* spp. and *Retitriletes* (*Zlivisporis blanensis*?)

Lower 110 m of the Arcillas de Socha Formation: In general the samples of this interval are rich in pollen, spores and sedimentary organic matter. Some characteristic species are: *Proxapertites operculatus*, *Proxapertites cursus*, *Bombacacidites annae*, *Psilamonocolpites medius*, *Longapertites vaneendenburgi*, *Foveotricolpites perforatus*, *Mauritiidites franciscoi*, *Aglaoreidia*? *foveolata*, *Corsinipollenites psilatus*, *Retidiporites magdalenensis*, *Clavatricolporites leticiae* and *Ephedripites vanegensis*. Some particular characteristics could also be noticed: *Proxapertites operculatus* became abundant and reaches 82 % in the sample CCN-73. High percentages (56 %) of *Ovoidites* occur in the sample CCN-82. *Striatopollis minor* (9 %) is present in the sample CCN-78 and *Retidiporites* "*cosguensis*" (10 %) in the

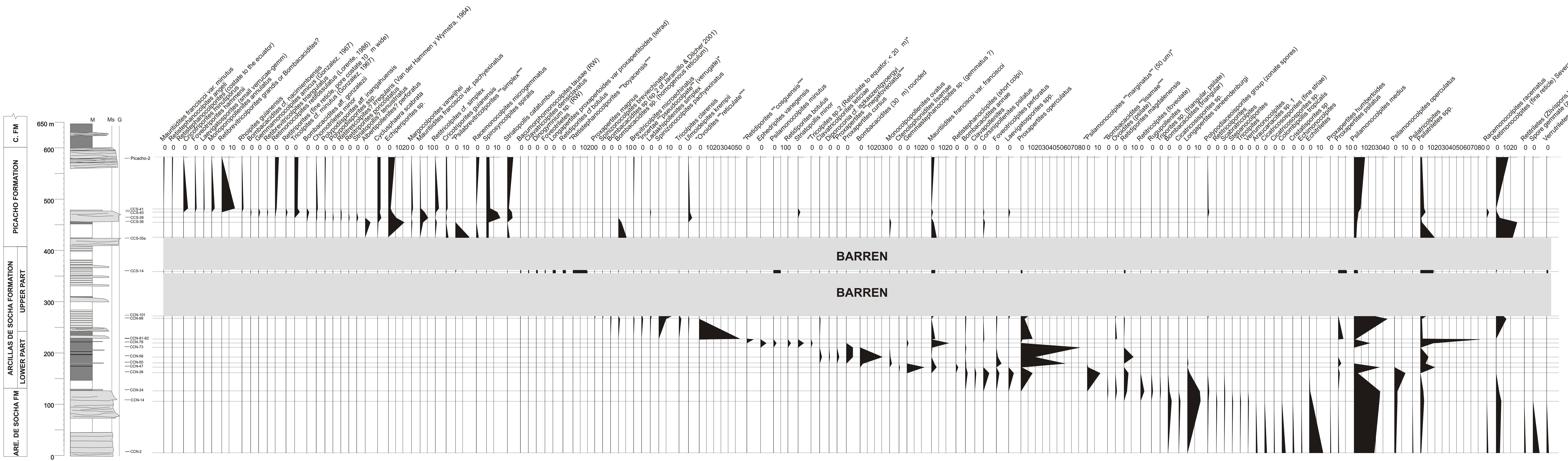


Figure 3.5. Stratigraphic distribution of relative percentages of pollen and spores (Paz de Río section).

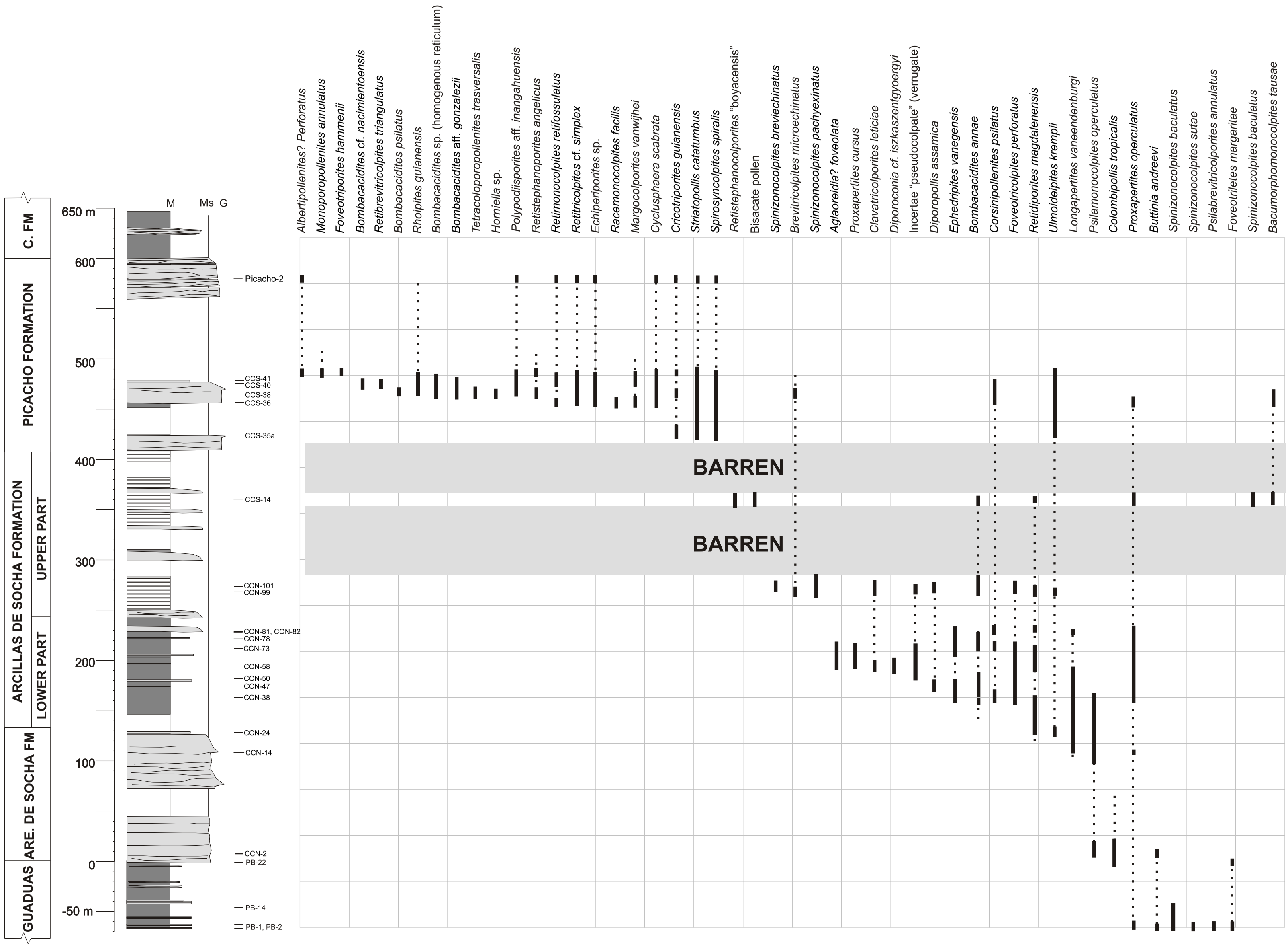


Figure 3.6. Stratigraphic distribution of selected pollen and spore species in the Paz de Rio section. ARE. DE SOCHA FM: Areniscas de Socha Formation; C. FM: Concentración Formation. For conventions see figure 3.4.

sample CCN-81. *Retidiporites botulus*, a common species in northern Colombia (e.g. Van der Kaars, 1983) occurs only in one sample of coal (4%; sample CCN-78). The species *Diporoconia* cf. *Diporoconia iszkaszentgyoergyi* (samples CCN-55 and CCN-58) and *Diporopollis assamica* (samples CCN 46 and CCN-101) are also present in this sector in very low percentages.

Last 168 m of the Arcillas de Socha Formation: Most of the samples of this interval are barren or poor in palynomorphs and microscopic organic matter. From 66 samples treated for palynological analysis only three (samples CCN-99, CCN-101 and CCS-14) are relatively rich in pollen and spores. Some species have their FAD in this interval: *Brevitricolpites microechinatus*, *Tricolpites clarensis*, *Bombacacidites* sp. (sp. 2 of Jaramillo and Dilcher, 2001) and *Spinizonocolpites pachyexinatus*. The latter species is relatively abundant (10-18 %); it has been described by Jaramillo & Dilcher (2001) at the Llanos border region in a similar stratigraphic position. Additionally, *Bombacacidites annae, Retidiporites magdalenensis, Proxapertites magnus, Foveotricolpites perforatus, Clavatricolporites leticiae* have their LAD in this interval. It is important to notice the high percentage of *Retstephanocolporites* "boyacensis" and low percentages of reworked palynomorphs (e.g. *Bacumorphomonocolpites tausae, Dinogymnium* sp., and *Spinizonocolpites baculatus*) in the sample CCS-14.

Interval 5 (Lower Picacho Formation): In this unit many pollen species have their first appearance datum (FAD): *Striatopollis catatumbus*, *Spirosyncolpites spiralis*, *Foveotriporites hamenii*, *Albertipollenites*? *perforatus*, *Retimonocolpites retifossulatus, Cyclusphaera scabrata, Retitrescolpites*? *irregularis*, *Retitricolpites* cf. *simplex, Retistephanoporites angelicus*, *Margocolporites vanwijhei*, *Retitriporites poricostatus*, *Monoporopollenites annulatus, Rugutricolporites* cf. *felix*, *Cricotriporites guianensis, Echiperiporites* sp., *Racemonocolpites microgemmatus*, *Polypodiisporites* aff. *inangahuensis*, *Echimorphomonocolpites gracilis*, *Gemmamonocolpites amicus*, *Psilastephanocolporites fissilis* and several forms of *Bombacacidites* (e.g. *Bombacacidites* aff. *gonzalezii, Bombacacidites psilatus, Bombacacidites pseudosimplireticulatus, Bombacacidites* cf. *nacimientoensis, Bombacacidites baumfalki, Bombacacidites soleaformis*). *Corsinipollenites* sp.**,** *Ulmoideipites krempii, Mauritiidites franciscoi* var. *pachyexinatus* are frequent. In contrast, *Proxapertites operculatus* is practically absent in this interval.

3.3.2. Comparison with some palynologic biozonations of NW South America

The stratigraphic distribution of pollen and spores of the Sogamoso-Paz de Río area is compared with the schemes of Germeraad et al. (1968), Muller et al. (1987), and some data of the Llanos border near Sabanalarga (e.g. Guerrero and Sarmiento, 1996; Jaramillo and Dilcher, 2001). Some of the palynological associations described by Gonzalez (1967) at the Catatumbo area are recognized in the studied section. Nevertheless, as was mentioned in the chapter 2, our observations in the MMVB and the data of Jaramillo et al. (2004), Jaramillo and Dilcher (2001) and Sarmiento (1995), obtained few kilometers apart of the Gonzalez section and in several logs of the Llanos border area, show important differences regarding the stratigraphic distribution of some taxa. This fact, together with some inconsistencies about the occurrence of several coal layers at the top of the Los Cuervos Formation, which is only recognized by Gonzalez (1967), compelled to re-studying these data.

The figure 3.7 shows the application of the palynologic zones of Germeraad et al. (1968) in the studied section. The upper part of the Guaduas Formation can be included in the *Foveotriletes margaritae* zone, based on the co-occurrence of *Foveotriletes margaritae, Stephanocolpites costatus, Longapertites vanendeenburgi* and the absence of pollen markers of the upper zones such as *Bombacacidites annae*, *Proxapertites cursus* and *Ctenolophonidites lisamae*. The presence of *Buttinia andreevi* at the base of this sequence could suggest the top *Proteacidites dehaani* Atlantic zone of Germeraad et al. (1968) to be located immediately bellow the *Foveotriletes margaritae* zone (not illustrated in the figure 3.7) .

The Areniscas de Socha Formation does not have enough productive samples to perform an accurate palynologic correlation. It is included, at least in part in the *Ctenolophonidites lisamae* zone due to presence of *Bombacacidites annae* and the absence of *Foveotricolpites perforatus*. Nevertheless, it is necessary to point out that some species described by Germeraad et al. (1968) in this biozone were not found (e.g. *Ctenolophonidites lisamae*, *Gemmastephanocolpites gemmatus* and *Proxapertites cursus*). The presence of one specimen of *Buttinia andreevi* at the base of this formation is considered here as reworked. The species *Foveotricolpites perforatus*, a pollen marker of the uppermost Paleocene Caribbean zone of Germeraad et al. (1968), has its FAD at the lower part of the Arcillas de Socha Formation. Several species co-occur in this interval: *Bombacacidites annae*, *Retidiporites magdalenensis*, *Ctenolophonidites lisamae*, *Proxapertites cursus* and *Proxapertites operculatus.* Among them, *Ctenolophonidites lisamae* and *Proxapertites cursus* have a shorter stratigraphic distribution that those described by Germeraad et al. (1968) (figure 3.7). As in the Middle Magdalena Valley section, the *Foveotricolpites perforatus* zone is followed by a barren interval, composed mainly of mottled shales (upper part of the Arcillas de Socha Formation).

The *Retibrevitricolpites triangulatus* zone can be located to the base of the Picacho Formation with the FAD of *Striatopollis catatumbus* and *Retitrescolpites*? *irregularis. Lanagiopollis crassa* is not recorded. The base of the *Monoporites annulatus* pantropical zone of Germeraad et al. (1968) can be identified 47 meters above the base of the Picacho Formation with the FAD of *Margocoporites vanwijeii*. *Rhoipites guianensis* appears some meters above. Nevertheless *Monoporopollenites annulatus*, the species defining the base of this zone, appears above *M. vanwijeii* and *R. guianensis* in contradiction with the Germeraad's schema. On the other hand, the species *Ranunculacidites operculatus* is not recorded. Thus, the *Psilatricolporites crassus* and *Psilatricolporites operculatus* Caribbean zones can not be identified. It can suggest a hiatus or condensed section. It is also possible that the real FAD of *M. annulatus* is further down in the sequence were the samples are poor in palynomorphs. As indicated previously by Germeraad et al. (1968), the first regular occurrence of this species is "rather gradual with alternating periods of higher or lower abundance". On the other hand, *Polypodiisporites usmensis*, *Cicatricosisporites dorogensis* and *Perisyncolporites pokornyi*, three species that appear at the base of the *Verrucatosporites usmensis* zone of Germeraad et al. (1968) are not found in the studied section. Moreover, Germeraad et al. (1968) included in their paper a palynological distribution of the "Paz de Río surface section", but its location is not well indicated (see the figures 1 and 17 of Germeraad et al., 1968). In this section, they used the names Cacho Sandstone ("Cacho Sst."), Bogotá and Limbo Sandstone ("Limbo Sst."), probably equivalent to the Areniscas de Socha, Arcillas de Socha and Picacho Formations respectively. Porta (1974) suggested that this section could be located near the

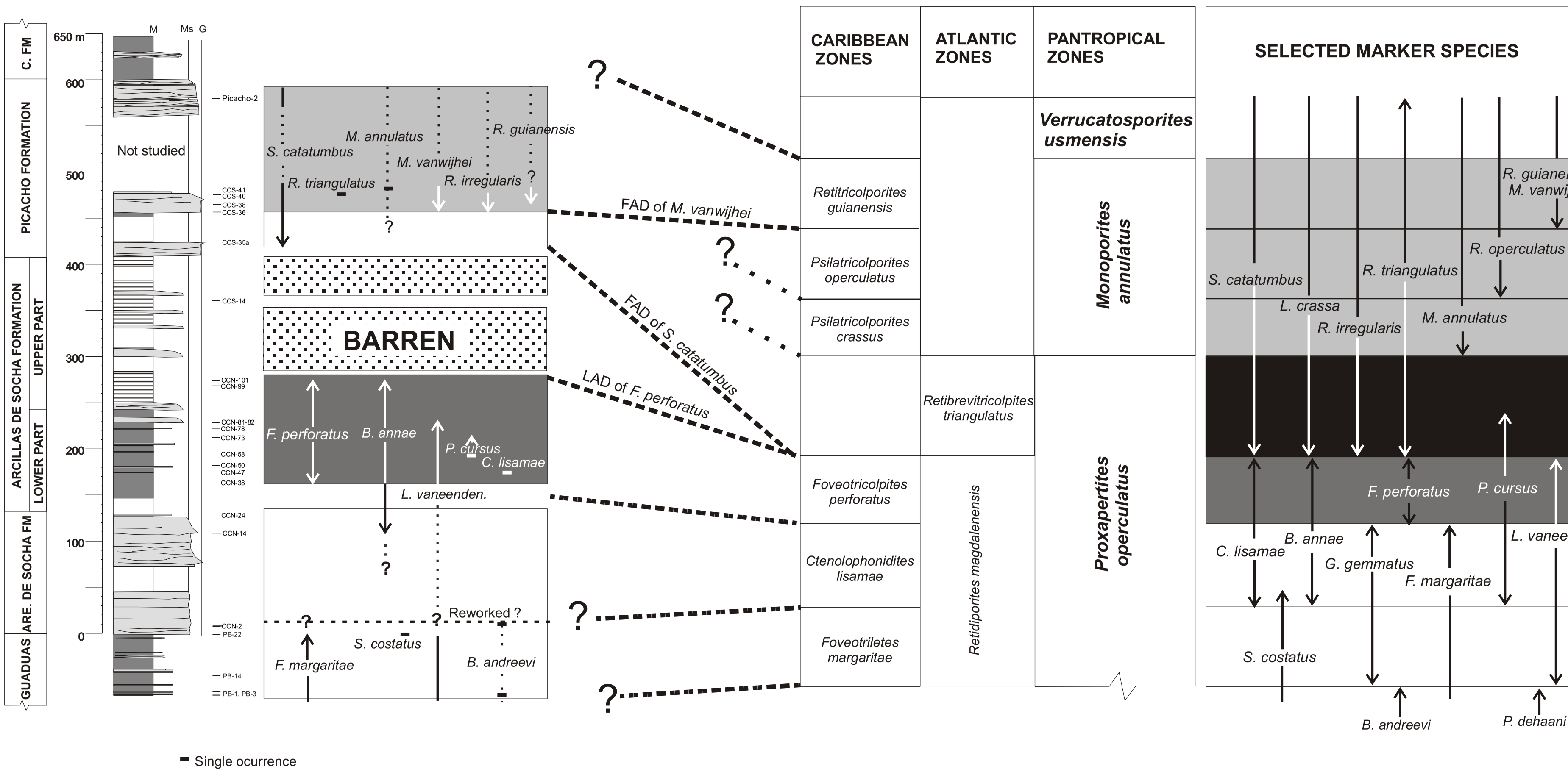


Figure 3.7. Correlation between the Paleocene-middle Eocene palynologic zones of Germeraad et al. (1968) and the Paz de Río section. See figure 3.4 for conventions.

Cravo Sur river in the eastern border of the Eastern Cordillera, where some of this lithostratigraphic names have been used. In any case, our results are in agreement with the palynostratigraphic position of their Cacho and Bogotá Formations; but the new data obtained at the base of the Picacho Formation, allow to identify the *Retibrevitricolpites triangulatus* and the *Monoporites annulatus* zones and not only the *R. triangulatus* zone suggested by Germeraad et al (1968) (figure 3.7).

The figure 3.8 shows the correlation of our palynostratigraphical data with those of Muller et al (1987). At the base of our section there are few marker species used by Muller et al. (1987) in their zonation. The Guaduas Formation has the LAD of *Spinizonocolpites baculatus* (sample PB-14), which indicates the upper limit of the zone 14 of Muller et al. (1987). Nevertheless, *Bombacacidites* and *Mauritiidites franciscoi* are not present in this interval. *Gemmastephanocolpites gemmatus*, a marker of the zone 15 of Muller et al. (1987) is not recorded in our study area. Nevertheless, the FAD of *Foveotricolpites perforatus* the marker species of the zone 16 of Muller et al. (1987) is located at the base of the Arcillas de Socha Formation. Thus, the *G. gemmatus* zone 15 could be located between the top of the Areniscas de Socha Formation and the uppermost Guaduas Formation. A specimen similar to *Rugutricolporites felix*, the marker species of the zone 17 of Muller et al. (1987), is identified only in one stratigraphic level 40 m above the contact with the Arcillas de Socha-Picacho Formations (sample CCS-36). Nevertheless, several species whose FAD is located by Muller et al. (1987) at the base of this zone (not showed in the figure 3.8), are well recorded in our section some meters below the sample CCS-36 (e.g. *Retitrescolpites*? *irregularis*, *Margocolporites vanwijhei*, *Striatopollis catatumbus* and *Spirosyncolpites spiralis*). *Retitrescolpites*? *magnus*, a marker species of the zone 19 of Muller et al. (1987) is not recorded in our section. Nevertheless, *Bombacacidites* sp. B another species that characterizes this zone, is present in the sample CCS-38, 58 m above the base of the Picacho Formation. *Bombacacidites soleaformis* is present at the top of the Picacho Formation (sample Picacho 2), which indicates the *Bombacacidites soleaformis* zone 19 of Muller et al. (1987). Nevertheless, in our section, the species *Rhoipites guianensis* used by Muller et al. (1987) to establish the zone 20, overlaying the *B. soleaformis* zone, is located below the level which *Bombacacidites soleaformis* occurs. This “anomaly” has been already noted by Jaramillo and Dilcher (2001) at the Pinalerita section in the Llanos border (figure 1.1).

The palynological data of Guerrero and Sarmiento (1996) and Jaramillo and Dilcher (2001) were grouped in a composite stratigraphic log in order to make a graphic correlation with our data (figure 3.9). The lower 300 meters of this log are based on the “Quebrada La Paz” and “Quebrada Guadualera” stratigraphic sections (Guerrero and Sarmiento, 1996), located in the Llanos border, 138 km to the SW of the Sogamoso-Paz de Río section. They include the Guaduas, Areniscas de Socha (= Areniscas del Morro) and the lowermost Arcillas de Socha (= Arcillas del Limbo) Formations (for a discussion about these nomenclatures see Guerrero and Sarmiento, 1996). The palynology of the last 770 meters of the composite section is based on the Piñalerita Section (Jaramillo and Dilcher, 2001), located 27 km to the east of the Guadualera section. It includes the Arcillas del Limbo, Areniscas del Limbo and lowermost San Fernando formations. The figure 3.9 shows the graphic correlation between these two regions. The correlation line must be divided into two segments due to the barren interval located to the upper part of the Arcillas de Socha and lower Picacho Formations. The lower segment was draw with the LAD of *Stephanocolpites costatus*, *Spinizonocolpites baculatus*

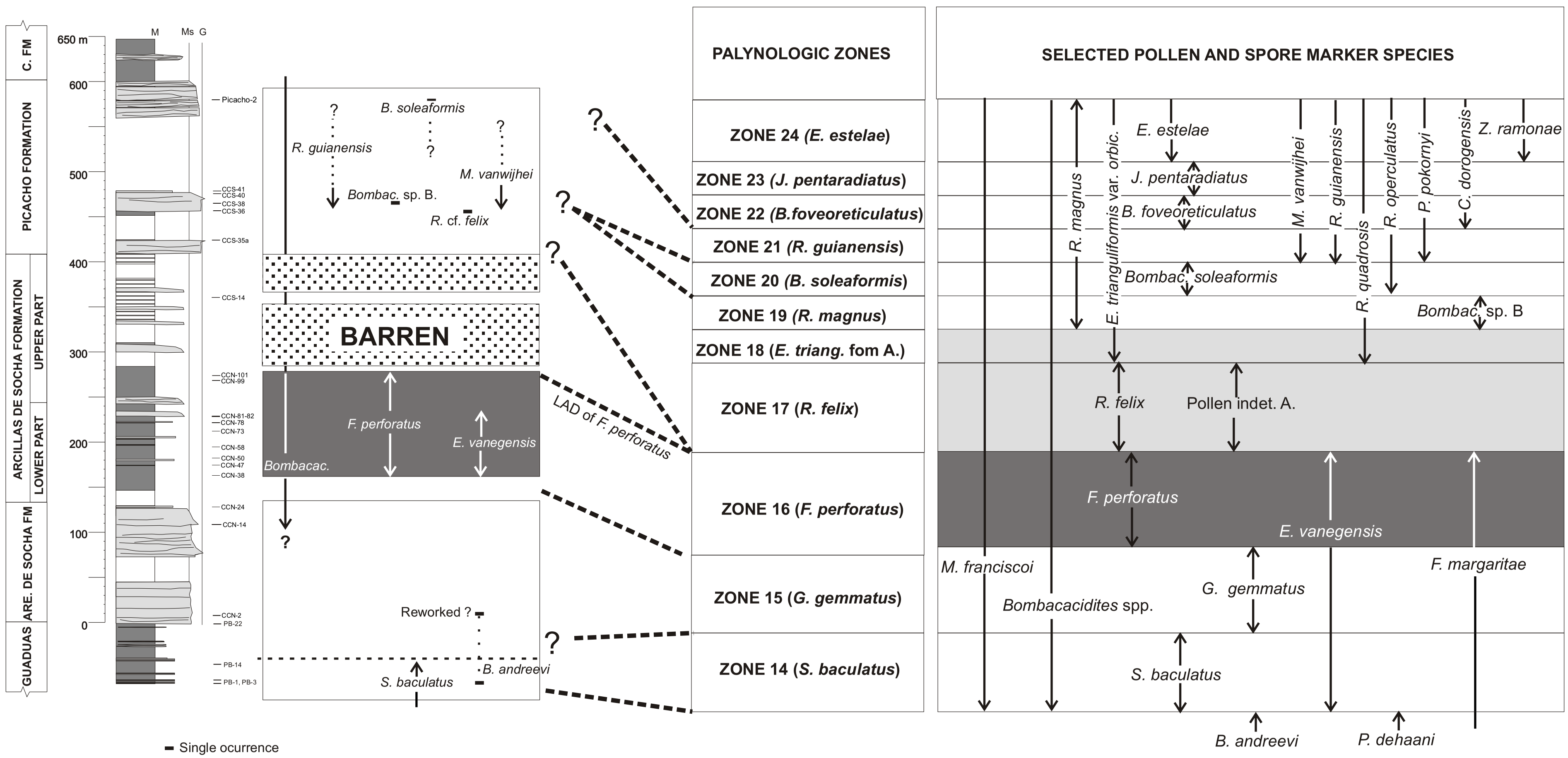


Figure 3.8. Correlation between the Paleocene-middle Eocene palynologic zones of Muller et al. (1987) and the Paz de Rio section. See figure 3.4 for conventions.

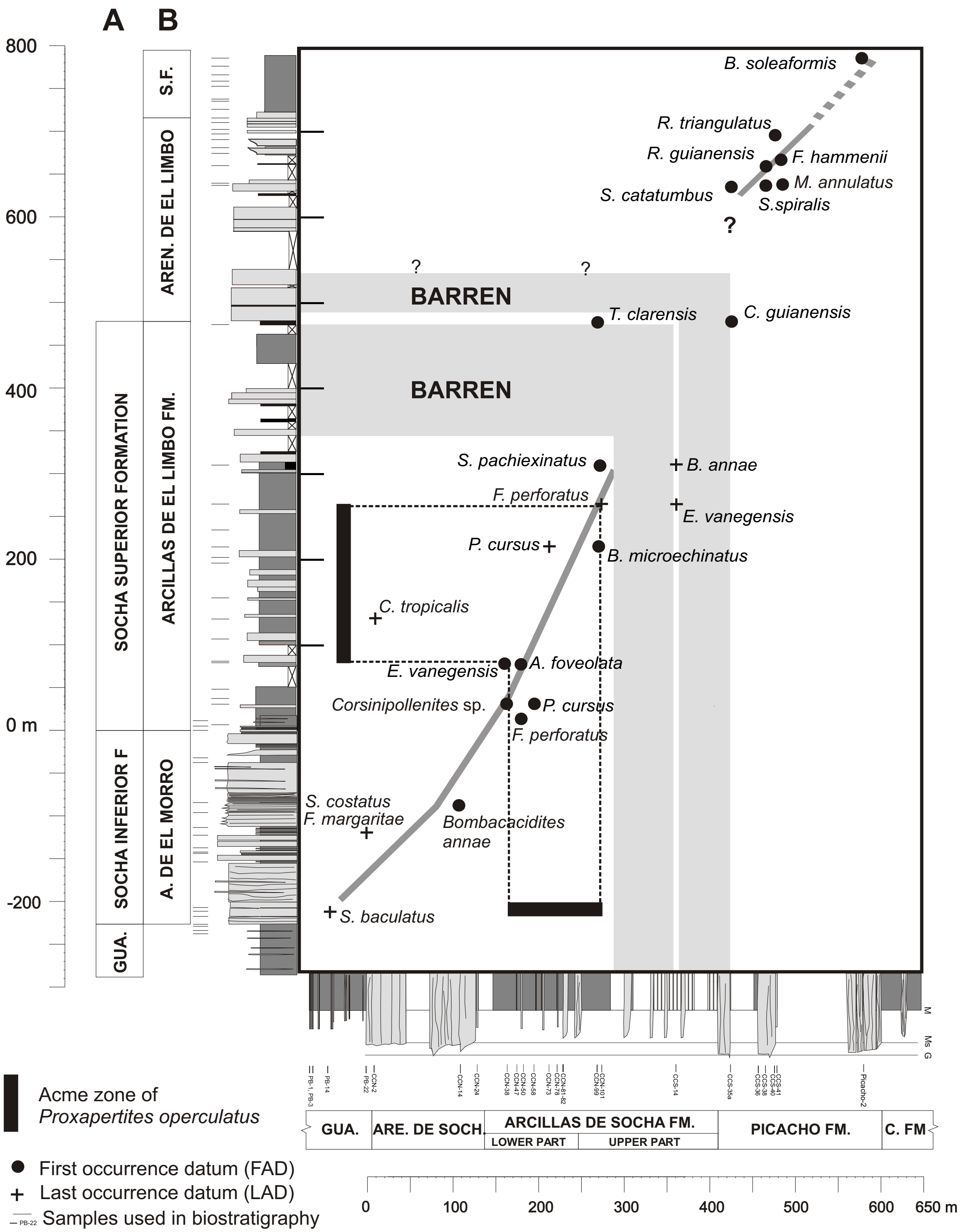


Figure 3.9. Graphic correlation between the Paz de Rio Section and the Llanos border (data of Guerrero and Sarmiento, 1996 and Jaramillo and Dilcher, 2001). A: Lithostratigraphic nomenclature used by Guerrero and Sarmiento (1966); B: nomenclature used by Jaramillo and Dilcher (2001). Gua: Guaduas Formation. A. de El Morro: Arenisca de El Morro Formation. Aren. de El Limbo: Areniscas de El Limbo Formation. S.F: San Fernando Formation. Are. de Soch: Areniscas de Socha Formation. C. Fm: Concentración Formation.

and *Foveotriletes margaritae*, which occur at the top of the Guaduas Formation in the Sogamoso-Paz de Río area and at the base of Areniscas de Socha in the Llanos border. This could reflect heterochrony between these lithologic units, but it could also be due to sampling gaps because the Areniscas de Socha Formation is very poor in pollen and spores at the Sogamoso-Paz de Río area. This fact diminishes the reliability of the correlation line in this interval. On the other hand, the FAD of *Bombacacidites annae* which seems to be an important stratigraphic marker in the basin is located at the upper part of the Socha inferior Formation in both areas. *Foveotricolpites perforatus*, *Corsinipollenites* sp. (*C. psilatus* of Jaramillo and Dilcher, 2001), *Proxapertites cursus, Ephedripites vanegensis* and *Aglaoreidia*? *foveolata* have their FAD at the lower part of the Socha Superior Formation. *Proxapertites magnus* is common in this interval in both areas.

The upper part of the Socha Superior Formation is characterized by the LAD of several pollen taxa in both sections (e.g. *Foveotricolpites perforatus*, *Proxapertites cursus*, *Bombacacidites annae* and *Ephedripites vanegensis*), but they occur below or between the mottled shales, making difficult the positioning of the correlation line. Therefore, we used the acme zone of *Proxapertites operculatus* for its location (figure 3.9). Additionally, *Spinizonocolpites pachyexinatus* a species that seems to have its FAD at the upper part of the Socha Superior Formation in both sections was also used in the correlation. The resulting line has a dip ranging between 50-65°, suggesting that the general mean rock accumulation in the Llanos border was higher than the Sogamoso-Paz de Río Section. Following the barren interval, several regional markers have their FAD at the Picacho Formation (e.g. *Striatopollis catatumbus*, *Spirosyncolpites spiralis*, *Monoporopollenites annulatus*, *Rhoipites guianensis*, *Foveotriporites hammenii*). Unfortunately, only a short interval of this formation was studied in detail and consequently the position of the correlation line cannot be well established.

Our data were also compared with data from the MMVB section (see chapter 2). The figure 3.10 shows the graphic correlation between these regions. As in the Llanos border section the correlation line is divided into two segments due to the occurrence of the barren interval. The high slope of the correlation line shows the great difference in the sediment accumulation rate between these areas. The vertical correlation line obtained in the lower part of the Picacho Formation suggests an unconformity or a condensed section at the Paz de Río area.

Sarmiento (1992b) performed a detailed palynologic analysis of the Guaduas Formation in the Sutatausa area 146 km to the SW of our section (see the chapter 1). In this region he subdivided this unit into two zones: the *Buttinia andreevi* zone (or zone I), which is equivalent to the *Proteacidites dehaani* of Germeraad et al. (1968) and the *Foveotriletes margaritae* zone (or zone II), equivalent to the *F. margaritae* of Germeraad et al. (1969). The zone II is also subdivided into two sub-zones: *Zonotricolpites variabilis* and *Syncolporites lisamae*. At the Peña Blanca area some of the samples taken in the last 65 m of the Guaduas Formation are relatively rich in pollen and spores and thus can be compared with the palynostratigraphic schema of Sarmiento. The following species are recorded: *Collombipollis tropicalis*, *Buttinia andreevi, Ulmoideipites krempii*, *Proxapertites humbertoides*, *Spinizonocolpites baculatus, Spinizonocolpites sutae, Proxapertites psilatus*, *Psilabrevitricolporites annulatus, Psilamonocolpites operculatus*, *Psilamonocolpites medius*, *Racemonocolpites racematus, Foveomonocolpites* sp., *Longapertites vaneendenburgi*, *Stephanocolpites costatus, Cicatricososporites* sp. and *Psilatriletes martinensis*. Between them, *Psilabrevitricolporites*

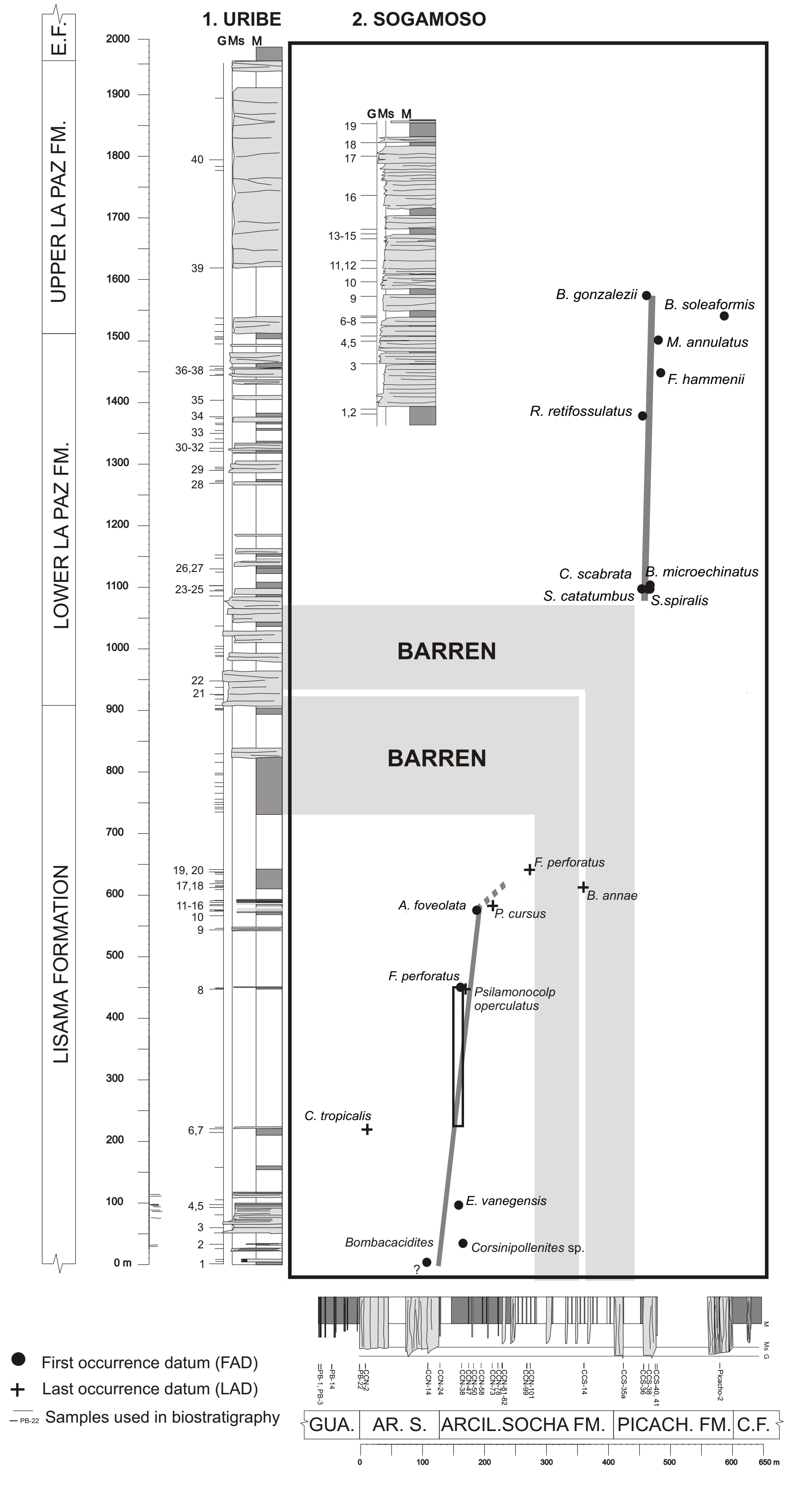


Figure 3.10. Graphic correlation between the Paz de Rio Section and the Uribe and Sogamoso sections (Middle Magdalena Valley Basin). GUA: Guaduas Formation; AR. S: Areniscas de Socha Formation; ARCIL. SOCHA FM: Arcillas de Socha Formation; PICACH. FM: Picacho Formation; C. F: Concentración Formation.

annulatus, Proxapertites psilatus, Longapertites vaneendenburgi and *Racemonocolpites racematus* appear within or few meters below the limit between the zones I and II of Sarmiento (1992). On the other hand, *Spinizonocolpites sutae* and *Psilatriletes martinensis* which characterize the sub-zone IIb occurs at the base of the studied sequence (samples PB-1 and PB-3). The *Syncolporites lisamae* species which is also characteristic this sub-zone, is not recorded. Thus, these new palynological data area is in disagreement with the hypothesis of Sarmiento (1994), who suggested an erosion phase of part of the zone IIa and all the zone IIb at the Peña Blanca area (see also Osorno, 1994). Additionally, the information obtained in this work shows that some pollen and spore species that occurs at the uppermost part of the Guaduas Formation at the Peña Blanca section, were not recorded by Sarmiento in the Sutatausa area (e.g. *Psilamonocolpites operculatus, Stephanocolpites costatus, Cicatricososporites* sp. and different zonate spores). Sarmiento (1992a) indicated that at the Sutatausa area the last 250 meters of the Guaduas Formation are composed of sandstones interbedded with green and red shales barren in pollen, spores and vegetal debris. This author interpreted these facies as meandering channel deposits associated with well-drained overbank and flood plain deposits. This fact prevents the location of the upper limit of the sub-zone IIb in this area. Additionally, the palynostratigraphy of the overlaying Cacho Formation (which has the same stratigraphic position and is lithologicaly similar to the Areniscas de Socha Formation), has not been studied in the Sutatausa area. In our section these green and red barren deposits are not present. This phenomenon could be explained by an erosion event or a lateral variation in the redox conditions that favoured the organic matter preservation at the Paz de Río area.

Based on palynological data, Guerrero and Sarmiento (1996) proposed a “late” Paleocene (“Thanetiano”) and early Eocene ("Ypresian") age for the Areniscas de Socha and Arcillas de Socha Formations respectively, at the Llanos Border area. These authors mentioned the presence of *Stephanocolpites costatus* and *Foveotriletes margaritae* in the lower part of the Areniscas de Socha Formation and the FAD of *Bombacacidit*es *annae* and *Longapertites vanendeenburgi* at its upper part. Based on these data an early-middle Paleocene age is more probable according to the Germeraad et al. (1968) and Muller et al. (1987) biozonal schemas. On the other hand, the age Ypresian proposed by Guerrero and Sarmiento (1996) for the Arcillas de Socha Formation is suggested by the presence of *Retibrevitricolpites triangulatus* species, which was used by Germeraad et al. (1968) to propose the *Retibrevitricolpites triangulatus* early Eocene Caribbean zone. Nevertheless, Guerrero and Sarmiento (1996) recorded also *Foveotricolpites perforatus* in this unit, a marker species of the lattermost Paleocene Caribbean zone of Germeraad et al. (1968) and Muller et al. (1987). This incompatibility was not discussed by the authors. Anyway, the palynological data obtained by Jaramillo and Dilcher (2001) for all the Arcillas de Socha Formation in this area suggest rather a “late” Paleocene age (*Foveotricolpites perforatus* zone of Germeraad et al. 1968), and are very similar to those found in the lower–middle part of the Arcillas de Socha Formation at the Paz de Río area.

3.3.3. Palynostratigraphic correlation across the Eastern Cordillera

With the information presented above we propose a biostratigraphic and lithostratigraphic correlation of the Paleocene-Eocene rocks from the Middle Magdalena Valley Basin, Eastern Cordillera and Llanos border. The chronostratigraphic calibration of the pollen distribution is based on Germeraad et al. (1968). The figure 3.11 shows the correlation between these regions. Based on the graphic correlation presented above, four "time equivalent" lines are included, which correspond to the FAD of some important pollen markers in the basin used by Germeraad et al. (1968) in their biozonation: *Bombacacidites*, *Foveotricolpites perforatus*, *Striatopollis catatumbus* and *Monoporopollenites annulatus*. It is important to point out that these first appearances are located near or inside the correlation lines constructed with several taxa (figures 3.9 and 3.10), supporting their chronostratigraphic correlation value. In the Middle Magdalena Valley Basin *Bombacacidites* is already present at the base of the Uribe section, preventing the location of the correlation line. Nevertheless, Van der Hammen (1954a) did not found this genus in the underlying Umir Formation in the Agua Blanca and the Río Lebrija sections near Vanegas (figure 2.1). Thus, we can constrain its FAD near the base of our section. In contrast, the FAD of *Bombacacidites* can be located with some degree confidence inside the Areniscas de Socha and the Areniscas del Morro Formations. In the same way, the FAD of *Foveotricolpites perforatus* is relatively well constrained at the Paz de Río and Llanos Border sections (figures 3.9 and 3.11). Unfortunately, due to a big covered interval in the MMVB, the FAD of the former species can be only inferred between the samples 7 and 8, separated by a 226 meters cover interval (figure 3.11).

As previously mentioned, there is a sequence of mottled shales at the top of the Lisama, Arcillas de Socha and Arcillas del Limbo Formations. The scarcity or absence of biostratigraphical information prevents to determine the synchrony or heterochrony of this phenomenon between the studied areas. Many authors have suggested a hiatus between the shaley Lisama- Arcillas de Socha-Arcillas del Limbo Formations and the sand dominated La Paz-Picacho and Areniscas de El Limbo Formations. As it can be observed in the figures 3.9 and 3.10 the resolution of the palynologycal data in this part of the sequences cannot give a direct answer about the occurrence and/or duration of this event. Nevertheless, it is interesting to remark the great difference in the separation of the FAD of *Striatopollis catatumbus* and *Monoporopollenites annulatus* between these areas: 413 meters in the Middle Magdalena Valley Basin, 55 meters at the Sogamoso-Paz de Río area, and 0 meter at the Llanos Border section. According to Germeraad et al. (1968), this interval represents the lattermost Paleocene-early Eocene. Thus a high accommodation rate in the MMVB can be suggested for this interval, and probably a hiatus (?) or a condensed section at the Sogamoso-Paz de Río and Llanos Border sections. The figure 3.12 illustrates a chronostratigraphic correlation between these areas using palynology and the seismic data of the MMVB (e.g. Gomez, 2001). Nevertheless, there are not enough solid independent chronostratigraphic data and consequently this schema must be considered as a working hypothesis. Two hiatus are indicated, the first one, is based on Sarmiento (1994) who demonstrated the absence of his palynological zones IIa and IIb, of probable Danian age, at the Llanos Border section. As some of the marker pollens of these biozones were found in the Paz de Río area, the available palynological resolution cannot demonstrate the presence of an unconformity. Nevertheless, we put a short duration hiatus in this area due to the high facies contrast between the Guaduas and the Areniscas de Socha Formations. At the MMVB the units with equivalent palynological associations (Umir and lower part of Lisama Formation) are thicker that in the former areas and their facies change seems to be rather gradual (cf. Van der Hammen, 1957). Nevertheless, detailed facies studies of this area are not published.

Some authors (e.g. Van der Hammen, 1958) have considered the Paleocene-Eocene boundary

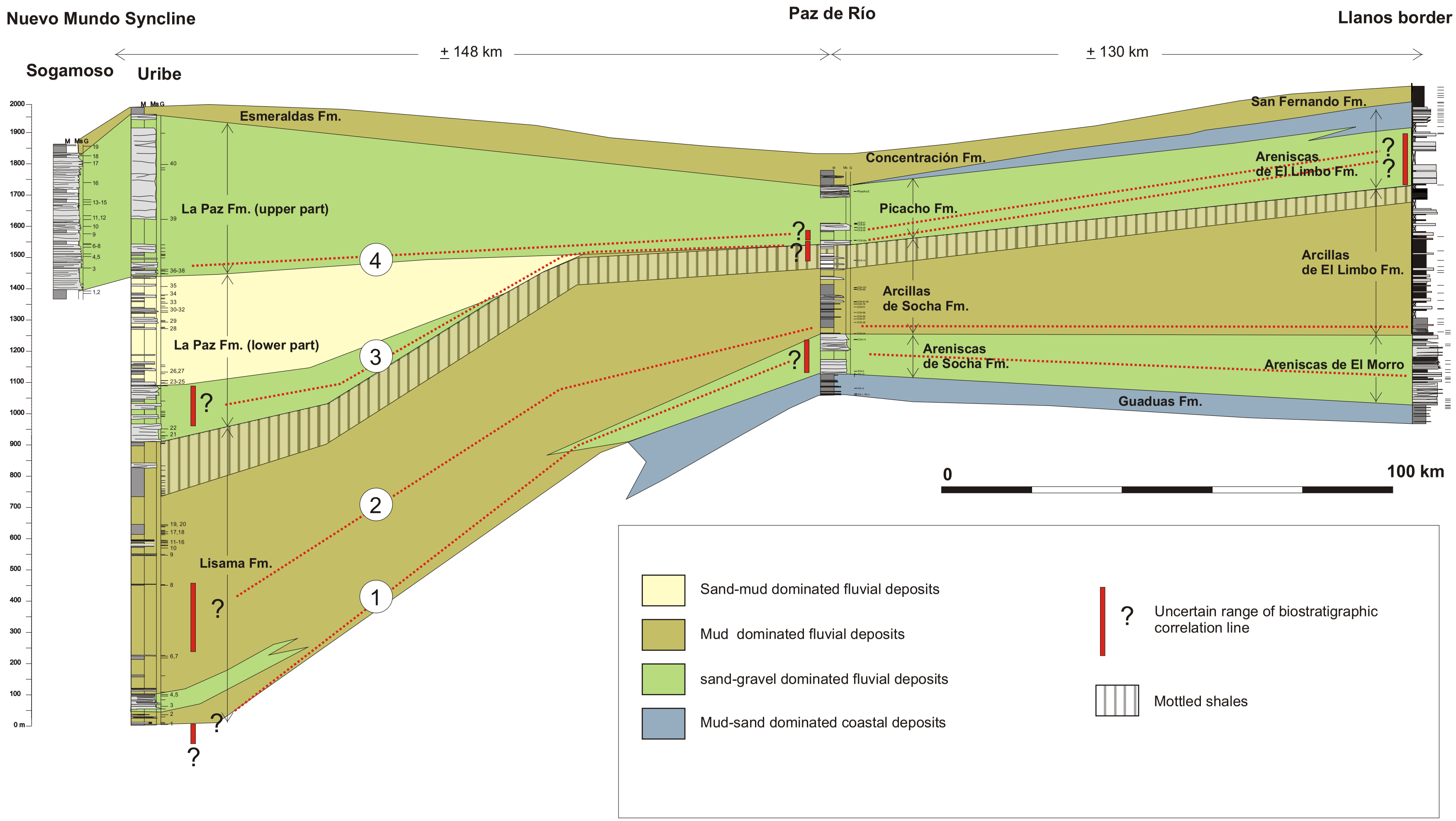


Figure 3.11. Main depositional environments and palynologic correlations of the Paleocene-Eocene rocks from the Llanos border (data from Jaramillo & Dilcher, 2001 and Guerrero & Sarmiento,1996), Paz de Rio composite section (this work) and the eastern Middle Magdalena Valley (Sogamoso and Uribe sections; Pardo et al., 2003). 1: FAD of *Bombacacidites*; 2: FAD of *Foveotricolpites perforatus*; 3: FAD of *Striatopollis catatumbus*; 4: FAD of *Monoporopollenites annulatus*.

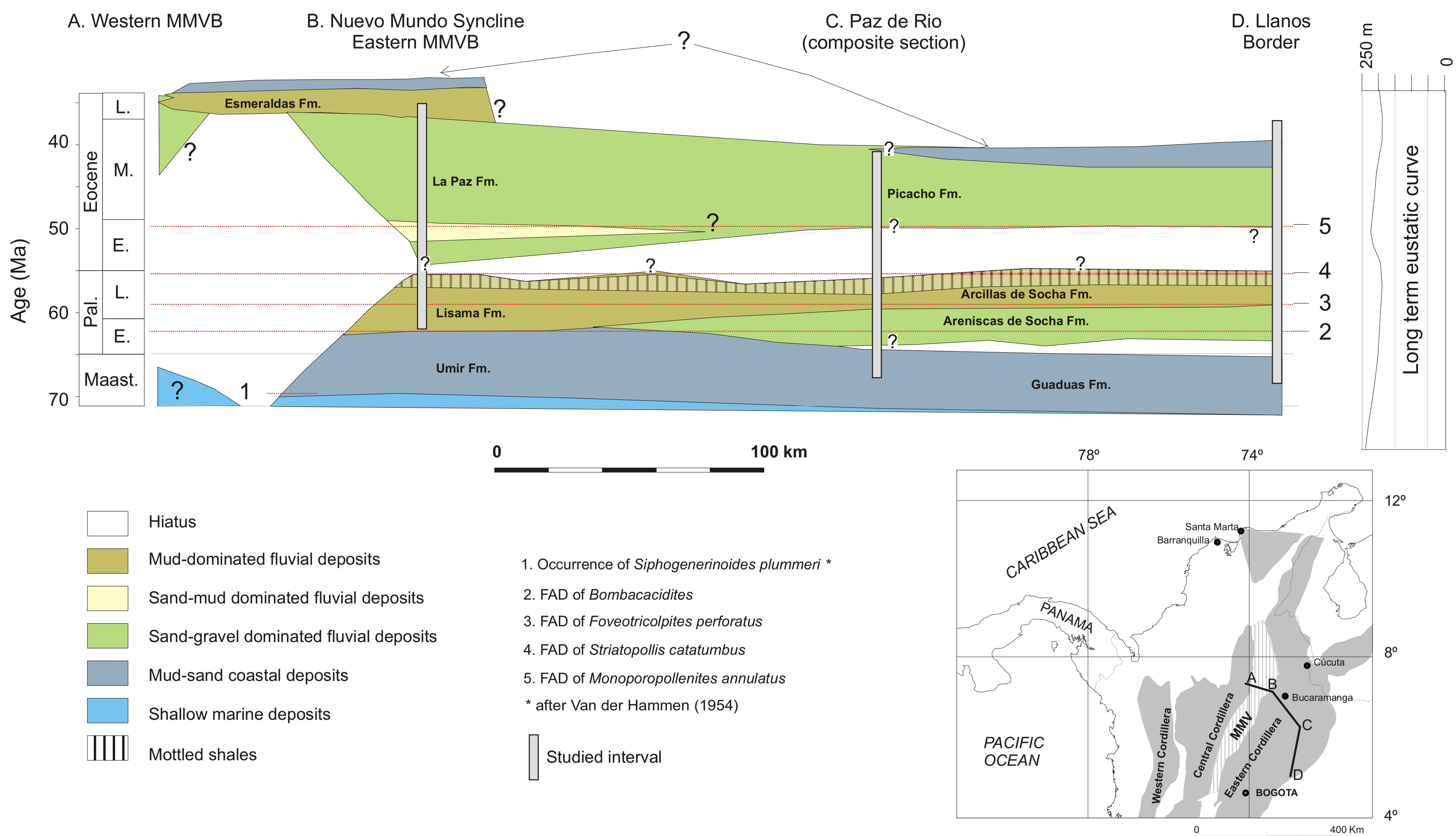


Figure 3.12. Hypothetical chronostratigraphic chart of the upper Cretaceous-Eocene deposits of the Llanos border (data from Jaramillo and Dilcher, 2001 and Guerrero & Sarmiento,1996), Paz de Rio section (this work) and Middle Magdalena Valley basin (MMVB) (Pardo et al., 2003 and Gómez,2001). The calibration of palynologic occurrences is based on Germeraad et al. (1968). Explanation in the text.

to be located at the upper part of the Arcillas de Socha Formation. In the present study more than fifty samples were prepared for this interval and only two of them gave some limited palynological information without any Eocene marker taxa. For this reason, we think that the location of the Paleocene-Eocene boundary in this sector is purely speculative. The presence of microscopic organic matter in some samples of this part of the sequence could be used to perform a carbon isotopes analysis in order to test the presence of the delta ^{13}C excursion adopted as the official Paleocene-Eocene boundary by the International Commission on Stratigraphy (ICS) (e.g. Gradstein et al., 2004).

3.3.4. General Palynofloral changes in the Paz de Río section

The figure 3.13 is a general diagram with the stratigraphic distribution of some selected palynomorph groups (see the chapter 1 for explanation of this diagram). It can be divided in 3 stratigraphic intervals:

Areniscas de Socha Formation: There are only 3 productive samples in this interval; the angiosperms, palms and spores are the most abundant groups. The Other angiosperms group has an increasing abundance, the palms have values near to 50 % and the spores have a decreasing abundance. *Bombacacidites* is present at the upper part (6%). In contrast *Mauritia*, *Proxapertites* and the reworked palynomorphs are present in very low percentage ($\leq$ 1 %).

Arcillas de Socha Formation: 11 samples were analyzed in this formation. The Other angiosperms group has a general decreasing abundance. The *Bombacacidites* group occurs generally in less than 7 % (the sample CCN-58 is an exception with 32 %). In the *Mauritia* group there are only two samples with more than 10 % (CCN-78 and CCN-82 with 26 and 13 % respectively). The Palms group has an abundance decreasing first then increasing to more than 70 % (sample CCN-99). The *Proxapertites* group is relatively abundant and can reach more than 80 % (sample CCN-73). It shows a general increasing-decreasing trend opposite of the Palms. The spores in general occur in less than 25 %, but exceptionally can reach more than 80 % (sample CCN 81). Reworked palynomorphs are not found in this interval. The uppermost part of the Arcillas de Socha Formation is very poor in pollen and spores. The sample CCS-14 is the only one productive in palynomorphs. In order of decreasing abundance it includes: Other angiosperms group (33%), Spores (23%), Palms (17%), *Proxapertites* (16%), *Mauritia* (6%), Reworked palynomorphs (4%) and *Bombacacidites* (1%).

Lower Picacho Formation: In this interval the Other angiosperms group is in general the most abundant. It surpasses the 50 % at the top of the studied interval. *Bombacacidites* and *Mauritia* have less than 10 %, except the sample CCS-38 with 14%. *Proxapertites* is practically absent. The reworked palynomorphs are present in almost all the studied samples but in very low percentages.

3.4. PALYNOFACIES

3.4.1. General remarks

The organic matter of the Paz de Río section has a TAI between 2+ and 3 (color scale of Traverse, 1988). The figure 3.14 shows the stratigraphical distribution of the different

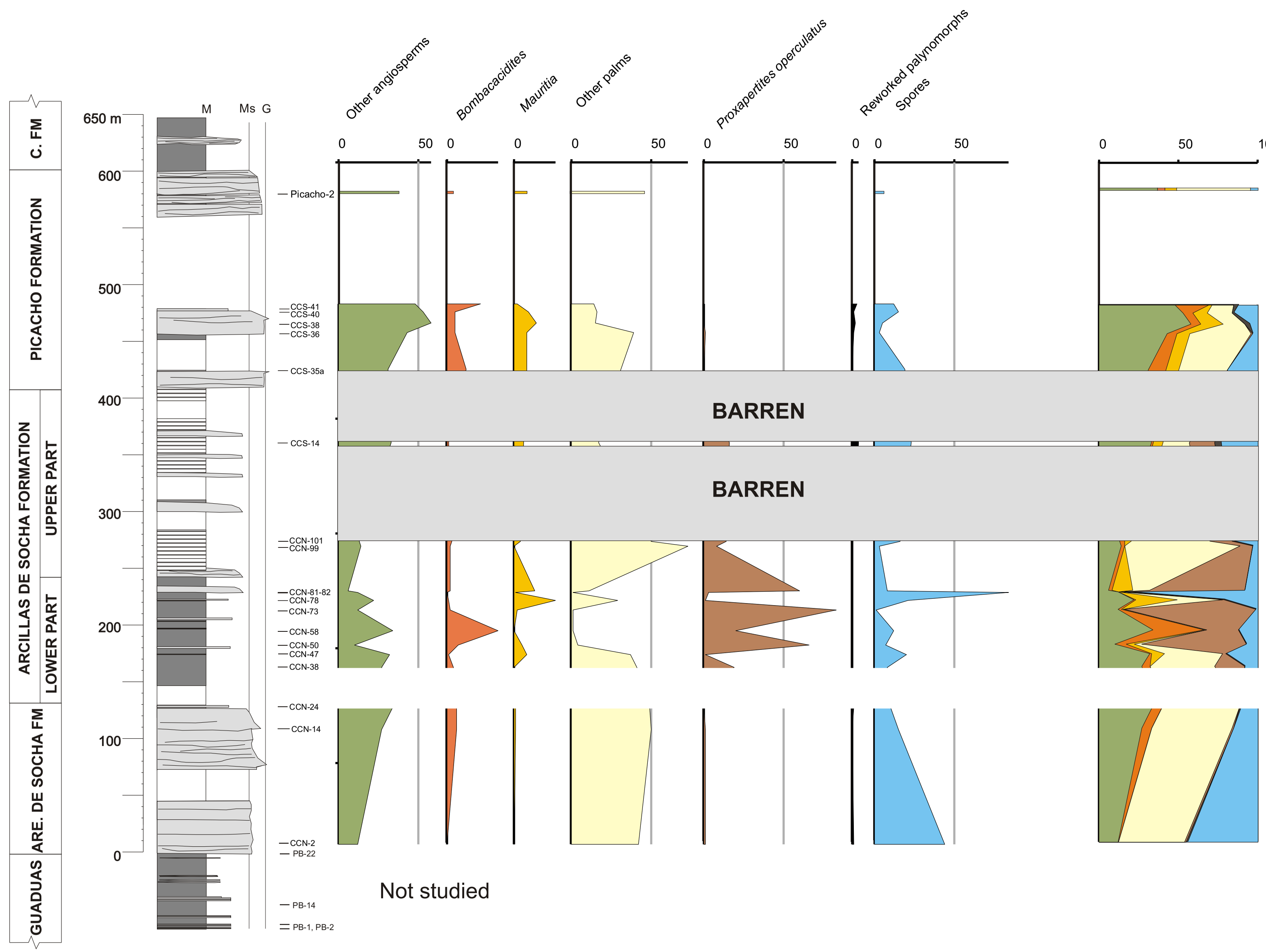


Figure 3.13. Stratigraphic distribution of general groups of palynomorphs at the Paz de Río section. For conventions, see figure 3.4.

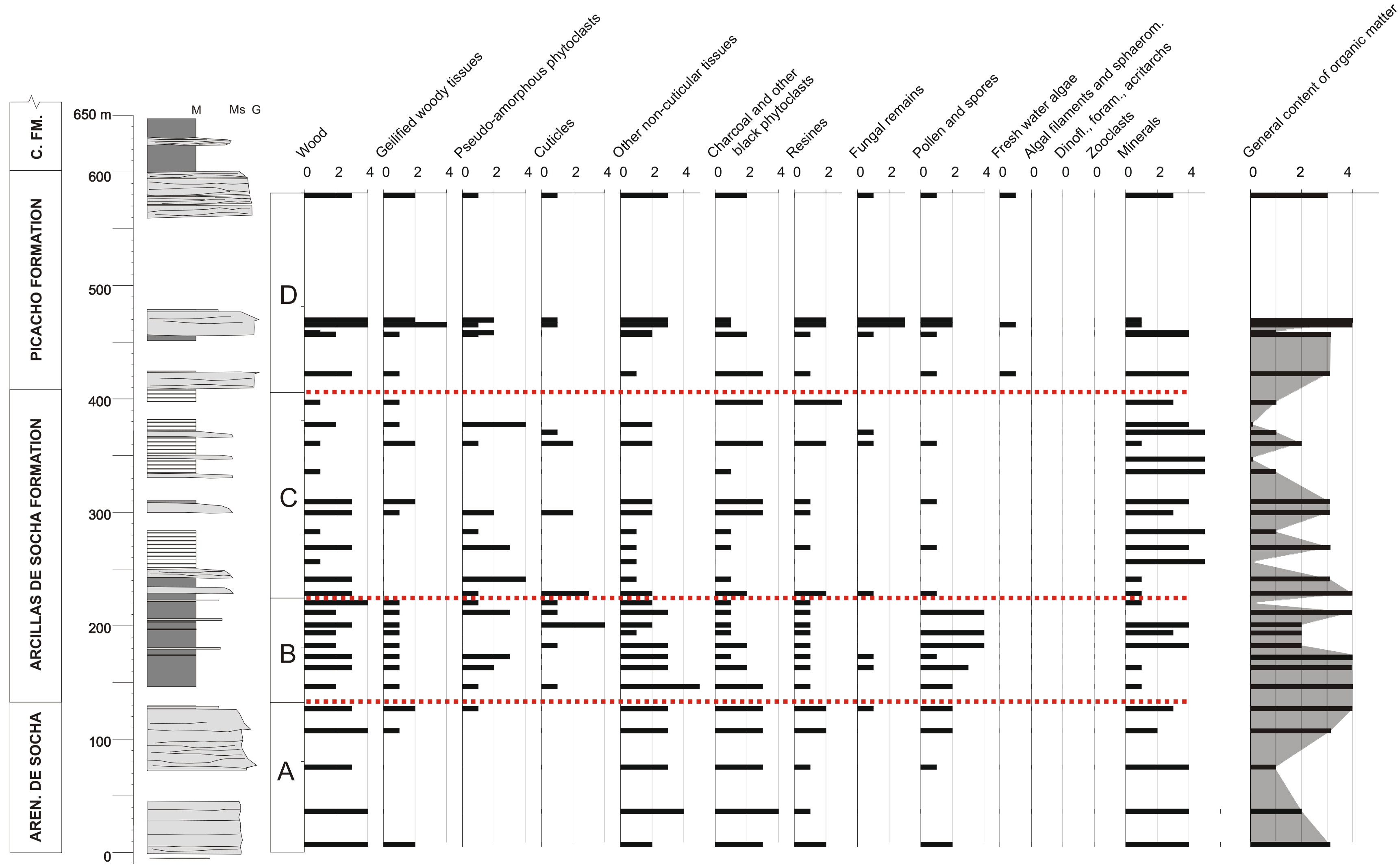


Figure 3.14. Semi-quantitative stratigraphic distribution of microscopic organic matter (Paz de Rio section). The letters represent the palynofacies described in the text. 1: present; 2: common; 3: abundant; 4: very abundant. See figure 3.4 for conventions.

categories of organic particles used in this study (see chapter 1). Four palynofacies types can be recognized which correspond to the main lithological types:

A. The samples of the Areniscas de Socha Formation are mainly composed of wood, other non-cuticular tissues, black phytoclasts and minerals. The gelified woody tissues, pseudo-amorphous phytoclasts and cuticles are practically absent.

B. The Lower Part of the Arcillas de Socha includes mostly terrestrial particles. The “other non-cuticular tissues” and the pollen and spores are particularly abundant.

C. The upper part of the Arcillas de Socha Formation. In this sector the terrestrial particles are less common and the proportion of detritic minerals increases. In the same way, there is a decreasing trend in the organic matter concentration. As previously suggested this phenomenon can be associated with post depositional oxidation of the organic matter (figure 3.14).

D. The Picacho Formation: in this part of the diagram the concentration of organic matter increases and the wood, gelified woody tissues and fungal remains became abundant.

At the upper part of the Arcillas de Socha and in the Picacho Formation sequence *Pediastrum* is common (appendix 3.2). In contrast, dinoflagellate cysts are recorded only in three levels in a very low percentage (one specimen by stratigraphic level).

3.4.2. Quantitative distribution of pollen, spores and fungal remains at the Paz de Río area

In the same way than for the Middle Magdalena area, a detailed count of pollen, spores and fungal remains was performed for the Paz de Río area. The figure 3.15 shows the results of this study. The samples of the Areniscas de Socha Formation have very low concentrations of pollen, spores and fungal remains (less than 1,000 palynomorphs by gram of rock). In contrast, the samples of the lower part of the Arcillas de Socha Formation have the highest concentrations. In one sample it surpasses the 100,000 pollen grains by gram of rock. In this interval, the fungal remains have lower concentration values than the pollen and spores. An important decrease in the palynomorph concentration can be observed in the samples located in the dominant mottled shale interval. In this part of the sequence the samples have less than 1,000 palynomorphs by gram of rock. At the Picacho Formation the relative percentage of fungal remains increases and its concentration values surpasses those of the pollen and spores (figure 3.15).

3.5. PALEOCURRENT ANALYSIS

In the studied units, there are many sandstone bodies with current-ripples and cross-bedding structures at different scales, which can be used to reconstruct the local and regional current flow patterns at the time of deposition. This information can be useful to interpret depositional environments, sedimentary sources, regional transport of the sediments and their associated organic matter (e.g. Potter and Pettijohn, 1963). Three sectors were chosen for the paleocurrent analysis: Vado Castro, Peña Blanca and the Curva de Cosgua section (figure 3.1).

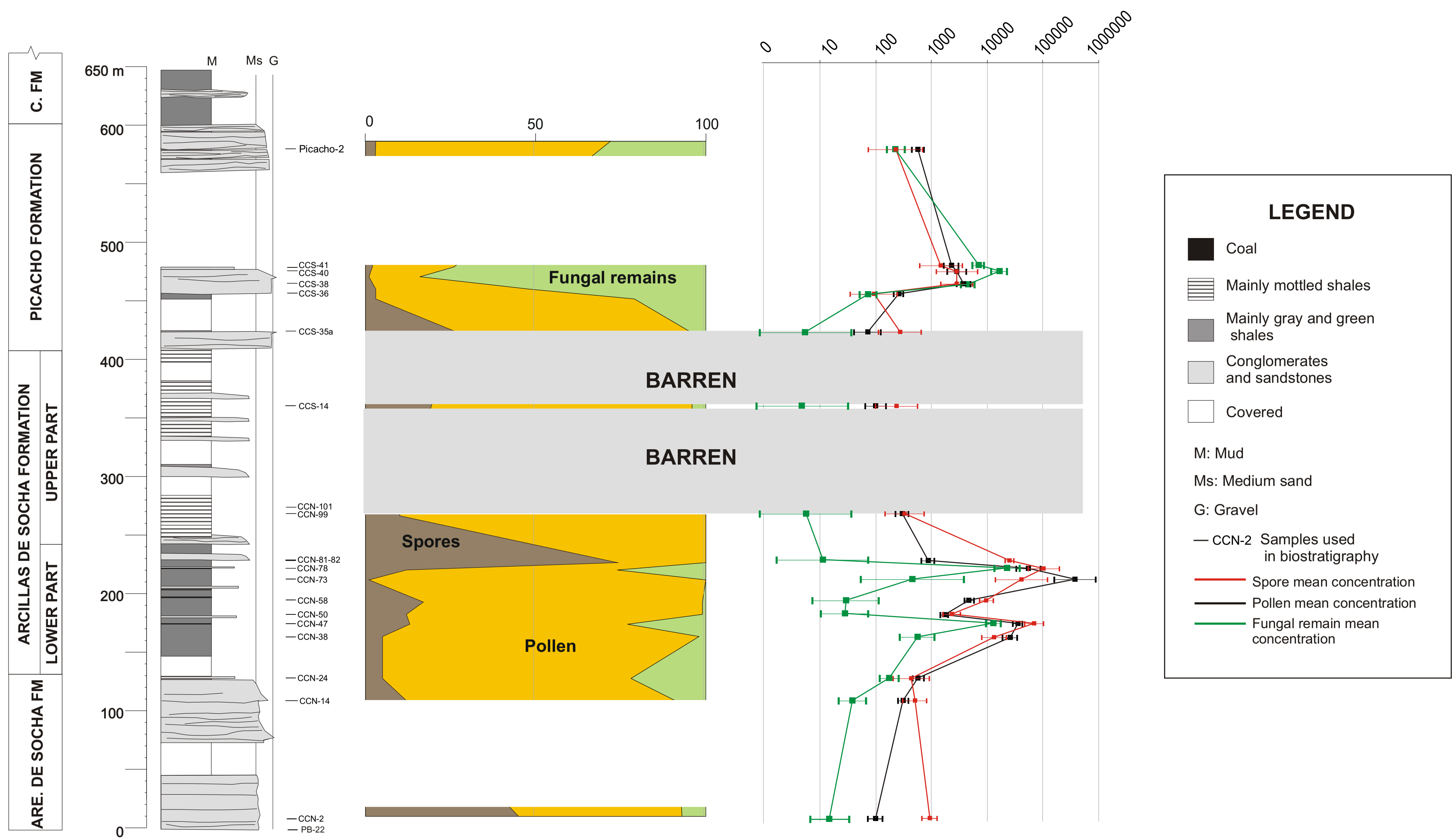


Figure 3.15. Relative percentages and concentration values of spores, pollen and fungal remains from the Paleocene-Eocene rocks from the Paz de Rio area. The biostratigraphical samples were only used in this study. Concentration values are in palynomorphs by gram of rock in logaritmic scale.

CURVA DE COSGUA

Areniscas de Socha Formation (CCN section)

No.	Meters with respect to the base of the CCN section	Strike and dip of foresets	Azimuth of dip of foreset	Dip of the foresets	Structure Type	Bedding	Corrected azimuth	Corrected dip	Type of structure
1	15	N25E/80SE	115	80	FCB		282,8	26,9	P
2	29	N40E/65SE	130	65	PCB		312	40,3	P
3	78-82	N40E/75SE	130	75	PCB		314,6	30,4	P
4	78-82	N50E/70SE	140	70	CB		328,3	38	P
5	78-82	N55E/80SE	145	80	CB		344,6	31,9	P
6	78-82	N60E/85SE	150	85	CB		357,9	31,8	P
7	85	N40E/75SE	130	75	CB	N35E/75W	314,6	30,4	P
8	94	N25E/80SE	115	80	CB		282,8	26,9	P
9	95	N35E/75SE	125	75	CB		305	30	P
10	97	N27E/75SE	117	75	CB		289,9	31	P
11	101	N20E/75SE	110	75	CB		278	33,5	P
12	102	N15E/75SE	105	75	CB		270,7	35,9	P
13	105	N45E/80SE	135	80	CB		327,2	26,9	P
14	107	N45E/80SE	135	70	CB		321	36,4	P
15	121	N40E/65SE	130	65	CB		312	40,3	P
16	122	N60E/85SE	150	85	CB		357,9	31,8	P

Arcillas de Socha Formation (CCN section)

1	179	N30E/75SE	120	75	CB	N45E/90	271	21	P
2	228	N35E/65SE	125	65	CB	N30E/90	311	26	P
3	231	N25E/85SE	115	85	CB		255	7	P
4	242	N60W/80SE	150	80	CB	N40E/90	13	22	P
5	243	N30E/60SE	120	60	CB		293	32	P
6	334	N20E/80SE	110	80	CB	N20E/75NW	290	22	P
7	355	N30E/60SE	120	60	CB	N20E/80NW	303	43	P

Picacho Formation (CCS section)

1	116	N10E/85NW	285	85	CB	N30E/70NW	254	21	P
2	119	N40E/80NW	310	80	CB		345	14	P
3	120	N15E/90	105	90	CB		262	25	P
4	121	N24E/90	114	90	CB		283	21	P
5	144	N40E/80NW	310	80	CB	N45E/80NW	225	5	P
6	162	N45E/85SE	135	85	CB		315	15	P
7	167	N60E/85SE	150	85	CB	N35E/70NW	352	35	P
8	170	N45E/80NW	315	80	CB		350	14	P
9	172	N55E/90	145	90	CB	N40E/70NW	348	25	P
10	173	N55E/90	145	90	CB		348	25	P
11	?	N40E/90	130	90	CB	N45E/70NW	301	21	P
12	?	N35E/85SE	125	85	CB		293	27	P

PENA BLANCA

Areniscas de Socha Formation

1		N20W/55NE	70	55	FCB	N20E/70W	255	67	P
2		N50E/45NW	320	45	FCB		72,2	35,2	P

Picacho Formation (over the road)

1		N45E/60NW	315	60	CB	N20E/45NW	351	25	P
2		N70E/45NW	340	45	CB		38	35	P
3		N45E/40NW	315	40	CB		46	18	P
4		N60E/50NW	330	50	CB	N30E/35W	6	25	P
5		N30E/75NW	300	75	CB		300	40	P
6		N50E/65NW	320	65	CB		334	33	P
7		N35E/60NW	305	60	CB		310	25	P
8		N60E/50NW	330	50	CB		6	25	P
9		N10E/55NW	280	55	CB		257	24	P
10		N-S/75E	90	75	CB		270	75	P
11		N45E/65NW	315	65	CB		326	32	P
12		N45/E/60NW	315	60	CB	N30E/45NW	329	27	P

Picacho Formation (over the railroad)

1		N20E/50NW	290	50	CB	N20E/70NW	110	20	P
2		N-S/75W	270	75	CB		212	20	P

VADO CASTRO

Picacho Formation

1		N50E/65NW	320	65	CB		348,6	28,4	P
2		N45E/75NW	315	75	CB		330,8	34,4	P
3		N40E/70NW	310	70	CB		326,3	27,9	P
4		N40E/65NW	310	65	CB		331,2	23,4	P
5		N30E/55NW	300	55	CB		317,6	10,7	P
6		N25E/65NW	295	65	CB	N25E/45W	295	20	P
7		N40E/45NW	310	45	CB		30,3	10,6	P

FCB Flat cross-bedding
CB Cross bedding
P planar structure

TABLE 3.1. Paleocurrent data (Paz de Río section)

A total of 58 cross-bedding sets, located in the Areniscas de Socha, Arcillas de Socha and Picacho Formations were measured. The Figure 3.16 shows the rose diagrams obtained after the correction of the tilt of the beds with a stereographic net. Because there are not previous paleocurrent analyses in this area, the present work must be considered as a first assessment to be continued laterally at different stratigraphic levels, in order to know the regional paleocurrent patterns. Nevertheless, in this study we can appreciate a main concentration of the paleocurrent data in the NW sector of the rose diagram (figure 3.16). The 18 values of cross-bedding taken from base to top of the Areniscas de Socha in the Curva de Cosgua area display an N-NW dominant trend of the current direction. The few cross-beds measured in the Arcillas de Socha Formation show the same tendency. The lower part of the Picacho Formation has many large scale cross-bedding sets (more than 3 m of thickness); they were formed by high scale bedforms which are a better guide to determinate prevailing flow than small-scale cross-bedding sets or ripples (Pettijohn et al., 1987). Similarly to the paleocurrent values of the Areniscas de Socha Formation, the rose diagrams obtained for the Picacho Formation in Vado Castro and the Curva de Cosgua sections show a clear N-NW tendency. At the Peña Blanca area the paleocurrent vectors are more dispersed. Nevertheless, the rose diagram of all the measurements obtained in this unit show that the N-NW tendency is dominant (figure 3.16).

3.6. PALEOENVIRONMENTAL INTERPRETATION

The sedimentologic and palynologic data presented here were integrated in order to interpret the depositional conditions of the Paleogene rocks from the Paz de Río region. Moreover, the biostratigraphic data allowed integrating this information in the regional evolution of the basin (see chapter 5). The analysis presented here was mainly based on vertical and lateral facies variations at outcrop scale. This information must be completed with high scale three dimensional architectural analyses in order to understand the lateral variations of sedimentary bodies and to recognize their hierarchical boundary limits (e.g. Lopez-Gomez and Arche, 1993; Miall, 1985). The presence of large outcrops in this region (e.g. plates 3.4 and 3.5), will greatly facilitate these kinds of researches.

Areniscas de Socha Formation:

Reyes (1984) interpreted this unit as “estuarine” and lacustrine deposits. Osorno (1994) studied this unit at the Peña Blanca section, over the Tasco-Corrales road (Figure 3.1). Based on its lithofacies characteristics and some palynological data of Gustavo Sarmiento (Universidad Nacional, Bogotá), Osorno (1994) interpreted the unit as meandering and braided fluvial deposits. Guerrero & Sarmiento (1996)**,** proposed a braided fluvial origin for a similar unit at the llanos border section.

Our study was performed only for the vertical section of the Curva de Cosgua area. Cartographic researches show a more or less uniform regional extension of this sandstone-dominated unit (e.g. Reyes, 1984). The presence of current-ripples and small dunes that cover the big cross-bedded units, indicate long and/or short-term changes in the flow regime. These associations can be interpreted as the result of migration of megaripples or bars in fluvial channels. The repetitive occurrence of ripples and dunes, some of them superimposed upon one another are dominant features of sandy bedload rivers (Collinson, 1996). The occurrence

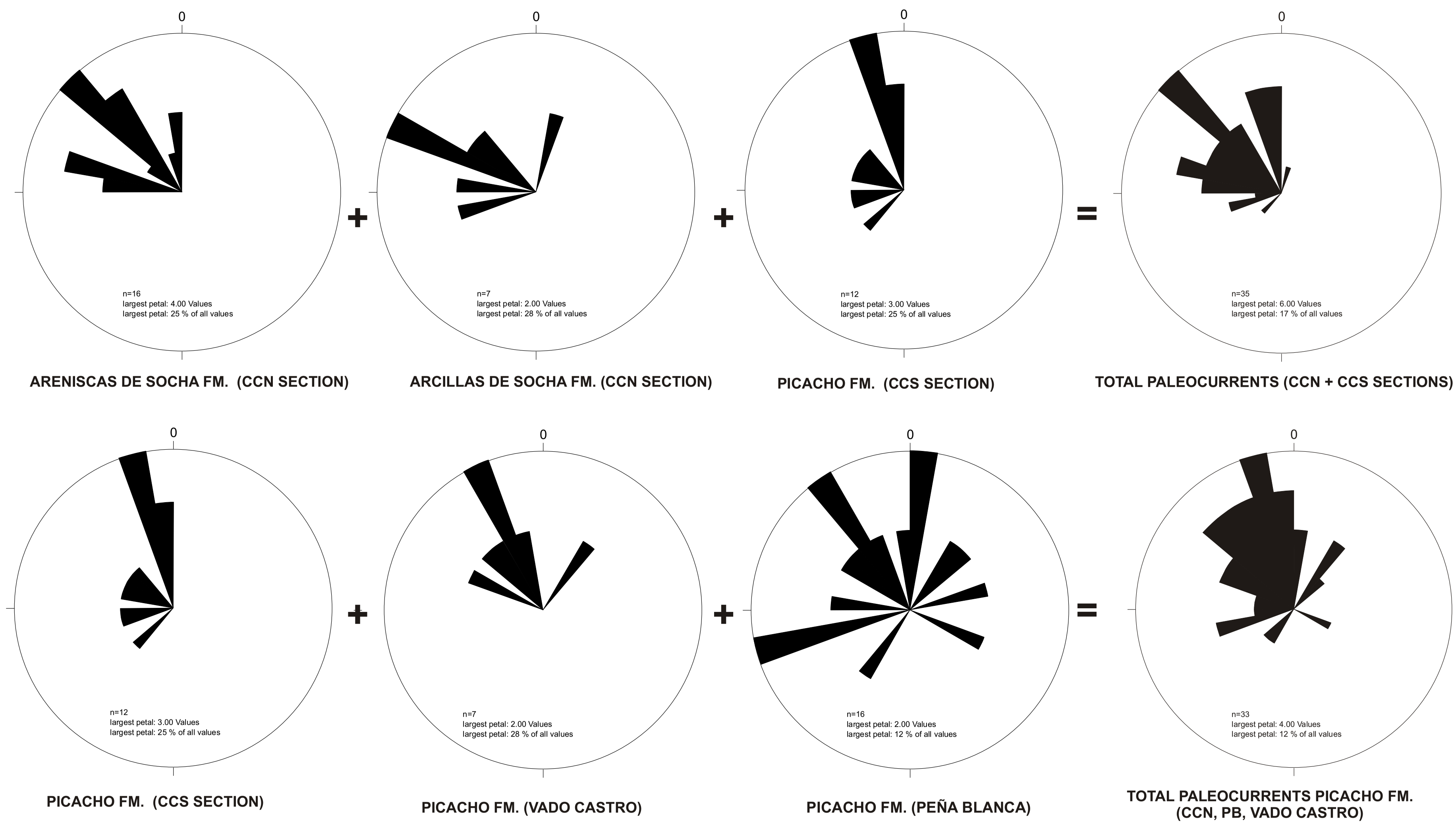


Figure 3.16. Rose diagrams of the paleocurrent data (Paz de Río area). For location see the figure 3.1.

of minor thin fine-grained clastic sediments indicates deposition in abandoned areas of normally active channels. Some of these deposits were eroded during the channel migration, an observation evidenced by the abundance of shale intraclasts at the base of the sandstone beds. The sandstone-dominated facies, together with the common erosion structures between the sand bodies (e.g. channels) and the low frequency of fine deposits, indicate a relatively low rate of vertical aggradation of the fluvial system (cf. Einsele, 2000). The only fossils found in our study were plant debris, pollen spores and terrestrial microscopic organic matter. The nature of these fossils and the unimodal N-NW paleocurrent pattern of the sandstone bodies are consistent with a fluvial origin of this unit.

Arcillas de Socha Formation:

The Arcillas de Socha Formation can be divided into two parts based in their facies characteristics:

Lower part of the Arcillas de Socha Formation (146-228 m): The fine-grained character of this formation indicates an increase in the accommodation space with regard to the Areniscas de Socha Formation. The abundance of fine-grained sediments, grey in color, with some coal layers and well preserved plant debris and root traces, indicate poor-drained soils covered with vegetation in floodplains (cf. Collinson, 1996). Some areas were predominantly submerged, with abundant shallow lakes. The presence of high quantities of *Ovoidites*, a form similar to the living freshwater algae *Spyrogira*, in a mudstone sample located at the upper part of the sequence, indicates stagnant shallow and more or less mesotrophic fresh-water habitats (Van Geel, 1979). Relatively high temperatures are required for fructification and these are often easily reached in shallow water exposed to direct radiation of the sun, at least during favorable season (Van Geel and Van der Hammen, 1978). In the same way, Rich et al. (1982) found a close association of *Ovoidites* with “open, freshwater marsh habitats, rather than densely shaded swamp habitats” in recent peat cores of Florida and Georgia (USA). The reducing chemical conditions of these deposits favored the preservation of plant tissues and palynomorphs (e.g. Behrensmeyer et al., 1992). This is also consistent with the relatively high concentration of pollen, spores and sedimentary organic matter obtained in the palynofacies study (Figures 3.14 and 3.15). The thin levels of laminated sandstones interbedded with siltstone and mudstone layers suggest minor crevasse splay deposits in which the episodic arrival of currents formed ripples and small dunes of less than 50 cm thick. The plate 3.2 (photo 3) shows a crevasse-splay deposit. The sequence is 5.20 meters thick and starts with medium-scale cross-bedded fine sandstones followed by fine to medium-scale rippled sandstones and siltstone interbeds. At the top, the beds are gradually thinning to fine-grained flood plain deposits. The regular sheet-like shape of the beds suggests vertical aggradation during deposition (cf. Miall, 1996). This kind of geometries is more apparent at some distance (a few hundred meters) from the channel (cf. Mjos et al., 1993).

Upper part of the Arcillas de Socha Formation: It is characterized by the abundance of mottled shales, which indicates a marked water-table fluctuation. In this situation oxidized conditions dominated, destroying most of the sedimentary organic matter. As in the lower part of this Formation, most of the sandstone and siltstone laminated levels can be associated to crevasse splay deposits. A fining upward sandstone sequence at the base of this interval is interpreted as a point bar deposits (cf. Collinson, 1996).

Picacho and lower part of Concentración Formations:

The sedimentary deposits of the lower part of the Picacho Formation can be interpreted as channel fluvial deposits. The cross-bedding paleocurrent data indicates a main N-NW transport direction. The abundance of *Pediastrum* in all of the fine-grained facies indicates the development of episodic fresh water lakes and ponds (cf. Farley Fleming, 1989), interrupted by the channel migration. The thickness of these facies and their limited lateral extension suggest ephemeral shallow lakes. Nevertheless, the mud intraclasts in the channel sandstones suggest erosion and reworking of these deposits and, consequently, a possible loss of part of their original geometry and thickness. The upper part of the Picacho formation (not studied in detail) is characterized by fining upward channel sandstone layers (FUS: Fining Upward Sequence; Plate 3.4, photo 2). In the studied area this sequence changes to the shale-dominated unit Concentración Formation. Nine kilometers to the north in the Paz de Río area, a layer of 2 to 12 meters thick of oolitic ironstones occurs at the lower part of this unit (Reyes, 1984). According to Kymberley (1980) these kinds of deposits are formed as littoral bars in inland seas. In the same way, Cazier et al. (1997) mentioned the presence of undetermined “dinoflagellate cyst assemblages” in the mudstones that encase the oolitic ironstone deposits of Paz de Río area, confirming the marine influence of these deposit. Unfortunately, there are not available data of this part of the sequence at the Curva de Cosgua area. Oolitic ironstones have been also mentioned by Kymberley (1980) in the Sabanalarga area, near to the Piñalerita section studied by Jaramillo (1999).

CHAPTER 4 - PALEOGENE PALYNOLOGY AND PALYNOFACIES FROM THE CESAR-RANCHERIA BASIN (NE COLOMBIA) AND THE MANUELOTE SYNCLINE (NW OF MARACAIBO BASIN, VENEZUELA)

ABSTRACT

A palynologic study was performed in NW Colombia and W Venezuela. The Colombian section is composed by 4 core logs (WRV04752, WRL04774, SIS-07 and ERV17954) from the El Cerrejón coal mine which includes the Manantial, Cerrejón and Palmito Formations (Paleocene). Here a detailed distribution of the pollen and spores of the WRL04774 is presented. The Venezuelan section is an outcrop located over the Riecito Maché creek in the Manuelote syncline which includes the Guasare, Paso Diablo and Misoa Formations (Paleocene-Eocene). 300 samples were treated for palynological analysis. The Cerrejón Formation is characterized by the presence of *Proxapertites operculatus*, *Proxapertites cursus*, *Ischyosporites problematicus*, *Gemmastephanocolpites gemmatus*, *Foveotricolpites perforatus*, *Diporopollis assamica*, *Ephedripites vanegensis*, *Psilastephanocolpites globulus*, *Syncolporites lisamae*, *Bombacacidites annae*, *Echitriporites trianguliformis*, *Psilabrevitricolpites simpliformis*, *Corsinipollenites psilatus*, *Momiptes* sp., *Triatriopollenites* sp., *Mauritiidites franciscoi* var. *pachyexinatus*, *Retidiporites magdalenensis*, *Retidiporites botulus*, *Ulmoideipites krempii*, *Ctenolophonidites lisamae*, *Malvacipollis* sp., *Psilatricolporites* “blessi” as the most characteristic species. These associations are very similar to those found in the Paso Diablo Formation in Venezuela. In contrast, the Misoa Formation is characterized by the occurrence of a great number of species: *Retitescolpites* ? *irregularis*, *Striatopollis catatumbus*, *Retibrevitricolpites triangulatus*, *Tetracolporopollenites transversalis*, *Siltaria mariposa*, *Tetracolporites pachyexinatus*, *Retitrescolpites* “machensis”. According with Germeraad et al (1968), the Paleocene-Eocene boundary can be roughly located at the upper part of the Paso Diablo Formation or at the lower part of the Misoa Formation. The presence of thick sandstone beds in this interval could suggest an unconformity.

At the WRV04774 log 87 samples were studied in detail. 114 different types of palynomorphs were identified. Among the pollen group, angiosperms are dominant in most of the samples (more than 80 %). *Psilamonocolpites* group (psilate, micropitted monocolpate pollen), *Proxapertites* group (*P. operculatus*, *P. cursus* and *P. psilatus*), *Mauritiidites franciscoi* and the small tricolporate pollen group (< 15 µm) are the most frequent fossils. In this interval some species have their first occurrence (*Ischyosporites problematicus* and *Foveotricolpites perforatus*) and can be used as biostratigraphic markers. Many coal beds are characterized by the high percentage of *Mauritiidites franciscoi* which suggest fresh water sedimentary conditions during the peat accumulation. Charcoal is relatively frequent in the coal beds, and in some cases surpasses 20 % of the total organic matter. This phenomenon could be explained as episodic droughts during the peat formation.

4.1. INTRODUCTION

The Cesar-Ranchería and the Maracaibo basins are structural depressions located in the NE region of Colombia and Western Venezuela. Nowadays these basins are separated by the Sierra de Perijá, a 200 km long, N-NE trend mountain chain, whose crest has been established as the international boundary between Venezuela and Colombia (figure 1.1). The Cretaceous-Tertiary units of these basins have received considerable interest due to their big coal and petroleum reservoirs. This area evolved through time from a Cretaceous to Eocene (transtensional) back-arc basin, to a (transpressive) foreland basin during post-Eocene time. This tectonic activity produced important lateral variations in facies and thickness of the lithologic units. In this condition, biostratigraphic researches are important to know time equivalent units and to improve the paleogeographic schemas. The late Cretaceous and Early Paleocene marine and coastal deposits have been dated with molluscan and foraminiferal fauna (Sutton, 1946). In contrast, the late Paleocene-Eocene fossils are scant and seems to be less reliable to use in correlation (e.g. Aguerrevere et al., 1956; Kuyl et al., 1955). In the Paleogene rocks located near the Sierra de Perijá (e.g. the Manuelote Syncline in Venezuela and El Cerrejón coal mine in Colombia) there are numerous coal beds and organic shales which are very rich in pollen, spores and microscopic organic matter. Some of the pollen species have regional distribution, and thus can be useful in biostratigraphy. However, because most of the palynologic researches have been performed by private companies, there are few published works in this area. For these reasons, we studied the stratigraphic distribution of pollen and spore species in order to improve the available database and integrate this information with other regions of NE Colombia discussed in previous chapters (e.g. the Middle Magdalena Valley Basin and the Eastern Cordillera).

4.2. STRATIGRAPHY

4.2.1. WESTERN MARACAIBO BASIN AREA

In the western Maracaibo area different stratigraphic nomenclatures have been employed for the Paleocene-Eocene units (e.g. Garner, 1926; Hedberg and Sass, 1937; Heintz et al., 1976; Sutton, 1946). Here we used the nomenclature of Hedberg and Sass (1937), Sutton (1946) and some modifications proposed by Scherer (1997). From base to top, they are the Guasare, Paso Diablo and Misoa Formations.

Guasare Formation

The name “Guasare Formation” was proposed by Hedberg and Sass (1937) to replace the term “Rio Guasare Formation” of Garner (1926), a calcareous unit that partially outcrops over the Guasare River. Hedberg and Sass (1937) indicated that “the top of the formation in the type section is marked by a 6 foot bed of tan to grey fossiliferous limestone exposed on the south bank of the river about 4 kilometers upstream from “El Carbón” and about 300 below the mouth of Caño Colorado”. Due to structural reversal, the base of this section is no visible and only a 120 m thick interval of this unit is exposed in this area. Hedberg and Sass (1937) mentioned a more complete section of 380 m on the Rio Cachiri, several kilometers to the south (Figure 4.1). Based on micro and macrofossils some authors have proposed a Paleocene

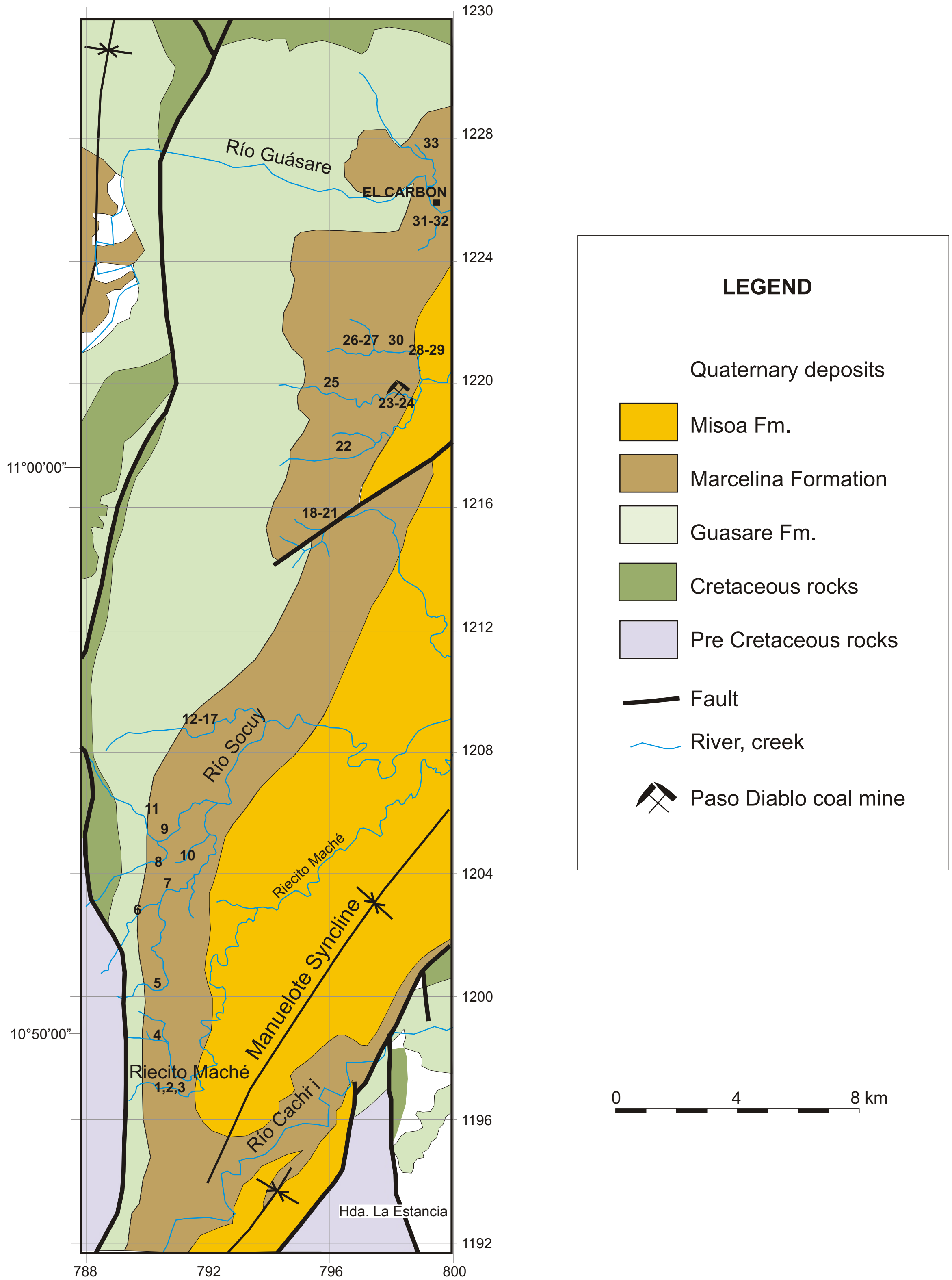


Figure 4.1. Geologic map of the Manuelote syncline area (western Venezuela) with the location of the stratigraphic sections studied by Martin Bless (see explanation in the text). The lithostratigraphic limits are based on Nogueira (1975; see also figure 4.4). 1, 2 & 3: Riecito Maché creek; 4: Seco creek; 5: Feliz-Burriola creek; 6: Miraflor creek; 7: Burriola creek; 8, 9 & 10: Socuy River; 11: Pedro-Socuy creek; 12-17: Pedrú creek; 18-21:Norte creek; 22-24: Paso Diablo creek; 25: El Palmar creek; 26-29: Grapón creek; 30: Baqueta creek; 31-32: Aceituno creek; 33: Marcelina creek. Geology from Nogueira et al. (1972).

