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Palynology of the Eocene Esmeraldas Formation, Middle Magdalena Valley Basin, Colombia
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The palynology of the Eocene Esmeraldas Formation in the Middle Magdalena Valley Basin, Colombia was analyzed in order to constrain the age of the unit. This formation is a very important oil reservoir in the Middle Magdalena Valley Basin, which is a product of the fragmentation of a Cenozoic foreland basin by the uplift of the Northern Andes. The lateral continuity of the formation, as well as its correlations with lithostratigraphic units in adjacent basins is not clearly understood. The Los Corros Fossil Horizon, a molluscan horizon in the upper part of the Esmeraldas Formation, has been used to trace the top of the formation. This horizon is not laterally continuous over the basin and its age is still debatable. Data from 82 samples from an outcrop section in the Nuevo Mundo Syncline area and from seven previously studied wells have been integrated with a palynological zonation of northern South America in order to date the Esmeraldas Formation. The age ranges from the late Early Eocene to the Late Eocene. The Esmeraldas Formation is correlative with the upper Picacho Formation and the lower part of the Concentracion Formation in the Eastern Cordillera, and the upper Mirador Formation and the base of the Carbonera Formation in the Llanos Foothills. The Los Corros Fossil Horizon is Late Eocene and is time-correlative with a marine transgression in the central Llanos Foothills. A non-metric multidimensional scaling analysis suggests that floras from the Middle Magdalena Valley were different from those in the Llanos Foothills area during the Middle to Late Eocene. This is apparently due to taphonomic effects. The results of this study will contribute to a better understanding of the overall evolution of the Middle Magdalena Valley Basin.

Keywords: Middle Magdalena Valley Basin; Esmeraldas Formation; Eocene; palynology; biostratigraphy; Colombia

1. Introduction

The Middle Magdalena Valley Basin (MMVB) (Figure 1) is an intramontane basin in Colombia. It is limited by the Eastern Cordillera to the east, the Central Cordillera to the west, the San Lucas Ridge (Palestina fault) to the northwest and the Piedras–Girardot transpressive fold belt (Montes et al. 2005) to the south and covers approximately 32,000 km² (Morales et al. 1958). MMVB is part of a major Cenozoic foreland basin that has been fragmented by the uplift of the Northern Andes (Gomez et al. 2005). Paleocene coastal to alluvial sediments (Lisama Formation, Figure 2) were deposited in the foreland basin formed by the Central Cordillera uplift (Gomez et al. 2005). Eocene–Neogene fluvial rocks (La Paz, Esmeraldas, Mugrosa and Colorado formations and Real and Mesa Groups, Figure 2) are evidence of fragmentation due to uplifting of the Eastern Cordillera. The MMVB has many stratigraphic and structural complexities, with abundant syntectonic deposits and very fast lateral facies and thickness changes (Gomez et al. 2005). Reliable stratigraphic models depend on biostratigraphy for accurate lateral correlations both at basinal and reservoir scale. Three fossil horizons, Los Corros, Mugrosa and Colorado, have been traditionally used as basin-wide correlation elements (Pilsbry and Olsson 1935). However, these fossil horizons are laterally discontinuous in the basin as a result of either unconformities between tectono-sequences (Suarez 1996) or lateral facies variations. In addition, the ages of the horizons are still debatable (Nuttal 1990).

Palynology appears to be the best paleontological tool for correlation because of the continental nature of the Cenozoic rocks in the MMVB (Pardo-Trujillo et al. 2003). Although many research studies have been carried out in the basin (mostly by the oil industry),

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limited information has been published (Rueda et al. 1996; Pardo-Trujillo et al. 2003). Some of the published studies have focused on the Paleocene to Lower Eocene interval (Lisama and La Paz formations) (Jaramillo and Dilcher 2001; Pardo-Trujillo et al. 2003) and three of them have studied the Esmeraldas Formation (Van der Hammen 1957, 1961; Germeraad et al. 1968; Jaramillo et al. 2006). Germeraad et al. (1968) did not publish any distribution chart or palynological counts, while the study by Jaramillo et al. (2006) had low sampling resolution. Jaramillo et al. (2006) did not report the presence of key Eocene datums (e.g. the last appearance datum or LAD of Spinizonocolpites grandis) in the Esmeraldas Formation.

The aim of this study was to analyze the pollen and spore contents of the fluvial Eocene Esmeraldas Formation in the Nuevo Mundo Syncline area (Figure 1) in order to refine the palynostratigraphy and to date the formation. Samples from the Nuevo Mundo Syncline were compared with those from the Medina Section in the Llanos Foothills (Jaramillo et al. 2011a) in order to determine their floristic similarities.

2. Stratigraphy of the Esmeraldas Formation

An average thickness of 1100 m has been reported for the Esmeraldas Formation at the eastern flank of the Nuevo Mundo Syncline and towards the east of the basin in general (Morales et al. 1958). In the western part of the basin, the Esmeraldas does not crop out, but well data indicate that the formation thins toward the west. Thin-bedded to laminated, fine-grained sandstones and siltstones dominate the formation. These sediments are interbedded with dark gray shales that are locally mottled brown, red and purple with scattered lignite seamlets (Morales et al. 1958). At the top of the unit, there is a 15 m thick interbedding of layers of packstone comprising fossils of freshwater bivalves and gastropods within shales (Los Corros...
The Esmeraldas Formation accumulated in an alluvial plain setting, while the Los Corros Fossil Horizon accumulated in freshwater lakes to backswamps (Gomez et al. 2005). Caballero (2010) reported sedimentary structures such as flaser and wavy laminations along the entire unit at the eastern flank of the Nuevo Mundo Syncline (Figure 1), suggesting some tidal influence in that area probably related to a fluvial-estuarine transition to the east but without any saline influence in the area.