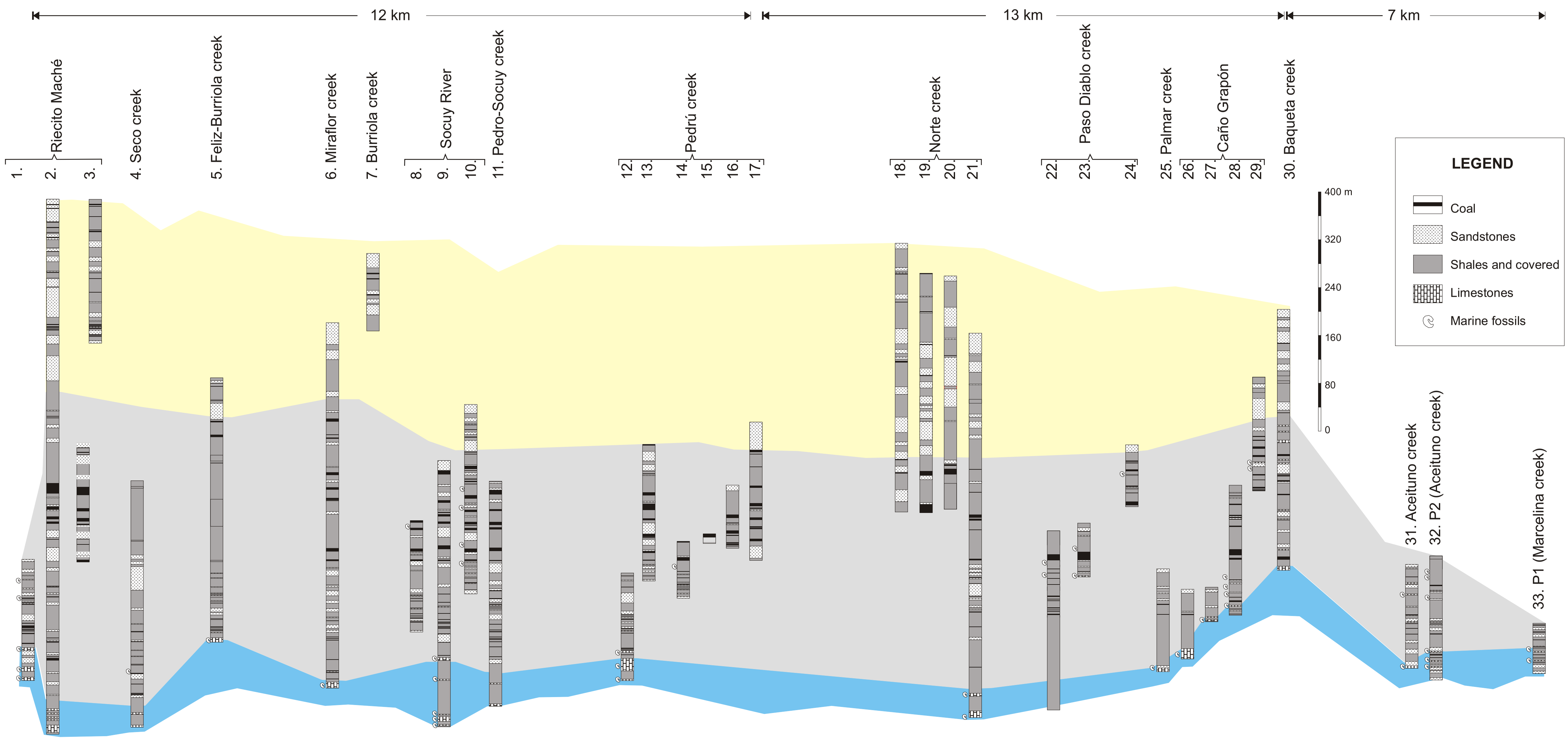


Figure 4.2. Correlation of stratigraphic logs from the western flank of the Manuelote Synclyne (after Bless, M.; unpublished). See the figure 4.1. for location. Blue: limestone dominated unit (Guasare Fm.); gray: shale-coal dominated interval (Paso Diablo Formation; sensu Scherer, 1997); yellow: sandstone-shaly unit (Misoa Formation).

age (Aguerrevere et al., 1956). The depositional environment suggested for this unit corresponds to a neritic marine environment with deltaic influence, especially to the south west where it is interfinged with the rocks of the Orocue Group (Jam, 1997). It is also interpreted as a mixed carbonate-terrigenous succession accumulated in a delta with tide and storm dominated conditions (Hernandez, 1996; Hernandez et al., 1996).

Paso Diablo Formation

Hedberg & Sass (1937) pointed out: "the Paso Diablo Formation was named by geologists of the Venezuela Gulf Oil Company from the section exposed in the Caño el Paso del Diablo in north-western part of the District of Mara. This caño is a north-eastward flowing tributary which enters the Rio Guasare a few kilometers below "El Carbón" near the ranch know as El Paso Diablo (figure 4.1). "The top of the Formation in the type section is the top of massive light grey calcareous sandstone which outcrops about 100 meters upstream from a deep water hole known as Pozo de Barqueta and about 1.6 kilometers below the junction of the west and south branches of the caño. The base of the formation is placed at the top of the first massive limestone of the Guasare formation encountered on the west branch of the Caño about 3.4 km airline west of the junction with the east branch". This unit is mainly composed by "massive, variably calcareous light grey thick-bedded sandstones; interlaminated light grey shales and dark grey shales with micaceous-carbonaceous bedding planes; and numerous beds of sub-bituminous to bituminous coals. In the lower half of the formation the sandstones are more calcareous than above, clay-ironstones and coals are more common and individual coal beds are much thicker…The total thickness of the formation is about 1,000 meters" (Hedberg and Sass, 1937). They mentioned that the fossils of this formation are rare and of little stratigraphic value and proposed an Eocene age based in its stratigraphic relations.

Later Sutton (1946) used the term Marcelina Formation to designate a "coal-bearing formation which crops out along the Caño Marcelina, a tributary of the Guasare River in the southwestern part of the District of Paez, Zulia. On the Guasare River the base of the Marcelina is marked by the top of the highest limestone bed of the Guasare Formation…, while the top is placed at the base of the coarse, massive Misoa sandstone…" It is composed mainly by "interbedded sandstones, shales, sandy shales and coal beds…Numerous beds of sub-bituminous to bituminous coal are present and their best development occurs in the lower part of the formation…" (Sutton, 1946). He calculated a thickness of 610 m for this unit in the type section. This unit is thus partially equivalent to the Paso Diablo Formation (e.g. González de Juana, 1951). At the Riecito Maché section, Bless & Paproth (1989) divided the Marcelina Formation in the Pedru, Maché, Miraflor and Indio Members, following the nomenclature of Heintz et al. (1976); but these terms are not officially accepted.

Scherer (1997), following the American Stratigraphic Nomenclature code priority norms, proposed to preserve the term "Paso Diablo Formation" instead of the "Marcelina Formation". Because the original stratotype has been destroyed by the mining works, he proposed a neostratotype in the Socuy River, 10 kilometers to the south of the original section. It includes the Caño Sierra Azul section until 3.5 km water down of the Socuy river (Scherer, 1997). The measured thickness in this section corresponds to 461 m. This author describes a "gradual and concordant" contact between the Paso Diablo and the upper Misoa Formation and put this limit at the base of a "thick grey-brown laminated sandstone sequence". It is important to remark that this criterion is different to those employed by Hedberg and Sass (1937) to limit the top of the Paso Diablo Formation in the precedent stratotype (“the top of massive light grey calcareous sandstone”; see above). Additionally, the thickness of 461 m obtained by Scherer contrast with the 1,000 m mentioned by Hedberg and Sass (1937) in the Paso Diablo section. At the Riecito Maché section, Nogueira (1975), uses the term Marcelina Formation and put its upper contact in a cross-bedded conglomeratic level with chert fragments (not recognized by Bless), located 942 m above the contact with the Guasare Formation (Figure 4.4). Eisenbau-Essen (1975) a german company that studied the stratigraphy of this area, indicates that the upper limit of the Marcelina Formation proposed by some previous works in the area (e.g. Bitterli, 1950) can not be easily recognized or mapped. On the other hand, it is necessary to outstand that both the Marcelina and Misoa Formations appear as valid stratigraphic names in the on-line stratigraphic code of petroleum basins of Venezuela (Comité Interfilial de Estratigrafía y Nomenclatura CIEN, 2004). All of these problems show the necessity of an official proposal of the Venezuelan Stratigraphic commission. Even though this problem is out of the scope of this investigation, it shows the importance of linking the paleontologic data to a detailed and well located stratigraphic log in this area.

Following the Scherer criterion, we put the upper contact of the Paso Diablo Formation at the base of the first group of thick channel sandstone layers, located 470 m above the contact with the Guasare Formation. This value is similar to those obtained by this author at the Rio Socuy. The figure 4.2 shows the correlation of several sections of the western flank of the Manuelote Syncline performed by Martin Bless. As can be observed, the limit proposed for the Paso Diablo and Misoa Formations at the Riecito Maché section, which divides a shale-coal unit from a sandstone-shaley unit, can be roughly followed across the area. On the other hand, the palynological data obtained in the Riecito Maché section show a strong variation of the pollen and spore associations in the coals located above and below this limit (see below). According to Scherer (1997), the Paso Diablo Formation is composed by 14 cyclothems of coal formed in a deltaic to paludal environment, with some marine incursions, in its lower and upper part.

Misoa Formation

This term is now employed in the Manuelote syncline to replace the names Mostrencos and Orumo Formations defined by Hedberg and Sass (1937) (Graves and Jam, 1997). Sutton (1964) defined this unit as a “thick, essentially sandstone deposits which constitute the Upper Eocene part of the original Misoa-Trujillo Formation. The type area of the Misoa Formation is the Cerro Misoa east of Lake Maracaibo in the District of Sucre, Zulia”… "hard, quartzitic, light grey to brownish grey, medium to coarse-grained, locally conglomeratic, thick-bedded to massive, sandstone. In the lower part of the formation are subordinate amounts of fine to medium, grey and dark grey, carbonaceous, micaceous, laminated and cross-laminated sandstone…Interbedded with the sandstones are grey to dark grey shales that probably comprise 15 per cent of the formation…Locally, the base of the formation consists of orbitoidal limestone, sandy limestone and calcareous sandstone”. Sutton (1964) pointed out that this unit has a thickness of 122 to 183 m in the foothills of the Sierra de Perijá in the western part of the districts of Maracaibo and Mara (Zulia estate). He also suggests that this unit can be correlated with the “La Paz sandstone” of the Magdalena Valley and with a part of the Paso Diablo Formation of Hedberg and Sass (1937). The Misoa Formation has been interpreted as upper and lower deltaic deposits (Graves and Jam, 1997). Higgs (1996) suggested a tidal-shelf sand sheets deposits influenced by storms and Casas (1995) a vast deltaic complex deposited in an extensive embayment or internal sea. The only published palynologic researches from this area are those of Germeraad et al (1968) and Rull (1999, 2000), and will be discussed in the biostratigraphy section.

4.2.2. THE CESAR RANCHERIA BASIN

The lithostratigraphy from the Cesar-Ranchería basin, have not been previously studied in detail. The names Hato Nuevo, Manantial, Cerrejón, Tabaco and Aguas Nuevas Formations have been employed for the Paleocene-Eocene units of this area (e.g. Tschanz et al., 1969), but there are not precise descriptions about their lithological characteristics and limits (see Porta, 1974, for a revision about the definition of these units). Here, we use the stratigraphic division used by the geologist of the El Cerrejón mine. From base to top they are: The Manantial Formation composed mainly by limestones; the Cerrejón Formation composed by dark color mudstones with sandstones and thick coal beds whose base is located in the first coal bed and the Palmito Formation composed by light color siltstones and sandstones with thin coal layers. Miller (1962) used the term La Jagua Group to include the late Cretaceous, Paleocene and Eocene (?) rocks of the middle eastern sector of the basin, near to La Jagua town. It is divided in the Guasare and the Santa Cruz Formations. The first one is compared with the Guasare of the Maracaibo basin and the second one is roughly equivalent to the Marcelina and Los Cuervos Formations at the Maracaibo basin (Miller, 1962).

There are few biostratigraphic studies in this area. Van der Hammen (1957b; 1958), mentioned the presence of a “typical Paleocene palynologic association” in the Hato Nuevo Formation and proposed an Eocene age for the Cerrejón Formation. Nevertheless, this author did not mention the species used for these determinations. Van der Kaars (1983), performed a detailed study of 26 coal beds from the El Cerrejón coal mine. The co-occurrence of *Foveotricolpites perforatus*, *Bombacacidites annae* and *Ctenolophonidites lisamae* in these associations suggest the *Foveotricolpites perforatus* Caribbean zone of Germeraad et al. (1968).

4.3. DESCRIPTION OF THE STUDIED SECTIONS

Two stratigraphic sections were studied in this area (figure 1.1): the first section is located to the eastern flank of the Sierra de Perijá mountain range (Venezuela), in the Riecito Maché River, a distributary of the Socuy River (western flank of the Manuelote Syncline, Figure 4.1). The stratigraphic section was measured by Martin J. Bless using a tape measuring and a compass. In this work, I redraw his data using AutoCad for PC. This schema fits well in the topographic map available for this area (figure 4.3). The geological information follows also the field notes of M. Bless (1974, unpublished), elaborated for the Venezuelan government. 92 samples distributed in 24 coal layers and 5 organic shales were treated for the palynologic analysis (table 4.1). The thick coal layers were sampled one meter apart.

The second section is located in the coal mine “El Cerrejón” (Valle del Cesar, Colombia), to the west of the Sierra de Perijá (figure 1.1); in this place four core-logs (SIS-07, WRV04774, WRV04752 and ERV 17954), which covers an interval of 1200 meters were employed for this study. These logs were described and sampled by Carlos Jaramillo and German Bayona

(Corporación Geológica Ares, Colombia). Two hundred and forty samples of organic-rich mudstones and coals were used for the palynologic analysis. Sampling was performed every 4 stratigraphic meters. The study of the WRV04752 core-log was performed by Milton Rueda (Corporación Geológica Ares, Colombia); the SIS-07 and ERV17954 logs samples were studied by Carlos Jaramillo and his students at the Instituto Colombiano de Petróleo (ICP, Colombia) and the WRL04774 core-log samples were studied by the author at Liege University (Belgium).

4.3.1. The Riecito Maché section (Maracaibo Basin)

The section has a W-NW E-SE trend and follows the Riecito Maché River (figures 4.1 and 4.3). The beds have an N-NE strike, and in general dip to the east. The westernmost part of the section is characterized by the high dip of the beds of the Guasare Formation (70º-90º), which form an anticline structure (figure 4.3). This part was not included in our log because it contrasts with the 40º-60º more or less regular deep of the rest of the sequence. This phenomenon can be linked to tectonic effects produced by a thrust fault located some meters to the west (figure 4.1). Nevertheless, two samples of this part are included in the palynological analysis (appendix 4.1). The general lithology of this part of the section is also presented in the table 4.1. The sequence was divided in several stratigraphic segments:

0-167 m. Upper part of the Guasare Formation: It is conformed by shales interlayed with sandstones, laminated sandy-shales, calcareous fossiliferous sandstones and shales, sandy limestones and shelly limestones. The sand beds have frequently ripple cross-lamination. In some sandstone-shale levels there are limonitic concretions.

167-220,6 m. It is mainly a covered interval; only a 1 m layer of laminated sandstone is exposed. In this part of the section M. Bless put the contact between the Guasare and Marcelina formations.

220,6-304 m. Composed by grey and black shales interlayed with sandstones and coal beds (coals 1 to 5 of Bless). The sandstones are micaceous, with cross bedding and ripple marks. Some of them are micaceous and have vegetal remains. The shales have root traces, vegetal remains and ferruginous levels. There are a 0.6 m thick layer of fossiliferous calcareous shale (the kind of fossils is not indicated).

304-400 m. It is mainly a covered interval. Only 2 m sandstone with ripple marks is described.

400-540 m. Interval conformed by shales and sandy shales interlayed with sandstones and coal layers. The shales are black in color; in some cases they have root traces and vegetal remains. The sandy shales have ripple marks. The sandstones have cross-bedding and/or ripple marks; some of them are channel fill sandstones. In this interval 5 thick coal beds are identified (coals 7 to 11); at the top of the interval one of them has 15 m thick (figure 4.4).

540-615. Covered.

615-645 m. Composed by shales, sandy shales, sandstones and thin coal beds. At the upper part a bed of “channel” sandstones appear. The contact between the Paso Diablo and Misoa

Table 4.1. Martin Bless field notes used to construct the stratigraphic section of the figure 4.3.

DELTA	Contra Azimut	Distance (m)	Thicknes-Lithology	Beds	No. Sample	Remarks	Corrected Thicknes	Cumulated Thickness
0-1	335	67,6	18.3 m. Limestone	274-85				
			12.4 m. Limestone and shale	297-85				
			14.7 m. Limestone and shale					
			22.2 m. Gray-yellow limestone with fossils					
1--2	325	120	Covered					
2--3	275	30	Covered					
3--4	286	30	Covered			Separation in two "caños"		
4--5	315	15,7	9 m. Covered					
			6.7 m.Gray shale with some limestone	278-90	1			
5--6	330	47,9	Covered					
6--7	10	22,5	Limestone					
7--8	8	30	Covered					
8--9	330	7	Covered					
9--10	330	5,2	Fine sandstone	93-82				
10--11	332	30	Covered					
11--12	315	39,4	Covered					
12--13	283	48,8	8.9 m. Covered					
			2.9 m. Limestone	95-80				
			3.8 m. Sandstone, Fe oxides, ripple marks					
			4 m. Gray-yellow limestone, very fossiliferous	95-75				
			4.3 m. Calcareous sandstone					
			0.3 m Sandstone					
			9.1 m. Fine sandstone, limestone and shale, laminated, ripple marks					
			5 m. Fine sandstone, quartzitic					
			2.0 Black shale, sandy laminations		2			
			2.4 m. Gray medium sandstone, lumaquelic					
			6.1 m. Covered					
13--14	270	26,8	1.6 m. Coarse sandstone, lumaquellic					
			25.2 m. Laminated sandy shale, interlayed with sandstone					
14--15	280	20,8	38.9 m. Covered					
			11.1 m.Fine laminated sandstone, limonite crusts	105-70				
			0.8 m. Blocks of ferruginous limestone, fossiliferous					
15--16	310	12,8	Laminated sandstone, shell fragment, Fe nodules	106-70				
16--17	280	16,6	0.5 m. Sandy limestone, shells	110-75				
			15.6 m. Fine sandstone, ripple marks			Waterfall		
17-18	200	207,4						
18-19	175	60	Covered					
19-20	195	30	Covered					
20-21	210	60	Limestone (0.8 thick)					
21-22	270	13,7	Covered					
22-23	220	15,2	The same sandstone of 15.6 m					
23-24	235	25	Same sandstone			Waterfall		
24-25	225	10,5	Finely laminated sandy-shale					
25-26	260	154	7.4 m. Transition	90-40			90	90
			4.10 m. Shelly limestone					
			23 m. Laminated shales interlayed with sandstones (limonitic concretions)					
			14 m. Covered;					
			16.7 m. Sandy shale, laminated, ripple marks	95-35				
			2 m. Calcareous sandstones, shell debris.	90-40				
			18.2 m. Sandy shale, laminated, ripple marks					
			7 m. Shaly sandstone interlayed with limestones					
			4.4 m. Shale					
			2.2 m. Sandy limestone, shell debris.					
			40.7 m. Sandy shale, laminated, sandstone interlayed					
			13 m. Covered					
			1.3 m. Sandy shale, ripple marks					
26--27	285	26,9	14.5 m. Covered				19	109
			12.4 m. Sanstones with masive limestones, shells			Waterfall		
27-28	268	14,3	11.5 m. Covered				10	119
			1.8 m. Sandy shale, ripple marks.	105-45				
			1 m. Sandy limestone, masive, red nodules, shell debris					
28-29	250	46,8	15 m. Sandy shale, ripple marks.				27	146
			25.6 m. Sandy limestone, masive, shell debris.					
			6.2 m. Covered					
29--30	260	35,8	1.0 m. Calcareous shale	85-40			21	167
			17.3 m. Sandy limestone, shel debris, rippled sandstone interlayed					
			10.5 m. Covered					
			7.0 m. Sandy shales and sandy limestones interlayed					
30-31	275	104,8	30 m. Covered				73	240
			1 m. Laminated sandstone, ripple marks					
			22.6 m. Covered					
			7.2 m. Medium sandstone, laminated, micaceous					
			15 m. Covered					
			2.5 m. Sandstone					
			6 m. Covered					
			9 m. Sandy shale					
			11.5 m. Covered					
31-32	285	22,6	13.4 m Coals 1-2,		3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14,15, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26		16	256
			4.8 m. Coal 1					
			4.o m. Black shale					
			0.4 m. Coal 2					
32-33	275	63,45	2.8 m. Gray shale, ferriginous levels				48	304
			2.4 m. Irregular bedded sandstone	100-50				
			8.6 m. Shaly sandstone, vegetal remains, ripple marks					
			3.6 m. Covered					
			3.8 m. Shaly sandstone	115-60				
			4 m. Covered					
			2 m. Black shale, bioturbated					
			0.6 m. Calcareous shale, fossiliferous		27			
			5.1 m. Shale, root traces, vegetal remains					
			0.7 m. Coal 3		28, 29			
			1 m. Black shale					
			0.5 m. Coal 4		30, 31			
			0.5 m. Sandy shale, micaceous, vegetal remains					
			1.7 m.Shaly sandstone, finelly laminated, ripple marks					
			2.4 m. Shale and sand interlayed					
			0.2 m. Sandstone					
			3.2 m. Sandy shale, root traces					
			0.5 m. Coal 5					
			5.6 m. Altered shale					
			6.3 m. Shale (type "rootball")					
			6.7 m. Sandy shale, laminated					
			1.3 m. Sandstone, cross bedding					
33-34	295	66,3	51.8 m. Covered			"Caracoli" tree.Parallele polygonal, samples 34 and 33	51	355
			14.5 m. Covered					

DELTA	Contra Azimut	Distance (m)	Thicknes-Lithology	Beds	No. Sample	Remarks	Corrected Thicknes	Cumulated Thickness
34-35	315	71,9	18.8 m. Covered				55	410
			2.5 m. Sandstone, ripple marks	130-53	32			
			36.7 m. Covered					
			4.8 m. Channel sandstone					
			4.6 m. Sandy shale					
			4.4 m. Covered					
35-36	345	83,35	44.2 m. Channel sandstones, sandy shale interlayed				63	473
			14.4 m. Covered					
			1.55 m. Coal 7	120-65				
			6 m. Shale					
			17.2 m. Shaly sandstone, cross bedding in the lower part, ripple marks, laminated					
36-37	333	79,55	19.6 m. Covered				53	526
			5.10 m. Coal 8		35, 36, 37, 38, 39, 40, 41, 42			
			7.6 m. Black shale, root traces					
			6.4 m. Coal 9	120-45				
			8.9 m. Shale, vegetal remains					
			4.6 m. Shaly sandstone, laminated					
			1.3 m. Shale, root traces to the top					
			6.55 m. Coal 10					
			3.6 m. Shaly sandstone, vegetal remains					
			7.6 m. Sandy shale, well laminated					
			5.1 m. Shaly sandstone, well laminated					
			0.5 m. Sandstone					
			1.3 m. Sandy shale, ripple marks					
			1.4 m. Channel sandstone					
37-38	315	29,3	11 m. Sandy shale, well laminated				89	615
			18.3 m. Coal 11		43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62			
38-39	290	87,5	Covered					
39-40	215	49	Masive sandstone					
40-41	235	54	Covered					
41-42	295	37	2 m. Sandstone	125-60			30	645
			12.5 m. Covered					
			8.2 m. Very sandy shale, root traces0.90 m. Coal 12					
			0.45 m. Shale					
			0.15 m. Coal 13					
			0.03 m. Coaly shale					
			0.17 m. Coal 14					
			9.40 m. Sandy shale, laminated ; to the top cut by channel sandstone					
			3.2 m. Channel sandstone					
42-43	275	21,3	Sandstone blocks				14	659
43-44	260	51,4	28.7 m. Sandstone blocks				27	686
			22.7 m. Channel sandstones					
44-45	295	50	Channel sandstones			Indian drawings	39	725
45-46	285	76,3	34.7 m. Covered				58	783
			15.6 m. Sandstone, hard					
			0.5 m. Shale, root marks					
			0.1 m. Coaly shale, Coal 15		63			
			2.6 m. Shale, root traces					
			0.1 m. Burned coal 16		64			
			1.4 m. Shale, root traces					
			0.15 m. Coal 17		65			
			1.5 m. Shales, root traces to the top					
			1.8 m. Coal 18		66, 67, 68, 69, 70			
			1.75 m. Shale, root traces to the top					
			0.70 m. Coal 19		71, 72, 73, 74			
			0.33 m. Laminated shale					
			0.75 m. Coal 20		75, 76, 77, 78			
			5.4 m. Sandy shale					
			8.9 m. Coarse sandstone, channels to the top, laminated	110-55				
46--47	300	138,7	60 m. Laminated sandstone, cross bedding				115	898
			0.15 m. Coal 21	110-58	79			
			18.5 m. Shaly sandstone, well laminated, ripple marks					
			0.30 m. coal 22+ shale					
			7.6 m. Sandy shale, well laminated		80, 81, 82, 83, 84			
			0.9 m. Coal 23	130-60				
			0.2 m. Shale					
			0.9 m. Channel sandstone					
			17.9 m. Sandy shale					
			1.7 m. Channel sandstone					
			11.4 m. Shaly sandstone, laminated					
			1.5 m. Sandstone					
			16.7 m. Shaly sandstone					
			0.9 m. Coal 24		85			
47--48	285	86,5	15.9 m. Sandy shale, laminated				61	959
			1 m. Hard sandstone					
			0.5 m. Root traces					
			0.93 m. Coal 25	123-55				
			12 m. Sandstone gradding to sandy shale to the top, root traces					
			0.16 m. Coal 26					
			9.1 m. Sandy shale					
			1.30 m. Coal 27		86, 87, 88, 89, 90, 91			
			10.2 m. Sandy shale					
			0.28 m. Coal 28		92			
			27.5 m. Shaly sandstone, well laminated					
			0.1 m. Coaly "earth"					
			6 m. Shaly sandstone					
			0.4 m. Shale, root traces					
			0.3 m. Coal 30					
			0.3 m. Black shale, plant remains					
			0.5 m. Hard sandstone					
			0.05 m. Black shale, plant remains					
48--49	280	28,9	20.3 m. Fine sandstone, well laminated, ripple marks				107	1066
			8.6 m. Sandy shale?					
49--50	0	153,4	153 m. Covered					
			0.35 m. Coal 31		93			
50-51	320	84,4	83.2 m. Shaly fine sandstone, well laminated				69	1135
			1.2 m. Coal 32	130-55				
51-52	295	279,5	9.1 m. Shaly sandstone, ripple marks				235	1370
			0.4 m. Coal 33		94, 95, 96			
			270 m. Sandy shale, laminated interlayed with fine sand, rippled					
52--53	210	18,4	Covered					
53--54	320	48	Covered					
54--55	320	54,6	Sandy shale					
55--56	0	20,66	3.66 m. Laminated sandstone	130-63				
			16 m. Sandy shale					
			1 m (aprox.) Coal A (=34)	120-66	97			
	30	48,6	Strike of coal					

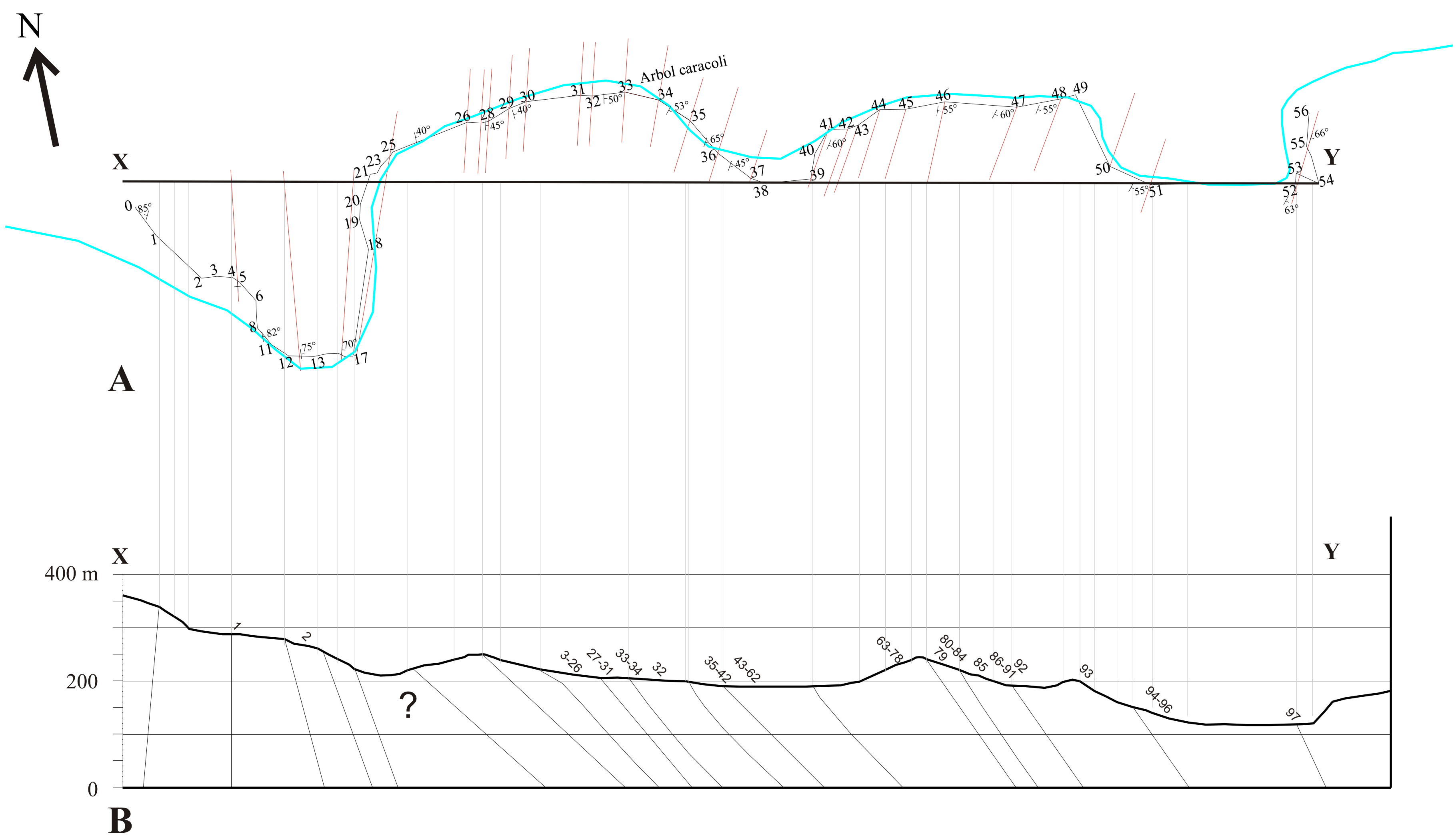


Figure 4.3. A. Stratigraphic section of the Riecito Maché creek. The numbers represent the stations used by Martin Bless during the field survey (see the table 4.1). In red: statification trend of the layers. In blue: Riecito Maché creek. B. Cross section of the Riecito Maché creek. The numbers correspond to the studied samples . For regional location see the figure 4.1.

Formations is put at the base of this bed.

645-725. It is mainly composed by channel sandstones.

725-780. Following a covered interval of more than 20 m, there are a sandstone layer and shales with thin intercalations of coal. Root traces are common.

780-830. Sandstone beds with cross-bedding.

830-970. Shales, sandy shales and sandstones interbedded with many coal beds of less than 1 m of thickness. The sandstones are well laminated and have ripple marks. Some shales are black in color and rich in plant remains.

970-1065. Covered.

1065-1390. Composed by sandstones, shaley sandstones, sandy shales with some coal beds.

4.3.2. The El Cerrejón section (Cesar-Ranchería Basin)

The general characteristics of the core logs studied in this work are described by C. Jaramillo & G. Bayona (written com.). The upper Manantial is composed by fossiliferous packstones and wackestones interbedded with calcareous sandstones and mudstones in thin to medium tabular beds. The fossils are mainly mollusks, which are broken and concentrated in thick to medium beds. The internal sedimentary structures are dominantly lenticular, wavy and ripple laminations; cross bedding is also present in the sandstones toward the top of the formation. Some levels have moderate bioturbation.

The Cerrejón Formation has ± 1,000 m thick and consists dominantly of shaly sandstones, dark-colored siltstones, black shales and coal seams. The base consists either of fossiliferous black shales and laminated black mudstones with thin lenticular laminaes of sandstones and/or flaser-laminated sandstones. These beds overlie or underlie thick coal seams. The middle part is composed mainly by bioturbated mudstones and sandstones with flaser and heterolithic lamination; plant remains are common. Both coarsening- and fining-upward trend of grain size can be observed. Coal seams have variable thickness in this part of the succession. The top of this succession is dominated by fine-grained, massive to lenticularly-laminated, mudstones and siltstones with abundant plant remains; bioturbation is conspicuous. These facies are cut by thick to very thick massive to cross-bedded sandstones. Medium to thin coal seams are common at the top of this type succession. The base of the Palmito Formation includes fining-upward successions from conglomeratic coarse-grained sandstones to massive light-colored mudstones and siltstones.

The conformable stratigraphic succession described above shows the onset of siliciclastic deposition over carbonate deposition, and the general progradation of continental settings over shallow-marine and tidal-dominated environments. Bayona (written com.) interpreted the Manantial Formation deposits as accumulated in a mixed shallow platform to fine-grained subtidal environments, crossed by subtidal channels to the top. The Cerrejón Formation is interpreted as anoxic lagoonal, flooded coastal-plains environments in its lower part, subtidal

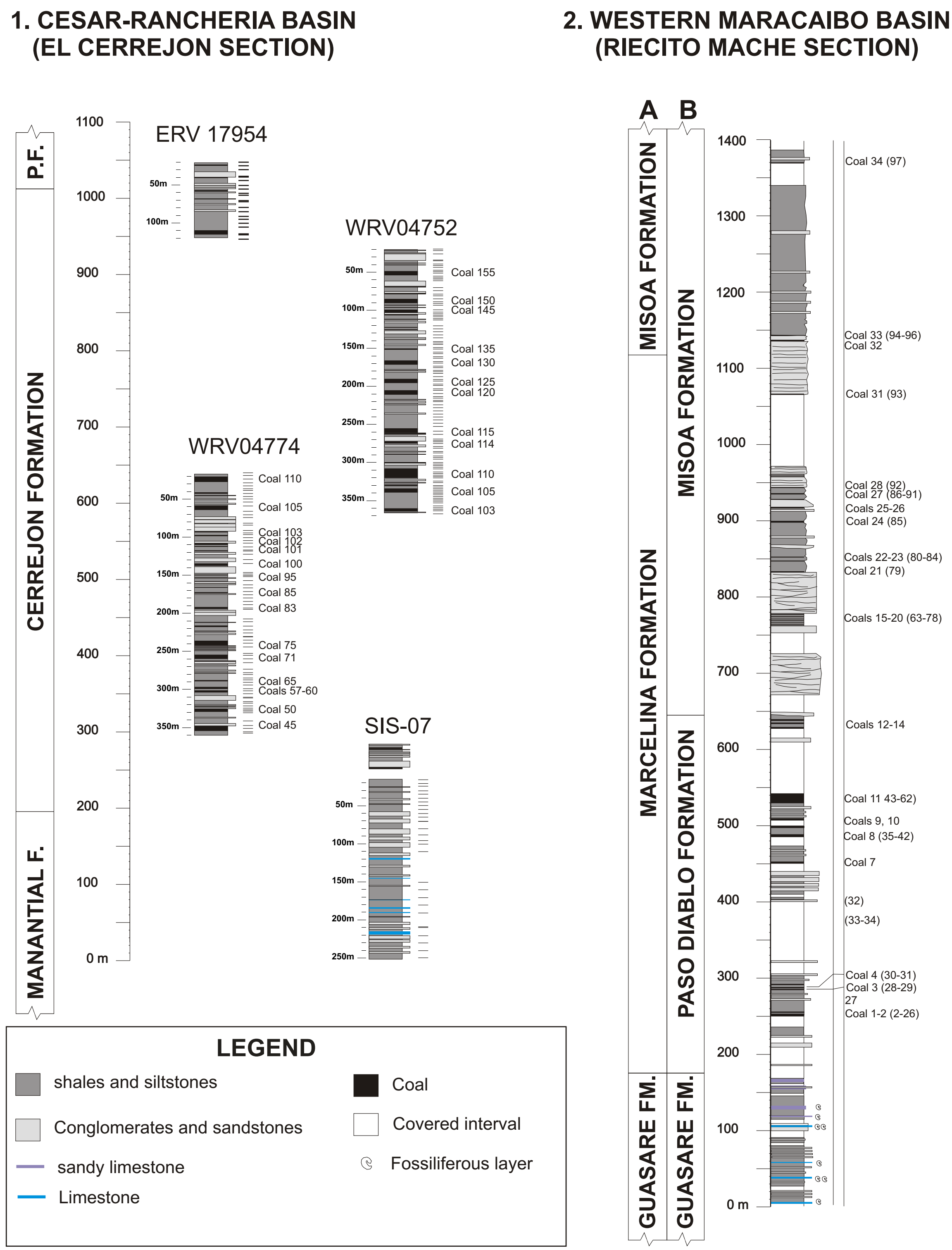


Figure 4.4. Stratigraphic sections studied in this work. The nomenclature is based on Tchanz et al. (1969), Hedberg and Sass (1937), Sutton (1946) and Garner (1926). The logs of the El Cerrejón section are based on descriptions made by Jaramillo & Bayona (unpublished). The Riecito Maché log is based on Martin Bless field data (unpublished). A. lithostratigraphic limits proposed by Nogueira (1975); B: lithostratigraphic limits proposed by Scherer (1997) and used in this work. See more explanation in the text. The numbers in parentheses correspond to the coal samples studied at the Riecito Maché section (see also the table 4.1). The palynologic samples of the El Cerrejon section are indicated by horizontal lines. The coal numbers correspond to the nomenclature used in the El Cerrejon mine. P.F: Palmito Formation.

and tidal flats deposits at its middle part and coastal plains crossed by channels in its upper part. The Palmito Formation deposits are interpreted as the filling of channel structures cutting coastal plains.

4.4. BIOSTRATIGRAPHY

4.4.1. The Riecito Maché section (Maracaibo Basin)

The two lower samples of this section belong to the Guasare Formation. As was mentioned, due to structural problems they were not included in the stratigraphic log. In these samples *Foveotriletes margaritae*, *Echimonocolpites protofranciscoi*, *Colombipollis tropicalis, Spinizonocolpites baculatus*, *Stephanocolpites* cf. *S. costatus, Retidiporites magdalenensis*, *Proxapertites operculatus* and some dinoflagellate cysts are recognized. This association linked to the absence of *Buttinia andreevi*, *Proteacidites dehaani* and *Ctenolophonidites lisamae* allow to locate these rocks in the *Foveotriletes margaritae* Caribbean zone of Germeraad et al. (1968).

The figure 4.5 shows the stratigraphic distribution of the main pollen and spore species of the Riecito Maché section. It is necessary to stand out that the only available samples for this study are coals and coaly shales. Thus the palynological results can be strongly controlled by the facies and the local vegetation can be over-represented (e.g. Traverse, 1988); nevertheless, the palynology of coals, in some cases, has been used successfully for biostratigraphic purposes (e.g. Smith, 1987). In spite of these problems, some of the traditional pollen and spore markers are well represented in these samples. The palynological distribution can be clearly divided in two parts (figure 4.5). The lower part is characterized by *Foveotricolpites perforatus*, *Ctenolophonidites lisamae*, *Diporopollis assamica*, *Ephedripites vanegensis*, *Gemmastephanocolpites gemmatus*, *Mauritiidites franciscoi* var. *pachyexinatus*, *Proxapertites operculatus*, *Psilatricolporites* “blessi”, *Psilastephanocolpites globulus*, *Retidiporites botulus*, *Triatriopollenites* sp., *Malvacipollis* sp. and *Retidiporites magdalenensis.* The upper association starts from the samples 63 to 78 (coals number 15 to 20, located between the 562-570 m above the base of the Paso Diablo Formation). In this interval several taxa appear: *Retibrevitricolpites triangulatus*, *Retitescolpites*? *irregularis*, *Retitrescolpites* “machensis”, *Tetracolporopollenites transversalis, Tetracolporites pachyexinatus, Mauritiidites franciscoi* (rounded colpi), *Polotricolporites* cf. *P. concretus* Guzman 1967, *Polypodiisporites* sp. unfortunately, these palynologic associations are separated by a 236 m thick interval without available samples and thus we can not appreciate the kind of variation between these associations.

This information allows comparing our data with those of Germeraad et al (1968) and Rull (1999). Germeraad et al (1968) included a 1700 m thick section named “Riecito Maché” (see their figure 17). Unfortunately, the precise geographic location of this section and the stratigraphic range of the pollen and spore taxa were never published. A curious fact is that Germeraad et al. (1968) included the late Cretaceous Colon Formation at the base of their section. In contrast, the data presented here, show the absence of this unit and a tectonic contact between the Guasare Formation and the Pre-Cretaceous rocks at the Riecito Maché creek (figures 4.1 and 4.3). This suggests that the log presented by Germeraad et al. (1968) is not exactly located at the Riecito Maché creek or that it could be a composite section.

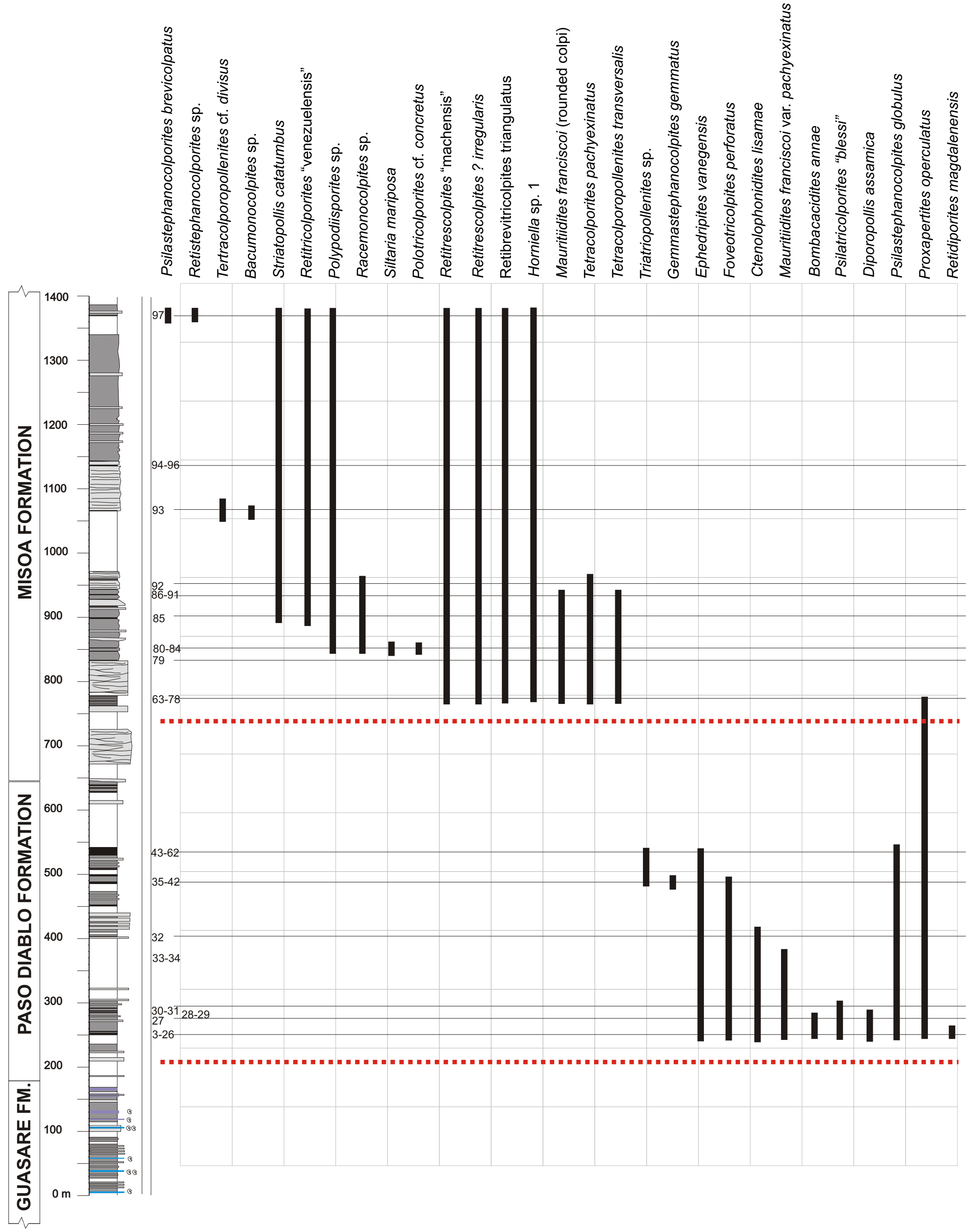


Figure 4.5. Stratigraphic distribution of some selected pollen and spore species of the Riecito Maché section. The numbers represent the studied samples (see the table 4.1 and the figure 4.3 for detailed location). The red lines represent the location of the limits between the *Ctenolophonidites lisamae*-*Foveotricolpites perforatus* (lower line) and *Foveotricolpites perforatus*- *Retibrevitricolpites triangulatus* (upper line) indicated by Germeraad et al. (1968) for the same section .

Anyway, they put the limit between the *Ctenolophonidites lisamae* and the *Foveotricolpites perforatus* at the contact of the Guasare-Paso Diablo Formations. Accordingly, our data show that the *F. perforatus* species is already present at the lowermost studied coal bed, few meters above the base of the Paso Diablo Formation. The boundary of the *Foveotricolpites perforatus* and the *Retibrevitricolpites triangulatus* zones is located by Germeraad et al. (1968) 520 m above the base of the Paso Diablo Formation. Due to sampling gaps we can not specify this limit in our section, but the presence of *Retibrevitricolpites triangulatus* and *Retitrescolpites*? *irregularis* in a coal bed located at 569 m above the base of the Guasare Formation is consistent with the Germeraad's data (figure 4.5). The FAD of *Striatopollis catatumbus*, another species that appears in the *Retibrevitricolpites triangulatus* biozone, is located 130 m above the former species. Germeraad et al. (1968) suggested that in this section there is a "sharp and distinct floral change at the base of the *Retibrevitricolpites triangulatus* zone" which might correspond to a hiatus.

Rull (1999a; 2000) presented a stratigraphic distribution chart of the "Riecito Maché" section. He pointed out that: "the sampling was carried out by H.W. Stekhoven at more or less regular intervals of about 8 m average". The section is considered as "continuous (i.e. without evident hiatuses) in the field recognizance". Unfortunately, he did not show the real stratigraphic position of his samples nor its relation with the sedimentary facies, only the general limits between the stratigraphic units. Considering the numerous covered and organic poor (sandstone dominated) intervals present in this section (figure 4.4) (see also Nogueira, 1975), the regular sampling mentioned by Rull seems difficult to perform in this section. Consequently the Rull's schema could be distorted. It is also important because this author (Rull, 2000; 2002), used this diagram to propose palynological cycles in this area. If the positions of the samples are not at the real scale, and some of the samples are separated by thick sandstone layers (see Nogueira, 1975), some of the cyclic patterns proposed by the author might be reconsidered. On the other hand, Rull (1999) pointed out that, at the Paleocene-Eocene boundary of this section "thirteen taxa disappeared just before or in the boundary. On the other hand, twenty one taxa appear for the first time slightly before, in the boundary or slightly after. These changes occur in a gradual, somewhat stepped, manner". We consider that these palynological changes must be analyzed together with the facies. Our field data show the arrival of thick channel sandstone bodies between the Paleocene and the Eocene palynological associations, which could be related to a stratigraphical discontinuity as have been previously suggested by Germeraad et al (1968).

4.4.2. The El Cerrejón section (Cesar-Rancheria Basin)

The El Cerrejón section was studied to determinate the feasibility of correlating the coal beds by means of pollen and spores and to provide a detailed stratigraphic chart of distribution of these fossils in the coal beds and their associated facies, mainly organic-rich shales and siltstones. Two hundred samples were collected for this study. In the present work, a general distribution of the main pollen and spore marker taxa in the entire studied interval is presented. With this information a correlation with the Riecito Maché section is established. Finally, the stratigraphic distribution of pollen and spores in 87 samples of the WRL04774 core-log samples is described in detail.

4.4.2.1. General Biostratigraphy

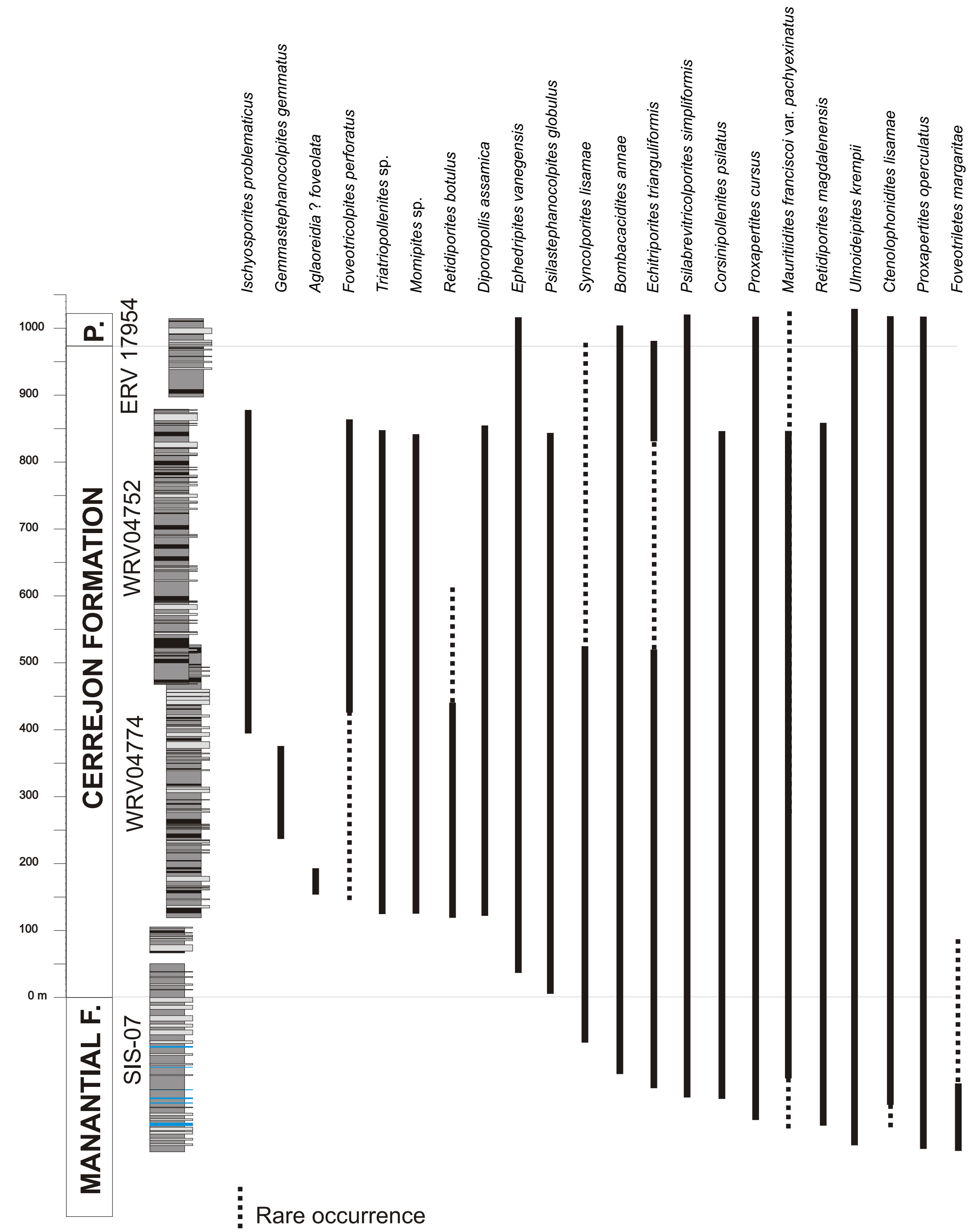


Figure 4.6. Stratigraphical distribution of selected pollen and spore species in the El Cerrejón area.P.: Palmito Formation. See figure 4.4 for conventions.

The figure 4.6.shows the stratigraphic distribution of some pollen and spore species of the El Cerrejón area. Some species, such as *Bombacacidites annae*, *Proxapertites cursus*, *Corsinipollenites psilatus*, *Psilabrevitricolporites simpliformis* seems to have their FAD at the Manantial Formation. At the Cerrejón Formation *Psilastephanocolpites globulus*, *Ephedripites vanegensis*, *Diporopollis assamica*, *Retidiporites botulus*, *Momipites* sp., *Triatriopollenites* sp., *Foveotricolpites perforatus*, *Aglaoreidia*? *foveolata*, *Gemmastephanocolpites gemmatus* and *Ischyosporites problematicus* have their FAD. The occurrence of *Ctenolophonidites lisamae* and *Bombacacidites annae* species some meters above the base of the SIS-07 log indicates the *Ctenolophonidites lisamae* zone of Germeraad et al. (1968). Nevertheless, the upper limit of this biozone is difficult to locate in this area because the FAD of *Foveotricolpites perforatus*, which indicates the top of this zone, is gradual and irregular. It appears in the lower-middle part of the WRV 04774 log but in very low quantities (from 66 samples only 2 occurrences, 2 specimens). In contrast it has a relatively regular occurrence at the upper part of the WRV 04774 log and it is present in all the stratigraphic interval of the WRV04752 log.

4.4.2.2. Palynology of the WRV04774 LOG

As part of a detailed biostratigraphic study of the Paleocene coal-bearing sequence, I studied 70 samples of the WRV04774 log, located in the lower part of the Cerrejón Formation. The vertical variations in the relative percentage and in the absolute abundance of pollen and spore species are presented here. As this study was performed in coals and shales, the variation in the relative frequency of pollen and spore species in these facies could be used to distinguish local from regional flora. Nevertheless, supplementary evidence is still necessary, especially with the study of plant megafossils.

Most of the samples are rich in microscopic organic matter. From 87 samples, 81 have pollen and spores; 35 of them gave more of 200 palynomorphs (pollen, pteridophyte spores and fungal spores) per slide. 114 different types of organic fossils were identified (appendix 5.1). Fungal spores are very abundant. Excluding them, angiosperms are dominant in most of the samples (more than 80 %). *Psilamonocolpites* group (psilate, micropitted monocolpate pollen), *Proxapertites* group (*P. operculatus*, *P. cursus* and *P. psilatus*), *Mauritiidites franciscoi* and the small tricolporate pollen group (< 15 µm) are the most frequent fossils.

The Figure 4.7 shows the stratigraphic distribution and the relative percentages of the pollen and spore species in the WRV04774 log. Most of them occur in variable percentages through the entire studied interval; consequently, they can not be used for biostratigraphical purposes. Nevertheless, some less frequent species seems to be useful for biostratigraphy. For instance *Ischyosporites problematicus* is more or less regularly found above 94,41 m. In the upper WRV04752 log this species is present irregularly in the entire studied interval. Thus, the first occurrence datum of this species could be used as biostratigraphic marker. *Foveotricolpites perforatus* is present in a more or less continuous occurrence at the top of the WRV04774 log. In the WRV04752 log this species has a more or less regular occurrence. This fact could be also used to differentiate the stratigraphic position of the coal beds in the sequence. *Diporopollis assamica* which seems to be restricted to the *Foveotricolpites perforatus* zone could be also used as a biostratigraphic marker. In the WRV04774 log it is present in the

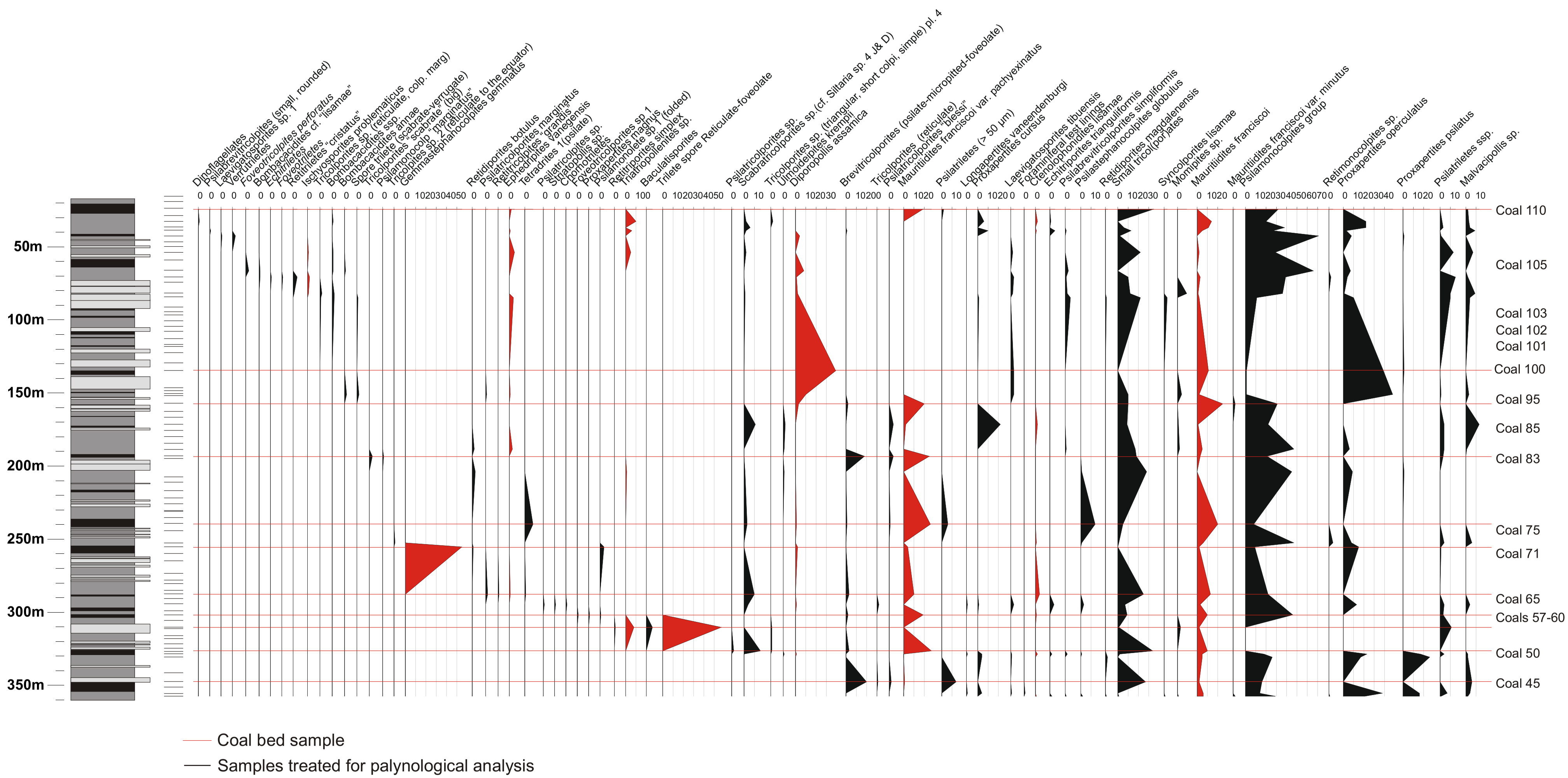


Figure 4.7. Stratigraphic distribution of relative percentages of pollen and spore species from the WRV04774 log,(lower part of the Cerrejón Formation). In red: some species discussed in the text. Samples with less than 100 pollen and spore grains were not considered.

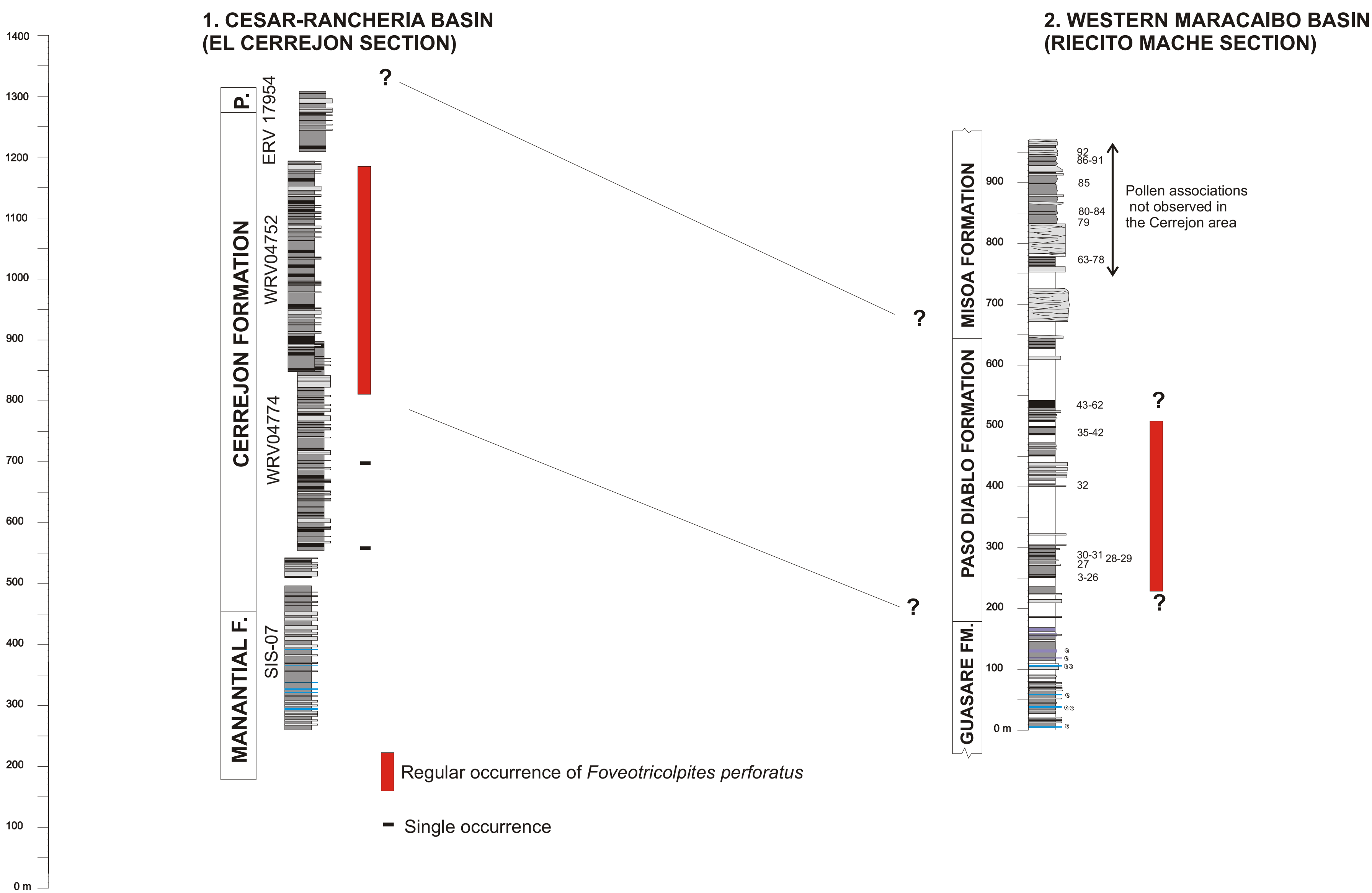


Figure 4.8. Palynological correlation of the Paleocene-Eocene rocks from the El Cerrejón and Riecito Maché sections.

entire studied interval but becomes more abundant at the upper part. On the other hand, some pollen and spore species are abundant in the coal beds: *Diporopollis assamica* at 134,6 m (40 %; coal bed No. 100); *Psilastephanocolpites globulus* at 239,3 m (14 %; coal bed No. 75); *Gemmastephanocolpites gemmatus* at 255.4 m (56 %; coal bed No. 71); the trilete spore Reticulate-foveolate at 310, 3 m (57 %; coal bed No. 57-60) and *Scabratricolporites* sp.(cf. *Siltaria* sp. 4 of Jaramillo & Dilcher, 2001) at 326,8 m (17 %; coal bed No. 50). This abundance could be controlled by local (environmental) or regional (climatic, eustatic?) factors. To differentiate these phenomena, it is necessary to perform a lateral study of the palynologic associations and thus test their stratigrahical value.

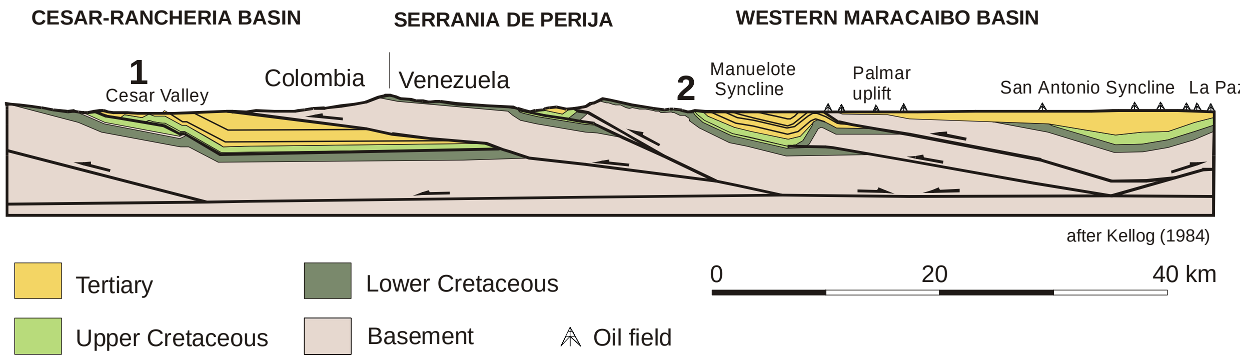
4.5. PALYNOLOGIC CORRELATION BETWEEN THE WESTERN MARACAIBO (MANUELOTE SYNCLINE) AND THE CESAR-RANCHERIA (EL CERREJON) BASINS.

The palynological data were used to correlate the studied sections. The pollen association recognized in the Cerrejón Formation is very similar to those of the Paso Diablo Formation. In contrast the palynologic assemblage observed in the Misoa Formation is not present at the Cerrejón area. The correlation between the two sectors (figure 4.8) shows a big difference in thickness of the coal bearing units above the calcareous Manantial and Guasare Formations. Several hypotheses could explain this phenomenon:

1. Tectonic repetition due to overthrusting at the Cerrejón area. Structural models of this region show a style of thrust faults involving basement (Kellogg, 1984); in this condition the probability of horizontal repetition increases (figure 4.9). Nevertheless, there are important differences in the palynomorph distribution throughout the Cerrejón Formation that discard major structural repetitions: *Proxapertites operculatus* is far more abundant in between coal beds 105 to 155 than in interval 45 to 105, *Gemmastephanocolpites gemmatus* is restricted to the interval between coal bed 45 and 100, *Aglaoreidia*? *foveolata* is restricted to coal 45 to 60 interval, *Retidiporites operculatus* is only found among coal beds 45 to 50, *Ischyosporites problematicus* is found only between the coal beds 101 to 155, and *Horniella* sp. 3 of Jaramillo & Dilcher is found between the 110 to 155 coal beds.

2. Different sedimentation rates and/or lateral facies change between the Guasare Formation limestones and the lower part of the Cerrejón Formation. Unfortunately, there are not available samples of the upper part of the Guasare Formation to locate the FAD of *Foveotricolpites Perforatus* species at the Riecito Maché section. According to Germeraad et al. (1968; fig. 17) it is located at the Guasare-Paso Diablo boundary in this section. If this is correct, the hypothesis of differential sedimentation rates at the Cerrejón area seems to be possible. Note for instance that this species has a regular occurrence from the base of the Paso Diablo Formation in contrast with the very rare presence in the middle-lower part of the WRV 04774 log (figure 4.8).

3. Another explanation could be the erosion of the upper part of the coal bearing sequence at the Riecito Maché section. Thus, the thick sandstone deposits of the base of the Misoa Formation were accumulated after this erosion event in this area. It could explain the occurrence of completely new associations of pollen above this limit.



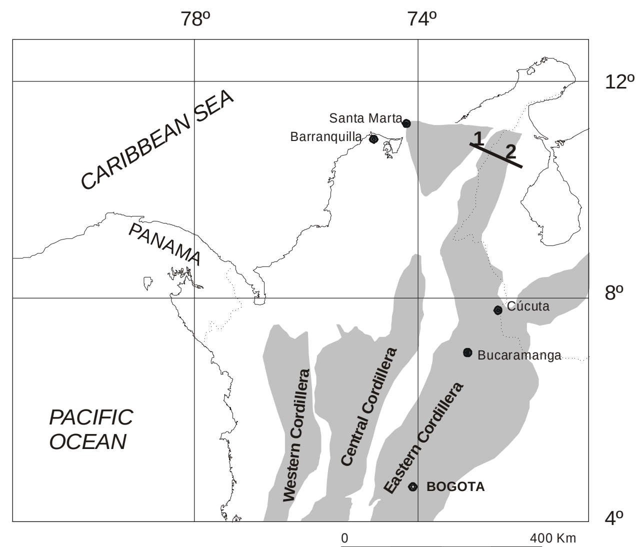


Figure 4.9. Cross section of the northern Sierra de Perijá. Note the low angle thrust faults which could produce repetitions in the Tertiary rocks of the Cesar Valley (from Kellogg, 1984). 1: El Cerrejón section; 2: Riecito Maché section.

4.6. PALYNOFACIES AND PALEOENVIRONMENTAL CONSIDERATIONS

The palynofacies of the El Cerrejón and Riecito Maché sections was not studied in detail. Nevertheless, some noteworthy characteristics observed during the palynological study will be mentioned. Charcoal is an important component in the coals of the Paso Diablo and Cerrejón Formations; in some cases it can reach more than 20 % of the total organic matter. In contrast it is scant or absent in the coal samples of the Misoa Formation at the Riecito Maché section. In the same way, Del Castillo & Scherer (1998) studied the petrography of some coals of the Paso Diablo Formation in the Socuy River area. They pointed out the presence of thick bands of fusinite in some samples of the coals located to the base of the Fm Paso Diablo at the Rio Socuy section 10 km to the north of the Riecito Maché section (see the figure 4.1 for location), which is coherent with our observations. This kind of particles suggests that forest or peat fires may have played a significant role in the mire environment (Taylor et al., 1998). This phenomenon could be of regional extension and thus useful for correlation. On the other hand, Riegel (2001) pointed out the abundance of fusain in the Lower Eocene lignites of Western Europe; this linked to the dominance of moss and fern spores in these coals favoured seasonal changes and episodic droughts. At the Riecito Maché and Cerrejón sections two coals rich in charcoal are dominated by fern spores (coal beds 11 of the Riecito Maché section and 57 of the Cerrejón Formation) which could suggest opportunistic vegetation installed after fire events. These spores are not exclusively associated with fire-prone environments but were able to tolerate, or take advantage of, the disturbance caused by fires through colonization of fire-prone settings (cf. Collinson, 2002).

One of the most important pollen species of these coals is the *Mauritiidites franciscoi* var. *pachyexinatus*, which can reach more than 20 % and in general contrasts with poor percentages in the surrounding shaley facies. This species is similar to pollen of the palm *Mauritia*, which lives nowadays in poorly drained soils in permanently inundated, fresh water swampy areas (Hoorn, 1994). If we consider that the current ecology of *Mauritia* palm was the same for the plant that produced *M. franciscoi* var. *pachyexinatus*, we can suggest that the peats that formed the coal did not have marine influence (e.g. estuaries or intertidal regions). This is also coherent with the very small quantity of marine palynomorphs found in the samples. Thus, the depositional environment of the coal could be similar to the "lower delta plain swamps" of the recent Orinoco delta (cf. Scheihing and Pfefferkorn, 1984). In this environment the old peat swamps have *Mauritia* palm stands. These peat deposits vary from 2 to 6 m and may exceed 10 m in thickness (Danielo, 1976, in Scheihing and Pfefferkorn, 1984). Nowadays, on the Brazilian coast there are swampy areas, were the mangrove vegetation (mainly *Rhizophora*) is succeeded directly by fresh water swamps dominated by *Mauritia flexuosa* (Chapman, 1976). An interesting fact is that this palm seems to be opportunistic, and able to colonize rapidly new habitats created by fire and climatic shifts (Rull, 1999b).

In the Cerrejón and Riecito Maché areas there are some groups of pollen and spores which were not found in the southern Colombian sections. Among them, triporate pollen grains such as *Momipites* and *Triatrioporopollenites* are relatively frequent in the Cerrejón and Paso Diablo Formations. In the Cerrejón area these species are relatively abundant in both coals and shales, and can reach 10 % of the pollen association. *Momipites* is described here for the first time in this area. This genus is morphologically similar to modern pollen grains of the *Engelhardia* complex (*Alfaroa*, *Engelhardia*, *Oreomunnea*; Juglandaceae) (Frederiksen, 1985). During the Early Tertiary, pollen of *Momipites* was very abundant in many lowland peat swamps of North America, Central America and Europe (Nichols, 1973; Nichols and Traverse, 1971). *Triatrioporopollenites* sp., is very similar to *Myrica* pollen (Myricaceae) another northern temperate element. Although it is necessary the study of plant macrofossils and vertebrates to find supplementary evidence, the discovery of these species in northern South America could suggest partial connexion between North and South America during Paleocene times. Tectonic regional models (e.g. Pindell, 1993; Pindell and Drake, 1998) suggest the presence of volcanic chains (Greater Antilles and Lesser Antilles volcanic arcs) between north western South America to the Bahamas platform and Yucatan area of North America. In this situation the presence of land bridges that could provide pathways for dispersal of continental vegetation seems probable. This hypothesis can be also supported by the identification of an interchange event of land mammal faunas between North and South America in the Late Paleocene (Marshall et al., 1997). Based in the magnetostratigraphic calibration of the arrival of some North American mammals to the southern Andean basins of Bolivia and NW Argentina, these authors proposed a ~58,2 and 56,5 Ma event; which could be linked to tectonic and eustatic factors (Marshall et al., 1997). The earliest occurrences of

Engelhardia pollen seems to found in the Maastrichtian of the Gulf Coast and western interior of the United States (Muller, 1981). In the Cerrejón area the first occurrence of this pollen is located at the base of the WRV04774 log which, can be included in the lower part of the *Foveotricolpites perforatus* late Paleocene Caribbean zone of Germeraad et al. (1968).

CHAPTER 5 - REGIONAL SYNTHESIS

In this chapter we integrate the stratigraphic and palynological information of 11 sections (figure 1.1): two in the Usme Syncline (Hoorn, 1988) (see chapter 1); two in the Llanos border (Guerrero and Sarmiento, 1996; Jaramillo and Dilcher, 2001); the Paz de Río section at the Eastern Cordillera (this work); the Uribe and Sogamoso sections at the Middle Magdalena Valley Basin (this work); the Regadera section and the Tarra-1 log at the Catatumbo area (Jaramillo and Dilcher, 2001; Rull, 1997b); the Cerrejón section at the Cesar-Ranchería Basin (this work); the Riecito Maché section (this work) and the Icotea log (Germeraad et al., 1968) at the Maracaibo basin. The classical Tibú section of Gonzalez (1967) was not used because it has inconsistencies with regard to some works performed in nearby areas (e.g. Jaramillo and Dilcher, 2001; Sarmiento, 1995) (see the chapter 2).

5.1. PALYNOSTRATIGRAPHIC SYNTHESIS

An outline of the palynostratigraphic information obtained in this study is presented. The table 5.1 shows the distribution and relative abundance of some species which seems to be useful for biostatigraphic or paleoecological studies. Only the sections with quantitative information were considered. Some remarks about the stratigraphic occurrence and possible environmental controls of some taxa traditionally used in biostratigraphy will be also discussed.

As has been indicated by many authors, *Bombacacidites annae* is a good biostratigraphic marker (Germeraad et al., 1968; Muller et al., 1987; Van der Hammen, 1954a). Its FAD is located at the base of *Ctenolophonidites lisamae* Caribbean zone of Germeraad et al. (1968). This genus is present in all the studied sections, but is more frequent at the southern part of the basin (MMVB, Paz de Río and Llanos Border sections). In these areas, it can reach more than 30 %. In contrast, at the Cerrejón and Riecito Maché sections, it is not very abundant and generally does not exceed 5 %. This could be related to paleoecological factors.

Ctenolophonidites lisamae is particularly frequent at the El Cerrejón and the Riecito Maché sections. On the contrary, it is not found at the Llanos Border and is very rare in the MMVB (unfortunately, this section has many covered intervals). At the Paz de Río section, it is limited to a single coal bed of the Arcillas de Socha Formation. This suggests a paleo-environmental control of its distribution which diminished its biostratigraphic value.

Foveotricolpites perforatus. This species is easy to identify and relatively frequent in all the studied sections. It is also found in shales and coals and thus is a good stratigraphic marker. Unfortunately, due to covered intervals we do not have information about its FAD at the Middle Magdalena Valley. At the El Cerrejón section, it seems that the FAD of this species is gradual and irregular. Probably the former section has the thickest deposits included in the *Foveotricolpites perforatus* biozone in NW South America.

Diporopollis assamica is a fungal spore described by Dutta & Sah (1970), from the lower Eocene beds of the Cherra sandstone (Therria stage, Jaintia Series,) of India. It is described here for the first time in South America. This species is relatively abundant in the Cerrejón and Riecito Maché sections and restricted to the zone *Foveotricolpites perforatus* of

Zone-species/Stratigraphic section	LLANOS BORDER. Piñalerita (Jaramillo & Dilcher 2001)	EASTERN CORDILLERA. Paz de Rio section (this work)	CATATUMBO. Regadera (Jaramillo & Dilcher 2001)	MIDDLE MAGDALENA VALLEY. Uribe and Sogamoso sections (this work)	Riecito Maché (this work, only coals)	Cerrejon (this work)
PALEOCENE ZONES Interval between the FAD of *Bombacacidites* and *Foveotricolpites perforatus*						
Psilamonocolpites operculatus	0	xx	NP	xx	NP	x
Bombacacidites annae	xx	x	NP	xx	NP	xx
Ctenolophonidites lisamae	0	0	NP	0	NP	xx
Corsinipollenites sp.	x	0	NP	x	NP	x
Proxapertites magnus	xx	x	NP	xx	NP	0
***Foveotricolpites perforatus* zone**						
Foveotricolpites perforatus	x	x	NP	x	x	x
Diporopollis assamica	0	x	NP	x	xx	xx
Diporoconia cf. *Diporoconia iszkaszentgyoergyi*	0	x	NP	x	0	x
Ctenolophonidites lisamae	0	x	NP	x	xx	xx
Momipites sp.	x(*1)	0	NP	0	x	xx
Intratriopollenites sp.	0	0	NP	0	xx	xx
Carya type	0	0	NP	0	x	x
Psilastephanocolpites globulus	0	0	NP	0	xx	xx
Bombacacidites annae	xx	xx	NP	xx	x	x
Gemmastephanocolpites gemmatus	0	xx- c	NP	0	xx-c	xx-c
Retidiporites magdalenensis	x	x	NP	xx	x	x
Ephedripites vanegensis	x	x	NP	xx	xx	x
Aglaoreidia? *foveolata*	x	x	NP	x	0	x
Corsinipollenites sp.	xx	xx	NP	xx	0	xx
Echitriporites trianguliformis	0	0	NP	0	0	x
Proxapertites operculatus	xx	xx	NP	xx	x	xx
proxapertites cursus	xx	xx	NP	x	x	xx
Proxapertites magnus	xx	x	NP	xx	0	x
Mauritiidites pachyexinatus	0	0	NP	x	xx	xx
Spinizonocolpites pachyexinatus	x	x	NP	x	0	0
Retidiporites botulus	0	x	NP	0	x	x
Psilatricolporites "blessi"	0	0	NP	0	x	x
Syncolporites lisamae	x	0	NP	0	0	xx
Psilabrevitricolporites simpliformis	x	0	NP	0	0	xx

	LLANOS BORDER Piñalerita (Jaramillo & Dilcher 2001)	EASTERN CORDILLERA Paz de Rio (this work)	CATATUMBO Regadera (Jaramillo & Dilcher 2001)	MIDDLE MAGDALENA VALLEY Uribe and Sogamoso sections (this work)	Riecito Maché (this work, only coals)	Cerrejon (this work)
EOCENE ZONES Zones *R trianguatus M annulatus* of Germeraad et al. (1968)						
Bombacacidites soleaformis	x	x	x	x	0	NP
Bombacacidites sp. 14	0	x	0	x	0	NP
Brevitricolpites microechinatus	0	x	x	xx	0	NP
Cricotriporites guianensis	x	xx	x	x	0	NP
Cyclusphaera scabrata	x	x	xx	x	0	NP
Echiperiporites sp.	0	xx	0	xx	0	NP
Lanagiopollis crassa	xx	0	xx	x	0	NP
Margocolporites vanwijhei	0	xx	x	0	0	NP
Monoporopollenites annulatus	x	x	x	x	0(*3)	NP
Psilabrevitricolpites "simplex"	0	x	0	x	0	NP
Psilastephanocolporites fissilis	x	x	0	0	0	NP
Racemonocolpites facilis	x	x	0	xx	0	NP
Ranunculacidites operculatus	x	0	0	0	0	NP
Retibrevitricolpites triangulatus	x	x	0	x	xx	NP
Retitrescolpites ? *irregularis*	xx	xx	x	x	xx	NP
Retitricolpites cf. *simplex*	0	xx	0	xx	0	NP
Spirosyncolpites spiralis	x	x	xx	x	0	NP
Striatopollis catatumbus	x	x	x	x	x	NP
Tetracolporopollenites maculosus	xx	0	x	xx	0	NP
Tetracolporopollenites transversalis	xx	x	x	x	x	NP
Rhoipites guianensis	xx	x	0	0	x	NP

CONVENTIONS

0=Not reported
x=Present
xx=Frequent
C=Asociated to coal

NP= Interval not studied or not covered by the section

TABLE 5.1. Occurrence of some Paleocene-Eocene pollen and spore species in the studied sections

*1 *Momipites africanus*
*3 Recorded by Rull (1999) at the lower part of the Misoa Formation

Germeraad et al. (1968). *Diporopollis assamica* is rare in the Middle Magdalena Valley and the Paz de Río sections.

Gemmastephanocolpites gemmatus is a species used by Germeraad et al. (1968) in their biozonation. At the Cerrejón section, it is present in high percentages in the coal beds, and is scanty or absent in the shales. It seems environmentally controlled.

Colombipollis tropicalis, a species described in the Guaduas Formation (Sutatausa area, north of Bogotá; Sarmiento 1994), is described in several sections of the basin (e.g. Guerrero and Sarmiento, 1996; Jaramillo and Dilcher, 2001; Pocknall et al., 2001). Its LAD is found at the Lisama Formation, Areniscas de Socha below the FAD of *Foveotricolpites perforatus*. At the Riecito Maché section, it is present in a sample of the Guasare Formation.

Aglaoreidia? *foveolata* has been found in all the studied sections in the *Foveotricolpites perforatus* biozone within a short stratigraphic interval. Unfortunately, this species is not abundant.

Monoporopollenites annulatus is present in all the stratigraphic section and can be considered as a good stratigraphic marker. Nevertheless, as has been indicated by Germeraad et al. (1968), the first regular occurrence of this species is not a sharply defined event; additionally, it is not abundant in the samples. A detailed counting and sampling in the sections are thus necessary in order to identify the FAD and occurrence of this species. For instance, at the Middle Magdalena Valley, it was recorded at the Sogamoso section but it is not found at the Uribe section where the sampling is sparse.

Foveotriporites hammenii is found in all the studied sections. It is relatively abundant, thus can be considered as a good stratigraphic marker. Muller et al (1987; table 2) put its FAD at the base of their *Rugotricolporites felix* zone. At the Middle Magdalena Valley (Sogamoso section), it appears some meters below *Monoporopollenites annulatus.*.

Racemonocolpites facilis is present in the Eocene deposits of all the studied sections and is especially abundant in the Middle Magdalena Valley (Sogamoso section).

Spirosyncolpites spiralis is abundant and occurs in all the studied sections. Its FAD could be considered as a good stratigraphic marker.

Cyclusphaera scabrata is found at the first productive levels above the barren interval and has been only recorded in the Eocene studied deposits.

Psilamonocolpites operculatus is a potentially useful species that was discovered at the Middle Magdalena Valley in the lower part of the Lisama Formation (Pardo-Trujillo et al., 2003). Nevertheless, the presence of several covered intervals in this section prevents to know its total stratigraphic extension. At the Paz de Río area, it is present at the top of the Guaduas Formation, the Areniscas de Socha Formation and is abundant at the base of the Arcillas de Socha Formation where it co-occurs with *Foveotricolpites perforatus*.

Brevitricolpites microechinatus. Its FAD seems to be located at the upper part of the

Paleocene associations. Nevertheless, it is not abundant. At the upper part of the La Paz Formation, this species has a regular occurrence.

Diporoconia cf. *D. iszkaszentgyoergyi*. This is the first record of this species in South America. At the Middle Magdalena, Paz de Río and El Cerrejón areas, it occurs into the *Foveotricolpites perforatus* zone of Germeraad et al. (1968), but always in very low percentages.

Ephedripites vanegensis. This species occurs regularly in all the studied sections, especially in the *Foveotricolpites perforatus* zone. It is not found in the Eocene deposits. Thus, its LAD can be a good stratigraphic marker. Muller et al. (1987) pointed out that this species has its FAD in the lower part of the *Foveotricolpites perforatus* zone (Zone 16), but in their range chart of palynomorphs (table II), they put this species in the zones 14, 15 and 16 (*S. baculatus*, *G. gemmatus* and *F. perforatus* respectively).

Corsinipollenites sp. (including *Corsinipollenites psilatus* of Jaramillo & Dilcher, 2001) is relatively frequent in the Paleocene deposits. It appears below the FAD of *Foveotricolpites perforatus* at the Piñalerita, Uribe and El Cerrejón sections. It is also observed in some Eocene sections (e.g. at the base of the Picacho Formation and at the upper part of the La Paz Formation). Similar forms have been described by Lorente (1986) in the upper Tertiary deposits of Venezuela.

Echitriporites trianguliformis. This species is relatively frequent at the Cerrejón Formation and is not found in time-equivalent units from the Middle Magdalena Valley, Paz de Río and Llanos Border sections. It is consistent with the Germeraad et al. (1968) data who suggest that this species was restricted to coastal environments.

Momipites and *Carya* type pollen. As has been mentioned in the chapter 4, these forms are similar to some pollen species described in the Paleogene deposits of North America and Europe. Their restricted abundance to the northern sections could be linked to paleoecological factors.

Triatriopollenites sp. is a form similar to pollen of Myricaceae. It is relatively frequent in the late Paleocene of the northern region of Colombia and Venezuela. As has been suggested by some authors (e.g. Chateauneuf, 1980), Myricacacae lived partially in coastal environments in the early Tertiary, perhaps in brackish-water marshes. A similar morphospecies (*Triatriopollenites guianensis*) has been described in the zones C and D (Eocene) of Surinam (Wijmstra, 1971).

5.2. COMPARISON OF SOME PALYNOSTRATIGRAPHIC ZONATIONS IN NW SOUTH AMERICA

In order to integrate the palynostratigraphic information presented in the previous chapters, we discuss here the lateral distribution of some palynologic zonations of northwestern South America, especially Germeraad et al. (1968) and Muller et al. (1987).

The figure 5.1 shows the lateral distribution of the Germeraad et al. (1968) biozones. The

Ctenolophonidites lisamae zone can be limited by the FAD of *Bombacacidites annae*. In contrast *Ctenolophonidites lisamae*, *Gemmastephanocolpites gemmatus*, and *Foveotriletes margaritae* are scanty or absent in the studied sections. The *Foveotricolpites perforatus* zone can be identified in most of the sections. To the south, facies with mottled barren shales increase. Thus, at the eastern border of the Usme Syncline, only one level with *Foveotricolpites perforatus* species was identified (Hoorn, 1988). As can be observed in this diagram, the limit between the *Foveotricolpites perforatus* and *Retibrevitricolpites triangulatus* zones can be only observed at the Riecito Maché and Icotea sections. Unfortunately, the low density of our sampling at the Riecito Maché section does not allow locating exactly the limit between these zones. Here, we used the boundary indicated by Germeraad et al. (1968) for this section.

Among the species that appear at the base of the *Retibrevitricolpites triangulatus* biozone, only *Striatopollis catatumbus* is regularly present in all the studied sections. Consequently, its FAD is used here as regional indicator of this zone. This is coherent with the ecology of plants that produce similar pollen (*Crudia*, *Anthonotha* and *Isoberlinia*, Fabaceae) (Germeraad et al., 1968), which live nowadays in fluvial lowlands. On the contrary, *Retibrevitricolpites triangulatus* and *Lanagiopollis crassa*, other species that were used by Germeraad et al. (1968) to limit this biozone are scarce, especially in the Middle Magdalena Valley Basin. This could indicate a paleoenvironmental control in its distribution. For instance *Lanagiopollis crassa*, a species similar to the extant mangrove *Pelliciera rizophorae*, seems to be more frequent in Venezuela were marine influence was stronger (figure 5.2).

The upper limit of *Retibrevitricolpites triangulatus* biozone seems to be a good stratigraphic marker. It is put at the first regular appearance of *Monoporopollenites annulatus* species which is recognized at basin scale (figure 5.1). This species is associated with the Poaceae family (Gramineae) which is mostly wind pollinated plants with widespread distribution and preservation potential. Thus, this species can be useful for biostratigraphic purposes. Based on foraminiferal data, Germeraad et al. (1968) indicated that its first appearance corresponds to the upper part of the early Eocene in Colombia and Venezuela. In contrast, Muller et al (1987) put, without comments, the FAD of this species in the lower Paleocene (see their table II). Our data and the published palynological distribution (e.g. Jaramillo & Dilcher, Rull 1997, Rull, 1999 and internal reports of the Colombian Institute of Petroleum, ICP) show that this species never occurs within the Paleocene pollen associations in the studied basin.

At the Piñalerita, Paz de Río, Regadera sections and in the Tarra 1 log, *Monoporopollenites annulatus* appears immediately after or few meters above the sterile interval. Thus, it could be possible that the pollen characteristic of the *Retibrevitricolpites triangulatus* zone was not preserved. Nevertheless, the relatively thin thickness of the Areniscas de El Limbo and the strong regional facies change between the upper Paleocene and the Eocene could be also related to an unconformity or to a condensed section in this part of the sequence (see chapter 1). Anyway, palynology cannot give a direct answer about this problem. Another fact that could suggest an unconformity is the location of the FAD of *Cicatricosisporites dorogensis* and *Perisyncolporites pokorny* which mark the base of the *Verrucatosporites usmensis* zone (middle-late Eocene) of Germeraad et al. (1968). At the Piñalerita and Regadera sections, the FAD of these species is located 180 and 260 m above the top of the barren shales respectively (figure 5.1). In contrast, these species are recorded immediately above the barren interval in

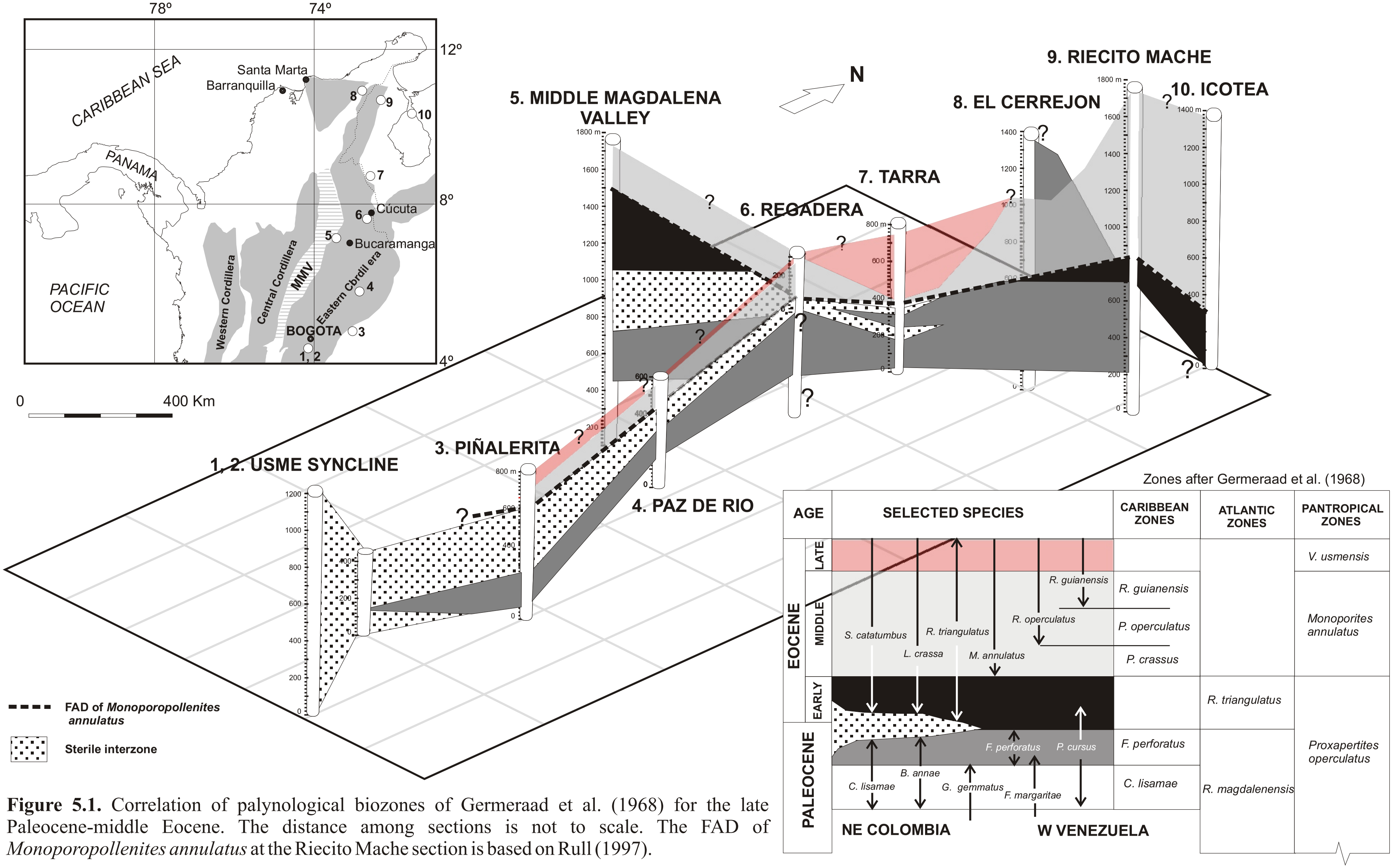


Figure 5.1. Correlation of palynological biozones of Germeraad et al. (1968) for the late Paleocene-middle Eocene. The distance among sections is not to scale. The FAD of *Monoporopollenites annulatus* at the Riecito Mache section is based on Rull (1997).

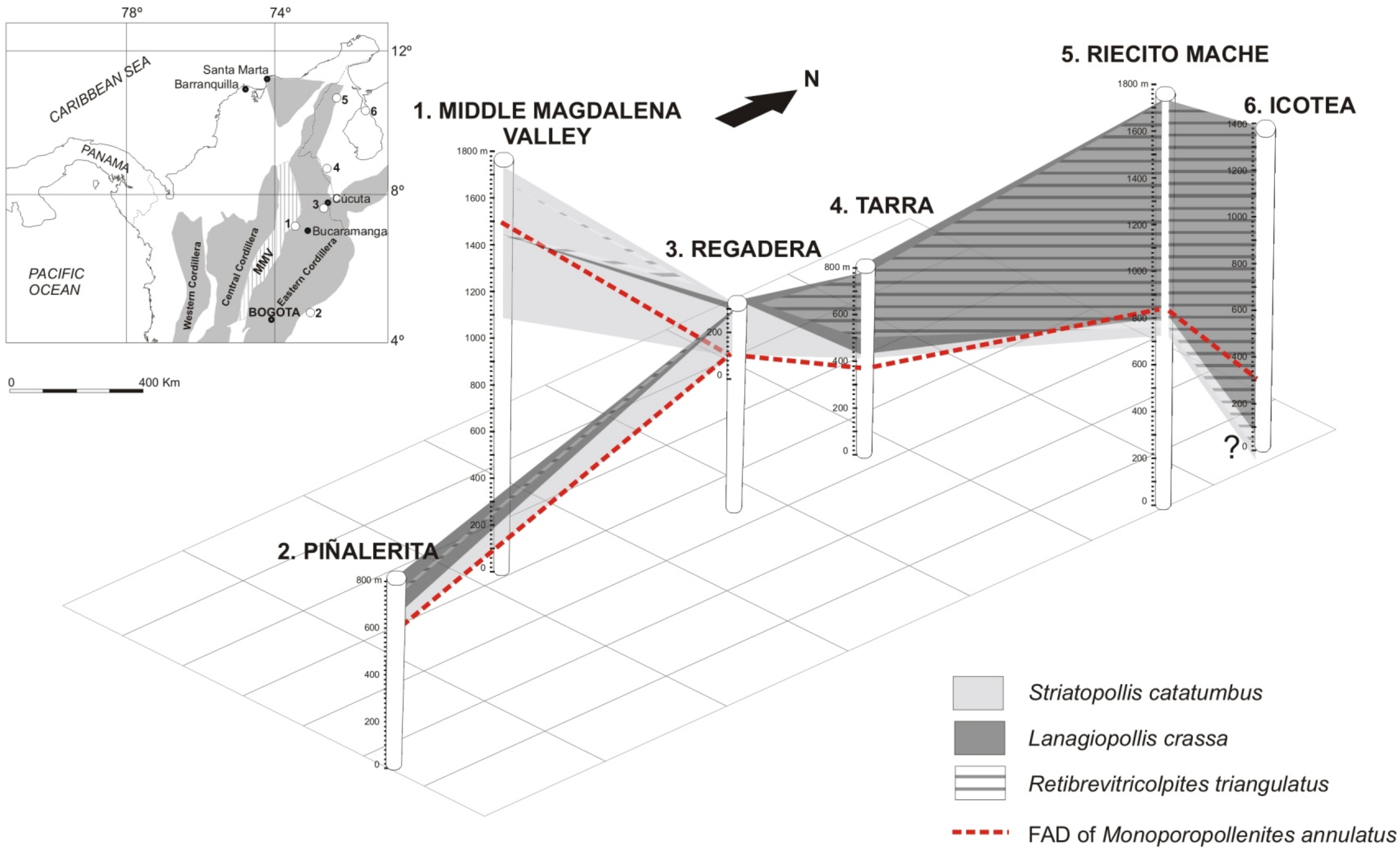


Figure 5.2. Lateral distribution of the species that define the *Retibrevitricolpites triangulatus* zone of Germeraad et al. (1968).

the Tarra-1 log. This fact suggests a hiatus that encompasses the lower and part of the middle Eocene in this area. At the Middle Magdalena Valley and the Icotea log, these species were not found. This suggests unconformities, condensed sections and/or a strong differential sedimentation rates between the studied sections.

On the other hand, there are difficulties to identify the Caribbean palynologic sub-zones defined by Germeraad et al. (1968) (figure 1.4) in the studied sections. For instance, at the Piñalerita section, *Lanagiopollis crassa* appears later than *Monoporopollenites annulatus* (as have been mentioned, *L. crassa* seems to be controlled by environmental factors); *Ranunculacidites operculatus* is very scantly (only one specimen) and *Rhoipites guianensis* appears simultaneously with *Perisyncolporites pokorny* and above of *Cicatricosisporites dorogensis*. At the Middle Magdalena Valley, *L. crassa* is present in one stratigraphic level (level 36 of the figure 2.8; one specimen) and *R. operculatus* is not found. Germeraad et al. (1968) interpreted this absence as resulting of a stratigraphic hiatus; here we suggest an environmental control (chapter 1). Additionally, Germeraad et al. (1968) mentioned the *R. guianensis* zone to the top of La Paz and Lower Esmeraldas Formation; in our detailed study of the Sogamoso section, this species was not found in this interval. Moreover, *C. dorogensis* and *P. pokorny* were not found in the studied interval. All of these anomalies suggest that the Caribbean zones proposed by Germeraad et al. (1968) are not applicable in the Colombian sections.

A comparison of the palynological zones of Muller et al (1987) has been discussed in previous chapters. Here we will mention some general remarks about the application of this schema in the studied sections.

The zone 14 (*Spinizonocolpites baculatus*): The base of this zone is defined with the FAD of *Spinizonocolpites baculatus*, *Bombacacidites* and *Mauritiidites franciscoi*. This section was defined in NW Venezuela (Rubio section). In the Colombian sections (e.g. the Paz de Río section, the Guadualera creek section of Guerrero and Sarmiento, 1966 and the Eleuterio log of Sarmiento, 1995), the co-occurrence between *Bombacacidites* and *Spinizonocolpites* cannot be appreciated. Instead, *Bombacacidites* seems to appear later. It can be explained by paleoenvironmental factors. *Spinizonocolpites baculatus* has been related to *Nypa* palm, which lives nowadays in back-mangrove regions of the Indo-Malesian area (Morley, 2000). Thus, if the FAD of this species is environmentally controlled, its first occurrence could not be isochronous along the basin. In contrast, the distribution of *Bombacacidites* seems to be more widespread in the basin (see bellow). This pollen genus is related to plants of Bombacaceae, some of which are common in the rain forest and in mixed swamps of tropical fluvial environments. Thus, unlike the *Spinizonocolpites* genus, *Bombacacidites* could be present in both coastal and terrestrial deposits.

The zone 15 (*Gemmastephanocolpites gemmatus*). As have been indicated *G. gemmatus* is practically absent in the studied sections and consequently this zone cannot be identified.

The zone 16 (*Foveotricolpites perforatus*). This zone was recognized in all the studied sections.

The Zone 17 (*Rugotricolporites felix*). The *Rugutricolporites felix* and Pollen indet. A species used to define this zone are not found or are very scantly in the studied sections.

The Zones 18, 19 and 20 (*Echitriporites trianguliformis* Forma A, *Retitricolpites magnus* and *Bombacacidites soleaformis*). These zones were not recognized in the studied sections. *Echitriporites trianguliformis* Forma A. of Muller et al. (1987) (formally named *Echitriporites trianguliformis* var. *orbicularis* by Jaramillo and Dilcher, 2001) is abundant in the Piñalerita section but it appears only in one stratigraphic level in the Middle Magdalena Valley; *Bombacacidites* sp. B is only recorded at the base of the Picacho Formation (1 specimen), *Retitrescolpites magnus* is not found at the Paz de Río area and is very rare in the Middle Magdalena Valley; *Bombacacidites soleaformis*, indicator of the zone 20, seems to be the only species which have been found in all the studied sections, but it is very scant (only one specimen by stratigraphic level). Additionally, *Bombacacidites foveoreticulatus*, *Janmulleripollis pentaradiatus* and *Echiperiporites estelae* are not found in the studied interval. Thus, the biozones 21-24 could not be identified. The shortage or absence of these species through the studied interval hinders to establish the limits of the Eocene zones described by Muller et al (1987). It is important to remark that Colmenares and Teran (1993) showed that in three sections of the Catatumbo region in Venezuela, only 5 of the 10 late Paleocene-middle Eocene palynologic zones proposed by Muller et al. (1987), could be identified.

5.3. CHRONOSTRATIGRAPHIC CHART OF THE PALEOGENE FROM NE COLOMBIA AND W VENEZUELA

In the chapter 3, we proposed a chronostratigraphic and lithostratigraphic correlation between the Cretaceous-Eocene rocks from the Middle Magdalena Valley Basin, Eastern Cordillera and Llanos border. Here we integrate this information with other places of NE Colombia and W Venezuela in order to construct a three-dimensional chart (figure 5.3). Because there are still not enough dating elements for the Paleogene rocks of this area, the model must be considered as provisional. Some critical points will be only mentioned.

The upper Cretaceous of Colombia and Venezuela is mainly composed by shallow marine and coastal deposits, which can be dated with foraminifera. At the south of the basin, these deposits have been used to date indirectly the overlying rocks (e.g. The Bogotá Formation in the western border of the Usme Syncline). The stratigraphic location of the Bogotá Formation has been, thus, only based on its stratigraphic relationships and on a single palynological sample (Hoorn, 1988).

A late Cretaceous-early Paleocene unconformity has been proposed by Sarmiento (1994) for the Llanos border area. It is based in the absence of the palynologic zone II described by this author at the Sutatausa region 85 km to the NW. Nevertheless, there are no marine microfossils to constrain the top of this biozone. As mentioned, the palynologic association of the zone II of Sarmiento (1994) is found in the upper part of the Guaduas Formation at the Paz de Río area. In this work, we put a short duration hiatus, due to the high facies contrast between the Guaduas and the Areniscas de Socha Formations. Nevertheless, the duration of this event cannot be determined with the available information. To the north, in the Catatumbo and western Venezuela regions, this unconformity has not been reported (e.g. Comité Interfilial de Estratigrafía y Nomenclatura CIEN, 2004).

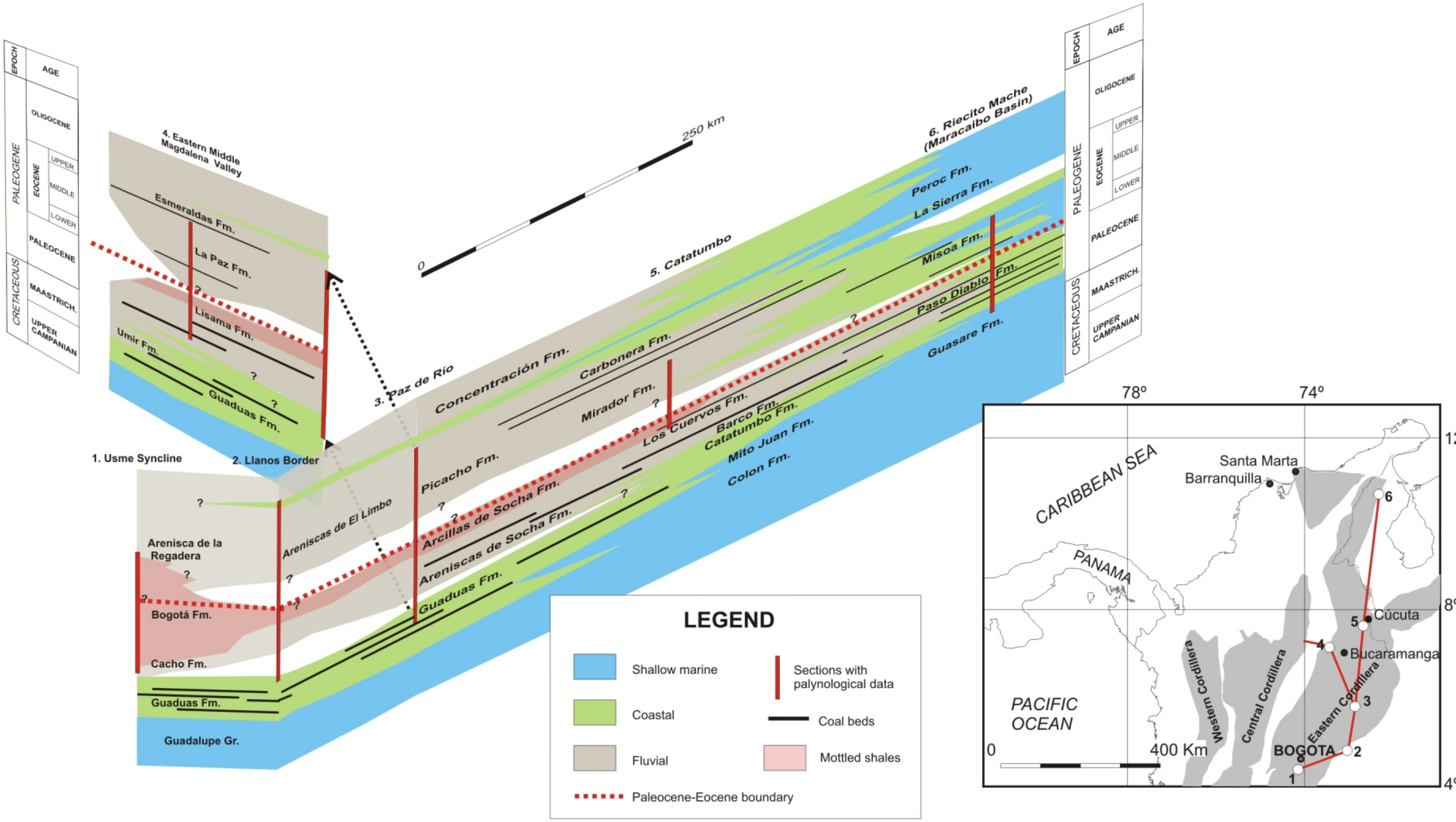


Figure 5.3. Chronostratigraphic chart and general paleoenvironments of the upper Cretaceous-Paleogene deposits from NE Colombia and W Venezuela. 1 Usme Syncline (Hoorn,1988); 2. Llanos Border (Jaramillo and Dilcher, 2001; Guerrero and Sarmiento, 1996); 3: Paz de Rio (this work); 4. Middle Magdalena Valley (Pardo et al., 2003 and Gómez, 2001); 5. Catatumbo (Jaramillo and Dilcher, 2001); 6. Riecito Mache (this work). The calibration of palynologic occurrences is based on Germeraad et al. (1968). See more explanation in the text.

The "Eocene" unconformity, indicated in the Figure 5.3, has been controversial. Some authors (e.g. Cooper et al., 1995a; Cooper et al., 1995b; Villamil, 1999) have suggested an early-middle Eocene hiatus in most of the Colombian territory. Nevertheless, as have been pointed out by Jaramillo and Dilcher (2001), there is nowhere a single locality with documented paleontological information supporting this hypothesis. The data obtained in this work show that, at least in the Colombian sections, palynology cannot give a direct answer to this problem due to the barren nature of the rocks that include this interval. Tentatively, we put a hiatus in our schema, mainly based on the strong facies change and palynologic content between the units located above and below this surface and on the contrasting distance in the FAD of some palynological marker species across the sections (e.g. *Striatopollis catatumbus*, *Monoporopollenites annulatus*). Nevertheless, if this hypothesis is correct, there are still no geological information (e.g. geochemical, radiometrical? or biostratigraphical data) to determinate the duration of this unconformity.

Hypothetically, we put in our diagram a widespread marine incursion event at the Eocene-Oligocene boundary. It correspond to the Los Corros fossiliferous horizon of the Middle Magdalena Valley (see the chapter 1); the fossiliferous horizon described by Cazier et al. (1997) which encases the oolitic ironstone deposits of the Paz de Río area, and the marine dinoflagelate beds described by Jaramillo & Dilcher (2001) in the Llanos border (Piñalerita section). Given the importance of these beds to establish time calibration points, a detailed biostratigraphic study of all of these localities is necessary, in order to demonstrate their synchrony or heterochrony.

5.4. PALEOCENE-EOCENE PALEOGEOGRAPHIC MODELS OF NW SOUTH AMERICA

Reconstructing Paleogene paleogeography of NW South America is difficult due to the absence of detailed biostratigraphical and sedimentological information. Additionally, the sedimentary conditions of some deposits were not favourable for the fossil preservation which prevents accurate correlations. For these reasons, general or approximate models are only available. Recently, the Colombian Geological Survey (Ingeominas) produced some paleofacies maps of Colombia for different periods of time (Cáceres et al., 2003). Nevertheless, the time included in each reconstruction is very large (see for instance their "Maastrichtian-Paleocene" paleogeographic chart) and consequently the lithostratigraphic units compared could be heterochronous, which leads to misinterpretations about the lateral distribution of the facies. In spite of the problems discussed in the precedent chapters, palynology is the only biostratigraphic tool available for correlate the Paleocene-Eocene continental deposits of NW South America. Thus, our study can be used to discuss some paleogeographical reconstructions of this region. The time calibration data of Germeraad et al. (1968) are the only available and are provisionally employed here (figure 5.1). The sections presented here can be included in the *Ctenolophonidites lisamae, Foveotricolpites perforatus, Retibrevitricolpites triangulatus* and *Monoporopollenites annulatus* Paleocene-middle Eocene zones of Germeraad et al. (1968). Two of the most extensively reported models correspond to Villamil (1999) and Cooper and will be discussed here.

The figure 5.4.A shows the "Lower Paleocene" paleogeographic chart of Villamil (1999). This map includes the Lower Socha (Areniscas de Socha Formation of this work) and Barco Formations which can be, at least partially, located in the *Ctenolophonidites lisamae* Paleocene palynologic zone of Germeraad et al. (1968). It is mainly deduced by the location of the FAD of *Bombacacidites annae* (Guerrero and Sarmiento, 1996; Sarmiento, 1995 and chapter 3 of this work). To the north, calcareous deposits of the upper part of the Guasare and Manantial Formations were accumulated (Rull, 1999a and chapter 4 of this work). Thus, the carbonate facies were more widespread to the west than those proposed in the Villamil's model. The increase in the rock thickness at the Middle Magdalena Valley (lower part of the Lisama Formation) suggests high subsidence rates. In contrast, relatively thin sandstone-dominated fluvial deposits were accumulated to the east (Areniscas de Socha and Areniscas de El Morro Formations) (figures 2.11; 3.10 and figure 3.11). The NNW paleocurrent values obtained in this work for the Areniscas de Socha Formation at the Paz de Río area (chapter 3) are coherent with the location of the depositional axis of the basin proposed by Villamil (figure 5.4.A). To the south of the basin, red mottled shales were dominant (e.g. Guaduala, Seca and upper part of the Guaduas Formations). The time position and correlation of these units is mainly based on their stratigraphic relations and lithology due to the absence of biostratigraphical data (Porta, 1974).

During the Late Paleocene (*Foveotricolpites perforatus* zone of Germeraad et al., 1968), the paleogeographic map is similar to the previous model (not illustrated by Villamil; figure 5.4.B). Nevertheless, shale-dominated fluvial and coastal deposits covered almost all the basin (Bogotá, Arcillas de Socha, Los Cuervos, upper part of Lisama, El Cerrejón. and Paso Diablo Formations), which indicates a basin-scale increase in the accommodation. This promoted also the formation of peat bogs, which were more frequent and thicker to the north (e.g. the Cerrejón and Paso Diablo Formations). At the end of this "sedimentary cycle", mottled shales were extensively produced at the southern-middle part of the basin (figure 5.4.B). The "Early Eocene" model of Villamil includes the "Socha Superior" and the Los Cuervos Formations. As have been mentioned, the palynological associations of these units can be included in the *Foveotricolpites perforatus* late Paleocene zone (Colmenares and Terán, 1993; Sarmiento, 1995 and chapter 3 of this work). The barren shales located at the top of these units, have probably been included by some authors in the Eocene based only in their stratigraphic position. Recently, Jaramillo et al. (2004) described an Eocene palynological association at the uppermost part of the Los Cuervos Formation in several core logs of the Llanos foothills. It could suggest erosion or sampling gaps around this level at the Middle Magdalena Valley and Paz de Río areas or that these facies became younger to the east.

After the accumulation of widespread shaley and coal beds of the late Paleocene "cycle", the sedimentation was mainly composed by sandstones and shales. The bases of some of these units are usually very poor in pollen and spores (e.g. lower part of the La Paz Formation), which made difficult their dating and correlation. Above these deposits, the occurrence of a great quantity of new pollen and spore species is characteristic. To correlate these deposits, we used the FAD of two pollen species which have been recorded at a basin-scale: *Striatopollis catatumbus* and *Monoporopollenites annulatus*, (see discussion in the previous section and in the chapter 3). Germeraad et al. (1968) used these species to define the *Retibrevitricolpites triangulatus* (late Paleocene?- early Eocene). As can be observed in the figure 5.1, the only deposits that can be included in this biozone are located in the Middle Magdalena Valley (lower part of the La Paz Formation) and the Maracaibo area (Riecito Maché and Icotea

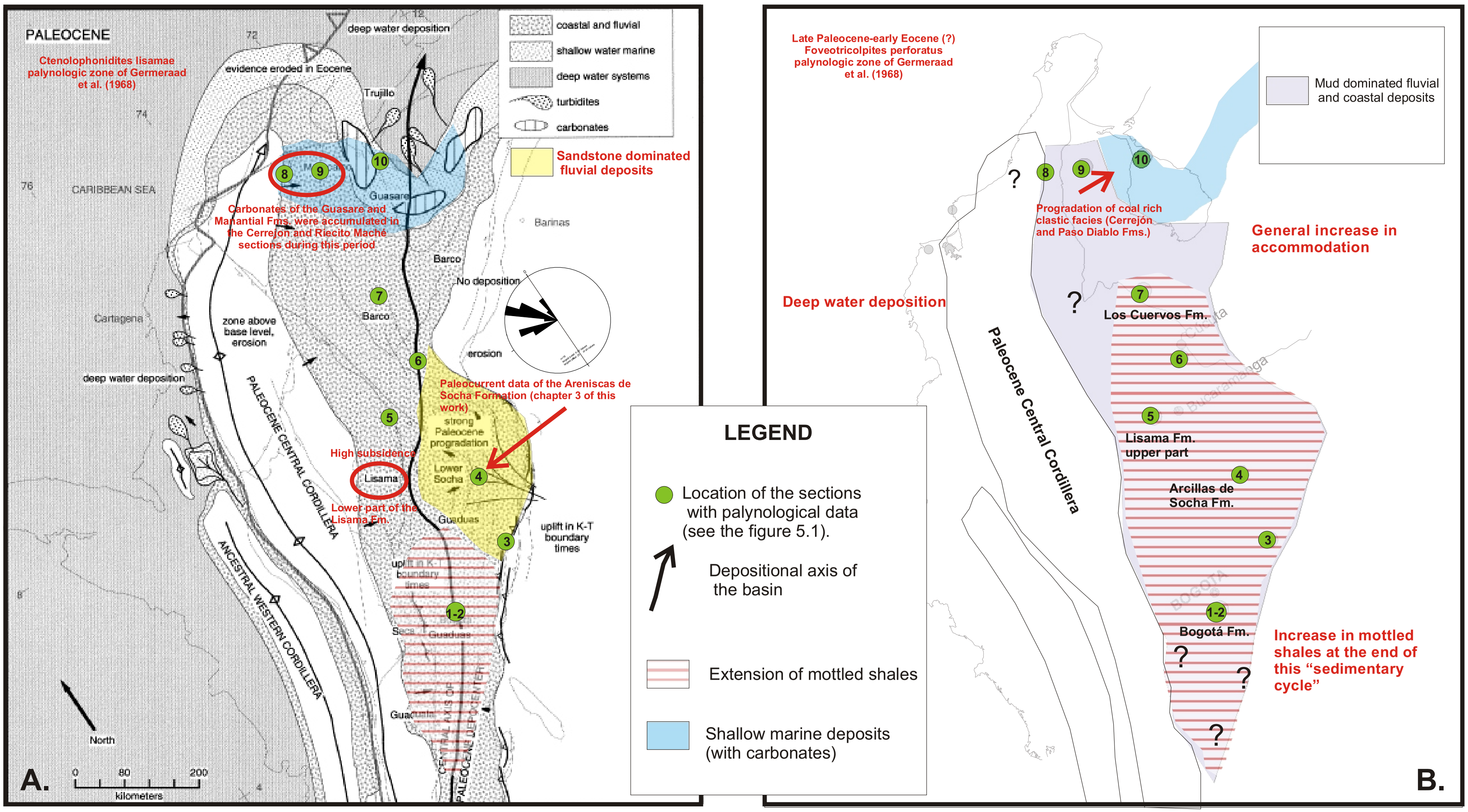


Figure 5.4. Paleocene paleogeographic charts of NW South America. A. "Lower Paleocene" model of Villamil (1999). Additions in red are from the present author. B. Late Paleocene paleogeographic model proposed in this work. 1-2: Usme Synclyne (Hoorn, 1988); 3: Piñalerita and Guadualera creek sections (Jaramillo and Dilcher, 2001; Guerrero and Sarmiento, 1996); 4: Paz de Río section (this work); 5: Sogamoso and Uribe sections (Pardo et al., 2003 and this work); 6: Regadera section (Jaramillo and Dilcher, 2001); 7: Tarra-1 log (Rull,1997); 8. El Cerrejón section (this work); 9: Riecito Maché section (Rull, 1999 and this work); 10: Icotea log (Germeraad et al., 1968).

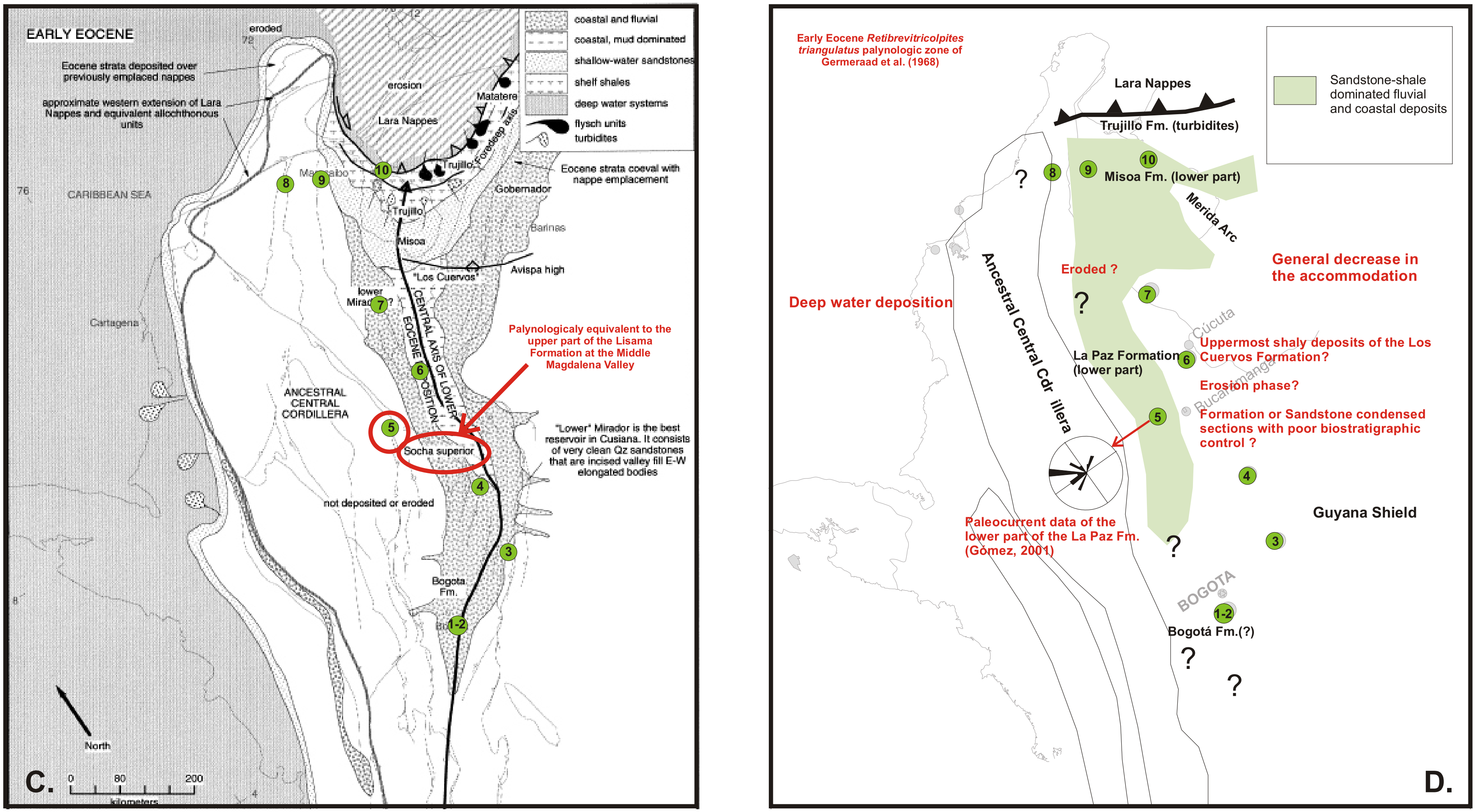


Figure 5.4. Early Eocene paleogeographic charts of NW South America. C: Chart of Villamil (1999). Additions in red are from the present author; D: Chart proposed in this work. 1-2: Usme Synclyne (Hoorn, 1988); 3: Piñalerita and Guadualera creek sections (Jaramillo and Dilcher, 2001; Guerrero and Sarmiento, 1996); 4: Paz de Río section (this work); 5: Sogamoso and Uribe sections (Pardo et al., 2003 and this work); 6: Regadera section (Jaramillo and Dilcher, 2001); 7: Tarra-1 log (Rull,1997); 8. El Cerrejón section (this work); 9: Riecito Maché section (Rull, 1999 and this work); 10: Icotea log (Germeraad et al., 1968);

sections). In contrast, the absence of this zone in the sections located to the east could be associated to unconformities and/or to thin coarse-grained condensed deposits without palynomorphs. Thus, our paleogeographic map is very different to those proposed by Villamil (1999) (figures 5.4.C and 5.4.D). The sedimentation was mainly located to the west of the present-day Eastern Cordillera and the eastern Middle Magdalena Valley. At the Maracaibo Lake area, the lower part of the Misoa and Trujillo Formations were accumulated in a foreland basin setting (Lugo and Mann, 1995). Nevertheless, supplementary biostratigraphical and sedimentological information is necessary in order to demonstrate the connexion between the Middle Magdalena Valley and the Maracaibo area proposed in our paleogeographic chart (figure 5.4.D). Likewise, there are no biostratigraphic information to constrain the facies distribution at the southernmost part of the basin (e.g. at the Mochuelo creek section south of Bogotá), (figure 5.4.D) (Porta, 1974).

Villamil (1999) considers that during the middle Eocene most of the Colombian territory experienced erosion or non-deposition phase (the “pre-Andean orogenic event”) due to an accelerated uplift rate of the Central Cordillera. Our palynological data show that most of the sandstone units located above the shaley-coaly late Paleocene deposits can be included in the middle-late Eocene *Monoporopollenites annulatus* and *Verrucatosporites usmensis* palynologic zones of Germeraad et al. (1968). Consequently, our paleogeographic chart for this period is completely different to those proposed by Villamil (figures 5.4.E and 5.4.F). We suggest that fluvial and coastal sandstone-dominated units were widespread in the entire basin (figure 5.4.F). The depositional axis of this basin was probably located at the eastern border of the present-day Eastern Cordillera. This is coherent with NNW and NNE paleocurrent data obtained for the Picacho Formation and the upper part of the La Paz Formation respectively (Gómez, 2001 and chapter 3 of this work). It is necessary to point out that the different occurrences of some pollen and spore species in the sections including this interval could be related to different accommodation rates and probably the development of local unconformities (?).

Villamil (1999) suggests, without biostratigraphic evidence, a Late Eocene age for the La Paz Formation. Consequently, in his “Late Paleocene” paleogeographic chart (not shown here) the La Paz Formation laterally changes to the east into the upper Mirador estuarine facies and the coastal mud-plain deposits of the Concentración Formation. According to our palynostratigraphic data (see chapter 1) the La Paz Formation is included in the *Retibrevitricolpitres triangulatus* and *Monoporopollenites annulatus* early-middle Eocene zones of Germeraad et al. (1968) and thus is younger than the Concentración Formation which is included by Germeraad et al. (1968; named “San Fernando shale”) in the late Eocene *Verrucatosporites usmensis* zone.

The variation on thickness of the studied sequences and the presence of syndepositional hiatus and growth strata (e.g. Gómez et al., 2003) suggest that tectonic activity played an important role in the sedimentation controls in the basin. The facies distribution presented in this work has implications about the geological evolution of the Paleogene of NW South America. Regional geologic models suggest that during the late Paleocene-middle Eocene interval, tectonic activity took place in Colombia due to an increase in the westward displacement of the Caribbean Plate (Pindell and Drake, 1998) and the arrival of the Caribbean plate to the NW of Venezuela (Lugo and Mann, 1995; Pindell, 1993). These events produced two foreland

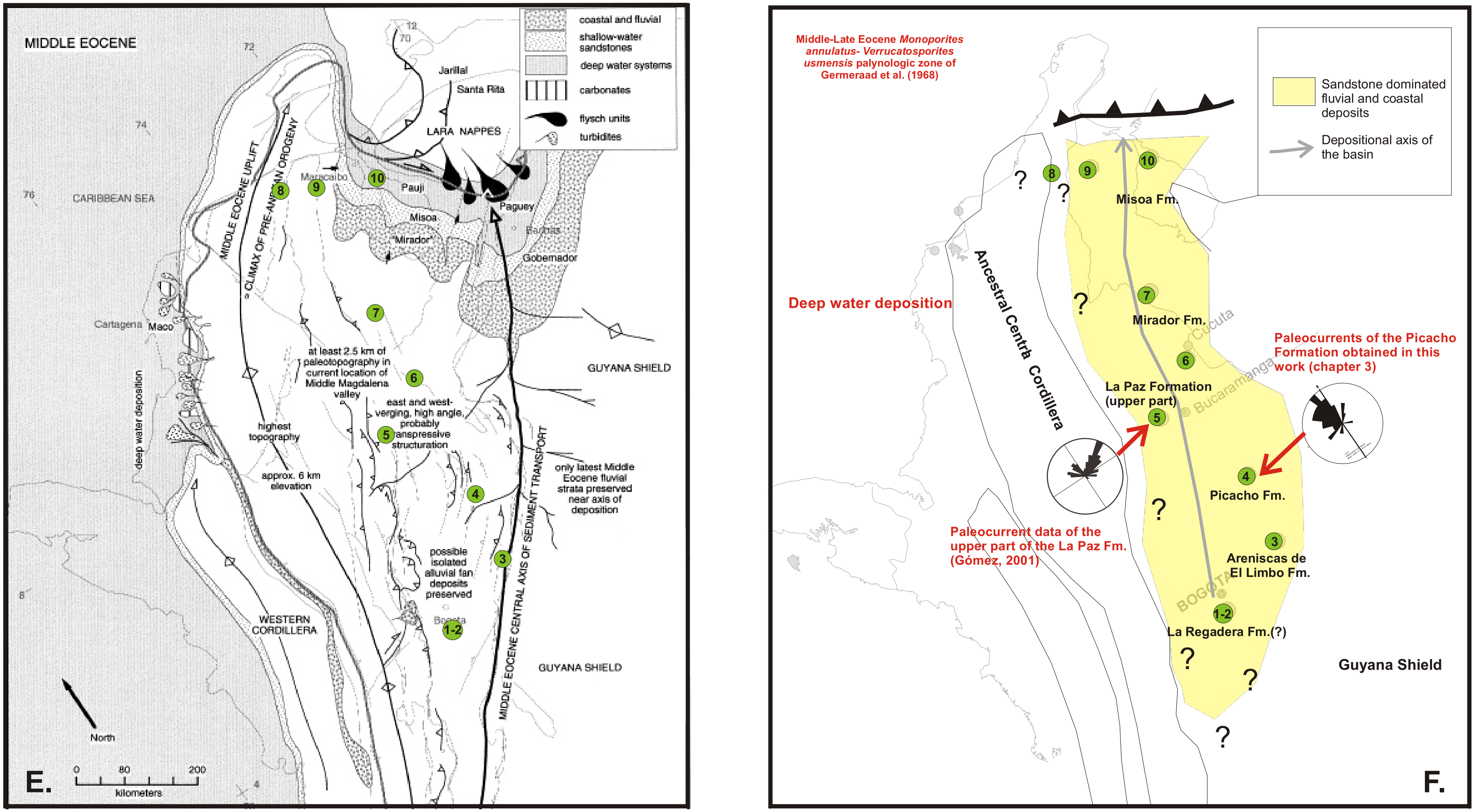


Figure 5.4. Middle Eocene paleogeographic charts of NW South America. E: Chart of Villamil (1999); F: Chart proposed in this work. 1-2: Usme Synclyne (Hoorn, 1988); 3: Piñalerita and Guadualera creek sections (Jaramillo and Dilcher, 2001; Guerrero and Sarmiento, 1996); 4: Paz de Río section (this work); 5: Sogamoso and Uribe sections (Pardo et al., 2003 and this work); 6: Regadera section (Jaramillo and Dilcher, 2001); 7: Tarra-1 log (Rull,1997); 8. El Cerrejón section (this work); 9: Riecito Maché section (Rull, 1999 and this work); 10: Icotea log (Germeraad et al., 1968).

basins, one formed by the uplift of the outer margin of the South American Continental Crust, (present-day position of the Central Cordillera) and the other by the thrusting of portions of the Caribbean plate in Venezuela ("Lara nappes"). Thus, the generalized high accommodation produced at the end of the Paleocene, which is characterized by dominance of overbank sediments with isolated high sinuosity fluvial channels (Los Cuervos, Lisama, Arcillas de Socha and Arcillas del Limbo Formations), could be related to a flexural subsidence phase during the development of these foreland basin (see also Gómez, 2001; Pindell et al., 2001). Copper et al. (1995a) suggest that the extension of these facies is possibly due to a "combination of transgression and early loading of the protoforeland basin due to deformation in the Central and Western Cordilleras". The increase in thickness of the coal beds and shales and the change in the sedimentation dynamics between the Guasare and Paso Diablo Formations in Venezuela, could be especially linked to the foreland basin subsidence following the oblique collision of the Caribbean plate. As have been indicated by McCabe (1991 in Parrish, 1998), foreland basins are the best settings for preservation of thick peat deposits. During the Early Eocene, the sedimentation seems to be restricted to the Middle Magdalena Valley and the northern part of the basin, while the Piñalerita, Paz de Río, Regadera and Tarra-1 sections were condensed. It is suggested here that this phenomenon could be a consequence of the westward displacement of the peripheral bulge adjacent to the subsiding areas of the foreland basin. Gomez (2001) suggests that a widening and narrowing phases of the foreland basin could be controlled by alternating periods of uplift and tectonic quiescence of the Central Cordillera.

An interesting aspect of the upper Paleocene rocks of the studied basin is the regional extension of mottled shales barren in microfossils. Jaramillo (2002) suggests that the formation of these deposits could be linked to a regional phenomenon that produced a greater fluctuation of the water table, presumably an indication of greater seasonality of precipitation. Additionally, this author suggests that this phenomenon could be linked to the effect that the abrupt global heating at the Paleocene-Eocene boundary had on the tropical climate. The regional data show that these facies appear early in the southern part of the basin and cannot be identified to the NW of the Catatumbo area (figures 5.4.A and 5.4.B). Due to these variations in time and space, we consider that tectonic factors and/or changes in the base level could also promote their formation. These effects are usually stronger in the inerland parts of the basin (e.g. the Bogotá Formation) where the proximity to the source area makes the accommodation space and sediment supply more complex (e.g. Shanley and McCabe, 1994).

Cooper et al. (1995a; Cooper et al., 1995b) presented a basin evolution model of the Llanos Basin, Eastern Cordillera and Middle Magdalena Valley. One of the most critical points of this model is the biostratigraphic information used to establish the depositional time of the stratigraphic units especially in the Paleogene. As discussed previously in the section 5.3, palynology cannot give a precise answer about this subject. Nevertheless, the detailed study of the localities presented in this work show that the pollen and spore content of the sandstone-dominated Picacho Formation is very similar to the Mirador Formation described at the Catatumbo region (e.g. Jaramillo and Dilcher, 2001). Thus the Chronostratigraphic schema of Cooper et al, (1995a) must be reconsidered because these units are put at different times and separated by an unconformity that encompasses the early-middle Eocene.

5.5. SOME COMMENTS ABOUT THE PALYNOFLORAL EVOLUTION IN NW SOUTH AMERICA DURING THE PALEOCENE-EOCENE

The figure 5.5 shows the stratigraphic distribution and correlation of relative percentages of general groups of palynomorphs in several places of the basin. The stratigraphic interval with most of the information corresponds to the *Foveotricolpites perforatus* upper Paleocene zone of Germeraad et al (1968). One of the most outstanding characteristic of this part of the diagram is the abundance of *Proxapertites operculatus* especially in the Cerrejón, Lisama and some parts of the Arcillas de Socha Formation. This phenomenon has been also mentioned for the Los Cuervos Formation at the Catatumbo area (Colmenares and Terán, 1990; Sarmiento, 1995) and at the Rio Lora section in the northern border of the Merida Andes (Rueda, M. and Jaramillo, C., oral communication). In contrast, in all the Eocene sections studied in Colombia and several described in the literature (e.g. Colmenares and Terán, 1990; Gonzalez, 1967; Jaramillo and Dilcher, 2001; Van der Hammen, 1954a), this species never surpasses 5 % (but see Rull, 1999 as an exception). The distribution of this species is pantropical and has its FAD at the upper Cretaceous rocks of the Caribbean area (Germeraad et al., 1968) (Figure 5.6.A), but it became abundant at the Paleocene. The increase in the relative frequency of this species during this period has been also recorded in other sections from northern South America (e.g. the Shelter Belt no. 3 well in Guiana of Leidelmeyer, 1966). The botanical affinity of this species is controversial. It has been associated with the palm *Astrocayum* (e.g. Lorente, 1986; Van der Hammen, 1957b); to an extant group of palms related to *Nypa* (Geermeraad et al. 1968) and recently to Araceae: Monstereae-Monsteroideae or Zamioculcadeae-Aroidae (Zetter et al., 2001) or *Epipremnum*, *Monstera* and *Rhaphidophora* (Thanikaimoni 1970 in Samant and Phadtare, 1997). Independently of this discussion, Van der Kaars (1983) considers that this kind of pollen (included in the "*Proxapertites operculatus* group", which comprises pollen with similar morphologies) can correspond to mangrove vegetation. This hypothesis is based on the variations of the relative percentage of *Proxapertites* with respect to the psilamonocolpate palm group which is similar to the curves of the *Rhizophora* (mangrove group) and the *Psilamonocolpites medius* group found by Van der Hammen & Wijmstra (1964) in the Shelter Belt no. 3 log of Guiana. Based on statistic grouping techniques (a non-metric multidimensional scaling, MDS), Jaramillo (1999) found an association between the *Proxapertites humbertoides*, *Retidiporites magdalenensis*, *Proxapertites cursus* and *Proxapertites operculatus* species ("Group B" of this author), and suggested a Paleocene coastal environments association. In contrast, Rull (1999a), using cluster analysis, interpreted the group *Proxapertites operculatus* and *Retidiporites magdalenensis* (group P1 of the author) as an "undefined continental association".

The quantitative information obtained in this work, linked with some published data (Jaramillo and Dilcher, 2001), allows to compare the lateral distribution of the palynoflora at a regional scale (figure 5.4). Two longitudinal sections were analyzed: the first one with a SSW-NNE direction, which allows to compare the variation in the palynological associations in a parallel direction to the axis of the basin, from terrestrial (Lisama Formation) to nearshore (Cerrejón Formations) depositional systems (figure 5.4.B). The second section, with a NW-SE trend, which shows the palynofloral changes in a transversal direction to the basin axis (Lisama, Arcillas de Socha and Arcillas de El Limbo Formations).

The figure 5.5 shows that during the late Paleocene (*Foveotricolpites perforatus* zone of

Taxa	Affinities	Paleoecology
Bombacacidites annae	Very similar to certain species of the genus *Bombax* (Bombacaceae), especially *B. ceiba* , *B. rhodognaphalon* and *B. pubescens* (Germeraad *et al.* , 1968; p. 342)	Rainy and marshy forests, especially along rivers and creeks (Hoorn, 1994; p. 228)
Bombacacidites nacimientoensis	Malvaceae s.l.	
Clavamonocolpites	Arecaceae, *Iriartea* type	Common in the lowland and premontane forests (Hoorn, 1994; p. 226)
Corsinipollenites spp.	Onagraceae	Lowland tropical humid forests (e.g. *Ludwingia*)
Ctenolophonidites lisamae	Probably an extinct species of *Ctenolophon* (Ctenolophonaceae) (Germeraad *et al* ., 1968; p. 328).	Tropical forest
Deltoidospora adriennis	Similar to *Acrostichum aureum* (Polypodiaceae)	Halophytic fern associated with mangroove vegetation (Hoorn, 1994; p. 232)
Echitriporites trianguliformis	Proteaceae ?	
Ephedripites vanegensis	Similar to *Ephedra* pollen (Ephedraceae) or to certain species of *Spathiphyllum* (Araceae) (Van der Hammen & García, 1966).	*Sphatiphyllum* is nowadays very common in wet regions with abundant *Mauritia* palms (Van der Hammen & García, 1966).
Triatriopollenites sp.	*Myrica*	Myricacaeae lived partially in coastal environments in the early Tertiary, perhaps in brackish-water marshes (e.g. Chateauneuf, 1980)
Kuylisporites waterbolkii	Similar to *Cyathea horrida* (Cyatheaceae) or *Cnemidaria* (Mohr, 2001)	Montane forest. *Cnemidaria* lives in south and central America between 500-1500 m (most common), up to 2500 m (Mohr, 2001)
Lanagiopollis crassa	Pellicieraceae	coastal plain
Longapertites microfoveolatus	Very similar to *Eremospatha* (Arecaceae) (Muller, 1979)	Tropical forest
Longapertites proxapertitoides	Annonaceae	Tropical forest
Longapertites vaneendenburgi	Annonaceae	Tropical forest
Luminidites colombianensis	Similar to *Phytelephas microcarpa* (Arecaceae) (Jaramillo & Dilcher, 2001; p. 133)	
Margocolporites vanwijhei	Pollen very similar to *Caesalpinia bonduc* and *C. coriaria* (Fabaceae). (Germeraad *et al* ., 1968; p: 342)	*Caesalpinia bonduc* (Family Caesalpiniaceae), a legume shrub of sandy tropical habitats (http://www.botgard.ucla.edu/html/botanytextbooks/generalbotany/plantarmature/a0604tx.html)
Mauritiidites franciscoi	Arecaceae	Common in palm swamps (named "aguajales"). Poorly drained soils in permanently inundated, swampy areas (Hoorn, 1994)
Momipites	Morphologically similar to modern pollen grains of the Engelhardia complex (*Alfaroa* , *Engelhardia* ,	
Monoporopollenites annulatus	Poaceae	Forms part of open vegetations in a range of envionments from humid to dry (Hoorn, 1994; p. 226)
Ovoidites	Zygnemataceae	
Pediastrum sp.	Chlorophyta	Planktonic alga of fresh, stagnant water and tolerant to a degree of brackishness (Hoorn, 1994, p. 232)
Perfotricolpites digitatus	Similar to *Merremia glabra* , *M. umbellata* (Germeraad *et al* ., 1968), and *M. microcalyx* (Muller, 1981) (Convolvulaceae)	
Podocarpites sp.	Podocarpaceae	Moist and rain lower montane and montane forest (Lorente, 1986; p. 208)
Proxapertites humbertoides	Anonaceae, similar to *Malmea* tribe (Muller, 1981)	
Proxapertites operculatus	Arecaceae; similar to *Astrocaryum* (Van der Hammen, 1956); *Nypa* related palm (Muller, 1968), Araceae	
Proxapertites tertiaria	Annonaceae ?	Tropical forests
Psilastephanocolporites fissilis	Polygalaceae	Canopy forest (Lianas, small trees, herbaceous (e.g. *Polygala*), (Gentry, 1993; p. 689)
Psilastephanoporites oculiporus	Haloragaceae	Marsh environments
Racemonocolpites facilis	Palmae, *Iriartea* type (Muller, 1981)	Common in the lowland and premontane forests (Hoorn, 1994; p. 226)
Racemonocolpites racematus	Palmae, *Iriartea* type (Muller, 1981)	Common in the lowland and premontane forests (Hoorn, 1994; p. 226)
Ranunculacidites operculatus	Euphorbiaceae	
Retidiporites magdalenensis	Similar to *Banksia collina* , *Dryanda longifolia* (Proteaceae) (Germeraad *et al* ., 1968)	coastal plain
Retitrescolpites ? *irregularis*	Similar to *Amanoa oblongifolia* and *A.strobilacea* (Euphorbiaceae) (Germeraad *et al* ., 1968; p. 339); (http://medias.obs-mip.fr/pollen/interface/pollenImages.php)	Abundant in scrub wood along creeks on peaty mud (Lindeman, 1953 *in* Germeraad *et al* ., 1968)
Spinizonocolpites spp.	Similar to *Nypa fruticans* (Arecaceae) (Germeraad *et al* ., 1968; p. 295)	Mangrove tropical forests
Striatopollis catatumbus	Fabaceae	Abundant in "tahuampas" (floodplains seasonally inundated) (Gentry, 1993; p. 517)
Tetracolporites pachyexinatus	Meliaceae ? (Jaramillo & Dilcher, 2001)	
Tetracolporopollenites maculosus	Sapotaceae, similar to *Chrysophyllum argenteum* (Lorente, 1986; p.195)	Lowland forest trees (Gentry, 1993; p. 771)
Tetracolporopollenites transversalis	Burseraceae	
Ulmoideipites krempii	Ulmaceae	
Verrucatosporites usmensis	Polypodiaceae	
Zonocostites ramonae	Rhizophoraceae	Mangrove forest. Well developed on soft mud along river estuaries and tidal rivers (Van der Hammen, 1963). Shows its optimal development on unconsolidated clayey to sandy soils in a marine to brackish environment, generally located along river and estuary banks (Muller & Caratini, 1977)

TABLE 5.2. Botanical affinities and ecology of some pollen species that occur in Paleogene beds of NW South America.

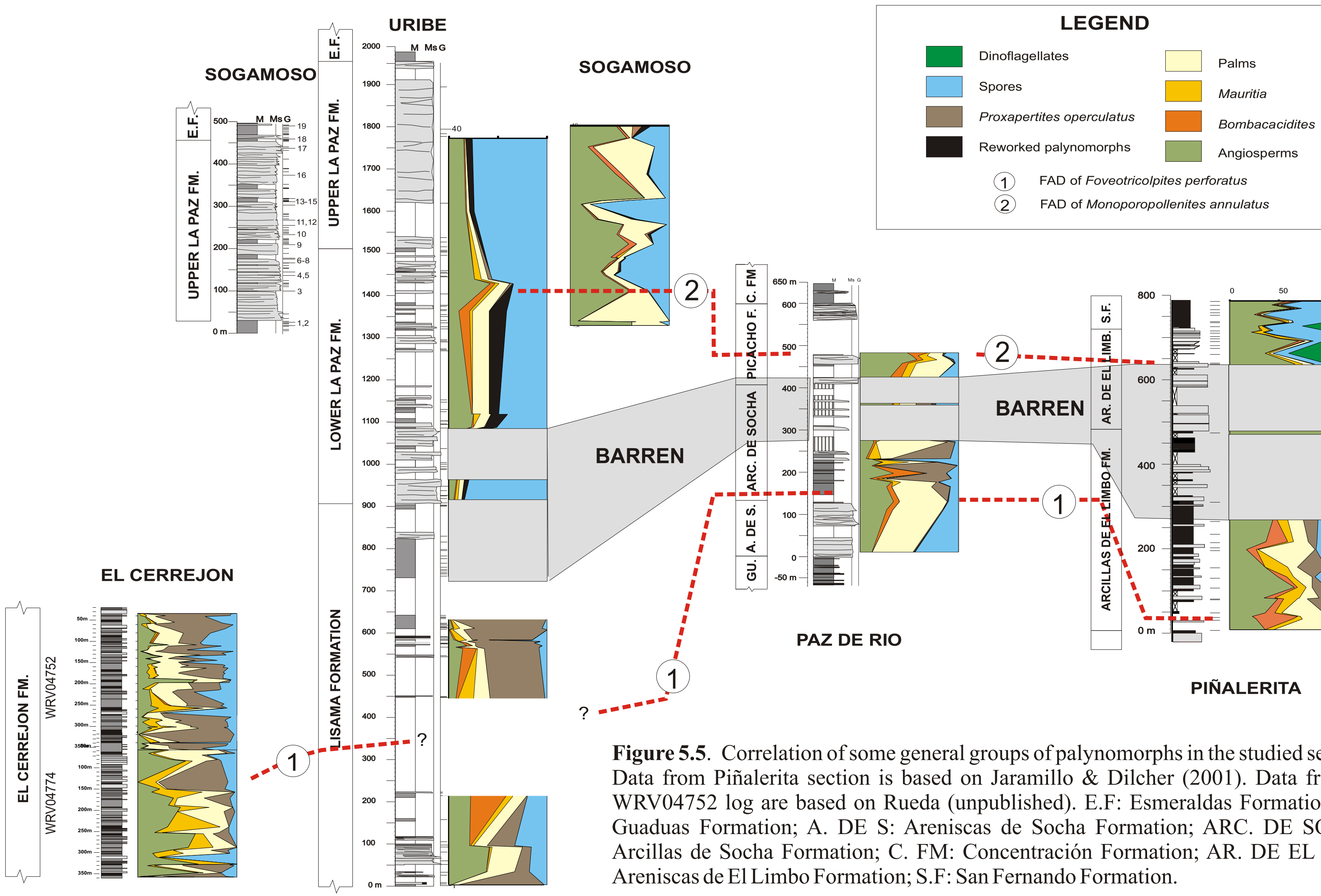


Figure 5.5. Correlation of some general groups of palynomorphs in the studied sections. Data from Piñalerita section is based on Jaramillo & Dilcher (2001). Data from the WRV04752 log are based on Rueda (unpublished). E.F: Esmeraldas Formation; GU: Guaduas Formation; A. DE S: Areniscas de Socha Formation; ARC. DE SOCHA: Arcillas de Socha Formation; C. FM: Concentración Formation; AR. DE EL LIMB: Areniscas de El Limbo Formation; S.F: San Fernando Formation.

Germeraad et al., 1968), the species *Proxapertites operculatus* was especially abundant in the El Cerrejón and the Middle Magdalena areas. This interval is dominated by shales with some coal and sandstone interbeds. The number and thickness of coal beds increase to the north. The presence of high relative percentages (in some cases more than 80 %) and high concentrations of this palynomorph in the Middle Magdalena Valley (upper part of the Lisama Formation), a sequence without evidence of marine influence, suggests that *Proxapertites operculatus* was not restricted to mangrove areas as it have been already suggested by some authors. On the other hand, a decreasing tendency of this species linked with an increasing in the relative percentage of the general angiosperm group to the Llanos border (Piñalerita section) can be noticed. As the Middle Magdalena Valley and El Cerrejón were areas of important subsidence, we hypothesize that in these regions the higher frequency in the formation of fresh water marshes could favored the occurrence of the vegetation that produced *Proxapertites operculatus*. Another interesting fact is the high percentage of *Mauritiidites* pollen in some coal beds of the Cerrejón and Paso Diablo Formations which suggests that during this period, fresh water marshes with communities of *Mauritia* were abundant in the northern region of Colombia and Venezuela. In contrast, *Nypa* is almost absent in these deposits. This could be linked to climatic factors unfavourable for the development of this plant (e.g. episodic droughts as can be suggested by the presence of high percentages of charcoal in the Cerrejón and Paso Diablo Coal beds), or that the back-mangrove regions containing *Nypa* were located further to the north of this area. The last hypothesis is improbable because marine or brackish water macrofossils have been recorded in the shaley facies associated with the coals of the Paso Diablo Formation (e.g. Bless and Paproth, 1989). Other common elements of the Paleocene deposits include pollen of Arecaceae (*Psilamonocolpites* sp.), Ctenolophonaceae (*Ctenolophonidites lisamae*), Bombacaceae (e.g. *Bombacacidites annae*, *Bombacacidites foveoreticulatus*, *Bombacacidites psilatus*) and Onagraceae (e.g. *Corsinipollenites psilatus*).

Above the sterile interval, the appearance of a great number of new species of pollen and spores can be noticed. Unlike the lower Paleocene beds, there are a very high number of morphospecies per sample, but, in general, the number of individuals by species is low. According to Jaramillo (2002), this pattern of abundance and distribution seems to be similar to pollen records of modern tropical rain forests. Unfortunately, less than 3 % of these species have been referred to living genera (table 5.2). At the base of this succession *Crudia* type pollen (*Striatopollis catatumbus*) became frequent; in some sections Bombacaceae, *Amanoa* (*Retitrescolpites? irregularis*), Sapotaceae (*Tetracolporopollenites maculosus*), *Mauritia* and different types of palms were common. The variety in Bombacacea pollen in these beds seems be higher than on the Paleocene deposits (figure 2.12). The first occurrence of Poaceae (*Monoporopollenites annulatus*) is present also in this interval (upper part of La Paz Fm, and lower Picacho Formation). The Pteridophyte (e.g. Polypodiaceae) spore content increases in most of the sections. At the upper part of the diagram, in the Sogamoso section there are alternations of spores, angiosperms and palm dominated levels. This phenomenon has been also observed in similar stratigraphc levels in other places of the basin (e.g. Colmenares and Terán, 1990; Gonzalez, 1967; Van der Hammen, 1954a) and could be related to local or regional factors. As have been noted by Rull (2000; 2002), some of these cyclic patterns could be useful in correlation but it is necessary to find independent elements of calibration in order to recognize local from regional phenomena and thus to avoid circular reasoning. An interesting fact observed in the Middle Magdalena Valley is the regular occurrence of spores of the genus *Kuylisporites* at the upper part of the La Paz Formation. It can be compared with *Cyathea horrida* (Cyatheaceae), which lives nowadays in mountain forest (table 5.2). In the same way, the regular presence of bissacates (probably *Podocarpites*) and the abundance in *Iriartea* type pollen (*Racemonocolpites racematus*), in the same stratigraphic interval of *Kuylisporites*, could suggest the presence of mountain sources during the accumulation of the La Paz Formation.

5.6. WORLDWIDE PALEOGEOGRAPHIC DISTRIBUTION OF SOME POLLEN GENUS

In this section we presented the global occurrences of the *Bombacacidites*, *Proxapertites* and *Spinizonocolpites* genera during the Cretaceous, Paleocene and Eocene. With this information we want to show a global framework of these groups which are or were largely distributed in NW South America.

Proxapertites.

Some occurrences of this genus during the Cretaceous-Paleogene are: late Cretaceous-Eocene of Colombia and Venezuela (Colmenares and Terán, 1993; Gonzalez, 1967; Jaramillo and Dilcher, 2001; Pocknall et al., 2001; Rull, 1997b, 1999a; Sarmiento, 1992b; Van der Hammen, 1956a; Van der Hammen and Garcia, 1966; Van der Kaars, 1983); Paleocene-early Eocene of E Brasil (Regali *et al*., 1974); Paleocene of Guyana (Leidelmeyer, 1966); Paleocene of South Argentina (Archangelsky, 1973); late Paleocene of Mississipii and Alabama (Frederiksen, 1996); Paleocene of Nigeria (Van Hoeken-Klinkenberg, 1966); Paleocene of Sudan (Kaska, 1989); Maastrichtian-Paleocene of Egypt (Tantawy *et al*., 2001); late Paleocene-Eocene (?) of Rumania (Petrescu and Codrea, 2003); middle and late Paleocene of Pakistan (Frederiksen, 1994); Paleocene of NW India (Saxena, 1979); Paleocene of Borneo (Germeraad et al., 1968; Muller, 1968); Eocene of the Gulf Coast, USA (Fairchild and Elsik, 1969); Paleocene of NW Nigeria (Adegoke *et al*., 1978); Eocene of Spain 40 % (Kedves *et al*., 1996); lower-middle Eocene of Malaga, Spain (Solé de Porta *et al*., 2004); early Eocene of Austria (Zetter *et al*., 2001; Zetter and Hofmann, 2001); Eocene of Turkey (Akyol, 1978. Plate IV, figs. 66-70 figured as "organisms indéterminés"); early Eocene of NW India (Samant and Phadtare, 1997).

Bombacacidites

For the current repartition of the family, see Braque (1987). See also Fuchs (1967) and Nilsson and Robyns (1986) for a revision of the pollen morphology. Wolfe (1975, 1976 in Muller, 1981) described *Cavanillesia* pollen from the Maastrichtian of southeast USA; this occurrence made that Muller (1981) suggests an eastern north American origin of the Bombacaceae family. Neverthless, (Askin, 1990) recorded a Maastrichtian ocurrence of *Bombacacidites* in the Seymour island (Antartica); upper Cretaceous of Argentina (Baldoni and Askin, 1993); Paleocene of Guyana (Leidelmeyer, 1966); Paleocene-Eocene of the Gulf Coast (Elsik, 1974; Fairchild and Elsik, 1969), Paleocene-Eocene from Argentina (Del Papa, 1999), Alaska (Frederiksen *et al*., 2002), Texas (Elsik, 1968b); Danian of California (Drugg, 1967; Frederiksen, 1983), late Paleocene of California (Lynn-Gaponoff, 1984) and South Carolina (Frederiksen, 1980c); Paleocene of Alabama (Srivastava, 1972); Danian of Maryland

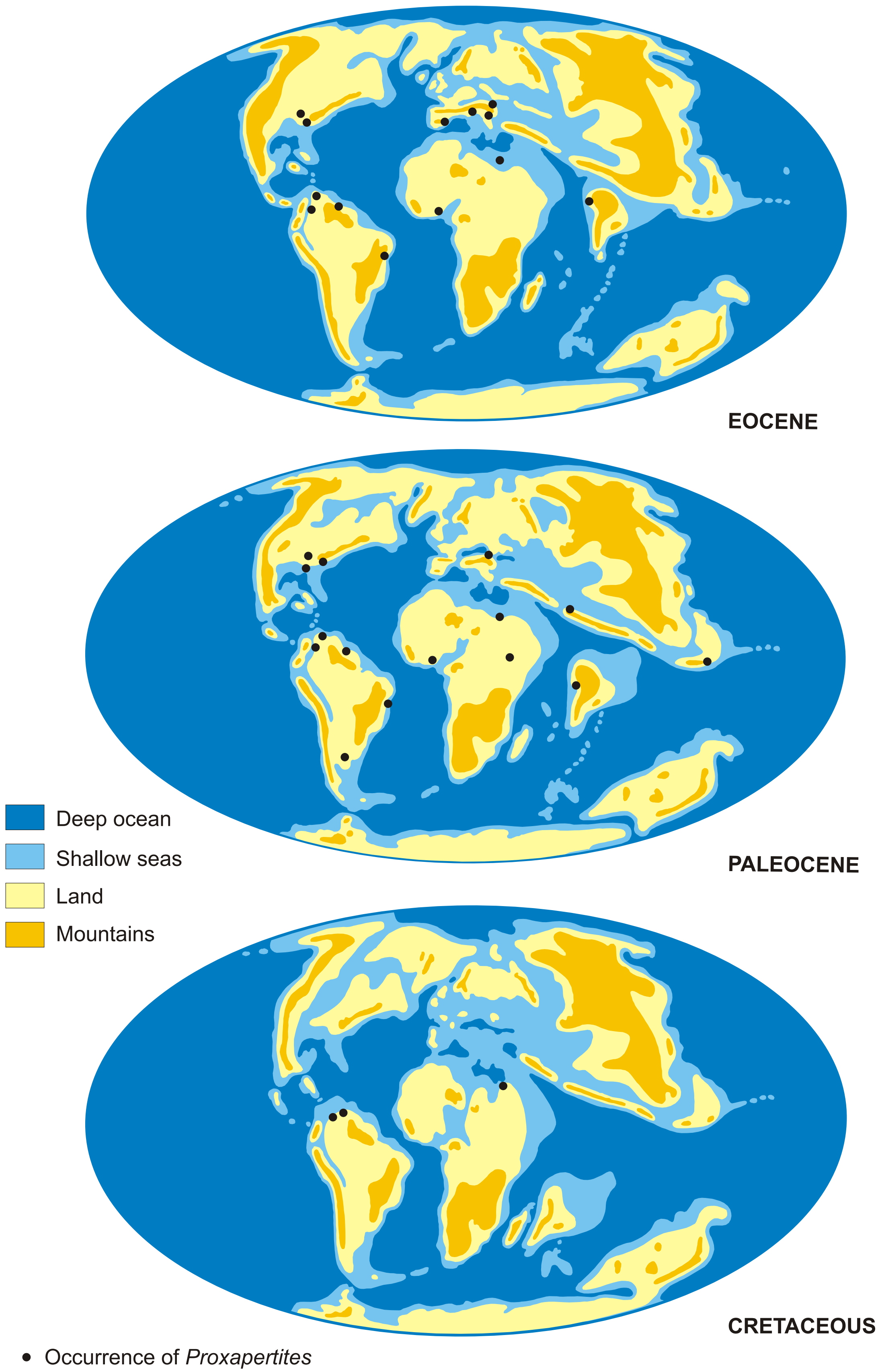


Figure 5.6.A. Late Cretaceous-Eocene world distribution of *Proxapertites* (see the text for references). Paleogeographic maps from Scotese (1997).

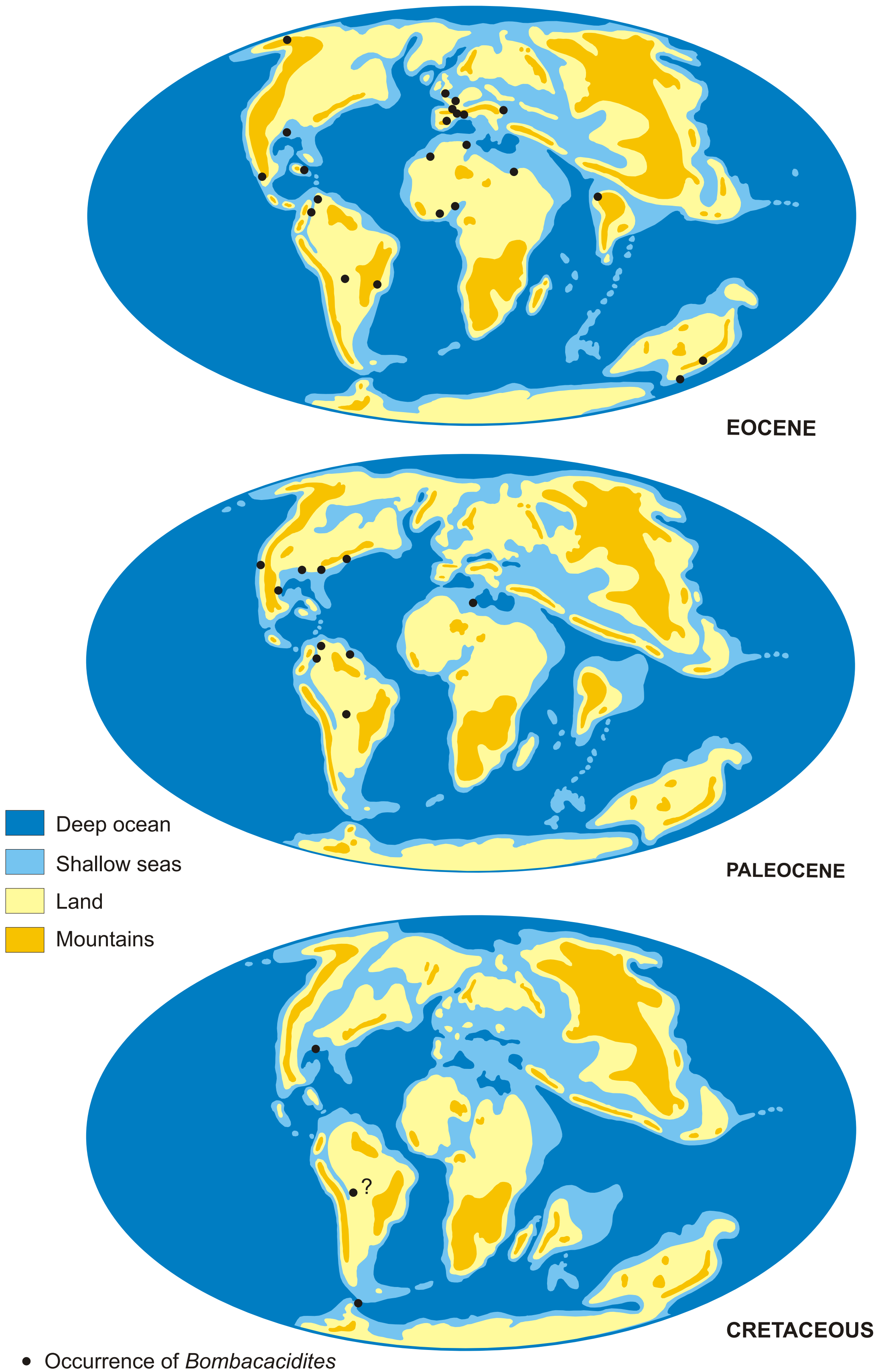


Figure 5.6.B. Late Cretaceous-Eocene world distribution of *Bombacacidites* (see the text for references). Paleogeographic maps from Scotese (1997).

(Groot and Groot, 1962); Thanetian of Tunisia “cf. *Bombacacidites*?” (Meon, 1990); late Paleocene-Eocene (?) of Rumania (Petrescu and Codrea, 2003); FAD Paleocene? or middle Eocene of Germany (Krutzsch, 1970); early Eocene of Belgium (Roche, 1988); early Eocene of the Paris Basin (Schuler et al., 1992); FAD in the Paleocene-Eocene transition in Nigeria (Germeraad *et al*., 1968); lower Eocene of Hungary (Kedves, 1969; Rákosi, 1973); Eocene of Spain (Kedves *et al*., 1996), Egypt (Tantawy *et al*., 2001), Oman “*Intratriporopollenites microreticulatus*” (El Beialy, 1998); Eocene of Marocco (Fechner, 1988; Mohr and Fechner, 1986); Eocene of Cameroon (Salard-Cheboldaeff, 1981); early Eocene of Australia (Stover & Partridge, 1973, Muller, 1981); early to middle Eocene of New Zeeland (Pocknall, 1990);

Spinizonocolpites

Upper Cretaceous of South Argentina (Baldoni and Askin, 1993); upper Cretaceous of Colombia (Sarmiento, 1992b); Maastrichtian-Eocene of Brasil (Regali *et al*., 1974); Campanian(?)-Paleocene of Egypt (Schrank, 1984; Tantawy et al., 2001); upper Cretaceous-Eocene of Caribbean and Nigeria (Germeraad *et al*., 1968); late Cretaceous-Eocene of Cameroun (Salard-Cheboldaeff, 1981); Maastrichtian of Senegal (Jardiné and Magloire, 1965), upper Cretaceous-recent of Borneo (Germeraad *et al*., 1968) ; Maastrichtian-Paleocene of Sarawak, Malaysia (Muller, 1968); upper Cretaceous of NE India (Nandi, 1990); Paleocene of South Argentina (Archangelsky, 1973); Paleocene of Pakistan (Frederiksen, 1994); late Paleocene-Eocene of N Argentina (Del Papa, 1999; Quattrocchio *et al*., 1997) ; early Eocene of Australia (Martin, 1992, in Morley, 2000); Eocene of southwestern Texas (Westgate and Gee, 1990), SE USA (Frederiksen, 1980b); upper Eocene Mississippi pollen named «Nymphaeaceae» (Tschudy and Van Loenen, 1970) ; early Eocene NW India (Samant and Phadtare, 1997) ; Eocene of Malaysia (see the fig. 1 of Baker *et al*., 1998); late Eocene of the Ivory Coast-Ghana transform margin (De La Rue and Oboh-Ikuenobe, 1998); lower to middle Eocene of Morocco, South Atlas border (Fechner, 1988); early-middle Eocene of New Zeland (Pocknall, 1990); (Morley, 1998), Tasmania the most southern occurrence at the paleolatitude 65° S (Pole and Macphail, 1996) ; middle Eocene of Spain (Cavagnetto and Anadón, 1995); early Eocene of England (Gruas-Cavagnetto, 1976); early Eocene of Belgium (Roche, 1988); early Eocene of the Paris Basin (Schuler et al., 1992); Eocene of Hungary (Kedves, 1969; Rákosi, 1973); early Eocene of Saudi Arabia (Srivastava and Binda, 1991); early to middle Eocene of New Zeland (Pocknall, 1990), middle-late Eocene of Turkey (Akgün *et al*., 2002); Eocene of Oman (El Beialy, 1998).

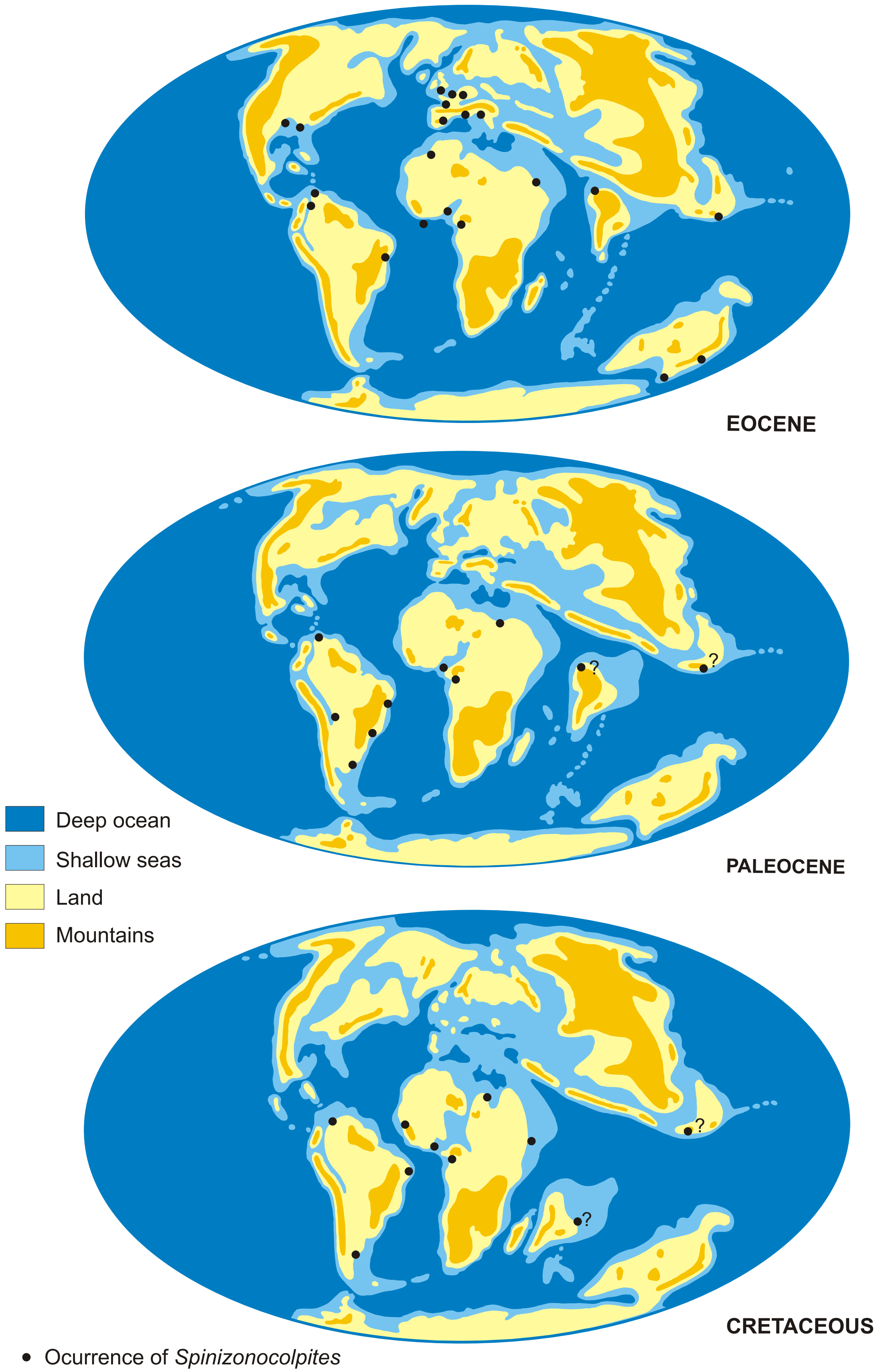


Figure 5.6.C. Late Cretaceous-Eocene world distribution of *Spinizonocolpites*. (see the text for references). Paleogeographic maps from Scotese (1997).

CHAPTER 6 - GENERAL CONCLUSIONS AND PERSPECTIVES

CONCLUSIONS

- The palynologic study of four Paleocene-Eocene sections of northeastern Colombia and western Venezuela allowed the identification of more than 300 morphologic types of pollen and spores. Based on these data, we can clearly differentiate the Paleocene from the Eocene pollen and spore associations.

- The Paleocene associations are characterized by different types of *Proxapertites* (e.g. *P. operculatus*, *P. cursus, P. magnus*), some species of *Bombacacidites* (e.g. *B. annae*, *B. protofoveoreticulatus*), *Foveotricolpites perforatus*, *Colombipollis tropicalis*, *Proxapertites cursus*, *Ephedripites vanegensis*, *Retidiporites magdalenensis*, *Psilamonocolpites operculatus*, *Aglaoreidia*? *Foveolata*, *Diporopollis assamica* and different monocolpate species (e.g. *Psilamonocolpites medius*, *Mauritiidites franciscoi*). Some of these deposits are also characterized by the highest concentrations of pollen and spores and a dominance of *Proxapertites operculatus*, which can amount 95 %. The high percentage and ubiquitous presence of this species in both coastal and terrestrial units discard a mangroove autoecology as have been suggested by some authors.

-At the upper part of some Colombian Paleocene units (Fms. Lisama, Arcillas de Socha, Arcillas del Limbo), there are no palynological information due to the presence of mottled shales barren in pollen and spores. This fact prevents to locate the Paleocene-Eocene boundary and to demonstrate directly the presence and duration of an unconformity proposed by several authors in this area. This barren interval increases in thickness to the south and makes difficult the correlation between the units.

-The Eocene associations are characterized by the first occurrence of a great number of species; many of them are present in very low quantities, which diminished their biostratigraphical value. Among them, *Bombacacidites* seems to have a higher morphological diversity than in the Paleocene deposits. On the other hand, some of the species traditionally used in biostratigraphy are relatively abundant in the studied sections and confirm their utility for correlation: *Striatopollis catatumbus*, *Spisosyncolpites spiralis*, *Foveotriporites hammenii*, *Monoporopollenites annulatus*, *Cricotriporites guianensis*. In contrast, some taxa used in some biozone schemes (e.g. *Lanagiopollis crassa*, *Ranunculacidites operculatus*, *Rugutricolporites felix*, *Retitrescolpites magnus*, *Rhoipites guianensis*, *Echitriporites trianguliformis* var. *orbicularis*) are scantly or absent.

-The Paleocene-middle Eocene biozones of Germeraad et al. (1968) can be recognized in the sections studied in Colombia; however, the presence of the regional barren interval among the *Foveotricolpites perforatus* and *Retibrevitricolpites triangulatus* justifies the creation of a sterile interzone. On the contrary, the Eocene Sub-zones of Germeraad et al. (1968) and the biozones of Muller et al. (1987) are difficult to identify in the studied sections. In the current state of knowledge, we do not whether this is due to stratigraphic hiatuses, poor preservation or environmental restrictions.

-Graphic correlation performed between the Paz de Río and Llanos Border sections shows similarities in the stratigraphic range of the pollen and spore species and thus in their correlation line. In contrast, the great slope of the correlation line obtained between these sections and the eastern Middle Magdalena area, suggest a relatively high sedimentation rate in the former locality.

- The palynofacies, together with the lithofacies and paleocurrent data suggest mainly a fluvial environment in all the studied units. The maximal concentration in pollen and spores, in some cases more than 100,000 palynomorphs/gram, are observed at the upper part of the Lisama Formation and the lower part of the Arcillas de Socha Formation, which can be correlated with the presence of organic-rich shales and coals with minor sandstone deposits. In contrast, the shales associated with the thick sandstone-dominated fluvial deposits of the La Paz and Picacho Formations are relatively scantly or barren in pollen and spores. As the tectonic was active during the sedimentation of the studied deposits, the paleocurrent data with good biostratigraphic control became particularly important to recognize emerged areas and source of sediments for particular periods of time.

PERSPECTIVES

- Most of the slides and samples obtained during the first researches performed in the Paleocene-Eocene deposits of NW South America are not available anymore (e.g. Gonzalez, 1967; Van der Hammen, 1954a; Van der Hammen, 1956a, 1957). Our information thus constitutes a public data base which will be improved as new sections become studied. Due to the high variety in morphological types of pollen and spores in the Paleocene deposits of NW South America, some subjects such as the taxonomy of many species were superficially considered here and will be improved during my future work at Caldas University (Manizales, Colombia).

- Among the studied sections, the Riecito Maché probably offers the best possibilities to perform a complete palynostratigraphic succession of the Paleocene Eocene deposits of NW South America. Unfortunately, in this study only coal samples were available, in some cases with large stratigraphic distance. The abundance in microscopic organic matter and terrestrial palynomorphs of the coal-rich deposits from the El Cerrejón section linked to new discoveries of a rich variety of plant macrofossils and some vertebrates (Jaramillo C., pers. Communication), show the great potential of these beds to study the Paleocene tropical ecosystems. Among the most terrestrial sequences, the Uribe section (Eastern Middle Magdalena) has the most complete palynological record. Nevertheless, the presence of covered intervals in the Lisama Formation prevents to know the real stratigraphic extension of some pollen and spore taxa. On the other hand, the presence of the barren interval and the shortage of palynomorphs in the lower part of the La Paz Formation, compel to search alternative dating methods.

- A dating method that will be tested in the Paleogene geological record of NW South America is the analysis of stable carbon isotopes (delta ^{13}C) in the sedimentary organic matter in order to find the negative carbon isotope excursion (CIE), whose base has been established as the

Paleocene-Eocene Boundary (Gradstein et al., 2004). Initially, we will apply this method in the Paz de Río section because it was sampled in detail (chapter 3); but probably the most promising sections are located to the north where the sedimentary conditions were more favorable for the organic matter preservation (e.g. Riecito Maché section). Another indirect dating method that could be tested in this area is the systematic search of some fossil vertebrates whose date of immigration from northern latitudes have been radiometricaly and paleomagneticaly established in volcanic beds from nearby countries (e.g. Marshall et al., 1997). It is also important to perform a detailed biostratigraphic study of the “Los Corros” marine horizon at the Middle Magdalena Valley, the stratigraphic interval containing oolitic ironstones at the Paz de Río region and the marine interval recognized at the top of the Areniscas del Limbo Formation at the Llanos Border (Jaramillo and Dilcher, 2001), in order to have elements (e.g. nanoplankton?, foraminifera?) to calibrate the palynological data in other stratigraphic levels.

- The problems on lithostratigraphic nomenclature and the absence of reference sections in most of the Paleogene rocks of Colombia and Venezuela show the necessity to perform the biostratigraphic researches including the most complete geographical and geological information of the localities. Our study shows also the importance of analyze the palynofacies data together with lithofacies and biofacies in order to have more elements of analysis for the paleoenvironmental interpretations.

REFERENCES

Comité Interfilial de Estratigrafía y Nomenclatura CIEN, 2004, Código Estratigráfico de las Cuencas Petroleras de Venezuela. http://www.pdv.com/lexico/lexicoh.htm.

Adegoke, O. S., R. E. Jan du Chene, A. E. Agumanu, and P. O. Ajayi, 1978, Palynology and Age of the Kerri-Kerri Formation, Nigeria: Revista Española de Micropaleontología, v. 10, p. 267-283.

Aguerrevere, S. E., H. Alberding, F. Balda, A. Bellizzia, S. J. Brown, W. M. Chappell, K. F. Dallmus, A. N. Dusenbury Jr, K. L. Edwards, J. Evanoff, G. Feo-Codecido, C. Francken, W. H. Hadley Jr, G. D. Johnson, I. A. Koves, R. Laforest, W. F. MacFarquhar, W. Maync, A. Bellizzia, M. A. Bellizzia, J. B. Miller, W. A. Mohler, R. P. Morrison, J. L. Padrón, C. Petzall, H. H. Renz, F. Rivero, G. Rivero, J. Royo y Gomez, J. M. Sellier de Civrieux, E. Von der Osten, L. Weingeist, N. E. Weisbord, and G. A. Young, 1956, Léxico estratigráfico de Venezuela: Boletín de Geología, Publicación Especial No 1, Ministerio de Minas e Hidrocarburos (Venezuela), p. 729.

Akgün, F., E. Akay, and B. Erdogan, 2002, Tertiary terrestrial to shallow marine deposition in central Anatolia: a palynological approach: Turkish Journal of Earth Sciences, v. 11, p. 127-160.

Akyol, E., 1978, Etude palynologique de l'Eocene de Bayat (Corum-Turquie) et essai de correlation entre Karakaya et Emirsah: Bulletin of the Mineral Research and Exploration Institute of Turkey, v. 91, p. 39-53.

Alvarado, B., and R. Sarmiento, 1944, Informe geológico sobre los yacimientos de hierro, carbón y caliza de la región de Paz del Río, Departamento de Boyacá, Bogotá, Servicio Geológico Nacional, informe 468 (unpublished), p. 132.

Anderson, F. M., 1927, Nommarine Tertiary deposits of Colombia: Geological Society of America Bulletin, v. 38, p. 591-644.

Anderson, J. L., 1945, Petroleum Geology of Colombia, South America: American Association of Petroleum Geologist Bulletin, v. 29, p. 1065-1142.

Archangelsky, S., 1973, Palinología del Paleoceno de Chubut, I. Descripciones sistemáticas: Ameghiniana, v. X, p. 339-399.

Askin, R. A., 1990, Campanian to Paleocene spore and pollen assemblages of Seymour Island, Antarctica: Review of Palaeobotany and Palynology, v. 65, p. 105-113.

Baker, W. J., M. J. E. Coode, J. Dransfield, S. Dransfield, M. M. Harley, P. Hoffmann, and R. J. Johns, 1998, Patterns of distribution of Malesian vascular plants, *in* R. Hall, and D. Holloway, eds., Biogeography and geological evolution of SE Asia: Leiden, Backhuys publishers, p. 243-258.

Baldoni, A. M., and R. A. Askin, 1993, Palynology of the lower Lefipan Formation (upper Cretaceous) of Barranca de los Perros, Chubut province, Argentina. Part II. Angiosperm pollen and discussion: Palynology, v. 17, p. 241-264.

Batten, D. J., 1982, Palynofacies, palaeoenvironments and petroleum: Journal of micropalaeontology, v. 1, p. 107-114.

Batten, D. J., 1996, Palynofacies, *in* J. Jansonius, and D. C. McGregor, eds., Palynology: principles and applications, v. 3: Tulsa, OK, AASP, p. 1011-1064.

Behrensmeyer, A. K., J. D. Damuth, W. A. DiMichele, R. Potts, H.-D. Sues, and S. L. Wing, 1992, Terrestrial ecosystems through time. Evolutionary paleoecology of terrestrial plants and animals: Chicago and London, 568 p.

Berggren, W. A., D. V. Kent, C. C. Swisher II, and M. Aubry, 1995, A revised Cenozoic geochronology and chronostratigraphy, *in* W. A. Berggren, D. V. Kent, M. P. Aubry, and J. Hardenbol, eds., Geochronology time scales and global stratigraphic correlation: SEPM Special Publication, v. 54: Tulsa, SEPM, p. 129-212.

Bitterli, P., 1950, Coal deposits in the Dibujo Synclimorium: Shell, unpublished report.

Bless, M. J. M., and E. Paproth, 1989, Diachronism and tripartition of peat accumulation in paralic paleoenvironments, Carboniferous and Cenozoic sequences in northwestern Europa: International Journal of Coal Geology, v. 12, p. 349-364.

Boulter, M. C., and A. Riddick, 1986, Classification and analysis of palynodebris from the Paleocene sediments of the Forties Field: Sedimentology, v. 33, p. 871-886.

Braque, R., 1987, Biogéographie des continents: Paris, Masson, 470 p.

Bueno, R., 1968, Ocurrencia y litología del Toro Shale: Boletín de Geología UIS, v. 21, p. 33-41.

Butler, K., and S. Schamel, 1988, Structure along the eastern margin of the central Cordillera, upper Magdalena Valley, Colombia: Journal of South American Earth Sciences, v. 1, p. 109-120.

Cáceres, C., F. Cediel, and F. Etayo-Serna, 2003, Mapas de distribución de facies sedimentarias y armazón tectónico de Colombia a través del Proterozoico y del Fanerozoico: Ingeominas, http://www.ingeominas.gov.co/web/productos/libro_facies.asp.

Caratini, C., and C. Tissot, 1988, Paleogeographical evolution of the Mahakam delta in Kalimantan, Indonesia during the quaternary and late pliocene: Review of Palaeobotany and Palynology, v. 55, p. 217-228.

Casas, J., 1995, Misoa Formation : A Big Delta Complex ?, http://www.geocities.com/jhonnycasas/Misoa.html.

Cavagnetto, C., and P. Anadón, 1995, Une mangrove complexe dans le Bartonien du bassin de l'Ebre (NE de l'Espagne): Palaeontographica Abt. B, v. 236, p. 147-165.

Cazier, E. C., M. A. Cooper, G. Eaton, and A. J. Pulham, 1997, Basin Development and Tectonic History of the Llanos Basin, Eastern Cordillera, and Middle Magdalena Valley, Colombia: Reply: AAPG Bulletin, v. 81, p. 1332-1335.

Chapman, V. J., 1976, Mangrove vegetation: J. Cramer, 447 p.

Chateauneuf, J. J., 1980, Palynostratigraphie et paléoclimatologie de l'Eocène Supérieur et de l'Oligocène du Bassin de Paris (France): Mémoire du Bureau de Recherches Géologiques et Minières (BRGM), v. 116, p. 1-360.

Collinson, J. D., 1996, Alluvial sediments, *in* H. G. Reading, ed., Sedimentary environments: processes, facies and stratigraphy: Oxford, Blackwell Science, p. 37-82.

Collinson, M. E., 2002, The ecology of Cainozoic ferns: Review of Palaeobotany and Palynology, v. 119, p. 51-68.

Colmenares, F., A. M. Mesa, I. C. Higuera, and J. H. Roncancio, 1995, Estratigrafía del Paleógeno Cordillera Oriental, Piedemonte occidental, Valle Medio del Magdalena, Bogotá, Geosearch, Instituto Colombiano de Petróleo internal report, p. 100.

Colmenares, O. A., and L. Terán, 1990, Formaciones Mirador y Carbonera: Edad y relaciones estratigráficas en el estado Táchira: Revista Técnica Intevep, v. 10, p. 209-212.

Colmenares, O. A., and L. Terán, 1993, A biostratigraphic study of Paleogene sequences in southwestern Venezuela: Palynology, v. 17, p. 67-89.

Combaz, A., 1964, Les Palynofaciès: Revue de Micropaleontologie, v. 7, p. 205-218.

Cooper, M. A., F. T. Addison, R. Alvarez, M. Coral, R. H. Graham, A. B. Hayward, S. Howe, J. Martinez, J. Naar, R. Penas, A. J. Pulham, and A. Taborda, 1995a, Basin development and tectonic history of the Llanos basin, Eastern Cordillera and Middle Magdalena Valley, Colombia: AAPG Bulletin, v. 79, p. 1421-1443.

Cooper, M. A., F. T. Addison, R. Alvarez, M. Coral, R. H. Graham, A. B. Hayward, S. Howe, J. Martinez, J. Naar, R. Penas, A. J. Pulham, and A. Taborda, 1995b, References used to construct the chronostratigraphic correlation diagrams and paleogeographic maps of gross depositional environments from the article AAPG Bulletin, Volume 79, Number 10, October 1995, pages 1421-1443., www.aapg.org/datashare/data_003/data_003.doc.

De La Rue, S. R., and F. E. Oboh-Ikuenobe, 1998, Eocene palynomorphs from a deep bathyal environment in the Equatorial Atlantic (ODP Hole 959D): preliminary biostratigraphic and paleoenvironmental observations: American Association of Stratigraphic Palynologists Annual Meeting, p. 18.

Del Castillo, H., and W. Scherer, 1998, La Formación Paso Diablo: Código Geológico de Venezuela. Afiches y posters. http://www.pdvsa.com/lexico/posters/hdcws9801.htm.

Del Papa, C., and M. Quattrocchio, 2002, Sedimentary facies and palynofacies assemblages in an Eocene perennial lake, Lumbrera formation, northwest Argentina: Journal of South American Earth Sciences, v. 15, p. 553-569.

Del Papa, C. E., 1999, Sedimentation on a ramp type lake margin: Paleocene-Eocene Maiz Gordo Formation, northwestern Argentina: Journal of South American Earth Sciences, v. 12, p. 389-400.

Drugg, W. S., 1967, Palynology of the Upper Moreno Formation (Late Cretaceous-Paleocene) Escarpado Canyon, California: Palaeontographica Abt. B, v. 120, p. 1-71.

Duque, H., 1990, The Choco Block in the Northwestern corner of South America: structural, tectonostratigraphic and paleogeographic implications: Journal of South America Earth Sciences, v. 3, p. 71-84.

Dutta, S. K., and S. C. D. Sah, 1970, Palyno-stratigraphy of the Tertiary sedimentary formations of Assam: 5. Stratigraphy and palynology of south Shillong Plateau: Palaeontographica Abt. B, v. 131, p. 1-72.

Ediger, V. S., 1981, Fossil fungal and algal bodies from Thrace basin, Turkey: Palaeontographica Abt. B, v. 179, p. 87-102.

Edwards, L. E., 1984, Insights on why graphic correlation (Shaw's method) works: Journal of Geology, v. 92, p. 583-597.

Einsele, 2000, Sedimentary Basins: Evolution, Facies and Sediment Budget, Springer-Verlag, 792 p.
Eisenbau-Essen, 1975, Informe parcial sobre el progreso de los estudios geológicos realizados en la Cuenca Carbonífera del Zulia en la época comprendida entre el 1 de diciembre de 1974 y el 28 de febrero de 1975, p. 33.
El Beialy, S. Y., 1998, Stratigraphic and palaeoenvironmental significance of Eocene palynomorphs from the Rusayls Shale Formation, Al Khawd, northern Oman: Review of Palaeobotany and Palynology, v. 102, p. 249-258.
Elsik, W. C., 1968b, Palynology of a Paleocene rockdale lignite, Milan county, Texas. II. morphology and taxonomy (end): Pollen et Spores, v. 10, p. 599-664.
Elsik, W. C., 1974, Characteristic Eocene palynomorphs in the Gulf Coast, U.S.A: Palaeontographica Abt. B, v. 149, p. 90-111.
Erlich, R. N., O. Macsotay I., A. J. Nederbragt, and M. A. Lorente, 1999, Palaeoecology, palaeogeography and depositional environments of Upper Cretaceous rocks of western Venezuela: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 153, p. 203-238.
Fabre, A., 1983, La Subsidencia de la Cuenca del Cocuy (Cordillera Oriental de Colombia) durante el Cretaceo y el Terciario Inferior primera parte estudio Cuantitativo de la Subsidencia: Geología Norandina, v. 8, p. 49-61.
Fairchild, W. W., and W. C. Elsik, 1969, Characteristic Palynomorphs of the lower Tertiary in the Gulf Coast: Palaeontographica Abt. B, v. 128, p. 81-89.
Farley Fleming, R., 1989, Fossil Scenedesmus (Chlorococcales) from the Raton Formation, Colorado and New Mexico, U.S.A.: Review of Palaeobotany and Palynology, v. 59, p. 1-6.
Fechner, G. G., 1988, Selected palynomorphs from the lower to middle eocene of the South Atlas Border Zone (Morocco) and their environmental significance: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 65, p. 73-79.
Fisher, M. J., 1980, Kerogen distribution and depositional environments in the Middle Jurassic of Yorkshire U.K.: Proceedings of the 2th International Palynological Conference, Lucknow, 1976-1977, p. 574-580.
Frederiksen, N. O., 1980b, Mid-Tertiary climate of southeastern United States: the sporomorph evidence: Journal of Paleontology, v. 54, p. 728-739.
Frederiksen, N. O., 1980c, Paleogene sporomorphs from South Carolina and quantitative correlations with the Gulf Coast: Palynology, v. 4, p. 125-179.
Frederiksen, N. O., 1983, Middle Eocene Palynomorphs from San Diego, California, Part II, Angiosperm Pollen and Miscellaneae: AASP Contributions Series, v. 12, p. 32-155.
Frederiksen, N. O., 1985, Review of Early Tertiary Sporomorph Paleoecology: AASP Contributions Series, v. 15, p. 92.
Frederiksen, N. O., 1994, Middle and late Paleocene angiosperm pollen from Pakistan: Palynology, v. 18, p. 91-137.
Frederiksen, N. O., 1996, Upper Paleocene pollen biostratigraphy and correlations in eastern North America, Sixth North American Paleontological Convention, Washington, D.C, Washington, D.C., http://geology.er.usgs.gov/eespteam/sergp/seabsts.html.
Frederiksen, N. O., L. E. Edwards, T. A. Ager, and T. P. Sheehan, 2002, Palynology of Eocene strata in the Sagavanirktok and Canning formations on the North Slope of Alaska: Palynology, v. 26, p. 59-.
Fuchs, H. P., 1967, Pollen morphology of the family Bombacaceae: Review of Palaeobotany and Palynology, v. 3, p. 119-132.
Garner, A. H., 1926, Suggested nomenclature and correlation of the geological formations in Venezuela: American Institute of Mining and Metallurgical Engineers Transactions, p. 677-684.
Gastaldo, R. A., 1994, The genesis and sedimentation of phytoclasts with examples from coastal environments, *in* A. Traverse, ed., Sedimentation of organic particles: Cambridge, Cambridge University Press, p. 103-139.
Gastaldo, R. A., K. Bartram, and J. R. Staub, 1994, Contemporaneous palynospectra from tidally-influenced fluvial settings in the Holocene Rajang river delta, Sarawak, east Malaysia: Abstracts of the proceedings of the twenty-sixth annual meeting of the American Association of Stratigraphic Palynologists, Palynology, v. 18, p. 245.
Gastaldo, R. A., and J. R. Staub, 1997, Water column and grab sample palynofacies assemblages from the Rajang river delta, Sarawak, East Malaysia: Palynology, v. 21, p. 145-172.
Germeraad, J. H., C. A. Hopping, and J. Muller, 1968, Palynology of Tertiary sediments from tropical areas: Review of Palaeobotany and Palynology, v. 6, p. 189-348.

Gómez, E., 2001, Tectonic controls on the Late Cretaceous to Cenozoic sedimentary fill of the Middle Magdalena Valley Basin, Eastern Cordillera and Llanos Basin, Colombia: Ph.D thesis, Cornell University, 619 p.
Gómez, E., and T. Jordan, 1997, Basic facies analysis of the Tertiary sedimentary record of the southernmost Middle Magdalena Valley Basin, Colombia, unpublished, p. 18.
Gómez, E., T. E. Jordan, R. W. Allmendinger, K. Hegarty, S. Kelley, and M. Heizler, 2003, Controls on architecture of the Late Cretaceous to Cenozoic southern Middle Magdalena Valley Basin, Colombia: Geological Society of America Bulletin, v. 115, p. 131-147.
Gómez, E., and P. Pedraza, 1994, El Maestrichtiano de la región Honda-Guaduas, límite N del Valle Superior del Magdalena: Registro sedimentario dominado por rios trenzados, *in* F. Etayo-Serna, ed., Estudios geológicos en el Valle Superior del Magdalena, v. III: Bogotá, Universidad Nacional, p. 1-20.
Gonzalez, A. E., 1967, A palynologic study on the upper Los Cuervos and Mirador formations (lower and middle Eocene), Tibú Area, Colombia: Leiden, E.J. Brill, 68 p.
González de Juana, C., 1951, Introducción al estudio de la Geología de Venezuela. Tercera parte, capítulo V. Las Formaciones del Eoceno en los Andes Venezolanos y en la Subcuenca del Lago de Maracaibo: Boletín de Geología, Ministerio de Minas e Hidrocarburos (Venezuela), v. 1, p. 265-288.
Gradstein, F. M., J. G. Ogg, A. G. Smith, W. Bleeker, and L. J. Lourens, 2004, A New Geologic Time Scale, with special reference to Precambrian and Neogene: Episodes, v. 27, p. 83-100.
Graham, A., and D. M. Jarzen, 1969, Studies in Neotropical Paleobotany. I. The Oligocene Communities of Puerto Rico: Annals of the Missouri Botanical Garden, v. 56, p. 308-357.
Graves, G., and G. Jam, 1997, Misoa, Formación: Código Estratigráfico de las Cuencas Petroleras de Venezuela. Comité Interfilial de Estratigrafía y Nomenclatura (CIEN), Venezuela. http://www.pdv.com/lexico/m43w.htm.
Groot, J. J., and C. R. Groot, 1962, Some plant microfossils from the Bright-Seat Formation (Paleocene) of Maryland: Palaeontographica Abt. B, v. 111, p. 161-171.
Gruas-Cavagnetto, C., 1976, Etude palynologique du Paléogène du sud de l'Angleterre: Cahiers de micropaléontologie, v. 1: Paris, 49 p.
Guerrero, J., and G. Sarmiento, 1996, Estratigrafía física, Palinológica, Sedimentológica y Secuencial del Cretácico Superior y Paleoceno del Piedemonte Llanero. Implicaciones en Exploración Petrolera: Geología Colombiana, v. 20, p. 3-66.
Haq, B. U., J. Hardenbol, and P. R. Vail, 1988, Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level changes, *in* C. K. Wilgus, B. S. Hastings, C. Kendall, H. W. Posamentier, C. A. Ross, and J. C. V. Wagoner, eds., Sea Level Changes: An Integrated Approach: SEPM Special Publication, v. 42, SEPM, p. 72-108.
Hardy, M. J., 2000, Origin, distribution, and degradation of sedimentary organic matter in a modern tropical deltaic system (Mahakam delta, Borneo, Indonesia), Louisiana State University, Louisiana, 368 p.
Hathon, L., and I. Espejo, 1997, Detrital modes of Tertiary units in the central Middle Magdalena Basin, Colombia: VI Simposio Bolivariano Exploracion Petrolera en las Cuencas Subandinas, Memorias, v. I, p. 150-162.
Hedberg, H. D., 1976, International stratigraphic guide. A guide to stratigraphic classification, terminology, and procedure: Wiley, New York, 200 p.
Hedberg, H. D., and L. C. Sass, 1937, Synopsis of the geologic formations of the western part of the Maracaibo Basin, Venezuela: Boletín de Geología y Minería (Ministerio de Fomento, Venezuela), v. 1, p. 73-112.
Heintz, P., E. Hilmer, A. Nogueira, and W. Schiebel, 1976, Carbón del Zulia: uno de los yacimientos más importantes de carbón coquizable de Latino-América: Congreso Carbón Instituto Latino Americano Fierro Acero, Mexico, 20 p.
Hernandez, E., 1996, The Guasare Formation (Paleocene), Maracaibo Basin: a carbonate or a terrigenous play?: American Association of Petroleum Geologists Bulletin, v. 80, p. 1301.
Hernandez, E., A. Oldershaw, and F. Krause, 1996, Significance of the pelecypod shell beds in the Guasare Formation, Maracaibo Basin, Venezuela: American Association of Petroleum Geologists Bulletin, v. 80, p. 1301.
Hettner, A., 1892, Die Kordillere von Bogotá: Petermanns Mitteilungen Erganzungsheft, v. 104, Bd. 22, 1-31 p.
Higgs, R., 1996, A facies analysis of the Misoa Formation (Eocene) of Venezuela: American Association of Petroleum Geologists Bulletin, v. 80, p. 1301.
Hofmann, C.-C., 2002, Pollen distribution in sub-Recent sedimentary environments of the Orinoco Delta (Venezuela) - an actuo-palaeobotanical study: Review of Palaeobotany and Palynology, v. 119, p. 191-

217.
Hoorn, C., 1988, Quebrada del Mochuelo, type locality of the Bogotá Formation: a sedimentological, petrographical and palynological study, Amsterdam, Hugo de Vries-Laboratory, University of Amsterdam, p. 21.
Hoorn, C., J. Guerrero, G. Sarmiento, and M. A. Lorente, 1995, Andean tectonics as a cause for changing drainage patterns in Miocene northern South America: Geology, v. 23, p. 237-240.
Hopping, C. A., 1967, Palynology and the Oil industry: Review of Palaeobotany and Palynology, v. 2, p. 23-48.
Hubach, E., 1957, Contribución a las Unidades estratigráficas de Colombia (enumeración regional, de más reciente a más antiguo), Informe No. 1212, Bogotá, Instituto Geológico Nacional, p. 166.
Iversen, J., and J. Troels-Smith, 1950, Pollenmorfologiske definitioner og Typer, v. 3, p. 54.
Jam, P., 1997, Guasare, Formación: Código Estratigráfico de las Cuencas Petroleras de Venezuela. Comité Interfilial de Estratigrafía y Nomenclatura (CIEN), Venezuela. http://www.pdv.com/lexico/g42w.htm.
Jansonius, J., and L. V. Hills, 1976, Genera File of Fossil Spores: Calgary, Canada, Special Publication, Dept. of Geology, University of Calgary, cards 1-3287 p.
Jaramillo, C., 1999, Middle Paleogene palynology of Colombia, South America: Biostratigraphic, sequence stratigraphic and diversity implications: Ph.D. thesis, University of Florida.
Jaramillo, C., and D. L. Dilcher, 2001, Middle Paleogene palynology of central Colombia, South America: A study of pollen and spores from tropical latitudes: Palaeontographica B, v. 285, p. 87-213.
Jaramillo, C. A., 2002, Response of tropical vegetation to Paleogene warming: Paleobiology, v. 28, p. 222-243.
Jaramillo, C. A., F. Muñoz, M. Cogollo, and F. De la Parra, 2004, Quantitative biostratigraphy for the Cuervos Formation (Paleocene) of the llanos foothills, Colombia: improving palynological resolution for oil exploration.
Jardiné, S., and L. Magloire, 1965, Palynologie et stratigraphie du Crétacé des bassins du Sénégal et de Côte d'Ivoire: Mémoire du Bureau de Recherches Géologiques et Minières (BRGM), v. 32, p. 187-245.
Julivert, M., 1961, Las Estructuras del Valle Medio del Magdalena y su significación: Boletín Geológico UIS, v. 6, p. 33-52.
Kaska, H. V., 1989, A spore and pollen zonation of early Cretaceous to Tertiary nonmarine sediments of central Sudan: Palynology, v. 13, p. 79-90.
Kedves, M., 1969, Palynological studies on Hungarian Early Tertiary deposits: Budapest, Akadémiai kiadó, 84 p.
Kedves, M., and N. Solé de Porta, 1963, Comparación de las esporas del género *Cicatricosisporites* R. Pot. Y Gell. 1933 de Hungría y Colombia. Algunos problemas referente a su significado estratigráfico: Boletín de Geología Universidad Industrial de Santander, v. 12, p. 51-76.
Kedves, M., N. Solé de Porta, and A. Martin-Algarra, 1996, Spores and pollen grains from Eocene layers of Málaga (Spain): Plant cell biology and development, v. 37-55.
Kehrer, W., 1933., El Carboniano del Borde Llanero de la Cordillera Oriental: Boletín de Minas y Petróleos, v. 49-54, p. 105-121.
Kellogg, J. N., 1984, Cenozoic tectonic history of the Sierra de Perijá, Venezuela- Colombia, and adjacent basins, *in* W. E. Bonini, R. B. Hargraves, and R. Shagam, eds., The Caribbean-South American Plate Boundary and Regional Tectonics, Geological Society of America, Memoir 162, p. 239-261.
Kimberley, M., 1980, The Paz de Rio oolitic inland-sea Iron Formation: Economic Geology, v. 75, p. 97-106.
Kroonenberg, S. B., J. G. M. Bakker, and M. A. van der Wiel, 1990, Late Cenozoic uplift and paleogeography of the Colombian Andes: constraints on the development of high-andean biota: Geologie en Mijnbouw, v. 69, p. 279-290.
Krutzsch, V. W., 1970, Einige neue pollenformen aus den familien Tiliaceen, Bombacaceen und Sterculiaceen aus dem mitteleuropäischen Alttertiär: Jb Geol. Bd. 3, p. 275-307.
Kuyl, O. S., J. Muller, and H. T. Waterbolk, 1955, The application of palynology to oil geology with reference to western Venezuela: Geologie en Mijnbouw, v. 17, p. 49-76.
Leidelmeyer, P., 1966, The Paleogene and Lower Eocene pollen flora of Guyana: Leidse Geologische Mededelingen, v. 38, p. 49-70.
Lopez-Gomez, J., and A. Arche, 1993, Architecture of the Cañizar fluvial sheet sandstones, Early Triassic, Iberian Ranges, eastern Spain, *in* M. Marzo, and C. Puigdefábregas, eds., Alluvial sedimentation: Oxford, Blackwell Scientific, p. 363-381.
Lorente, M., 1986, Palynology and Palynofacies of the Upper Tertiary in Venezuela: Berlin, J. Cramer, 222 p.
Lorente, M. A., 1990, Textural characteristics of organic matter in several subenvironments of the Orinoco Upper Delta: Geologie en Mijnbouw, v. 69, p. 263-278.
Lugo, J., and P. Mann, 1995, Jurassic-Eocene tectonic evolution of Maracaibo Basin, Venezuela, *in* A. J.

Tankard, R. Suarez Soruco, and H. J. Welsink, eds., Petroleum basins of South America: Memoir 62, American Association of Petroleum Geologists, p. 699-725.
Lynn-Gaponoff, S., 1984, Palynology of the Silverado Formation (Late Paleocene), Riverside and Orange counties, California: Palynology, v. 8, p. 71-106.
Maher, J., Louis J., 1981, Statistics for microfossil concentration measurements employing samples spiked with marker grains: Review of Palaeobotany and Palynology, v. 32, p. 153-191.
Mahmoud, M. S., 2003, Palynology and palaeoenvironment of the Quseir Formation (Campanian) from central Egypt: Journal of African Earth Sciences, v. 36, p. 135-148.
Mantell, C. L., 1968, Carbon and graphite handbook: New York, Interscience Publishers, John Wiley and Sons, 538 p.
Marshall, L. G., T. Sempere, and R. F. Butler, 1997, Chronostratigraphy of the mammal-bearing Paleocene of South America: Journal of South American Earth Sciences, v. 10, p. 49-70.
Martini, E., ed., 1971, Standard Tertiary and Quaternary calcareous nannoplankton zonation: Proceedings of the 2nd Planktonic Conference, Roma, v. 2, 739-785 p.
Meon, H., 1990, Palynologic studies of the Cretaceous-Tertiary boundary interval at El Kef outcrop, northwestern Tunisia: Paleogeographic implications: Review of Palaeobotany and Palynology, v. 65, p. 85-94.
Miall, A. D., 1984, Principles of sedimentary basin analysis: New York, Springer-Verlag, 490 p.
Miall, A. D., 1985, Architectural-element analysis: A new method of facies analysis applied to fluvial deposits: Earth-Science Reviews, v. 22, p. 261-308.
Miall, A. D., 1988, Reservoir heterogeneities in fluvial sandstones: lessons from outcrop studies: American Association of Petroleum Geologist Bulletin, v. 72, p. 682-697.
Miller, J. B., 1962, Tectonic trends in Sierra de Perijá and adjacent parts of Venezuela and Colombia: American Association of Petroleum Geologist, v. 46, p. 1565-1595.
Mjos, R., O. Walderhaug, and E. Prestholm, 1993, Crevasse splay sandstone geometries in the Middle Jurassic Ravenscar Group of Yorkshire, UK: Special publications International Association of Sedimentologists, v. 17, p. 167-184.
Mohr, B., and G. Fechner, 1986, Eine Eozäne mikroflora (sporomorphae und dinoflagellaten-zysten) aus der Südatlas-Randzone westlich boumalne du dades (Marokko): Berliner geowiss. Abh. A, v. 66, p. 381-414.
Morales, L. G., D. J. Podesta, W. C. Hatfield, H. Tanner, S. H. Jones, M. H. S. Barker, D. J. O'Donoghue, C. E. Mohler, E. Dubois, C. Jacobs, and C. R. Goss, 1958, General Geology and Oil occurrences of Middle Magdalena Valley, Colombia, *in* L. G. Weeks, ed., Habitat of Oil: Tulsa, OK, AAPG, p. 641-695.
Moreno-Sanchez, M., and A. Pardo-Trujillo, 2003, Stratigraphical and sedimentological constraints on western Colombia: implications on the evolution of the Caribbean Plate, *in* C. Bartolini, R. T. Buffler, and J. Blickwede, eds., The Circum-Gulf of Mexico and the Caribbean: hydrocarbon habitats, basin formation and plate tectonics, AAPG Memoir 79, p. 891-924.
Morley, R. J., 1998, Palynological evidence for Tertiary plant dispersals in the SE Asian region in relation to plate tectonics and climate, *in* R. Hall, and D. Holloway, eds., Biogeography and geological evolution of SE Asia: Leiden, Backhuys publishers, p. 211-234.
Morley, R. J., 2000, Origin and evolution of tropical rain forests: New York, John Wiley & Sons, 632 p.
Muller, J., 1959, Palynology of Recent Orinoco delta and shelf sediments: Micropaleontology, v. 5, p. 1-23.
Muller, J., 1968, Palynology of the Pedawan and Plateau Sandstone Formations (Cretaceous-Eocene) in Sarawak, Malaysia: Micropaleontology, v. 14, p. 1-37.
Muller, J., 1981, Fossil pollen records of extant angiosperms: The Botanical review, v. 47, p. 1-142.
Muller, J., E. Di Giacomo, and A. Van Erve, 1987, A palynologic zonation for the Cretaceous, Tertiary and Quaternary of Northern South America: AASP Contribution Series, v. 19, p. 7-76.
NACSN, 1983, North American Stratigraphic Code: American Association of Petroleum Geologist Bulletin, v. 67, p. 841-875.
Nandi, B., 1990, Palynostratigraphy of upper cretaceous sediments, Meghalaya, northeastern India: Review of Palaeobotany and Palynology, v. 65, p. 119-129.
Nichols, D. J., 1973, North American and European species of *Momipites* ("*Engelhardtia*") and related genera: Geoscience and man, v. VII, p. 103-117.
Nichols, D. J., and A. Traverse, 1971, Palynology, Petrology, and Depositional Environments of some Early Tertiary Lignites in Texas: Geoscience and Man, v. 3, p. 37-48.
Nilsson, S., and A. Robyns, 1986, World pollen and spore flora 14. Angiospermae. Bombacaceae Kunth,

Almquist & Wiksell Periodical Company, 59 p.
Nogueira, A., 1975, Excursión N° 3-Sierra de Perijá. Carbones Piemontinos Riecito de Maché, Cuenca Carbonífera del Zulia: Boletín de Geología, Ministerio de Minas e hidrocarburos (Venezuela), publicación especial N° 7. Memoria, segundo congreso Latinoamericano de Geología, v. 1, p. 318-324.
Notestein, F. B., C. W. Hubman, and J. W. Bowler, 1944, Geology of the Barco Concession, Republic of Colombia, South America: Bulletin of the Geological Society of America, v. 55, p. 1165-1216.
Nuttall, C. P., 1990, A review of the Tertiary non-marine molluscan faunas of the Pebasian and other inland basins of north-western South-America: Bulletin of the British Museum Natural History (Geology), v. 45, p. 165-371.
Osorno, J. F., 1994, Estratigrafia y ambientes de depósito de la secuencia regresiva localizada al noreste de Sogamoso, unpublished thesis, Universidad de Caldas, Manizales, 105 p.
Pardo, S., 1997, Estratigrafía y sedimentología de la Formación La Paz, Cerro La Paz, Valle Medio del Magdalena, Universidad Nacional, Bogotá, 125 p.
Pardo-Trujillo, A., C. A. Jaramillo, and F. Oboh-Ikuenobe, 2003, Paleogene palynostratigraphy of the eastern Middle Magdalena Valley, Colombia: Palynology, v. 27, p. 151-174.
Parrish, J. T., 1998, Interpreting pre-Quaternary climate from the geologic record: Columbia University Press, 348 p.
Petrescu, I., and V. Codrea, 2003, The signification of the Paleocene microflora from Jibou (Salaj district) for the Paleogene palinological heritage of Romania: Acta Palaeontologica Romaniae, v. 4, p. 1-7.
Pettijohn, F. J., P. E. Potter, and R. Siever, 1987, Sand and sandstone: New York, Springer-Verlag, 553 p.
Pilsbry, H. A., and A. A. Olsson, 1935, Tertiary fresh-water mollusks of the Magdalena Embayment, Colombia: Proceedings of the Academy of Natural Sciences of Philadelphia, v. 87, p. 7-21.
Pindell, J. L., 1993, Regional synopsis of Gulf of Mexico and Caribbean evolution: Mesozoic and early Cenozoic development of the Gulf of Mexico and Caribbean region SEPM Foundation Annual Research Conference, 13th, p. 251-274.
Pindell, J. L., 1998, Cenozoic palinspastic reconstruction, paleogeographic evolution and Hydrocarbon setting of the northern Margin of South America, *in* J. L. Pindell, and C. L. Drake, eds., Paleogeographic Evoloution and Non-Glacial Eustasy, Northern South America, v. 58, Society of Economic Petrologists and Mineralogists Special Publication, p. 45-85.
Pindell, J. L., and C. L. Drake, 1998, Paleogeographic evolution and non-glacial eustasy, Northern South America: SEPM Special Publication 58: Tulsa, SEPM, 324 p.
Pindell, J. L., L. Kennan, and R. Higgs, 2001, Paleogene "negative flexure" basins in Colombia and Venezuela, AAPG national meeting, abstracts, Houston, Texas, http://aapg.confex.com/aapg/hu2002/techprogram/paper_43432.htm.
Pocknall, D. T., 1990, Palynological evidence for the early to middle Eocene vegetation and climate history of New Zealand: Review of Palaeobotany and Palynology, v. 65, p. 57-69.
Pocknall, D. T., R. N. Erlich, J. A. Stein, and M. A. Lorente, 2001, The palynofloral succession across the Cretaceous to Paleocene transition zone, Merida Andes, western Venezuela, *in* D. K. Goodman, and R. T. Clarke, eds., Proceedings of the IX International Palynological Congress, Houston, Texas, U.S.A., 1996, American Association of Stratigraphic Palynologists Foundation (AASP), p. 171-179.
Pole, M. S., and M. K. Macphail, 1996, Eocene Nypa from Regatta Point, Tasmania: Review of Palaeobotany and Palynology, v. 92, p. 55-67.
Porta, J. d., 1962, Consideraciones sobre el estado actual de la estratigrafía del Terciario en Colombia: Boletín de Geología Universidad Industrial de Santander, v. 9, p. 543.
Porta, J. d., 1974, Colombie (deuxieme partie), Tertiaire et Quaternaire: Lexique Stratigraphique International, Amerique Latine, v. V (4b): Paris, Centre National de la Recherche Scientifique, 689 p.
Porta, J. d., and N. Solé de Porta, 1962, Discusión sobre las edades de las formaciones Hoyón, Gualanday y la Cira en la región de Honda-San Juan de Rio Seco: Boletín de Geología Universidad Industrial de Santander, v. 9, p. 69-85.
Potter, P. E., and F. J. Pettijohn, 1963, Paleocurrents and Basin Analysis: Berlin, Springer-Verlag, 296 p.
Poumot, C., 1989, Palynological evidence for eustatic events in the tropical neogene: Bulletin des Centres de Recherches Exploration-Production Elf Aquitaine, v. 13, p. 437-453.
Punt, W., S. Blackmore, S. Nilsson, and A. L. Thomas, 1994, Glossary of Pollen and Spore terminology: Utrecht, LPP Foundation, 71 p.
Quattrocchio, M., W. Volkheimer, and C. del Papa, 1997, Palynology and paleoenvironment of the "Faja Gris" Mealla Formation (Salta Group) at Garabatal Creek (NW Argentina): Palynology, v. 21, p. 231-247.

Rákosi, L., 1973, Palynologie des formations Paléogènes du bassin de Dorog: Annales Instituti Geologici Publici Hungarici, v. 55, p. 554-697.

Regali, M., N. Uesugui, and A. Santos, 1974, Palinologia dos sedimentos Meso-Cenozoicos do Brasil: Boletim Tecnico da Petrobras, v. 17, p. 177-191.

Renzoni, G., 1967, Geología del cuadrángulo J-12, Tunja: Boletín Geológico del Ingeominas (Bogotá), v. 24, p. 35-48.

Reyes, I., 1984, Geología de la región de Duitama-Sogamoso-Paz de Río (departamento de Boyacá): Universidad Pedagógica y tecnológica de Colombia (UPTC): Sogamoso, unpublished, 108 p.

Rich, F. J., D. Kuehn, and T. D. Davies, 1982, The paleoecological significance of *Ovoidites*: Palynology, v. 6, p. 19-28.

Roche, E., 1988, Sporopollinic biostratigraphy and Ypresian paleoenvironment: Bulletin de la Société belge de Géologie, v. 97, p. 373-383.

Rodriguez, A. J., and O. Solano, 2000, Mapa geoloógico del departamento de Boyacá, memoria explicativa: Ingeominas, Santa Fé de Bogotá, 120 p.

Ruiz, O., and D. Pons, 1996, Una asociación microflorística del Eoceno-Oligoceno en el piedemonte llanero (Casanare-Colombia): VII Congreso Colombiano de Geología, Santafé de Bogota, v. II, p. 307-319.

Rull, V., 1995, Organic matter assemblages from recent sediments of the Tacarigua coastal lagoon (northern Venezuela): Geologie en Mijnbouw, v. 74, p. 93-104.

Rull, V., 1997b, Sequence analysis of western Venezuelan Cretaceous to Eocene sediments using palynology: chrono-paleoenvironmental and paleovegetational approaches: Palynology, v. 21, p. 79-90.

Rull, V., 1999a, Palaeofloristic and palaeovegetational changes across the Paleocene/Eocene boundary in northern South America: Review of Palaeobotany and Palynology, v. 107, p. 83-95.

Rull, V., 1999b, A palynological record of a secondary succession after fire in the Gran Sabana, Venezuela: Journal of Quaternary Science, v. 14, p. 137-152.

Rull, V., 2000, Ecostratigraphic study of Paleocene and early Eocene palynological cyclicity in northern South America: Palaios, v. 15, p. 14-24.

Rull, V., 2002, High-impact palynology in petroleum geology: applications from Venezuela (northern South America): American Association of Petroleum Geologist Bulletin, v. 86, p. 279-300.

Salard-Cheboldaeff, M., 1981, Palynologie maestrichtienne et tertiaire du cameroun. Resultats botaniques: Review of Palaeobotany and Palynology, v. 32, p. 401-439.

Samant, B., and N. R. Phadtare, 1997, Stratigraphic palynoflora of the Early Eocene Rajpardi lignite, Gujarat and the lower age limit of the Tarkeswar Formation of South Cambay Basin, India: Palaeontographica Abt. B, v. 245, p. 1-108.

Sarmiento, G., 1992a, Estratigrafía y medios de depósito de la Formación Guaduas: Boletín Geológico Ingeominas, v. 32, p. 3-44.

Sarmiento, G., 1992b, Palinología de la Formación Guaduas - estratigrafía y sistemática: Boletín Geológico Ingeominas, v. 32, p. 45-126.

Sarmiento, G., 1994, Visión regional de la Formación Guaduas: Publicaciones geológicas Especiales del Ingeominas, v. 20, p. 165-180.

Sarmiento, G., 1995, Palinología de las formaciones Catatumbo, Barco y Los Cuervos, Sardinata (Norte de Santander): Ingeominas, Internal report, unpublished.

Saxena, R. K., 1979, Palynology of the Matanomadh Formation in the type area, north-western Kutch, India (Part 2). Systematic description of Gymnospermous and Angiospermous pollen grains: The Palaeobotanist, v. 26, p. 130-143.

Scheihing, M. H., and H. W. Pfefferkorn, 1984, The taphonomy of land plants in the Orinoco delta: A models for the incorporation of plant parts in clastic sediments of late Carboniferous age of Euramerica: Review of Palaeobotany and Palynology, v. 41, p. 205-240.

Scherer, W., 1997, Paso Diablo, Formación: Código Estratigráfico de las Cuencas Petroleras de Venezuela. Comité Interfilial de Estratigrafía y Nomenclatura (CIEN), Venezuela. http://www.pdv.com/lexico/p26w.htm.

Schrank, E. S., 1984, Organic-geochemical and palynological studies of a Dakhla shale profile (Late Cretaceous) in southeast Egypt. Part A: succession of microfloras and depositional environment: Berliner geowiss. Abh. A, v. 50, p. 189-207.

Schuler, M., C. Cavelier, C. Dupuis, E. Steurbaut, N. Vandenberghe, J. Riveline, E. Roche, and M. Soncini, 1992, The Paleogene of the Paris and Belgian basins. Standard-stages and regional stratotypes: Cahiers de Micropaléontologie, v. 7, p. 29-92.

Schuler, M., and J. Doubinger, 1970, Observations Palynologiques dans le Bassin D'Amaga (Colombie): Pollen et Spores, v. 12, p. 429-450.
Scotese, C. R., 1997, Paleogeographic Atlas, PALEOMAP Progress Report 90-0497: University of Texas at Arlington: Texas, 37 p.
Shanley, K. W., and P. J. McCabe, 1994, Perspectives on the sequence stratigraphy of continental strata: American Association of Petroleum Geologist, v. 78, p. 544-568.
Shaw, A. B., 1964, Time in stratigraphy: New York, McGraw-Hill, 365 p.
Smith, A. H. V., 1987, Stratigraphic ranges of selected miospores in coal seams of Upper Coal Measures age in Oxfordshire and S.E. Warwickshire: Journal of micropalaeontology, v. 6, p. 21-37.
Solé de Porta, N., 1961a, Contribución a la Palinología del Terciario del norte de Colombia: Boletín Geológico, Servicio geológico Nacional (Bogota), v. VIII, p. 75-94.
Solé de Porta, N., 1961b, Contribución al estudio palinológico del Terciario de Colombia: Boletín de Geología, Universidad Industrial de Santander, v. 7, p. 55-81.
Solé de Porta, N., 1963, Asociación esporo-polínica hallada en una serie perteneciente a la Formación La Cira del Valle del Magdalena (Colombia): Boletin Geologico, Servicio Geológico Nacional (Bogota), v. XI, p. 5-16.
Solé de Porta, N., 1970, Estudio esporo-polínico de la Formación Guaduas (Maastrichtiano-Paleoceno) en la Sabana de Bogotá, Colombia: Unpublished thesis, Universidad de Barcelona, 560 p.
Solé de Porta, N., 1971, Algunos géneros nuevos de polen procedentes de la Formación Guaduas (Maastrichtiense) Paleoceno de Colombia: Studia Geologica, v. 2, p. 133-143.
Solé de Porta, N., 1972, Contribución a la Palinología del Nivel de Lutitas y Arenas (Campaniense) en Guataquí (Valle del Magdalena, Colombia): Revista Española de Micropaleontología, v. IV, p. 225-250.
Solé de Porta, N., C. Jaramillo, and A. Martín-Algarra, 2004, Pantropical palynomorphs in the Eocene of the Malaguides (Betic Cordillera, southern Spain): Polen. Abstracts of the XI IPC, v. 14, p. 189.
Srivastava, S. K., 1972, Some spores and pollen from the Paleocene Oak Hill member of the Naheola Formation, Alabama (USA): Review of Palaeobotany and Palynology, v. 14, p. 217-285.
Srivastava, S. K., and P. L. Binda, 1991, Depositional history of the Early Eocene Shumaysi Formation, Saudi Arabia: Palynology, v. 15, p. 47-61.
Stockmarr, J., 1971, Tablets with spores used in absolute pollen analysis: Pollen et Spores, v. XIII, p. 615-621.
Streel, M., and M. J. M. Bless, 1980, Occurrence and significance of reworked palynomorphs: Mededelingen Rijks Geologische Dienst, v. 32-10, p. 69-80.
Suárez, M., 1996, Facies analysis of the upper Eocene La Paz Formation, and regional evaluation of post-middle Eocene stratigraphy, northern Middle Magdalena Valley Basin.: MSc., unpublished thesis, University of Colorado, Boulder, 88 p.
Suárez, M., P. Weimer, M. J. Kraus, and A. J. Pulham, 1997, Facies analysis of the Upper Eocene La Paz Formation, Provincia Field, northern Middle Magdelena Valley Basin, Colombia, in K. W. Shanley and B. F. Perkins, eds., 18th Annual GCSSEPM Research Conference, p. 319-330. 1997, http://emarc.colorado.edu/rgeology/FAUELP.html.
Suárez, M. A., 1997a, Stratigraphy and petroleum potential of the La Paz Formation, Middle Magdalena Valley Basin (northern part), Colombia: Annual Meeting Abstracts - American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, v. 6, p. 112.
Sutton, F. A., 1946, Geology of Maracaibo Basin, Venezuela: AAPG Bulletin, v. 30, p. 1621-1742.
Tantawy, A. A., G. Keller, T. Adatte, W. Stinnesbeck, A. Kassab, and P. Schulte, 2001, Maastrichtian to Paleocene depositional environments of the Dakhla Formation, western desert, Egypt: sedimentology, mineralogy and integrated micro- and macrofossil biostratigraphies: Cretaceous Research, v. 22, p. 795-827.
Taylor, G. H., M. Teichmüller, A. Davis, C. F. K. Diessel, R. Littke, and P. Robert, 1998, Organic Petrology: Berlin.
The Geological Society of America, 1995, Rock-color chart.
Théveniaut, H., and P. Freyssinet, 2002, Timing of lateritization on the Guiana Shield: synthesis of paleomagnetic results from French Guiana and Suriname: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 178, p. 91-117.
Traverse, A., 1988, Paleopalynology: New York, Academic Press, 600 p.
Tschanz, C. M., A. Jimeno, and C. Vesga, 1969, Geology of the Sierra Nevada de Santa Marta area (Colombia): Ingeominas, informe 1829, p. 288.
Tschudy, R. H., and S. D. Van Loenen, 1970, Illustrations of plant microfossils from Yazoo Clay (Jackson

Group, Upper Eocene) Mississippi: Geological Survey Professional Paper, v. 643-E, p. 5 p.
Tyson, R. V., 1995, Sedimentary Organic Matter, Organic facies and palynofacies: London, Chapman and Hall, 615 p.
Ulloa, C., E. Rodriguez, and G. I. Rodriíguez, 2001, Geología de la plancha 172 Paz de Río. Escala 1:100 000: Ingeominas, p. 114.
Van der Hammen, T., 1954a, El desarrollo de la flora colombiana en los periodos geológicos: I, Maestrichtiano hasta el Terciario más inferior: Boletín Geológico (Bogotá), v. 2, p. 49-106.
Van der Hammen, T., 1954b, Principios para la nomenclatura palinológica sistemática: Boletín Geológico (Bogotá), v. 2, p. 1-21.
Van der Hammen, T., 1956a, Description of some genera and species of fossil pollen and spores: Boletín Geológico (Bogotá), v. 4, p. 103-109.
Van der Hammen, T., 1956b, A Palynological Systematic Nomenclature: Boletín Geológico (Bogotá), v. 4, p. 63-101.
Van der Hammen, T., 1957, Estratigrafía palinológica de la Sabana de Bogota (Cordillera Oriental de Colombia): Boletín Geológico, Servicio Geológico Nacional, Bogotá, v. 5, p. 189-203.
Van der Hammen, T., 1957a, Palynologic stratigraphy of the Sabana de Bogota (East Cordillera of Colombia): Boletín Geológico (Bogotá), v. 5, p. 187-203.
Van der Hammen, T., 1957b, Climatic periodicity and evolution of South American Maestrichtian and Tertiary Floras: a study based on pollen analysis in Colombia: Boletín Geológico (Bogotá), v. 5, p. 49-91.
Van der Hammen, T., 1958, Estratigrafía del Terciario y Maestrichtiano continentales y Tectonogénesis de los Andes Colombianos: Boletín Geológico (Bogotá), v. 6, p. 67-128.
Van der Hammen, T., 1961, Upper Cretaceous and Tertiary climatic periodicities and their causes: Annals of the New York Academy of Sciences, v. 95, p. 440-448.
Van der Hammen, T., and C. Garcia, 1966, The Paleocene pollen flora of Colombia: Leidse Geologische Mededelingen, v. 35, p. 105-116.
Van der Hammen, T., and C. García, 1955, Aplicación palinológica a la correlación de los mantos de carbón del yacimiento "La Chapa" Acerias Paz de Río (Boyacá), Instituto Geológico Nacional, Informe 1087, p. 1-7.
Van der Hammen, T., J. Werner, and H. Dommelen, 1973, Palynologic record of the upheaval of the Northern Andes: a study of the Pliocene and Lower Quaternary of the Colombian Eastern Cordillera and the Early evolution of its high-Andean biota: Review of Palaeobotany and Palynology, v. 16, p. 1-122.
Van der Hammen, T., and T. A. Wymstra, 1964, A palynological study on the Tertiary and Upper Cretaceous of British Guayana: Leidse Geologische Mededelingen, v. 30, p. 183-241.
Van der Kaars, W. A., 1983, A palynological-paleoecological study of the lower Tertiary coal-bed sequence from El Cerrejón (Colombia): Geología Norandina, v. 8, p. 33-48.
Van Geel, B., 1979, Preliminary report on the history of Zygnemataceae and the use of their spores as ecological markers: IV International Palynol. conf., Lucknow, 1976-77, v. 1, p. 467-469.
Van Geel, B., and T. Van der Hammen, 1978, Zygnemataceae in Quaternary Colombian sediments: Review of Palaeobotany and Palynology, v. 25, p. 377-392.
Van Hoeken-Klinkenberg, P. M. J., 1966, Maastrichtian Paleocene and Eocene pollen and spores from Nigeria: Leidse Geologische Mededelingen, v. 38, p. 37-48.
Vargas, R., A. Arias, L. Jaramillo, and N. Telles, 1981, Geología del cuadrángulo H-13 Pamplona, Colombia. Escala 1:100 000: Ingeominas.
Venkatachala, B. S., 1981, Differentiation of amorphous organic matter types in sediments, *in* J. Brooks, ed., Organic maturation studies and fossil fuel exploration: London, Academic Press, p. 177-200.
Villamil, T., 1999, Campanian-Miocene tectonostratigraphy, depocenter evolution and basin development of Colombia and western Venezuela: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 153, p. 239-275.
Westgate, J. W., and C. T. Gee, 1990, Paleoecology of a middle Eocene mangrove biota (vertebrates, plants, and invertebrated) from southwest Texas: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 78, p. 163-177.
Wheeler, O. C., 1935, Tertiary stratigraphy of the Middle Magdalena Valley: Proceedings of the Academy of Natural Sciences of Philadelphia, v. 87, p. 21-31.
Wijmstra, T. A., 1971, The Palynology of the Guiana Coastal Basin: Utrecht, Drukkerij de Kempenaer, Oegstgeest, 62 p.
Yepes, O., 2001, Maastrichtian-Danian dinoflagellate cyst biostratigraphy and biogeography from two Equatorial

sections in Colombia and Venezuela: Palynology, v. 25, p. 217-249.

Zachos, J. C., K. C. Lohmann, J. C. Walker, and S. W. Wide, 1993, Abrupt climate change and transient climates during the Paleogene: A marine perspective: Journal of Geology, v. 101, p. 191-213.

Zetter, R., M. Hesse, and A. Frosch-Radivo, 2001, Early Eocene zona-aperturate pollen grains of the *Proxapertites* type with affinity to Araceae: Review of Palaeobotany and Palynology, v. 117, p. 267-279.

Zetter, R., and C. C. Hofmann, 2001, New aspects of the palynoflora of the lowermost Eocene (Krappfeld area, Carinthia), *in* W. E. Piller, and M. W. Rasser, eds., Paleogene of the Eastern Alps: Wien, Österreichischen Akademie der Wissenschaften, p. 473-507.

PLATES

PLATE 1.1

TYPES OF SEDIMENTARY ORGANIC MATTER OF THE PALEOCENE-EOCENE ROCKS FROM COLOMBIA AND WESTERN VENEZUELA.

EF: England finder coordinate.

1. Structured wood debris. Sample UR 531+100; slide number 57277; EF: R41/1.
2. Structured wood debris. Sample UR 62; slide number 57068; EF: Q40.
3. Wood debris showing cells filling with humic gels (cf. Hardy, 2000; p. 154). Sample UR 723+10; slide number 57329, EF: H45/3.H.
4. Degraded wood debris. Sample UR 754+100; slide number 57363; EF: L42/3.
5. Phytoclast infested by fungal hyphae. Sample UR 816; slide number 57399; EF: O55.
6. Black-brown wood debris with pyrite inclusions. Sample UR 148; slide number 57098, EF: J46. Transmitted light.
7. Same of 6. Reflected light.
8. Gelified wood. Sample CCN 38; slide number 58046; EF: Q48.
9. Brown clear gelified wood (?). Sample CCN 45; slide number 58484; EF: Q37.
10. Gelified wood. Sample CCN 69; slide number 58555; EF: P48/1. Transmitted light.
11. Same of 10. Reflected light.
12. Pseudo amorphous phytoclasts. Sample UR 531+100; slide number 57277; EF: R43.
13. Highly degraded phytoclast contaminated by fungal hyphae.
14. Well-preserved cuticle. Sample CCN 73; slide number 57969; EF: E47/4.
15. Degraded cuticle. Sample IC-PE-2 (12,6); slide number 55711; EF: M52.
16. Brown clear thin debris without internal structure. Sample IC-CC-7 (11,6); slide number 55846(ICP); EF: L44/1.

PLATE 1.1

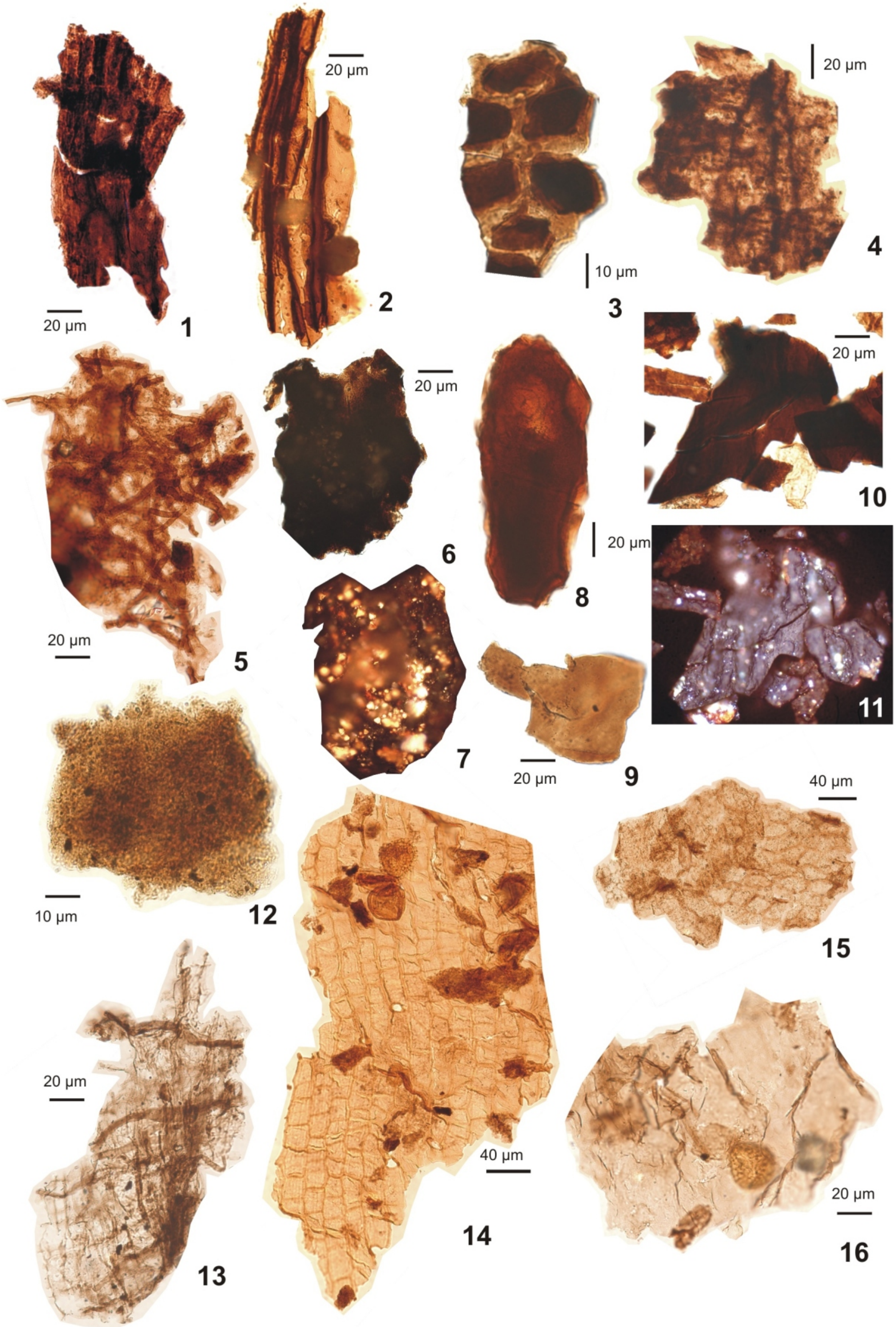


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PLATE 1.2

TYPES OF SEDIMENTARY ORGANIC MATTER OF THE PALEOCENE-EOCENE ROCKS FROM COLOMBIA AND WESTERN VENEZUELA.

EF: England finder coordinate.

1. Brown clear degraded thin debris. Sample CCN 73; slide number 57969.
2. Charcoal fragment with internal structure. Sample CCN 14; slide number 57991; EF: K51/2.
3. Black elongated debris. Sample CCN 47; slide number 58585; EF: X40. Transmitted light.
4. Same of 3, reflected light.
5. Black debris. Sample CCN 38; slide number 58046; EF: E49/2.
6. Black equidimensional debris. Sample SD-D-8D (19.5); slide number 56265.
7. Same of 6 in reflected light.
8. Resin spherical debris. Sample Venezuela 97; slide number 50035; EF: K51/1.
9. Irregular mass of resin. Sample IC-FA-3 (64,85); slide number 55764; EF: H41/1,2.
10. Resin rod. Sample IC-CC-7(23,18); slide number 55845; EF: Q41/4.
11. Resin rod. Sample IC-CC-7 (23,18); slide number 55845; EF: N40/4.
12. Fungal hyphae. Sample UR 813+90; slide number 57398; EF: G55/2.
13. Chain of fungal spore units. Sample Venezuela 97; slide number 50035; EF: R46/4.
14. Fungal spore. Sample Venezuela 97; slide number 50035; EF: K53/1.
15. Fungal spore. Sample IC-FP-1 (165,52); slide number 55996; EF: J39/4.
16. Fungal spore. Sample IC-FP-1 (174,2); slide number 55979; EF: M35/4.
17. Fruiting body (ascostroma). Sample UR 701+130; slide number 57334; EF: E46/2.
18. Stephanocolpate pollen grain. Sample Venezuela 4; slide number 57440; EF: Q51/1.
19. Tricolporate pollen grain. Sample UR 219+150; slide number 57158; EF: P38/4.
20. Spore trilete psilate. Sample Venezuela 4; slide number 57440; EF: O51.
21. *Pediastrum*. Sample CCN 101; slide number 59453; EF: U49.
22. *Spirogyra* (cf. Van Geel and Van der Hammen, 1978). Sample CCN 82; slide number 58645,; EF: S32.
23. Sphaeromorph. Sample SD-D-8D (44,9); slide number 56254; EF: W51/4.
24. Algal filament. Sample IC-FP-1 (165,52); slide number 55986; EF: J48/3.
25. Dinoflagellate cyst. Sample UR 531+100; slide number 57839; EF: N31/4.
26. Foraminiferal linning (dark, reworked?). Sample IC-CC-7 (23,18); slide number 55845; EF: R46/4.
27. Animal hair. Sample IC-FP-1 (165,6); slide number 55980(ICP); EF: K57/3-4.

PLATE 1.2

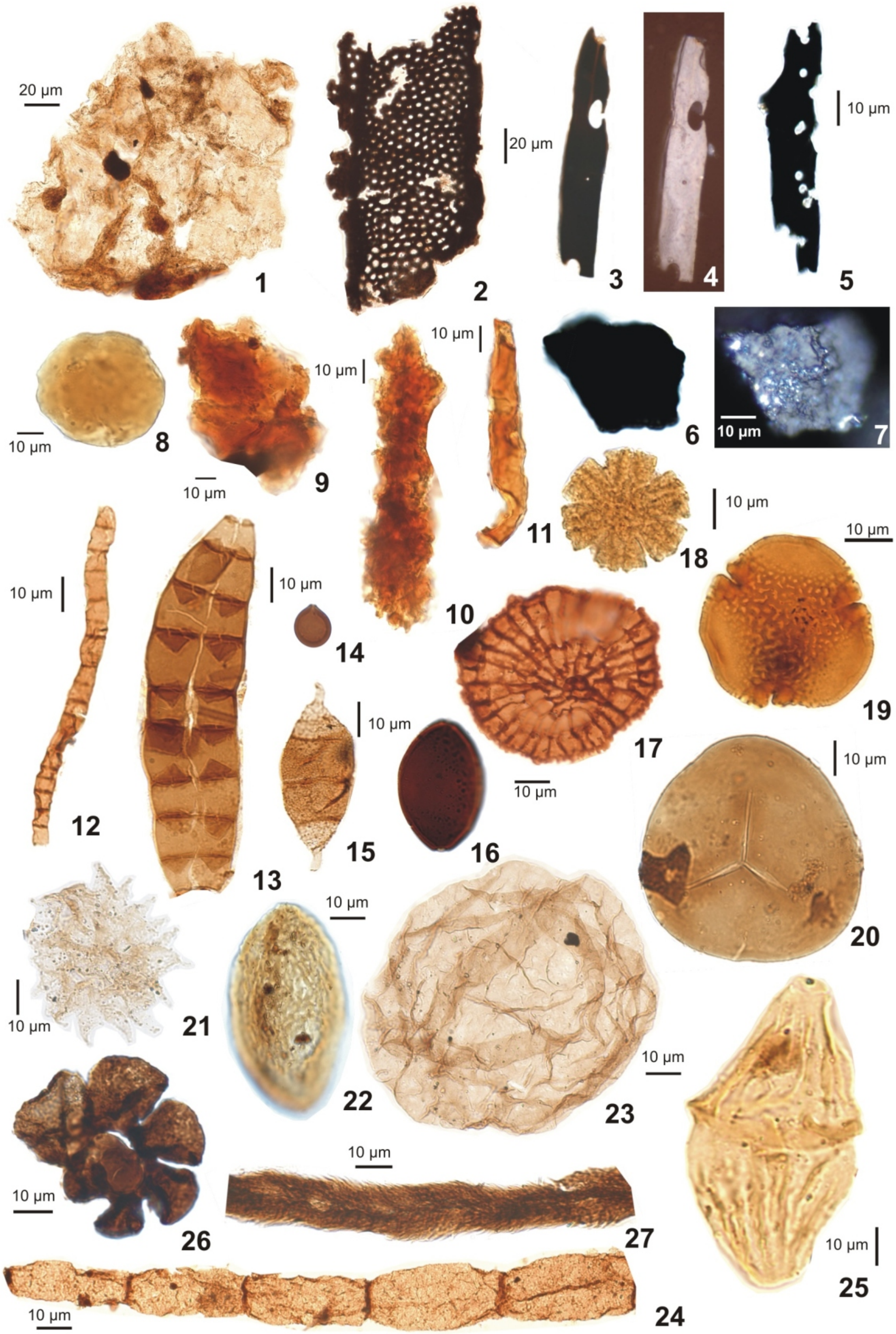
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PLATE 2.1

LITHOFACIES OF THE LA PAZ FORMATION LOGS (SOGAMOSO SECTION)

The bar represents 1 cm aprox. The indicated tickness represents the well deep (not corrected).

1. Conglomeratic sandstone. Upper part of the La Paz Formation; well IC-FP-1 (134 m aprox. below the top).
2. Lithic conglomerate with a matrix cemented by iron oxides. Upper part of the La Paz Formation; well IC-FP-1 (64 m aprox below the top).
3. Conglomeratic sandstone with shale intraclasts (center of the picture). Upper part of the La Paz Formation; well IC-FP-1 (194.6 m aprox. below the top).
4. Cross-bedded sandstone. Upper part of the La Paz Formation; well IC-FP-1 (125 m below the top).
5. Sandstones with truncated cross lamination. Upper part of the La Paz Formation; well IC-TD-1 (19 m aprox. below the top).
6. Fine sandstones with ripple cross lamination. Upper part of the La Paz Formation; well IC-TD-1 (31 m aprox. below the top).
7. Fine sandstones and organic matter-rich shales interbedded. Upper part of the La Paz Formation; well IC-FP-1 (116 m aprox. below the top).
8. Dark grey organic-rich homogeneous shales. Upper part of the La Paz Formation ; well IC-FP-1 (157 m aprox. below the top).
9. Red mottled green silty shales. Esmeraldas Formation; well SD-D-8D log (19 m aprox below the top).

PLATE 2.1

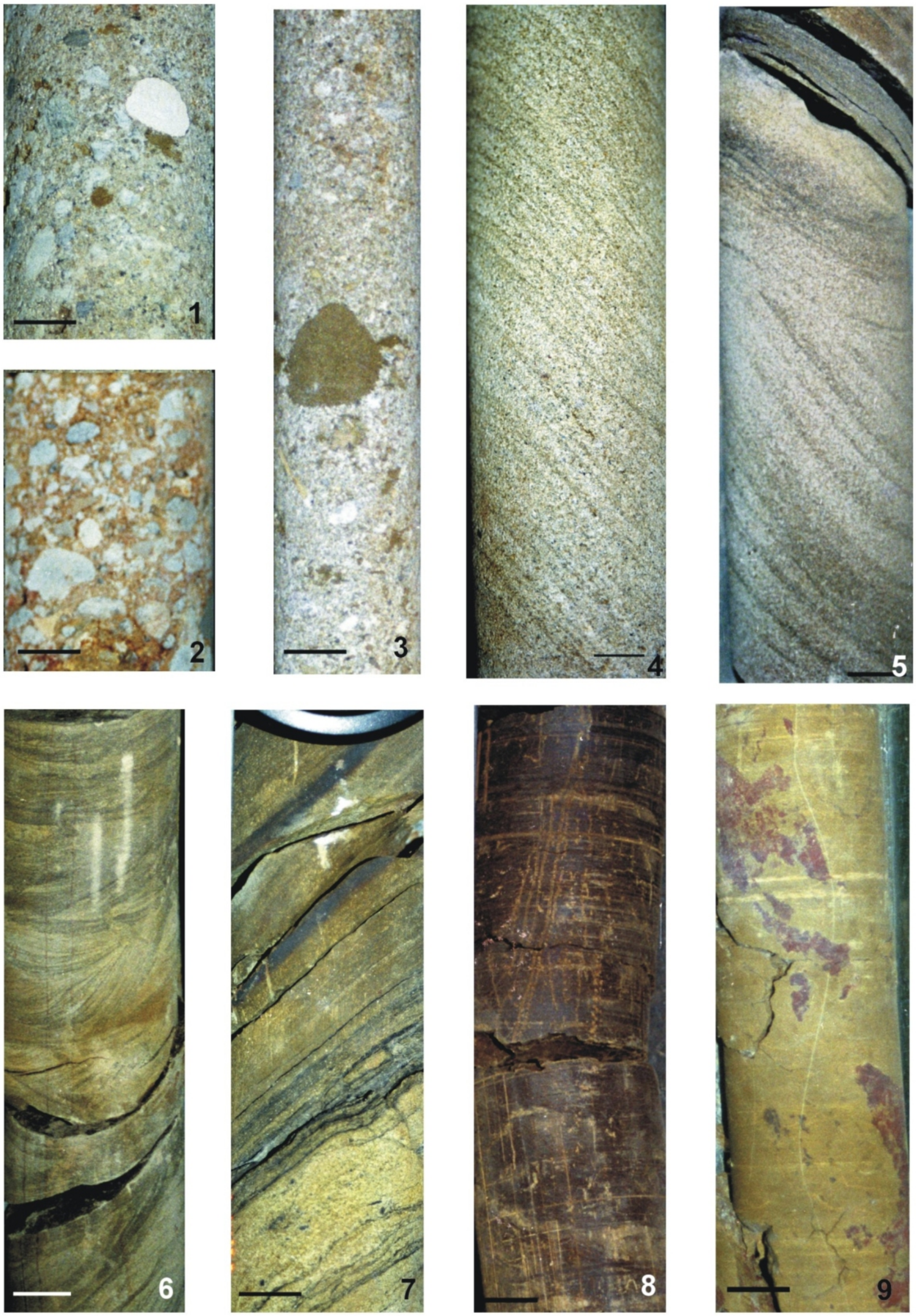

PLATE 3.1

1. Geomorphologic aspect of the Paleogene units of the Curva de Cosgua Norte section (Chicamocha river valley, Paz de Río region, Colombia). G: Guaduas Formation; A.S: Areniscas de Socha Formation; Arc. S: Arcillas de Socha Formation; P: Picacho Formation Conc. Fm: Concentración Formation. The arrow indicates the north.

2. Top of a sandstone layer with small-scale dunes, which are covered by sinuous current-ripples. Note that the foreset of the dunes (pointed by the geologist Juan Pablo SALAZAR) are oriented more or less in the same direction than the current-ripples. The arrow marks the paleocurrent direction. Layer located between Δ6- Δ7 stations of the stratigraphic section (figure 3.2). Upper part of the Areniscas de Socha Formation; Curva de Cosgua Norte (CCN) section.

3. Sandstone layers that show successive current-ripples with similar crest orientation. The arrows indicate the paleocurrent direction. The beds are located inmediatelly above the Δ11 station of the stratigraphic section (figure 3.2). Upper part of the Areniscas de Socha Formation; Curva de Cosgua Norte (CCN) section.

4. Sinuous current-ripples (detail of the photo 3). For localization see the black frame in the photo 3. The arrow indicates the paleocurrent direction.

PLATE 3.1

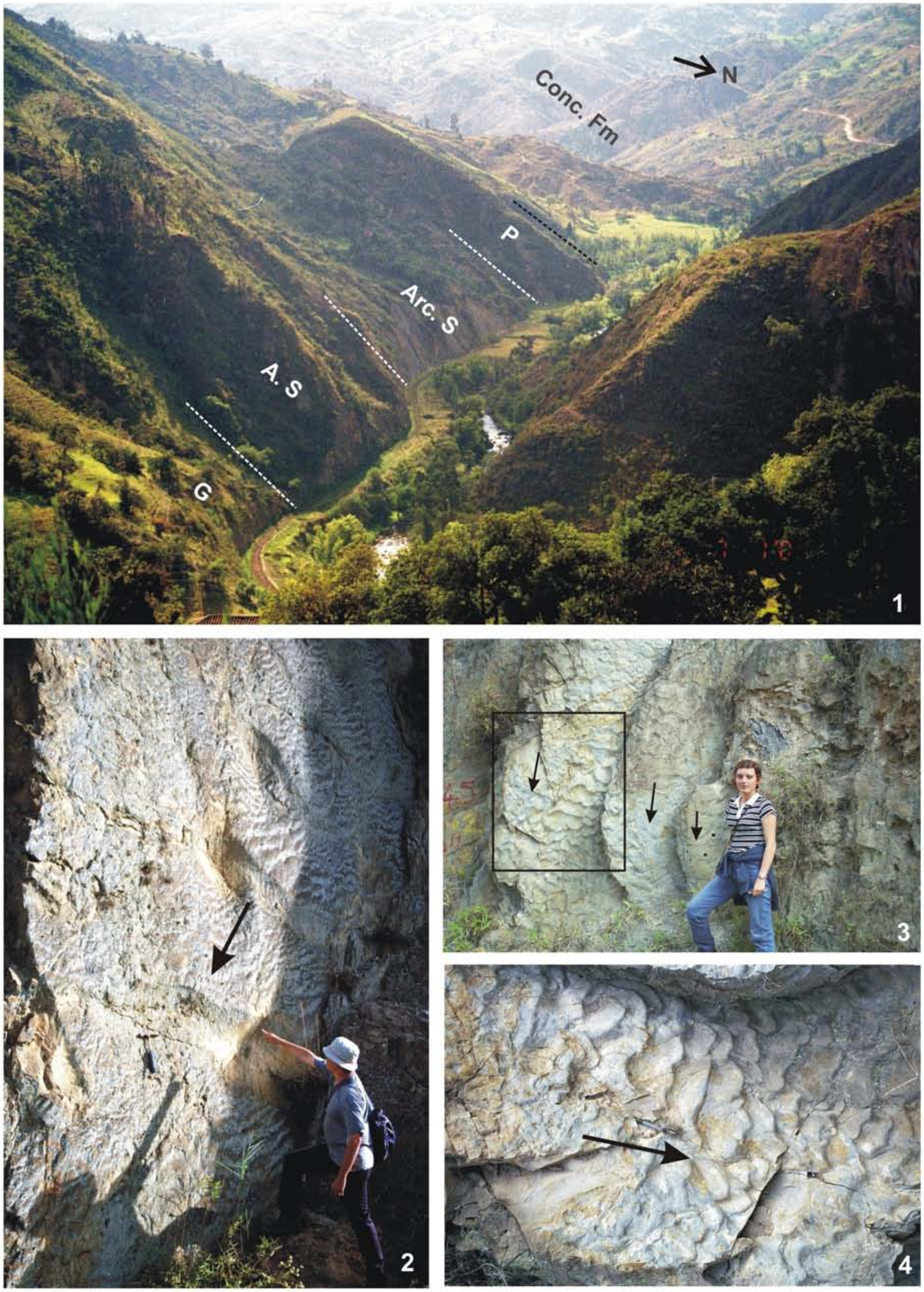

PLATE 3.2

1. Organic rich mudstones and siltstones with different resistance to erosion. Δ13- Δ14 interval of the Curva de Cosgua Norte (CCN) section. Lower part of the Arcillas de Socha Formation.

2. Grey mudstones, siltstones of the Arcillas de Socha Formation. A coal bed is located at the right side of the picture (black layer). Δ14-Δ15 interval of the Curva de Cosgua Norte (CCN) section.

3. Overbank deposits (levee?) composed by tabular rippled strata with siltstone interbeds. Δ16 station of the Curva de Cosgua Norte (CCN) section. Arcillas de Socha Formation.

4. Coal bed interlayed with laminated siltstones. Detail of the photo 5. Arcillas de Socha Formation; Curva de Cosgua Norte section.

5. Fine grained deposits composed by coal (black layer of the left), siltstones and mudstones. Δ16- Δ18 interval of the Curva de Cosgua Norte (CCN) section. Arcillas de Socha Formation. Forefront: railroad track of the Acerias Paz de Río Company.

PLATE 3.2

PLATE 3.3

1. Outcrop aspect of the Δ17- Δ18 interval composed mainly by grey shales (lower part of the Arcillas de Socha Formation). Numbers represent the localization of palynological samples (see the figure 3.3). Top of the sequence is located to the right. Curva de Cosgua Norte (CCN) section.

2. Sandstone layer with sharp base (left) and gradual change to mud dominated deposits. Finning upward sequence interpreted as an overbank fluvial deposit.

3. Δ18- Δ19 interval of the Curva de Cosgua Norte (CCN) section. Two Fining upward sequences (FUS) can be apreciated. Figure 2 shows a detail of the left sequence. The right sequence is interpreted as a poin bar deposit. Arcillas de Socha Formation.

4. Tool marks at the base of a fine sandstone layer. Two meters below Δ15; Arcillas de Socha Formation; Curva de Cosgua Norte (CCN) section.

5. Ripple lamination in a fine sandstone layer located some centimeters above Δ 4. Upper part of the Arcillas de Socha Formation; Curva de cosgua Sur section (CCS).

6. Layers of sandstones interbedded with mottled shales at the upper part of the Arcillas de Socha Formation. The top is located to the left of the picture. Outcrop located between the Δ5-Δ6 (Curva de Cosgua Sur section). The geologist Christian DUPUIS is located on Δ5.

7. Geomorphological contrast between the shale-dominated Arcillas de Socha Formation (Arc. S) and the Sandstone-dominated Picacho Formation (Pic.). The picture was taken from the Curva de Cosgua Sur section. Forefront: train of the Paz de Río Company.

PLATE 3.3

1
CCN-70
CCN-71
CCN-72
CCN-73
CCN-74
CCN-75
CCN-76
CCN-77
Δ18
2
3
FUS
FUS
Δ18
Δ19
4
5
Canon
6
Δ5
7
Arc. S
Pic.

PLATE 3.4

1. Lenticular cross-bedded sandstone sets at the base of the Picacho Formation. The red arrow shows a cross-bedding surface located in a 3 m thick set. At in the upper part (left side of the picture). There are some fine grained layers partially covered by coluvial deposits. Outcrop located between Δ9 to Δ14 stations. Curva de Cosgua Sur (CCS) section.

2. Geomorphological contrast between the Picacho (right) and the Concentración Formations. Note the thinning upward tendency in the sandstone layers of the Picacho Formation. The picture was taken near to the Peña Blanca rail station.

3. Amalgamated sandstone layers (right), which passes to sandstone-shale intercalations. Outcrop located between the Δ15-Δ16 stations of the Curva de Cosgua Sur (CCS) section.

4. Lenticular sandstone layers with thinning upward pattern. Outcrop located at the upper part of the Picacho Formation (Curva de Cosgua Norte section).

5. Large scale cross-lamination in a quartz-sandstone layer. Lower part of the Picacho Formation. Peña Blanca sector (Tasco-Corrales road).

6. Outcrop of the Picacho Formation with interference current-ripples which indicates fluctuating current direction under lower flow regimen. Peña Blanca sector (Tasco-Corrales road).

PLATE 3.4

PLATE 3.5.

1. Organic mudstones with thin sandstone interbeds. Guaduas Formation; Peña Blanca (PB) section. See figure 3.3.A for location in the stratigraphic log.

2. Amalgamated sandstone layers of the lower part of the Areniscas de Socha Formation (Peña Blanca section). Notice the lenticular shape of a sandstone bed (center of the picture).

3. Geometry of sandstone layers of the upper part of the Picacho Formation. Peña Blanca sector.

4-5. Geomorphology of the Picacho (P) and Concentración (C) Formations at the Peña Blanca sector.

PLATE 3.5

APPENDIXES

APPENDIX 1.1. DESCRIPTION OF SOME POLLEN AND SPORE SPECIES AND PLATES

The pollen and spores are presented in morphologic groups based in class level subdivision of Iversen and Troels-Smith (1950). Genera and species are organized in alphabetical order. An alphabetic index with all the species illustrated in the plates is presented to the end of this appendix. The informal species are put in quotation marks, and only the most important are described. Some of the specimens that occur in a single stratigraphic level are not considered here (with some exceptions in the Middle Magdalena Valley which was used as the reference section); in this case, only the name of the section, stratigraphic level and England finder coordinate (EF) are indicated (e.g. Paz de Río, CCS42, 59181, EF: K51-4); some pictures were taken with differential interference contrast (DIC). The El Cerrejón section was studied for the coal industry in order to find the most important pollen markers. In the plates 4.1 to 4.6 we illustrated most of the species founded in these deposits. Nevertheless, as the taxonomic work is in progress, most of them have informal names. The slides and holotypes described in this research are available in the Geologic Museum at Caldas University (Colombia) and at the Instituto Colombiano de Petróleo (Bucaramanga, Colombia).

Division II POLLENITES POTONIÉ, 1893

CLASS Inaperturatae IVERSEN & TROELS-SMITH 1950
CLASS Monoporatae IVERSEN & TROELS-SMITH 1950
CLASS Monocolpatae IVERSEN & TROELS-SMITH 1950
CLASS Diporatae IVERSEN & TROELS-SMITH 1950
CLASS Triporatae IVERSEN & TROELS-SMITH 1950
CLASS Stephanoporatae IVERSEN & TROELS-SMITH 1950
CLASS Tricolpatae IVERSEN & TROELS-SMITH 1950
CLASS Stephanocolpatae IVERSEN & TROELS-SMITH 1950
CLASS Tricolporatae IVERSEN & TROELS-SMITH 1950
CLASS Stephanocolporatae IVERSEN & TROELS-SMITH 1950
CLASS Pericolporatae IVERSEN & TROELS-SMITH 1950
CLASS Syncolpatae IVERSEN & TROELS-SMITH 1950
CLASS Vesiculatae IVERSEN & TROELS-SMITH 1950
CLASS Tetradeae IVERSEN & TROELS-SMITH 1950

DESCRIPTIONS

CLASS Inaperturatae **IVERSEN & TROELS-SMITH 1950**

Genus *Araucariacites* COOKSON & COUPER 1953

Araucariacites sp.
Plate 4.2, photo 1.

CLASS Monoporatae **IVERSEN & TROELS SMITH, 1950**

Genus *Aglaoreidia* ERDTMAN 1960

Aglaoreidia? *foveolata* JARAMILLO & DILCHER 2001
Plate 1.1, photos 1, 2. Plate 4.2, photos 9, 10.
Remarks: Our specimens are bigger that described by Jaramillo & Dilcher (2001). As it is restricted to the upper part of Arcillas del Limbo (Jaramillo & Dilcher, 2001) and Lisama formations seems to be a good stratigraphic marker. This species was also found in the lower part of the Arcillas de Socha Formation at the Paz del Río area.

Genus *Foveomonoporites* PARDO ET AL. 2003

Foveomonoporites variabilis PARDO ET AL. 2003

Plate 1.1, photos 3-9.

Genus *Monoporopollenites* **MEYER, 1956**

Monoporopollenites annulatus (VAN DER HAMMEN 1954) JARAMILLO AND DILCHER 2001
Plate 1.1, photos 10-12.

Monoporopollenites sp. 1
Plate 1.1, photos 13, 14.
Description: pore simple, circular, 5 µm diam., exine simple: 1.5-2 µm thick, atectate, sculpture scabrate irregularly distributed.
Dimensions:. 25 µm.
Frequency: rare
Remarks: *M. annulatus* VAN DER HAMMEN 1954 has pore costate and thinner exine.
Botanical affinities: unknown.

CLASS Monocolpatae **IVERSEN & TROELS SMITH, 1950**

Genus *Arecipites* WODEHOUSE 1933

Arecipites regio (VAN DER HAMMEN & GARCIA 1966) JARAMILLO & DILCHER 2001
Not illustrated in the plates

Genus *Baculamonocolpites* SOLE DE PORTA 1971

Baculamonocolpites sp.
Not illustrated in the plates
Paz de Rio, CCS38, 58455, V42-4

Baculamonocolpites sp. 1
Not illustrated in the plates
Riecito Maché, VENEZUELA93, 50728, K44-4

Genus *Bacumorphomonocolpites* SOLE DE PORTA 1971

Bacumorphomonocolpites tausae SOLE DE PORTA 1971
Plate 1.1, photo 15.

Genus *Clavamonocolpites* GONZALÁLEZ 1967

Clavamonocolpites microclavatus MULLER ET AL. 1987
Plate 1.1, photos 16, 17

Clavamonocolpites terrificus GONZÁLEZ 1967
Plate 1.1, photo 18.

Genus *Crusafontites* SOLE DE PORTA 1971

Crusafontites grandiosus SOLE DE PORTA, 1971
Plate 1.1, photo 19.

Crusafontites megagemmatus JARAMILLO & DILCHER 2001
Plate 1.1, photo 20.

Crusafontites “minor”
Plate 1.1, photo 21.
Specimens: IC-FA-4 (73.85) Upper La Paz Formation; slide 55939; EF : P51/2.
Type locality: Río Sogamoso, 7° 5 ' 48.38 N - 73° 23 ' 59.33 W, Colombia, lower La Paz Formation, Eocene.
Etymology: after its small size.

Description: Monad, bilateral, isopolar, amb circular, zonasulcate, atectate, exine 3 µm thick, sculpture gemmate especially distributed around the sulcus, gemmae: 4 µm long., more or less uniform, some verrucae are present, psilate between the sculpture elements, equatorial diam. 24 µm long., 20 µm width, 3 specimens observed.
Comparisons: *Crusafontites grandiosus* SOLE DE PORTA, 1971 is bigger and is verrucate; *Crusafontites megagemmatus* JARAMILLO & DILCHER 2001is bigger and has two kinds of gemmae.

Crusafontites sp. 2 (50 µm)
Not illustrated in the plates
IC-FA-4(34.2), 55974(2), H47-3.tif
Remarks: *Crusafontites grandiosus* is smaller.

Genus *Curvimonocolpites* LEIDELMEYER 1966

Curvimonocolpites inornatus LEIDELMEYER 1966
Plate 1.1, photo 22.

Genus *Echimonocolpites* VAN DER HAMMEN & GARCIA 1966

Echimonocolpites “minutus”
Plate 1.1, photos 23, 24.
Sample IC-FA-4 (34.2)55974(1), upper La Paz Formation, EF: J46.
Description: monad, bilateral, isopolar, amb eliptical, colpus long cross all the grain, costae, exine simple (< 1µm), sculpture echinate, echinae 3 µm long, conical, densely distributed in the grain, psilate between the sculptural elements. Dimensions: 15-20 µm.
Comparisons: *Echimonocolpites protofranciscoi* SARMIENTO 1992 is bigger, *Echimonocolpites coni* has collumela visible and is bigger (28-30um x 21-23), *Echimonocolpites ruedae* (VAN DER HAMMEN 1954) VAN DER HAMMEN & GARCÍA 1965 is bigger.
Remarks: relatively abundant and only found at the upper part of the La Paz Formation (Sogamoso section).

Echimonocolpites protofranciscoi SARMIENTO 1992
Plate 1.1, photos 25-27.

Genus *Echimorphomonocolpites* GONZÁLEZ 1967

Echimorphomonocolpites gracilis GONZÁLEZ 1967
Plate 1.5, photo 4.

Genus *Gemmamonocolpites* VAN DER HAMMEN & GARCIA 1966

Gemmamonocolpites amicus GONZÁLEZ 1967
Plate 1.1, photos 28, 29.

Gemmamonocolpites gemmatus (VAN DER HAMMEN 1954) VAN DER HAMMEN & GARCIA 1966
Plate 1.2, photo 1.

Gemmamonocolpites ovatus GONZÁLEZ, 1967
Plate 1.2, photo 2.

Gemmamonocolpites “digemmatus”
Plate 1.2, photo 3.
Specimen: IC-FA-3(6.12) upper La Paz Formation; slide 55771(2); EF: T33/3.
Description: Monad, bilateral, anisopolar, amb circular, ectosulcus simple, obscured by sculpturing, exine < 1µm, sculpture gemmate distributed irregulary, gemmae circular in plane view, elliptical in transversal view, 2-4 µm diameter, 3 µm high, sculpture inter gemmae clavate-gemmate < 1 µm long densely distributed. Dimensions: 27 µm long , 5 specimens observed.
Comparisons: we propose this name to replace the *Gemmamonocolpites* sp. 1 of JARAMILLO & DILCHER (2001). *Gemmamonocolpites perfectus* JARAMILLO & DILCHER 2001 is bigger and scabrate between the gemmae, *Racemonocolpites* GONZÁLEZ 1967 has densely distributed gemmae, *Gemmamonocolpites ovatus* GONZÁLEZ 1967 is psilate between the gemmae.

Gemmamonocolpites sp. 2 (20 µm)
Plate 1.2, photo 4.
Description: amb circular, monosulcate, ectosulcus obscured by sculpturing, intectate, exine 1 µm, sculpture gemmate, gemmae between 5-2 µm diam. Circular in plane and cross section, uniformly distributed on the grain,
Dimensions: 20 x 15 µm.
Frequency: rare
Remarks*: Racemonocolpites facilis* GONZÁLEZ 1967 has more densely distributed gemmae and is bigger (35-50 µm), *Gemmamonocolpites. Perfectus* JARAMILLO & DILCHER 2001 has gemmae dispersed and is bigger.

Gemmamonocolpites sp. 3
Plate 1.2, photo 5.
Specimen: IC-CC-7 (9.5), slide 55847, K50.
Description: amb elliptic, monosulcate, sculpture gemmate, gemmae 1 µm diam. irregularly distributed on the grain.
Dimensions: 27 x 12 µm long
Frequency: rare
Remarks: *Gemmamonocolpites gemmatus* (VAN DER HAMMEN 1954) VAN DER HAMMEN & GARCIA 1966 has the gemmae more densely distributed.

Genus *Gemmazonocolpites* JAN DU CHÊNE 1977

Gemmazonocolpites sp. 1
Plate 1.2, photo 6.
Description: amb elliptic, monosulcate, colpus long cross all the grain, sculpture gemmate and psilate, the gemmae are located along the colpus.
Dimensions: 35 x 27 µm.
Frequency: rare, occurs only at the upper part of the La Paz Fm.
Remarks: *Gemmazonocolpites cingulatus* JAN DU CHÊNE 1977 is bigger

Genus *Longapertites* VAN HOEKEN KLINKENBERG 1964

Longapertites proxapertitoides var. *proxapertitoides* VAN DER HAMMEN & GARCIA 1966
Plate 1.2, photos 7, 8.
Dimensions: 62 x 37 µm.
Frequency: rare.
Remarks: our specimen has a more accentuated variation in the size of the reticule than the specimen illustrated by Van der Hammen and García (1966).

Longapertites (smooth reticle)
Plate 1.2, photo 9, 10.
Description: in this category are included longaperturate grains with thin reticule (lumina < 1 µm). Not formally defined.
Frequency: rare, only found at the upper part of the La Paz Formation.

Longapertites proxapertitoides var. *reticuloides* VAN DER HAMMEN & GARCIA 1966
Plate 1.2, photo 11.

Longapertites vaneendenburgi GERMERAAD ET AL. 1968
Plate 2.2, photo 10; plate 4.3, photo 4.

Longapertites sp. 3
Plate 1.2, photos 12, 13.
Description: amb eliptic, monosulcate, sulcus simple, semitectate, exine 5 µm, nexine < 1 µm, columella 2.5 µm, tectum 1.5 µm, sculpture reticulate, lumina 10-5 µm wide, polygonal, vertices angular to rounded, muri 1-1.5 µm, simplicolumellate
Dimensions: 70 x 50 µm.
Frequency: rare only one specimen at the upper part of the La Paz Formation.

Longapertites (psilate).
Plate 1.2, photos 14., 15.

Description : amb eliptic, monosulcate, sulcus costate, 1.5-2 µm wide; atectate, exine < 1 µm; sculpture psilate;
Dimensions: 40 x 28 µm.
Frequency: rare.
Remarks: *Curvimonocolpites inornatus* LEIDELMEYER 1966 has a convex side and a sulcus simple.

Longapertites ? sp. (gemmate)
Plate 1.2, photo 16.
Description: amb elliptic circular, longaperturate ? (or inaperturate ?); atectate, exine: 1 µm simple, sometimes folded; sculpture gemmate, gemmae 2-3 µm long, distributed irregularly over the entire surface, psilate between the sculpture elements.
Dimensions: 45 x 35 µm.
Frequency: rare, occurs at the upper part of the La Paz Fm.
Remarks:*Gemmamonocolpites perfectus* JARAMILLO & DILCHER 2001 is clearly monosulcate and scabrate between the gemmae.

Genus *Luminidites* POCKNALL & MILDENHALL 1984

Luminidites colombianensis JARAMILLO & DILCHER 2001
Plate 1.2, photo 17.
Remarks: rare, only found at the upper part of the La Paz Fm.

Genus *Mauritiidites* VAN HOEKEN-KLINKENBERG 1964

Mauritiidites franciscoi var. *franciscoi* (VAN DER HAMMEN 1956a) VAN HOEKEN KLINKENBERG 1964
Plate 1.2, photos 18, 19; plate 1.3, photo 1; plate 4.2, photo 11.

Mauritiidites franciscoi var. *minutus* VAN DER HAMMEN & GARCIA 1966
Plate 1.3, photo 2.

Mauritiidites franciscoi var. *pachyexinatus* VAN DER HAMMEN & GARCIA 1966
Plate 1.3, photos 3, 4; plate 4.2, photo 12.

Genus *Monocolpopollenites* PFLUG & THOMSON in THOMSON & PFLUG 1953, emend. NICHOLS et al. 1973

Monocolpopollenites ovatus JARAMILLO & DILCHER 2001
Plate 1.3 , photo 5.
Remarks: not differentiated at the Riecito Maché and the El Cerrejón sections.

Genus *Proxapertites* VAN DER HAMMEN 1956a, emend. SINGH 1975

Proxapertites cursus VAN HOEKEN KLINKENBERG 1966
Plate 1.3, photos 6, 7; plate 4.2, photo 18-20.

Proxapertites humbertoides (VAN DER HAMMEN 1954) SARMIENTO 1992
Plate 1.3, photo 8.

Proxapertites magnus MULLER et al. 1987
Plate 1.3, photo 9; plate 4.2, photo 21.

Proxapertites operculatus (VAN DER HAMMEN 1956a) GERMERAAD et al. 1968
Plate 1.3, photos 10, 11.

Proxapertites psilatus SARMIENTO 1992
Plate 1.3, photos 12.

Proxapertites cf. *verrucatus* SARMIENTO 1992
Plate 1.4, photo 1; plate 2.1, photos 8, 9

Proxapertites (triangulate)

Plate 1.3, photo 13.
Remarks: in this informal category we included some zonasulcate specimens with amb triangular and a perforate ornamentation similar to *Proxapertites operculatus*. Dimensions: 30 x 25 µm.
Frequency: rare.

Genus *Psilamonocolpites* VAN DER HAMMEN & GARCIA 1966

Psilamonocolpites grandis (VAN DER HAMMEN 1954) VAN DER HAMMEN & GARCIA 1966
Plate 1.4, photo 2.

Psilamonocolpites “marginatus”
Plate 1.4, photo 9; plate 4.2, photo 13.
Description: monad, bilateral, anisopolar, amb elliptic; monosulcate, sulcus bordered by a margo of 7 µm thick that thinning to the borders; atectate, nexine 2 µm thick; sculpture psilate-micropitted. Dimensions: 52 x 40 µm, 2 specimens observed.

Psilamonocolpites medius (VAN DER HAMMEN 1954) VAN DER HAMMEN & GARCIA 1966
Plate 1.4, photo 2.

Psilamonocolpites minutus VAN DER HAMMEN 1954
Plate 1.4, photos 4, 5.

Psilamonocolpites operculatus PARDO ET AL. 2003
Plate 1.4, photos 6-8.

Genus *Racemonocolpites* GONZÁLEZ 1967

Racemonocolpites facilis GONZÁLEZ 1967
Plate 1.4, photo 10.

Racemonocolpites microgemmatus MULLER ET AL. 1987
Plate 1.4, photo 11.

Racemonocolpites racematus (VAN DER HAMMEN 1954) GONZÁLEZ 1967
Plate 1.4, photos 12, 13.

Genus *Retimonocolpites* PIERCE, 1961

Retimonocolpites longicolpatus LORENTE 1986
Plate 1.4, photo 14.

Retimonocolpites retifossulatus LORENTE 1986
Plate 1.4, photos 15, 16.

Retimonocolpites tertiarius GONZALEZ 1967
Plate 1.4, photos 17, 18.

Genus *Rugumonocolpites* n. gen.

Type species: *Rugumonocolpites Pacificus* n. sp.
Diagnosis: Monosulcate pollen grains, trapezoidal-eliptical, long sulcus, tectate, moderately thick, and sculpture rugulate verrugate uniformly distributed.
Etymology: after sculpturing of the exine.

Rugumonocolpites pacificus n sp.
Plate 1.4, photos 19.
Specimens: holotype IC-CC-12 (37.75), slide 55803(2), EF: J59/2.
Type locality: Río Sogamoso, 7° 5 ' 48.38 N - 73° 23 ' 59.33 W, Colombia, upper La Paz Formation, Eocene.
Etimology: after La Paz Formation

Diagnosis: Monad, bilateral, anisopolar, amb eliptical-trapezoidal; monosulcate, sulcus simple, long, wider to the borders; atectate (?), collumellae indistinct; sculpture rugulate, sometimes verrugate, uniformly distributed, lumina < 1µm, muri ± 2 µm, verrucae 1-2 µm wide, 0.5 high. Dimensions: 40 x 30 µm, 11 specimens observed.

Genus *Spinizonocolpites* MULLER 1968

Spinizonocolpites baculatus MULLER 1968
Plate 1.4, photo 20.

Spinizonocolpites cf. *S. baculatus* MULLER 1968
Plate 1.4, photo 21.

Spinizonocolpites (forma 2) "brevibaculatus"
Plate 1.4, photo 22.
Remarks: *Spinizonocolpites baculatus* has longer baculae.

Spinizonocolpites baculatus sp. (form 3)
Plate 1.4, photo 23.
Remarks: In this specimen the bacula are thinner to the base.

Spinizonocolpites breviechinatus JARAMILLO & DILCHER, 2001
Plate 1.5, photo 1.

Spinizonocolpites echinatus MULLER 1968
Plate 1.5, photo 2.

Spinizonocolpites cf. *echinatus* MULLER 1968 (psilate)
Plate 1.5, photo 3.

Spinizonocolpites sutae SARMIENTO 1994
Plate 2.1, photo 3.

CLASS *Diporatae* **IVERSEN & TROELS SMITH, 1950**

Genus *Diporoconia* Frederiksen et al. 1985

Diporoconia cf. Diporoconia iszkaszentgyoergyi (KEDVES 1965) FREDERIKSEN ET AL. 1985
Plate 1.5, photos 5-7; plate 4.5, photos 22, 23..

Genus *Retidiporites* VARMA & RAWAT 1963

Retidiporites "cosguensis"
Plate 2.2, photos 1-4.
Specimens: holotype CCN 81, slide 58644, EF: R43/2-4.
Type locality: Paz de Río, Colombia, Arcillas de Socha Formation.
Etimology: after "La Curva de Cosgua" the section where it was found.
Diagnosis: Monad, bilateral, anisopolar, amb elliptical or circular; diporate, pores simple, offset toward one face, 10 µm. wide; tectate, exine 1 µm. thick; sculpture reticulate, lumina 1 µm. wide, circular to polygonal, some elements are jointed forming an elliptic pattern, muri ≤ 1 µm distributed regularly in all the surface. Dimensions: 30 x 20 µm, 97 specimens observed.
Comparisons: *Retidiporites magdalenensis* VAN DER HAMMEN & GARCIA 1966 is micro-reticulate, *Retidiporites poricostatus* has pores costate.

Retidiporites magdalenensis VAN DER HAMMEN & GARCIA 1966
Plate 1.5, photo 8.

Retidiporites botulus LEIDELMEYER 1966
Plate 2.2, photo 5; plate 4.5, photos 24-26.

Retidiporites operculatus VAN DER KAARS 1983

Plate 4.5, photo 29.

CLASS Triporatae **IVERSEN & TROELS SMITH, 1950**

Genus *Caryapollenites* POTONIÉ 1960 ex. RAATZ 1937

Carya type pollen
Plate 4.5, photos 30, 31 ; plate 4.6, photo 13.

Genus *Corsinipollenites* NAKOMAN 1965

Corsinipollenites psilatus JARAMILLO & DILCHER 2001
Plate 1.5, photo 9, 10.

Genus *Cricotriporites* LEIDELMEYER 1966

Cricotriporites guianensis LEIDELMEYER 1966
Plate 1.5, photo 11; plate 2.2, photo 6.

Cricotriporites macroporus JARAMILLO & DILCHER 2001
Plate 1.5, photo 12.

Genus *Duplotriporites* SARMIENTO 1992

Duplotriporites ariani SARMIENTO 1992
Plate 1.5, photo 13.

Genus *Echitriporites* VAN DER HAMMEN 1956b ex VAN HOEKEN KLINKENBERG 1964

Echitriporites "annulatus"
Plate 1.5, photo 14.
Type locality: Río Sogamoso, 7° 5 ' 48.38 N - 73° 23 ' 59.33 W, Colombia, upper La Paz Formation, Eocene.
Samples: IC-CC-7 (11.6), 55846 (1), EF: F34/2-4.
Diagnosis: monad, radial, isopolar, amb circular; triporate, pores costate, circular, 3.5 µm diameter, costae 3 µm, slightly protruding; intectate, exine thin < 0.5 µm, collumela indistinct; sculpure echinate, echinae 1.5-2 µm high, 1-2 µm wide, 2-8 µm apart, sparsely distributed, psilate between the sculptural elements. Dimensions: 41x 38, 4 specimens observed.
Comparisons: *Echitriporites trianguliformis* var. *orbicularis* (MULLER ET AL. 1987) JARAMILLO & DILCHER 2001 is smaller in size and the spines are densely distributed and smaller; *Echitriporites variabilis* JARAMILLO & DILCHER 2001 has triangular shape, echinae bigger and more densely distributed; *Echitriporites* sp. 1 JARAMILLO & DILCHER 2001 has smaller spines; *Echitriporites* sp. 2 is reticulate between the spines, *Echitriporites* sp. 3 has thicker exine and bigger spines, *Echitriporites nuriae* DUEÑAS 1980 has bigger echinae (> 6 µm) and is reticulate between the echinae.

Echitriporites trianguliformis VAN HOEKEN KLINKENBERG 1964
Plate 1.5, photos 15, 16; plate 4.6, photos 2, 3.

Genus *Foveotriporites* GONZÁLEZ 1967

Foveotriporites hammenii GONZÁLEZ 1967
Plate 1.5, photo 17.

Foveotriporites sp. 1
Plate 1.5, photos 18.
Description: monad, radial, isopolar, amb circular; triporate, pores 1 µm wide, ecto and endopores costate, ectopore 3 µm wide, 2.5 µm thick, endopore 2 µm thick; exine 1 µ thick thickening to the pores, collumela distinct, 0.5 µm thick; sculpture micro-foveolate, foveolae rounded, lumina 0.5 µm wide, 1 µm apart, uniformly distributed. Dimensions: equatorial diameter 33-34 µm, 2 specimens observed.
Comparisons: *Foveotriporites* sp. 1 JARAMILLO & DILCHER 2001 is bigger (50 µm), its pores are wider and it has only the endopores costate.

Genus *Intratriporopollenites* PFLUG & THOMSON in THOMSON & PFLUG 1953

Intratriporopollenites sp.
Plate 1.10, photos 14-16.

Genus *Momipites* WODEHOUSE 1933

Momipites sp.
Plate 4.6, photos 8-12.

Genus *Proteacidites* (COOKSON 1950) ex COUPER 1953

Proteacidites dehaani GERMERAAD ET Al. 1968
Plate 1.5, photo 19.

Proteacidites triangulatus LORENTE 1986
Plate 1.5, photo 20.

Genus *Psilatriporites* (VAN DER HAMMEN) MATHUR ex HOORN 1993

Psilatriporites annulatus nov. comb.
Basionym: *Triporites annulatus* VAN DER HAMMEN 1954
Plate 1.6, photo 11.
Description: amb circular, triporate, psilate, pore costate, protruding. Dimensions: 27 µm, 2 specimens observed.

Psilatriporites sp. 1.
Plate 1.6, photos 8, 9.
Description: monad, radial, isopolar, amb triangular-obtuse-convex; triporate, pores simple, circular, 4 µm diameter; atectate, exine < 0.5 µm; sculpture psilate. Dimensions: ecuatorial diameter 35 µm, nm. 1. One specimen observed.
Comparisons: *Momipites africanus* VAN HOEKEN-KLINKENBERG 1966 has atrium

Genus *Retitriporites* RAMANUJAM 1966

Retitriporites cf. *federicii* GONZÁLEZ 1967
Plate 1.5, photo 21.
Description: Monad, radial, isopolar, amb elliptical, triporate, pores elongated, 7 µm long, 2,5 µm wide, annulate, annuli 3 µm thick; tectate, exine 1 µm, columella visible < 0,5 µm thick; sculpture reticulate, polygonal to rounded, lumina 1-3 µm, muri 1 µm. Dimensions: 40 x 25 µm. One specimen observed.
Comparisons: *Retitriporites federicii* GONZALEZ 1967 has thicker exine (2-3 µm) and thicker annuli.

Retitriporites aff. *poricostatus* JARAMILLO & DILCHER 2001
Plate 1.6, photos 1, 2.
Description: Monad, radial, isopolar, amb circular, triporate, pores 4 µm wide, costate, 5 µm thick, protruding; tectate (?), exine < 0,5 µm; sculpture reticulate, lumina ≤ 1 µm, muri 0,5 µm. Dimensions: 26 µm. One specimen observed.
Comparisons: *Retitriporites poricostatus* JARAMILLO & DILCHER 2001 has triangular shape and a bigger lumina (1.5- 2 µm).

Retitriporites simplex VAN DER KAARS 1983
Plate 4.6, photo 7.

Retitriporites sp. 3 (60 µm).
Plate 1.6, photos 3-5.
Sample: IC-CC-7 (11.6), 55846(1), EF: F34/2-4.
Description: monad, radial, isopolar, amb circular; triporate, pores costate, 5 µm diameter, costae 5 µm wide, 4 µm thick, protruding; tectate, exine 2 µm thick, nexine < 0.5 µm, columella 0.5 µm, tectum 1 µm, simplicolumellate; sculpture reticulate, lumina 1-3 µm, polygonal, rounded, muri 1-1.5 µm wide. Dimensions: polar view 60 µm x 53 µm. One specimen observed.

Genus *Striatriporites* VAN HOEKEN-KLINKENBERG 1966

Striatriporites sp. 1
Plate 1.6, photo 6.
Description: monad, radial, isopolar, amb circular; triporate, pores 7 µm diameter, sharp borders, annulate, annulus 2 µm; atectate, endexine 0.5 µm thick, endexine folded connecting pores; sculpture striate, striae very fine, < 0.5 µm wide, muri < 0.5 µm. Dimensions: equatorial diameter 32-34 µm, 2 specimens observed.

Genus *Triatriopollenites* PFLUG IN THOMSON & PFLUG 1953

Triatriopollenites sp.
Plate 3.1, photo 3; plate 4.6, photos 14-20.

Triatriopollenites sp. 1
Plate 1.6, photo 7.

CLASS Stephanoporatae **IVERSEN & TROELS SMITH, 1950**

Genus *Echiperiporites* VAN DER HAMMEN & WYMSTRA 1964

Echiperiporites sp.
Plate 1.6, photos 12, 13.
Description: monad, radial, isopolar, amb circular-elliptical; stephanoporate, pores < 1 µm wide, 6 pores disposed around the equator, in some cases they are indistinct, endopore costate; intectate (?), exine 1-1.5 µm thichening to the pores (2 µm), the exine frequently is folded; sculpture echinate, spines < 0.5 µm long, < 0.2 µ wide, densely et uniformly distributed over all the grain, some specimens have also gemmae or verrucae. Dimensions:
Comparisons: *Malvacipollis spinulosa* FREDERIKSEN 1983 is similar but is bigger in size (27-37 µm) and in the size of its spines (0.7-1 µm diam, 1.2-1.5 long) and pores (1.5-2.3 µm in diameter).

Genus *Malvacipollis* HARRIS 1965

Malvacipollis sp.
Plate 4.6, photos 31-35.

Genus *Psilastephanoporites* REGALI ET. AL. ex HOORN 1993

Psilastephanoporites "oculiporus"
Plate 1.6, photos 14, 15.
Sample: UR 62; slide 57083; Lisama Formation; EF: L 44.
Description: monad, radial, isopolar, amb hexagonal, bridge-like thickening zones connecting the pores.
Comparisons: *Alnipollenites* has pores with vestubilum, *Ulmoideipites. krempii* has verrucate ornamentation.

Genus *Retistephanoporites* GONZÁLEZ 1967

Retistephanoporites minutiporus JARAMILLO & DILCHER 2001
Plate 1.6, photos 16, 17.

Retistephanoporites sp. 1
Plate 1.6, photos 18.

Retistephanoporites sp. 2
Plate 1.6, photos 19.

Genus *Ulmoideipites* ANDERSON 1960

Ulmoideipites krempii (ANDERSON 1960) ELSIK 1968b
Plate 1.6, photos 20, 21; plate 4.6, photos 29, 30.

CLASS Tricolpatae **IVERSEN & TROELS SMITH, 1950**

Genus *Albertipollenites* SRIVASTAVA 1969

*Albertipollenite*s? *perforatus* (GONZÁLEZ 1967) JARAMILLO & DILCHER 2001
Plate 1.6, photos 22, 23.

Genus *Brevitricolpites* GONZÁLEZ 1967

Brevitricolpites “densiechinatus”
Plate 1.6, photos 24, 25.
Description: Monad, radial, isopolar, amb elliptic; tricolporate, colpi short 3 µm long, pores costate, slightly protruding; tectate, endexine 1,5 µm, ectexine 1 µm, thickening to 3 µm around the pores; sculpture echinate, echinae 1,5-2 µm long, distributed uniformly in all the surface. Dimensions: 37 x 35 µm, 54 specimens observed.
Comparisons: *Brevitricolpites microechinatus* JARAMILLO & DILCHER 2001 has the echinae sparsely distributed.

Brevitricolpites microechinatus JARAMILLO & DILCHER 2001
Plate 1.7, photo 1.

Brevitricolpites aff. *microechinatus* JARAMILLO & DILCHER 2001
Plate 1.7, photo 2, 3.

Brevitricolpites sp. 1 (gemmate)
Plate 1.7, photo 4.
Description: amb circular; tricolporate, colpi short, slightly costate, 5 µm long; atectate, collumela not visible; sculpture gemmate, gemmae 0.5 µm diameter, densely distributed, rooted in the exine. Dimensions: equatorial diameter 30 µm, 1specimen observed.

Brevitricolpites sp. 2 (baculate)
Plate 1.7, photo 5.
Description: amb triangular-obtuse-convex; tricolporate, pore 2 µm wide, costate, costae 10 µm, 3 µm thick, slightly protruding, ectocolpi very short, simple, ends rounded; sculpture baculate, baculae < 1 µm long, 2-4 µm apart, distributed uniformly, surface interbaculae micropitted. Dimensions: equatorial diameter 35 µm, 3 specimens observed.

Brevitricolpites sp. 3 (triangular, echinate)
Plate 1.7, photo 6.

Brevitricolpites sp. 5 (spines < 1 µm long)
Plate 1.7, photos 7, 8.

Brevitricolpites sp. (psilate, micropitted-foveolate)
Plate 4.3, photos 26-29.

Genus *Clavatricolpites* PIERCE 1961

Clavatricolpites densiclavatus JARAMILLO & DILCHER 2001
Plate 1.7, photos 9, 10.

Clavatricolpites sp. 1
Plate 1.7, photos 11, 12.
Remarks: sculpture clavate and gemmate

Genus *Foveotricolpites* PIERCE 1961

Foveotricolpites perforatus VAN DER HAMMEN & GARCIA 1966
Plate 1.7, photos 13.

Foveotricolpites sp.
Plate 1.8, photo 10.

Foveotricolpites sp. (fossulate)
Plate 1.8, photo 11.
Femarks : foveolate-fossulate sculpture.

Genus *Ladakhipollenites* MATHUR & JAIN 1980

Ladakhipollenites minutus nov comb.
Basionym *Psilatricolpites minutus* GONZÁLEZ 1967
Plate 1.7, photos 14, 15.

Ladakhipollenites simplex (GONZÁLEZ 1967) JARAMILLO & DILCHER 2001
Plate 1.7, photo 16.

Genus *Perfotricolpites* GONZÁLEZ 1967

Perfotricolpites cf. *digitatus* GONZÁLEZ 1967
Plate 1.7, photos 17-19.
Remarks: These specimens are smaller than those described by González (1967).

Genus *Poloretitricolpites* JARAMILLO & DILCHER 2001

Poloretitricolpites absolutus (GONZÁLEZ 1967) JARAMILLO & DILCHER 2001
Plate 3.1, photos 8, 9.

Genus *Psilabrevitricolpites* VAN HOEKEN KLINKENBERG 1966

Psilabrevitricolpites sp.
Plate 1.7, photo 20.

Genus *Psilatricolpites* (VAN DER HAMMEN) PIERCE 1961

Psilatricolpites papilioniformis REGALI ET AL. 1974
Not illustrated in the plates.
UR743+50, 57859, S33-3.

Psilatricolpites sp.
Plate 4.3, photo 14.

Genus *Retibrevitricolpites* VAN HOEKEN KLINKENBERG 1966

Retibrevitricolpites triangulatus VAN HOEKEN KLINKENBERG 1966
Plate 1.7, photo 21; plate 3.1, photos 10, 11.

Retibrevitricolpites sp. 1 (sp. 2 of Jaramillo and Dilcher, 2001).
Not illustrated in the plates.
IC-CC-7(11.6), 55846(2), J49-3.

Genus *Retitrescolpites* SAH 1967

Retitrescolpites cf. *baculatus* JARAMILLO & DILCHER 2001
Plate 1.7, photo 22.

*Retitrescolpite*s? cf. *irregularis* (VAN DER HAMMEN & WYMSTRA 1964) JARAMILLO & DILCHER 2001
Plate 1.7, photo 23.

Retitrescolpites “machensis”

Plate 3.1, photo 6, 7.
Etimology: after Riecito Maché section.
Diagnosis: Monad, radial, isopolar, amb elliptic, tricolporate, ectocolpi simple 20 µm long; semitectate exine 5 µm, nexine 1 µm, columella 1,5-2 µm, tectum 1 µm; sculpture reticulate, lumina 2-4 µm polygonal irregular, usually elongated, muri 1 µm. Dimensions: 50-65 µm equatorial diameter, 6 specimens observed (slides not studied in detail).
Comparisons: *Retitrescolpites baculatus* JARAMILLO & DILCHER 2001 has a ticker exine and the collumellae usually are not connected by the tectum.

Retitrescolpites magnus (GONZÁLEZ 1967) JARAMILLO & DILCHER 2001
Plate 1.7, photos 24, 25.

Retitrescolpites saturum (GONZÁLEZ 1967) JARAMILLO & DILCHER 2001
Not illustrated in the plates.
IC-FA-4 (101.38), 55926(2), F50-1.

Genus *Retitricolpites* (VAN DER HAMMEN) PIERCE 1961.

Retitricolpites cf. *simplex* GONZÁLEZ 1967
Plate 1.8, photos 3, 4.
Remarks: These specimens are smaller than those described by González (1967).

Retitricolpites cf *R. retiaphelis* LEIDELMEYER 1966
Plate 1.8, photo 7.

Genus *Rousea* SRIVASTAVA 1969

Rousea florentina (GONZÁLEZ 1967) JARAMILLO & DILCHER 2001
Plate 1.7, photo 26.

Genus *Rugutricolpites* SARMIENTO 1992

Rugutricolpites sp. 1
Plate 1.7, photo 27.

Genus *Scabratricolpites* (VAN DER HAMMEN) GONZALEZ 1967

Scabratricolpites sp. 1
Plate 1.8, photo 8.

Genus *Tricolpites* COOKSON EX COUPER 1953, emend. JARZEN & DETTMANN 1989

Tricolpites clarensis (GONZÁLEZ 1967) JARAMILLO & DILCHER 2001
Plate 1.7, photo 28.

Tricolpites conciliatus (GONZÁLEZ 1967) n. comb.
Plate 1.7, photo 29, 30.

Tricolpites cf. *minutus* (GONZÁLEZ 1967) n. comb.
Plate 1.8, photo 1.

Tricolpites protoclarensis JARAMILLO & DILCHER 2001
Plate 1.8, photo 2.

Tricolpites "simetricus"
Plate 1.8, photo 5, 6.
Description: monad, radial, isopolar, tricolpate, colpi simple, 30 µm long, 10 µm wide; tectate, nexine < 1 µm, columellae 0,5 µm, tectum 0,5 µm thinner to the colpi; sculpture reticulate, lumina < 1 µm rounded, muri 1 µm. Dimensions: equatorial diameter 30-45 µm, 31 specimens observed.

Tricolpites sp. 2
Plate 1.8, photo 9; plate 4.5, photos 19, 20.
Characteristics: pollen grains with a reticle that gradually diminished in size to the polar regions.

Genus *Verrutricolpites* PIERCE 1961

Verrutricolpites sp. 1
Plate 1.8, photo 12.

CLASS Stephanocolpatae **IVERSEN ET TROELS SMITH, 1950**

Genus *Ctenolophonidites* VAN HOEKEN-KLINKENBERG 1966

Ctenolophonidites lisamae (VAN DER HAMMEN & GARCIA 1965) GERMERAAD ET AL. 1968
Plate 3.1, photos 21, 22; plate 4.3, photos 15, 16.

Genus *Gemmastephanocolpites* VAN DER HAMMEN & GARCIA 1965

Gemmastephanocolpites gemmatus VAN DER HAMMEN & GARCIA 1965
Plate 4.3, photos 17-19. Plate 3.1, photos 19, 20.
Remarks: these specimens are identical to those illustrated by Van der Hammen & García 1965 but some authors (e.g. Van der Kaars, 1983) probably included them in the *Gemmastephanocolpites asteroformis* LEIDELMEYER 1966 species.

Genus *Psilastephanocolpites* LEIDELMEYER 1966

Psilastephanocolpites globulus VAN DER KAARS 1983
Plate 3.1, photo 23; plate 4.3, photos 20-22.

Psilastephanocolpites sp.
Plate 4.3, photo 23.

Genus *Retistephanocolpites* LEIDELMEYER 1966

Retistephanocolpites angeli LEIDELMEYER 1966
Not illustrated in the plates
Picacho 2, 59177, H45-4.

Retistephanocolpites sp. (foveolate)
Plate 1.8, photos 13, 14.

Retistephanocolpites sp. 1 (microreticulate, 7 colp.).
Plate 1.8, photo 15, 16.

Genus *Stephanocolpites* (VAN DER HAMMEN 1954) ex. POTONIÉ 1960

Stephanocolpites costatus VAN DER HAMMEN 1954
Plate 2.1, photo 16.

Stephanocolpites “scabratus“
Plate 4.3, photo 24.

CLASS Tricolporatae **IVERSEN ET TROELS SMITH, 1950**

Genus *Araliaceoipollenites* (POTONIÉ 1951) ex POTONIÉ 1960

Araliaceoipollenites? sp. 1
Plate 1.8, photo 17.
Remarks: Very similar to *Araliaceoipollenites*? sp. 1 Jaramillo & Dilcher (2001)

Araliaceoipollenites? sp. 2
Plate 1.8, photo 18.

Genus *Bombacacidites* COUPER 1960, emend. KRUTZSCH 1970

Bombacacidites annae (VAN DER HAMMEN 1954) GERMERAAD ET AL. 1968
Plate 1.8, photo 19.

Bombacacidites (homogenous reticulum) cf. *Bombacacidites baumfalki* LORENTE 1986
Plate 1.8, photo 20.
Some forms included in the category *Bombacacidites* (homogemous reticulum) have the colpi marginate, and thus they are similar to *B. baumfalki* LORENTE 1986 species.

Bombacacidites (homogenous reticulum)
Plate 1.8, photo 21.

Bombacacidites aff. *gonzalezii* JARAMILLO & DILCHER 2001
Plate 1.8, photos 22, 23.

Bombacacidites "fossulatus"
Plate 1.9, photos 8, 9.
Description: Monad, radial, isopolar, amb triangular-obtuse-convex, tricolporate, colpi 7 µm long, costate 4 µm thick, protruding; tectate, exine 2 µm, columella visible < 0.5 µm thickening to the colpi (1,5 µm); sculpture fossulate-reticulate at apocolpia (fossulae 3-4 µm long) changing abruptly to micropitted and psilate to mesocolpia. Dimensions: equatorial diameter 37 µm, 2 specimens observed.

Bombacacidites" lisamae"
Plate 1.8, photos 24-26.
Description: monad, radial, isopolar, amb circular, tricolporate, colpi 6 µm long, costate 2.5 µm wide, slightly protruding; semitectate, exine 1 µm tickening to the colpi (2 µm), columella distinct (< 1 µm); sculpture foveolate-micropitted, 0,7 µm wide at apocolpia diminishing to < 0,5 µm at mesocolpia. Dimensions: 35-40 µm equatorial diameter, 27 specimens observed.
Comparisons: *Bombacacidites annae* is reticulate at apocolpia.

Bombacacidites "magnificum"
Plate 1.11, photo 1.
Remarks: only one specimen observed

Bombacacidites cf. *nacimientoensis* (ANDERSON 1960) ELSIK 1968b
Plate 1.9, photos 1, 2.

Bombacacidites "pseudosimplireticulatus"
Plate 1.9, photo 5.
Description: Monad, radial, isopolar, amb triangular-obtuse-straight, tricolporate, ectocolpi costate, colpi ± 7 µm, protruding, costae 3 µm wide, endopores indistinct; semitectate, exine 3 µm thick, nexine < 0,5 µm, columella 1,5 µm, tectum 0,5-1 µm, reduced to mesocolpia; sculpture reticulate, lumina < 2 µm, muri < 1,5 µm at apocolpia, decreasing in size towards the mesocolpia and changing to foveolate, lumina < 0,5 µ, muri < 0,5 µ. Dimensions: 60 µm, 3 specimens observed.
Comparisons: *Bombacacidites simplireticulatus* JARAMILLO & DILCHER 2001 is similar, but it has wider lumina and the sculpture changes more abruptly at the mesocolpia.

Bombacacidites psilatus JARAMILLO & DILCHER 2001
Plate 1.9, photos 6, 7.

Bombacacidites cf. *soleaformis* MULLER et al. 1987
Plate 1.9, photo 10.

Bombacacidites sp. 1
Plate 1.9, photo 11.

Description: Monad, radial, isopolar; amb triangular obtuse convex to circular; tricolporate, ectocolpi costate, colpi 1.2 µm wide, tectate, exine < 1 µm, columella visible < 0.5 µm diminishing in thickness to the mesocolpia; sculpture reticulate, lumina < 1 µm, rounded in apocolpia and pass gradually to micropitted at mesocolpia, muri < 1 µm. Dimensions: equatorial diameter 26 µm, 1 specimen observed.

Bombacacidites sp. 2
Plate 1.9, photo 12.
Description: monad, radial, isopolar; amb circular, tricolporate, ectocolpi costate 2.5 µm continuous around the colpi, slightly protruding ; tectate ?, exine < 1 µm, columelle indistinct; sculpture reticulate, lumina max. 5 µmm, rounded to poligonal, muri 1.5 µm, the reticulate sculpture pass gradually to foveolate at mesocolpia, < 1 µm lumina. Dimensions: equatorial diameter 57 µm, 1 specimen observed.

Bombacacidites sp. 3
Plate 1.9, photo 13.
Sample: IC-FA-3 (6.12) Upper La Paz Formation; slide 55771(1); EF: D48/2.
Description: Monad, radial, isopolar; amb triangular-obtuse-convex to elliptic, tricolporate, colpi short 2 µm long., costate 3.5 µm wide, slightly protruding ; tectate ?, exine < 1 µm; sculpture reticulate polygonal, lumina 2,5 µm (max.) at apocolpia diminishing gradually at mesocolpia (1 µm). Dimensions: 39x35 µm, one specimen observed.

Bombacacidites sp. 4 (cf. sp. 2 de JARAMILLO & DILCHER 20001)
Not illustred in the plates.

Bombacacidites sp. 5
Plate 1.9, photo 14.
Description: Monad, radial, isopolar; amb triangular-obtuse-straigth; tricolporate, colpi 5 µm, costate 3 µm wide, slightly protruding ; semitectate ? exine < 1 µm, columella not visible ; sculpture reticulate, lumina 2 µm (max.), muri <1 µm at apocolpia changing gradually to foveolated-micropitted to mesocolpia. Dimensions: equatorial diameter 30-31 µm, 2 specimens observed.

Bombacacidites sp. 6
Plate 1.9, photos 15, 16.
Remarks: similar to *Bombacacidites* sp. 5, but the former has a thinner lumina.

Bombacacidites sp. 7
Plate 1.9, photo 17.
Description: Monad, radial, isopolar; amb elliptic; tricolporate, colpi 8 µm long, costate 2 µm wide, protruding; pores distinct 5 µm wide; tectate, exine 1-1,5 µm, nexine < 0,5 µm, columella < 1 µm; sculpture reticulate-foveolate, lumina ≤ 0,5 µm uniform, muri 0,5-1 µm. Dimensions: equatorial diameter 49 x 37 µm, No. 1, Nm. 1.
Comparison: similar to *Bombacacidites* sp. 1 of Jaramillo & Dilcher 2001.

Bombacacidites sp. 8 (fossulate, vermiculate reticle)
Plate 1.9, photos 18, 19.
Description: Monad, radial, isopolar; amb triangular-obtuse-straight; tricolporate, colpi 7 µm long, costate 2 µm wide, slightly protruding; semitectate?, exine < 1 µm, columella not visible; sculpture reticulate, lumina rounded < 0.8 µm at apocolpia which gradually diminishes to the mesocolpia < 0,5 µm, muri < 1 µm, in the apocolpia the reticle and the muri are aligned forming a fossulate structure. Dimensions: equatorial diameter 45-40 µm, 5 specimens observed.

Bombacacidites sp. 9 (>60µm)
Plate 1.10, photo 1.
Description: monad, radial, isopolar; amb elliptic, tricolporate, colpi 8 µm long, simple; tectate, exine 2 µm, endexine < 0,5 µm, columella 1,5 µm, tectum < 0,5 µm; sculpture reticulate, lumina rounded or elliptical, lumina 1-1,5 µm at the apocolpia which gradually increases until 5 µm at the mesocolpia. Dimensions: equatorial diameter 65 x 54 µm, 2 specimens observed.

Bombacacidites sp. 10 (50µm) “foveolate”
Plate 1.10, photos 2, 3.
Description: monad radial, isopolar; amb elliptic, tricolporate, colpi 10 µm long (polar view), costate, 3 µm wide, thiner to the polar area; atectate, exine 1 µm thickening to 2,3 µm to the colpi; sculpture foveolate,

uniformly distributed over all the surface of the grain, lumina < 0,5 µm rounded, muri 1,5-2 µm. Dimensions: equatorial diameter 52 x 41 µm, 2 specimens observed.

Bombacacidites sp. 11 (20µm)
Plate 1.10, photo 4.
Description: Monad, radial, isopolar, amb triangular-obtuse-straight, tricolporate, colpi very short 2 µm. long, costate, 1,3 µm wide; semitectate, exine 0,7 µm. thick; sculpture reticulate at apocolpia, lumina ≤ 1 µm, muri < 0,5 µm., psilate to mesocolpia. Dimensions: equatorial diameter 20 µm, 1 specimen observed

Bombacacidites sp. 12 (lumina 5µm)
Plate 1.10, photo 5.
Description: monad, bilateral, isopolar, amb triangular, tricolporate, two symmetrical colpi of 0,7 µm long, the other colpus has 20 µm long, costae, 2,5 µm wide, thinning to the polar zones, two colpi are bordered by a fine reticle; tectate (bad preserved), exine ± 1 µm; sculpture reticulate, polygonal, muri 1,5 µm, lumina 5 µm decreasing to < 1 µm to mesocolpia only in one side. Dimensions: 73 x 65 µm, 1 specimen observed.

Bombacacidites sp.13
Plate 1.10, photos 6, 7.
Description: Monad, radial, isopolar; amb elliptical, tricolporate, short colpi, 5 µm long, costae 3 µm wide, uniform, protruding; semitectate, exine 2 µm, columella not visible; sculpture reticulate, lumina 1 µm rounded to elliptical, muri ≤ 1 µm, uniformly over all the grain. Dimensions: 30 x 34 µm, 1 specimen observed.

Bombacacidites sp.14
Plate 1.10, photos 8-10.
Description: Monad, radial, isopolar; amb circular, tricolporate, colpi 10 µm long, costate 4-5 µm ide, protruding; tectate, nexine < 0,5 µm, pluricolumellate, columella 1,5 µm thick, tectum < 1 µm, thinning to the colpi; sculpture reticulate, muri 1 µm, lumina rounded to elliptical, 2-2,5 µm at apocolpia gradually passing to < 1 µm at mesocolpia (foveolate sculpture). Dimensions: 47-65 µm equatorial diameter, 6 specimens observed.

Bombacacidites sp.15
Plate 1.10, photo 11.
Description: Monad, radial, isopolar; amb triangular-obtuse-convex, tricolporate, colpi 5 µm long; tectate, exine 1 µm, columella < 0,5 µm, tectum < 0,5 µm; sculpture foveolate, lumina 1,0-0,5 µm at apocolpia gradually passing to micropitted-psilate structure to mesocolpia. Dimensions: 24-30 µm equatorial diameter, 3 specimens observed.

Bombacacidites sp.16 (sp. 3 of Jaramillo & Dilcher, 2001)
Plate 1.10, photo 12.
Description: monad, radial, isopolar; amb rounded, tricolpate, colpi 7 µm long, costae, 2 µm, pore visible; semitectate, exine 1,5 µm, nexine < 0,5 µm, columella < 1 µm, tectum < 0,5 µm; sculpture reticulate-foveolate, foveolate at apocolpia, lumina 0,5-1 µm gradually changing to reticulate at mesocolpia, lumina 1-1,5 µm, muri 1 µm. Dimensions: equatorial diameter 43 µm, 1 specimen observed.

Bombacacidites sp.17
Plate 1.10, photo 13
Description: Monad, radial, isopolar; amb circular; tricolporate, ectocolpi costate, 11 µm long, costate 1,5-2 µm wide, slightly protruding, semitectate, exine 1-1,5 µm, nexine < 0,5 µm, columella < 1 µm,tectum < 0,5 µm; sculpture reticulate, lumina 1,5 µm wide rounded, muri 1-1,5 µm, uniformly distributed. Dimensions: equatorial diameter 45 µm, 1 specimen observed.

Genus *Clavatricolporites* LEIDELMEYER 1966

Clavatricolporites leticiae LEIDELMEYER 1966
Plate 1.11, photo 4; plate 2.2, photo 25.

Clavatricolporites sp.
Plate 4.5, photos 14-16.

Genus *Colombipollis* SARMIENTO 1992

Colombipollis tropicalis SARMIENTO 1992
Plate 1.11, photo 5; plate 2.1, photo 11.

Genus *Foveotricolporites* PIERCE 1961

Foveotricolporites cf. *F.* sp.3 JARAMILLO & DILCHER 2001
Plate 1.11, photo 6; plate 4.4, photos 1, 2.

Foveotricolporites sp.
Plate 4.3, photos 30, 31.

Genus *Gemmatricolporites* LEIDELMEYER 1966

Gemmatricolporites sp. 1
Plate 1.11, photo 9.

Gemmatricolporites sp.
Plate 4.4, photo 3.

Genus *Horniella* TRAVERSE 1955

Horniella "sogamosa"
Plate 1.11, photo 7.
Etymology: after Sogamoso River.
Diagnosis: monad, radial, isopolar, amb circular; tricolporate, ectocolpi simple, 9 µm. Long, borders straight, ends rounded, polar area 14 µm. wide, endopore costate, 6 x 4 µm.; tectate, exine 1 µm. decreasing towards the colpi; sculpture foveolate-reticulate, lumina 0,5-1,0 µ, muri < 1 µm, distributed homogeneously. Dimensions: 35 µm. ecuatorial diameter. 5 specimens observed.
Comparisons: in *Horniella* sp. 3 JARAMILLO & DILCHER 2001 the costae pores are bigger and the reticle has thinner lumina.

Horniella sp. UR806
Plate 1. 11, photo 12.

Horniella sp. 1 (pores costate)
Plate 1.11, photo 10.

Horniella sp. 2 (cf. sp. 2 of Jaramillo & Dilcher, 2001)
Plate 1.11, photo 24.

Genus *Lanagiopollis* MORLEY 1982

Lanagiopollis crassa (VAN DER HAMMEN & WYMSTRA 1964) FREDERIKSEN 1988
Plate 1.11, photo 11.

Genus *Margocolporites* RAMANUJAN 1966 ex SRIVASTAVA 1969, emend POCKNALL & MILDENHALL 1984

Margocolporites vanwijhei GERMERAAD ET AL. 1968
Plate 2.2, photo 17.

Margocolporites sp.
Plate 4.4, photo 4.

Genus *Polotricolporites* GONZALEZ 1967

Polotricolporites cf. *P. concretus* GONZALEZ 1967
Plate 3.1, photo 5.

Genus *Psilabrevitricolporites* VAN DER KAARS 1983

Psilabrevitricolporites annulatus SARMIENTO 1992
Plate 2.1, photos 6, 7.

Psilabrevitricolporites "simplex"
Plate 1.11, photos 15, 17.

Psilabrevitricolporites simpliformis VAN DER KAARS 1983
Plate 4.4, photos 8, 9.

Psilabrevitricolporites triangularis (VAN DER HAMMEN & WYMSTRA 1964) JARAMILLO & DILCHER 2001
Plate 1.11, photo 18.

Psilabrevitricolporites sp. 1
Plate 1.11, photo 14.

Psilabrevitricolporites sp. 2
Plate 1.11, photo 16.

Genus *Psilatricolporites* VAN DER HAMMEN ex PIERCE 1961

Psilatricolporites "blessi"
Etymology: in honour of Martin BLESS, geologist that studied the Manuelote Syncline (Venezuela).
Plate 4.4, photos 45-50. Plate 3.1, photos 17, 18.
Diagnosis: monad, radial, isopolar, amb circular; tricolporate, colpi 10 µm long costate 5 µm wide, ecto-colpi thinning to the pore region, pore distinct, 1 µm wide; atectate, exine 3 µm thick; sculpture psilate to micropitted.
Dimensions: equatorial diameter 17-22 µm, 6 specimens measured.
Remarks: abundant at the El Cerrejón and Riecito Maché sections.

Psilatricolporites costatus DUEÑAS 1980
Plate 1.11, photo 19.

Psilatricolporites marginatus VAN DER KAARS 1983
Plate 4.4, photos 10-14.

Psilatricolporites normalis GONZALEZ 1967
Plate 1.1, photo 20.

Psilatricolporites pachyexinatus VAN DER KAARS 1983
Plate 4.4, photo 15.

Psilatricolporites sp.
Plate 4.4, photo 16.

Psilatricolporites sp. 1
Plate 1.11, photo 22.

Genus *Retibrevitricolporites* LEGOUX 1978

Retibrevitricolporites cf. *R. grandis* JARAMILLO & DILCHER 2001
Plate 1.11, photo 23.

Genus *Retitricolporites* (VAN DER HAMMEN) VAN DER HAMMEN & WYMSTRA 1964

Retitricolporites "doradensis"
Plate 3.1, photos 12, 13.
Etymology: in honour of Jorge DORADO, geologist, professor at Caldas University (Colombia).
Diagnosis: Monad, radial, isopolar, amb triangular-obtuse-convex, tricolporate, colpi 7 µm long, simple, pores indistinct; semi-tectate (?), exine 1,5 µm; sculpture reticulate, lumina 2,5 µm, rounded to elliptic, diminishing to

< 1 µm near the colpi. Dimensions: equatorial diameter 25 µm, 6 specimens observed (slide not studied in detail).

Retitricolporites "poricostatus"
Plate 1.11, photo 25.

Retitricolporites "venezuelensis"
Plate 3.1, photos 14, 15.
Etymology: after Venezuela.
Description: Monad, radial, isopolar, amb circular, tricolporate, colpi simple, 20 µm long, pores ; semitectate, exine 3,0 µm, sculpture reticulote-fossulate, lumina 1-1,5 µm wide, fossulae 2-2,5 µm long, muri 2 µm diminishing in size to the colpi (< 1 µm wide). Dimensions: equatorial diameter 45 µm, 7 specimens observed.
Remarks: relatively abundant in some coal beds of the Misoa Formation (Riecito Maché section).

Retitricolporites cf. *R. equatorialis* GONZÁLEZ 1967
Plate 1.11, photo 26.

Retitricolporites finitus GONZÁLEZ 1967
Plate 1.11, photo 27.

Genus *Rugotricolporites* GONZÁLEZ 1967

Rugotricolporites cf. *felix* GONZÁLEZ 1967
Plate 2.2, photos 13, 14.

Genus *Scabratricolporites* ROCHE & SCULER 1976

Scabratricolporites sp. (cf. *Siltaria* sp. 4 Jaramillo & Dilcher 2001)
Plate 4.4, photos 17-20.

Scabratricolporites sp.
Plate 2.2, photo 21.

Genus *Siltaria* TRAVERSE 1955

Siltaria mariposa (LEIDELMEYER 1966) JARAMILLO & DILCHER 2001
Plate 1.11, photo 28; plate 3.1, photo 16.

Siltaria sp. 4 JARAMILLO & DILCHER 2001
Plate 1.11, photo 29.

Genus *Striatopollis* KRUTZSCH 1959b

Striatopollis catatumbus (GONZÁLEZ 1967) TAKAHASHI & JUX 1989
Plate 1.12, photos 1, 2.

Striatopollis minor (WIJMSTRA 1971) JARAMILLO & DILCHER 2001
Plate 1.12, photo 3.

Striatopollis? *tenuistriatus* JARAMILLO & DILCHER 2001
Plate 1.12, photos 4, 5.

Striatopollis sp. (small)
Plate 4.4, photos 31-33.

Genus *Striatricolporites* LEIDELMEYER 1966

Striatricolporites digitatus JARAMILLO & DILCHER 2001
Plate 1.12, photos 7, 8.

Striatricolporites cf. *pimulis* VAN HOEKEN-KLINKENBERG 1966
Plate 1.12, photo 6.

Genus *Tricolporites* COOKSON 1947

In this genus were provisionally included some morphospecies from the El Cerrejón section, which were not formally described. See plate 4.4. photos, 34-44.

Genus *Verrutricolporites* VAN DER HAMMEN & WIJMSTRA 1964

Verrutricolporites haplites GONZALEZ 1967
Plate 1.12, photo 17.

Genus *Zonocostites* GERMERAAD et al. 1968

Zonocostites minor JARAMILLO & DILCHER 2001
Plate 1.12, photos 18, 19.

CLASS Stephanocolporatae **IVERSEN ET TROELS SMITH, 1950**

Genus *Psilastephanocolporites* LEIDELMEYER 1966

Psilastephanocolporites cf. *P. brevicolpatus* JARAMILLO & DILCHER 2001
Plate 1.12, photo 20; plate 3.1, photos 28, 29.

Psilastephanocolporites fissilis LEIDELMEYER 1966
Plate 1.12, photo 21; plate 2.2, photo 23; plate 4.5, photo 21.

Psilastephanocolporites sp. 2
Not illustrated in the plates
IC-FA-4(34.2), 55974(1), U42-2.

Psilastephanocolporites sp. 3
Plate 1.12, photo 22.

Genus *Tetracolporites* COUPER 1963

Tetracolporites pachyexinatus JARAMILLO & DILCHER 2001
Plate 3.1, photos 24, 25.

Genus *Tetracolporopollenites* PFLUG & THOMSON in THOMSON & PFLUG 1953

Tetracolporopollenites cf. *T. divisus* REGALI ET AL. 1974
Plate 3.1, photo 27.

Tetracolporopollenites “grandis”
Plate 1.12, photo 12.
Diagnosis: tricolporate, colpi short, exine 3 µm., thickening to the equator. Dimensions: 50 x 35 µm. One specimen observed.

Tetracolporopollenites maculosus (REGALI et al. 1974) JARAMILLO & DILCHER 2001
Plate 1.12, photos 10, 11.

Tetracolporopollenites (« minutus »)
Plate 1.12, photo 9.
Remarks: Only 1 specimen observed.

Tetracolporopollenites spongiosus JARAMILLO & DILCHER 2001
Plate 1.12, photo 14.

Tetracolporopollenites transversalis (DUEÑAS 1980) JARAMILLO & DILCHER 2001
Plate 1.12, photo 15.

Tetracolporopollenites "triploporatus"
Plate 1.12, photo 16.
Remarks: this form has three pores by colpus. Only 1 specimen observed.

Tetracolporopollenites sp. (pore lalongate 8 µm)
Plate 1.12, photo 13.

Tetracolporopollenites? sp. 2 JARAMILLO & DILCHER 2001
Not illustrated in the plates.
IC-FP-1(165.6), 55980(2), P54-3.

Genus *Retistephanocolporites* VAN DER HAMMEN & WIJMSTRA 1964

Retistephanocolporites "boyacensis"
Plate 2.2. photo 26.
Etymology: after the Boyacá department (Colombia).
Diagnosis: monad, radial, isopolar, amb pentagonal, stephanocolporate, 5 pores, endopores costate, in some specimens the pores have an operculum (?); semitectate, exine 1 µm.; sculpture reticulate, lumina < 1 µm. wide, circular uniform, muri < 1 µm. Dimensions: 30 µm. 28 specimens observed.

Retistephanocolporites (costate to the ecuator)
Plate 2.2, photo 24.

Retistephanocolporites sp. 1
Plate 1.12, photos 23-25.

Retistephanocolporites sp. 2
Plate 1.12, photo 31.

Retistephanocolporites sp.
Not illustrated in the plates.
CCN14, 58000, N48-3.

CLASS Syncolpatae **IVERSEN ET TROELS SMITH, 1950**

Genus *Psilasyncolporites* LEIDELMEYER ex GONZÁLEZ 1967

Psilasyncolporites? sp. 1
Plate 1.12, photo 26.

Psilasyncolporites? sp. 2
Plate 1.12, photo 27.

Genus *Spirosyncolpites* GONZÁLEZ 1967, emend. LEGOUX 1978

Spirosyncolpites spiralis GONZÁLEZ 1967
Plate 1.12, photos 29, 30.

Genus *Syncolporites* VAN DER HAMMEN 1954

Syncolporites lisamae VAN DER HAMMEN 1954
Plate 4.3, photos 7, 8.

Syncolporites cf. *S. marginatus* SARMIENTO 1992
Plate 1.12, photo 28.

Syncolporites sp. 2 (12µm)
IC-FP-1(91.4), 55019, G47.
Description: Amb triangular, psilate, syncolporate, 12 µm. diameter. 1 specimen observed.

CLASS Vesiculatae IVERSEN & TROELS-SMITH 1950

Bisacate pollen
Plate 4.2, photo 2.

CLASS Tetradeae IVERSEN & TROELS-SMITH 1950

Tetrad (psilate)
Plate 4.2, photo 7.

Tetrad (reticulate)
Plate 4.2, photo 8.

Class Polyplicates ERDTMAN 1952

Genus *Ephedripites* BOLKHOVITINA 1953 ex POTONIÉ 1958

Ephedripites vanegensis VAN DER HAMMEN & GARCIA 1966
Plate 4.2, photos 4- 6.

Ephedripites sp.
Plate 4.2, photo 3.

Division I SPORITES H. POTONIÉ, 1893

CLASS A Triletes

Genus *Chomotriletes* NAUMOVA 1939

Chomotriletes minor (KEDVES 1961) POCOCK 1970
Not illustrated in the plates

Genus *Cicatricosisporites* POTONIÉ & GELLETICH 1933

Cicatricosisporites sp.
Not illustrated in the plates

Genus *Camarozonosporites* PANT ex POTONIÉ 1956, emend KLAUS 1960

Camarozonosporites sp.
Plate 4.1, photos 18-20.

Genus *Kuylisporites* POTONIÉ 1956

Kuylisporites type spore. The distinctive feature of these spores is the conspicuous pits in the wall (Graham, 1979). It is very similar to some spores of the Cyatheaceae (e.g. *Sphaeropteris*) or *Cnemidaria* (Mohr and Lazarus, 1994). The difference between our specimens with *Kuylisporites waterbolkii* POTONIÉ 1956 is that the 3 pits are not symmetrically distributed at the center of the three sides.

Genus *Foveotriletes* VAN DER HAMMEN ex POTONIÉ 1956

Foveotriletes margaritae (VAN DER HAMMEN) GERMERAAD ET AL. 1968
Plate 2.1, photo 19.

Foveotriletes ssp.

General group (e.g. Plate 4.1, photo 4).

Genus *Ischyosporites* BALME 1957 emend FENSOME 1987

Ischyosporites problematicus JARAMILLO & DILCHER 2001
Plate 4.1, photos 5, 6.

Genus *Polypodiaceoisporites* POTONIÉ 1951 ex POTONIÉ 1956

Polypodiaceoisporites group (zonate spores)
Polypodiaceoisporites? fossulatus

Genus *Polypodiisporites* POTONIÉ 1931? In POTONIÉ & GELLETICH 1933 ex POTONIÉ 1956

Polypodiisporites (sp. 2 of Jaramillo & Dilcher 2001)
Polypodiisporites aff. *Inangahuensis* (COUPER 1953) POTONIÉ 1956 emend. POCKNALL & MILDENHALL 1984
Polypodiisporites aff. *specious* SAH 1967
Polypodiisporites echinatus JARAMILLO & DILCHER 2001
Polypodiisporites ssp.

Genus *Psilatriletes* VAN DER HAMMEN 1954 ex POTONIÉ 1956

Psilatriletes (>50 µm)
Plate 4.1, photo 14.
General group.

Psilatriletes martinensis SARMIENTO 1992
Plate 2.1, photo 17.

Psilatriletes spp.
Plate 4.1, photo 15

Genus *Retitriletes* PIERCE 1961

Retitriletes "cristatus"
Plate 4.1, photos 7, 8.

Genus *Rugutriletes* PIERCE 1961

Rugutriletes

Genus *Striatriletes* POTONIÉ 1956

Striatriletes sp.
Plate 4.1, photo 25.

Genus *Zlivisporis* PACLTOVA 1964

Zlivisporis blanensis

Genus *Gemmatriletes* PIERCE 1961

Gemmatriletes sp.

Genus *Trilobosporites* POTONIÉ 1956

Trilobosporites sp.
Plate 4.1, photo 24.

Genus *Verrucingulatisporites* HILTMANN 1967

Verrucingulatisporites sp.

Genus *Verrutriletes* VAN DRE HAMMEN ex POTONIÉ 1956

Verrutriletes "viruelensis"
Plate 4.1, photo 16.

Verrutriletes spp.

Genus *Baculatisporites* PFLUG & THOMSON in THOMSON & PFLUG 1953

Baculatisporites spp.

CLASS B Monoletes

Genus *Cicatricososporites* PFLUG & THOMSON in THOMSON & PFLUG 1953

Cicatricososporites (fine striae)
Plate 2.1, photo 18.
Cicatricososporites eocenicus
Cicatricososporites sp. 1

Genus *Laevigatosporites* IBRAHIM 1933

Laevigatosporites spp.
Laevigatasporites sp. 3

Laevigatosporites sp. 1 of Jaramillo & Dilcher 2001
Plate 4.1, photo 9.

Laevigatosporites tibuensis
Plate 4.1, photo 11.

FUNGI

Diporopollis assamica DUTTA & SAH 1970
Plate 4.6, photos 41, 42.

DINOFLAGELLATE CYSTS AND OTHER ALGAE

Andallusiella sp.
Plate 2.1, photo 20.

Dynogymnium sp.
Plate 4.6, photo 37.

Ovoidites (reticulate)

Incertae sedis

Incertae “pseudocolpate” (verrugate)
Plate 2.2, photo 22.

Incertae (*Aquilapollenites* ?)
Plate 4.5, photo 18.

Genus *Cyclusphaera* ELSIK 1966

Cyclusphaera scabrata JARAMILLO & DILCHER 2001

Cyclusphaera (psilate)

FORAMINIFERAL TEST LININGS
Plate 4.6, photo 39.

REFERENCIAS

Graham, A., 1979, *Mortoniodendron* (Tiliaceae) and *Sphaeropteris*/ *Trichipteris* (Cyatheaceae) in Cenozoic deposits of the Gulf-Caribbean region: Annals of the Missouri Botanical Garden, v. 66, p. 572-576.

Iversen, J., and J. Troels-Smith, 1950, Pollenmorfologiske definitioner og Typer, v. 3, p. 54.

Mohr, B. A. R., and D. B. Lazarus, 1994, Paleobiogeographic distribution of *Kuylisporites* and its possible relationship to the extant fern genus *Cnemidaria* (Cyatheaceae): Annals Missouri Botanical Garden, v. 81, p. 758-767.

Van der Kaars, W. A., 1983, A palynological-paleoecological study of the lower Tertiary coal-bed sequence from El Cerrejón (Colombia): Geología Norandina, v. 8, p. 33-48.

SPECIES	PLATE	PHOTO
Aglaoreidia? foveolata JARAMILLO & DILCHER 2001, UR216+60, 57155, EF:Q36/1.	PLATE 1.1	1-2.
Acritarch, (small), Cerrejon 311,28, EF:P55/3-4.	PLATE 4.6	36
Aglaoreidia? foveolata JARAMILLO & DILCHER 2001, Cerrejon 328,6, EF:J18/2.	PLATE 4.2	9--10
Albertipollenites? perforatus, (GONZALEZ 1967) JARAMILLO & DILCHER 2001, IC-PE-2 (22,5), 55708(1), EF: T46, ecuatorial view	PLATE 1.6	23
Albertipollenites? perforatus, (GONZALEZ 1967) JARAMILLO & DILCHER 2001, IC-PE-2 (12,6), 55711, EF: D44/2, polar view.	PLATE 1.6	22
Andallusiella sp., PB3, 59967, EF:L32.	PLATE 2.1	20
Araliaceoipollenites? sp. 1 JARAMILLO & DILCHER 2001, IC-FA-4 (101,38), 55926 (2), EF:S46/4.	PLATE 1.8	17
Araliaceoipollenites? sp. 2 JARAMILLO & DILCHER 2001, UR212+130, 57112, EF:F45.	PLATE 1.8	18
Araucariacidites sp., Cerrejon 150,45, EF:G17/3-4.	PLATE 4.2	1
Baculatisporites sp., Cerrejon 301,88, EF:O28/2.	PLATE 4.1	12
Baculatisporites sp., Cerrejon 310,3, EF:R37/3.	PLATE 4.1	13
Bacumorphomonocolpites tausae SOLE DE PORTA 1971, UR512, 57853, EF:U52-2.	PLATE 1.1	15
Bisacate pollen, Cerrejon 278,12, EF:H18/2.	PLATE 4.2	2
Bombacacidites "fossulatus", UR219+150(57158), EF:P38/4.	PLATE 1.9	8,9
Bombacacidites "lisamae", UR 224+10, 57161, EF:E37/1.	PLATE 1.8	26
Bombacacidites "lisamae", UR 212+130, 57112, EF:S43/3.	PLATE 1.8	24
Bombacacidites "lisamae", UR 238+40, 57241, EF:T49/2.	PLATE 1.8	25
Bombacacidites "magnificum", UR806, 57387, EF:M37.	PLATE 1.11	1
Bombacacidites "pasivus", Cerrejon 252,66, EF:T31-2.	PLATE 4.3	11, 12
Bombacacidites (homogenous reticulum), UR531+100, 57839, G53/3.	PLATE 1.8	21
Bombacacidites (homogenous reticulum; cf. *B. baumfalki* LORENTE 1986), IC-FP-1 (174,2), 55979(2), EF:K44/2.	PLATE 1.8	20
Bombacacidites " pseudosimplireticulatus", IC-FA-3 (64.85), 55756, EF:Q45/4.	PLATE 1.9	5
Bombacacidites annae (VAN DER HAMMEN 1954) GERMERAAD et al. 1968, UR212+130, 57112, EF:W37/2.	PLATE 1.8	19
Bombacacidites cf. *nacimientoensis* (ANDERSON 1960) ELSIK 1968, IC-FA-3 (64.85), 55764(1), EF:R48/3.	PLATE 1.9	2
Bombacacidites cf. *nacimientoensis* (ANDERSON 1960) ELSIK 1968, UR806, 57387, EF:G49/1.	PLATE 1.9	1
Bombacacidites cf. *Soleaformis* MULLER et al. 1987, IC-FA-4(101.38), 55926(2), EF:D56/1.	PLATE 1.9	10
Bombacacidites protofoveoreticulatus JARAMILLO & DILCHER 2001, UR 147, 57850, EF:P56/3.	PLATE 1.9	3,4
Bombacacidites psilatus JARAMILLO & DILCHER 2001, IC-PE-2(12.6), 55711(1), EF:P37/1	PLATE 1.9	6,7
Bombacacidites sp. 1, IC-FA-3 (64.85), 55764(2), EF:L50-4.	PLATE 1.9	11
Bombacacidites sp. 2. IC-FA-3 (17.1), 55817, EF:S32/1.	PLATE 1.9	12
Bombacacidites sp. 3. IC-FA-3 (6.12), 55771(1), EF:D48/2.	PLATE 1.9	13
Bombacacidites sp. 5. IC-CC-12 (37.75) 55803(2), EF:F56.	PLATE 1.9	14
Bombacacidites sp. 6, IC-CC-12(37,75), 55803(1), EF:H58/1.	PLATE 1.9	15,16
Bombacacidites sp. 7 sp 1. de JARAMILLO & DILCHER 2001, IC-CC-12(37.75), 55803(1), EF:S57/4.	PLATE 1.9	17
Bombacacidites sp. 8 (fossulate, vermiculate reticle), IC-CC-7 (11.6), 55846(1), EF:N43/3.	PLATE 1.9	18, 19
Bombacacidites sp. 8 (Fossulate, vermiculate reticle), IC-FA-4 (101.38), 55882, EF:X50/3.	PLATE 1.9	20
Bombacacidites sp 9, IC-FA-4 (101,38), 55926(2), EF:J39/2.	PLATE 1.10	1
Bombacacidites sp. 10 (50 µm) foveolate, IC-FA-4 (48,85), 55973(2), EF:M37/3.	PLATE 1.10	2, 3
Bombacacidites sp. 11 (20 µm), IC-FA-4 (34,2), 55974 (1), EF:E48.	PLATE 1.10	4
Bombacacidites sp. 12 (lumina 5 µm), IC-FP-1(91,4), 56035(2), EF:O34/4.	PLATE 1.10	5
Bombacacidites sp. 13, IC-FP-1 (91,4), 55019, EF:L33/3.	PLATE 1.10	6, 7
Bombacacidites sp. 14, IC-FP-1(18,53), 57305, EF:P43/3.	PLATE 1.10	8, 9
Bombacacidites sp. 14, IC-FP-1(18,53), 57305, EF:Q38/2.	PLATE 1.10	10
Bombacacidites sp. 15 (foveolate in the polar region), SD-D-8D (44,9), 56254(1), EF:U42.	PLATE 1.10	11
Bombacacidites sp. 16 (sp. 3 of JARAMILLO & DILCHER 2001), SD-D-8D(44,9), 56254(2), EF:J54.	PLATE 1.10	12
Bombacacidites sp. B (4 colpi), UR 224+10, 57161, EF:F46/2.	PLATE 1.11	2
Bombacacidites sp. B MULLER et al. 1987, CS38, 58455, EF:K50.	PLATE 2.2	18
Bombacacidites sp. C (4 colpi), UR 732+30, 57330, EF:P50/1.	PLATE 1.11	3
Bombacacidites sp., Cerrejon 118,25, EF:W31/1.	PLATE 4.5	4, 5
Bombacacidites sp., Cerrejon 150,45, EF:F31.	PLATE 4.5	7
Bombacacidites sp., Cerrejon 150,45, EF:U26.	PLATE 4.5	10
Bombacacidites sp., Cerrejon 321,66, EF:H33/1.	PLATE 4.5	8
Bombacacidites sp., Cerrejon 321,66, EF:P51/3.	PLATE 4.5	6
Bombacacidites sp., Cerrejon 328,60, EF:D25/1.	PLATE 4.5	12
Bombacacidites sp., Cerrejon 328,60, EF:H33/1.	PLATE 4.5	2
Bombacacidites sp., Cerrejon 42,71, EF:N33/2-4.	PLATE 4.5	13
Bombacacidites sp., Cerrejon 53,95, EF:S22/4.	PLATE 4.5	3
Bombacacidites sp., Cerrejon 66,15, EF:P37.	PLATE 4.5	9
Bombacacidites sp., Cerrejon 74,30, EF:W29/1.	PLATE 4.5	11
Bombacacidites sp., Cerrejon 84,35, EF:X29.	PLATE 4.5	1
Bombacacidites sp.17, SD-D-8D (9.06), 56262, EF:V54.	PLATE 1.10	13
Bombacidites aff. *gonzalezii* JARAMILLO & DILCHER 2001, IC-FA-4(48,85), 55973(1), EF:F55/2.	PLATE 1.8	23
Bombacidites aff. *gonzalezii* JARAMILLO & DILCHER 2001, IC-FP-1(174,2), 55979 (2), EF:T35/2.	PLATE 1.8	22
*Brevitricolpites "*densiechinatus*"*, IC-FA-4 (48,85), 55973(1), EF:O42/1.	PLATE 1.6	24, 25
Brevitricolpites aff. *microechinatus* JARAMILLO & DILCHER 2001, IC-FP-1(91,4), 55019, EF:N43/3.	PLATE 1.7	2,3
Brevitricolpites macroexinatus JARAMILLO & DILCHER 2001, CCS36, 58445, EF:X47-2.	PLATE 2.2	16
Brevitricolpites microechinatus JARAMILLO 2001, IC-FP-1(165.52), 55996(2), EF:N45/3.	PLATE 1.7	1
Brevitricolpites sp 2. (baculate), IC-FA-4 (34.2), 55974(2), EF C48/1.	PLATE 1.7	5
Brevitricolpites sp 3 (triangular, echinate), SD-D8D (9.06), 56262, EF:L49.	PLATE 1.7	6
Brevitricolpites sp 5 (spines < 1 µm), UR 396, 57844, EF:L27/1-2.	PLATE 1.7	7,8
Brevitricolpites sp. 1 (gemmate), IC-FA-4 (101.38), 55926(2), EF:D59/3.	PLATE 1.7	4
Brevitricolporites sp. (psilate-micropitted-foveolate), Cerrejon 287,52, EF:Q27/4.	PLATE 4.3	28
Brevitricolporites sp. (psilate-micropitted-foveolate), Cerrejon 347,54, E44/3.	PLATE 4.3	29
Brevitricolporites sp. (psilate-micropitted-foveolate), Polar view, Cerrejon 107-108,85, EF:W34/1.	PLATE 4.3	26, 27
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Camarozonosporites sp,. Cerrejon 91,38, EF:F20.	PLATE 4.1	18
Camarozonosporites sp., Cerrejon 310,3, EF:V34/4.	PLATE 4.1	19--20
Carya type Cerrejon 278,12, EF:O28/3.	PLATE 4.5	30, 31
Carya type VENEZUELA3, 50709, EF:T43-2.	PLATE 3.1	4
Carya type, Cerrejon 278,12, EF:H35.	PLATE 4.6	13
Cicatricososporites sp. (fine striae), PB22, 59206, EF:R37-1.	PLATE 2.1	18
Clavamonocolpites microclavatus MULLER et al. 1987, UR 743+ 50, 57859, EF:J38/2.	PLATE 1.1	16, 17
Clavamonocolpites terrificus GONZALEZ 1967, IC-FP-1 (18,53), 56024, EF:R54.	PLATE 1.1	18
Clavatricolpites densiclavatus JARAMILLO & DILCHER 2001, Polar view. IC-PE-2 (12.6), 56058, EF:G41.	PLATE 1.7	9
Clavatricolpites densiclavatus JARAMILLO & DILCHER 2001, Equatorial view, IC-FA-3 (64.85), 55764 (1), EF:E54.	PLATE 1.7	10
Clavatricolpites sp. 1. IC-CC-12 (37.75), 55803(1), EF:R49/4.	PLATE 1.7	11,12
Clavatricolporites leticiae LEIDELMEYER 1966, CCN58, 58527, EF:V39-4.	PLATE 2.2	25
Clavatricolporites leticiae LEIDELMEYER 1966, UR238+40, 57245, EF:E43-3.	PLATE 1.11	4
Clavatricolporites sp., (polar view), Cerrejon 15.05, EF:M64.	PLATE 4.5	14
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Colombipollis tropicalis SARMIENTO 1992, PB1, 59965, EF:E54-3.	PLATE 2.1	11
Corsinipollenites psilatus JARAMILLO & DILCHER 2001, CCS36, 58445, EF:S37-4.	PLATE 2.2	7
Corsinipollenites psilatus JARAMILLO & DILCHER 2001, IC-PE-2 (22,5), 56686, EF:H50.	PLATE 1.5	9

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Corsinipollenites psilatus JARAMILLO & DILCHER 2001, UR 235, 57244, EF:X53.	PLATE 1.5	10
Corsinipollenites sp. Cerrejon 46,75. EF:R23.	PLATE 4.6	1
Corsinipollenites sp., Cerrejon 259,81, EF:X23/1.	PLATE 4.5	32
Cricotriporites guianensis LEIDELMEYER 1966, CCS42, 59181, EF:U43-2,4.	PLATE 2.2	6
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Crusafontites grandiosus SOLE DE PORTA 1971, IC-FA-4(34,2), 55974, EF:J43/2.	PLATE 1.1	19
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Ctenolophonidites lisamae (VAN DER HAMMEN & GARCIA 1966) GERMERAAD et al. 1968, (ecuatorial view), Cerrejon 216,9, EF:H28.	PLATE 4.3	15
Ctenolophonidites lisamae (VAN DER HAMMEN & GARCIA 1966) GERMERAAD et al. 1968, (polar view), Cerrejon 36.55, EF:G60.	PLATE 4.3	16
Ctenolophonidites lisamae (VAN DER HAMMEN & GARCIA 1966) GERMERAAD et al. 1968, VENEZUELA34, 57524, EF:D46.	PLATE 3.1	22
Ctenolophonidites lisamae (VAN DER HAMMEN & GARCIA 1966) GERMERAAD et al. 1968, VENEZUELA34, 57524, EF:E54-3.	PLATE 3.1	21
Curvimonocolpites inornatus LEIDELMEYER 1966, LIS 147, 57109, EF:N45/3.	PLATE 1.1	22
Diporoconia cf. *iszkaszentgyoergyi* (KEDVES 1965) FREDERIKSEN et al. 1985, Cerrejon 129,52, EF: K19/4.	PLATE 4.5	23
Diporoconia cf. *iszkaszentgyoergy* i (KEDVES 1965) FREDERIKSEN et al. 1985, Cerrejon 188,64, EF:U29.	PLATE 4.5	22
Diporoconia cf. *iszkaszentgyoergyi* (KEDVES 1965) FREDERIKSEN et al. 1985, UR 215+90, 57113, EF:F48/3.	PLATE 1.5	7
Diporoconia cf. *iszkaszentgyoergyi* (KEDVES 1965) FREDERIKSEN et al. 1985, UR 216+60, 57155, EF:E37.	PLATE 1.5	5, 6
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Diporopollis assamica DUTTA & SAH 1970, (polar view), Cerrejon 157, EF:O46/3.	PLATE 4.6	42
Duplotriporites ariani SARMIENTO 1992, UR512, 57276, EF:M55/4.	PLATE 1.5	13
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Echimonocolpites protofranciscoi SARMIENTO 1992, UR512, 57853, EF:S49.	PLATE 1.1	26, 27
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Echiperiporites sp. IC-FA-3 (17,1), 55817, EF: K53-1, polar view.	PLATE 1.6	12
Echitriletes sp., Cerrejon 175,75, EF:S22/4.	PLATE 4.1	2
Echitriletes sp., Cerrejon 221,09, EF:E30/2.	PLATE 4.1	3
Echitriletes sp., Cerrejon 94,41, EF:L15/1,2.	PLATE 4.1	1
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Echitriporites trianguliformis VAN HOEKEN KLINKENBERG 1964, Cerrejon 38,63, EF:P19/1-3.	PLATE 4.6	2
Echitriporites trianguliformis VAN HOEKEN KLINKENBERG 1964, PB3, 59967, EF:K54-1,3.	PLATE 2.1	5
Echitriporites trianguliformis VAN HOEKEN KLINKENBERG 1964, UR 531+100, 57839, EF:E53/1.	PLATE 1.5	15
Echitriporites trianguliformis VAN HOEKEN KLINKENBERG 1964, UR732+30, 57852, EF:E50/3.	PLATE 1.5	16
Ephedripites sp., Cerrejon 273.50, EF:R16.	PLATE 4.2	3
Ephedripites vanegensis VAN DER HAMMEN & GARCIA 1966, Cerrejon 150,45, EF:G35/1-2.	PLATE 4.2	6
Ephedripites vanegensis VAN DER HAMMEN & GARCIA 1966, Cerrejon 151,82, EF:F36/4.	PLATE 4.2	4
Ephedripites vanegensis VAN DER HAMMEN & GARCIA 1966, Cerrejon 166,80, EF:D28/3-4.	PLATE 4.2	5
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Foveomonoporites variabilis PARDO et al. 2003, LIS 447, 57109, EF:L50/4.	PLATE 1.1	5, 6
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Foveomonoporites variabilis PARDO et al. 2003, LIS 447, 57109, EF:S50/2.	PLATE 1.1	8
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Foveotricolpites perforatus VAN DER HAMMEN & GARCIA 1966, CCN47, 58585, EF:E40-3.	PLATE 2.2	11
Foveotricolpites perforatus VAN DER HAMMEN & GARCIA 1966, Cerrejon 66,15, EF:W22/3-4.	PLATE 4.3	13
Foveotricolpites sp. (fossulate), UR746+50, 57859, EF:U51/2	PLATE 1.8	11
Foveotricolpites sp., SD-D-8D (9.06), 56262, EF:U57.	PLATE 1.8	10
Foveotricolporites cf. sp.3 (JARAMILLO & DILCHER 2001), UR732+30, 57852, EF:W60.	PLATE 1.11	6
Foveotricolporites sp 1 (sp. 3 of JARAMILLO & DILCHER 2001), Cerrejon 301,88, EF:R30.	PLATE 4.4	1, 2
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Foveotriporites hammenii GONZALEZ 1967, SD-D-8D (44,9), 56254(1), EF:V51/2.	PLATE 1.5	17
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Gemmamonocolpites amicus GONZALEZ 1967, IC-FA-3 (64,85), 55764, EF:G44.	PLATE 1.1	28, 29
Gemmamonocolpites gemmatus VAN DER HAMMEN & GARCIA1965, UR212+130, 57112, EF:U39/1.	PLATE 1.2	1
Gemmamonocolpites ovatus GONZALEZ 1967, UR 512, 57276, EF:J48/4.	PLATE 1.2	2
Gemmamonocolpites sp. 2 (20 µm), IC-FP-1 (91,4), 55019, EF:K50/2.	PLATE 1.2	4
Gemmamonocolpites sp. 3 (small gemmae), IC-CC-7 (9,5), 55847, EF:K50.	PLATE 1.2	5
Gemmastephanocolpites gemmatus VAN DER HAMMEN & GARCIA 1966, (ecuatorial view), Cerrejon 151,82, EF:K37/3.	PLATE 4.3	18
Gemmastephanocolpites gemmatus VAN DER HAMMEN & GARCIA 1966, (ecuatorial view), Cerrejon 255,35, EF:M34/2.	PLATE 4.3	19
Gemmastephanocolpites gemmatus VAN DER HAMMEN & GARCIA 1966, (polar view), Cerrejon 255,35, EF:S28.	PLATE 4.3	17
Gemmastephanocolpites gemmatus VAN DER HAMMEN & GARCIA 1966, VENEZUELA35, 50029, EF:F55-3.	PLATE 3.1	19
Gemmastephanocolpites gemmatus VAN DER HAMMEN & GARCIA 1966, VENEZUELA35, 50029, EF:J43-4.	PLATE 3.1	20
Gemmatricolporites sp. 1, IC-FA-4(73,85), 55939(1), EF:W34-1.	PLATE 1.11	9
Gemmatricolporites sp., Cerrejon 225,91, EF:X29/1-3.	PLATE 4.4	3
Gemmazonocolpites sp. JAN DU CHENE 1977, IC-FA-4 (101,38), 55926, EF:F44/2.	PLATE 1.2	6
Horniella "sogamosa", IC-FA-3 (64,85), 55764(1), EF:R45/1.	PLATE 1.11	7
Horniella sp. 2 (cf. sp. 2 de JARAMILLO 2001), IC-FA-3(64,85), 55764(2), EF:P46/4.	PLATE 1.11	24
Horniella sp. UR806, 57877, EF:G46-3.	PLATE 1.11	12
Horniella sp., IC-CC-7(11.6), 55846 (1), EF:F55-4.	PLATE 1.11	8
Horniella sp.1 (pores costate), UR62, 57848, EF:V55.	PLATE 1.11	10
Incertae "pseudocolpate" (verrugate), CCN58, 58527, EF:G44.	PLATE 2.2	22
Incertae (Aquilapollenites?), Cerrejon 244.2, EF:N25	PLATE 4.5	18
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Psilastephanocolporites fissilis LEIDELMEYER 1966, CCS42, 59181, EF:O45-1,3.	PLATE 2.2	23
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Psilatricolporites costatus DUENAS 1980, IC-CC-7(11,6), 55846(1), EF:N55/4.	PLATE 1.11	19
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Psilatricolporites marginatus VAN DER KAARS 1983, Cerrejon 294,28, EF:E27/1.	PLATE 4.4	14
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Psilatricolporites pachyexinatus VAN DER KAARS 1983, Cerrejon 148,50, EF:Q27/2.	PLATE 4.4	15
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Retibrevitricolpites triangulatus VAN HOEKEN KLINKENBERG 1966, IC-FP-1 (156,52), 55996(2), EF:Q47/3.	PLATE 1.7	21
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Retidiporites botulus LEIDELMEYER 1966, Cerrejon 104.56, EF:H29/3.	PLATE 4.5	25
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Retidiporites magdalenensis VAN DER HAMMEN & GARCIA 1966, Cerrejon 84.35, S24/2.	PLATE 4.5	28
Retidiporites magdalenensis VAN DER HAMMEN & GARCIA 1966, LIS 447, 57109, EF:S52/1.	PLATE 1.5	8
Retidiporites operculatus VAN DER KAARS 1983, Cerrejon 42.71, EF:T23/2.	PLATE 4.5	29
Retimonocolpites longicolpatus LORENTE 1986, IC-FA- 4 (101,38), 55926 (ICP), EF:E59.	PLATE 1.4	14
Retimonocolpites retifossulatus LORENTE 1986, IC-PE-2 (22,5), 55708, EF:H49/4.	PLATE 1.4	15, 16
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Retimonocolpites tertiarius GONZALEZ 1967, IC-FP-1 (18,53), 56024, EF:M33.	PLATE 1.4	17, 18
Retistephanocolpites sp. (foveolate), IC-FP-1 (165,52), 55996 (1), EF:K48/2.	PLATE 1.8	13, 14
Retistephanocolpites sp. 1 (microret, 7 colp,), UR 743+50, 57859, EF:B33/1-2.	PLATE 1.8	15, 16
Retistephanocolpites sp., CCS38, 58455, EF:D48-3.	PLATE 2.2	21
Retistephanocolporites "boyacensis", CCS14, 58089, EF:K51.	PLATE 2.2	26
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Retitrescolpites ? *irregularis* VAN DER HAMMEN & WYMSTRA 1964 (JARAMILLO & DILCHER 2001), IC-FA-4 (48.85), 55973 (1), EF:U43/2.	PLATE 1.7	23
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Retitricolpites "grandis", Cerrejon 19, EF:S52/4.	PLATE 4.3	9
Retitricolpites cf. *R. retiaphelis* LEIDELMEYER 1966, UR 216+60, 57155, EF:L43/4.	PLATE 1.8	7
Retitricolpites cf. *simplex* GONZALEZ 1967, IC-FP-1 (91,4), 56035(1), EF:J47.	PLATE 1.8	3
Retitricolpites cf. *simplex* GONZALEZ 1967, SD-D-8D (44.9), 56254(1), EF:R42/2.	PLATE 1.8	4
Retitricolpites microreticulatus (VAN DER HAMMEN 1954) VAN DER HAMMEN & WYMSTRA 1964, PB1, 59959, K50-3.	PLATE 2.1	12, 13
Retitricolporites "doradensis", circular, VENEZUELA97, 50035, EF:R44.	PLATE 3.1	12
Retitricolporites "doradensis", VENEZUELA97, 50035, EF:O44-4.	PLATE 3.1	13
Retitricolporites "poricostatus", IC-FP-1(174,2), 55979(1), EF:N41.	PLATE 1.11	25
Retitricolporites "venezuelensis", VENEZUELA97, 50035, EF:K37.	PLATE 3.1	14
Retitricolporites "venezuelensis", VENEZUELA97, 50035, EF:Q38-3,4.	PLATE 3.1	15
Retitricolporites cf. *equatorialis* GONZALEZ 1967, IC-FP-1(165,52), 55996(2), EF:R36/4.	PLATE 1.11	26
Retitricolporites finitus GONZALEZ 1967, IC-PE-2(12,6), 55711, EF:Q49/2.	PLATE 1.11	27
Retitriletes "cristatus", Cerrejon 70,08, EF:V32/1.	PLATE 4.1	8
Retitriletes "cristatus", Cerrejon 81,08, EF:L18/3.	PLATE 4.1	7
Retitriporites cf. *federicii* GONZALEZ 1967, SD-D-8D (9,06), 56262, EF:T39/3.	PLATE 1.5	21
Retitriporites cf. *poricostatus* JARAMILLO & DILCHER 2001, SD-D-8D (44,9), 56254(2), EF: P60/4.	PLATE 1.6	1, 2
Retitriporites simplex VAN DER KAARS 1983, Cerrejon 221,09, EF:C30/1.	PLATE 4.6	7
Retitriporites sp. 1, Cerrejon 259,81, EF:R18/1-3.	PLATE 4.6	4
Retitriporites sp. 2, (pore costate), Cerrejon 252,66, EF:M22.	PLATE 4.6	6
Retitriporites sp. 2, (pore costate), Cerrejon 259,81, EF:T14/3.	PLATE 4.6	5
Retitriporites sp. 3, IC-CC-7 (11,6), 55846(1), EF: F34/2-4.	PLATE 1.6	3, 4, 5
Rhoipites guianensis (VAN DER HAMMEN & WYMSTRA 1964) JARAMILLO & DILCHER 2001, CCS42, 59181, E47-2,4.	PLATE 2.2	19
Rhoipites guianensis (VAN DER HAMMEN & WYMSTRA 1964) JARAMILLO & DILCHER 2001, CCS42, 59181, E47-2,4.	PLATE 2.2	20
Rousea florentina GONZALEZ 1967 (JARAMILLO & DILCHER 2001), IC-CC-7 (9.5), 55847 (1), EF:Q46/3	PLATE 1.7	26
Rugumonocolpites "pacificus", IC-CC-12 (37,75), 55803 (ICP), EF:J59/2.	PLATE 1.4	19

SPECIES	PLATE	PHOTO
Rugutricolpites . IC-PE-2 (22.5). 55708(1). EF:W48/1.	PLATE 1.7	27
Rugutricolporites cf. *felix* GONZALEZ 1967, CCS36, 58445, EF:E53.	PLATE 2.2	13, 14
Rugutrilete, Cerrejon 150,45, EF:W32/1.	PLATE 4.1	21
Scabratricolpites sp.1 (24-30 µm long), UR62, 57848, EF:K46/2.	PLATE 1.8	8
Scabratricolporites sp. (cf. Siltaria sp. 4 JARAMILLO & DILCHER 2001), Cerrejon 326,82, EF:M40.	PLATE 4.4	17, 18
Scabratricolporites sp.(cf. Siltaria sp. 4 JARAMILLO & DILCHER 2001), Cerrejon 171,57, EF:V23/2.	PLATE 4.4	19
Scabratricolporites sp.(cf. Siltaria sp. 4 JARAMILLO & DILCHER 2001), Cerrejon 326,82, EF:P36/2.	PLATE 4.4	20
Scabratricolporites sp., Cerrejon 184,55, EF:E14/3.	PLATE 4.4	22
Scabratricolporites sp., Cerrejon 285,08, EF:H28/3.	PLATE 4.4	21
Siltaria mariposa (LEIDELMEYER 1966) JARAMILLO & DILCHER 2001, IC-PE-2(12,6), 55711, EF:K31/2.	PLATE 1.11	28
Siltaria mariposa (LEIDELMEYER 1966) JARAMILLO & DILCHER 2001, VENEZUELA80, 50033, EF:T43-2.	PLATE 3.1	16
Siltaria sp. 4, JARAMILLO & DILCHER 2001, UR531+100, 57839, EF:J35/1.	PLATE 1.11	29
Small *tricolporates* .	PLATE 4.4	23--30
Cerrejon 171,57, EF:P32/3.	PLATE 4.4	30
Cerrejon 188,64, EF:H26/3.	PLATE 4.4	28
Cerrejon 22,69-24,55, EF:U28/1,3.	PLATE 4.4	24
Cerrejon 235,32, EF:G31/3.	PLATE 4.4	25
Cerrejon 244,20, EF:M34/3.	PLATE 4.4	26
Cerrejon 252,66, EF:J27.	PLATE 4.4	27
Cerrejon 287,52, EF:G28/4.	PLATE 4.4	29
Cerrejon 96,65, EF:J27/2.	PLATE 4.4	23
Spinizonocolpites baculatus MULLER 1968, UR 743+50, 57859, EF:O46/3-4.	PLATE 1.4	20
Spinizonocolpites baculatus (forma 2) "brevibaculatus" MULLER 1968, IC-FA-3 (6,12), 55771(1), EF:X55/1	PLATE 1.4	22
Spinizonocolpites baculatus (forma 3) MULLER 1968, IC-FA-3 (6,12), 55771 (ICP), EF:N41/2.	PLATE 1.4	23
Spinizonocolpites breviechinatus JARAMILLO & DILCHER 2001, UR 219+150, 57158, EF:F38/1.	PLATE 1.5	1
Spinizonocolpites cf. *Spinizonocolpites baculatus* MULLER 1968, UR 531+100, 57277, EF:K42/1-2.	PLATE 1.4	21
Spinizonocolpites echinatus (psilate), IC-FP-1 (174,2), 55979, EF:H52/1.	PLATE 1.5	3
Spinizonocolpites echinatus MULLER 1968, Cerrejon 184.55 , EF:P19/1.	PLATE 4.3	6
Spinizonocolpites echinatus MULLER 1968, SD-D-8D (44,9), 56254, EF:T38/3.	PLATE 1.5	2
Spinizonocolpites pachyexinatus JARAMILLO & DILCHER 2001, CCN 101, 59452, EF:U47.	PLATE 2.2	15
Spinizonocolpites sutae SARMIENTO 1992, PB1, 59965, EF:D52-1.	PLATE 2.1	3
Spirosyncolpites spiralis GONZALEZ 1967, 55803(1), EF:M59/3.	PLATE 1.12	29, 30
Spore trilete (scabrate-verrugate), Cerrejon 148,50, EF:Q30.	PLATE 4.1	17
Stephanocolpites "scabratus", Cerrejon 330,65, EF:C27/4.	PLATE 4.3	24
Stephanocolpites (psilate, 4 colpi), Cerrejon 36,55, EF:E58/1.	PLATE 4.3	25
Stephanocolpites costatus VAN DER HAMMEN 1954, PB22, 59206, EF:U52-2.	PLATE 2.1	16
Stephanoporate scabrate, Cerrejon 19, EF:O58.	PLATE 4.6	28
Stephanoporites sp., Cerrejon 28,65, EF:X49/4.	PLATE 4.6	27
Striatopollis catatumbus (GONZALEZ 1967) TAKAHASHI & JUX 1989, IC-PE-2 (12,6), 56058, EF:R53/3-4.	PLATE 1.12	1
Striatopollis catatumbus (GONZALEZ 1967) TAKAHASHI & JUX 1989, SD-D-8D(44.9)56254(1), EF:J40-1.	PLATE 1.12	2
Striatopollis minor JARAMILLO & DILCHER 2001, IC-PE-2(22,5), 56686, EF:L51.	PLATE 1.12	3
Striatopollis sp., (small), Cerrejon 112,90, EF:S24/3-4.	PLATE 4.4	31, 33
Striatopollis ? *Tenuistriatus* JARAMILLO & DILCHER 2001, UR743+50, 57859, EF:R48/2-4.	PLATE 1.12	4
Striatopollis ? *Tenuistriatus* , JARAMILLO & DILCHER 2001, IC-FA-4 (48,85), 55973(2), EF:D42.	PLATE 1.12	5
Striatricolporites cf. *pimulis* VAN HOEKEN-KLINKENBERG 1966, IC-FP-1(174,2), 55979(2), EF:O53/3.	PLATE 1.12	6
Striatricolporites digitatus JARAMILLO 2001, IC-PE-2(12,6), 55711, EF:K47/1.	PLATE 1.12	7,8
Striatriletes sp., Cerrejon 104,56, EF:D26/1.	PLATE 4.1	25
Striatriporites sp. 1, IC-FA-3 (64,85), 55764 (2), EF: L39.	PLATE 1.6	6
Syncolporites cf. *marginatus* SARMIENTO 1992, UR531+100, 57277, EF:P47.	PLATE 1.12	28
Syncolporites lisamae VAN DER HAMMEN 1954, Cerrejon 15,05, EF:E59/1.	PLATE 4.3	8
Syncolporites lisamae VAN DER HAMMEN 1954, Cerrejon 66,15 , EF:K28/4.	PLATE 4.3	7
Tertracolporopollenites cf. *d* ivisus REGALI et al. 1974, VENEZUELA93, 50728, EF:G45-1.	PLATE 3.1	27
Tetracolporites pachyexinatus JARAMILLO & DILCHER 2001, VENEZUELA90, 57804, EF:S54-2.	PLATE 3.1	24
Tetracolporites pachyexinatus JARAMILLO & DILCHER 2001, VENEZUELA92, 57949, EF:P48-4.	PLATE 3.1	25
Tetracolporopollenites "grandis". SD-D-8D(44,9), 56254(2), EF:R52.	PLATE 1.12	12
Tetracolporopollenites "triploporatus", IC-FP-1(165,52), 55986, EF:J47.	PLATE 1.12	16
Tetracolporopollenites ("minutus") UR221+40, 57160, EF:G47/3.	PLATE 1.12	9
Tetracolporopollenites maculosus REGALI et al. 1974, IC-FA-4(73,85), 55939(2), EF:J40/3.	PLATE 1.12	10,11
Tetracolporopollenites sp. (pore lalongate 8 µm) IC-FA-4(101.38)55926(1)Tricolporzon, EF:H50-3.	PLATE 1.12	13
Tetracolporopollenites spongiosus JARAMILLO & DILCHER 2001, UR221+40, 57160, EF:N51/4.	PLATE 1.12	14
Tetracolporopollenites transversalis (DUEÑAS 1980) JARAMILLO & DILCHER 2001, VENEZUELA80, 50033, EF:K43-2.	PLATE 3.1	26
Tetracolporopollenites transversalis DUEÑAS 1980, IC-CC-7(11.6), 55846(1), EF:P54.	PLATE 1.12	15
Tetrad (psilate), Cerrejon 239,29, EF:H30.	PLATE 4.2	7
Tetrad (reticulate), Cerrejon 96,65, EF:X27.	PLATE 4.2	8
Triatriopollenites sp. *UR224+10, 57161,* EF: O46/1.	PLATE 1.6	7
Triatriopollenites sp. VENEZUELA50, 50711, EF:M45-2.	PLATE 3.1	3
Triatriopollenites sp., (ecuatorial view), Cerrejon 96,65, EF:P31/4.	PLATE 4.6	20
Triatriopollenites sp., Cerrejon 15,05, EF:X53.	PLATE 4.6	17
Triatriopollenites sp., Cerrejon 19, EF:N56/3.	PLATE 4.6	14
Triatriopollenites sp., Cerrejon 310,3, EF:T34/1.	PLATE 4.6	16
Triatriopollenites sp., Cerrejon 32.6, EF:S55. DIC.	PLATE 4.6	18, 19
Triatriopollenites sp., Cerrejon 53,95, EF:F20/2.	PLATE 4.6	15
Tricolpites "simetricus", polar view, IC-PE-2(22.5), 55708(1), EF:D42-3	PLATE 1.8	5
Tricolpites "simetricus". Equatorial view, (IC-PE-2, 22,5), IC-PE-2 (22.5), 55708 (1), EF:O44/2.	PLATE 1.8	6
Tricolpites cf. *minutus* GONZALEZ 1967, IC-PE-2 (22.5), 56062, EF:V49/2.	PLATE 1.8	1
Tricolpites clarensis GONZALEZ 1967, IC-FP-1 (18.53), 56024, EF:H45.	PLATE 1.7	28
Tricolpites conciliatus GONZALEZ 1967, Equatorial view, IC-FP-1 (156,52), 55996(1), EF:H53/2.	PLATE 1.7	29
Tricolpites conciliatus GONZALEZ 1967, Polar view, IC-FP-1 (156,52), 55996(1), EF:O35.	PLATE 1.7	30
Tricolpites protoclarensis JARAMILLO & DILCHER 2001, SD-D-8D (9,06), 56262, EF:L49/4.	PLATE 1.8	2
Tricolpites sp. 2 (reticulate to the equator), Cerrejon 252,66, EF:L19/1.	PLATE 4.5	20
Tricolpites sp. 2 (reticulate to the equator), Cerrejon 74,30, EF: W37/4.	PLATE 4.5	19
Tricolpites sp.2 (reticulate to the equator; < 20 µm), UR 221+40, 57160, EF:P48/3.	PLATE 1.8	9
Tricolporites "scabrate", (ecuatorial view), Cerrejon 193, EF:Q44.	PLATE 4.4	40
Tricolporites "scabrate", (polar view), Cerrejon 112,90, EF:K32/4.	PLATE 4.4	39
Tricolporites sp., (reticulate), Cerrejon 100,60, EF:F28/1-3.	PLATE 4.4	37,38
Tricolporites sp., (reticulate), Cerrejon 112,90, EF:S34.	PLATE 4.4	36
Tricolporites sp., (reticulate, colpi marginate), Cerrejon 70,08, EF:S17/4.	PLATE 4.4	43, 44
Tricolporites sp., (triangular, short colpi, simple), Cerrejon 310,3, EF:L29/3.	PLATE 4.4	35
Tricolporites sp., (triangular, short colpi, simple), Polar view, Cerrejon 107-108,85, EF:U30/2.	PLATE 4.4	34
Tricolporites, (triangular pore and colpi costate), Cerrejon 318,14, EF:J23/1.	PLATE 4.4	41, 42
Trilete spore (reticulate-foveolate). Cerrejon 310,3, EF:X48/3.	PLATE 4.1	22, 23
Trilobosporites sp., Cerrejon 46,75, EF:E24/2.	PLATE 4.1	24
Triporites sp 1, (triangular), Cerrejon 216,9, EF:R32/2.	PLATE 4.6	21
Triporites sp. 2, (psilate, small), Cerrejon 252,66, EF:R20.	PLATE 4.6	22
Triporites sp. 3, (reticulate), Cerrejon 285,08, EF:E22/1.	PLATE 4.6	23, 24

SPECIES	PLATE	PHOTO
Ulmoideipites krempii (4 pores) (ANDERSON 1960) ELSIK 1968b, UR 62, 57848, EF: C45/3.	PLATE 1.6	20
Ulmoideipites krempii (5 pores) (ANDERSON 1960) ELSIK 1968b, UR 512, 57853, EF: M52/4.	PLATE 1.6	21
Ulmoideipites krempii (ANDERSON 1960) ELSIK 1968b, Cerrejon 188,64, EF:C24/1.	PLATE 4.6	29, 30
Verrutricolpites sp. 1, IC-FA-4 (101,38), 55926(1), EF:J45.	PLATE 1.8	12
Verrutricolporites haplites GONZALEZ 1967, IC-FP-1(174,2), 55979(1), EF:U40/3-4.	PLATE 1.12	17
Verrutricolporites sp., Cerrejon 184.55, EF:E21/2.	PLATE 4.6	25
Verrutricolporite s, Cerrejon 19, EF:K67.	PLATE 4.5	17
Verrutrilete "viruelensis", Cerrejon 46,75, EF:P29/1.	PLATE 4.1	16
Zonocostites minor JARAMILLO & DILCHER 2001, IC-FA-4(73,85), 55939(2), EF:R56/3.	PLATE 1.12	18

PLATES

PLATE 1.1

Pollen and spores from the Middle Magdalena Valley Basin (Monoporates-Monocolpates)

1, 2. *Aglaoreidia*? *foveolata* JARAMILLO & DILCHER 2001, UR216+60, 57155, EF: Q36/1.
3, 4. *Foveomonoporites variabilis* PARDO et al. 2003, LIS 447, 57099, EF: J34/4.
5, 6. *Foveomonoporites variabilis* PARDO et al. 2003, LIS 447, 57109, EF: L50/4.
7. *Foveomonoporites variabilis* PARDO et al. 2003, LIS 447, 57109, EF: H55.
8. *Foveomonoporites variabilis* PARDO et al. 2003, LIS 447, 57109, EF: S50/2.
9. *Foveomonoporites variabilis* PARDO et al. 2003, LIS 447, 57109, EF: Q47/1-3.
10. *Monoporopollenites annulatus* (VAN DER HAMMEN 1954) JARAMILLO & DILCHER 2001, IC-CC-12 (37,75), 55803, EF: L59/3.
11. *Monoporopollenites annulatus* (VAN DER HAMMEN 1954) JARAMILLO & DILCHER 2001, IC-FA-4 (48,85), 55973, EF: M40/2.
12. *Monoporopollenites annulatus* (VAN DER HAMMEN 1954) JARAMILLO & DILCHER 2001, IC-FP-1 (91,4), 56035, EF: W43/2.
13, 14. *Monoporopollenites* sp. 1, UR806, 57387, EF: S43.
15. *Bacumorphomonocolpites tausae* SOLE DE PORTA 1971, UR512, 57853, EF: U52-2.
16, 17. *Clavamonocolpites microclavatus* MULLER et al. 1987, UR 743+ 50, 57859, EF: J38/2.
18. *Clavamonocolpites terrificus* GONZALEZ 1967, IC-FP-1 (18,53), 56024, EF: R54.
19. *Crusafontites grandiosus* SOLE DE PORTA 1971, IC-FA-4(34,2), 55974, EF: J43/2.
20. *Crusafontites megagemmatus* JARAMILLO & DILCHER 2001, IC-FA-3(17,1), 55817, EF: M42/1.
21. *Crusafontites* "minor", IC-FA-4(73,85), 55939, EF: P51/2.
22. *Curvimonocolpites inornatus* LEIDELMEYER 1966, LIS 147, 57109, EF: N45/3.
23, 24. *Echimonocolpites* « minutus », IC-FA-4(34,2), 55974(1), EF: J46.
25. *Echimonocolpites protofranciscoi* SARMIENTO 1992, UR 743+50, 57859, EF: Q55/3.
26, 27. *Echimonocolpites protofranciscoi* SARMIENTO 1992, UR512, 57853, EF: S49.
28, 29. *Gemmamonocolpites amicus* GONZALEZ 1967, IC-FA-3 (64,85), 55764, EF: G44.

PLATE 1.1

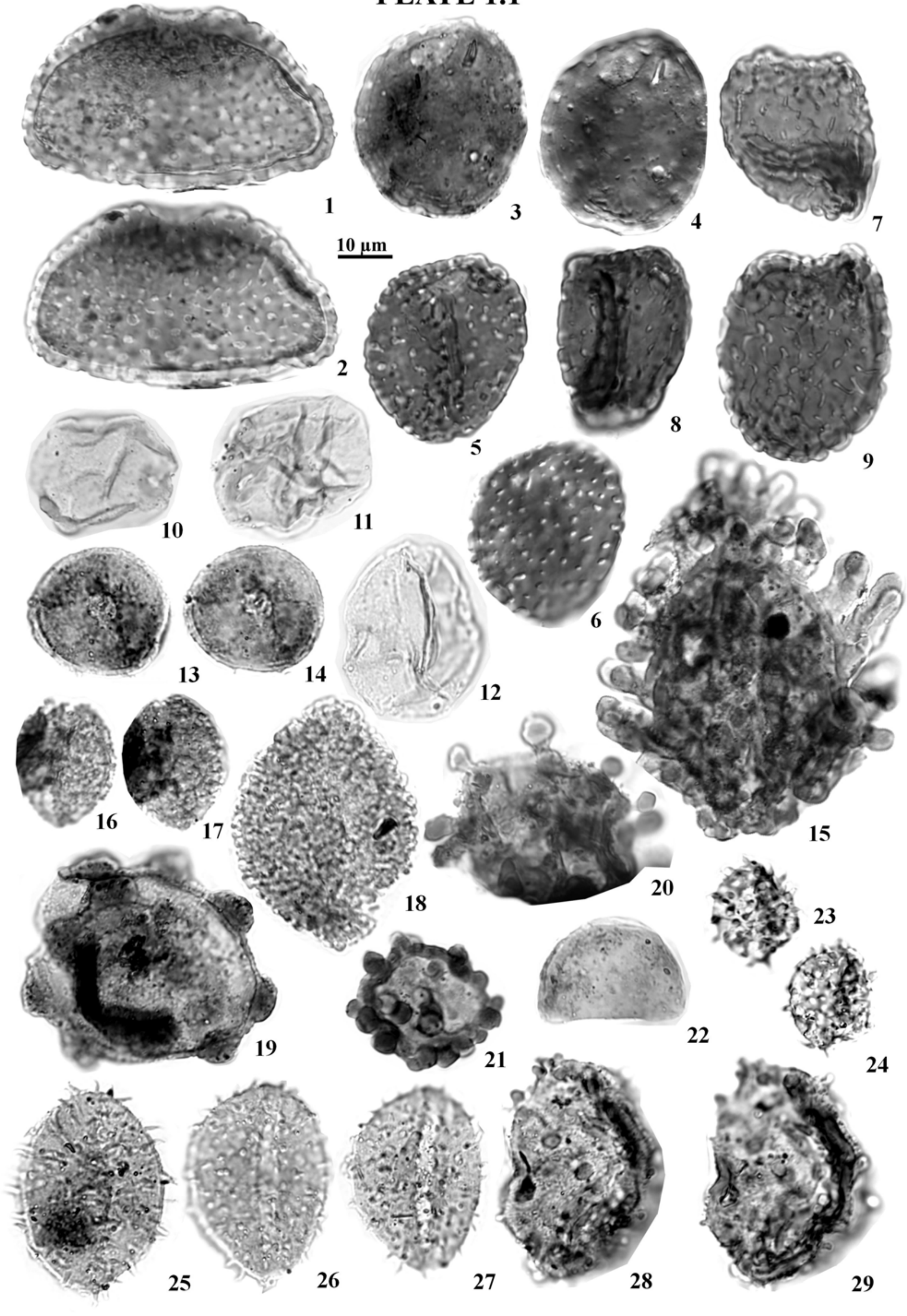
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PLATE 1.2

Pollen and spores from the Middle Magdalena Valley Basin (Monocolpates)

1. *Gemmamonocolpites gemmatus* VAN DER HAMMEN & GARCIA1965, UR212+130, 57112, EF: U39/1.
2. *Gemmamonocolpites ovatus* GONZALEZ 1967, UR 512, 57276, EF: J48/4.
3. *Gemmamonocolpites* "digemmatus" (*Gemmamonocolpites* sp. 1 of JARAMILLO & DILCHER 2001), IC-FA-3 (6,12), 55771 (ICP), EF: T33/3.
4. *Gemmamonocolpites* sp. 2 (20 µm), IC-FP-1 (91,4), 55019, EF: K50/2.
5. *Gemmamonocolpites* sp. 3 (small gemmae), IC-CC-7 (9,5), 55847, EF: K50.
6. *Gemmazonocolpites* sp. JAN DU CHENE 1977, IC-FA-4 (101,38), 55926, EF: F44/2.

7, 8. *Longapertites proxapertitoides* var. *proxapertitoides* VAN DER HAMMEN & GARCIA 1966, IC-PE-2 (12,6), 55711(ICP), EF: M31/3.

9. *Longapertites* sp. (smooth reticle), IC-PE-2 (12,6), 55711, EF: T42.
10. *Longapertites* sp. (smooth reticle), UR 743+50, 57859, EF: R51/4.
11. *Longapertites proxapertitoides* var. *reticuloides* VAN DER HAMMEN & GARCIA 1966, IC-FA-4 (34,2), 55974, EF: N55/1.

12, 13. *Longapertites* sp. 3, IC-FP-1 (91,4), 56035, EF: L49/2.

14, 15. *Longapertites* (psilate). IC-FP-1 (91,4), 55019, EF: M52.

16. *Longapertites*? sp. (gemmate), SD-D-8D (44,9), 56254, EF: J39/1.
17. *Luminidites colombianensis* JARAMILLO & DILCHER 2001, SD-D-8D (9,06), 56262, EF: E52/4.
18. *Mauritiidites franciscoi* var. *franciscoi* (VAN DER HAMMEN 1956a) VAN HOEKEN-KLINKENBERG 1964, UR 221+40, 57160, EF: P52/1, detail of the deep rooted spines.
19. *Mauritiidites franciscoi* var. *franciscoi* (VAN DER HAMMEN 1956a) VAN HOEKEN-KLINKENBERG 1964, UR 806, 57387, EF: R54/1.

PLATE 1.2

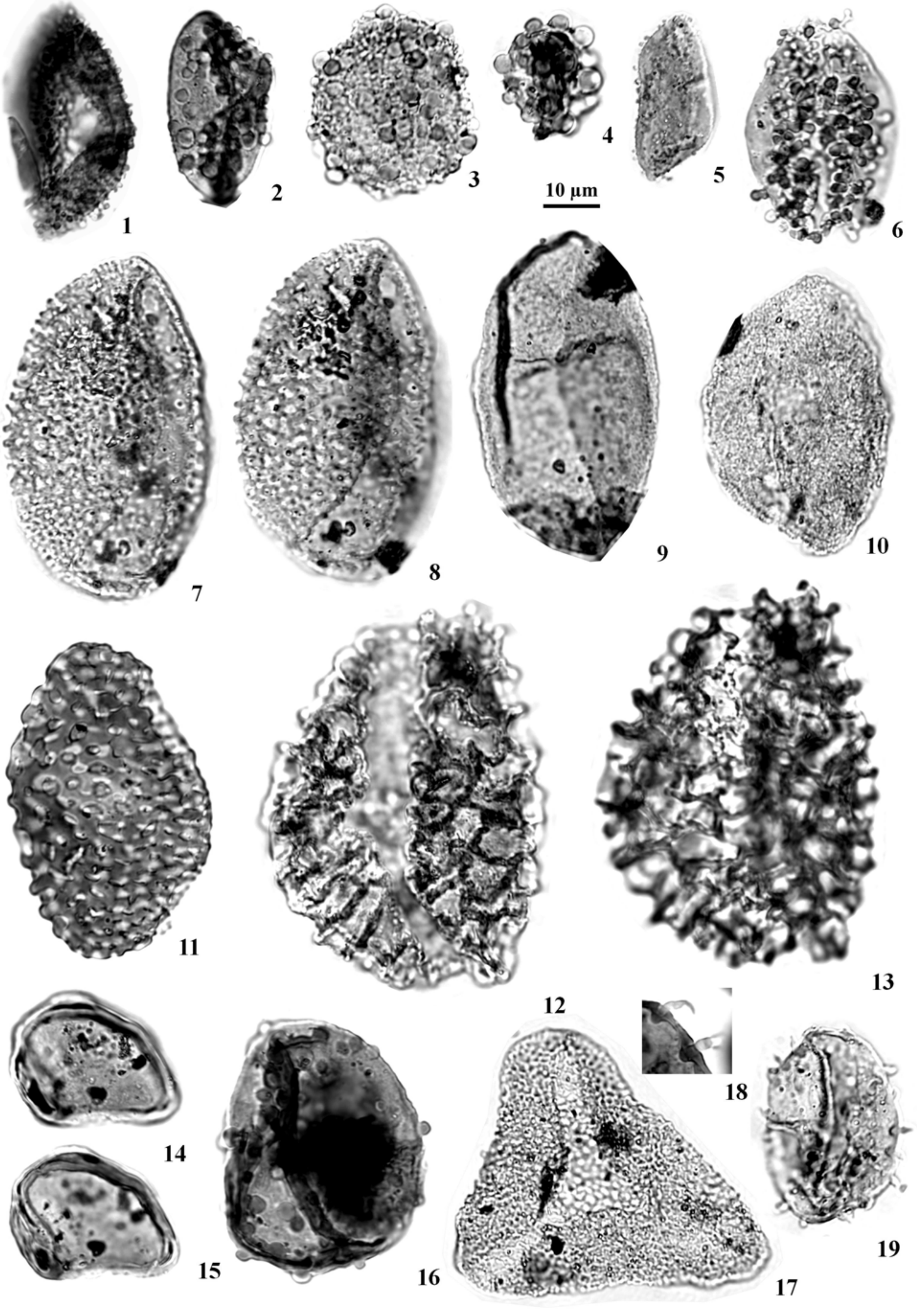

PLATE 1.3

Pollen and spores from the Middle Magdalena Valley Basin (Monocolpates)

1. *Mauritiidites franciscoi* var. *franciscoi* (VAN DER HAMMEN 1956a) VAN HOEKEN-KLINKENBERG 1964, UR 238+40, 57245, EF: Q44/1-2.
2. *Mauritiidites franciscoi* var. *minutus* VAN DER HAMMEN & GARCIA 1966, IC-FA-4 (34,2), 55974 (ICP), EF: L52/4.
3. *Mauritiidites franciscoi* var. *pachyexinatus* VAN DER HAMMEN & GARCIA 1966, IC-FA-4 (71), 55940, EF: K42/1.
4. *Mauritiidites franciscoi* var. *pachyexinatus* VAN DER HAMMEN & GARCIA 1966, UR 224+10, 57161, EF: K41.
5. *Monocolpopollenites ovatus* JARAMILLO & DILCHER 2001, UR 219+150, 57158, EF: L35.

6, 7. *Proxapertites cursus* VAN HOEKEN-KLINKENBERG 1966, UR 219+150, 57158, EF: F46/2.

8. *Proxapertites humbertoides* (VAN DER HAMMEN 1954) SARMIENTO 1992, UR 512, 57276, EF: P44.
9. *Proxapertites magnus* MULLER et al. 1987, UR 62, 57083, EF: O48/4.
10. *Proxapertites operculatus* (VAN DER HAMMEN 1956a) GERMERAAD et al. 1968, UR 221+40, 57160, EF: O37.
11. *Proxapertites operculatus* (VAN DER HAMMEN 1956a) GERMERAAD et al. 1968, LIS 447, 57109, EF: J39.
12. *Proxapertites psilatus* SARMIENTO 1992, UR 62, 57848, EF: U57.
13. *Proxapertites* (triangulate), UR 238+40, 57245, EF: P37/4.

PLATE 1.3

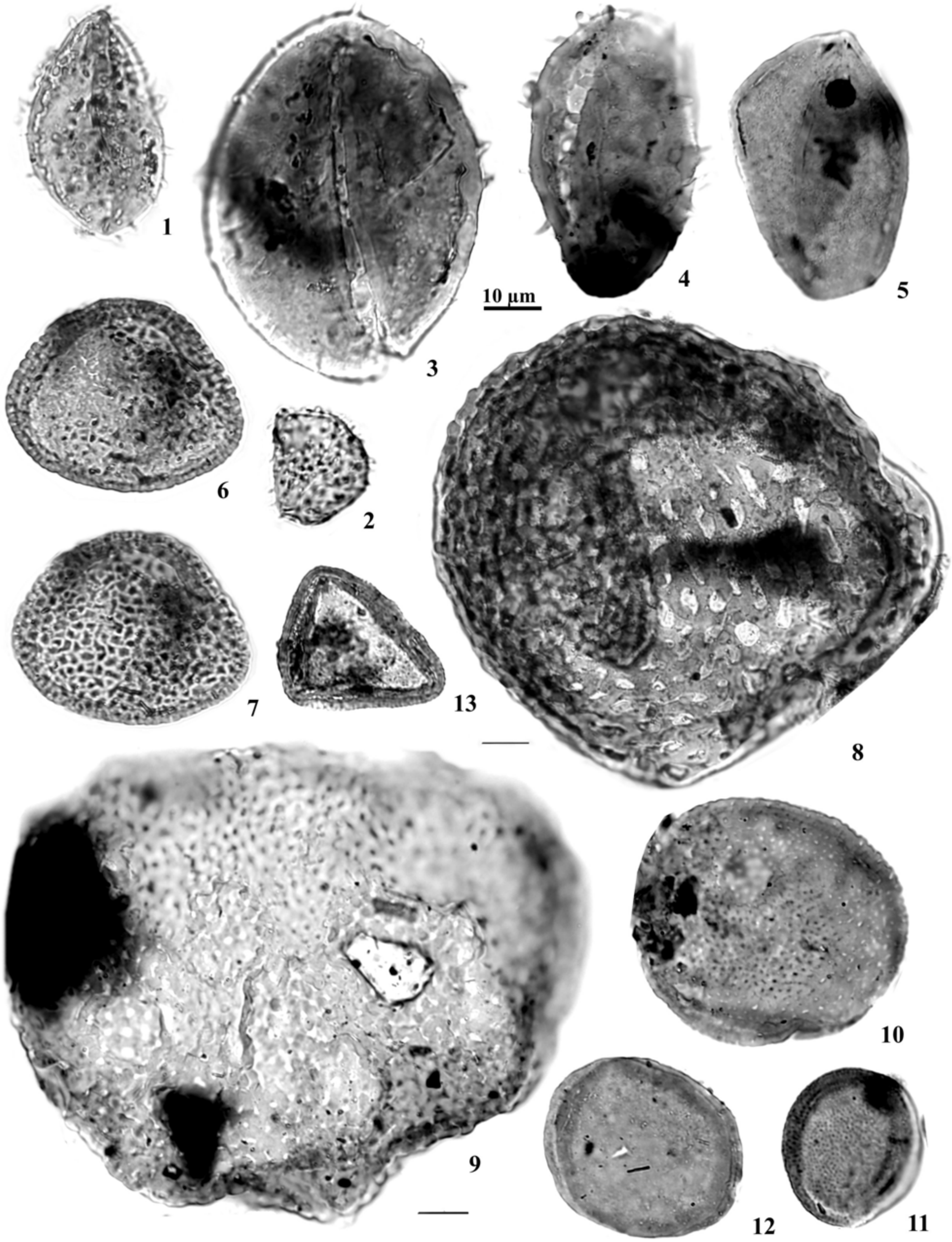

PLATE 1.4

Pollen and spores from the Middle Magdalena Valley Basin (Monocolpates)

1. *Proxapertites* cf. *verrucatus* SARMIENTO 1992, UR 216+60, 57155, EF: D34.
2. *Psilamonocolpites grandis* (VAN DER HAMMEN 1954) VAN DER HAMMEN & GARCIA 1966, IC-PE-2 (22,5), 56686, EF: M42/4.
3. *Psilamonocolpites medius* (VAN DER HAMMEN 1954) VAN DER HAMMEN & GARCIA 1966, UR 235, 57244, EF: T45/4.
4. *Psilamonocolpites minutus* (VAN DER HAMMEN 1954) VAN DER HAMMEN & GARCIA 1966, LIS 447, 57109, EF: X42/4.
5. *Psilamonocolpites minutus* (VAN DER HAMMEN 1954) VAN DER HAMMEN & GARCIA 1966, IC-FA-4 (48,85), 55973, EF: V40.
6. *Psilamonocolpites operculatus* PARDO et al. 2003, LIS 447, 57109, EF: L34/2-4.
7. *Psilamonocolpites operculatus* PARDO et al. 2003, LIS 447, 57099, EF: L35
8. *Psilamonocolpites operculatus* PARDO et al. 2003, LIS 447, 57109, EF: L42/1, specimen without the operculum.
9. *Psilamonocolpites* "marginatus" (>40 µm long; exine 2 µm), UR 221+40, 57160, EF: E50/1.
10. *Racemonocolpites facilis* GONZALEZ 1967, IC-CC-12 (37,75), 55803 (ICP), EF: T41.
11. *Racemonocolpites microgemmatus* MULLER et al. 1987, IC-FA-4 (73,85), 55939, EF: R52/3,
12. *Racemonocolpites racematus* (VAN DER HAMMEN 1954) GONZALEZ 1967, UR 62, 57848, EF: W32.
13. *Racemonocolpites racematus* (VAN DER HAMMEN 1954) GONZALEZ 1967, UR 743+50, 57859, EF: U37/2.
14. *Retimonocolpites longicolpatus* LORENTE 1986, IC-FA- 4 (101,38), 55926 (ICP), EF: E59.

15, 16. *Retimonocolpites retifossulatus* LORENTE 1986, IC-PE-2 (22,5), 55708, EF: H49/4.

17, 18. *Retimonocolpites tertiarius* GONZALEZ 1967, IC-FP-1 (18,53), 56024, EF: M33.

19. *Rugumonocolpites* "pacificus", IC-CC-12 (37,75), 55803 (ICP), EF: J59/2.
20. *Spinizonocolpites baculatus* MULLER 1968, UR 743+50, 57859, EF: O46/3-4.
21. *Spinizonocolpites* cf. *Spinizonocolpites baculatus* MULLER 1968, UR 531+100, 57277, EF: K42/1-2.
22. *Spinizonocolpites baculatus* (forma 2) "brevibaculatus" MULLER 1968, IC-FA-3 (6,12), 55771(1), EF: X55/1
23. *Spinizonocolpites baculatus* (forma 3) MULLER 1968, IC-FA-3 (6,12), 55771 (ICP), EF: N41/2.

PLATE 1.4

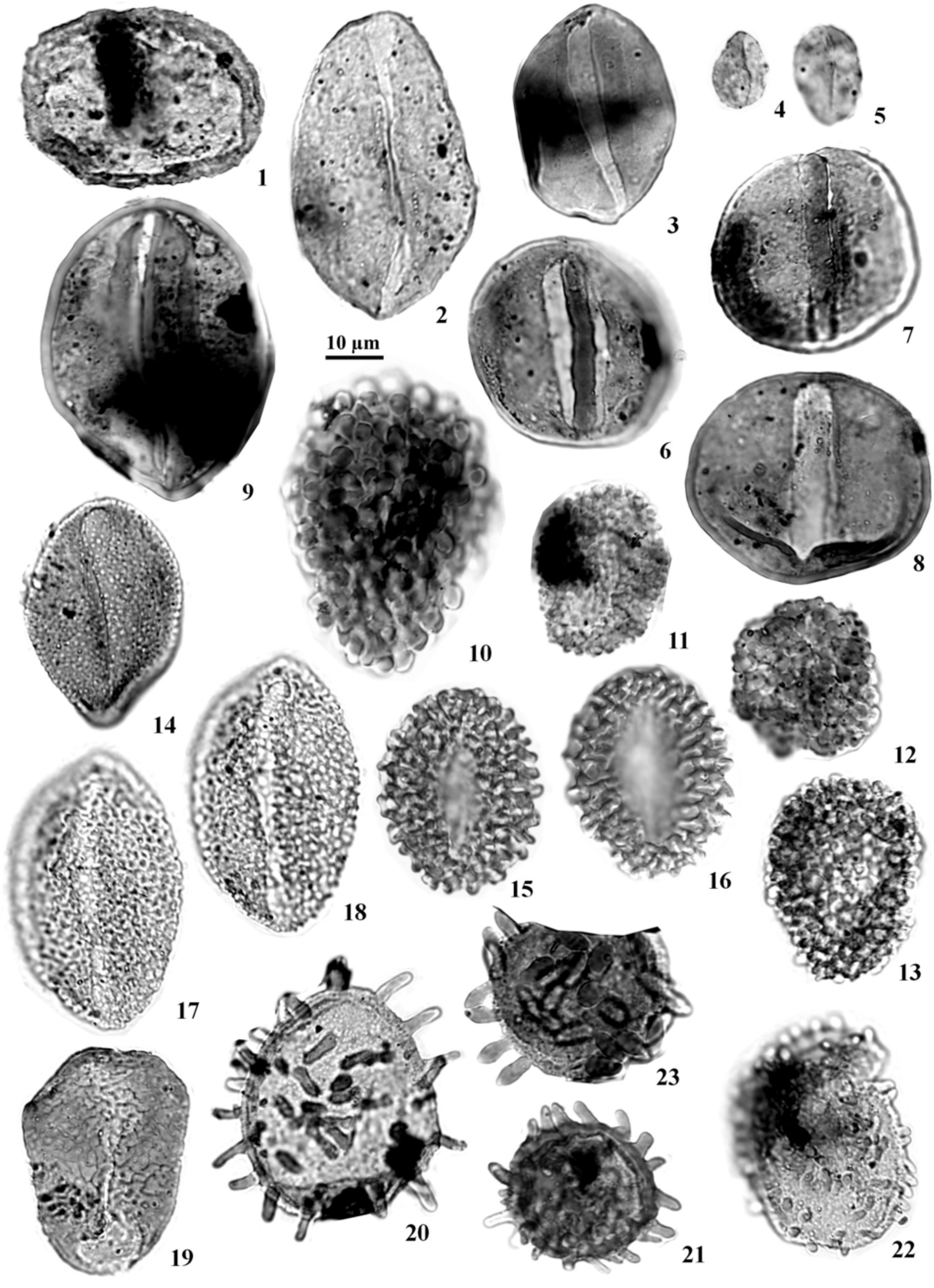

PLATE 1.5

Pollen and spores from the Middle Magdalena Valley Basin (Monocolpates-triporates)

1. *Spinizonocolpites breviechinatus* JARAMILLO & DILCHER 2001, UR 219+150, 57158, EF: F38/1.
2. *Spinizonocolpites echinatus* MULLER 1968, SD-D-8D (44,9), 56254, EF: T38/3.
3. *Spinizonocolpites echinatus* (psilate), IC-FP-1 (174,2), 55979, EF: H52/1.
4. *Echimorphomonocolpites gracilis* GONZALEZ 1967, IC-CC-7(11,6), 55846 (2), EF: E55/2.

5, 6. *Diporoconia* cf. *D. iszkaszentgyoergyi* (KEDVES 1965) FREDERIKSEN et al. 1985, UR 216+60, 57155, EF: E37.

7. *Diporoconia* cf. *D. iszkaszentgyoergyi* (KEDVES 1965) FREDERIKSEN et al. 1985, UR 215+90, 57113, EF: F48/3.
8. *Retidiporites magdalenensis* VAN DER HAMMEN & GARCIA 1966, LIS 447, 57109, EF: S52/1.
9. *Corsinipollenites psilatus* JARAMILLO & DILCHER 2001, IC-PE-2 (22,5), 56686, EF: H50.
10. *Corsinipollenites psilatus* JARAMILLO & DILCHER 2001, UR 235, 57244, EF: X53.
11. *Cricotriporites guianensis* LEIDELMEYER 1966, IC-FA-4 (73,85), 55939(1), EF: Q34/1.
12. *Cricotriporites macroporus* JARAMILLO & DILCHER 2001, UR212+130, 57112, EF: K46-2.
13. *Duplotriporites ariani* SARMIENTO 1992, UR512, 57276, EF: M55/4.
14. *Echitriporites* "annulatus", IC-CC-12 (37,75), 55803(1), EF: N60.
15. *Echitriporites trianguliformis* VAN HOEKEN KLINKENBERG 1964, UR 531+100, 57839, EF: E53/1.
16. *Echitriporites trianguliformis* VAN HOEKEN KLINKENBERG 1964, UR732+30, 57852, EF: E50/3.
17. *Foveotriporites hammenii* GONZALEZ 1967, SD-D-8D (44,9), 56254(1), EF: V51/2.
18. *Foveotriporites* sp. 1 JARAMILLO & DILCHER 2001, IC-FA-3 (6,12), 55771(1), EF: Q36/3.
19. *Proteacidites* cf. *dehaani* GERMERAAD et al. 1968, IC-FA-4 (73,85), 55939(1), EF: V44/2.
20. *Proteacidites triangulatus* LORENTE 1986, SD-D-8D (9,06), 56262, EF: O36/4.
21. *Retitriporites* cf. *federicii* GONZALEZ 1967, SD-D-8D (9,06), 56262, EF: T39/3.

PLATE 1.5

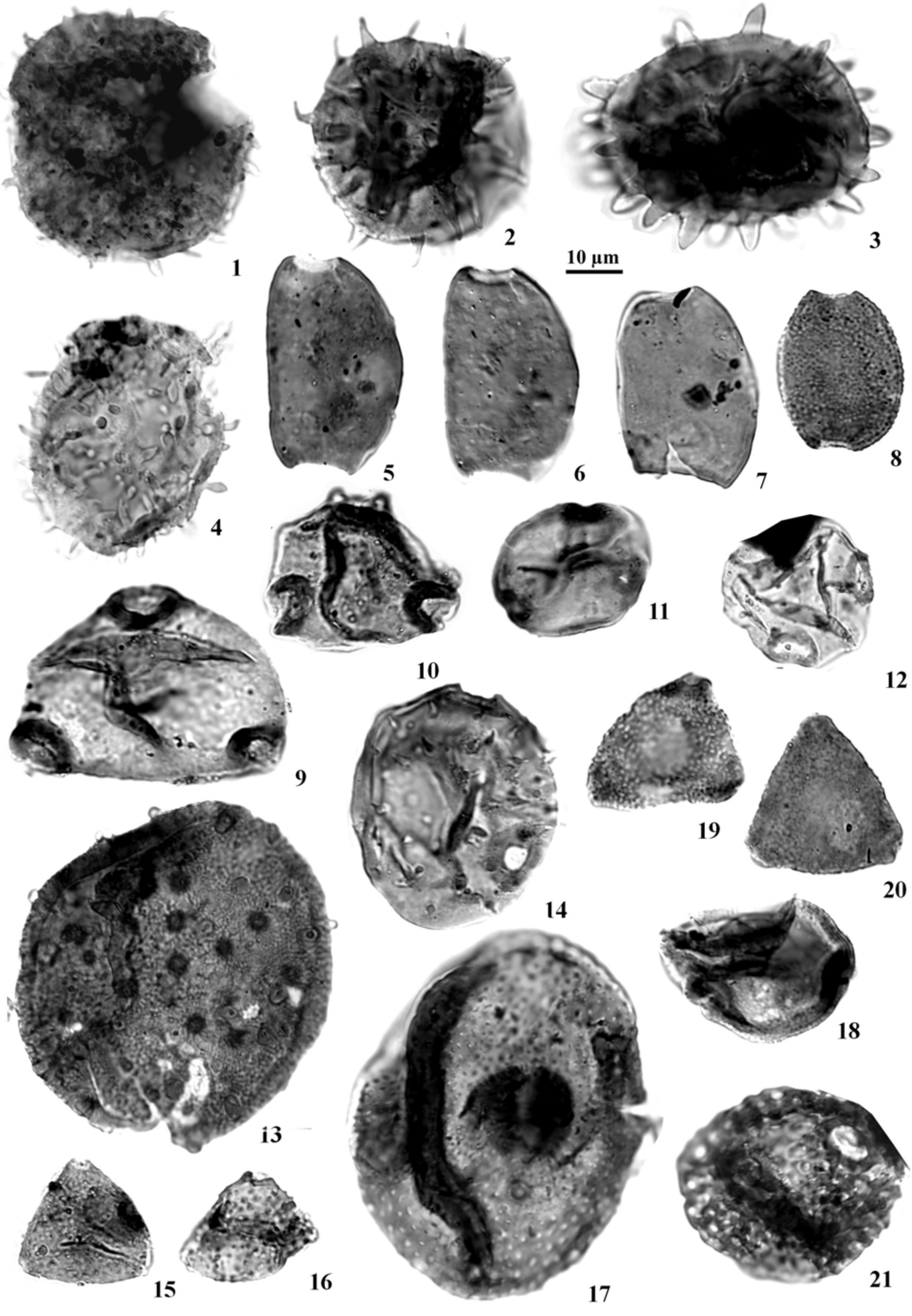

PLATE 1.6

Pollen and spores from the Middle Magdalena Valley Basin (Triporates-Tricolpates)

1, 2. *Retitriporites* cf. *poricostatus* JARAMILLO & DILCHER 2001, SD-D-8D (44,9), 56254(2), EF: P60/4.
3, 4, 5. *Retitriporites* sp. 3, IC-CC-7 (11,6), 55846(1), EF: F34/2-4.
6. *Striatriporites* sp. 1, IC-FA-3 (64,85), 55764 (2), EF: L39.
7. *Triatriopollenites* sp. UR224+10, 57161, EF: O46/1.
8, 9. *Psilatriporites* sp. 1 (triangular), IC-FP-1 (165,6), 55980(2), EF: G49/4.
10. *Psilatriporites,* IC-PE-2 (12,6), 55711(1), EF: R35.
11. *Triporites annulatus* VAN DER HAMMEN 1954, UR531+100, 57839, EF: S52.
12. *Echiperiporites* sp. IC-FA-3 (17,1), 55817, EF: K53-1, polar view.
13. *Echiperiporites* sp. IC-PE-2 (12,6), 56058, EF: G47.
14. *Psilastephanoporites* "oculiporus", UR 62, 57083, EF: L44.
15. *Psilastephanoporites* "oculiporus", UR 147, 57107, EF: S49/2.
16, 17. *Retistephanoporites minutiporus* JARAMILLO & DILCHER 2001, IC-PE-2 (12,6), 55711, EF: J35/3.
18. *Retistephanoporites* sp.1, IC-CC-7 (9,5), 55847 (1), EF: V42/4.
19. *Retistephanoporites* sp. 2, IC-CC-7 (9,5), 55833, EF: R36/2.
20. *Ulmoideipites krempii* (4 pores) (ANDERSON 1960) ELSIK 1968b, UR 62, 57848, EF: C45/3.
21. *Ulmoideipites krempii* (5 pores) (ANDERSON 1960) ELSIK 1968b, UR 512, 57853, EF: M52/4.
22. *Albertipollenites*? *perforatus,* (GONZALEZ 1967) JARAMILLO & DILCHER 2001, IC-PE-2 (12,6), 55711, EF: D44/2, polar view.
23. *Albertipollenites*? *perforatus,* (GONZALEZ 1967) JARAMILLO & DILCHER 2001, IC-PE-2 (22,5), 55708(1), EF: T46, ecuatorial view.
24, 25. *Brevitricolpites* "densiechinatus", IC-FA-4 (48,85), 55973(1), EF: O42/1.

PLATE 1.6

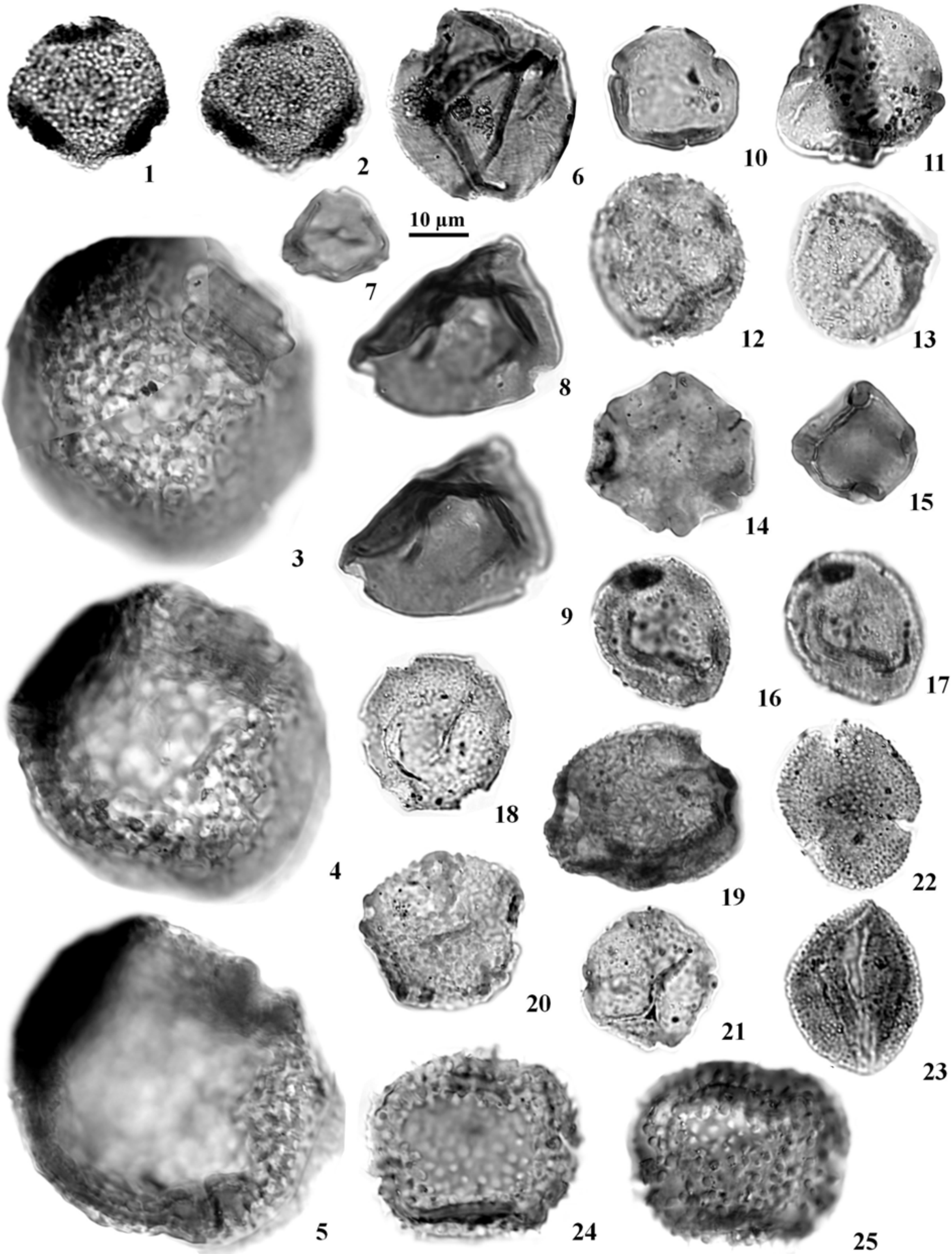

PLATE 1.7

Pollen and spores from the Middle Magdalena Valley Basin (Tricolpates)

1. *Brevitricolpites microechinatus* JARAMILLO 2001, IC-FP-1(165.52), 55996(2), EF: N45/3.
2, 3. *Brevitricolpites* aff. *microechinatus* JARAMILLO & DILCHER 2001, IC-FP-1(91,4), 55019, EF: N43/3.
4. *Brevitricolpites* sp. 1 (gemmate), IC-FA-4 (101.38), 55926(2), EF: D59/3.
5. *Brevitricolpites* sp. 2 (baculate), IC-FA-4 (34.2), 55974(2), EF: C48/1.
6. *Brevitricolpites* sp. 3 (triangular, echinate), SD-D8D (9.06), 56262, EF: L49.
7, 8. *Brevitricolpites* sp. 5 (spines < 1 µm), UR 396, 57844, EF: L27/1-2.
9. *Clavatricolpites densiclavatus* JARAMILLO & DILCHER 2001, Polar view. IC-PE-2 (12.6), 56058, EF: G41.
10. *Clavatricolpites densiclavatus* JARAMILLO & DILCHER 2001, Equatorial view, IC-FA-3 (64.85), 55764 (1), EF: E54.
11, 12. *Clavatricolpites* sp. 1. IC-CC-12 (37.75), 55803(1), EF: R49/4.
13. *Foveotricolpites perforatus* VAN DER HAMMEN & GARCIA 1966, UR 238+40, 57245, EF: K41
14, 15. *Ladakhipollenites* "minutus", IC-CC-12 (37,75), 55803 (1), EF:S50/2, 33: IC-CC-7 (9,5), 55847 (1), EF: U33.
16. *Ladakhipollenites simplex* (GONZALEZ 1967) JARAMILLO & DILCHER 2001, IC-PE-2 (12.6), 55711(1), EF: E36.
17, 18. *Perfotricolpites* cf. *digitatus* GONZALEZ 1967, IC-FA-3 (6,12), 55771(1), EF: M40/2.
19. *Perfotricolpites* cf. *digitatus* GONZALEZ 1967, IC-CC-7 (11,6), 55846 (1), EF: Q46/2.
20. *Psilabrevitricolpites* sp. IC-CC-7 (9,5), 55833, EF: K43/1.
21. *Retibrevitricolpites triangulatus* VAN HOEKEN KLINKENBERG 1966, IC-FP-1 (156,52), 55996(2), EF: Q47/3.
22. *Retitrescolpites* cf. *baculatus* JARAMILLO & DILCHER 2001, IC-FP-1 (174.2), 55979(2), EF: W37/2.
23. *Retitrescolpites*? *irregularis* VAN DER HAMMEN & WYMSTRA 1964 (JARAMILLO & DILCHER 2001), IC-FA-4 (48.85), 55973 (1), EF: U43/2.
24, 25. *Retitrescolpites magnus* GONZALEZ 1967 (JARAMILLO & DILCHER 2001), IC-PE-12 (12.6), 55711 (1), EF: V56/2.
26. *Rousea florentina* GONZALEZ 1967 (JARAMILLO & DILCHER 2001), IC-CC-7 (9.5), 55847 (1), EF: Q46/3
27. *Rugutricolpites* sp. 1. IC-PE-2 (22.5). 55708(1). EF: W48/1.
28. *Tricolpites clarensis* GONZALEZ 1967, IC-FP-1 (18.53), 56024, EF: H45.
29. *Tricolpites conciliatus* GONZALEZ 1967, Equatorial view, IC-FP-1 (156,52), 55996(1), EF: H53/2.
30. *Tricolpites conciliatus* GONZALEZ 1967, Polar view, IC-FP-1 (156,52), 55996(1), EF: O35.

PLATE 1.7

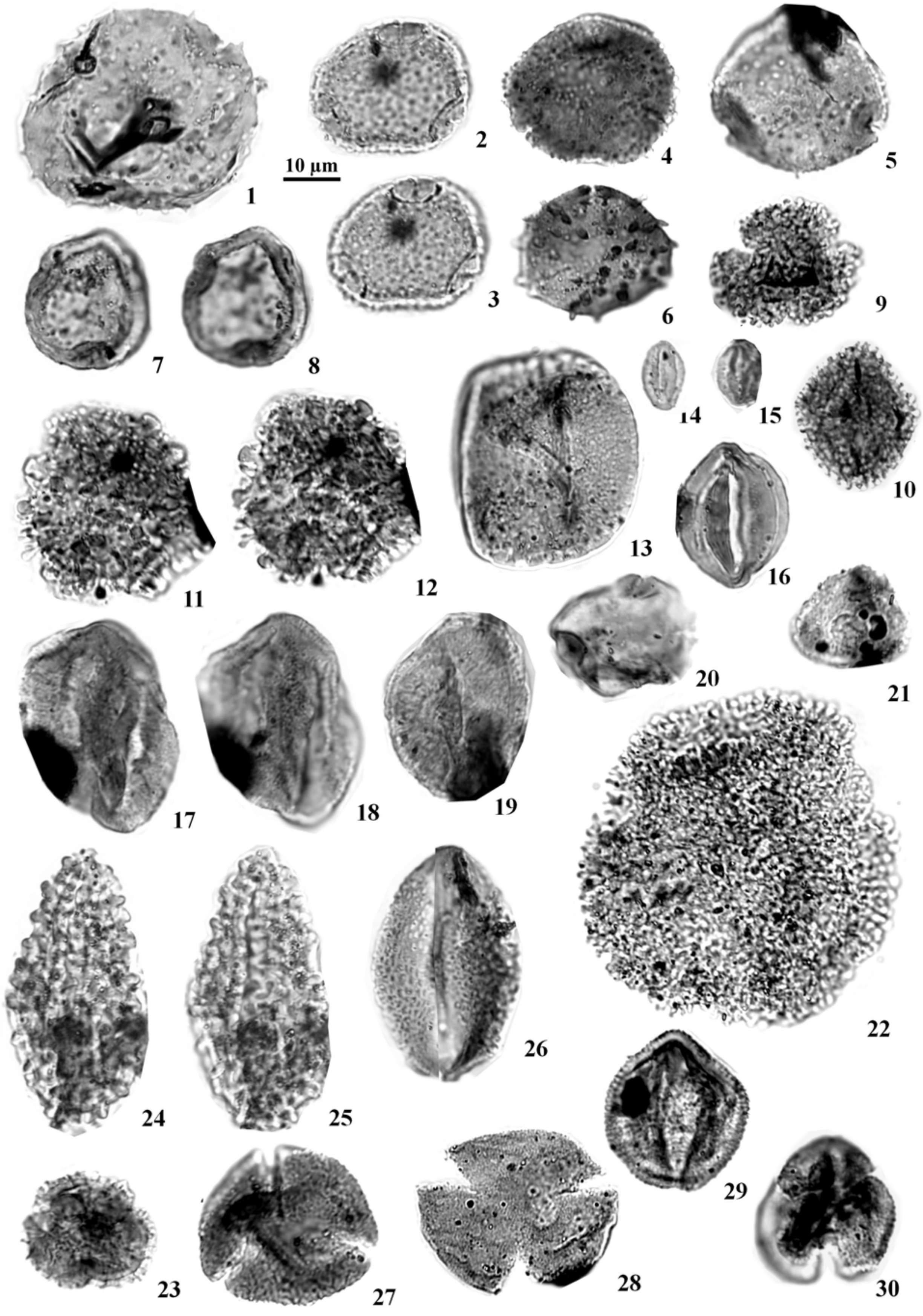
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PLATE 1.8

Pollen and spores from the Middle Magdalena Valley Basin (Tricolpates-Stephanocolpates-Tricolporates)

1. *Tricolpites* cf. *minutus* GONZALEZ 1967, IC-PE-2 (22.5), 56062, EF: V49/2.
2. *Tricolpites protoclarensis* JARAMILLO & DILCHER 2001, SD-D-8D (9,06), 56262, EF: L49/4.
3. *Retitricolpites* cf. *simplex* GONZALEZ 1967, IC-FP-1 (91,4), 56035(1), EF: J47.
4. *Retitricolpites* cf. *simplex* GONZALEZ 1967, SD-D-8D (44.9), 56254(1), EF: R42/2.
5. *Tricolpites* "simetricus", polar view, IC-PE-2(22.5), 55708(1), EF: D42-3
6. *Tricolpites* "simetricus", Equatorial view, (IC-PE-2, 22,5), IC-PE-2 (22.5), 55708 (1), EF: O44/2.
7. *Retitricolpites* cf. *R. retiaphelis* LEIDELMEYER 1966, UR 216+60, 57155, EF: L43/4.
8. *Scabratricolpites* sp.1 (24-30 µm long), UR62, 57848, EF: K46/2.
9. *Tricolpites* sp.2 (reticulate to the equator; < 20 µm), UR 221+40, 57160, EF: P48/3.
10. *Foveotricolpites* sp., SD-D-8D (9.06), 56262, EF: U57.
11. *Foveotricolpites* sp. (fossulate), UR746+50, 57859, EF: U51/2
12. *Verrutricolpites* sp. 1, IC-FA-4 (101,38), 55926(1), EF: J45.
13, 14. *Retistephanocolpites* sp. (foveolate), IC-FP-1 (165,52), 55996 (1), EF: K48/2.
15, 16. *Retistephanocolpites* sp. 1 (microret, 7 colpi), UR 743+50, 57859, EF: B33/1-2.
17. *Araliaceoipollenites*? sp. 1 JARAMILLO & DILCHER 2001, IC-FA-4 (101,38), 55926 (2), EF: S46/4.
18. *Araliaceoipollenites*? sp. 2 JARAMILLO & DILCHER 2001, UR212+130, 57112, EF:F45.
19. *Bombacacidites annae* (VAN DER HAMMEN 1954) GERMERAAD et al. 1968, UR212+130, 57112, EF: W37/2.
20. *Bombacacidites* (homogenous reticulum; cf. *B. baumfalki* LORENTE 1986), IC-FP-1 (174,2), 55979(2), EF: K44/2.
21. *Bombacacidites* (homogenous reticulum), UR531+100, 57839, EF: G53/3.
22. *Bombacidites* aff. *gonzalezii* JARAMILLO & DILCHER 2001, IC-FP-1(174,2), 55979 (2), EF: T35/2.
23. *Bombacidites* aff. *gonzalezii* JARAMILLO & DILCHER 2001, IC-FA-4(48,85), 55973(1), EF: F55/2.
24. *Bombacacidites* "lisamae", UR 212+130, 57112, EF: S43/3.
25. *Bombacacidites* "lisamae", UR 238+40, 57241, EF: T49/2.
26. *Bombacacidites* "lisamae", UR 224+10, 57161, EF: E37/1.

PLATE 1.8

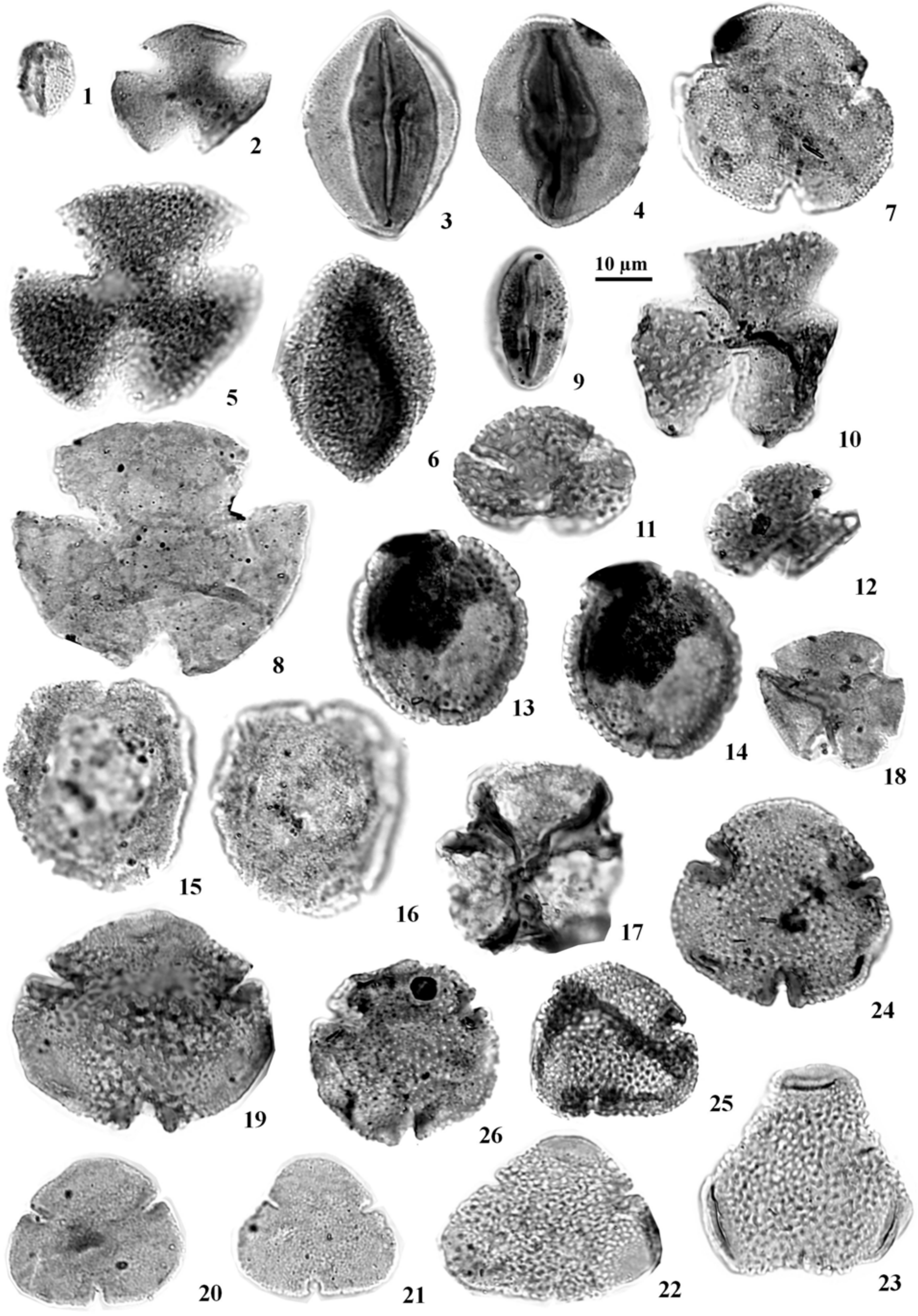

PLATE 1.9

Pollen and spores from the Middle Magdalena Valley Basin (Tricolporates)

1. *Bombacacidites* cf. *nacimientoensis* (ANDERSON 1960) ELSIK 1968, UR806, 57387, EF: G49/1.
2. *Bombacacidites* cf. *nacimientoensis* (ANDERSON 1960) ELSIK 1968, IC-FA-3 (64.85), 55764(1), EF: R48/3.

3, 4. *Bombacacidites protofoveoreticulatus* JARAMILLO & DILCHER 2001, UR 147, 57850, EF: P56/3.

5. *Bombacacidites* “pseudosimplireticulatus”, IC-FA-3 (64.85), 55756, EF: Q45/4.

6, 7. *Bombacacidites psilatus* JARAMILLO & DILCHER 2001, IC-PE-2 (12.6), 55711(1), EF: P37/1

8, 9. *Bombacacidites* "fossulatus", UR219+150, 57158, EF: P38/4.

10. *Bombacacidites* cf. *Soleaformis* MULLER et al. 1987, IC-FA-4 (101.38), 55926(2), EF: D56/1.
11. *Bombacacidites* sp. 1, IC-FA-3 (64.85), 55764(2), EF: L50-4.
12. *Bombacacidites* sp. 2. IC-FA-3 (17.1), 55817, EF: S32/1.
13. *Bombacacidites* sp. 3. IC-FA-3 (6.12), 55771(1), EF: D48/2.
14. *Bombacacidites* sp. 5. IC-CC-12 (37.75) 55803(2), EF: F56.

15, 16. *Bombacacidites* sp. 6, IC-CC-12(37,75), 55803(1), EF: H58/1.

17. *Bombacacidites* sp. 7 sp 1. de JARAMILLO & DILCHER 2001, IC-CC-12(37.75), 55803(1), EF: S57/4.

18, 19. *Bombacacidites* sp. 8 (fossulate, vermiculate reticle), IC-CC-7 (11.6), 55846(1), EF: N43/3.

20. *Bombacacidites* sp. 8 (Fossulate, vermiculate reticle), IC-FA-4 (101.38), 55882, EF: X50/3.

PLATE 1.9

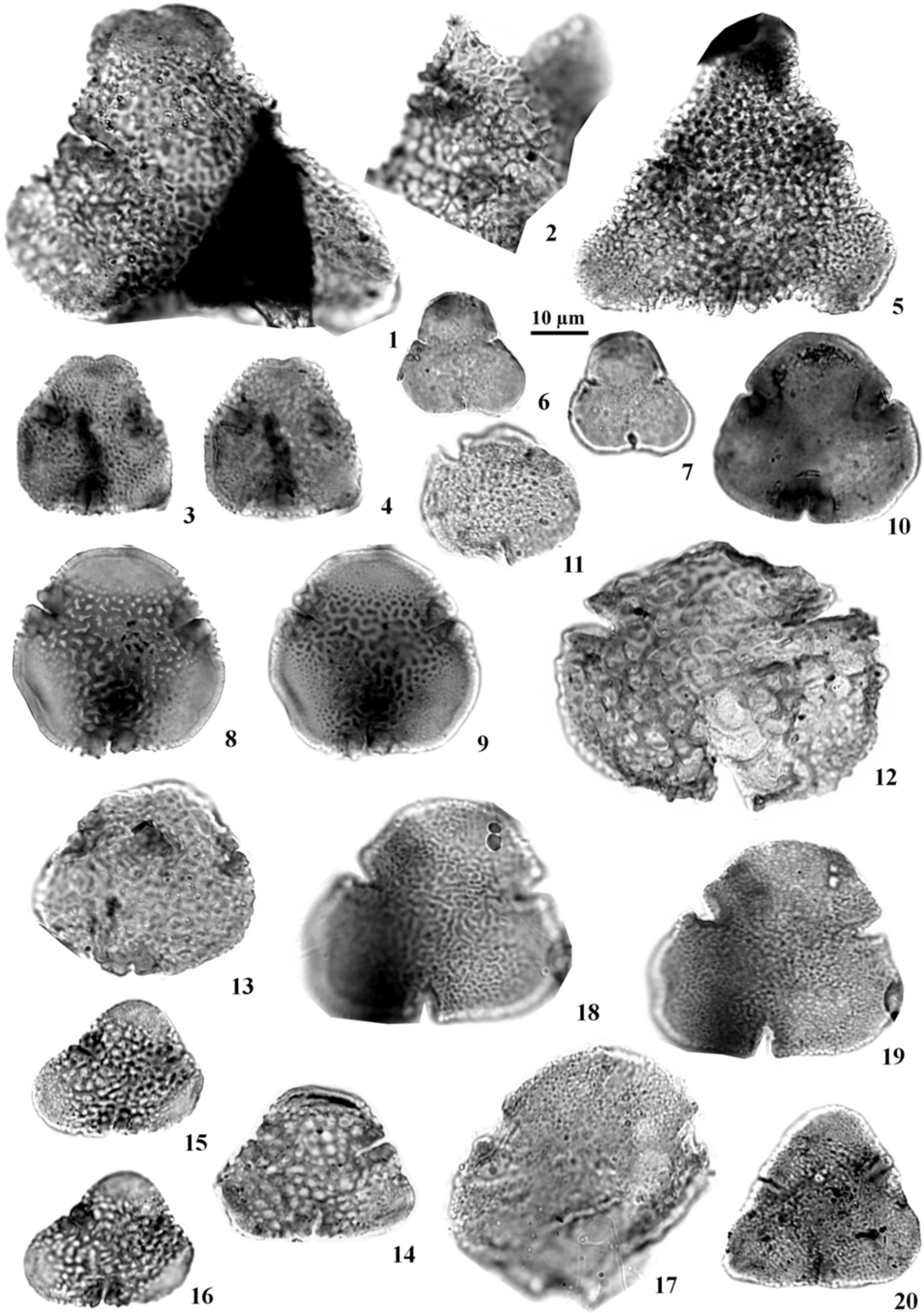

PLATE 1.10

Pollen and spores from the Middle Magdalena Valley Basin (Tricolporates)

1. *Bombacacidites* sp 9, IC-FA-4 (101,38), 55926(2), EF: J39/2.
2, 3. *Bombacacidites* sp. 10 (50 µm) foveolate, IC-FA-4 (48,85), 55973(2), EF: M37/3.
4. *Bombacacidites* sp. 11 (20 µm), IC-FA-4 (34,2), 55974 (1), EF: E48.
5. *Bombacacidites* sp. 12 (lumina 5 µm), IC-FP-1 (91,4), 56035(2), EF: O34/4.
6, 7. *Bombacacidites* sp. 13, IC-FP-1 (91,4), 55019, EF: L33/3.
8, 9. *Bombacacidites* sp. 14, IC-FP-1 (18,53), 57305, EF: P43/3.
10. *Bombacacidites* sp. 14, IC-FP-1 (18,53), 57305, EF: Q38/2.
11. *Bombacacidites* sp. 15 (foveolate in the polar region), SD-D-8D (44,9), 56254(1), EF: U42.
12. *Bombacacidites* sp. 16 (sp. 3 of JARAMILLO & DILCHER 2001), SD-D-8D (44,9), 56254(2), EF: J54.
13. *Bombacacidites* sp.17, SD-D-8D (9.06), 56262, EF: V54.
14, 15. *Intratriporopollenites* sp. UR 216+60, 57155, EF: Q40/4.
16. *Intratriporopollenites* sp. UR 216+60, 57155, EF: E45/2.

PLATE 1.10

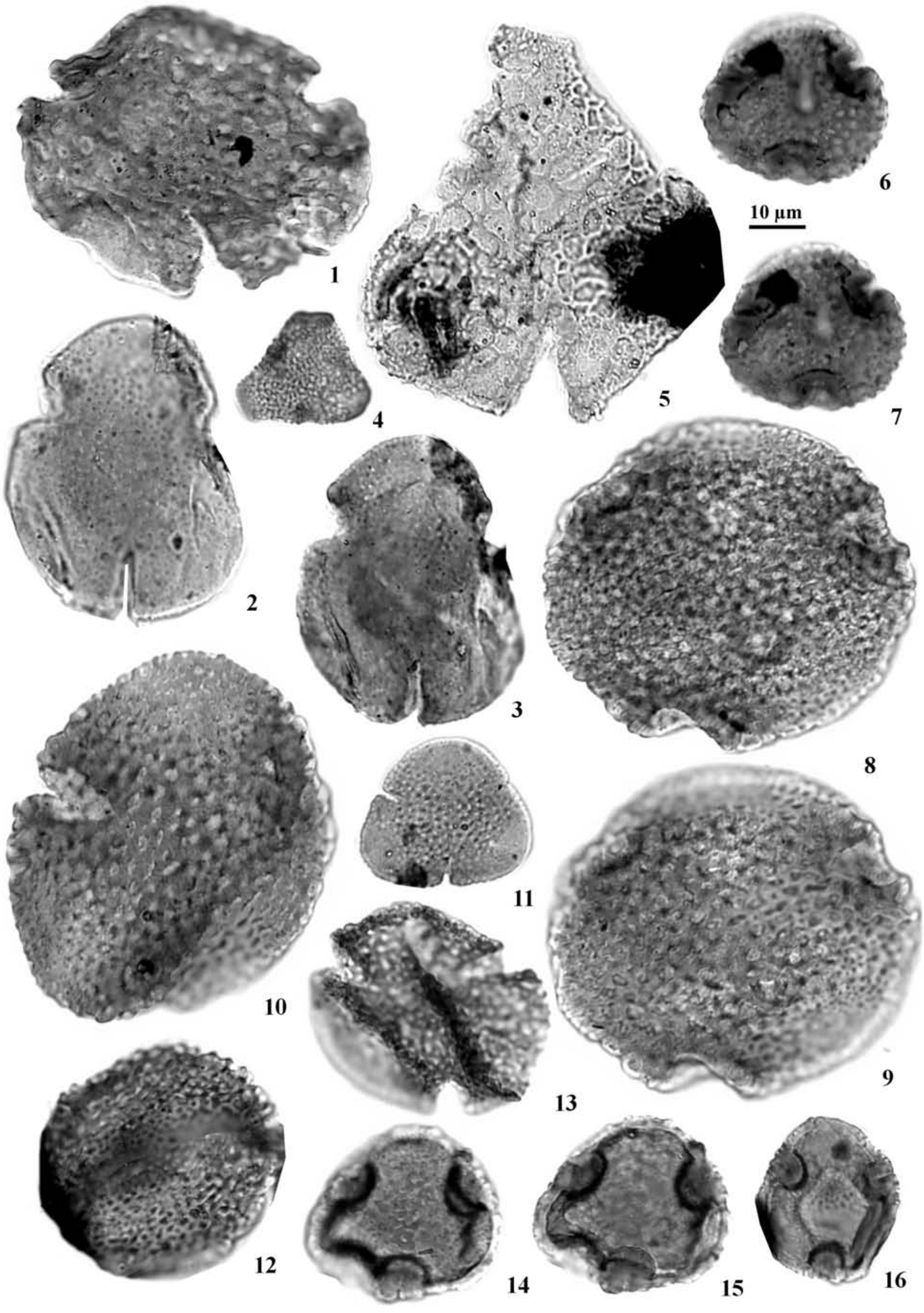

PLATE 1.11

Pollen and spores from the Middle Magdalena Valley Basin (Tricolporates)

1. *Bombacacidites* "magnificum", UR806, 57387, EF: M37.
2. *Bombacacidites* sp. B (4 colpi), UR 224+10, 57161, EF: F46/2.
3. *Bombacacidites* sp. C (4 colpi), UR 732+30, 57330, EF: P50/1.
4. *Clavatricolporites leticiae* LEIDELMEYER 1966, UR238+40, 57245, EF: E43-3.
5. *Colombipollis tropicalis* JARAMILLO & DILCHER 2001, UR147, 57850, EF: D63/3-4.
6. *Foveotricolporites* cf. sp.3 (JARAMILLO & DILCHER 2001), UR732+30, 57852, EF: W60.
7. *Horniella* "sogamosa", IC-FA-3 (64,85), 55764(1), EF: R45/1.
8. *Horniella* sp., IC-CC-7(11.6), 55846 (1), EF: F55-4.
9. *Gemmatricolporites* sp. 1, IC-FA-4(73,85), 55939(1), EF: W34-1.
10. *Horniella* sp.1 (pores costate), UR62, 57848, EF: V55.
11. *Lanagiopollis crassa* (VAN DER HAMMEN & WYMSTRA 1964) FREDERIKSEN 1988, UR806, 57365, EF: V48.
12. *Horniella* sp. UR806, 57877, EF: G46-3.
13. *Polotricolporites mocinnii* GONZALEZ 1967, IC-FA-3(64.85), 55756, EF: H49-2.
14. *Psilabrevitricolporites* sp. 1, IC-CC-12(37.75), 55803(2), EF: G60-1.
15. *Psilabrevitricolporites* "simplex", UR396, 57304, EF: S50/2-4.
16. *Psilabrevitricolporites* sp. 2, UR531+100, 57839, EF: U62-1.
17. *Psilabrevitricolporites* "simplex", UR531+100, 57277, EF: M53/1.
18. *Psilabrevitricolporites triangularis* (VAN DER HAMMEN & WYMSTRA 1964) JARAMILLO & DILCHER 2001, UR531+100, 57839, EF: U48/1-2.
19. *Psilatricolporites costatus* DUEÑAS 1980, IC-CC-7(11,6), 55846(1), EF: N55/4.
20. *Psilatricolporites normalis* GONZALEZ 1967, IC-FA-3(64,85), 56133, EF: O38/3.
21. *Psilatricolporites* "minutus", UR216+60, 57155, EF: Q46.
22. *Psilatricolporites* sp. 1 IC-FA-3 (17,1), 55817, EF: V45/4.
23. *Retibrevitricolporites* cf. *R. grandis* JARAMILLO & DILCHER 2001, IC-PE-2(12,6), 56058, EF: N59/4.
24. *Horniella* sp. 2 (cf. *H.* sp. 2 de JARAMILLO 2001), IC-FA-3(64,85), 55764(2), EF: P46/4.
25. *Retitricolporites* "poricostatus", IC-FP-1(174,2), 55979(1), EF: N41.
26. *Retitricolporites* cf. *equatorialis* GONZALEZ 1967, IC-FP-1(165,52), 55996(2), EF: R36/4.
27. *Retitricolporites finitus* GONZALEZ 1967, IC-PE-2(12,6), 55711, EF: Q49/2.
28. *Siltaria mariposa* (LEIDELMEYER 1966) JARAMILLO & DILCHER 2001, IC-PE-2(12,6), 55711, EF: K31/2.
29. *Siltaria* sp. 4, JARAMILLO & DILCHER 2001, UR531+100, 57839, EF: J35/1.

PLATE 1.11

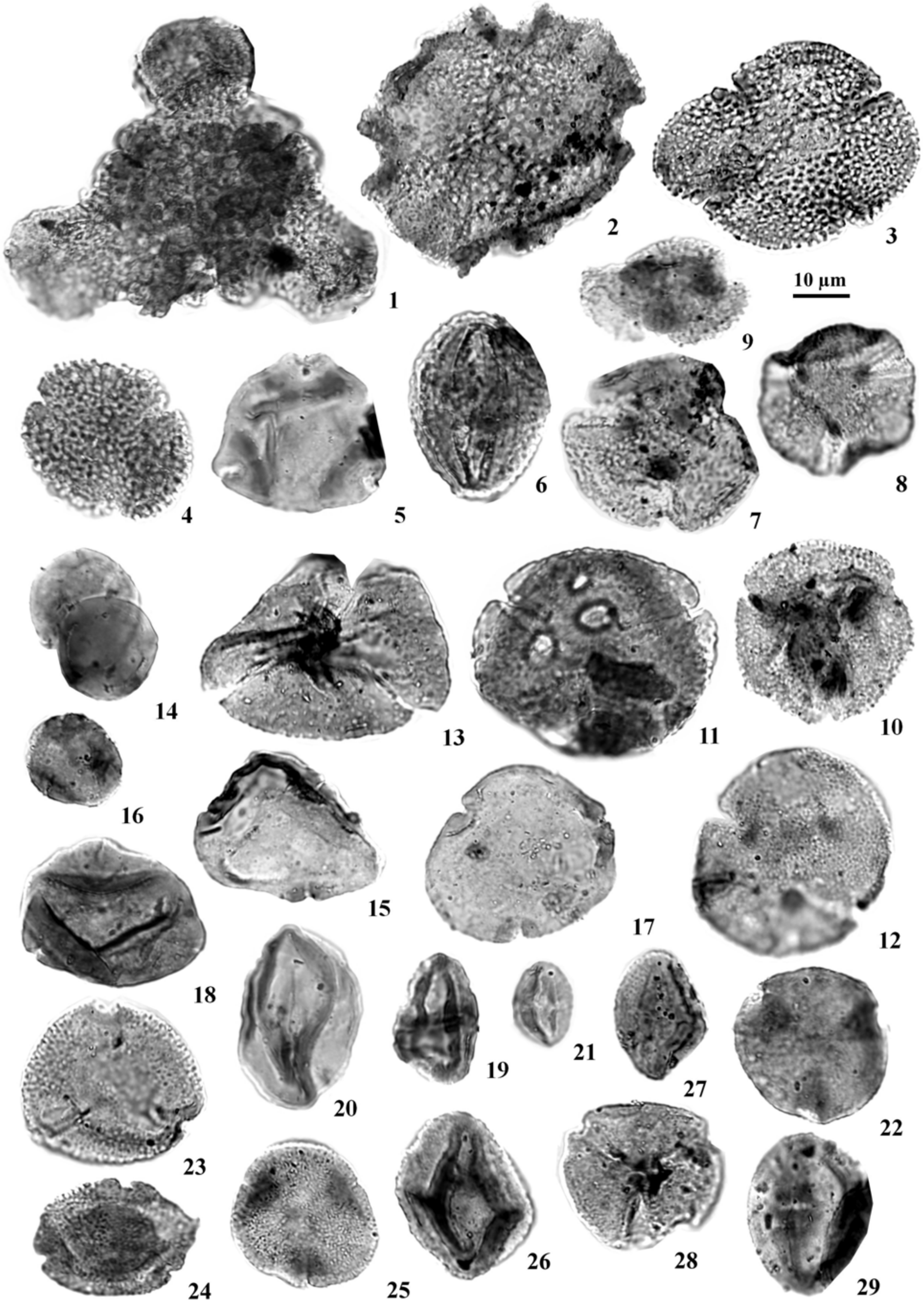
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PLATE 1.12

Pollen and spores from the Middle Magdalena Valley Basin (Tricolporates-Stephanocolporates-Syncolporates)

1. *Striatopollis catatumbus* (GONZALEZ 1967) TAKAHASHI & JUX 1989, IC-PE-2 (12,6), 56058, EF: R53/3-4.
2. *Striatopollis catatumbus* (GONZALEZ 1967) TAKAHASHI & JUX 1989, SD-D-8D(44.9)56254(1), EF: J40-1.
3. *Striatopollis minor* (WIJMSTRA 1971) JARAMILLO & DILCHER 2001, IC-PE-2(22,5), 56686, EF: L51.
4. *Striatopollis*? *Tenuistriatus* JARAMILLO & DILCHER 2001, UR743+50, 57859, EF: R48/2-4.
5. *Striatopollis*? *Tenuistriatus*, JARAMILLO & DILCHER 2001, IC-FA-4 (48,85), 55973(2), EF: D42.
6. *Striatricolporites* cf. *S. pimulis* VAN HOEKEN-KLINKENBERG 1966, IC-FP-1(174,2), 55979(2), EF: O53/3.

7, 8. *Striatricolporites digitatus* JARAMILLO 2001, IC-PE-2(12,6), 55711, EF: K47/1.

9. *Tetracolporopollenites* ("minutus") UR221+40, 57160, EF: G47/3.

10, 11. *Tetracolporopollenites maculosus* REGALI et al. 1974, IC-FA-4(73,85), 55939(2), EF: J40/3.

12. *Tetracolporopollenites* "grandis". SD-D-8D(44,9), 56254(2), EF: R52.
13. *Tetracolporopollenites* sp. (pore lalongate 8 µm) IC-FA-4(101.38)55926(1)Tricolporzon, EF: H50-3.
14. *Tetracolporopollenites spongiosus* JARAMILLO & DILCHER 2001, UR221+40, 57160, EF: N51/4.
15. *Tetracolporopollenites transversalis* DUEÑAS 1980, IC-CC-7(11.6), 55846(1), EF: P54.
16. *Tetracolporopollenites* "triploporatus", IC-FP-1(165,52), 55986, EF: J47.
17. *Verrutricolporites haplites* GONZALEZ 1967, IC-FP-1(174,2), 55979(1), EF: U40/3-4.
18. *Zonocostites minor* JARAMILLO & DILCHER 2001, IC-FA-4(73,85), 55939(2), EF: R56/3.
20. *Psilastephanocolporites* cf. *P. brevicolpatus* JARAMILLO 2001, IC-FP-1(165,52), 55996(1), EF: G32/4.
21. *Psilastephanocolporites fissilis* LEIDELMEYER 1966, UR806, 57387, EF: G55/4.
22. *Psilastephanocolporites* sp. 3, IC-FA-4(34,2), 55974(1), EF: L42.

23, 24, 25. *Retistephanocolporites* sp. 1, IC-PE-2(12,6), 55711(1), EF: X40/3.

26. *Psilasyncolporites*? sp. 1. IC-FA-4(48.85)55973(2), EF: M42-1.
27. *Psilasyncolporites*? sp. 1., UR147, 57850(2), EF: B55/1.
28. *Syncolporites* cf. *S. marginatus* SARMIENTO 1992, UR531+100, 57277, EF: P47.

29, 30. *Spirosyncolpites spiralis* GONZALEZ 1967, 55803(1), EF: M59/3.

31. *Retistephanocolporites* sp. 2, UR 806, 57387, EF: J41/3.

PLATE 1.12

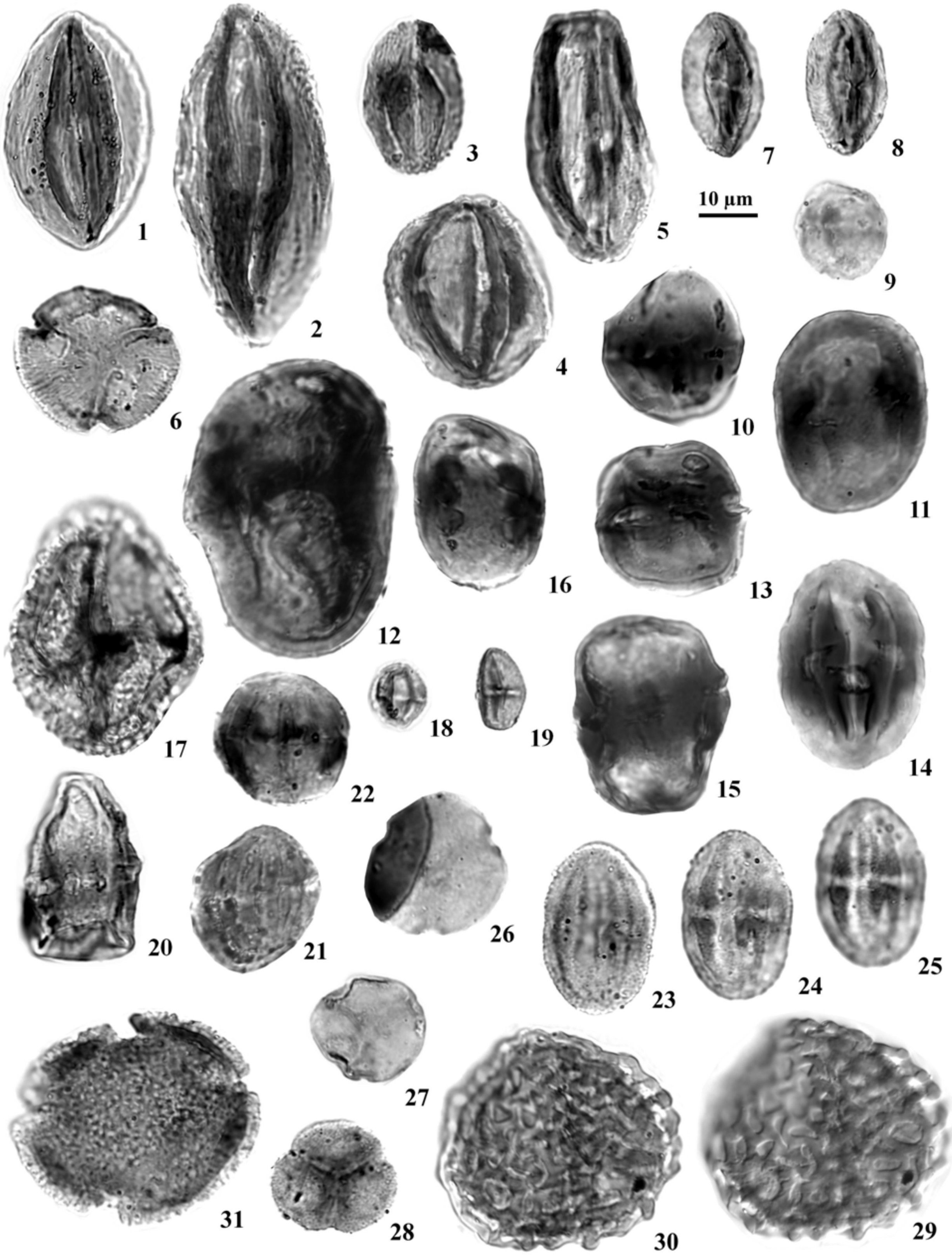
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PLATE 2.1

Palynomorphs from the Guaduas Formation (Paz de Río area)

1, 2. *Buttinia andreevi* BOLTENHAGEN 1967, PB1, 59965, EF: J50-4.
3. *Spinizonocolpites sutae* SARMIENTO 1992, PB1, 59965, EF: D52-1.
4. *Psilabrevitricolpites marginatus* SARMIENTO 1992, PB14, 60112, EF: H48.
5. *Echitriporites trianguliformis* VAN HOEKEN KLINKENBERG 1964, PB3, 59967, EF: K54-1,3.
6, 7. *Psilabrevitricolporites annulatus* SARMIENTO 1992, PB1, 59965, EF: K45.
8, 9. *Proxapertites verrucatus* SARMIENTO 1992, PB1, 59965, EF: E54-3.
10. *Racemonocolpites racematus* (VAN DER HAMMEN 1954) GONZALEZ 1967, PB3, 59967, EF: M40-1.
11. *Colombipollis tropicalis* SARMIENTO 1992, PB1, 59965, EF: E54-3.
12, 13. *Retitricolpites microreticulatus* (VAN DER HAMMEN 1954) VAN DER HAMMEN & WYMSTRA 1964, PB1, 59959, EF: K50-3.
14. *Psilamonocolpites operculatus* PARDO et al. 2003, PB22, 59206, EF: J34.
15. *Psilamonocolpites operculatus* PARDO et al. 2003, PB22, 59206, EF: S42.
16. *Stephanocolpites costatus* VAN DER HAMMEN 1954, PB22, 59206, EF: U52-2.
17. *Psilatriletes martinensis* SARMIENTO 1992, PB3, 59967, EF: N47.
18. *Cicatricososporites* sp. (fine striae), PB22, 59206, EF: R37-1.
19. *Foveotriletes margaritae* (VAN DER HAMMEN 1954) GERMERAAD et al. 1968, PB3, 59967, EF: H39-4.
20. *Andallusiella* sp., PB3, 59967, EF: L32.

PLATE 2.1

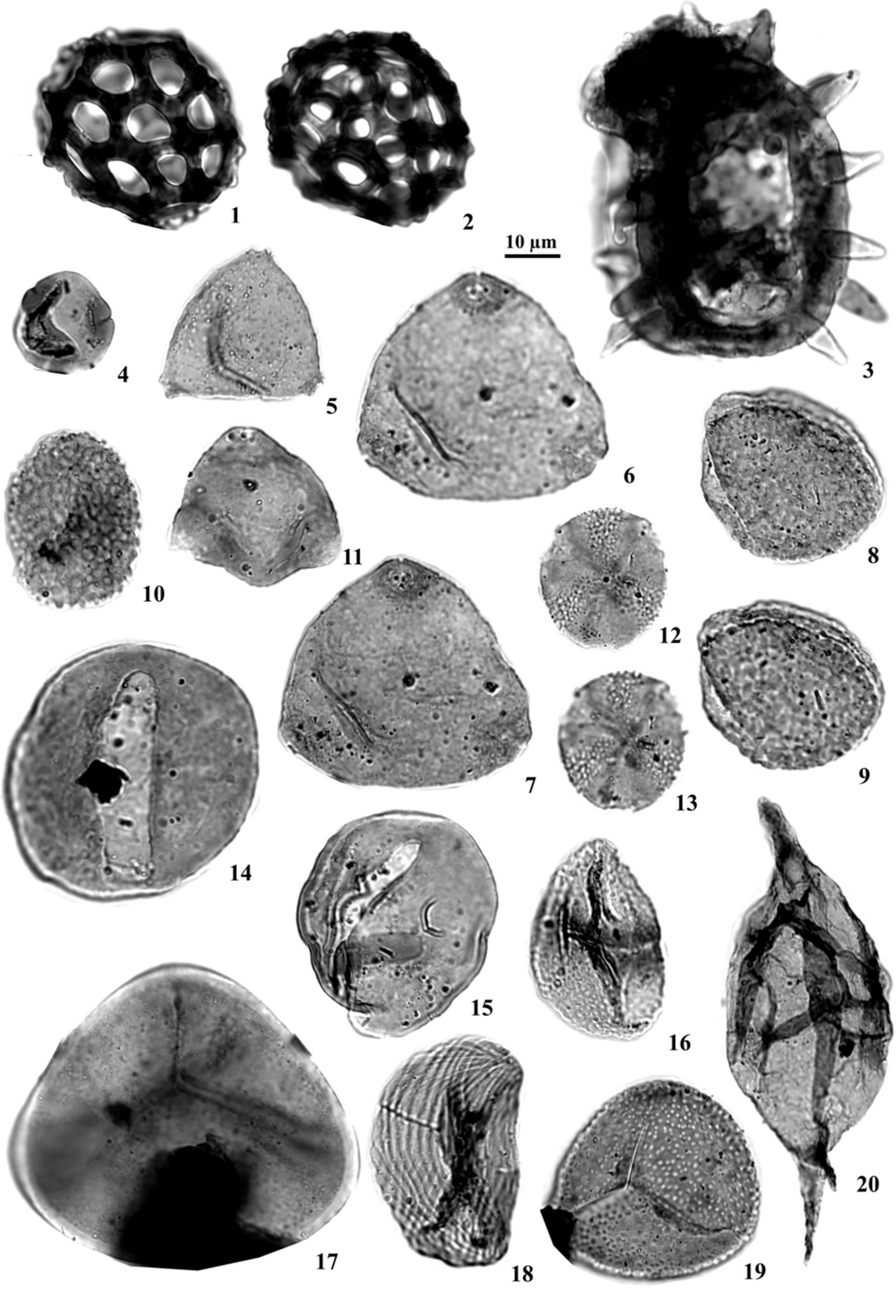

PLATE 2.2

Palynomorphs from the Paz de Río area

1. *Retidiporites* "cosguensis", CCN81, 58644, EF: R43/2,4.
2-4. *Retidiporites* "cosguensis", CCN81, 58644, EF: M44/3.
5. *Retidiporites botulus* LEIDELMEYER 1966, CCN78, 58589, EF: T39.
6. *Cricotriporites guianensis* LEIDELMEYER 1966, CCS42, 59181, EF: U43/2,4.
7. *Corsinipollenites psilatus* JARAMILLO & DILCHER 2001, CCS36, 58445, EF: S37/4.
8, 9. *Retitrescolpites*? *irregularis* (VAN DER HAMMEN & WYMSTRA 1964) JARAMILLO & DILCHER 2001, CCS36, 58445, EF: M48/3.
10. *Longapertites vaneendenburgi* GERMERAAD et al. 1968, CCN38, 58046, EF: C39/4.
11. *Foveotricolpites perforatus* VAN DER HAMMEN & GARCIA 1966, CCN47, 58585, EF: E40/3.
12. *Psilabrevitricolporites* "simplex", CCS35a, 59180, EF: L53/3.
13, 14. *Rugutricolporites* cf. *felix* GONZALEZ 1967, CCS36, 58445, EF: E53.
15. *Spinizonocolpites pachyexinatus* JARAMILLO & DILCHER 2001, CCN 101, 59452, EF: U47.
16. *Brevitricolpites macroexinatus* JARAMILLO & DILCHER 2001, CCS36, 58445, EF: X47/2.
17. *Margocolporites vanwijhei* GERMERAAD et al. 1968, CCS42, 59181, EF: P38/1.
18. *Bombacacidites* sp. B MULLER et al. 1987, CS38, 58455, EF: K50.
19. *Rhoipites guianensis* (VAN DER HAMMEN & WYMSTRA 1964) JARAMILLO & DILCHER 2001, CCS42, 59181, EF: E47/2,4.
20. *Rhoipites guianensis* (VAN DER HAMMEN & WYMSTRA 1964) JARAMILLO & DILCHER 2001, CCS42, 59181, EF: E47/2,4.
21. *Retistephanocolpites* sp., CCS38, 58455, EF: D48/3.
22. *Incertae* "pseudocolpate" (verrugate), CCN58, 58527, EF: G44.
23. *Psilastephanocolporites fissilis* LEIDELMEYER 1966, CCS42, 59181, EF: O45/1,3.
24. *Retistephanocolporites* (costate to the equator), CCN47, 58585, EF: F41/1.
25. *Clavatricolporites leticiae* LEIDELMEYER 1966, CCN58, 58527, EF: V39/4.
26. *Retistephanocolporites* "boyacensis", CCS14, 58089, EF: K51.

PLATE 2.2

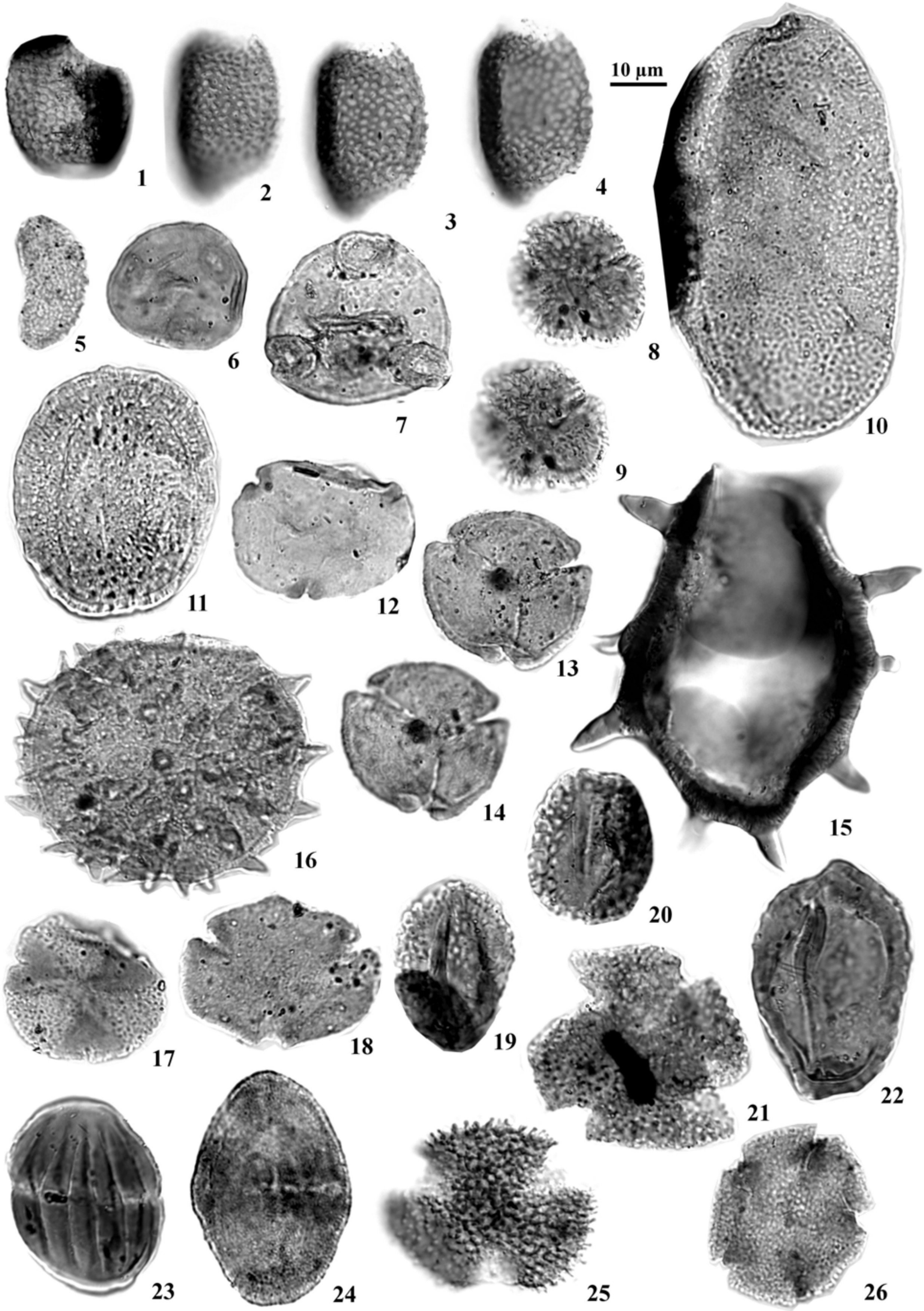

PLATE 3.1

Palynomorphs from the Riecito Maché sections (Venezuela)

1. *Mauritiidites franciscoi* (rounded colpi), VENEZUELA90, 57804, EF: J47-2.
2. *Proxapertites* (fossulate), VENEZUELA64, 57948, EF: H39-1.
3. *Triatriopollenites* sp. VENEZUELA50, 50711, EF: M45-2.
4. *Carya* type pollen VENEZUELA3, 50709, EF: T43-2.
5. *Polotricolpites* cf. *P. concretus* GONZALEZ 1967, VENEZUELA80, 50033, EF: K43-2.

6, 7. *Retitrescolpites* “machensis”, VENEZUELA73, 50714, EF: M45-2.

8. *Poloretitricolpites absolutus* (GONZALEZ 1967) JARAMILLO & DILCHER 2001, VENEZUELA97, 50035, EF: J45.
9. *Poloretitricolpites absolutus* (GONZALEZ 1967) JARAMILLO & DILCHER 2001, VENEZUELA97, 50035, EF: P49-1,2.

10, 11. *Retibrevitricolpites triangulatus* VAN-HOEKEN-KLINKENBERG 1966, VENEZUELA79, 50715, EF: N41.

12. *Retitricolporites* "doradensis", VENEZUELA97, 50035, EF: R44.
13. *Retitricolporites* "doradensis", VENEZUELA97, 50035, EF: O44-4.
14. *Retitricolporites* “venezuelensis”, VENEZUELA97, 50035, EF: K37.
15. *Retitricolporites* “venezuelensis”, VENEZUELA97, 50035, EF: Q38-3,4.
16. *Siltaria mariposa* (LEIDELMEYER 1966) JARAMILLO & DILCHER 2001, VENEZUELA80, 50033, EF: T43-2.
17. *Psilatricolporites* "blessi", VENEZUELA3, 50030, EF: P53-4.
18. *Psilatricolporites* "blessi", VENEZUELA31, 50709, EF: O47.
19. *Gemmastephanocolpites gemmatus* VAN DER HAMMEN & GARCIA 1966, VENEZUELA35, 50029, EF: F55/3.
20. *Gemmastephanocolpites gemmatus* VAN DER HAMMEN & GARCIA 1966, VENEZUELA35, 50029, EF: J43/4.
21. *Ctenolophonidites lisamae* (VAN DER HAMMEN & GARCIA 1966) GERMERAAD et al. 1968, VENEZUELA34, 57524, EF: E54/3.
22. *Ctenolophonidites lisamae* (VAN DER HAMMEN & GARCIA 1966) GERMERAAD et al. 1968, VENEZUELA34, 57524, EF: D46.
23. *Psilastephanocolpites globulus* VAN DER KAARS 1983, VENEZUELA3, 50030, EF: R56/1.
24. *Tetracolporites pachyexinatus* JARAMILLO & DILCHER 2001, VENEZUELA90, 57804, EF: S54/2.
25. *Tetracolporites pachyexinatus* JARAMILLO & DILCHER 2001, VENEZUELA92, 57949, EF: P48/4.
26. *Tetracolporopollenites transversalis* (DUEÑAS 1980) JARAMILLO & DILCHER 2001, VENEZUELA80, 50033, EF: K43/2.
27. *Tertracolporopollenites* cf. *T. d*ivisus REGALI et al. 1974, VENEZUELA93, 50728, EF: G45/1.
28. *Psilastephanocolporites brevicolpatus* JARAMILLO & DILCHER 2001, VENEZUELA97, 50035, EF: K41.
29. *Psilastephanocolporites brevicolpatus* JARAMILLO & DILCHER 2001, VENEZUELA97, 50035, EF: D46/2.

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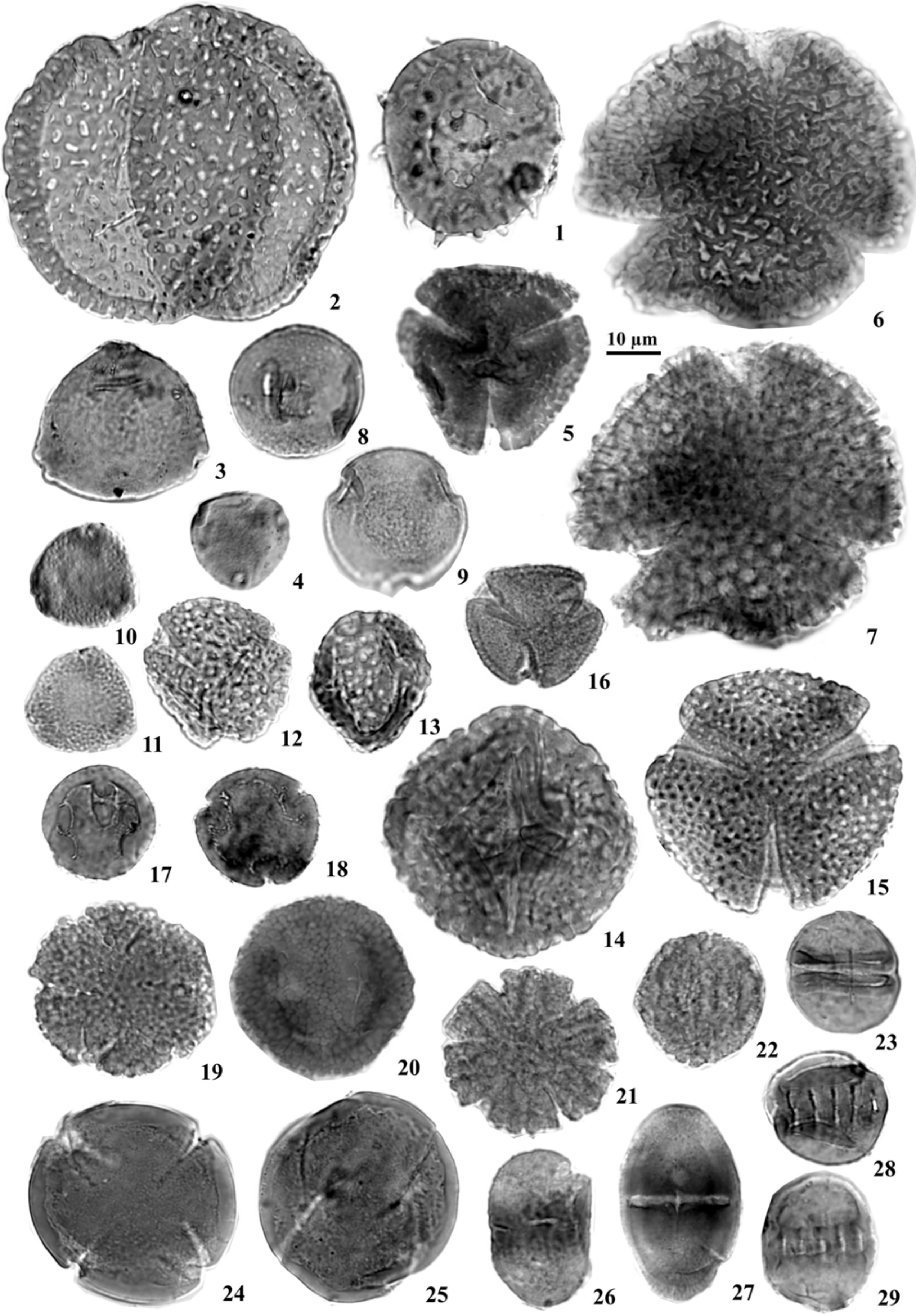

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PLATE 4.1

Palynomorps from the El Cerrejón area

1. *Echitriletes* sp., Cerrejon 94,41, EF: L15/1,2.
2. *Echitriletes* sp., Cerrejon 175,75, EF: S22/4.
3. *Echitriletes* sp., Cerrejon 221,09, EF: E30/2.
4. *Foveotriletes* sp., Cerrejon 264,94, EF: J30/1.
5, 6. *Ischyosporites problematicus* JARAMILLO & DILCHER 2001, Cerrejon 118,25, EF: J16.
7. *Retitriletes* "cristatus", Cerrejon 81,08, EF: L18/3.
8. *Retitriletes* "cristatus", Cerrejon 70,08, EF: V32/1.
9. *Laevigatosporites* sp. 1 of JARAMILLO & DILCHER 2001, Cerrejon 330,65, EF: Q22/4.
10. *Psilamonoletes* sp. 1 (folded), Cerrejon 301,88, EF: E26/4.
11. *Laevigatosporites tibuensis*, Cerrejon 151,82, EF: K37/2.
12. *Baculatisporites* sp., Cerrejon 301,88, EF: O28/2.
13. *Baculatisporites* sp., Cerrejon 310,3, EF: R37/3.
14. *Psilatriletes* sp. (> 50 µm), Cerrejon 116,82, EF: J36/4.
15. *Psilatriletes* sp., Cerrejon 122,47, EF: L15.
16. *Verrutriletes* "viruelensis", Cerrejon 46,75, EF: P29/1.
17. Trilete spore (scabrate-verrugate), Cerrejon 148,50, EF: Q30.
18. *Camarozonosporites* sp,. Cerrejon 91,38, EF: F20.
19, 20. *Camarozonosporites* sp., Cerrejon 310,3, EF: V34/4.
21. *Rugutriletes,* Cerrejon 150,45, EF: W32/1.
22, 23. Trilete spore (reticulate-foveolate). Cerrejon 310,3, EF: X48/3.
24. *Trilobosporites* sp., Cerrejon 46,75, EF: E24/2.
25. *Striatriletes* sp., Cerrejon 104,56, EF: D26/1.

PLATE 4.1

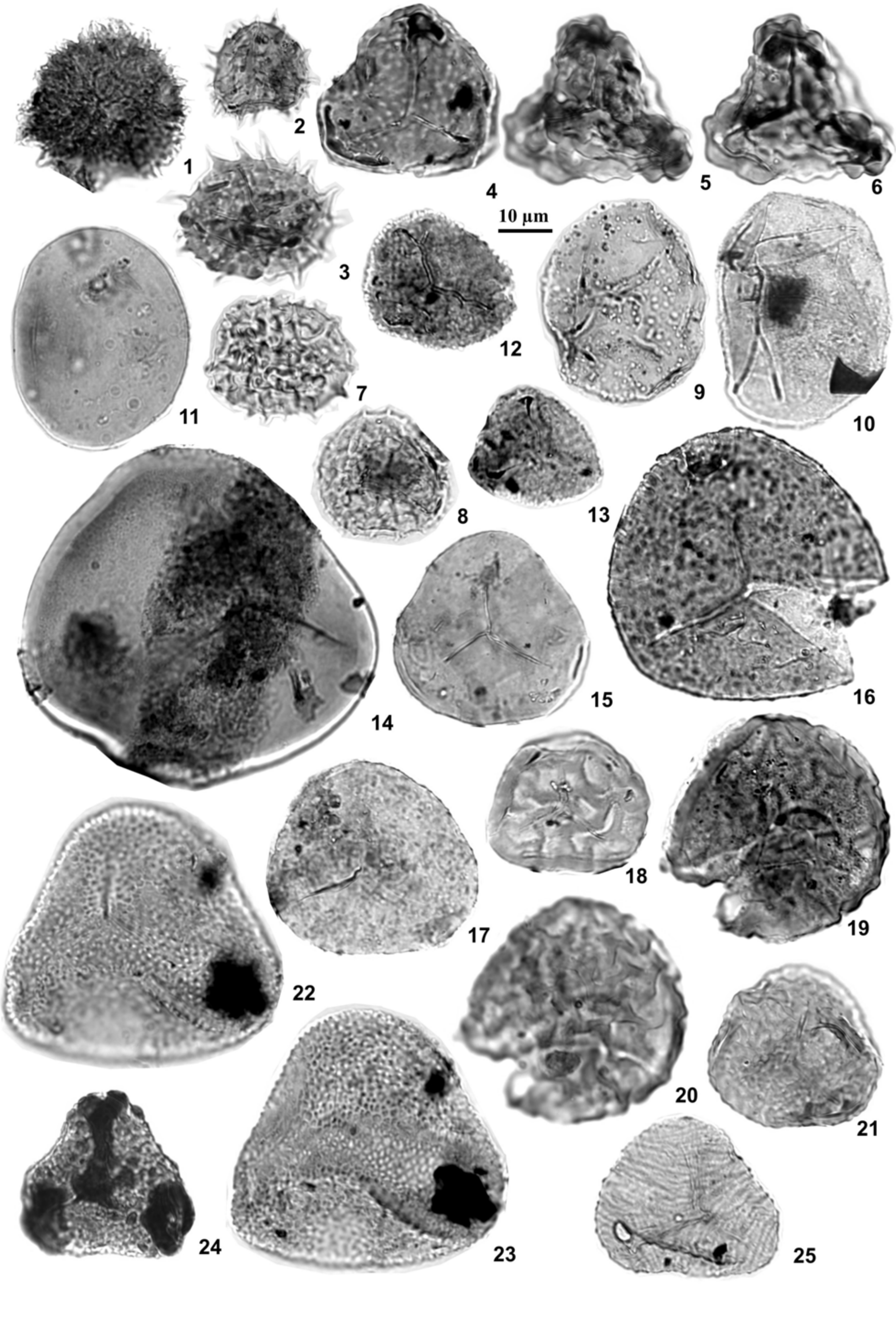

PLATE 4.2

Palynomorps from the El Cerrejón area

1. *Araucariacites* sp., Cerrejon 150,45, EF: G17/3-4.
2. Bisacate pollen, Cerrejon 278,12, EF: H18/2.
3. *Ephedripites* sp., Cerrejon 273.50, EF: R16.
4. *Ephedripites vanegensis* VAN DER HAMMEN & GARCIA 1966, Cerrejon 151,82, EF: F36/4.
5. *Ephedripites vanegensis* VAN DER HAMMEN & GARCIA 1966, Cerrejon 166,80, EF: D28/3-4.
6. *Ephedripites vanegensis* VAN DER HAMMEN & GARCIA 1966, Cerrejon 150,45, EF: G35/1-2.
7. Tetrad (psilate), Cerrejon 239,29, EF: H30.
8. Tetrad (reticulate), Cerrejon 96,65, EF: X27.

9, 10. *Aglaoreidia*? f*oveolata* JARAMILLO & DILCHER 2001, Cerrejon 328,6, EF: J18/2.

11. *Mauritiidites franciscoi* var. *franciscoi* VAN DER HAMMEN 1956a, Cerrejon 184.55 ; EF: K22.
12. *Mauritiidites franciscoi* var. *pachyexinatus* VAN DER HAMMEN & GARCIA 1966, Cerrejon 171.57 ; EF: F21/2.
13. *Psilamonocolpites* "marginatus", Cerrejon 36.55 ; EF: T52/1.
14. *Psilamonocolpites* sp. (*Psilamonocolpites* group), Cerrejon 112.90, EF: X29/2
15. *Psilamonocolpites* sp. (*Psilamonocolpites* group), Cerrejon 252.66 ; EF: P33.
16. *Racemonocolpites racematus* (VAN DER HAMMEN 1954) GONZALEZ 1967, Cerrejon 225.91, EF: D15/2.
17. *Retimonocolpite*s sp., Cerrejon 118.25; EF: F33/1.
18. *Proxapertites* cf. *P. cursus* VAN HOEKEN-KLINKENBERG 1966, Cerrejon 38.63, EF: R24.

19, 20. *Proxapertites cursus* VAN HOEKEN-KLINKENBERG 1966, Cerrejon 216.9, EF: K16/2.

21. *Proxapertites magnus* MULLER et al. 1987, Cerrejon 301, 88. EF: T37/2.
22. *Proxapertites operculatus* (VAN DER HAMMEN 1956a) GERMERAAD et al. 1968, Cerrejon 36.55, EF: P62/2.

PLATE 4.2

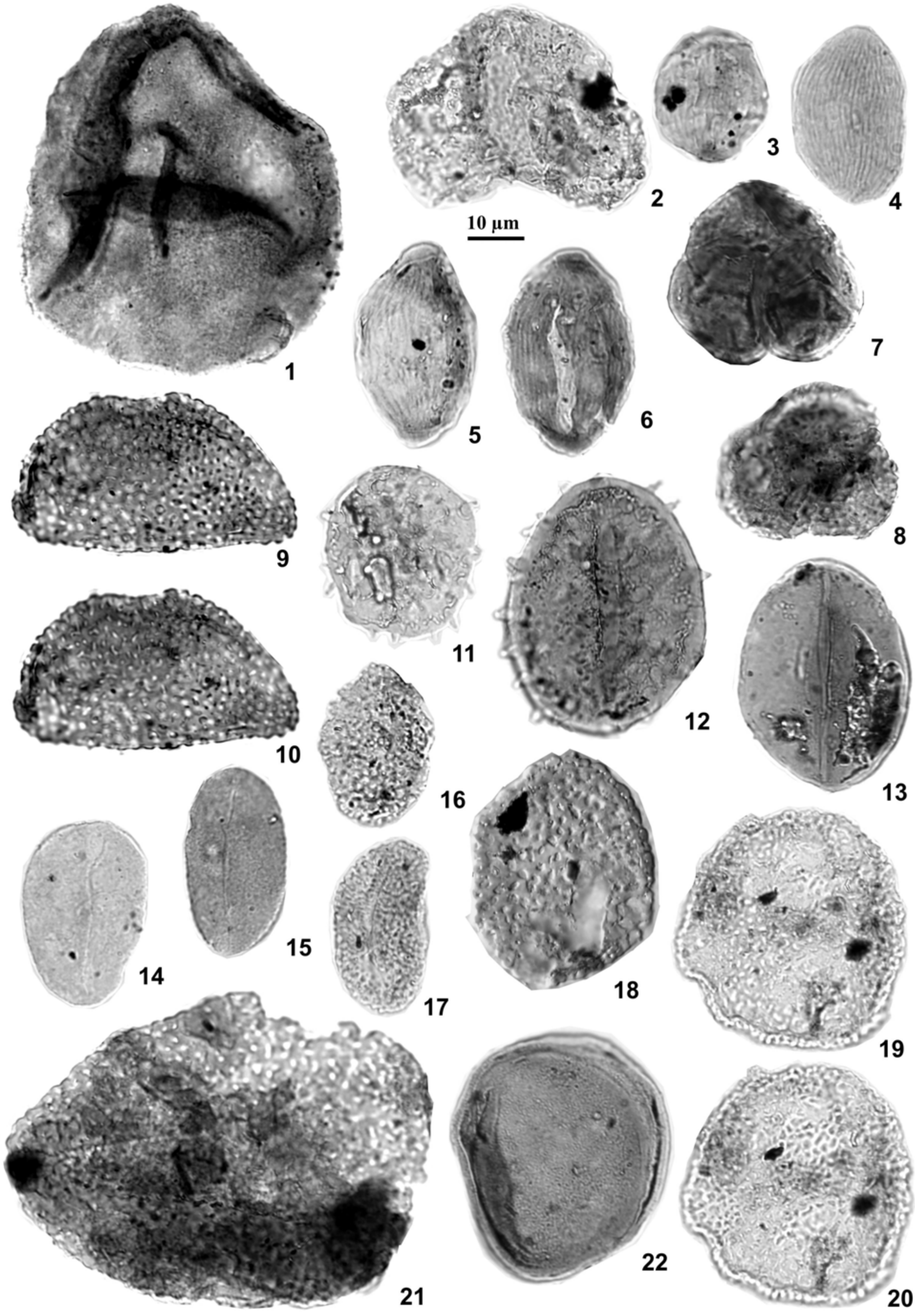

PLATE 4.3

Palynomorps of the El Cerrejón area

1. *Proxapertites operculatus* (VAN DER HAMMEN 1956a) GERMERAAD et al. 1968, Cerrejon 112.90, EF: J30/4.
2. *Proxapertites operculatus* (VAN DER HAMMEN 1956a) GERMERAAD et al. 1968, Cerrejon 252.66, EF: L35/1.
3. *Proxapertites psilatus* SARMIENTO 1992, Cerrejon 252.66, EF: M34/2.
4. *Longapertites vanendeenburgi* GERMERAAD et al. 1968, Cerrejon 94.41, EF: S16/2.
5. *Psilamonocolpites operculatus* PARDO et al.2003, Cerrejon 19, EF: T55.
6. *Spinizonocolpites echinatus* MULLER 1968, Cerrejon 184.55, EF: P19/1.
7. *Syncolporites lisamae* VAN DER HAMMEN 1954, Cerrejon 66,15, EF: K28/4.
8. *Syncolporites lisamae* VAN DER HAMMEN 1954, Cerrejon 15,05, EF: E59/1.
9. *Retitricolpites* "grandis", Cerrejon 19, EF: S52/4.
10. *Retitricolpites* "communis", Cerrejon 216,9, EF: V19.

11, 12. *Bombacacidites* "pasivus", Cerrejon 252,66, EF: T31/2.

13. *Foveotricolpites perforatus* VAN DER HAMMEN & GARCIA 1966, Cerrejon 66,15, EF: W22/3-4.
14. *Psilatricolpites* sp., Cerrejon 216,9, EF: S33/4.
15. *Ctenolophonidites lisamae* (VAN DER HAMMEN & GARCIA 1966) GERMERAAD et al. 1968, (ecuatorial view), Cerrejon 216,9, EF: H28.
16. *Ctenolophonidites lisamae* (VAN DER HAMMEN & GARCIA 1966) GERMERAAD et al. 1968, (polar view), Cerrejon 36.55, EF: G60.
17. *Gemmastephanocolpites gemmatus* VAN DER HAMMEN & GARCIA 1966, (polar view), Cerrejon 255,35, EF: S28.
18. *Gemmastephanocolpites gemmatus* VAN DER HAMMEN & GARCIA 1966, (ecuatorial view), Cerrejon 151,82, EF: K37/3.
19. *Gemmastephanocolpites gemmatus* VAN DER HAMMEN & GARCIA 1966, (ecuatorial view), Cerrejon 255,35, EF: M34/2.
20. *Psilastephanocolpites globulus* VAN DER KAARS 1983, (polar view), Cerrejon 285,08, EF: O35/3.
21. *Psilastephanocolpites globulus* VAN DER KAARS 1983, (ecuatorial view), Cerrejon 285,08, EF: U27/3-4.
22. *Psilastephanocolpites globulus* VAN DER KAARS 1983, big (ecuatorial view), Cerrejon 310,3, EF: T36/2-4.
23. *Psilastephanocolpites* sp., Cerrejon 46,75, EF: J37/1.
24. *Stephanocolpites* "scabratus", Cerrejon 330,65, EF: C27/4.
25. *Stephanocolpites* (psilate, 4 colpi), Cerrejon 36,55, EF: E58/1.

26, 27. *Brevitricolpites* sp. (psilate-micropitted-foveolate), Polar view, Cerrejon 107-108,85, EF: W34/1.

28. *Brevitricolpites* sp. (psilate-micropitted-foveolate), Cerrejon 287,52, EF: Q27/4.
29. *Brevitricolpites* sp. (psilate-micropitted-foveolate), Cerrejon 347,54, EF: E44/3.
30. *Foveotricolporites* sp., Cerrejon 116,82, EF: X29/4.
31. *Foveotricolporites* sp. (polar view), Cerrejon 116,82, EF: H37.

PLATE 4.3

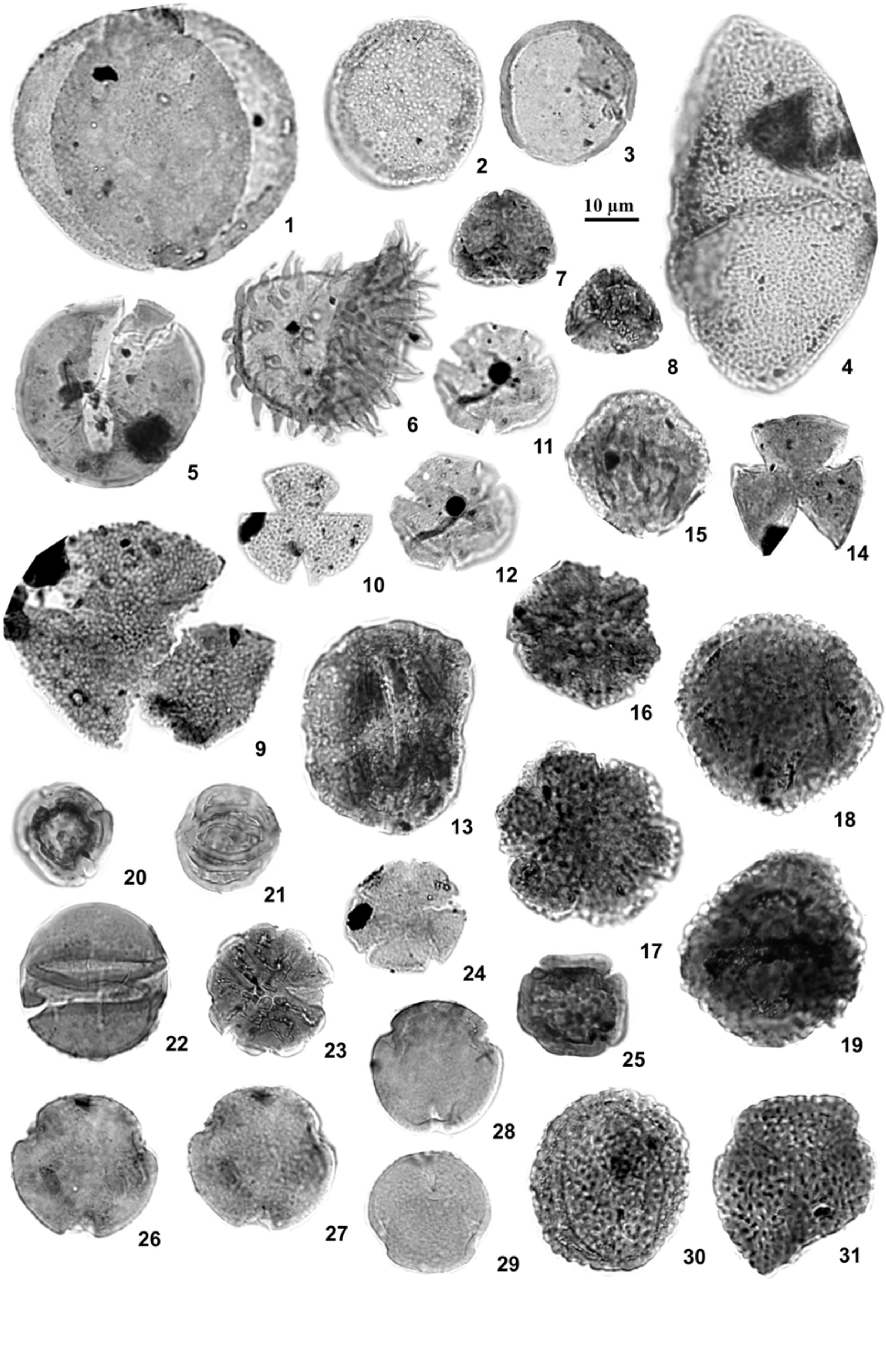
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PLATE 4.4

Palynomorps from the El Cerrejón area

1, 2. *Foveotricolporites* sp 1 (sp. 3 of JARAMILLO & DILCHER 2001), Cerrejon 301,88, EF: R30.
3. *Gemmatricolporites* sp., Cerrejon 225,91, EF: X29/1-3.
4. *Margocolporites* sp., Cerrejon 70,08, EF: S24/4.
5, 6. *Psilabrevitricolpites* sp., (small, rounded), Cerrejon 38,63, EF: G26/3.
7. *Psilabrevitricolporites simpliformis* VAN DER KAARS 1983, (small), Cerrejon 38,63, EF: G19/4.
8, 9. *Psilabrevitricolporites simpliformis* VAN DER KAARS 1983, (big), Cerrejon 91,38, EF: J16/2-4.
10-12. *Psilatricolporites marginatus* VAN DER KAARS 1983, Cerrejon 326,82, EF: L35/2.
13. *Psilatricolporites marginatus* VAN DER KAARS 1983, (small), Cerrejon 84,35, EF: Y20/2-4.
14. *Psilatricolporites marginatus* VAN DER KAARS 1983, Cerrejon 294,28, EF: E27/1.
15. *Psilatricolporites pachyexinatus* VAN DER KAARS 1983, Cerrejon 148,50, EF: Q27/2.
16. *Psilatricolporites* sp., Cerrejon 207,50, EF: T20/4.
17, 18. *Scabratricolporites* sp. (cf. Siltaria sp. 4 JARAMILLO & DILCHER 2001), Cerrejon 326,82, EF: M40.
19. *Scabratricolporites* sp. (cf. *Siltaria* sp. 4 JARAMILLO & DILCHER 2001), Cerrejon 171,57, EF: V23/2.
20. *Scabratricolporites* sp. (cf. *Siltaria* sp. 4 JARAMILLO & DILCHER 2001), Cerrejon 326,82, EF: P36/2.
21. *Scabratricolporites* sp., Cerrejon 285,08, EF: H28/3.
22. *Scabratricolporites* sp., Cerrejon 184,55, EF: E14/3.
23-30. Small tricolporates.
23. Cerrejon 96,65, EF: J27/2.
24. Cerrejon 22,69-24,55, EF: U28/1,3.
25. Cerrejon 235,32, EF: G31/3.
26. Cerrejon 244,20, EF: M34/3.
27. Cerrejon 252,66, EF: J27.
28. Cerrejon 188,64, EF: H26/3.
29. Cerrejon 287,52, EF: G28/4.
30. Cerrejon 171,57, EF: P32/3.
31, 33. *Striatopollis* sp., (small), Cerrejon 112,90, EF: S24/3-4.
34. *Tricolporites* sp., (triangular, short colpi, simple), Polar view, Cerrejon 107-108,85, EF: U30/2.
35. *Tricolporites* sp., (triangular, short colpi, simple), Cerrejon 310,3, EF: L29/3.
36. *Tricolporites* sp., (reticulate), Cerrejon 112,90, EF: S34.
37, 38. *Tricolporites* sp., (reticulate), Cerrejon 100,60, EF: F28/1-3.
39. *Tricolporites* "scabrate", (polar view), Cerrejon 112,90, EF: K32/4.
40. *Tricolporites* "scabrate", (ecuatorial view), Cerrejon 193, EF: Q44.
41, 42. *Tricolporites*, (amb triangular pore and colpi costate), Cerrejon 318,14, EF: J23/1.
43, 44. *Tricolporites* sp., (reticulate, colpi marginate), Cerrejon 70,08, EF: S17/4.
45. *Psilatricolporites* "blessi", Cerrejon 171,57, EF: Q22/4.
46. *Psilatricolporites* "blessi", Cerrejon 22,69-24,55, EF: T45/3.
47. *Psilatricolporites* "blessi", Cerrejon 287,52, EF: O32.
48. *Psilatricolporites* "blessi", Cerrejon 193, EF: O31/2.
49, 50. *Psilatricolporites* "blessi", Cerrejon 15,05, EF: G49.

PLATE 4.4

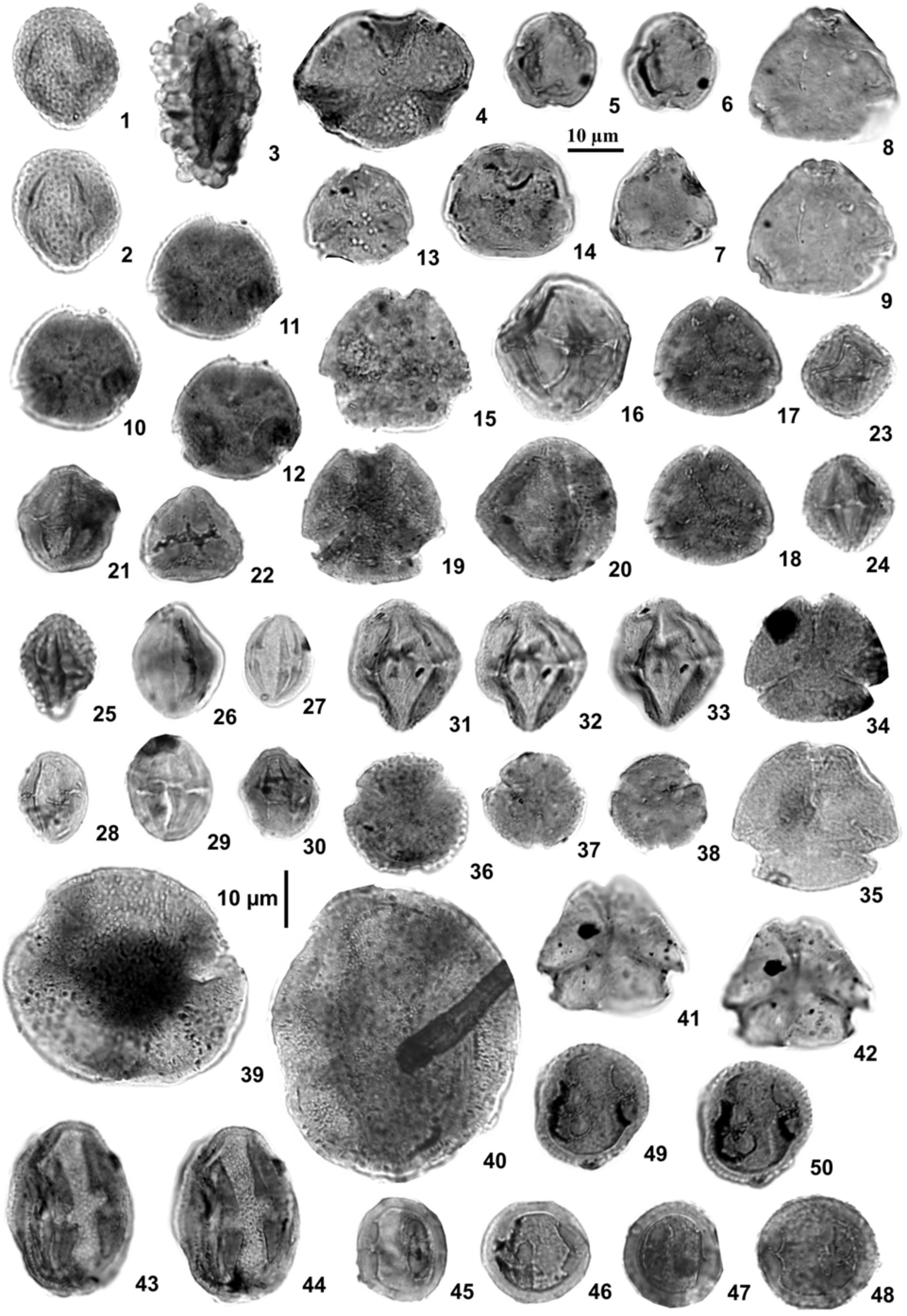

PLATE 4.5

Palynomorps from the El Cerrejón area

1. *Bombacacidites* sp., Cerrejon 84,35, EF: X29.
2. *Bombacacidites* sp., Cerrejon 328,60, EF: H33/1.
3. *Bombacacidites* sp., Cerrejon 53,95, EF: S22/4.
4, 5. *Bombacacidites* sp., Cerrejon 118,25, EF: W31/1.
6. *Bombacacidites* sp., Cerrejon 321,66, EF: P51/3.
7. *Bombacacidites* sp., Cerrejon 150,45, EF: F31.
8. *Bombacacidites* sp., Cerrejon 321,66, EF: H33/1.
9. *Bombacacidites* sp., Cerrejon 66,15, EF: P37.
10. *Bombacacidites* sp., Cerrejon 150,45, EF: U26.
11. *Bombacacidites* sp., Cerrejon 74,30, EF: W29/1.
12. *Bombacacidites* sp., Cerrejon 328,60, EF: D25/1.
13. *Bombacacidites* sp., Cerrejon 42,71, EF: N33/2-4.
14. *Clavatricolporites* sp., (polar view), Cerrejon 15.05, EF: M64.
15, 16. *Clavatricolporites* sp., (ecuatorial view), Cerrejon 330,65, EF: R32/2.
17. *Verrutricolporite*s, Cerrejon 19, EF: K67.
18. *Incertae sedis* (*Aquilapollenites*?), Cerrejon 244.2, EF: N25
19. *Tricolpites* sp. 2 (reticulate to the equator), Cerrejon 74,30, EF: W37/4.
20. *Tricolpites* sp. 2 (reticulate to the equator), Cerrejon 252,66, EF: L19/1.
21. *Psilastephanocolporites fissilis* LEIDELMEYER 1966, Cerrejon 15,05, EF: G51/3.
22. *Diporoconia* cf. *D. iszkaszentgyoergy*i (KEDVES 1965) FREDERIKSEN et al. 1985, Cerrejon 188,64, EF: U29.
23. *Diporoconia* cf. *D. iszkaszentgyoergyi* (KEDVES 1965) FREDERIKSEN et al. 1985, Cerrejon 129,52, EF: K19/4.
24. *Retidiporites botulus* LEIDELMEYER 1966, Cerrejon 211.13, reference not available.
25. *Retidiporites botulus* LEIDELMEYER 1966, Cerrejon 104.56, EF: H29/3.
26. *Retidiporites botulus* LEIDELMEYER 1966, Cerrejon 203.40, EF: P22/1.
27. *Retidiporites magdalenensis* VAN DER HAMMEN & GARCIA 1966, Cerrejon 252.66, EF: W31.
28. *Retidiporites magdalenensis* VAN DER HAMMEN & GARCIA 1966, Cerrejon 84.35, EF: S24/2.
29. *Retidiporites operculatus* VAN DER KAARS 1983, Cerrejon 42.71, EF: T23/2.
30, 31. *Carya* type pollen, Cerrejon 278,12, EF: O28/3.
32. *Corsinipollenites* sp., Cerrejon 259,81, EF: X23/1.

PLATE 4.5

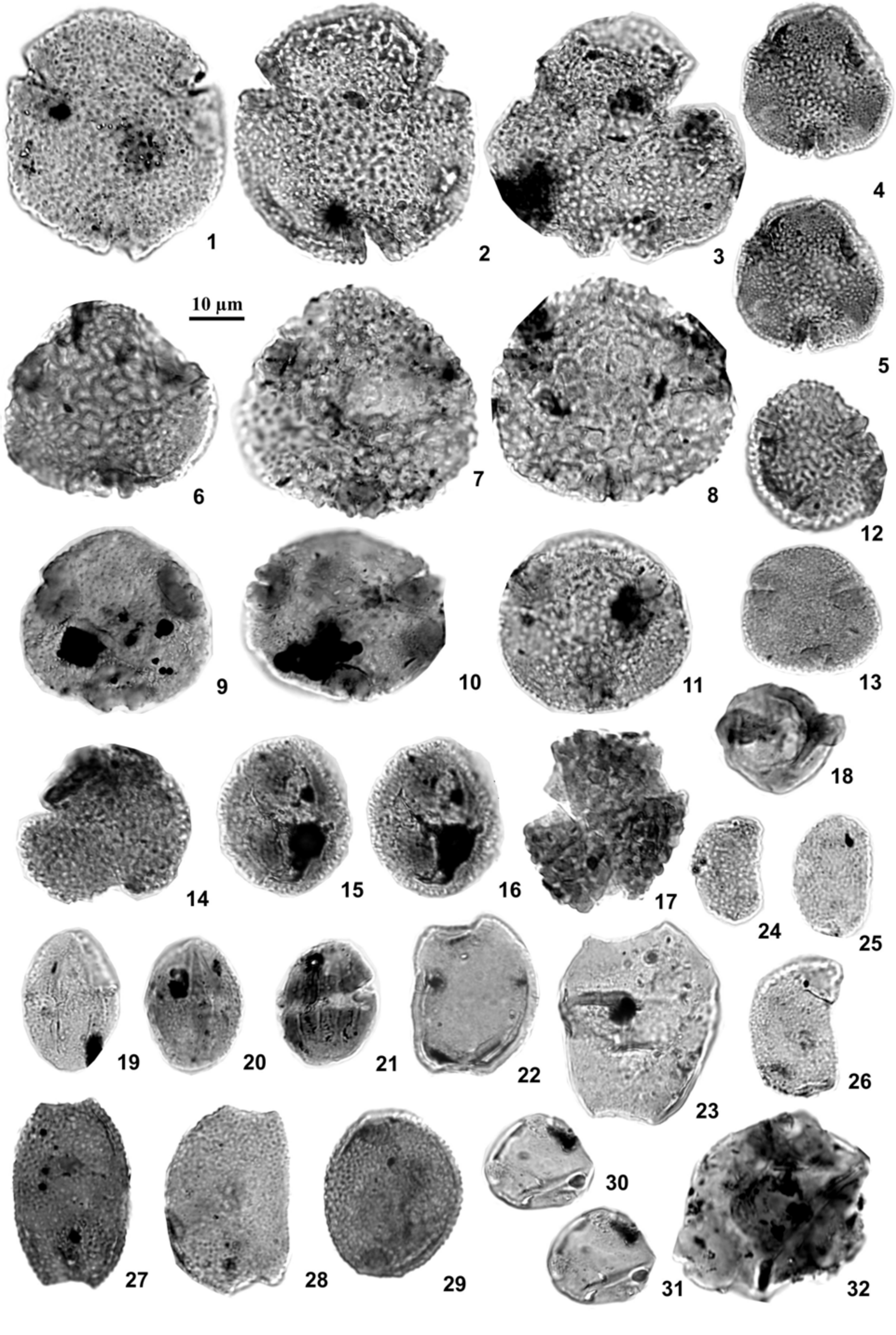

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PLATE 4.6

Palynomorps from the El Cerrejón area

1. *Corsinipollenites* sp. Cerrejon 46,75. EF: R23.
2. *Echitriporites trianguliformis* VAN HOEKEN KLINKENBERG 1964, Cerrejon 38,63, EF: P19/1-3.
3. *Echitriporites Trianguliformis* VAN HOEKEN KLINKENBERG 1964, Cerrejon 294,28, EF: M25.
4. *Retitriporites* sp. 1, Cerrejon 259,81, EF: R18/1-3.
5. *Retitriporites* sp. 2, (pore costate), Cerrejon 259,81, EF: T14/3.
6. *Retitriporites* sp. 2, (pore costate), Cerrejon 252,66, EF: M22.
7. *Retitriporites simplex* VAN DER KAARS 1983, Cerrejon 221,09, EF: C30/1.
8. *Momipites* sp., Cerrejon 259,81, EF: Q31/2.

9, 10. *Momipites* sp.,Cerrejon 316,16, EF: M23/3.

11. *Momipites* sp., Cerrejon 146,55, EF: M24.
12. *Momipites* sp., Cerrejon 184.55, EF: S24/3.
13. *Carya* type, Cerrejon 278,12, EF: H35.
14. *Triatriopollenites* sp., Cerrejon 19, EF: N56/3.
15. *Triatriopollenites* sp., Cerrejon 53,95, EF: F20/2.
16. *Triatriopollenites* sp., Cerrejon 310,3, EF: T34/1.
17. *Triatriopollenites* sp., Cerrejon 15,05, EF: X53.

18, 19. *Triatriopollenites* sp., Cerrejon 32.6, EF: S55. DIC.

20. *Triatriopollenites* sp., (ecuatorial view), Cerrejon 96,65, EF: P31/4.
21. *Triporites* sp 1, (triangular), Cerrejon 216,9, EF: R32/2.
22. *Triporites* sp. 2, (psilate, small), Cerrejon 252,66, EF:R20.

23, 24. *Triporites* sp. 3, (reticulate), Cerrejon 285,08, EF: E22/1.

25. *Verrutricolporites* sp., Cerrejon 184.55, EF: E21/2.
26. *Psilastephanoporites* "oculiporus", Cerrejon 278,12, EF: O32/1.
27. *Stephanoporites* sp., Cerrejon 28,65, EF: X49/4.
28. Stephanoporate scabrate, Cerrejon 19, EF: O58.

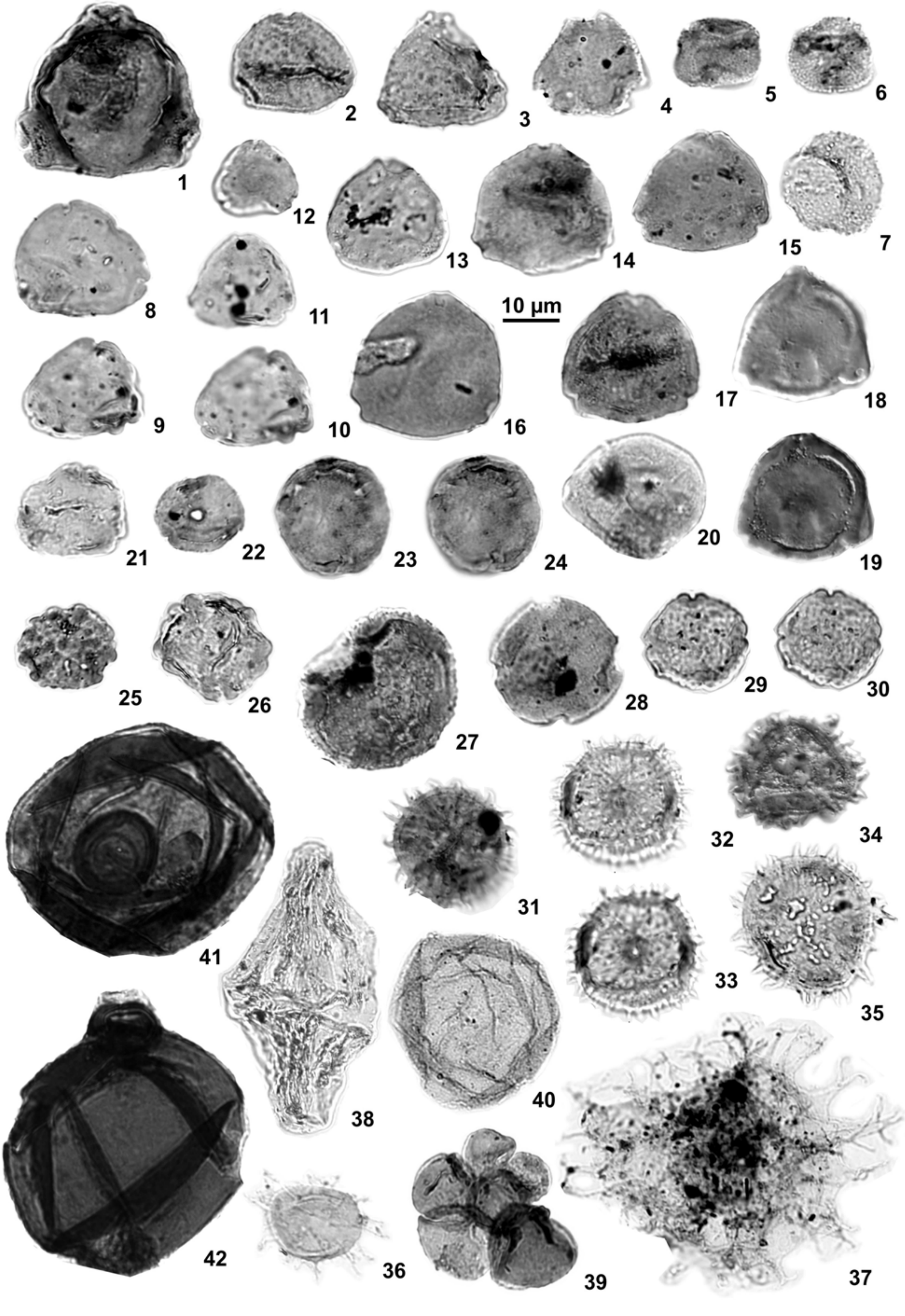
29, 30. *Ulmoideipites krempii* (ANDERSON 1960) ELSIK 1968b, Cerrejon 188,64, EF: C24/1.

31. *Malvacipollis* sp., 290,77, EF: P44/2.

32, 33. *Malvacipollis* sp., Cerrejon 112,90, EF: Q23/3.

34. *Malvacipollis* sp., Cerrejon 38,63, EF: H25/3.
35. *Malvacipollis* sp., Cerrejon 84,35, EF: X30/2.
36. Acritarch, Cerrejon 311,28, EF: P55/3-4.
37. Dynoflagellate, Cerrejon 32,6, EF: E53/4.
38. *Dynogymnium* sp., Cerrejon 46,75, EF: J30/3.
39. Foraminiferal test linning, Cerrejon 355,64, EF: R16/4.
40. *Leiospheridia*, Cerrejon 207,50, EF: M25/4.
41. *Diporopollis assamica* DUTTA & SAH 1970, (ecuatorial view), Cerrejon 134,6, EF: L29/3.
42. *Diporopollis assamica* DUTTA & SAH 1970, (polar view), Cerrejon 157, EF: O46/3.

PLATE 4.6



APENDICE 1.2

PREPARACIÓN DE MUESTRAS PALINOLOGICAS (TÉCNICA DEL LABORATORIO DE PALINOLOGIA DE LA UNIVERSIDAD DE LIEJA).

Nota: el número indicado en cada procedimiento corresponde al número de las figuras incluidas al final del texto.

1) Probar la presencia de carbonato en las muestras introduciendo un pedazo de cada una en un recipiente con HCl (30%).

2) Lavar las muestras de roca con agua y cepillo. Dejarlas secar al horno a 50^{o} C.

3) Tomar los tarros de plástico con tapa de rosca, bien lavados y numerados. Cuando el análisis es cuantitativo, cada tarro se coloca en la balanza analítica. Poner la balanza en 0,00 gr para comenzar a agregar la muestra.

4) Tomar un poco de muestra (5-10 gr) y con un mortero metálico, partirla en trocitos pequeños (1-2mm. El ripio fino no se utiliza. Se recomienda tomar los fragmentos más oscuros), apoyar el mortero sobre un trapo grueso para proteger la mesa. Introducir los trozos en un tarro de plástico. Continuar el procedimiento hasta completar 25, 00 gr aproximadamente. Lavar y limpiar muy bien el mortero antes de continuar con la muestra siguiente. Anotar en un papel la equivalencia entre el numero de muestra y el numero del tarro y su peso preciso con dos dígitos así:

I............IC-D-3 (73,5 m)..............25. 02 gr
II...........IC-D-3 (80 m).................25. 07 gr

Etc....

5) Si la muestra contiene carbonato realizar el procedimiento que se explica al final del texto. Las muestras que no contienen carbonato se les agrega entre 100 a 150 ml (depende del tamaño del tarro de plástico) de HF (38-40 %) .

6) Dejar los tarros en los rodillos durante toda la noche para obtener una reacción mas rápida y completa.

7) Al otro día: Limpiar las tapas y la parte superior de los tarros para hacer descender todo el material. Para ello se utiliza agua de la llave y la botella de pico angosto que se muestra en la figura..

8) Introducir todo el contenido del lavado en los tarros especiales para la centrifugadora (ver figura). Equilibrar el contenido de agua revisando su peso en la balanza. Centrifugar durante 5 minutos a 3000 r.p.m como mínimo.

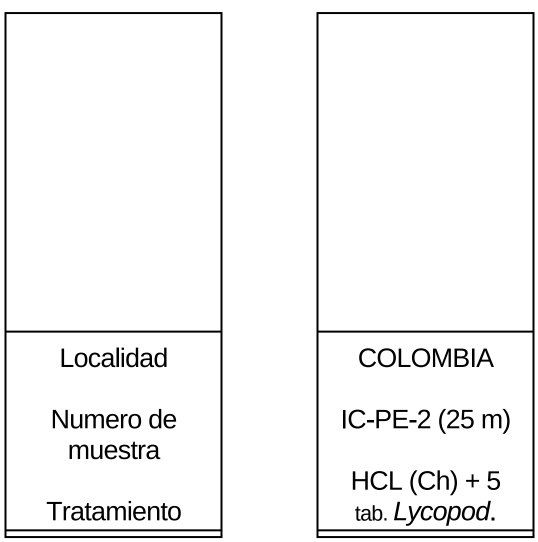
9) Desechar rápidamente el agua mas ácido en el lugar especial que se encuentra en la campana (neutralizador de ácidos). Agregar un poco de agua de la llave y revolver la materia orgánica con un tubo de vidrio para dejarla en suspensión (limpiar bien el tubo con agua para no perder muestra y lavarlo para reutilizarlo con la muestra siguiente). Para cada muestra, disolver cinco tabletas de *Lycopodium* en un beaker con un poco de HCl (10 %) (se recomienda que cada beaker tenga un número equivalente al de la muestra para no olvidar a cual de ellas ya se le han agregado las tabletas).

10) Agregar las tabletas de *Lycopodium* en los recipientes que contienen la muestras. Llenar con agua de la llave para centrifugar una vez mas (5 minutos a 3000 rpm); después de centrifugar botar el agua (no es necesario tener mucho cuidado porque ya fueron agregadas las tabletas de *Lycopodium*).

11) Despegar el material de los tarros con un poco de agua y la varilla de vidrio. Verter cada muestra en los beakers de 250 ml que fueron utilizados anteriormente. Agregar HCl (30-36 %) más o menos en un 25 % del volumen total de la muestra. Calentar hasta la ebullición (colocarlo lo mas alejado de la compuerta de la campana de extracción para evitar escape de vapores). Dejar en ebullición durante 5-10

minutos (depende de la riqueza en materia orgánica de la muestra: cuanto más rica se debe dejar más tiempo).

12) Limpiar los tamices de 12 μ con agua y jabón en un recipiente especial (ultrasonido), limpiarlos uno a uno en este recipiente y extraer bien el jabón con agua de la llave. Lavar los materiales necesarios para comenzar el filtrado (vidrios, pinza etc...).
13) Filtrar la muestra agregando agua de la llave y cuando sea necesario (depende de la riqueza en materia orgánica). La muestra se considera limpia cuando el agua procedente del filtrado sea transparente.
14) Extraer el residuo orgánico tomando el tamiz dentro de un tubo de vidrio (que previamente fue marcado con los datos de la muestra) y agregando **agua destilada** a presión para extraer adecuadamente toda la materia orgánica.
15) Colocar los tubos en la centrifugadora pequeña (5 minutos a 3000 rpm). Extraer con cuidado el exceso de agua en el lavamanos con el fin de concentrar la materia orgánica para la elaboración de las láminas.
16) Elaboración de las laminas: Tomar los vidrios especiales con un hoyo redondo en el centro y montarlos en la lupa binocular; limpiarlos con un trapo seco. Tomar los vidrios cobertores de placas y limpiarlos de la misma manera. Pegar el vidrio pequeño con un poco de saliva al vidrio grande cuidando de que solo quede una parte sobre el orificio.
17) Agregar una gran gota de hidroxietil celulosa (HEC) sobre el vidrio cobertor. Agitar bien el tubo de ensayo con la muestra para uniformizar el material. Extraer con un vidrio capilar un poco de la muestra (depende de la riqueza en materia orgánica) y colocarla en la gota de HEC. Con un alfiler mezclar los dos materiales y repartirlos de manera uniforme a través de todo el vidrio cobertor sin salirse del borde. Repetir el procedimiento para cada muestra cuidando que no se produzca contaminación (utilizar capilares diferentes para cada muestra).
18) Marcar las muestras y llevarlas a un horno a 60 °C.
19) Cuando las muestras estén secas: Tomar el vidrio cobertor con la muestra rotarlo y sostenerlo con una pinza. Tomar las láminas para montar los vidrios protectores; limpiarlos con un trapo seco. Marcarlas con el numero de la muestra y las características principales eg:



Agregar dos o más gotas de Euparal en el centro del vidrio. Tomar con una pinza el vidrio protector con la muestra. Colocarlo lentamente sobre la gota de Euparal comenzando por un extremo y dejarlo que se vaya uniendo lentamente. Tener cuidado que la cara del vidrio protector donde se encuentra la materia orgánica sea la que se pega a la placa de vidrio.

Para limpiar los palinomorfos (HNO_3):

1. Tomar los beakers usados anteriormente, lavarlos bien. Agregar el contenido de cada tubo de ensayo con la muestra y lavar con agua corriente para no perder el material.
2. Agregar un volumen HNO_3 al 65 % igual al contenido de la muestra más agua. Cronometrar 2 minutos (se recomienda agitar los beakers con las muestras ricas en materia orgánica para acelerar la reacción).
3. Después de los 2 minutos llenar los beakers con agua corriente.
4. Repetir el procedimiento de filtrado y de preparación de las laminas.

Almacenamiento de las muestras

Las preparaciones palinológicas se almacenan en tubos de plástico de la siguiente manera:
Tomar los tubos de plástico y agregar a cada uno una etiqueta con los datos de cada muestra a almacenar e.g.

PAIS No de Pozo (código de la muestra) No. de gramos utilizado para el tratamiento + No. de tabletas de *Lycopodium* empleadas. Fecha de maceración de la muestra	COLOMBIA IC-FA-3 (45 m) 25,05 + 5 lic. 03-03-00

Extraer manualmente el exceso de agua de los tubos de ensayo. Agregar la muestra con la ayuda de la botella con agua destilada. Colocar el tapón y almacenar en una caja. Anotar al exterior de la caja el número de muestra, fecha de maceración etc...

SI LA MUESTRA CONTIENE CARBONATO

Agregar 250 ml de HCl al 10 % y dejarlas reaccionar toda una noche. Al otro día, agregar 50 ml de HCl puro, si la muestra aun reacciona al ácido, agregar mas HCl puro (30-50 ml). Pasar el material a los recipientes de plástico para la centrifugadora cuidando que no se pierda material (utilizar la botella de pico pequeño). Dejar la muestra en la centrifugadora entre 5 – 10 minutos a 3000 rpm. Botar el agua más ácido. Levantar el material con la barra de vidrio y agregar agua hasta llenar el tarro. Centrifugar una vez más y botar el agua. Medir 150 ml de HF puro (40%) y agregarlo lentamente en el recipiente de plastico (usar guantes). Simultáneamente levantar la muestra con una cuchara de Niquel. Introducir la muestra en el tarro de plástico utilizando la cuchara y teniendo cuidado que no se pierda material. Ir al paso numero 5.

Cuando la muestra contiene muchos minerales (Lámina orgánica)

Agitar bien la muestra que se halla en el tubo de ensayo. Verterla en un vidrio de reloj. Desplazar la muestra de tal forma que la materia orgánica se separe de los minerales por diferencia de densidad. Con un tubo capilar se intenta extraer solo la fracción orgánica . Repetir el proceso anotando en el vidrio de la lamina LO (“lámina orgánica”).

TRATAMIENTO DE CARBONES PARA ANÁLISIS PALINOLOGICO

1.Tomar la muestra de carbón (1 cm^3). Lavarla con agua y secarla al horno (60° C).
2. Pulverizar unos gramos de carbón en un mortero metálico. Simultáneamente pulverizar unos gramos de clorato de potasio, realizando movimientos circulares.
3. Sobre una hoja de papel (puede ser satinado) puesto sobre la balanza analítica, pesar 1,00 gr. de carbón y 2, 00 gr de clorato de potasio.
4. Introducir la mezcla en un erlenmeyer
5. En la campana extractora: Agregar 25 ml de HNO_3 fumante (100% de pureza) a la mezcla (UTILIZAR MASCARA Y GUANTES PROTECTORES). Dejar que se produzca reacción durante 10 minutos. Agitar la mezcla de vez en cuando realizando movimientos circulares.
6. Cortar la reacción con agua corriente. Preparar los elementos para el filtrado
7. Filtrar normalmente agregando inicialmente el agua pura en el erlenmeyer.

TECNICA DE ACETOLICE

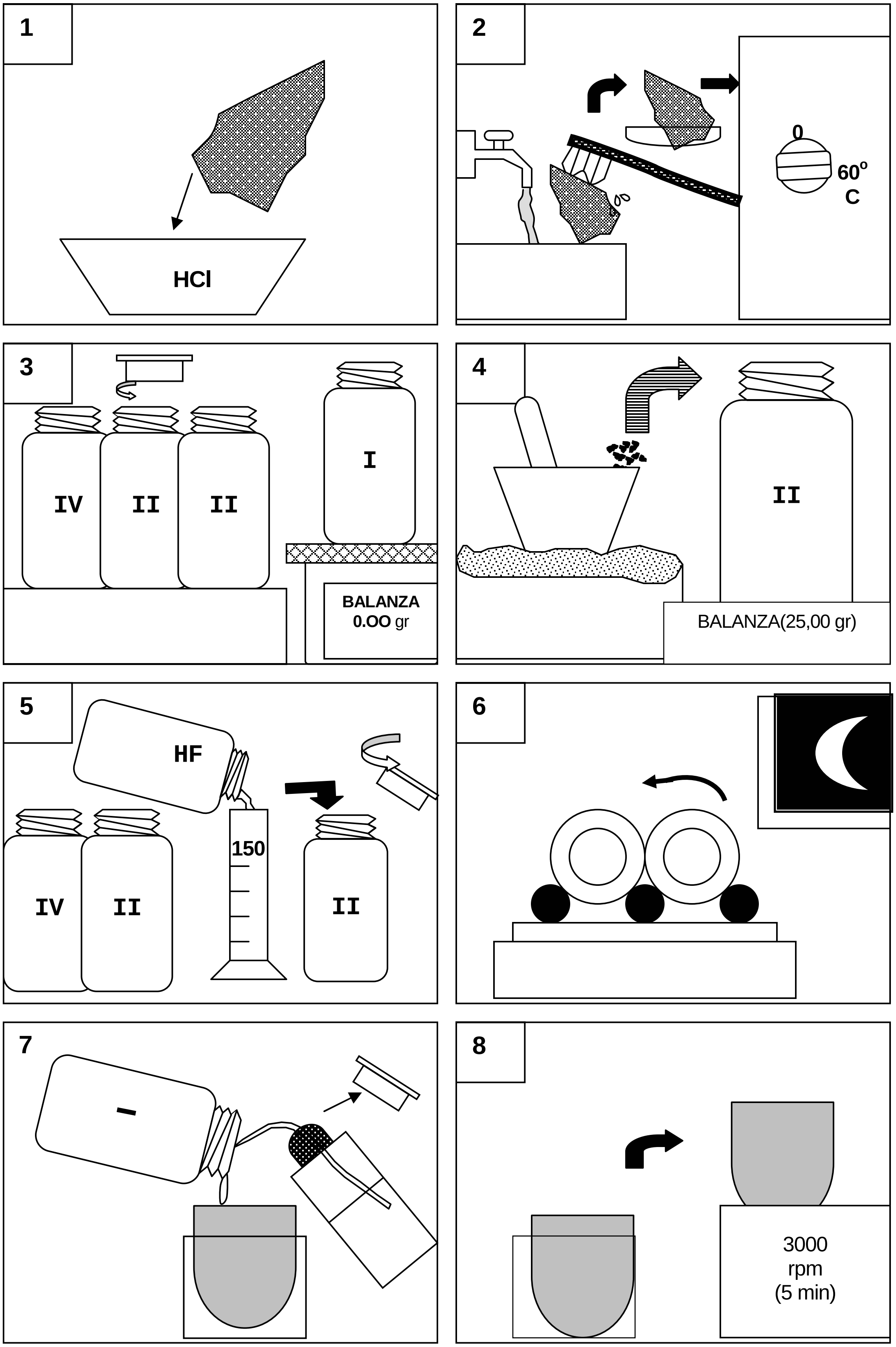
1.Después del tratamiento de ataque al HF (ver los pasos de la técnica anterior). Introducir la muestra en tubos de ensayo (normalmente más grandes que los usados en la otra técnica ya que la materia orgánica es mucho mas abundante). Agregar ácido acético glacial (30 cc aprox para tubos de 100 cc), con el fin de eliminar el agua de la muestra. Poner la muestra en suspensión con una barra de cristal (usar una barra para cada muestra).

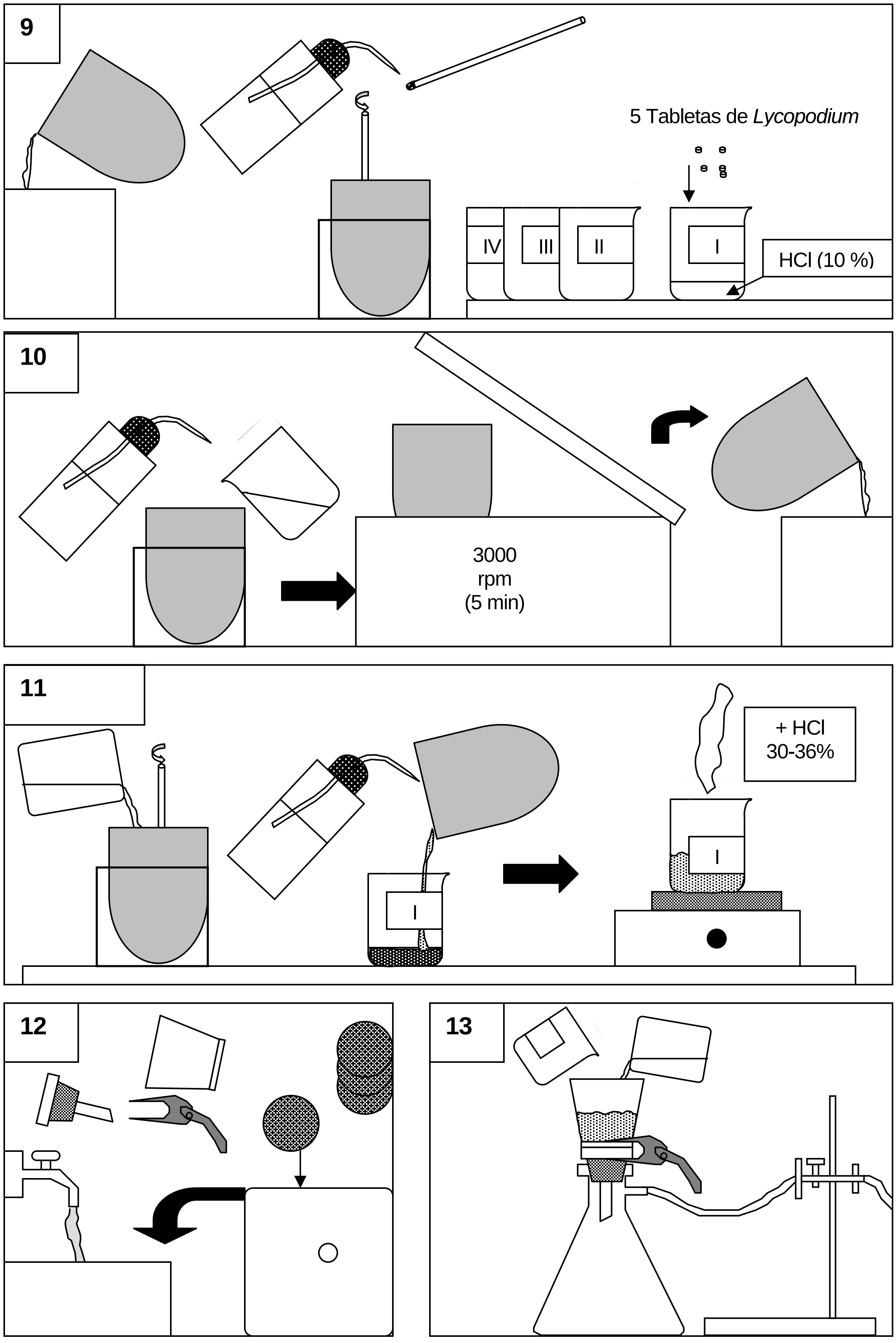
2. Equilibrar el contenido de cada tubo con una piseta de ácido acético. Centrifugar y eliminar el ácido en el neutralizador.

Preparar el ACETOLICE:

3. Preparar 200 ml de acetolice (para 8 muestras), mezclando 1 parte de ácido sulfúrico (H_2SO_4 al 95 %; debe agregarse primero) y 9 partes de anhídrido acético $(CH_3CO)_2$. Preparar el aparato para el baño maría
4. Agregar el acetolice a cada muestra (30 cc aproximadamente para tubos de 100 cc). Mezclar y poner en suspensión la muestra con una barra de vidrio (muy importante !).
5. Tomar los tubos con las pinzas e introducirlas en el aparato para el baño María durante 15 minutos, revolviendo de vez en cuando.
6. Extraer las muestras y dejarlas en reposo mientras se enfrían. Verter la muestra con mucho cuidado a través de la barra de vidrio (ver la figura). Extraer el remanente del tubo con una piseta con agua.
7. Filtrar y continuar el procedimiento normal para hacer las láminas.

SI LA MUESTRA NO CONTIENE CARBONATO

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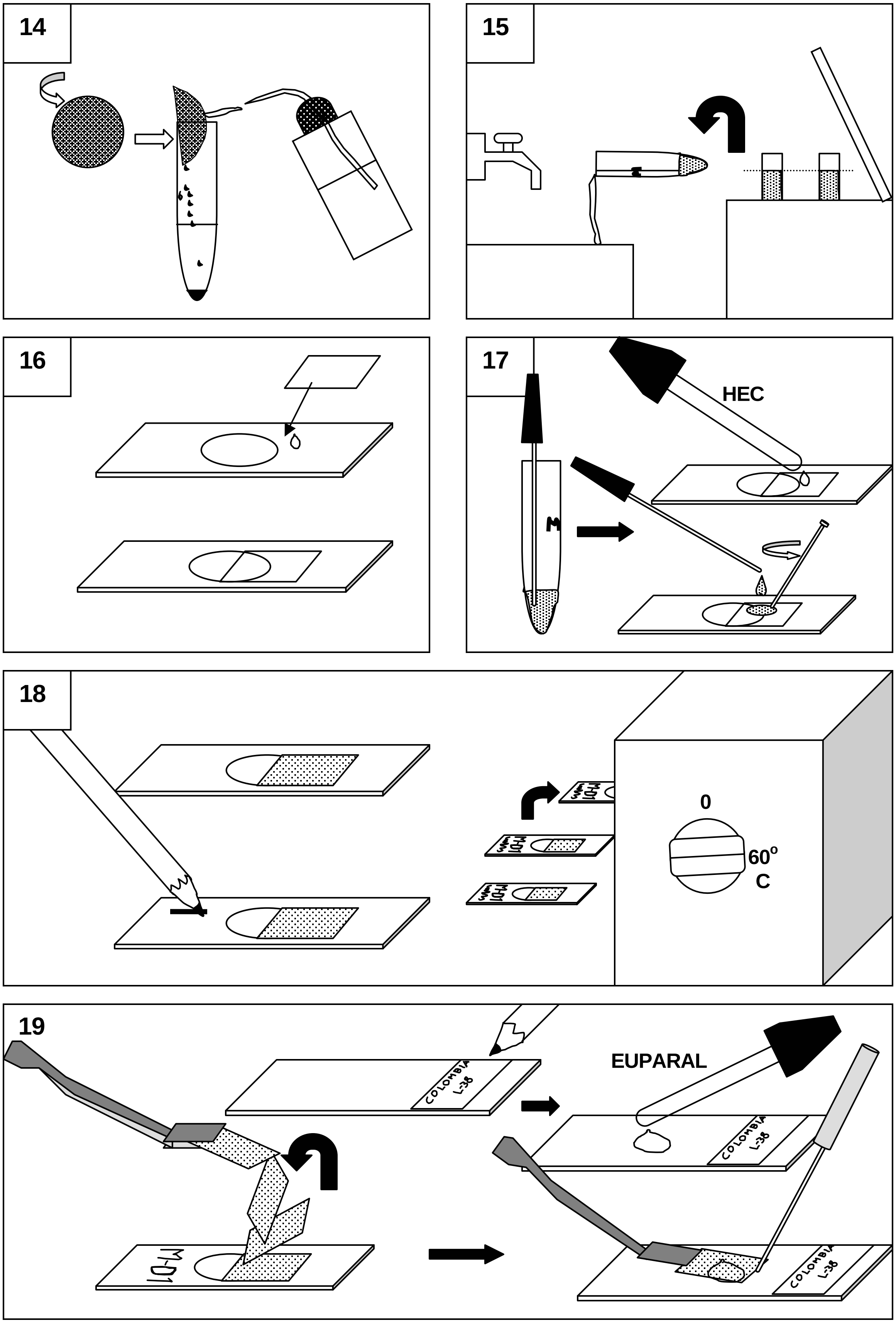
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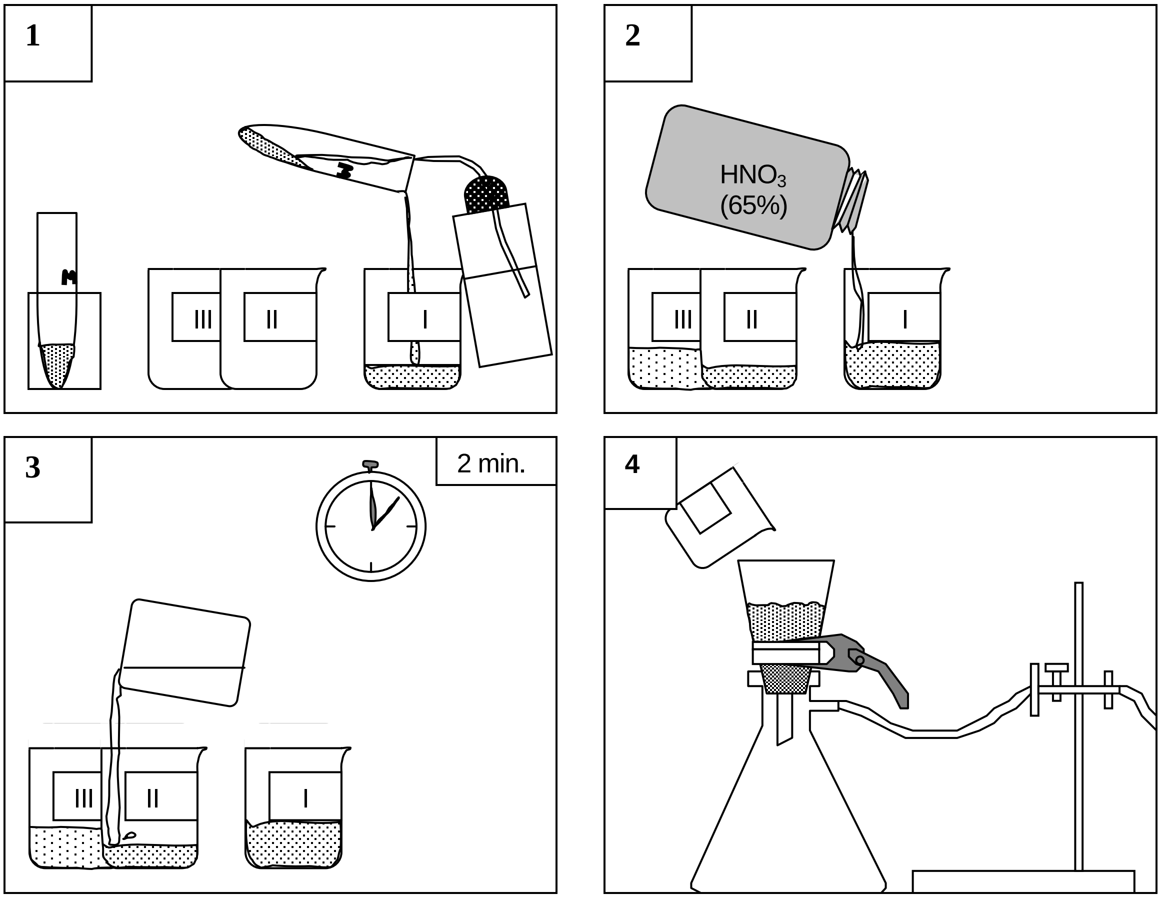
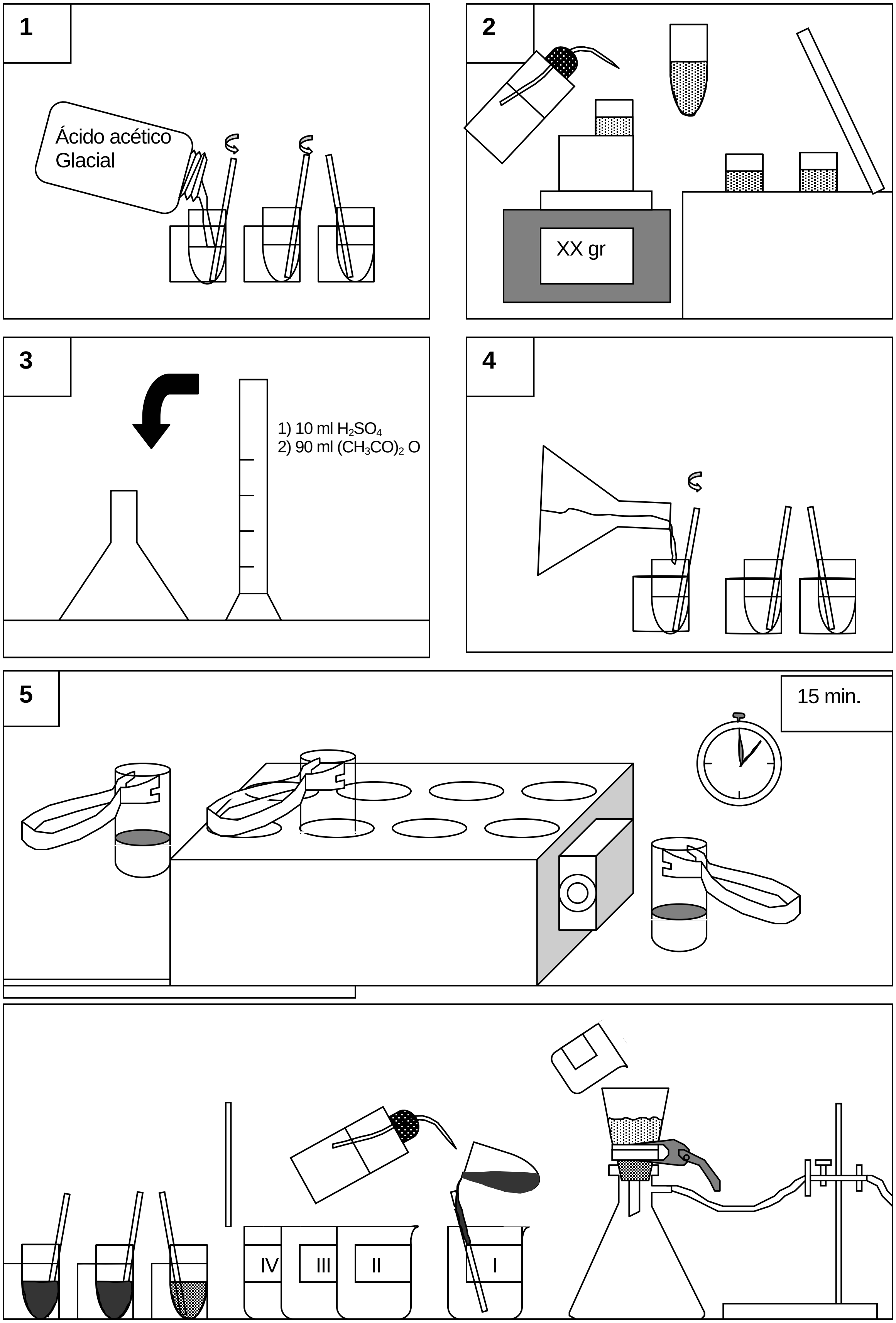
TECNICA PARA LIMPIAR LOS PALINOMORFOS



TÉCNICA DEL ACETOLICE



Appendix 2.1. A. Lithologic description of samples studied in the Middle Magdalena Valley Basin (Sogamoso section)

Biostratigraphic sample (number used in the stratigraphic log of the figure 2,3)	Cumulative meters from the base of sandstone dominated facies (general log)	cumulative meters from the top (general log)	Reference (University of Liege code)	Well	Depth (well)	Number of sample (well)	Lithostratigraphic unit	Lithology	Color of the sample	Code of color (Munsell)	Remarks
	-26	493	19527	IC-PE-2	38,7	1	La Paz Formation	Mudrock		5 GY 6/1 Light olive grey	Red mottled
			19528	IC-CC-2	21,12	4	La Paz Formation	Siltstone		10 GY 5/2 greyish green	
			19529	ICF-A-4	93,59	9	La Paz Formation	Siltstone		5 GY 4/1 Dark greenish grey	Carbonized plant remains
			19530	SD-D-8D	31,7	11	La Paz Formation	Mudrock		5 GY 4/1 Dark greenish grey	
	-22	489	19531	IC-PE-2	34,7	2	La Paz Formation	Mudrock		5 Y 6/1 Light olive grey	Red mottled
	-15	482	19532	IC-PE-2	24,7	3	La Paz Formation	Claystone		5 Y 6/1 Light olive grey	Red mottled
1	-13	480	19533	IC-PE-2	22,5	4	La Paz Formation	Mudrock		5 Y 5/1 Light olive grey-Olive grey	
	-9	476	19534	IC-PE-2	18,05	5	La Paz Formation				
	-8	475	19535	IC-PE-2	15,7	6	La Paz Formation	Siltstone		5 Y 6/1 Light olive grey	
2	-5	472	19536	IC-PE-2	12,6	7	La Paz Formation	Mudrock		5 Y 4/1 Olive grey	
	-3	470	19537	IC-PE-2	9,65	8	La Paz Formation	Siltstone		5 Y 8/1 Yellowish grey	
	4	463	19538	IC-PE-1	33,37	1	La Paz Formation	Siltstone		5 Y 6/1 Light olive grey	Micaceous, carbonized plant remains
	15	452	19539	IC-PE-1	20	2	La Paz Formation	Siltstone		5 Y 4/1 Olive grey	Micaceous, carbonized plant remains
3	69	398	19540	IC-FA-3	64,85	1	La Paz Formation	Siltstone		N4 Medium dark grey	
	79	388	19541	IC-FA-3	50,65	2	La Paz Formation	Siltstone		5 GY 4/1 Dark greenish grey	
	83	384	19542	IC-FA-3	46,03	3	La Paz Formation	Siltstone		5 GY 5/1 Greenish grey-Dark greenish grey	
	87	381	19543	IC-FA-3	41,4	4	La Paz Formation	Siltstone		5 GY 4/1 Dark greenish grey	Micaceous, carbonized plant remains
	87	380	19544	IC-FA-3	40,8	5	La Paz Formation	Siltstone		5 GY 4/1 Dark greenish grey	Some mica
	94	374	19545	IC-FA-3	32,3	6	La Paz Formation				
4	106	361	19546	IC-FA-3	17,1	7	La Paz Formation	Siltstone		5 GY 5/2 Dusky yellow green	Some mica
5	114	353	19547	IC-FA-3	6,12	8	La Paz Formation	Siltstone		N4 Medium dark grey	Poor in mica
	121	346	19548	IC-TD-1	34,47	1	La Paz Formation	Siltstone		N4 Medium dark grey	Abundant mica
			19549	IC-TD-1	31,03	2	La Paz Formation	Siltstone		N4 Medium dark grey	
			19550	IC-TD-1	23,9	3	La Paz Formation	Siltstone		5 BG 5/2 greyish blue green	Some mica
			19551	IC-TD-1	16,82	4	La Paz Formation	Sandy-Silt.		5 Y 5/1 Light olive-Olive grey	Abundant mica
6	136		19552	IC-CC-12	37,75	1	La Paz Formation	Siltstone		5 GY 4/1 Dark greenish grey	Some mica
			19553	IC-CC-12	36	2	La Paz Formation	Sandstone		5 GY 5/1 Greenish grey-Dark greenish grey	Micaceous, carbonized plant remains
			19554	IC-CC-12	35	3	La Paz Formation	Not treated			Not treated
			19555	IC-CC-12	24,03	4	La Paz Formation	Siltstone		5 BG 5/2 greyish blue green	
			19556	IC-CC-12	22,45	5	La Paz Formation	Siltstone		5 BG 5/2 greyish blue green	Poor mica
			19557	IC-CC-12	20,84	6	La Paz Formation	Mudrock		N 5 Medium grey	Red mottled
			19558	IC-CC-12	18,55	7	La Paz Formation	Mudrock		N 5 Medium grey	Greyish-red mottled
			19559	IC-CC-12	16,7	8	La Paz Formation	Mudrock		10 YR 6/2 Pale yellowish brown	Weathered
			19560	IC-CC-12	14,85	9	La Paz Formation	Mudrock		5B5/1Medium bluish grey;5Y 5/2Light olive	Poor in mica
	123	344	19561	IC-CC-7	37,05	1	La Paz Formation	Mudrock		N4 Medium dark grey	Some mica
	129	338	19562	IC-CC-7	29,65	2	La Paz Formation	Siltstone		5GY4/1 Dark greenish grey	Some mica
	135	332	19563	IC-CC-7	23,18	3	La Paz Formation				
7	144	323	19564	IC-CC-7	11,6	4	La Paz Formation	Mudrock		5BG 5/2greyish blue green	
8	146	321	19565	IC-CC-7	9,5	5	La Paz Formation	Mudrock		5GY4/1Dark greenish grey	Some mica
			19566	IC-CC-2	27,05	1	La Paz Formation	Siltstone		5GY4/1Dark greenish grey	Some mica
			19567	IC-CC-2	25,6	2	La Paz Formation	Siltstone		N5 Medium grey	Break in fine fragments
			19568	IC-CC-2	22,25	3	La Paz Formation	Mudrock		N4 Medium dark grey	Break in fine fragments
			19569	IC-CC-2	18,2	5	La Paz Formation	Siltstone		5GY5/1 Dark greenish grey	Break in fine fragments, some mica
			19570	IC-CC-2	16,05	6	La Paz Formation	Siltstone		10G4/2 greyish green	Poor in mica
			19571	IC-CC-2	14,4	7	La Paz Formation	Siltstone		5GY4/1 Dark greenish grey	Poor in mica
			19572	IC-CC-2	12,9	8	La Paz Formation	Siltstone		5GY4/1 Dark greenish grey	Break in fine fragments, abundant mica
			19573	IC-FA-4	139	1	La Paz Formation	Mudrock		5GY4/1 Dark greenish grey	Some mica
			19574	IC-FA-4	137,3	2	La Paz Formation	Mudrock		5GY4/1 Dark greenish grey	
			19575	IC-FA-4	135,5	3	La Paz Formation	Mudrock		5GY4/1 Dark greenish grey	Some mica
	157	310	19576	IC-FA-4	125,8	4	La Paz Formation	Very fine sandstone-silt		N4 Medium dark grey	Some mica, laminated, carbonized plant remains
	169	298	19577	IC-FA-4	112,1	5	La Paz Formation	Mudrock		5BG5/2 greyish blue green	
9	179	288	19578	IC-FA-4	101,38	6	La Paz Formation	Very fine sandstone-silt		5G5/1 Greenish grey	Abundant mica
	181	286	19579	IC-FA-4	98,9	7	La Paz Formation	Siltstone		N5 Medium grey	Cross laminated wit fine sand
	183	284	19580	IC-FA-4	96,24	8	La Paz Formation	Siltstone		N4 Medium dark grey	Some mica, carbonized plant remains
	189	279	19581	IC-FA-4	89,9	10	La Paz Formation	Siltstone		5G4/2greyish green	Carbonized plant remains
	190	277	19582	IC-FA-4	88,3	11	La Paz Formation	Siltstone		5G4/2greyish green	Abundant mica
	193	274	19583	IC-FA-4	85,14	12	La Paz Formation	Siltstone		N4 Medium dark grey	Abundant mica
10	202	265	19584	IC-FA-4	73,85	13	La Paz Formation	Very fine sandstone		5G4/1Dark greenish grey	Some mica, carbonized plant remains
	215	252	19585	IC-FA-4	71	14	La Paz Formation	Siltstone		N4 Medium dark grey	
	206	261	19586	IC-FA-4	70,14	15	La Paz Formation				
	210	257	19587	IC-FA-4	65,35	16	La Paz Formation	Siltstone		N4 Medium dark grey, partially altered	Poor mica, carbonized remains
	214	254	19588	IC-FA-4	61	17	La Paz Formation	Siltstone		N4 Medium dark grey	
	219	249	19589	IC-FA-4	55,3	18	La Paz Formation	Siltstone		N4 Medium dark grey	Poor mica
11	224	243	19590	IC-FA-4	48,85	19	La Paz Formation	Siltstone		5G4/1Dark greenish grey altered to 10YR	
12	237	230	19591	IC-FA-4	34,2	20	La Paz Formation	Siltstone		5G4/1 Dark greenish grey	Poor mica, carbonized remains
	239	228	19592	IC-FA-4	31,5	21	La Paz Formation	Mudrock		5GY5/2 Dusky yellow green	Some mica
	245	222	19593	IC-FA-4	24,45	22	La Paz Formation				
	250	217	19594	IC-FA-4	19,6	23	La Paz Formation	Siltstone		5G5/1 Greenish grey	Abundant mica, carbonized remains
	251	216	19595	IC-FA-4	17,45	24	La Paz Formation	Siltstone		5GY6/1 Greenish grey	Some mica, carbonized plant remains
13	272	195	19596	IC-FP-1	174,2	1	La Paz Formation	Mudrock		N4 Partially altered to 10 YR 4/2	
14	280	188	19597	IC-FP-1	165,6	2	La Paz Formation	Mudrock		5Y 4/1 Olive grey	Micaceous
	281	186	19598	IC-FP-1	164,6	3	La Paz Formation				
	307	160	19599	IC-FP-1	163,55	4	La Paz Formation	Siltstone		N4 Partially altered to NY 4/1	Micaceous
	283	184	19600	IC-FP-1	161,4	5	La Paz Formation	Mudrock		5Y 4/1 Olive grey	Micas, bad preserved coaly plant remains
	285	182	19601	IC-FP-1	159,04	6	La Paz Formation	Siltstone		N4 Partially altered to 5Y 4/1	
	286	181	19602	IC-FP-1	157,65	7	La Paz Formation	Mudrock		N4 Partially altered to 10 YR 4/2	Less micaceous than 4
15	287	180	19603	IC-FP-1	156,52	8	La Paz Formation	Mudrock		N4 Partially altered to 10 YR 4/2	Less micaceous than 4
	310	157	19604	IC-FP-1	129,05	9	La Paz Formation	Siltstone		N4 Partially altered to 5Y 5/2	Micaceous
	311	156	19605	IC-FP-1	128,05	10	La Paz Formation	Siltstone		N4 Medium dark grey	Micas, bad preserved coaly plant remains
	312	155	19606	IC-FP-1	127,18	11	La Paz Formation				
	321	146	19607	IC-FP-1	116,86	12	La Paz Formation	Claystone		10Y 6/2 Cemented N3	Very cemented
16	343	124	19608	IC-FP-1	91,4	13	La Paz Formation	Mudrock		5GY 6/1 Greenish grey	Friable, coarse sand at the border (intraclast?)
	351	117	19609	IC-FP-1	82,45	14	La Paz Formation	Siltstone		N6 Medium light grey	Micaceous, coaly remains
	357	110	19610	IC-FP-1	74,27	15	La Paz Formation	Siltstone		N4 Partially altered to 5Y 4/1	Micaceous
	359	108	19611	IC-FP-1	72,86	16	La Paz Formation				
	380	87	19612	IC-FP-1	47,75	17	La Paz Formation	Claystone		N7 Light grey	
17	406	61	19613	IC-FP-1	18,53	18	La Paz Formation	Claystone		N6 Medium light grey	
	401	66	19614	SD-D-8D	76,3	1	La Paz Formation	Siltstone		N4 Partially altered to 10 YR 4/2	
	409	58	19615	SD-D-8D	66,68	2	La Paz Formation	Very fine sandstone		5Y 5/2 Light olive grey	Micaceous, laminated
	423	44	19616	SD-D-8D	51,08	3	Esmeraldas Formation	Mudrock		N4 Partially altered to 10 YR 4/2	
	424	43	19617	SD-D-8D	49,7	4	Esmeraldas Formation	Mudrock		N4 Partially altered to 10 YR 4/2	
	425	42	19618	SD-D-8D	48,5	5	Esmeraldas Formation	Mudrock		N4 Partially altered to 10 YR 4/2	
	427	40	19619	SD-D-8D	46,2	6	Esmeraldas Formation	Mudrock		N4 Partially altered to 10 YR 4/2	
18	428	39	19620	SD-D-8D	44,9	7	Esmeraldas Formation	Mudrock		N4 Partially altered to 10 YR 4/2	
	432	35	19621	SD-D-8D	41,09	8	Esmeraldas Formation	Sandstone		5Y 4/1 Olive grey	
	438	29	19622	SD-D-8D	33,79	9	Esmeraldas Formation	Siltstone		N4 Partially altered to 5Y 4/1	Micaceous
	439	28	19623	SD-D-8D	32,6	10	Esmeraldas Formation	Mudrock		5R 4/2 With greenish patches	
	442	25	19624	SD-D-8D	28,76	12	Esmeraldas Formation	Mudrock		5GY 6/1 With patches 5R 4/2	
	446	21	19625	SD-D-8D	24,88	13	Esmeraldas Formation	Mudrock		5R 4/2 With greenish patches	
	450	17	19626	SD-D-8D	20,36	14	Esmeraldas Formation	Mudrock		10Y 6/2 Altered to 5Y 6/4 with reddish patch	Siliceous?
	453	15	19627	SD-D-8D	16,8	15	Esmeraldas Formation	Mudrock		10Y 6/2 Altered to 5Y 6/4 with reddish patches	
	455	12	19628	SD-D-8D	14,22	16	Esmeraldas Formation	Mudrock		5Y 6/1 With reddish patches	
19	459	8	19629	SD-D-8D	9,06	17	Esmeraldas Formation	Siltstone		N4 Partially altered to 5Y 5/2	
	461	6	19630	SD-D-8D	6,77	18	Esmeraldas Formation	Siltstone		N4 Partially altered to 5Y 5/2	
			19631	IC-D-3	46,2	1	Esmeraldas Formation				Not treated
			19632	IC-D-3	14,5	2	Esmeraldas Formation	Very fine sandstone		5G4/1 Dark greenish grey	Not treated, some mica, carbonized remains

Appendix 2.1.B. Lithologic description of samples studied in the Middle Magdalena Valley Basin (Uribe section)

Studied by JARAMILLO	Studied by PARDO	Biostratigraphic sample (number used in the stratigraphic log)	Cumulative meters from the base	Cumulative meters from the top	Reference (Liege University code)	Sample code	Lithostratigraphic unit	Lithology	Color (Munsell)	Remarks
X		1	1,5	1893,5		UR 1	Lisama Formation	Dark gray ct		
	X		3,0	1892,0	20303	UR 2	Lisama Formation	Fine sandstone, silt level	5GY 6/1 (Greenish gray)	Micaceous
	X		5,8	1889,2	20304	UR 3 + 126	Lisama Formation	Siltstone-fine sandstone	N4 (Medium dark grey)	Fine wavy lamination
	X		9,0	1886,0	20305	UR 6	Lisama Formation	Siltstone	N5 (Medium grey)	Micaceous
	X		28,0	1867,0	20306	UR 18 + 100	Lisama Formation	V. fine sandstone	N5 (Medium grey)	Micaceous, cross lamination
X		2	33,1	1862,0		UR 22 + 05	Lisama Formation	Grey vf muscovitic Qzsd		
	X		52,6	1842,4	20307	UR 35 + 10 intraclast	Lisama Formation	Siltstone	5G 4/1 (Dark greenish grey)	Intraclast in sandstone
X		3	60,1	1835,0		UR 40 + 05	Lisama Formation	Grey vf muscovitic Qzsd		
	X		81,0	1814,0	20308	UR 54	Lisama Formation	Quartz sandstone		Laminated, micaceous
	X	4	93,0	1802,0	20309	UR 62	Lisama Formation	Siltstone	N4 (Medium dark grey)	Micaceous,f. sand interbeds
X		5	97,5	1797,5		UR 65	Lisama Formation	Grey muscovitic md, pp lamination		
	X		106,5	1788,5	20310	UR 71	Lisama Formation	Silty claystone	5Y 6/1 (Light olive grey)	Friable
X			157,5	1737,5		UR 105	Lisama Formation	Grey ct		
X		6	214,5	1680,5		UR 143	Lisama Formation	Dark grey ct		
	X	7	220,5	1674,5	20311	UR 147	Lisama Formation	Siltstone	N4 (Medium dark grey)	laminated, fine sand interbeds
	X		222,0	1673,0	20312	UR 148	Lisama Formation	Siltstone	N5 (Medium grey)	Coaly levels, micacoeous
	X	8	447,0	1448,0	20313	Lis 447m	Lisama Formation	Mudrock	N3 (Dark grey)	
	X		448,0	1447,0	20314	Lis 448m	Lisama Formation	V. fine sandstone	5Gy 6/1 (Greenish grey)	Some mica
X			449,0	1446,0		Lis 449m	Lisama Formation	Grey greenish muscovitic f Qzsd		
	X		450,0	1445,0	20315	Lis 450m	Lisama Formation	Mudrock	N4 (Medium dark grey)	Fine plane lamination, some mica
X		9	543,8	1351,2		UR 200 + 180	Lisama Formation	Coal		
X			546,6	1348,4		UR 202 + 60	Lisama Formation	Brown md + lenses of white m Qzsd		
	X	10	567,3	1327,7	20316	UR 212 + 130	Lisama Formation	Siltstone	N4 (Medium dark grey)	
	X	11	572,9	1322,1	20317	UR 215 + 90	Lisama Formation	Siltstone	N3 (Dark grey)	Organic
	X		573,0	1322,0	20318	UR 215 + 100	Lisama Formation	Mudrock	N2 (Grayish black)	Organic
	X	12	574,6	1320,4	20319	UR 216 + 60	Lisama Formation	Mudrock	N3 (Dark grey)	Organic
	X		574,8	1320,2	20320	UR 216 + 80	Lisama Formation	Coal	N1 (Black)	Mudrocks interbedded
	X		575,0	1320,0	20321	UR 216 + 100	Lisama Formation	V. fine muddy sandstone	N4 (Medium dark grey)	Micaceous, coal fragments
	X		575,2	1319,8	20322	UR 216 + 120	Lisama Formation	Mudrock	N5 (Medium grey)	Micaceous, coal fragments
	X	13	581,5	1313,5	20323	UR 219 + 150	Lisama Formation	Mudrock	N2 (Grayish black)	
	X		582,0	1313,0	20324	UR 220	Lisama Formation	Mudrock	N4 (Medium dark grey)	Some mica
	X	14	584,4	1310,6	20325	UR 221 + 40	Lisama Formation	Mudrock	5Y 4/1 (Olive grey)	Sand laminae, coaly fragments
X		15	588,0	1307,0		UR 223	Lisama Formation	Grey md, massive		
	X	16	590,0	1305,0	20326	UR 224 + 10	Lisama Formation	Mudrock	N4 (Medium dark grey)	Thin mica
	X		591,2	1303,8	20327	UR 224 + 120	Lisama Formation	Mudrock	N4 (Medium dark grey)	Micaceous
	X		610,0	1285,0	20328	UR 234 + 40	Lisama Formation	Mudrock	5B 5/1 (Med. Bluish grey)	Varicolored
	X	17	612,0	1283,0	20329	UR 235	Lisama Formation	Medium lithic sd	5YR 4/1 (Brownish grey)	Black mudrock fragments
	X		614,0	1281,0	20330	UR 236	Lisama Formation	Mudrock	N5 (Medium grey)	Some mica
	X		616,0	1279,0	20331	UR 237 + 10	Lisama Formation	Fine sandstone-silt	5G 6/1 (Greenish grey)	mottled (10YR 5/4)
	X	18	618,4	1276,6	20332	UR 238 + 40	Lisama Formation	Mudrock	N3 (Dark grey)	Some mica
X			621,6	1273,4		UR 239 + 160	Lisama Formation	Reddish ct		
	X		623,0	1272,0	20333	UR 240 + 100	Lisama Formation	Mudrock	5B 5/1 (Med. Bluish grey)	Some mica
	X		632,2	1262,8	20334	UR 245 + 20	Lisama Formation	V. fine sandstone	N5 (Medium grey)	Some mica
	X		637,0	1258,0	20335	UR 247 + 100	Lisama Formation	Mudrock	5R 4/2-5B 5/1	Varicolored
	X	19	638,0	1257,0	20336	UR 248	Lisama Formation	Mudrock	N4 (Medium dark grey)	Some mica
X		20	642,0	1253,0		UR 250	Lisama Formation	Light grey md		
	X				20337	UR 261	Lisama Formation	Fine sandstone	5G 6/1 (Greenish grey)	Some mica
	X				20338	UR 261 + 20	Lisama Formation	Sandy mudrock	5PB 5/2 (Grayish blue)	
X			736,0	1159,0		UR 297	Lisama Formation	Light grey ct		
	X		740,0	1155,0	20339	UR 299	Lisama Formation	Fine sandstone-silt	10R 4/2 (Grayish red)	Some mica
	X		742,0	1153,0	20340	UR 300	Lisama Formation	V. fine sandstone-siltstone	10R 5/2 (Grayish red)	Bioturbed; grey and red patches
X			747,0	1148,0		UR 302 + 100	Lisama Formation	Grey ct		
	X		750,0	1145,0	20341	UR 304	Lisama Formation	Siltstone	N5 (Medium grey)	Grayish-red patches; some mica
X			754,2	1140,8		UR 306 + 20	Lisama Formation	Grey ct		
X			764,0	1131,0		UR 311	Lisama Formation	Light grey ct		
X			776,0	1119,0		UR 317	Lisama Formation	Light grey ct		
X			782,0	1113,0		UR 320	Lisama Formation	Red md		
X			796,0	1099,0		UR 327	Lisama Formation	Grey ct		
X			798,0	1097,0		UR 328	Lisama Formation	Reddish grey md		
X			814,0	1081,0		UR 336	Lisama Formation	Light grey ct		
X			830,0	1065,0		UR 344	Lisama Formation	Lithic medium QzSd		
X			900,0	995,0		UR 376	Lisama Formation	light grey massive md		
X			901,5	993,5		UR 379	Lisama Formation	friable light grey md		
X			902,0	993,0		UR 380	Lisama Formation	Light grey siliceous md		
	X		909,0	986,0	20342	UR 384	La Paz Formation	Fine-coarse sandstone	N5 (Medium grey)	
	X		919,5	975,5	20343	UR 391	La Paz Formation	Calcareous mudrock	5GY 6/1 (Greenish grey)	Very hard
X			926,7	968,3		UR 395+120	La Paz Formation	coal		
	X	21	927,0	968,0	20344	UR 396	La Paz Formation	Medium sandstone	Greenish-grey	Intraclast levels
X			927,0	968,0		UR 396 trunk coal	La Paz Formation			
	X		938,0	957,0	20345	UR 403 + 50	La Paz Formation			
X		22	947,2	947,8		UR 409+70	La Paz Formation	medium lithic sd		
	X		987,2	907,8	20346	UR 436 + 20	La Paz Formation			
	X		988,6	906,4	20347	UR 437 + 10	La Paz Formation	Sandy mudrock	N6 (Medium light grey)	Siliceous
X			989,0	906,0		UR 437+5	La Paz Formation	light brown lithic sd, massive		
X			994,5	900,5		UR 441	La Paz Formation	Red mudstone		
X			1000,5	894,5		UR 445	La Paz Formation	friable light grey md, red spots		
	X		1003,5	891,5	20348	UR 447	La Paz Formation	Siltstone	5Y 6/1 (Light olive grey)	Grayish-red patches
X			1038,0	857,0		UR 470	La Paz Formation	light grey massive md		
X		23	1086,0	809,0		UR 502	La Paz Formation	f qzsd, lithics, x-bedding		
X		24	1092,0	803,0		UR 506	La Paz Formation	White f Qzsd		
X			1093,5	801,5		UR 507	La Paz Formation	vcoarse coaly sd, very poorly sorted, grains in a coaly matrix		
	X	25	1101,0	794,0	20349	UR 512	La Paz Formation	Limestone-V. fine sandstone		Some mica

Studied by JARAMILLO	Studied by PARDO	Biostratigraphic sample (number used in the stratigraphic log)	Cumulative meters from the base	Cumulative meters from the top	Reference (Liege University code)	Sample code	Lithostratigraphic unit	Lithology	Color (Munsell)	Remarks
X			1124,5	770,5		UR 527 + 100	La Paz Formation	Coal		
	X	27	1130,5	764,5	20350	UR 531+100	La Paz Formation	Mudrock	N5 (Medium grey)	Some mica, coaly fragments
X		26	1130,7	764,3		UR 531+120	La Paz Formation	black md, pp lamination, muscovite		
	X		1131,1	763,9	20351	UR 532 + 10	La Paz Formation	Sandy mudrock	N5 (Medium grey)	Some mica, coaly fragments
X			1146,4	748,6		UR 542+40	La Paz Formation	f qzsd, white matrix, massive		
X			1150,5	744,5		UR 545	La Paz Formation	f qzsd, light grey, massive		
X		28	1267,0	628,0		La Paz 361 m	La Paz Formation	Black md, pp lamination, muscovite		
X			1268,0	627,0		La Paz 362m	La Paz Formation	Grey md, pp. lamination		
X			1269,0	626,0		La Paz 363m	La Paz Formation			
X			1270,0	625,0		La Paz 364m	La Paz Formation			
X			1271,0	624,0		La Paz 365m	La Paz Formation			
X			1272,0	623,0		La Paz 366m	La Paz Formation			
	X	29	1287,8	607,2	20352	UR 701 + 130	La Paz Formation	Siltstone	N4 (Medium dark grey)	Some mica
X			1291,1	603,9		UR 704+10	La Paz Formation	Black md, pp lamination + fwQz		
	X		1294,1	600,9	20353	UR 706 + 10	La Paz Formation	Coarse sandstone	5Y 5/2 (Light olive grey)	Some ox. Fe
	X	30	1319,0	576,0	20354	UR 722 + 100	La Paz Formation	Medium coarse sandstone		Ox Fe grey intraclasts
	X		1320,7	574,3	20355	UR 723 + 120	La Paz Formation	Medium sandstone	N5 (Medium grey)	Mud intraclasts
X		31	1324,0	571,0		UR 726	La Paz Formation	Black sandy md, friable, non distinct lamination		
X			1333,0	562,0		UR 732	La Paz Formation	Black shale		
	X	32	1333,3	561,7	20356	UR 732 + 30	La Paz Formation	Medium sandstone		Mud intraclasts, coal fragments
	X		1340,5	554,5	20357	UR 737	La Paz Formation	Fine sandstone	N7 (Light grey)	Plane lamination, organic rich milimetric levels
	X	33	1350,0	545,0	20358	UR 743+50	La Paz Formation	Medium sandstone	5Y 5/2 (Light olive grey)	Mud intraclasts, coal fragments
	X		1353,5	541,5	20359	UR 745 + 10	La Paz Formation	Fine sandstone	N6 (Medium light grey)	Plane lamination, organic rich milimetric levels
	X		1364,0	531,0	20360	UR 752+100	La Paz Formation	Fine sandstone-Sandy mudstone	N5-N6 (Medium-medium light grey)	Carbonized plant remains
	X		1367,0	528,0	20361	UR 754 + 100	La Paz Formation	Mudrock	N3 (Dark grey)	Poor mica
	X		1373,2	521,8	20362	UR 758 + 120	La Paz Formation	Mudrock	N5 (Medium grey); mottled (10R 4/2)	Small (1 mm) grey rounded "nodules"
X		34	1376,5	518,5		UR 761	La Paz Formation	Friable, dark grey ct		
X		35	1406,7	488,3		UR 781+20	La Paz Formation	dark grey md, muscovite, massive		
	X	36	1444,0	451,0	20363	UR 806	La Paz Formation	Very fine sandstone-Mudrock	N5 (Medium grey)	Plane lamination, sinsedimentary fold, carrbonized plant remains, some mica
	X		1445,6	449,5	20364	UR 807 + 05	La Paz Formation	Very fine sandstone	N5 (Medium grey)	Ripple lamination, bioturbed, some mica
X		37	1453,0	442,0		UR 812	La Paz Formation	Black md, muscovite + Qzsd, pp lamination		
	X		1453,5	441,5	20365	UR 812 + 50	La Paz Formation	Mudrock	N4 (Medium dark grey)	Ripple sandstone levels, some mica
	X		1455,4	439,6	20366	UR 813+ 90	La Paz Formation	Mudrock	N 4 (Medium dark grey)	Homogeneous, some coaly fragments, mica
	X	38	1459,0	436,0	20367	UR 816	La Paz Formation	Fine sandstone-Mudrock	N4 (Medium dark grey) Mudrocks	Plane lamination, wavy, carbonized plant remains mark the lamination, some mica
	X		1495,0	400,0	20368	UR 840	La Paz Formation	Medium sandstone	N6 (Medium light grey)	Plane lamination, some mica
	X		1502,5	392,5	20369	UR 845	La Paz Formation	Mudrock	5G 4/1 (Dark greenish grey)	Poor mica
	X		1505,5	389,5	20370	UR 847	La Paz Formation	Mudrock	5GY 6/1 (Greenish grey)	With 5YR 4/1 (brownish grey) patches
X			1508,5	386,5		UR 849	La Paz Formation	dark grey friable ct, massive, red spots		
X			1514,5	380,5		UR 853	La Paz Formation	Reddish md + white m Qzsd lenses		
X			1528,0	367,0		La Paz 622m	La Paz Formation			
X			1538,0	357,0		La Paz 632m	La Paz Formation	Yellowish m Qzsd, lithics, thin black md laminae		
X		39	1618,0	277,0		La Paz 712 m	La Paz Formation	black md + pillows of QZSD		
X			1777,0	118,0		La Paz 871m	La Paz Formation	Grey shale, was not washed		
X			1782,0	113,0		La Paz 876m	La Paz Formation			
X		40	1792,0	103,0		La Paz 886 m	La Paz Formation	Black shale + pillows of QZSD		

Appendix 2.2. A. Sogamoso palynological range chart. Numbers represent the specimens counted by stratigraphic level. CJ: Carlos Jaramillo samples

Specie/sample	(1)IC-PE-2(22,5)	IC-PE-2(13.11)CJ	(2)IC-PE-2(12,6)	IC-PE-2(5,84)CJ	(3)IC-FA-3(64,85)	(4)IC-FA-3(17,1)	(5)IC-FA-3(6,12)	(6)IC-CC-12(37,75	(7)IC-CC-7(11,6)	(8)IC-CC-7(9,5)	(9)IC-FA-4(101,38	(10)IC-FA-4(73,85	(11)IC-FA-4(48,85	(12)IC-FA-4(34,2)	(13)IC-FP-1(174,2)	(14)IC-FP-1(165,6)	(15)IC-FP-1(156,5	(16)IC-FP-1(91,4)	(17)IC-FP-1(18,53)	(18)SD-D-8D(44,9	(19)SD-D-8D(9,06
Stratigraphic meters above the base of the sandstone dominated facies.	-12,7	-4,8	-4,7	-2,3	69	105,8	114,1	135,7	144,5	146,7	178,6	202,3	224,3	236,7	272,2	280,2	287,9	342,8	406,5	428,5	459,3
Sample number used in the Figure 2.3.	1		2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Albertipollenites ? perforatus	10		30							2						3					
Araliaceoipollenites ? sp. 1 (Jaramillo & Dilcher, 2001)										1	2										
Araucariacites sp. 1						1	1							1							
Baculatisporites sp.						2						1									
Bacumorphomonocolpites tausae																					2
Big reticulate spore																		1			
Bisacate pollen					1		1	1	3	1	1		1						8		
Bombacacidites aff. *gonzalezii*											1		1		1			2		1	
Bombacacidites annae (RW)																		1			
Bombacacidites cf. *soleaformis*										1	1										
Bombacacidites pseudosimplireticulatus					2						1										
Bombacacidites psilatus			6												4			3	1		
Bombacacidites sp. (homogenous reticulum)										1	1			1	1				1		
Bombacacidites sp. 1					1																
Bombacacidites sp. 2						2				1											
Bombacacidites sp. 3							1													1	
Bombacacidites sp. 4 (sp.2 of Jaramillo & Dilcher, 2001)							1			3	2				2	1		1		1	
Bombacacidites sp. 5							1	2		1											
Bombacacidites sp. 6								2		1											
Bombacacidites sp. 7								1													
Bombacacidites sp. 8 (fossulate, vermiculate reticle)									1	1	3										
Bombacacidites sp. 9 (>60µ)										1	1										
Bombacacidites sp.10 (50µ) foveolate												1	1								
Bombacacidites sp.11 (20µ)														1							
Bombacacidites sp.12 (lumina 5µ)																		1			
Bombacacidites sp.13																		1			
Bombacacidites sp.14																			6		
Bombacacidites sp.15 (foveolate in the polar region)											1?								1	1	
Bombacacidites sp.16 (sp. 3 of Jaramillo & Dilcher, 2001)																				1	
Bombacacidites sp.17																					2
Brevitricolpites "densiechinatus"													5			1		1	11	36	
Brevitricolpites AIC5				1																	
Brevitricolpites macroexinatus						1							1					1			1
Brevitricolpites microechinatus										2			1			1	1	13			
Brevitricolpites sp. 1 (gemmate)											1										
Brevitricolpites sp. 2 (baculate)											1			1							
Brevitricolpites sp. 3 (triangular, echinate)																					1
Brevitricolpites, IC-FP-1(91,4), 55019, EF:N43/3.																		1			
Chomotriletes group			3		7	12	19	24	13	29	20	3	1	7	1	3				6	2
Cicatricososporites eocenicus							1														
Cicatricososporites sp. 1					1																
Clavainaperturites cordatus					1																
Clavamonocolpites terrificus																			1		
Clavatricolpites densiclavatus	2	3	7		29		5	2	3		4										
Clavatricolpites sp. 1					1			1				1									
Corsinipollenites psilatus	13			1																	
Cricotriporites AIC13		1																			
Cricotriporites cf. *elongatoporus*									1												
Cricotriporites guianensis					1?		2	1	3			1			1			2			3
Cricotriporites minutiporus									1	1		1									
Crusafontites "minor" (20 µ)												1									
Crusafontites grandiosus														1							
Crusafontites megagemmatus						1			1												
Crusafontites sp. 2 (55 µ)														1							
Cyclusphaera ("psilate")								2		9											
Cyclusphaera scabrata			2		2	2	6		4	29	7		3	2		4		2	1	1	
Duplotriporites ariani							1	2													
Echimonocolpites "minutus"													15	13	7	1					
Echimonocolpites sp. 1			1																	1	
Echimonocolpites sp. 3														3		3				1	2
Echimorphomonocolpites gracilis									1												
Echiperiporites sp.	20		20		2	25	6	12	2	8	11	4	25	1	6	1	3		6	2	
Echitrilete spores					7	12	30	40	21	4	2			9	12	8		7		8	
Echitriporites "annulatus"								1			1										
Echitriporites trianguliformis							1									1					
Echitriporites trianguliformis var. *orbicularis*				1																	
Equisetosporites sp. A (Pons, 1988)RW									1												1
Foveotriletes sp.									1									1			
Foveotriporites hammenii					1	3		2			2									6	
Foveotriporites sp. 1							1	1													
Gemmamonocolpites "digemmatus" (*G.* sp. 1 of Jaramillo & Dilcher, 2001)							1														
Gemmamonocolpites amicus					2																
Gemmamonocolpites gemmatus										1				1							
Gemmamonocolpites ovatus	1		2		2		1				2										
Gemmamonocolpites sp. 2 (20 µ)																		1			
Gemmamonocolpites sp. 3 (small gemmae)										1											
Gemmatricolpites sp. 1															2						
Gemmatricolporites sp. 1 (pores costate)												1									
Gemmazonocolpites sp. 1	1										1										
Horniella "sogamosa"					4		1		2				4								
Horniella sp. IC-CC-7 (11.6), 55846 (1), EF: F55-4.									1												
Horniella sp. 2 (cf. sp. 2 of Jaramillo & Dilcher, 2001)					1		1	1													
Horniella sp. 7				1																	
Inaperturate verrugate 1					1								1							1	
Inaperturate verrugate 2									2												
Kuylisporites type spore						3	3	1	7	10		3				1	1	1			
Ladakhipollenites minutus								2		1		1					2				
Ladakhipollenites simplex		1	1		1	1	1			3		2				1		3			
Laevigatasporites sp. 3		1																			
Laevigatosporites (small verrucae)																		1			
Longapertites proxapertitoides var. *proxapertitoides*	2	1	2	7				1													
Longapertites proxapertoides var. *reticuloides*														1							
Longapertites psilate																		1			
Longapertites sp. (smooth reticle)			8					2				2									
Longapertites sp. 1				1																	
Longapertites sp. 3																		1			

Specie/sample	(1)IC-PE-2(22.5)	IC-PE-2(13.11)CJ	(2)IC-PE-2(12,6)	IC-PE-2(5.84)CJ	(3)IC-FA-3(64,85)	(4)IC-FA-3(17,1)	(5)IC-FA-3(6,12)	(6)IC-CC-12(37,75	(7)IC-CC-7(11,6)	(8)IC-CC-7(9,5)	(9)IC-FA-4(101,38	(10)IC-FA-4(73,85	(11)IC-FA-4(48,85	(12)IC-FA-4(34,2)	(13)IC-FP-1(174,2	(14)IC-FP-1(165,6	(15)IC-FP-1(156,5	(16)IC-FP-1(91,4)	(17)IC-FP-1(18,53	(18)SD-D-8D(44,9	(19)SD-D-8D(9,06
Stratigraphic meters above the base of the sandstone dominated facies.	-12,7	-4,8	-4,7	-2,3	69	105,8	114,1	135,7	144,5	146,7	178,6	202,3	224,3	236,7	272,2	280,2	287,9	342,8	406,5	428,5	459,3
Sample number used in the Figure 2.3.	1		2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Longapertites ? sp. (gemmate)																				3	
Luminidites colombianensis							2														9
Luminidites sp. 1				41																	
Mauritiidites franciscoi var. *franciscoi*				1																	
Mauritiidites franciscoi var. *minutus*				1			2	4		9				1							1
Monocolpites minutispinosus												1									
Monocolpopollenites ovatus	3		1	317													2		1		1
Monocolpopollenites sp. 3				14																	
Monoporopollenites annulatus						1	1	13	1	5	3		3	1				2			
Perfotricolpites cf. *digitatus*							1		1			1									
Polotricolporites mocinnii					1																
Polypodiaceoisporites group (zonate spores)					5	12	3	9	9	22	10		2	4	2	1		2		1	
Polypodiisporites (sp. 2 of Jaramillo & Dilcher 2001)												1									
Polypodiisporites AIC13		1																			
Polypodiisporites AIC5				1																	
Polypodiisporites ssp.			12		3	12	2	4	3	13	2	5	2	2		3	1	1		3	
Proteacidites cf. *dehaani*												1									
Proteacidites triangulatus												1									1
Proxapertites humbertoides					1	2	1	1		2		1		2							
Proxapertites magnus				1								3?				2					
Proxapertites operculatus					1		1					2						1			9
Proxapertites psilatus								2													
Psilabrevitricolpites sp. IC-CC-7 (9,5), 55833, EF:K43/1.										1											
Psilabrevitricolpites sp. 1 (small gemmae)												1									
Psilabrevitricolporites sp. 1								2													
Psilamonocolpites grandis	1																				
Psilamonocolpites medius	4		7		7	1	7	6	5	8	8	7	2		3	7	5	5	13		
Psilamonocolpites minutus	3	1	3									5	5	5	8						
Psilamonoletes			10		10	8	6		1	9											
Psilastephanocolporites cf. *brevicolpatus*																	1			1	
Psilastephanocolporites sp. 1			1																		
Psilastephanocolporites sp. 2														1			1				
Psilastephanocolporites sp. 3														1							
Psilasyncolporites sp. 1													3								
Psilasyncolporites sp. 2																1					
Psilatricolporites costatus									5		2	2		2		1					
Psilatricolporites normalis			1		5		2														
Psilatricolporites sp. 1						1												1		1	
Psilatriletes spp.	2				7	33	40	57	11	45	2	3		13	549	17		14	34	42	17
Psilatriporites IC-PE-2 (12,6)			2																		
Psilatriporites sp. 1				2																	
Racemonocolpites facilis	7	1	46		12	4	10	4	1		4		21	2							
Racemonocolpites microgemmatus											1	4		1							
Racemonocolpites racematus											2	1	25			1					
Retibrevitricolpites sp. 1 (sp. 2 of Jaramillo & Dilcher 2001)									1												
Retibrevitricolpites triangulatus																	1				
Retibrevitricolporites cf. *grandis*		1			2																
Retimonocolpites AIC13		1																			
Retimonocolpites longicolpatus + *Retimonocolpites tertiarius*			4		3	8	6			1	7			5		3		10	30	1	1
Retimonocolpites retifossulatus	68		47									1			37		9	20	94		
Retimonocolpites sp. 1		3		9																	
Retipollenites	26																				
Retistephanocolpites sp. (foveolate)																	1				
Retistephanoporites minutiporus			3				1	1													
Retistephanoporites sp. 1										1											
Retistephanoporites sp. 2										1											
Retitrescolpites cf. *baculatus*	10		6							1					2			7		5	
Retitrescolpites magnus			1																		
Retitrescolpites saturum				2							1										
Retitrescolpites? cf. *irregularis*									1				1								
Retitricolpites cf. *simplex*							1		2				6		24	2	2	18	18	5	
Retitricolporites "poricostatus"															1						
Retitricolporites AIC13		1																			
Retitricolporites AIC13		1																			
Retitricolporites cf. *equatorialis*																	1				
Retitricolporites finitus			11																		
Retitriletes															1						
Retitriletes big											2										
Retitriporites cf. *federicii*																					1
Retitriporites cf. *poricostatus*																				1	
Retitriporites sp. 3 (60 µ)									1												
Rousea florentina										1											
Rugumonocolpites "pacificus"					1	1	4	2		2										1	
Rugutricolpites sp.	9	1		7																	
Siltaria mariposa			5																		
Spinizonocolpites baculatus (form 2) "brevibaculatus"							1					1									1
Spinizonocolpites baculatus (form 3)							1														
Spinizonocolpites baculatus (RW?)						2	5?	1	1			1		4		1		2		1	4
Spinizonocolpites breviechinatus										1	3	1	2		2	1(34µ)					
Spinizonocolpites cf. *S. baculatus* (form 1)							1			1											
Spinizonocolpites echinatus			1		5	3	1	5			2		2					2		5	1
Spinizonocolpites echinatus (psilate)															1						
Spirosyncolpites spiralis	10		14	1	3	9	6	28	15	30	20	3	2	2	36	1		3		2	6
Striatopollis AIC13		1																			
Striatopollis catatumbus	18		106	7	20	5	11	26	7	28	24	1		2	2	2	2	9	1	8	29
Striatopollis minor	1						1														
Striatopollis ? *tenuistriatus*					2		3	1						1						1	
Striatricolpites cf. *pimulis*			3												1						
Striatricolporites digitatus			2		1																
Striatricolpites sp. 4		2																			
Striatriporites sp. 1					1		1														
Syncolporites ? sp. 1									2				2								
Syncolporites sp. 2 (12µ; "Myrtaceidites")																		1			
Tetracolporopollenites sp. 1			1																		
Tetracolporopollenites "grandis" (long: 50µ; 3µ exine)																				1	
Tetracolporopollenites "triploporatus"																	1				
Tetracolporopollenites ? sp. 2 (Jaramillo & Dilcher, 2001)																2					

Specie/sample	(1)IC-PE-2(22.5)	IC-PE-2(13.11)CJ	(2)IC-PE-2(12,6)	IC-PE-2(5.84)CJ	(3)IC-FA-3(64,85)	(4)IC-FA-3(17,1)	(5)IC-FA-3(6,12)	(6)IC-CC-12(37,75	(7)IC-CC-7(11,6)	(8)IC-CC-7(9,5)	(9)IC-FA-4(101,38	(10)IC-FA-4(73,85	(11)IC-FA-4(48,85	(12)IC-FA-4(34,2)	(13)IC-FP-1(174,2	(14)IC-FP-1(165,6	(15)IC-FP-1(156,5	(16)IC-FP-1(91,4)	(17)IC-FP-1(18,53	(18)SD-D-8D(44,9	(19)SD-D-8D(9,06
Stratigraphic meters above the base of the sandstone dominated facies.	-12,7	-4,8	-4,7	-2,3	69	105,8	114,1	135,7	144,5	146,7	178,6	202,3	224,3	236,7	272,2	280,2	287,9	342,8	406,5	428,5	459,3
Sample number used in the Figure 2.3.	1		2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Tetracolporopollenites maculosus											2	1	13		3		6	2			
Tetracolporopollenites sp.												1					2				
Tetracolporopollenites transversalis					1	1			2	7							10				
Tricolpites "simetricus"	31									1											
Tricolpites (reticulum dim. Colpi)									1												
Tricolpites cf. *minutus*	27		14		12		3		6			1									
Tricolpites clarensis											1								4	1	
Tricolpites conciliatus																	22				
Tricolpites protoclarensis					1				1										1	1	
Tricolporate (fine reticle) pore lalongate									3			3	16	7			3				
Tricolporate reticulate			2																		
Triporites , IC-PE-2 (12,6), 55711(1), EF: R35.			2																		
Triporites sp. 1 (triangular)																1					
Ulmoideipites krempii											1							2			
Verrucingulatisporites sp. Kedves 1961						1	1	1		1	1			1							
Verrutricolpites sp. 1											1										
Verrutricolporites haplites															1						
Verrutrilete spores						1			4		3	2		1		1	1	2		1	
Zonocostites minor			8									2				1					
total number of palynomorphs	269	21	395	416	170	170	205	268	152	302	167	76	166	101	710	76	78	150	232	152	95
Number of studied slides	3	1	3	1	4	2	2	2	2	2	2	2	2	2	2	2	2	3	2	2	2

Appendix 2.2. B. Uribe palynological range chart. Numbers represent the specimens counted by stratigraphic level. Top Lisama formation: 906 , Top la Paz Formation: 1952

sample label	UR 1	UR 22 + 05	UR 40 + 05	UR-62(93m)	UR 65	UR 143	UR-147(220,5m)	LIS-447(447m)	UR 200 + 180	UR-212+130 (567m)	UR-215+90(573m)	UR-216+60(575m)	UR-219+150 (582m)	UR-221+40(584)	UR 223	UR-224+10(590m)	UR-235(612m)	UR-238+40(618m)	UR-248(638)	UR 250	UR-396(927m)	UR 409+70	UR 502	UR 506	UR512(1101m)	UR 531+120	UR-531+100 (1131	La Paz 361 m	UR-701+130(1288)	UR-722+100(1317m	UR 726	UR-732+30(1333m)	UR 743+50 (1350 m)	UR 761	UR 781+20	UR 806 (1444 m)	UR 812	UR 816 (1459 m)	La Paz 712 m	La Paz 886 m
cumulative meters from base section	1,5	33,1	60,1	93	97,5	214,5	220,5	447	543,8	567	573	575	582	584	588,0	590	612	618	638	642,0	927	947,2	1086	1092,0	1101	1130,7	1131	1267	1288	1317	1324	1333	1350	1376,5	1406,7	1444	1453	1459	1618	1792
Sample number used in the Figure 2.3.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Acritarcha sp. A																																			1					
Aequitriradites verrucosus (RW)																								2																
Aglaoreidia ? foveolata											1	8	1			1																								
Algae																							1																	
Algae A																						3																		
Alisogymnium euclaense (RW)																																			1					
Apiculatasporites obscurus		1			4																																		1	1
Apiculatasporites ? cingulatus																																			1		1			
Araliaceoipollenites sp. 4															1																									
Araliaceoipollenites ? sp. 1																										1											2			
Araliaceoipollenites ? sp. 2 Jaramillo & Dilcher 2001										1																														
Araucariacites sp. 1							3																																	
Araucariacites sp. 2	2	3	2																													2								
Araucariacites sp. 2 (cf. sp. 1 Jaramillo & Dilcher 2001)																		1							3		7													
Araucariacites sp. 3																								1																
Arecipites regio		1	1				2	3		11	10	4	9	8		5	27	18																						
Baculamonocolpites hammenii																												1												
Baculamonocolpites sp. 1																																		1						
Baculatisporites sp. 1																					1																			
Baculatisporites sp. 2																							1								1									
Baculatisporites spp.							1					1		1											1															
Bacumorphomonocolpites tausae (RW)																							1	1	2				1			1	1							
Bombacacidites "fossulatus"													2																											
Bombacacidites "lisamae"										10		1		2		1	1	2	9		1																			
Bombacacidites "magnificum"																																				1				
Bombacacidites annae			1			130	4	4	1	44	5	10	14		5	1		2																		1				
Bombacacidites cf. *nacimientoensis*																								1	1				1						1	2				
Bombacacidites cf. *simplireticulatus*																													1											
Bombacacidites protofoveoreticulatus				2			3	1		12	3	4	7		2																									
Bombacacidites psilatus							2																		1									15	1				1	
Bombacacidites simplireticulatus																																								1
Bombacacidites sp. (homogenous reticulum)																											1								2					
Bombacacidites sp. 15																				10																				
Bombacacidites sp. 2		1	2		1	9																																		
Bombacacidites sp. A												1																												
Bombacacidites sp. B (4 colp)																1	1																							
Bombacacidites sp. C (4 colp)																																1								
Brevitricolpites macroexinatus																																						1		
Brevitricolpites microechinatus																									1	4							1						2	18
Brevitricolpites sp. 5 (spines < 1µm)																					2																			
Brevitricolpites sp. 6																								1																
Buttinia andreevi (RW)																							2	1	2		1											1		
Camarozonosporites sp. 1														1	1																						1			2
Chomotriletes				2			2												3		1				11		1		2	3		4	3			9		5		
Chomotriletes minor		1			1																			1				2	1		1			8	5					
Cicatricosisporites sp. 1			1																																					
Cicatricosisporites sp. 2				1																																				
Cicatricosisporites sp. 3				1			2																																	
Classopollis sp.							1																																	
Clavamonocolpites AUR143						1																																		
Clavamonocolpites microclavatus																																	1							
Clavamonocolpites sp. 2			1		1																																			
Clavamonocolpites ? sp. A																																					1			
Clavapollenites AUR22		1																																						
Clavapollenites AUR40			2																																					
Clavapollenites sp. 1																																								
Clavatricolpites densiclavatus					1																																			
Clavatricolporites leticiae										1		1	1					1																						
Colombipollis tropicalis				1			1																																	
Concavisporites AUR22		1																																						
Concavisporites sp. 1		1																																						
Conifer sp. 1															1									1																
Corsinipollenites psilatus		1	1	2		6								1	2	1	1	1																						
Crassitricolpites cf. *costatus*				2																																				
Cricotriporites guianensis																																				4	3			
Cricotriporites macroporus										1															2															
Cricotriporites minutiporus						1																																		
Crototricolpites cf. annemariae																										1														
Crototricolpites protoannemariae									1																															
Crusafontites "minor" (20 µ) RW?																					1						1													
Crusafontites megagemmatus																																				1				
Curvimonocolpites inornatus	1					2		1																																
Cycadopites AUR506																								2																
Cycadopites sp. 1	1														1																									
Cycadopites sp. 2	4					12																																		
Cycadopites sp. 3			1		4																																			
Cycadopites sp. 5	3																																							
Cyclusphaera scabrata																								1		1			3						2		1	1	3	4
Cyclusphaera? sp. 1	33				1																																			
Dinocyst (RW)																								6																
Dinocyst indet.																										2		1			1			2	1					
Dinocyst sp.		1	1												1																									
Dinocyst sp. 10		3	2		1																																			
Dinocyst sp. 11			1																																					
Dinocyst sp. 12																																								
Dinocyst sp. 12 (RW)																								1																
Dinocyst sp. 8		1																																						
Dinocyst sp. 9	1	1			1																																			
Dinogymnium acuminatum (RW)																																							1	1
Dinogymnium sp. (RW)																						1				1	7			1				3						1
Dinogymnium undulosum (RW)																																		5						
Diporoconia cf. *Diporoconia iszkaszentgyoergyi*												1		1																										
Distaverrusporites aff. simplex															1																									
Distaverrusporites sp. 1			1		2																																			
Duplotriporites ariani (RW)																									2	1								1					2	
Echidiporites sp. 1	1																																							
Echimonocolpites protofranciscoi																									5		9		1			1	1			1				
Echimonocolpites sp. B																																							1	
Echinatisporis AUR506																								1																
Echinatisporis brevispinosus					2										3									1				2												
Echinatisporis sp. A																										1														
Echinatisporis? sp. 3															1																									
Echiperiporites sp.																																						1		
Echipollenites AUR65					1																																			
Echitrilete big (> 80 µm)																											2			8										
Echitrilete spores				6			6									2	1				5				3		5		4	11		1	4			2				
Echitriporites sp. 8																								3																
Echitriporites trianguliformis																									1		1					1								
Echitriporites trianguliformis var. *orbicularis*																																			6					
Echitriporites variabilis																																		2						
Echitriporites? sp. A																										1														
Ephedripites sp. 1																									1															
Ephedripites vanegensis					1			4	1	1	27	57	19	8		4																								
Foveomonoporites variabilis								6																																
Foveopollenites AUR506																								2																
Foveopollenites AUR506																								1																
Foveotricolpites perforatus								1		8		1		1	3			1		1																				
Foveotricolpites perforatus (RW)																								1																
Foveotricolporites cf. sp.3 (Jaramillo & Dilcher, 2001)																																1								
Foveotricolporites sp. A																																					1			
Foveotriporites hammenii																																				2	2		2	
Gemmainaperturites? sp. A																																							1	
Gemmamonocolpites "digemmatus"																																2					2			
Gemmamonocolpites amicus																																						1		
Gemmamonocolpites gemmatus										1																														
Gemmamonocolpites ovatus																									1															
Hamulatisporis sp. 2					1																																			
Horniella sp. UR806																																				1				
Horniella sp. 1 (pores costate)				1																					5												1	1		
Horniella sp. 2												5																												
Incertae dinocyst B																										1														
Incertae dinocyst C																										1														
Incertae sedis sp. C																										1														
Intratriporopollenites sp.											1	3																												
Ischyosporites problematicus		1																			20																			
Ischyosporites sp.							1																																	
Kuylisporites type spore																																						1		
Ladakhipollenites minutus																													1			1								
Ladakhipollenites simplex				6			5																		1															
Laevigatosporites (small verrucae-gemm)														2		4													1											
Laevigatosporites AUR22		1																																						
Laevigatosporites AUR223															3																									
Laevigatosporites AUR65					1																																			
Laevigatosporites sp. C																												1												
Laevigatosporites sp. D																																		3						
Laevigatosporites spp.																		1			1								1			1	1			1				
Laevigatosporites tibuensis		1	3		3				1						125								2			1					1			2			51	2	13	14
Lanagiopollis crassa																																				1				
Longapertites microfoveolatus	2	1	1		5	12									2									1																
Longapertites proxapertitoides var reticuloides																																		5	1					
Longapertites proxapertitoides var. proxapertitoides															2											1								1						
Longapertites sp. (smooth reticle)																																	1							
Longapertites sp. B																																					2			
Lonicerapollis sp. 2															1																									
Lygodiumsporites sp. 1															5									4																
Mauritiidites franciscoi var. *franciscoi*		1		2	3	25	1	44		7				20?	28	19	8	22	8		2							1			1			4	1	3	7	1		
Mauritiidites franciscoi var. *minutus*													5													7									1		1			
Mauritiidites franciscoi var. *pachyexinatus*												2				2		1														1					1			
Monocolpopollenites AUR22		1																																						
Monocolpopollenites ovatus										2	2	2	12		2				?				1		2	9	2	2	1			11	1	17	1	2	7		1	
Monocolpopollenites sp. 1	1					6									3																									
Psilamonocolpites "marginatus" (>40 m l; exine 2)														1				1																						
Monocolpopollenites sp. 3															3									1																
Monocolpopollenites sp. 4															1																									
Monocolpopollenites sp. 5						43									1																									
Monoporopollenites sp.2																																				1				
Nothofagidites sp. 2						1																																		
Odontochitina sp. (RW)																						2						1			1									
Oligosphaeridium sp. (RW)																																		1						
Palaeohystrichophora infusorioides (RW)																										2														
Pediastrum	3				3																					2		1												
Periretisyncolpites giganteus (RW)																								1															1	
Planisporites? sp. 1															1																									
Podocarpites sp.																1			2																					
Polyade sp. 1																								1																
Polyapodiaceoisporites AUR22		2																																						
Polypodiaceoisporites group (zonate spores)				1			3			1									5		4				1				1	1										
Polypodiaceoisporites? fossulatus			2		1																																3		11	16
Polypodiisporites aff. *inangahuensis*															2																	1					1	3	1	1
Polypodiisporites aff. *Specious*																																3	1	2		2	5			
Polypodiisporites echinatus																										11														

sample label	UR 1	UR 22 + 05	UR 40 + 05	UR-62(93m)	UR 65	UR 143	UR-147(220,5m)	LIS-447(447m)	UR 200 + 180	UR-212+130 (567m	UR-215+90(573m)	UR-216+60(575m)	UR-219+150 (582m	UR-221+40(584)	UR 223	UR-224+10(590m)	UR-235(612m)	UR-238+40(618m)	UR-248(638)	UR 250	UR-396(927m)	UR 409+70	UR 502	UR 506	UR512(1101m)	UR 531+120	UR-531+100 (1131	La Paz 361 m	UR-701+130(1288)	UR-722+100(1317m	UR 726	UR-732+30(1333m)	UR 743+50 (1350 m	UR 761	UR 781+20	UR 806 (1444 m)	UR 812	UR 816 (1459 m)	La Paz 712 m	La Paz 886 m
cumulative meters from base section	1,5	33,1	60,1	93	97,5	214,5	220,5	447	543,8	567	573	575	582	584	588,0	590	612	618	638	642,0	927	947,2	1086	1092,0	1101	1130,7	1131	1267	1288	1317	1324	1333	1350	1376,5	1406,7	1444	1453	1459	1618	1792
Sample number used in the Figure 2.3.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Acritarcha sp. A																																			1					
Aequitriradites verrucosus (RW)																								2																
Polypodiisporites sp. 1																										2								1						
Polypodiisporites sp. 2																																							1	
Polypodiisporites sp. 8															1																									
Polypodiisporites ssp.										1									1		1				1		4		3	1		5								
Polypodiisporites ? AUR40			1																																					
Proxapertites (triangulate)																		3																						
Proxapertites cf. *verrucatus*											1	34	31					4					1			1														
Proxapertites cursus		7								3	8		7																					1						
Proxapertites humbertoides		4			2	53				1					1	4			1					3	1	2	3		1				1							
Proxapertites magnus	2	28	3	13	4	10	8			48	2				2				4																					
Proxapertites magnus (RW)																																		1				1		7
Proxapertites operculatus	198	16	2	2	26	3		146	12	235	230	263	243	241	36	129	239	257	599	4					1											2	5			
Proxapertites psilatus	5	2		8	1	1	1	9		35	8	7	42	6		1	1	7													2									
Psilabrevitricolpites sp. 3 (cont.pentagon)				1																																				
Psilabrevitricolporites "simplex"																					1						1													
Psilabrevitricolporites AUR506																								1																
Psilabrevitricolporites simpliformis			2						1																															
Psilabrevitricolporites sp. 2																					1						1													
Psilabrevitricolporites sp. 3																								4																
Psilabrevitricolporites triangularis																									2		1													
Psilamonocolpites " marginatus"														1																										
Psilamonocolpites grandis										1	1																													
Psilamonocolpites medius	14	29	12	35	12	2	17	41	7	21	61	6	12	22	25	2	3	13	1		2			4	1		3				1	5		3	1	4				
Psilamonocolpites minutus	2			2				4			2	1	5			7											2		2											
Psilamonocolpites operculatus n. sp.								12																																
Psilastephanocolporites fissilis																																				1				
Psilastephanocolporites sp. 1													1																											
Psilastephanocolporites sp. A																																							1	
Psilastephanoporites "oculiporus"				1			2																																	
Psilastephanoporites sp. 1																																		1						
Psilasyncolporites ? sp. 1							2																									1								
Psilatricolpites (>80 µm!)																		9																						
Psilatricolpites AUR200									1																															
Psilatricolpites papilioniformis RW																																	1							
Psilatricolpites sp (colpi costate)										1	1																													
Psilatricolporites " minutus"												3																												
Psilatricolporites AUR65					1																																			
Psilatriletes sp. E					2																																			
Psilatriletes sp. F															1																									
Psilatriletes spp.	8	13	5	1	14	76	8	6	1	36	29	19	62	16	40	23	0	17	3	10	18	5	5	86	56	22	36	6	5	4	6	9	10	46	11	21	9	10	53	61
Psilatriporites annulatus																									1		1													
Psilatriporites AUR40			1																																					
Psilatriporites AUR65					1																																			
Psilatriporites sp. 1														1																										
Psilatriporites sp. 2																1																								
Psilatriporites sp. C																																					1			
Psilodiporites sp. 2																											1													
Pteridacidites sp. 1																																							1	1
Racemonocolpites facilis				1?																									1				2			1	1		1	1
Racemonocolpites racematus											1													5	6								1	1						
Racemonocolpites sp. 1																										1														
Retibrevitricolpites sp. A																																					1			
Retibrevitricolpites triangulatus																																					2			
Retibrevitricolporites grandis																										1											2			
Retibrevitricolporites speciosus																																					1			
Retidiporites magdalenensis				4			2	1		2	13	15	18	22	1	1																								
Retimonocolpites AUR143						1																																		
Retimonocolpites AUR200									3																															
Retimonocolpites AUR22		1																																						
Retimonocolpites retifossulatus																																				1				
Retimonocolpites tertiarius																									1				5	1		1								
Retipollenites AUR200									1																															
Retipollenites AUR250																				1																				
Retipollenites AUR40			1																																					
Retipollenites AUR506																								1																
Retipollenites BUR40			1																																					
Retisporites AUR22		1																																						
Retistephanocolpites angeli															1																									
Retistephanocolpites sp. 1 (microret, 7 colp.)																																	1							
Retistephanocolporites festivus																																			2					
Retistephanocolporites sp. 2																																				1				
Retistephanoporites sp. 1																																							1	
Retistephanoporites sp. B																							1																	
Retitricolporites (pore lalong)																																	6							
Retitricolporites AUR223															2																									
Retitricolporites sp. A																							1																	
Retitriporites poricostatus																																							1	
Retitriporites sp. 1							1																																	
Retitriporites? AUR22		1																																						
Rhoipites sp. 8															1																									
Rhoipites squarrosus																																1								
Rugomonocolpites AUR65					1																																			
Scabratricolpites sp.1 (24-30 µm long)				2			1			1?																														
Scabratricolpites thomasi (Sarmiento, 1994)				1																																				
Scabratriletes AUR200									1																															
Scabratriporites sp. 1																1																								
Senegalinium sp. A (RW?)																										1								9						
Siltaria sp. 2																															1									
Siltaria sp. 3																																					1			
Siltaria sp. 4																											4													
Spinidinium sp. (RW?)																												1						1						
Spinidinium sp. 1		2																																						
Spiniferites cf. mirabilis																															1									
Spinizonocolpites aff. *baculatus* (RW)																																		1						
Spinizonocolpites baculatus (forma 2) "brevibaculatus"																																	3							
Spinizonocolpites baculatus (RW)																					1		1		10	10			3				2	3		1		1	1	
Spinizonocolpites breviechinatus						4				1			1																											
Spinizonocolpites echinatus																											1													
Spinizonocolpites pachyexinatus																										1									1					
Spinizonocolpites sp. 1																								11																
Spinozonocolpites cf. *S. baculatus* (RW)																										1	1		2											
Spirosyncolpites spiralis																							1	2	3	1	3	1			3		3	1	3	3	3	1	10	
Spore trilete (>80 µm, small spines)																											2			10										
Stephanocolpites costatus (RW)																																		1						
Stephanocolporate							2																																	
Stephanoporate							1																																	
Stephanoporate sp. B																1																								
Striatopollenites AUR506																								1																
Striatopollis AUR250																				1																				
Striatopollis AUR65					1																																			
Striatopollis catatumbus																							3		7		3		3	3	1	14	10	1		17	1	3		1
Striatopollis minor																														1										
Striatopollis sp. 1 (pore lalongate)																																1								
Striatopollis ? *tenuistriatus*																												1			1	4	4			1	8			
Striatricolporate				2			1																																	
Striatricolporites sp. 1																									2															
Striatricolporites sp. 5															1																									
Striatricolporites sp. A																																			11					
Subtilisphaera sp. 1			1																																					
Syncolporites ? sp. 1				1																																				
Syncolporites cf. *marginatus*				1																							1													
Syncolporites lisamae							6																																	
Syncolporites sp. A																							1																	
Tetracolporopollenites ("minutus")														1																										
Tetracolporopollenites maculosus																												1											2	
Tetracolporopollenites sp.2 (pore lalongate 8 µm)																											1													
Tetracolporopollenites spongiosus		2			1		1		1					1																										
Tetracolporopollenites transversalis																													1											
Tetracolporopollenites ? sp. 2																										3									1					
Tetradrites cf. *umirensis*							1																																	
Tetradrites magnus													2					1																						
Tricolpate reticulate. cf. *R. retiaphelis* LEIDELMEYER 1966												4																												
Tricolpites cf. *Minutus*																																4								
Tricolpites clarensis																																1								
Tricolpites protoclarensis				2						1						1 (30 µm)																								
Tricolpites sp.2 (Reticulate to equator; < 20 µm)														1		1																								
Tricolporate retic. (pore costae)				1																																				
Triporopollenites? sp. 2						1																																		
Triporopollenites? tenuiexinatus																								1		1					1									
Tuberositriletes sp. 5															1																									
Tuberositriletes sp. A																															1									
Tuberositriletes verrucatus																																							1	
Ulmoideipites krempii				9	2	1	2							1										1	3	6	2													
Verrumonocolpites sp. 1													6	1		1	2	25																						
Verrumonocolpites sp. 2																											1													
Verrumonoletes AUR65					1																																			
Verrupollenites AUR506																								1																
Verrusporites AUR40			1																																					
Verrustephanoporites AUR506																								1																
Verrutriletes AUR200									2		1			1																										
Verrutriletes spp.				9	2		2							1		3					4				2				3			1	2					1		
Verrutriporites AUR65					1																																			
Zlivisporis blanensis (RW)			1	1	1																			1	1															
Zonocostites minor																																						1		
total sum of palynomorphs	281	131	54	123	111	400	95	283	34	486	407	453	500	342	314	217	284	387	636	27	66	11	22	159	144	102	109	22	48	44	24	79	61	143	55	87	128	36	114	130
Species illustred in the plates																																								

Appendix 2.3.A. Palynofacies data (Sogamoso section)

Biostratigraphic sample (number used in the stratigraphic log)	cumulative meters from the base of sandstone dominated facies (general log)	cumulative meters from the top (general log)	Reference (UIg)	Well	Depth (well)	Number of sample (well)	Lithologic unit	Wood (structured)	Gelified woody tissues	Cuticles	Charcoal	Resin fragments	Fungal remains	Pollen-Spores	*Pediastrum*	Zooclasts	Marine Palynomorphs	Pseudo-amorphous phytoclasts	Other non-cuticular tissues	Sphaeromorphs	Algal(?) filaments	Lycopods	Remarks
	-26	493	19527	IC-PE-2	38,7	1	La Paz Formation																Barren
			19528	IC-CC-2	21,12	4	La Paz Formation		100	7	6	1	11	1	0	0	0	0	17	0	0	0	
			19529	ICF-A-4	93,59	9	La Paz Formation	Same of 19580															
			19530	SD-D-8D	31,7	11	La Paz Formation																Not analysed
	-22	489	19531	IC-PE-2	34,7	2	La Paz Formation																Barren
	-15	482	19532	IC-PE-2	24,7	3	La Paz Formation	4	36	3	2	0	0	6	0	0	0	26	100	0	0	120	
1	-13	480	19533	IC-PE-2	22,5	4	La Paz Formation	2	45	53	0	1	0	15	0	0	0	75	80	0	0	24	
	-9	476	19534	IC-PE-2	18,05	5	La Paz Formation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Barren
	-8	475	19535	IC-PE-2	15,7	6	La Paz Formation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Barren
2	-5	472	19536	IC-PE-2	12,6	7	La Paz Formation	152	8	50	2	13	2	22	0	0	0	8	140	0	0	3	
	-3	470	19537	IC-PE-2	9,65	8	La Paz Formation																Not treated
	4	463	19538	IC-PE-1	33,37	1	La Paz Formation	108	12	0	3	1	10	0	0	0	0	3	52	0	0	0	
	15	452	19539	IC-PE-1	20	2	La Paz Formation	205	43	7	4	1	9	1	0	0	0	3	39	0	0	1	1 dino
3	69	398	19540	IC-FA-3	64,85	1	La Paz Formation	87	58	14	9	16	5	7	0	0	1	2	104	0	0	13	1 dino
	79	388	19541	IC-FA-3	50,65	2	La Paz Formation	190	21	2	3	2	42	2	1	0	0	1	110	0	0	0	
	83	384	19542	IC-FA-3	46,03	3	La Paz Formation	171	19	3	2	2	26	0	1	0	0	1	70	0	0	2	
	87	381	19543	IC-FA-3	41,4	4	La Paz Formation	153	17	1	10	2	15	3	0	0	0	0	58	0	0	2	
	87	380	19544	IC-FA-3	40,8	5	La Paz Formation	189	82	7	16	4	34	2	0	0	0	0	62	0	0	3	
	94	374	19545	IC-FA-3	32,3	6	La Paz Formation	180	20	6	2	5	22	4	0	0	0	0	73	0	0	4	
4	106	361	19546	IC-FA-3	17,1	7	La Paz Formation														0		Very poor material, 1 dino
5	114	353	19547	IC-FA-3	6,12	8	La Paz Formation	96	24	5	25	14	2	6	0	0	0	3	87	0	0	13	1 dino(?)
	121	346	19548	IC-TD-1	34,47	1	La Paz Formation	157	18	2	0	2	48	1	0	0	0	0	96	0	0	1	
			19549	IC-TD-1	31,03	2	La Paz Formation																
			19550	IC-TD-1	23,9	3	La Paz Formation																Barren
			19551	IC-TD-1	16,82	4	La Paz Formation																
6	136		19552	IC-CC-12	37,75	1	La Paz Formation																1 dino
			19553	IC-CC-12	36	2	La Paz Formation																
			19554	IC-CC-12	35	3	La Paz Formation																
			19555	IC-CC-12	24,03	4	La Paz Formation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Barren
			19556	IC-CC-12	22,45	5	La Paz Formation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Barren
			19557	IC-CC-12	20,84	6	La Paz Formation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Barren
			19558	IC-CC-12	18,55	7	La Paz Formation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Barren
			19559	IC-CC-12	16,7	8	La Paz Formation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Barren
			19560	IC-CC-12	14,85	9	La Paz Formation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Barren
	123	344	19561	IC-CC-7	37,05	1	La Paz Formation	184	46	5	6	4	48	2	0	0	0	0	140	0	0	1	1 dino(?)
	129	338	19562	IC-CC-7	29,65	2	La Paz Formation	114	13	3	4	5	1	1	0	0	0	2	30	0	0	116	
	135	332	19563	IC-CC-7	23,18	3	La Paz Formation	88	22	3	8	24	10	13	0	0	0	9	65	0	0	100	1 dino(?), 1 foram lin.
7	144	323	19564	IC-CC-7	11,6	4	La Paz Formation	182	21	14	14	9	63	7	0	0	0	0	180	0	0	5	1 dino(?)
8	146	321	19565	IC-CC-7	9,5	5	La Paz Formation	12	2	2	5	24	0	5	0	0	0	6	34	1	0	68	
			19566	IC-CC-2	27,05	1	La Paz Formation																Barren
			19567	IC-CC-2	25,6	2	La Paz Formation		120	8	6	3	20	2	0	0	0	0	25	0	0	0	
			19568	IC-CC-2	22,25	3	La Paz Formation		100	8	10	3	6	1	0	0	0	0	23	0	0	0	
			19569	IC-CC-2	18,2	5	La Paz Formation		107	11	4	1	26	1	0	0	0	0	22	0	0	0	
			19570	IC-CC-2	16,05	6	La Paz Formation		111	7	5	1	35	2	0	0	0	0	17	0	0	1	
			19571	IC-CC-2	14,4	7	La Paz Formation		176	14	14	3	24	7	0	0	0	0	19	0	0	0	
			19572	IC-CC-2	12,9	8	La Paz Formation		180	13	12	0	12	0	0	0	0	0	23	0	0	2	
			19573	IC-FA-4	139	1	La Paz Formation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Barren
			19574	IC-FA-4	137,3	2	La Paz Formation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Barren
			19575	IC-FA-4	135,5	3	La Paz Formation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Barren
	157	310	19576	IC-FA-4	125,8	4	La Paz Formation	165	71	10	1	3	52	2	0	0	0	0	154	0	0	3	
	169	298	19577	IC-FA-4	112,1	5	La Paz Formation																Barren
9	179	288	19578	IC-FA-4	101,4	6	La Paz Formation	70	65	15	6	41	5	14	0	0	0	14	83	0	0	56	
	181	286	19579	IC-FA-4	98,9	7	La Paz Formation																1 acritarch(?)
	183	284	19580	IC-FA-4	96,24	8	La Paz Formation	315	35	5	7	5	110	3	0	0	0	1	125	0	0	4	
	189	279	19581	IC-FA-4	89,9	10	La Paz Formation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Barren
	190	277	19582	IC-FA-4	88,3	11	La Paz Formation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Barren
	193	274	19583	IC-FA-4	85,14	12	La Paz Formation	256	64	4	1	5	105	1	0	0	0	1	135	0	0	3	
10	202	265	19584	IC-FA-4	73,85	13	La Paz Formation	253	28	3	6	7	88	6	0	0	0	2	124	1	0	1	1 dino
	215	252	19585	IC-FA-4	71	14	La Paz Formation	257	14	7	4	6	90	5	0	0	0	2	130	1	0	1	
	206	261	19586	IC-FA-4	70,14	15	La Paz Formation	Same of 19585															
	210	257	19587	IC-FA-4	65,35	16	La Paz Formation	180	20	4	4	12	63	6	0	0	0	2	121	0	0	4	
	214	254	19588	IC-FA-4	61	17	La Paz Formation	200	50	3	11	6	29	2	4	0	0	0	65	0	0	4	
	219	249	19589	IC-FA-4	55,3	18	La Paz Formation	113	29	0	3	0	11	0	0	0	0	2	90	0	0	0	
11	224	243	19590	IC-FA-4	48,85	19	La Paz Formation	10	7	2	4	4	5	1	0	0	0	3	133	0	0	3	
12	237	230	19591	IC-FA-4	34,2	20	La Paz Formation	245	105	5	15	6	41	0	0	0	0	3	100	0	0	5	
	239	228	19592	IC-FA-4	31,5	21	La Paz Formation	106	26	4	3	5	5	4	0	0	0	3	36	0	0	33	
	245	222	19593	IC-FA-4	24,45	22	La Paz Formation	33	22	1	4	9	2	2	0	0	0	3	29	0	0	32	
	250	217	19594	IC-FA-4	19,6	23	La Paz Formation																Not analysed
	251	216	19595	IC-FA-4	17,45	24	La Paz Formation	166	41	1	8	3	30	3	0	0	0	4	72	0	0	11	
13	272	195	19596	IC-FP-1	174,2	1	La Paz Formation	94	23	6	21	8	10	30	21	0	0	8	150	1	1	16	
14	280	188	19597	IC-FP-1	165,6	2	La Paz Formation	228	25	4	16	5	94	3	18	0	0	3	90	0	1	4	
	281	186	19598	IC-FP-1	164,6	3	La Paz Formation	221	25	5	13	4	100	2	10	0	0	3	85	0	0	4	
	307	160	19599	IC-FP-1	163,6	4	La Paz Formation	200	50	2	8	3	74	4	0	0	0	0	90	0	0	1	
	283	184	19600	IC-FP-1	161,4	5	La Paz Formation																Not analysed
	285	182	19601	IC-FP-1	159	6	La Paz Formation	178	45	0	16	4	32	2	5	0	0	2	84	0	1	3	
	286	181	19602	IC-FP-1	157,7	7	La Paz Formation	160	40	0	11	4	37	2	3	0	0	1	78	0	1	4	
15	287	180	19603	IC-FP-1	156,5	8	La Paz Formation	27	40	1	5	3	5	1	7	0	0	15	120	1	1	7	
	310	157	19604	IC-FP-1	129,1	9	La Paz Formation																Not analysed
	311	156	19605	IC-FP-1	128,1	10	La Paz Formation																Not analysed
	312	155	19606	IC-FP-1	127,2	11	La Paz Formation	140	130	2	8	4	85	1	0	0	0	0	100	0	0	1	
	321	146	19607	IC-FP-1	116,9	12	La Paz Formation																Not analysed
16	343	124	19608	IC-FP-1	91,4	13	La Paz Formation	150	100	3	20	12	15	1	0	0	0	2	132	1	0	13	
	351	117	19609	IC-FP-1	82,45	14	La Paz Formation	138	92	1	4	1	17	1	0	0	0	1	50	0	0	2	
	357	110	19610	IC-FP-1	74,27	15	La Paz Formation																Not analysed
	359	108	19611	IC-FP-1	72,86	16	La Paz Formation	115	110	1	3	3	41	2	0	0	0	0	70	0	0	1	1 dino
	380	87	19612	IC-FP-1	47,75	17	La Paz Formation	3	6	20	20	7	0	0	0	0	0	2	46	0	0	55	
17	406	61	19613	IC-FP-1	18,53	18	La Paz Formation	15	36	1	35	13	0	3	1	0	0	0	54	1	0	52	1 dino
	401	66	19614	SD-D-8D	76,3	1	La Paz Formation	211	23	11	17	15	65	11	0	0	0	2	200	1	0	2	
	409	58	19615	SD-D-8D	66,68	2	La Paz Formation																Not treated
	423	44	19616	SD-D-8D	51,08	3	Esmeraldas Formation																Not analysed
	424	43	19617	SD-D-8D	49,7	4	Esmeraldas Formation	198	22	5	23	3	26	2	0	0	0	0	88	15	8	31	
	425	42	19618	SD-D-8D	48,5	5	Esmeraldas Formation	40	10	12	5	1	14	3	0	0	0	1	49	4	20	10	
	427	40	19619	SD-D-8D	46,2	6	Esmeraldas Formation														Abundant		1 dino
18	428	39	19620	SD-D-8D	44,9	7	Esmeraldas Formation	120	13	10	16	13	13	3	3	0	0	0	110	11	3	38	insect
	432	35	19621	SD-D-8D	41,09	8	Esmeraldas Formation																Not treated
	438	29	19622	SD-D-8D	33,79	9	Esmeraldas Formation	270	30	5	7	0	46	3	0	0	0	0	95	0	0	1	
	439	28	19623	SD-D-8D	32,6	10	Esmeraldas Formation	46	19	9	40	26	0	5	2	0	0	4	132	2	0	43	
	442	25	19624	SD-D-8D	28,76	12	Esmeraldas Formation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Barren
	446	21	19625	SD-D-8D	24,88	13	Esmeraldas Formation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Barren
	450	17	19626	SD-D-8D	20,36	14	Esmeraldas Formation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Barren
	453	15	19627	SD-D-8D	16,8	15	Esmeraldas Formation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Barren
	455	12	19628	SD-D-8D	14,22	16	Esmeraldas Formation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Barren
19	459	8	19629	SD-D-8D	9,06	17	Esmeraldas Formation	50	54	4	47	16	1	12	0	0	0	15	78	0	0	19	2 dino, pyrofusinite
	461	6	19630	SD-D-8D	6,77	18	Esmeraldas Formation	53	55	6	45	2	0	0	0	0	0	9	55	2	0	37	Insect, pyrofusinite
			19631	IC-D-3	46,2	1	Esmeraldas Formation																Not treated
			19632	IC-D-3	14,5	2	Esmeraldas Formation																Not treated

Appendix 2,3. Palynofacies data (Uribe section)

Biostratigraphic sample (number used in the figure 2.3)	cumulative meters from the base	cumulative meters from the top	Reference (Ulg)	sample code	pollen sum	CaCo3	Wood (structured)	Gelified woody tissues	Cuticles	Charcoal	Resin fragments	Fungal remains	Pollen-Spores	*Pediastrum*	Zooclasts	Marine Palynomorphs	Pseudo-amorphous phytoclasts	Other non-cuticular tissues	Sphaeromorphs	Algal(?) filaments
1	1,5	1893,5		UR 1	281															
	3,0	1892,0	20303	UR 2		0	1	1	1	1	1	0	0	1	0	0	1	1	0	0
	5,8	1889,2	20304	UR 3 + 126		0	2	4	2	1	1	2	1	0	0	0	2	4	0	0
	9,0	1886,0	20305	UR 6		0	2	4	0	2	1	2	1	0	0	0	2	2	0	0
	28,0	1867,0	20306	UR 18 + 100		0	2	2	0	3	1	0	1	0	0	0	3	2	0	0
2	33,1	1862,0		UR 22 + 05	131															
	52,6	1842,4	20307	UR 35 + 10 intraclast																
3	60,1	1835,0		UR 40 + 05	54															
	81,0	1814,0	20308	UR 54		0	2	5	1	2	1	0	0	0	0	0	1	1	0	0
4	93,0	1802,0	20309	UR 62	123	0	3	2	1	1	1	2	2	1	0	0	1	2	0	0
5	97,5	1797,5		UR 65	111															
	106,5	1788,5	20310	UR 71		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	157,5	1737,5		UR 105																
6	214,5	1680,5		UR 143	400															
7	220,5	1674,5	20311	**UR 147**	95	0	3	3	1	1	1	1	1	0	0	1	1	2	1	0
	222,0	1673,0	20312	UR 148		0	4	4	1	1	1	1	1	1	0	0	0	3	0	0
8	447,0	1448,0	20313	Lis 447m	283	0	1	3	3	1	2	1	2	0	0	0	3	4	0	0
	448,0	1447,0	20314	Lis 448m		0	1	1	0	2	3	0	1	0	0	0	1	1	0	0
	449,0	1446,0		Lis 449m																
	450,0	1445,0	20315	Lis 450m		0	1	3	3	3	2	1	2	0	0	0	1	2	0	0
9	543,8	1351,2		UR 200 + 180	34															
	546,6	1348,4		UR 202 + 60																
10	567,3	1327,7	20316	UR 212 + 130	486	0	1	1	2	3	3	1	3	0	0	0	0	3	0	0
11	572,9	1322,1	20317	UR 215 + 90	407	0	4	3	2	1	2	1	3	0	0	0	0	3	0	0
	573,0	1322,0	20318	UR 215 + 100																
12	574,6	1320,4	20319	UR 216 + 60	454															
	574,8	1320,2	20320	UR 216 + 80																
	575,0	1320,0	20321	UR 216 + 100		0	3	3	1	4	1	1	1	0	0	0	1	2	0	0
	575,2	1319,8	20322	UR 216 + 120																
13	581,5	1313,5	20323	UR 219 + 150	499	0	4	3	3	1	2	1	3	0	0	0	1	2	0	0
	582,0	1313,0	20324	UR 220																
14	584,4	1310,6	20325	UR 221 + 40	341	0	3	3	2	2	1	2	3	0	0	0	1	4	0	0
15	588,0	1307,0		UR 223	314															
16	590,0	1305,0	20326	UR 224 + 10	221	0	2	3	2	3	2	3	2	0	0	0	1	3	0	0
	591,2	1303,8	20327	UR 224 + 120																
	610,0	1285,0	20328	**UR 234 + 40**		0	1	1	1	1	1	0	0	0	0	0	1	1	0	0
17	612,0	1283,0	20329	UR 235	284	0	2	2	5	2	2	1	3	0	0	0	1	4	0	0
	614,0	1281,0	20330	UR 236		0	0	1	1	1	1	0	0	0	0	0	1	1	0	0
	616,0	1279,0	20331	UR 237 + 10		1	1	1	0	1	0	0	0	0	0	0	1	0	0	0

18	618,4	1276,6	20332	UR 238 + 40	388		2	2	4	2	1	1	2	0	0	0	0	4	0	0
	621,6	1273,4		UR 239 + 160																
	623,0	1272,0	20333	UR 240 + 100		0	1	1	0	3	0	1	0	0	0	0	0	1	0	0
	632,2	1262,8	20334	UR 245 + 20		0	1	1	0	2	1	0	0	0	0	0	0	1	0	0
	637,0	1258,0	20335	UR 247 + 100		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	638,0	1257,0	20336	UR 248	636	1	2	2	1	3	2	1	2	0	0	0	0	1	0	0
20	642,0	1253,0		UR 250	27															
			20337	UR 261		1	1	1	1	0	0	0	0	0	0	0	0	1	0	0
			20338	UR 261 + 20		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	736,0	1159,0		UR 297																
	740,0	1155,0	20339	UR 299		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	742,0	1153,0	20340	UR 300		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	747,0	1148,0		UR 302 + 100																
	750,0	1145,0	20341	UR 304		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	754,2	1140,8		UR 306 + 20																
	764,0	1131,0		UR 311																
	776,0	1119,0		UR 317																
	782,0	1113,0		UR 320																
	796,0	1099,0		UR 327																
	798,0	1097,0		UR 328																
	814,0	1081,0		UR 336																
	830,0	1065,0		UR 344																
	900,0	995,0		UR 376	0															
	901,5	993,5		UR 379	0															
	902,0	993,0		UR 380																
	909,0	986,0	20342	UR 384		1	1	3	1	2	1	1	0	0	0	0	2	1	0	0
	919,5	975,5	20343	UR 391		1	2	1	0	2	0	1	0	0	0	0	0	1	0	0
	926,7	968,3		UR 395+120	1790															
21	927,0	968,0	20344	UR 396	65	1	2	2	0	1	2	1	1	0	0	0	1	1	0	0
	927,0	968,0		UR 396 trunk coal																
	938,0	957,0	20345	UR 403 + 50																
22	947,2	947,8		UR 409+70	11															
	987,2	907,8	20346	UR 436 + 20																
	988,6	906,4	20347	UR 437 + 10	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	989,0	906,0		UR 437+5	0															
	994,5	900,5		UR 441																
	1000,5	894,5		UR 445	0															
	1003,5	891,5	20348	UR 447		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1038,0	857,0		UR 470	0															
23	1086,0	809,0		UR 502	22															
24	1092,0	803,0		UR 506	159															
	1093,5	801,5		UR 507	8															
25	1101,0	794,0	20349	UR 512	143	0	3	3	2	1	1	2+	1	0	0	0	1	3	0	0
	1124,5	770,5		UR 527 + 100																
27	1130,5	764,5	20350	UR 531+100	108	0	3	2	2	2	1	2+	1	0	0	1	1	1	1	0
26	1130,7	764,3		UR 531+120	102															
	1131,1	763,9	20351	UR 532 + 10		0	3	2	1	1	1	2+	1	0	0	0	1	2	1	0
0: not observed; 1: present; 2: common; 3: abundant; 4: very abundant; 5: exceptionally abundant																				

Appendix 2.4. Counting values of pollen, spores and fungal debris (Sogamoso and Uribe sections)

Sogamoso section														
Sample label	(2)IC-PE-2(12,6)	(3)IC-FA-3(64,85)	(5)IC-FA-3(6,12)	(7)IC-CC-7(11,6)	(9)IC-FA-4(101,38)	(11)IC-FA-4(48,85)	(13)IC-FP-1(174,2)	(14)IC-FP-1(165,6)	(17)IC-FP-1(18,53)	(19)SD-D-8D(9,06)				
Spores	3	5	13	14	18	2	70	3	4	6				
Pollen	145	40	51	32	41	50	23	24	39	23				
Fungal remains	39	59	73	660	23	109	149	61	0	2				
Lycopods	56	211	160	51	492	71	99	131	1247	308				
TOTAL	243	315	297	757	574	232	341	219	1290	339				
Uribe section														
sample label	UR-62(93m)	UR-147(220,5m)	LIS-447(447m)	UR-212+130 (567m)	UR-216+60(575m)	UR-224+10(590m)	UR-238+40(618m)	UR-248(638)	UR-396(927m)	UR512(1101m)	UR-531+100 (1131m	UR-701+130(1288)	UR-732+30(1333m)	UR 806 (1444 m)
Sample number used in the Text-Figure 2	4	7	8	10	12	16	18	19	21	25	27	29	32	36
cumulative meters from base section	93	221	447	567	575	590	618	638	927	1101	1131	1288	1333	1444
Spores	19	21	7	27	16	26	29	7	14	18	17	11	10	11
Pollen	70	39	621	366	395	188	481	279	13	22	22	31	40	82
Fungal remains	56	251	2	0	191	228	11	1	111	308	540	729	535	673
Lycopods	748	416	16	214	8	113	24	963	1239	113	178	97	140	157
TOTAL	893	727	646	607	610	555	545	1250	1377	461	757	868	725	923

Appendix 3.1. Lithological description of samples studied in the Paz de Río area (Curva de Cosgua Norte section).

Reference (Liege University code)	Number of sample (figure 3,3)	Lithologic unit	Texture	Color (Munsell)	Remarks	Pollen and microscopic organic matter abundance	Carbonate
20831	CCN-1	Areniscas de Socha Fm.	V. f. sandstone	N6 (Medium light gray)	Fe oxides	P:1; SOM:1	
20832	CCN-2	Areniscas de Socha Fm.	Siltstone	N4 (Medium dark gray)	Homogeneous	P: 2; SOM: 2	
20833	CCN-3	Areniscas de Socha Fm.	Siltstone	N5 (Medium gray)	Homogeneous	P:0; SOM: 1	
20834	CCN-4	Areniscas de Socha Fm.	Siltstone	N6 (Medium light gray)	Wavy lamination	P:0; SOM: 1	
20835	CCN-5	Areniscas de Socha Fm.	Claystone	N6 (Medium light gray)	Fissility	P:0; SOM: 1	
20836	CCN-6	Areniscas de Socha Fm.	V. f. sandstone	N5 (Medium gray)	Micaceous, gypsum	P:0; SOM: 1	
20837	CCN-7	Areniscas de Socha Fm.	Silt-V. f. sand		Micaceous, gypsum, pyrite	P:0; SOM: 1	
20838	CCN-8	Areniscas de Socha Fm.	V. f. sandstone	N4 (Medium dark gray)	Parallel lamination,micaceous, pyrite	P:1; SOM:2	
20839	CCN-9	Areniscas de Socha Fm.	Silt-f. sand		Parallel lamination,micaceous, plant debris	P:1; SOM:2	
20840	CCN-10	Areniscas de Socha Fm.	Fine sand	N4 (Medium dark gray)	Laminated, micaceous, plant debris	P:0-1; SOM:2	
20841	CCN-11	Areniscas de Socha Fm.	Fine sand	N3-N4	Laminated, micaceous, plant debris	P:1;SOM:2-3	
20842	CCN-12	Areniscas de Socha Fm.	Fine sand	N4 (Medium dark gray)	Laminated, micaceous, plant debris	P:1; SOM:2	
20843	CCN-13	Areniscas de Socha Fm.	Muddy sandstone	N5 (Medium gray)	Coaly plant rich level	P:0;SOM:2-3	
20844	CCN-14	Areniscas de Socha Fm.	Silty claystone	N4 (Medium dark gray)	Homogeneous	P:2; SOM:2-3	
20845	CCN-15	Areniscas de Socha Fm.	Sand-silt levels	N5 (Medium gray) fine levels	Climmbing lamination, micaceous	Barren	
20846	CCN-16	Areniscas de Socha Fm.	Sandy siltstone	N4 (Medium dark gray)	Parallel lamination, micaceous	P:0; SOM: 1	
20847	CCN-17	Areniscas de Socha Fm.	Siltstone	N4 (Medium dark gray)	Abundant plant debris	P:1; SOM:3	
20848	CCN-18	Areniscas de Socha Fm.	Siltstone-V.f sandstone	N4 (Medium dark gray)	Laminated, micaceous	P:1; SOM:3	
20849	CCN-19	Areniscas de Socha Fm.	Siltstone	N4 (Medium dark gray)	Laminated, micaceous	P:1; SOM:3	
20850	CCN-20	Areniscas de Socha Fm.	Siltstone	N4 (Medium dark gray)	Laminated, micaceous	P:0-1; SOM:1	
20851	CCN-21	Areniscas de Socha Fm.	V. f. sandstone		Laminated, micaceous	P:2;SOM:3	
20852	CCN-22	Areniscas de Socha Fm.	V. f. sandstone	N5 (Medium gray)	Micaceous	P:0; SOM:2	
20853	CCN-23	Areniscas de Socha Fm.	V. f. sandstone		Laminated, micaceous	P:1; SOM:2	
20854	CCN-24	Areniscas de Socha Fm.	Silt-f. sand	N5 (Medium gray)	Laminated, micaceous	P:2-3; SOM:3	
20855	CCN-25	Areniscas de Socha Fm.	Silty claystone	N6 (Medium light gray)	Some mica	P: 2; SOM: 2	
20856	CCN-26	Arcillas de Socha Fm.	Siltstone	N4 (Medium dark gray)	Homogeneous, plant debris	P:1-2; SOM:3	
20857	CCN-27	Arcillas de Socha Fm.	Silty claystone	N5 (Medium gray), patches 5R 4/2 (G. red)	Hexagonal holes	Barren	
20858	CCN-28	Arcillas de Socha Fm.	Siltstone	N5 (Medium gray)	Homogeneous, some "holes"	Barren	
20859	CCN-29	Arcillas de Socha Fm.	Siltstone	N4 (Medium dark gray)	Hexagonal holes, oxyd. Fe	P:0;SOM:3	
20860	CCN-30	Arcillas de Socha Fm.	Clayey siltstone	N6 (Medium light gray)	Hexagonal holes	Barren	
20861	CCN-31	Arcillas de Socha Fm.	Silty claystone	N6 (Medium light gray)	Homogeneous, some "holes"	Barren	
20862	CCN-32	Arcillas de Socha Fm.	Siltstone	N6 (Medium light gray)	Hexagonal holes	Barren	
20863	CCN-33	Arcillas de Socha Fm.	Siltstone	N6 (Medium light gray)	Homogeneous, cubic "holes" with Ox. Fe	P:0; SOM: 1	
20864	CCN-34	Arcillas de Socha Fm.	Clayey siltstone	N4 (Medium dark gray)	Homogeneous	Barren	
20865	CCN-35	Arcillas de Socha Fm.	Claystone	N6 (Medium light gray)	Root traces	P:0; SOM: 1	
20866	CCN-36	Arcillas de Socha Fm.	Clayey siltstone	N6 (Medium light gray)	Homogeneous	P:0; SOM: 2	
20867	CCN-37	Arcillas de Socha Fm.	Claystone	N5 (M. gray)-5YR 6/1 (L. Brownish gray)	Fissility, abundant plant debris	P:1; SOM:3	
20868	CCN-38	Arcillas de Socha Fm.	Silty claystone	N3 (Dark gray)	Root traces, coaly debris	P:2-3; SOM:3	
20869	CCN-39	Arcillas de Socha Fm.	Siltstone-V.f sandstone	N4-N5	Some mica, cross and parallel lamination, abbundant well preserved plant debris	P:2-3; SOM:3	
20870	CCN-40	Arcillas de Socha Fm.	Siltstone	N5 (Medium gray) altered to 5Y 6/1	Some mica,bad preserved plant debros (<1mm)	P:2; SOM:3	
20871	CCN-41	Arcillas de Socha Fm.	Silty claystone	??	Some mica, some Fe oxides filling cracks	P:1;SOM:2	
20872	CCN-42	Arcillas de Socha Fm.	V. f. sandstone	N5 (Medium gray)	Some mica, rock partially altered	P:0;SOM:1	
20873	CCN-43	Arcillas de Socha Fm.	Siltstone	N4 (Medium dark gray)	Some sand grains floating in the rock	P:1;SOM:2	
20874	CCN-44	Arcillas de Socha Fm.	Silty claystone	N6-N7 (altered)	Sand grains	P:0;SOM:1	
20875	CCN-45	Arcillas de Socha Fm.	Clayey siltstone	N4-N5	Organic black debris, homogeneous	P:0?;SOM:2	
20876	CCN-46	Arcillas de Socha Fm.	Claystone	N4 (Medium dark gray)	Fisility, abbundant plant debris	P:2;SOM:2	
20877	CCN-47	Arcillas de Socha Fm.	Coal			P:2-3;SOM:3	
20878	CCN-48	Arcillas de Socha Fm.	Siltstone	N4 (Medium dark gray)	Homogeneous, some mica	P:0;SOM:3	
20879	CCN-49	Arcillas de Socha Fm.	Clayey siltstone	N3-N4	Homogeneous, some "holes" (<1mm)	P:1;SOM:1	

Reference (Liege University code)	Number of sample (figure 3,3)	Lithologic unit	Texture	Color (Munsell)	Remarks	Pollen and microscopic organic matter abundance	Carbonate
20880	CCN-50	Arcillas de Socha Fm.	Siltstone	N5 (Medium gray)	Pyrite ? casts, some mica	P:3;SOM:3	
20881	CCN-51	Arcillas de Socha Fm.	Silty claystone	N3 (Dark gray)	Homogeneous, break in fine pieces	P:1;SOM:1	
20882	CCN-52	Arcillas de Socha Fm.	Claystone	N5 (Medium gray)	Homogeneous	P:0;SOM:1	
20883	CCN-53	Arcillas de Socha Fm.	Claystone	N3 (Dark gray)	Homogeneous	P:2;SOM:3	
20884	CCN-54	Arcillas de Socha Fm.	Claystone	N5 (Medium gray)	Homogeneous, plant debris	P:2;SOM:3	
20885	CCN-55	Arcillas de Socha Fm.	Silty claystone	N3 (Dark gray)	Carbonized plant debris	P:3;SOM:3	
20886	CCN-56	Arcillas de Socha Fm.	Siltstone	N6 (Medium light gray)	Homogeneous, plant debris	P:2-3;SOM:3	
20887	CCN-57	Arcillas de Socha Fm.	Silty claystone	N3 (Dark gray)	Homogeneous, plant debris	P:3;SOM:3	
20888	CCN-58	Arcillas de Socha Fm.	Silty claystone	N5 (Medium gray)	Some mica	P:2-3;SOM:2	
20889	CCN-59	Arcillas de Socha Fm.	Siltstone	N5 (Medium gray)	Root traces, coaly debris, some mica	P:2;SOM:3	
20890	CCN-60	Arcillas de Socha Fm.	Coal	Black	Brilliant	P:1;SOM:3	
20891	CCN-61	Arcillas de Socha Fm.	Siltstone	N5 (Medium gray)	Root traces, some mica, bitter taste	P:1;SOM:2-3	
20892	CCN-62	Arcillas de Socha Fm.	Coal	Black		P:1-2;SOM:2	
20893	CCN-63	Arcillas de Socha Fm.	Claystone	N3 (Dark gray)	Root traces, burrows, coal fragments, gypsum vein	P:2-3;SOM:3	
20894	CCN-64	Arcillas de Socha Fm.	Claystone	N4 (Medium dark gray)	Homogeneous, break in fine pieces	P:3;SOM:3	
20895	CCN-65	Arcillas de Socha Fm.	Silty claystone	N4 (Medium dark gray)	Homogeneous, break in fine pieces	P:1;SOM:3	
20896	CCN-66	Arcillas de Socha Fm.	Siltstone	N5 (Medium gray)	Homogeneous, some mica	P:1;SOM:2	
20897	CCN-67	Arcillas de Socha Fm.	Silty claystone	N3-N4	Homogeneous, root traces ?	P:1;SOM:3	
20898	CCN-68	Arcillas de Socha Fm.	Coal	Black	Opaque	P:1;SOM:1	
20899	CCN-69	Arcillas de Socha Fm.	Pure claystone	N6 (Medium light gray)	Homogeneous, locally oxidize	P:1;SOM:2-3	
20900	CCN-70	Arcillas de Socha Fm.	Siltstone	5G 6/1 (Greenish gray)	Many small (< 1mm) Fe nodules	P:0;SOM:1	
20901	CCN-71	Arcillas de Socha Fm.	Silty claystone	N5 (Medium gray)	Homogeneous, carbonized fragments	P:1;SOM:2	
20902	CCN-72	Arcillas de Socha Fm.	Impure coal, organic shale	Black	Brilliant, slikenside	P:1;SOM:2-3	
20903	CCN-73	Arcillas de Socha Fm.	Claystone	N3 (Dark gray)		P:3; SOM:3	
20904	CCN-74	Arcillas de Socha Fm.	Pure claystone	N4 (Medium dark gray)	Homogeneous, fragile	P:3; SOM:3	
20905	CCN-75	Arcillas de Socha Fm.	Claystone	N2-N3	Abbundant plant debris	P:3; SOM:3	
20906	CCN-76	Arcillas de Socha Fm.	Silty claystone	N4 (Medium dark gray)	Homogeneous, some pyrite? Casts	P:0?; SOM:1	
20907	CCN-77	Arcillas de Socha Fm.	Claystone	N4 (Medium dark gray)	Homogeneous	P:0-1;SOM:2	
20908	CCN-78	Arcillas de Socha Fm.	Impure coal	N2 (Grayish black)	Treatment lignite, parte en planos	P:3; SOM:3	
20909	CCN-79	Arcillas de Socha Fm.	Siltstone-V.f sandstone	5G 6/1 (Greenish gray)	Similar to CCN 70, abbundant mica, small Fe nodules	P:0-1;SOM:1	
20910	CCN-80	Arcillas de Socha Fm.	Silty claystone	N6 (Medium light gray)	Homogeneous, locally oxidize, similar to 69	P:0?; SOM:1	
20911	CCN-81	Arcillas de Socha Fm.	Silty claystone	N5 (Medium gray)	Plant debris ("roots"?)	P:2;SOM:2	
20912	CCN-82	Arcillas de Socha Fm.	Silty claystone	N2-N3	Patches 5YR 6/1, carbonized debris	P:1;SOM:2	
20913	CCN-83	Arcillas de Socha Fm.	Clayey siltstone	N5 (medium gray)	Homogneous	P:1;SOM:1	
20914	CCN-84	Arcillas de Socha Fm.	Clayey siltstone	5Y 6/1(light olive gray)	Homogeneous	P:0-1;SOM:1	
20915	CCN-85	Arcillas de Socha Fm.				P:0?; SOM:3	
20916	CCN-86	Arcillas de Socha Fm.	Claystone	5Y 5/2 (light olive gray)	Homogeneous	P:0;SOM:1	
20917	CCN-87	Arcillas de Socha Fm.	Claystne	N3-N4 (dark-medium dark gray)	Homogeneous (apparently, small sample)	Barren	
20918	CCN-88	Arcillas de Socha Fm.	Claystone	N5 (medium gray)	Altered to lght gray, a level with small coaly debris is present	P:0;SOM:2	
20919	CCN-89	Arcillas de Socha Fm.	Silty claystone	Mottled patches 5GY 6/1 (greenish gray), 5R 4/2 (grayish red)		Barren	
20920	CCN-90	Arcillas de Socha Fm.	Silty claystone	5Y 4/1 (olive gray)	Small patches grayish red and dusky yellow	P:0;SOM:1	
20921	CCN-91	Arcillas de Socha Fm.	Clayey siltstone	N5 (medium gray)	Partially altered to pinkish gray (5YR 8/1) "patches"	P:0;SOM:1	
20922	CCN-92	Arcillas de Socha Fm.	Claystone	N3-N4 (dark-medium dark gray)	Patches light olive gray	P:0;SOM:2	
20923	CCN-93	Arcillas de Socha Fm.	Siltstone-V.f sandstone	N6 (Medium light gray)	Some mica, bioturbated?	Barren	
20924	CCN-94	Arcillas de Socha Fm.	Siltstone	N5 (medium gray)	Mottled grayish red and dusky yelloy, root marks	P:0;SOM:0-1	
20925	CCN-95	Arcillas de Socha Fm.	Silty claystone	N8 (very light gray)	Red and brown patches	Barren	
20926	CCN-96	Arcillas de Socha Fm.	Silty claystone	N6 (Medium light gray)		P:1;SOM:1-2	
20927	CCN-97	Arcillas de Socha Fm.	Siltstone	5Y 6/1 (light olive gray)	Coaly remains(<2mm),abbundant mica	P:1;SOM:1-2	
20928	CCN-98	Arcillas de Socha Fm.	Sandy siltstone	N6-N7 (light-very light gray)	Laminated, mica abbundant, small coaly debris	P:0-1;SOM:1	
20929	CCN-99	Arcillas de Socha Fm.	Sandy siltstone	N6 (Medium light gray)	Similar to CCN 98	P:1;SOM:2	

Reference (Liege University code)	Number of sample (figure 3,3)	Lithologic unit	Texture	Color (Munsell)	Remarks	Pollen and microscopic organic matter abundance	Carbonate
20930	CCN-100	Arcillas de Socha Fm.	Sandy siltstone	5GY 6/1 (Greenish gray)	Laminated, mica abbundant, carbonized plant debris.	P:2;SOM 2-3	
20931	CCN-101	Arcillas de Socha Fm.	Siltstone-V.f sandstone	N6 (Medium light gray) oxidized with patches to 5Y 6/4 (Dusky yellow)	Parallel lamination, pirite "casts" (<1 mm), abbundant mica.	P:2-3;SOM:2-3	
20932	CCN-102	Arcillas de Socha Fm.	Sandy siltstone	N6 (Medium light gray) partially oxidized	Parallel lamination	P:0;SOM:2-3	
20933	CCN-103	Arcillas de Socha Fm.	Siltstone	N6 (Medium light gray) partially oxidized	Partially laminated, pirite "casts" (<1 mm), mica, some carbonized plant debris.	Barren	
20934	CCN-104	Arcillas de Socha Fm.	Clayey siltstone	N6-N7 (light-very light gray)	Bioturbed, gypsum cristals, some mica	P:0;SOM:1	
20935	CCN-105	Arcillas de Socha Fm.	Siltstone	5GY 6/1 (Greenish gray)	Mottled blackish red 5R 2/2	P:0;SOM:0-1	
20936	CCN-106	Arcillas de Socha Fm.	Siltstone	5Y 6/1(light olive gray)	Mottled, "root traces", brown yellowish brown	P:0;SOM:0-1	
20937	CCN-107	Arcillas de Socha Fm.	Clayey siltstone	5Y 6/1(light olive gray)	Mottled, yellowish brown	P:0;SOM:0-1	
20938	CCN-108	Arcillas de Socha Fm.				P:0?;SOM:1	
20939	CCN-109	Arcillas de Socha Fm.	Clayey siltstone	Mottled grayish purple, pale olive, yellowish brown		P:0?;SOM:2	
20940	CCN-110	Arcillas de Socha Fm.	Clayey siltstone	N5 (medium gray)	Small patches dusky yellow (5Y 6/4) and grayish red	Barren	
20941	CCN-111	Arcillas de Socha Fm.	Siltstone-V.f sandstone	N5 (medium gray) some lamina yellowish gray (5y 8/1)	Plane parallel lamination, micaceous	P:1;SOM:2	
20942	CCN-112	Arcillas de Socha Fm.	Siltstone-V.f sandstone	5Y 7/2 (yellowish gray)	Laminated, micaceous, abundant plant debris	P:1;SOM:2	
20943	CCN-113	Arcillas de Socha Fm.	Clayey siltstone	N6 (Medium light gray)	Micaceous, homogeneous	P:0?;SOM:1	
20944	CCN-114	Arcillas de Socha Fm.	Clayey siltstone	5Y 7/2 (yellowish gray)	laminated, micaceous	P:0?;SOM:1	
20945	CCN-115	Arcillas de Socha Fm.	Clayey siltstone	5GY 4/1 (dark greenish gray)	Micaceous, altered to 5 Y 7/2 (yellowish gray) to the outer part	P:1;SOM:1-2	
20946	CCN-116	Arcillas de Socha Fm.	Siltstone-V.f sandstone	5Y 7/2 (yellowish gray)	Micaceous, bad preserved plant debris	P:0;SOM:1	
20947	CCN-117	Arcillas de Socha Fm.	Siltstone	Mottled, dusky yellow, grayish blue 5 PB (5/2)			x
20948	CCN-118	Arcillas de Socha Fm.	Siltstone	Mottled, pale blue, dusky yellow, pale redish brown			x
20949	CCN-119	Arcillas de Socha Fm.	Clayey siltstone	N5 (medium gray)		Barren	
20950	CCN-120	Arcillas de Socha Fm.	Clayey siltstone	N5 (medium gray)		Barren	
20951	CCN-121	Arcillas de Socha Fm.	Clayey siltstone	5GY 6/1 (Greenish gray)	Root traces		x
20952	CCN-122	Arcillas de Socha Fm.	Clayey siltstone	N4 (Medium dark gray)	Homogeneous	Barren	
20953	CCN-123	Arcillas de Socha Fm.	Siltstone	N4 (Medium dark gray)	Homogeneous	Barren	
20954	CCN-124	Arcillas de Socha Fm.	Siltstone	5Y 6/1(light olive gray)	Oxidized pirite? casts	Barren	
20955	CCN-125	Arcillas de Socha Fm.	Clayey siltstone	N4-N5	Homogeneous	Barren	
20956	CCN-126	Arcillas de Socha Fm.	Clayey siltstone	N4-N5	Homogeneous	P:0;SOM:0-1	
20957	CCN-127	Arcillas de Socha Fm.	Siltstone	N4 (Medium dark gray)	Homogeneous	Barren	
20958	CCN-128	Arcillas de Socha Fm.	Silty claystone	N6 (Medium light gray)	Small "holes" (< 1 mm)	Barren	
P: palynomorphs		1: present					
SOM: sedimentary organic matter		2: frequent					
		3: abundant					

Appendix 3.1. Lithologic description of samples studied in the Paz de Río area. Curva de Cosgua Sur (CCS) section

Reference (Ulg)	Number of sample	Lithologic unit	Texture	Colour (Munsell)	Remarks	Pollen and SOM abundance
20965	CCS-1	Arcillas de Socha Fm.	Fine sandstone	G 7/1 (Greenish gray)	Cubic "holes", some mica	Barren
20966	CCS-2	Arcillas de Socha Fm.	Fine sandstone	Varicolored (5RP 4/2;GY 7/2; 5Y 7/4)	Bioturbed	Barren
20967	CCS-3	Arcillas de Socha Fm.	Siltstone	Varicolored (5P 4/2)		Barren
20968	CCS-4	Arcillas de Socha Fm.	Siltstone	Varicolored (5PB 5/2 Grayish blue with patches 5Y 6/4)		Barren
20969	CCS-5	Arcillas de Socha Fm.	Siltstone	Varicolored (5PB 5/2 Grayish blue with patches 5Y 6/4)		Barren
20970	CCS-6	Arcillas de Socha Fm.	Silty claystone	Varicolored (5RP 4/2 with patches 10YR 5/4)		Barren
20971	CCS-7	Arcillas de Socha Fm.	Clayey siltstone	Grayish blue with patches 10YR 6/6, dark yellowish		Barren
20972	CCS-8	Arcillas de Socha Fm.	Siltstone	Varicolored (5P 6/2 pale purple…)		Barren
20973	CCS-9	Arcillas de Socha Fm.	V. f. sandstone	10Y 6/2 (Pale olive)	Micaceous	P:0-1; SOM:1
20974	CCS-10	Arcillas de Socha Fm.	Claystone	5G 6/1 (Greenish gray with patches 5RP 4/2)		Barren
20975	CCS-11	Arcillas de Socha Fm.				Barren
20976	CCS-12	Arcillas de Socha Fm.	Silt-V.f. sand	N6 (M. light gray with patches 5GY 8/1)		Barren
20977	CCS-13	Arcillas de Socha Fm.				Barren
20978	CCS-14	Arcillas de Socha Fm.	Claystone	N5 (Medium gray)	Fissility	P:2;SOM:2
20979	CCS-15	Arcillas de Socha Fm.	Claystone	5Y 8/1 (Yellowish gray with patches 5RP 4/2)		Barren
20980	CCS-16	Arcillas de Socha Fm.	Claystone	N6 (Medium light gray)	Homogeneous	P:1; SOM:1
20981	CCS-17	Arcillas de Socha Fm.	Claystone	N6 (Medium light gray)	Wavy lamination (3mm thick)	P:1; SOM:2
20982	CCS-18	Arcillas de Socha Fm.	Claystone	N6 (Medium light gray)	Micaceous	P:0?;SOM:0-1
20983	CCS-19	Arcillas de Socha Fm.	Siltstone	N5 (Medium gray) with patches 10R 4/2 grayish red		Barren
20984	CCS-20	Arcillas de Socha Fm.	Claystone	N4 (Medium dark gray) with patches grenish gray and grayish red		Barren
20985	CCS-21	Arcillas de Socha Fm.	Claystone	5 Y5/1 (Olive gray with patches grayish red)		P:0?;SOM:2
20986	CCS-22	Arcillas de Socha Fm.	Claystone	N5 (Medium gray)	Micaceous	P:0;SOM:1
20987	CCS-23	Arcillas de Socha Fm.	Silty claystone	5G 6/1 (Greenish gray with patches 5 PB 5/2 and 10 R 4/2)		P:0?;SOM:1
20988	CCS-24	Arcillas de Socha Fm.	Claystone	Varicolored (5R 4/2 Grayish red, redish brown, greenish gray..)		P:0?;SOM:1-2
20989	CCS-25	Arcillas de Socha Fm.	Sandy siltstone	10Y 6/2 (Pale olive)	Very micaceous	Barren
20990	CCS-26	Arcillas de Socha Fm.	Siltstone	Varicolored (Grayish blue 5PB 5/2, pale purple, greenish gray, grayish red etc…)		Barren
20991	CCS-27	Arcillas de Socha Fm.	Silty claystone	Grayish red purple 5RP 4/2 with patches greenish gray and dark yellowish orange 10 YR 6/6		
20992	CCS-28	Arcillas de Socha Fm.	Siltstone	N4 (Medium dark gray)	Homogeneous, cubic casts filled with Fe oxides	P:0;SOM:1
20993	CCS-29	Arcillas de Socha Fm.	Siltstone	N4 (Medium dark gray)	Homogeneous, cubic casts filled with Fe oxides	P:0;SOM:1
20994	CCS-30	Arcillas de Socha Fm.	Siltstone	N5 (Medium gray)	Homogeneous	Barren
20995	CCS-31	Arcillas de Socha Fm.	Silty claystone	N5 (Medium gray)	Cracks filled with Fe oxides	Barren
20996	CCS-32	Arcillas de Socha Fm.	Silty claystone	N5 (Medium gray)	Small "holes"	P:0;SOM:1
20997	CCS-33	Arcillas de Socha Fm.	Siltstone	N5 (Medium gray)	Small "holes"	Barren
20998	CCS-34	Picacho Fm.	Silty claystone	N6 (Medium light gray)	Micaceous	P:0;SOM:1
20999	CCS-35	Picacho Fm.	Sandy siltstone	N5 (Medium gray)	Micaceous, small coaly debris	P:0;SOM:1
	CCS-35a	Picacho Fm.				P:1;SOM:1
21000	CCS-36	Picacho Fm.	Claystone	N6 (Medium light gray)	Homogeneous	P:1-2;SOM:2
21001	CCS-37	Picacho Fm.	V. f. sandstone	N5 (Medium gray)	Micaceous, small coaly debris	P:0?;SOM:3
21002	CCS-38	Picacho Fm.	Clayey siltstone	N6 (Medium light gray)	Micaceous, small coaly debris	P:2;SOM:3
21003	CCS-39	Picacho Fm.	Siltstone	5YR 6/1 (light brownish gray) to N6 (Medium light gray)	Abbundant bad preserved plant debris	P:1;SOM:2
21004	CCS-40	Picacho Fm.	Clayey siltstone	N5 (Medium gray)	Bitter taste	P:1;SOM:3
21005	CCS-41	Picacho Fm.	Clayey siltstone	N5 (Medium gray)	Parallel lamination (1 mm thick)	P:1;SOM:3
	CCS-42	Picacho Fm.				P:3-SOM:3

Appendix 3.2. Palynostratigraphy of the Paz de Río section.

sample label	PB-1	PB-3	PB-19	PB-14	PB-20	PB-22	CCN-2	CCN-14	CCN-24	CCN-38	CCN-47	CCN-50	CCN-58	CCN-73	CCN-78	CCN-81	CCN-82	CCN-99	CCN-101	CCS-14	CCS-35a	CCS-36	CCS-38	CCS-40	CCS-42	PICACHO-2
cumulative meters from base of Areniscas de Socha Fm.							8,8	109	128	163	174	182	194	212	221	228	228,4	268	273	358	425	454	462	473	480	580
Aglaoreidia ? foveolata														1												
Albertipollenites ? perforatus																						19			1	1
Andalusiella sp.	■																									
Araucariacites sp. 1							4																			
Baculamonocolpites sp.																							1			
Bacumorphomonocolpites tausae (RW)																				2		1	1			
Bisacate																				1						
Bombacacidites "fossulatus"														1			1									
Bombacacidites "lisamae"									3			2														
Bombacacidites (30 µm) rounded										2		15	75													
Bombacacidites (triangular)								9	4																	
Bombacacidites aff. *gonzalezii*																							2	3		
Bombacacidites annae								1		10	4	6		14	1			1	2	1						
Bombacacidites baumfalki																							1		1	1
Bombacacidites cf. *nacimientoensis*																								1		
Bombacacidites pseudosimplireticulatus																										1
Bombacacidites psilatus																							1			
Bombacacidites soleaformis																										1
Bombacacidites sp (sp 2 of Jaramillo & Dilcher 2001)																		1	2							
Bombacacidites sp. (homogenous reticulum)																		2?			3	10				
Bombacacidites sp. 14 (see Upper La Paz)																							1			
Bombacacidites sp. 9 (see upper La Paz Fm.)																						1				
Bombacacidites sp. B (Muller et al., 1987)																							1			
Brevitricolpites macroexinatus																						1				
Brevitricolpites microechinatus																		1					1			2
Buttinia andreevi (RW?)	■						1																			
Chomotriletes minor	■	■							1													1	2	1	3	
Cicatricosisporites sp.								4	1																	
Cicatricososporites (fine striae)			■			■	5																			
Cicatricososporites sp.							2																			
Clavamonocolpites sp.																									1	
Clavapollenites							1		1	6																
Clavatricolpites densiclavatus																				2						
Clavatricolporites leticiae													7					1	1							
Colombipollis tropicalis						■	9																			
Corsinipollenites psilatus										23				1		14	3					6	1	1		
Cricotriporites cf. *elongatoporus*																						1				
Cricotriporites guianensis																					1		2		3	2
Cricotriporites minutiporus																									7	
Cristatisporites sp							4	1																		
Ctenolophonidites lisamae											4															
Cyclusphaera scabrata																						4	8	3	5	6
Dinoflagellate																			1	1					1	
Dinogymnium sp. (RW)																				3						
Diporoconia cf. *iszkaszentgyoergyi*													3													
Diporopollis assamica																			1							
Echimonocolpites							2	1	1																	
Echimorphomonocolpites gracilis																							1			1
Echiperiporites sp.																						54	16	4	4	12
Echitriletes							30	7	2																1	
Echitriporites trianguliformis	■																									
Ephedripites vanegensis										1	2			1	9		1									
Foveodiporites guianensis									1																	
Foveotricolpites perforatus										11	1	23	6	5				1	2							
Foveotriletes																				2						
Foveotriletes margaritae	■					■																				
Foveotriporites hammenii																									3	
Gemmamonocolpites amicus (Gonzalez, 1967)																								2		
Gemmastephanocolpites sp. (gemmatus ?)											69				3											
Horniella sp.																							1			
Incertae "pseudocolpate" (verrugate)												2	1	6				2	3							
Ladakhipollenites simplex																		1	4					1		1
Laevigatosporites (small verrucae-gemm)																									2	
Laevigatosporites spp.										20	xxx								4					2	1	1
Longapertites proxapertoides var *proxapertitoides* (tetrad)																				6						
Longapertites vaneendenburgi	■							29	29	9	1	6	2				1									
Margocolporites vanwijhei																						3		1	3	
Mauritiidites franciscoi var. *franciscoi*								1	1		22	15	1	13	27	5	8		5	8	2	9	1	2		6
Mauritiidites franciscoi var. *minutus*																							1			2
Mauritiidites franciscoi var. *pachyexinatus*																						10	16	5	2	1
Monocolpopollenites ovatus												12	3	1			1					6				
Monoporopollenites annulatus																									5	
Ovoidites "reticulate"																6	87									
Ovoidites (psilate)							1	1	5	1					1	3	4		2							
Pediastrum									1	1								x	xx	x	xxx	xxx	xxx	xxx	xxx	xx
Periretisyncolpites sp. 1										1																
Polypodiaceoisporites group (zonate spores)						■		2	5										3				1	2	2	
Polypodiisporites aff. *inangahuensis*																							2	1	1	2
Polypodiisporites ssp.													2							1			2			
Proxapertites "megafoveolatus"													7			2										
Proxapertites (triangulate)														2												
Proxapertites cursus													22	83												
Proxapertites humbertoides	■					■	2																			
Proxapertites magnus								1		2		1	1		1	1			3							
Proxapertites operculatus		■						1		44	4	193	45	694	1	24	26	4	17	4		1				
Proxapertites psilatus			■				2	1		8		14	1	3		3	11	1		17		1				
Psilabrevitricolpites marginatus				■																						
Psilabrevitricolporites "simplex"																					5					
Psilabrevitricolporites annulatus	■	■																								
Psilamonocolpites "marginatus" (50 um)										52	3			2												
Psilamonocolpites medius	■	■	■	■	■	■	44	55	62	16	99	1		4	25	10	6	36	46	8	1	10	8	5	11	19
Psilamonocolpites minutus															5	1				15						
Psilamonocolpites operculatus						■	4	7	7	42																
Psilamonocolpites sp. (rounded)																2										
Psilastephanocolporites fissilis																									1	
Psilatricolpites							2																			
Psilatricolporites (20 um)									1																	
Psilatriletes martinensis				■																						
Psilatriletes spp.					■	■	2	8	8	2	56	22	27	7	21	814	5	2	13	25	5	6	2	6	6	3
Psilatriporites									1																	
Racemonocolpites facilis																						1				
Racemonocolpites microgemmatus																					1	2	1			5
Racemonocolpites racematus						■	4	1																3		
Racemonocolpites sp. 1 of Jaramillo & Dilcher (2001)																							1			
Retibrevitricolpites triangulatus																								1		
Retibrevitricolporites grandis or *Bombacacidites* ?																						1			22	
Retidiporites "cosguensis"																97										
Retidiporites botulus															5											
Retidiporites cf *botulus*																				6						
Retidiporites magdalenensis									8	18			32	1				1		3						
Retimonocolpites (fine reticle) Several types					■	■	9	11	8	2	1							11	17		6	72	7	1		22
Retimonocolpites retifossulatus (Lorente, 1986)																						2		1	3	7
Retistephanoclopites (short colpi)											9															
Retistephanocolpites angeli																										2
Retistephanocolporites "*boyacensis*"																				28						
Retistephanocolporites (costate to the ecuator)											2															
Retistephanocolporites sp								1																		

sample label	PB-1	PB-3	PB-19	PB-14	PB-20	PB-22	CCN-2	CCN-14	CCN-24	CCN-38	CCN-47	CCN-50	CCN-58	CCN-73	CCN-78	CCN-81	CCN-82	CCN-99	CCN-101	CCS-14	CCS-35a	CCS-36	CCS-38	CCS-40	CCS-42	PICACHO-2
cumulative meters from base of Areniscas de Socha Fm.							8,8	109	128	163	174	182	194	212	221	228	228,4	268	273	358	425	454	462	473	480	580
Retistephanoporites angelicus																							1		1	
Retitrescolpites ? irregularis (Van der Hammen y Wymstra, 1964)																						1	2	1		
Retitricolpites (foveolate)									10																	
Retitricolpites cf. *simplex*																						5		1	6	1
Retitricolporites								3																		
Retitriletes (*Zlivisporis blanensis* ?)							4																			
Retitriporites (fine reticle, pore costate 10 µm wide)																							1	2		
Retitriporites poricostatus																							2			
Rhoipites guianensis																							1		3	
Rugupollenites									4																	
Rugutricolporites cf. *felix*																						1				
Scabratricolpites								2	2	2																
Spinizonocolpites baculatus	■			■																						
Spinizonocolpites baculatus (RW)																				1						
Spinizonocolpites breviechinatus																			2							
Spinizonocolpites echinatus					■																					
Spinizonocolpites pachyexinatus																		8	29							
Spinizonocolpites sutae	■	■																								
Spirosyncolpites spiralis																					1	8	27	12	6	6
Spore gemmate (zonate)							15																			
Spore verrugate							1																			
Stepanocolporites								2	1	1																
Stephanocolpites costatus						■																				
Striatopollis										2																
Striatopollis catatumbus																					1		10	5	3	10
Striatopollis minor															10								1?	3		
Striatopollis ? tenuistriatus																							3			
Tetracolporopollenites transversalis																							1			
Tetradrites magnus						■								3												
Tricolpites								3																		
Tricolpites (Reticulate to the polar region, small)														1												
Tricolpites cf. *minutus* (Gonzalez, 1967)																								6	5	7
Tricolpites clarensis																		3	3			2				
Tricolpites sp.2 (Reticulate to equator; < 20 µm)											1			1	3											
Triporites sp. (triangular, psilate)									2																	
Ulmoideipites krempii						■			1									1				2	8	2	3	1
Verrumonocolpites							1	2	1																	
Verrutriletes spp.							5	1												3						1
Wilsonipites margocolpatus																							1		1	
Total pollen and spores							149	154	171	276	278	312	235	844	112	982	154	75	160	134	26	241	138	78	116	123

■	Presence
(grey)	Illustred in the plates
x	Present
xx	common
xxx	abundant

Appendix 3.3. Palynofacies data (Paz de Río section)

No. of sample	Depth	Wood	Geilified woody tissues	Pseudo-amorphous phytoclasts	Cuticles	Other non-cuticular tissues	Charcoal and other black phytoclasts	Resines	Fungal remains	Pollen and spores	Fresh water algae	Algal filaments and sphaeromorphs	Dinofl., foram., acrit.	Zooclas.	Minerals	General content of organic matter	REMARKS
Picacho-2	0	3	2	1	1	3	2	0	1	1	1	0	0	0	3	3	*Pediastrum*
CCS-41	111	4	2	2	1	3	1	2	3	2	0	0	0	0	1	4	
CCS-38	115	4	4	1	1	3	1	2	3	2	1	0	0	0	1	4	*R. guianensis* (V49-3)
CCS-36	123	2	1	1	0	2	2	1	1	1	0	0	0	0	4	3	
CCS-35a	158	3	1	0	0	1	3	1	0	1	1	0	0	0	4	3	Bad preserved *Pediastrum*
CCS-32	122	1	0	2	0	2	0	0	0	0	0	0	0	0	4	1	
CCS-28	182,5	1	1	0	0	0	3	3	0	0	0	0	0	0	3	3	Resines or gelified phytoclasts?
CCS-24	202,5	2	1	4	0	2	0	0	0	0	0	0	0	0	4	3	
CCS-19	209	0	0	0	1	0	0	0	1	0	0	0	0	0	5	1	
CCS-14	219,5	1	2	1	2	2	3	2	1	1	0	0	0	0	1	0	
CCS-8	233,5	0	0	0	0	0	0	0	0	0	0	0	0	0	5	1	Barren
CCS-1	244,5	1	0	0	0	0	1	0	0	0	0	0	0	0	5	2	
CCN-116	270,5	3	2	0	0	2	3	1	0	1	0	0	0	0	4	0	
CCN-112	280,5	3	1	2	2	2	3	1	0	0	0	0	0	0	3	1	
CCN-106	296,5	1	0	1	0	1	1	0	0	0	0	0	0	0	5	3	
CCN-99	311,5	3	0	3	0	1	1	1	0	1	0	0	0	0	4	3	
CCN-91	323	1	0	0	0	1	0	0	0	0	0	0	0	0	5	1	
CCN-88	338	3	0	4	0	1	1	0	0	0	0	0	0	0	1	3	
CCN-82	351	3	0	1	3	2	2	2	1	1	0	0	0	0	1	3	
CCN-77	359,5	4	1	1	1	2	1	1	0	0	0	0	0	0	1	4	
CCN-73	367,5	2	1	3	1	3	1	1	0	4	0	0	0	0	0	4	
CCN-66	378,5	3	1	0	4	2	1	1	0	0	0	0	0	?	4	2	Organic slide, big oranges debris (insects?)
CCN-58	385	2	1	0	0	1	1	1	0	4	0	0	0	0	3	2	
CCN-50	397,7	2	1	0	1	3	2	1	0	4	0	0	0	0	4	2	
CCN-46	406,5	3	1	3	0	3	1	1	1	1	0	0	0	0	0	4	*Retidiporites botulus*
CCN-38	416,5	3	1	2	0	3	2	1	1	3	0	0	0	0	1	4	
CCN-26	433	2	1	1	1	5	3	1	0	2	0	0	0	0	1	4	
CCN-24	452	3	2	1	0	3	3	2	1	2	0	0	0	0	3	4	
CCN-14	471	4	1	0	0	3	3	2	0	2	0	0	0	0	2	3	
CCN-5	504,7	3	0	0	0	3	3	1	0	1	0	0	0	0	4	1	Organic slide
CCN-4	542	4	0	0	0	4	4	1	0	0	0	0	0	0	4	2	
CCN-2	572	4	2	0	0	2	3	2	0	2	0	0	0	0	4	3	

1: present
2: common
3: abundant
4: very abundant

sample label	CCN-2	CCN-14	CCN-24	CCN-38	CCN-47	CCN-50	CCN-58	CCN-73	CCN-78	CCN-81	CCN-99	CCS-14	CCS-35a	CCS-36	CCS-38	CCS-40	CCS-42	PICACHO-2
cumulative meters from base section	8,8	109	128	163	174	182	194	212	221	228	268	358	425	454	462	473	480	580
Spores	38	16	7	22	27	33	67	9	19	230	6	5	5	4	10	6	5	3
Pollen	40	101	93	422	138	248	327	850	100	78	54	21	13	111	134	60	76	76
Fungal remains	6	12	28	9	50	4	2	1	41	1	0	1	1	31	157	338	228	30
Lycopods	1094	798	427	49	412	390	157	6	20	246	501	577	495	912	72	44	90	356
TOTAL	1178	927	555	502	627	675	553	866	180	555	561	604	514	1058	373	448	399	465

Appendix 3.4. Counting values of pollen, spores and fungal debris (Paz de Río section)

Appendix 4.1.A. Pollen and spore distribution (Riecito Maché section)

Coal layer	Fm. Guasare	Fm. Guasare	1--2	Shale	3	4	Parallele section "Caracoli tree"	Sandstone-ripple marks?	8	11	15	16	17	18	19	20	21	22-23	24	27	28	31	33	A
Sample	1	2	3--26	27	28-29	30-31	33-34	32	35-42	43-62	63	64	65	66-70	71-74	75-78	79	80-84	85	86-91	92	93	94-96	97
Cumulative meters above base Paso Diablo Fm.			42	63	71	78		193	279	326	562	564	565	567	569	570	624	642	689	727	737	858	935	1164
Baculamonocolpites sp.																						x		
Bombacacidites annae			x	x																				
Cicatricososporites eocenicus																							xx	
Clavamonocolpites sp.																								
Clavatricolporites leticiae			x																					
Colombipollis tropicalis	x																							
Cricotriporites macroporus			x																					
Ctenolophonidites lisamae			xxx	x	xx	x	xx																	
Dinoflagellate	x																							
Diporopollis assamica			xx		x																			
Echimonocolpites protofranciscoi	x																							
Ephedripites vanegensis			xx	x	x	x				x														
Foveotricolpites perforatus			x		xx	xx			xx			x												
Foveotricolporites sp																				x				xx
Foveotriletes margaritae		xx								xxx														
Gemmastephanocolpites gemmatus									xx															
Gemmatriletes sp.										x														
Horniela sp. 1 (pores costate)						xx																		
Magnotetradrites magnus				x																				
Malvacipollis sp.			xxx			x																		
Mauritiidites franciscoi (rounded colpi)															xxx		x		x	xxx				
Mauritiidites franciscoi var. *franciscoi*					x																			
Mauritiidites franciscoi var. *pachyexinatus*			xxx	x	xxx	x	xxx																	
Poloretitricolpites absolutus																			x	xx				x
Polotricolporites cf. *P. concretus* (Gonzalez 1967)																		x						
Polypodiisporites sp.																		x			xx	x		x
Proxapertites "fossulatus"												xxx												
Proxapertites cursus			xx	x																				
Proxapertites operculatus		x	xx	x	x				x															
Psilabrevitricolporites sp.																						x		
Psilamonocolpites sp.			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Psilastephanocolpites globulus			xx							x														
Psilastephanocolporites brevicolpatus																								x
Psilatricolporites "blessi"			x		x	x																		
Psilatriporites sp.						x																		
Racemonocolpites sp.																		x	x		x			
Retibrevitricolpites triangulatus															xxx		xx		xxx	xx				xx
Retidiporites botulus					x																			
Retidiporites magdalenensis		x	x																					
Retimonocolpites sp.	x																							
Retimonocolpites tertiarius																		x						
Retistephanocolporites sp.																								x
Retitrescolpites ? irregularis															xx		x			xx		x		xx
Retitrescopites "machensis"															xx									xx
Retitricolporites "doradensis" (thick lumina, circular)																								xx
Retitricolporites "venezuelensis"																			x	x	x			xx
Rhoipites guianensis																				x				
Siltaria mariposa																		x						
Spinizonocolpites baculatus	x																							
Stephanocolpites cf. *S. costatus*	x																							
Stephanocolpites sp.																								x
Striatopollis catatumbus																			x	x				xx
Striatopollis sp. (reticulate)			x																					
Tertracolporopollenites cf. *divisus*																						xx		
Tetracolporites pachyexinatus														xx						xx	x			
Tetracolporopollenites transversalis														x				x		x				
Triatriopollenites sp.									xx	xxx														
Tricolporites (thick reticle to the polar area)																	x							
x Present																								
xx Frequent																								
xxx Abundant																								

Appendix 4.1.B. Pollen and spore distribution (El Cerrejón WRV 04774 log)

Species/deep of sample	15.5	19	22.69-24.55 (coal)	28.65	32.6	36.55	38.63	42.71	46.75	49.94	53.95	58-60 (coal)	66.15	70.8	74.3	81.8	84.35	91.38	94.41	96.65 (coal)	100.6	104.56	107-108.85 (coal)	112.9	116.82(coal)	118.25	122.47	129.52	134.6 (coal)	146.55	148.5	150.45	151.82 (coal)	157 (coal)	162.67	166.8	171.57	175.75	179.95	184.55	188.69	193 (coal)	194.97	230.4	207.5	211.13	216.9	221.9	225.91	231.16 (coal)	235.32 (coal)	239.29 (coal)	244.2	252.66	255.35 (coal)	259.81	264.94	273.5	278.12	280.47	285.08	287.52 (coal)	290.77	294.28	298-300 (coal)	301.88 (coal)	305.75	310.3 (coal)	311.28	318.14	316.16	321.66	324.7 (coal)	326.82 (coal)	328.6	330.65	341.44	347.54 (coal)	351.3 (coal)	355.64	357.59
Number of Coal bed			110									105								103			102		101				100			1 m below 95	??								83								??	75	75			71							65			60	57		??					50	50				45	45		
Acritarch																																																																				1												
Aglaoreidia ? foveolata																																																																	1									2						
Araucariacidites sp.																																1																																																	
Baculatisporites sp.																																																																		1		7													
Bisacates																																																	1										3				1								3										
Bombacacidites "pasivus"																																																						1																												
Bombacacidites annae					1				1				2														1				1		3																																											1					
Bombacacidites cf. "lisamae"						1			1				2	2							1																													2						1																1				1					
Bombacacidites ssp.				1	2						2		2		1	3	3															1												1			1		1								1				1		1		1													1	3			1	1				1	1
Brevitricolporites sp. (psilate-micropitted-foveolate)							2											1			5	1	3										3								24								2	1	3							2		4		1		4									5	1			23		1	1
Camarozonosporites sp.						1											1																																																															
Carya type																																																											2																							
Chomotriletes							1							1																																																					1	2																			
Clavatricolporites sp.	1																																																					1																							1					
Corsinipollenites sp.							1	1	2				1		1																1	1	1			1												1		1	1									1		1			1																														
Ctenolophonidites lisamae			1		3	1	2														3																1			3				1			1			1					1	1	2						1		6				2		1									6	3		1		1	2
Dinoflagellates					2	1																																																										1														2			1	
Dinogymnium sp.									1																														1																			1																													
Diporoconia cf. *Diporoconia iszkaszentgyoergyi*																																									1																																						2					1
Diporoconia cf. *Diporoconia iszkaszentgyoergyi*																		1												1																																																						1	1					
Diporopollis assamica								8	9	2			15	2	5	3	5														3	61	1		13		4	7	2							1				1	1	2		2		1	5	1						1		3												1	4	1		1			1
Echitriletes ssp.											1			2				1																						1							1			1							1			2							1		5						1				2	3			
Echitriporites trianguliformis					2		6																					1									2				2							1								1												8			1		1							6	3					4
Ephedripites sp																																																											1					1											1										
Ephedripites vanegensis		2	3			1	2				6		3		4	1	5					1								2		2	2	1	1	34		1	3	1	4		1		1		1	1	1			1		1					1				2		1						8				1	2	1	2			1	1
Foraminiferal test linings	1																																																																												1	2				2	1
Foveotricolpites perforatus	1								2	1			7		2																																				1																																				1
Foveotricolporites sp 1 (sp, 3 of Jaramillo & Dilcher 2001)																																																																		2																
Foveotricolporites sp.																									15																																																											
Foveotriletes ssp.														2	1																																										1																										
Fungal spores	26	12	375	6	25	14	32	125	16	68	32	186	178	85	174	25	353	534	63	21	15	172	287	129	359	25	11	58	643	285	6	341	274	376	9	188	17	14	176	93	24	228	215	273	17	82	111	87	81	219	112	496	53	32	559	13	88	1	124	23	221	330	82	391	5	488	7	33	12	27	61	8	25	284	115	117	3	412	72	34	58
Gemmastephanocolpites gemmatus																																	3																						109																									
Gemmatricolporites sp.																																																	1																															
Incertae (Aquilapollenites?)																																																					1																											
Ischyosporites problematicus											2			3	3	2		1	2							16																																																						
Laevigatosporites sp. 1 of Jaramillo & Dilcher 2001					1			3	1						1			2			1	1		1											1															1			1					1						1																	1	1				
Leiospheridia																																													xxx												xxx		xx																				
Longapertites vanendeenburgi														1					1		1					1																																								3										3					2	
Malvacipollis sp.		2	4	1	4	6	11				9			3		14	5	1				6	1		4	5	2			4		5				2	19		1	1	2		3	1	1	1		2	2					8			1	1	2	5	2		10	8													6	8	1	7		8	4
Margocolporites sp.														1																																																																		
Mauritiidites franciscoi var. *franciscoi*	9	4		5	15	15	6	1			3	8	1	4	3	2	3		1		1	1		2		2	1		17			3	3	31	4		2			1	6	5	1				1	1	2	1	2	36	2	8	4			1				17	1	6		20		3							15	15	17	6	3		13	13
Mauritiidites franciscoi var. *pachyexinatus*			26										18								2		1	8					1								25			3						34								6	1	46			9	1							14			1	36									38	2	1	1	2			
Mauritiidites minutus																																		3																																														4
Other trilete spores															3									5		5		1		2		1			2											1	1			1					1					1	1				1				1														
Pediastrum																																				1																																									1	1			
Proxapertites cursus	1	1		1	7	1	12		1								2											1		1					2		33	1									2	15	1			1		3					1						5	2	2				1						13	13				9	1
Proxapertites magnus																																																																		2																
Proxapertites operculatus	1	8		5	23	29	4	14	8	1	1		14	5	2	2	12	1				7	2		8		2	3	9	61	3		62	8			4		4	3	2	8		2	15	2	1	6	6	5		1	1	3	11	31		1		1	1			15	22	1					1	1	4			67	57	35			73	41
Proxapertites psilatus								2	4		1																		3															2		1				2				1	1		1	1		1			4	1			1		1		1			51	84	7			31	31
Psilabrevitricolpites sp. (small, rounded)							2																																																																										
Psilabrevitricolporites simpliformis							2	1		1	1		7	2	3	3	6	2			3	1	5	1		2		1				1			2				1	1?	2			1	1	2		1			1			1		1	1	1		1										1		2				6		1				2
Psilamonocolpites "marginatus"						1																								1														2																																				1	2	1			
Psilamonocolpites group	21	7	44	7	21	49	31	123	24	7	35	7	118	47	29	52	13	22	5	15	1	11	11	33	4	19	5	32	2	26	2	2	43	38	25	6	33	14	35	2	56	29	42	69	12	17	7	18	28	8	4	14	19	58	19	16	14	1	2	27	19	29	47	57	1	85	9		16	6	14	3			52	84	1	18		28	55
Psilamonocolpites operculatus		1																																																				1													1									1				
Laevigatosporites tibuensis		1									3		1	4		3	1			1		1	1			3	1		6	1		5	22	1	1	2	1	3		3			2	1					5		1			1	1	2	2	1	5	1	1		1	5						6				4	4	3			3	
Psilamonolete sp 1 (folded)																																																							9											3																
Psilastephanoporites "oculiporus"																											1																																2	1																1				
Psilastephanocolpites globulus												1																											1	3	1			3							3	25		2						3	27	1		6				1				8	8		5	3					5
Psilastephanocolpites sp									1												1																																																													
Psilastephanocolporites fissilis	1																																																																															
Psilatricolpites sp. (plate 4.5, photo 14)																																															1													1				2																		
Psilatricolporites "blessi"	1		1		1		1																														7				6	1								1	3		1							1	1																		3		
Psilatricolporites marginatus							1		1		1	3			1		1					1										2				1	2					2											1							3		1										1		2					1
Psilatricolporites pachyexinatus																															2																														2																1		
Psilatricolporites sp.																																													1							2					1		3														4						
Psilatriletes (>50 µm)	2	1	4									4						1		4			5		5				1				3																	1	1	11				1								1	1									1	1		16	4		
Psilatriletes ssp.	4	3		1	3	4	1	3	9	2	16		1	18	4	15	12	3	6	3	1	4	2	9		26	12	2	1	2	1	2	7	1	6		7	6	1	5	5	5	1	1	3	3		2	2	2	1		1	5	3		1		7	5	12		1	7		6	4	12	2	2	2	3			12	1				15	3
Racemonocolpites racematus																																																	4																		1	1														
Retidiporites botulus			1															1			2	1	1			1				1			1						1		3			5		2				1			1	1	3	2						1	1															1			1
Retidiporites magdalenensis	2						1							1		2							2														1?																	1										1	1									1		5	7	2			1	2
Retidiporites operculatus																																																																														1	1			
Retimonocolpites sp.			1											3								1		4		1										1					2					1			1						6			2			1															1	3					2
Retitricolpites "grandis"		1						1																																																								2																		
Retitricolpites "communis"																																															1													1																				
Retitriletes "cristatus"														5		2										1																						2				1										1																1	3			1						1
Retitriporites simplex																								1																								2																				2												
Retitriporites sp. 1																																																								1																									1
Retitriporites sp. 2 (pore costatel)																																																						1		3																											
Rugutriletes																																1																																																	
Scabratricolporites sp.(cf. Siltaria sp. 4 Jaramillo & Dilcher 20	3	2	1	2	3	8	3		1		3	26	1	1		2	2	2	1	7			1				1	4		5							16		1					3								2	6										13		7			1							23	1	1		1			
Scabratricolporites sp.																				1			2																				3	1																						9														1		1					1
Scolecodont																																																																																1	
Small tricol(por)ates			48	2		8	15	5		2	27	12	1	13	11	18	25	35	7	6	9	16	45	7	1	2	5	7		13	9	13	1	13	4	3	14	18	11	7	21	24	17	43	2	5	3	3	8	3	8	10	3	2		4	5	1	12	5	9	32	1	12		18		2	3			1	1	48	8	3		30	5		2
Spinizonocolpites echinatus																																								1																										1															
Spore (irregular reticle)																																																																				1														
Trilete spore (reticulate-foveolate)																																																																				62														
Spore trilete (scabrate-verrugate)								1	3								2					1						2		2	1	3						1																																											
Stephanocolpites "scabratus"		1				1																																																						1																1				
Stephanocolpites (psilate, 4 colpi)						1																																																																										
Stephanoporites sp.		1																																																																														
Striatopollis sp.																1								2																								1	1								1																							1						1
Striatopollis tricolp estria-retic																	1																																					1						1			2																	
Striatriletes sp.																						1																																																										
Syncolporites lisamae	1							1					1				4	2																						1				1		1									1		3				1							1																2
Tetradrites 1(psilate)	2										1																																										15										2																			
Tetradrites 1(reticulate)												1								2																																																										1		
Momipite s sp.																14	1	5			2	1		1			2			1		6			1		2						3		2				1	1	3						2	3		5	1	2		1					4			2	7			1						2
Triatriopollenites sp.	1	5		1	11		7	1			6				1	1	1			4																												2																								9								2				
Tricolpites sp. 2 (reticulate to the equator)	1														1		1								1																																2											1																
Tricolporites "scabrate" (big)																								1																				4																											1					1							1		
Tricolporites sp. (reticulate, colpi marginate)														1	1	4	2	2																																									2		2						1																	
Tricolporites sp. (reticulate)																								1																																			1	1			4														2		
Tricolporites sp. (triangular, short colpi, simple)					3																										2																	5																					2							2		1				
Tricolporites sp. (triangular pore and colpi costate)																																																																						1										
Tricolporites sp. (triangular, short colpi, simple)																							2					1																																																				
Trilobosporites sp.									1																																																																							
Triporite sp. 1 (triangular)																																															1		1																										1				
Triporites sp. 2 (psilate small)																																																						1																											1
Triporites sp. 3 (reticulate)																																																											1		2		1							1										
Ulmoideipites krempii					1		1		1		1		1																				1					3		1		2			2		1						1		1				1		1	2																3		1			
Verrutricolporites sp.		1																																																																														
Verrutriletes "viruelensis"								6	6								1																													2		2																																		