3. Previous biostratigraphic studies

Published biostratigraphic data of the Esmeraldas Formation has mainly focused on the Los Corros Fossil Horizon, Pilsbry and Olsson 1935; Nuttal 1990; Gomez et al. 2005). The Esmeraldas Formation accumulated in an alluvial plain setting, while the Los Corros Fossil Horizon accumulated in freshwater lakes to backswamps (Gomez et al. 2005). Caballero (2010) reported sedimentary structures such as flaser and wavy laminations along the entire unit at the eastern flank of the Nuevo Mundo Syncline (Figure 1), suggesting some tidal influence in that area probably related to a fluvial-estuarine transition to the east but without any saline influence in the area.

Figure 2. General Cenozoic stratigraphic column of the Middle Magdalena Valley Basin (modified from Gomez et al. 2005).
mollusc fossil horizons (Pilsbry and Olsson 1935; Nuttal 1990). Pilsbry and Olsson (1935) dated the Los Corros horizon as Late Eocene by comparing the molluscan record with data from other localities in the Caribbean. Nuttal (1990) questioned the taxonomy of Pilsbry and Olson (1935) and concluded that there were no taxonomical similarities between the marker types chosen in the fossil horizons and the compared types. Based on his taxonomical conclusions and comparison with reported Cenozoic mollusk, Nuttal (1990) dated the Los Corros as ‘not more precise than Paleogene’. Van der Hammen (1957, 1961) used a zonation based on the periodicity of relative abundance peaks of pollen groups that he related to climatic cycles. These studies correlate the upper part of the Esmeraldas with the Late Eocene and with the palynological Zone A of the Lower Oligocene. He also recognized acmes of Psilamono-copites medius, Maurititidites franciscoi and Psilamono-noltes tibui (now Laevigatorites tibuensis) in the major part of the Esmeraldas, which were considered characteristic of the Late Eocene. These approaches are however strongly affected by the ‘closed sum’ statistical artifact (Moore et al. 1991; Kovach and Batten 1994; Jaramillo et al. 2011a). As the relative abundance of one species increases the others decrease, even though their real abundances do not decrease. Germeraad et al. (1968) indicate that the Esmeraldas Formation lies in the Retriticolporites guianensis (now Rhoiptites guianensis) and Verruco-tosporites usmensis Zones of Middle to Late Eocene age.

4. Methods
GEMS LTDA (2009) measured four sections (A, B, C and D) in the Esmeraldas Formation on the eastern flank of the Nuevo Mundo Syncline area (Figure 1) and constructed a composite reference section that was 1238 m thick (Figure 3). A complete section at a single site is difficult to find because of poor exposures. Eighty-two samples from the Esmeraldas Formation were collected and analyzed for palynology (Table 1). Sample spacing averaged 10 m. The samples were processed at Instituto Colombiano del Petroleo using standard techniques outlined by Traverse (2007).

Taxonomic identifications were carried out using Jansonius and Hills (1976 and supplements), references related to tropical palynology (e.g. Germeraad et al. 1968; Jaramillo and Dilcher 2001) and the morphological database of Jaramillo et al. (2011b). Key taxa were located using the England Finder™ coordinate system.

The palynological data from the outcrop section was correlated with seven previously studied wells along the basin (Figure 1) using Graphic Correlation (Shaw 1964; Edwards 1984, 1989) and GraphCor® (Hood 1998). Correlation was carried out to determine the stratigraphic distribution of palynomorphs within the Esmeraldas Formation using the composited outcrop section as the standard reference section. The composite section was correlated with the zonation of Jaramillo et al. (2011a) in order to constrain the age of the Esmeraldas Formation.

The palynofloras of the Esmeraldas Formation were compared to the Middle to Late Eocene floras in the Medina section of the Llanos Foothills (Jaramillo et al. 2011a) to evaluate their degree of similarity. The Sorensen (Sorensen 1948; Magurran 2004) and Morisita Horn 1966 in Wolda 1981) indices were used to compare presence-absence and abundances of species, respectively. Only samples with counts above 100 grains were used in this analysis, since samples with lower counts have a low probability of representing the total amount of species and their relative abundances (Hayek and Buzas 1997). A non-metric multidimensional scale analysis (MDS, Kovach 1989) was performed using both indices as linkage between the samples. The program R for Statistical Computing (R-development-core-team 2005) and the package Vegan (Oksanen et al. 2005) were used for the analysis. The diversity of the composite section was calculated by using the rarefaction technique. Species diversity (number of species, Rosenzweig 1995) was calculated for the composite section by using the rarefaction technique (Sanders 1968) and relative abundances (Hayek and Buzas 1997) in order to understand the vegetation composition of the Esmeraldas Formation. The sample size cutoff for the rarefaction was 100.

5. Results
The lowest 335.3 m (1100 feet, 24 samples) of the studied section are virtually barren of terrestrial organic matter. In the upper 914.4 m (3000 feet), the terrestrial organic matter and palynomorph recovery ranges from poor to excellent and preservation is moderate to good. The organic matter is fully continental and mainly comprising structured phytoclases (woody fragments, plant tissues and cuticles). In sample D 246 (38 m, 128 feet) amorphous organic matter dominates the organic matter recovered. D 246 contains fossil remains of bivalves of 2–3 cm in size, which correspond to those found in the Los Corros Fossil Horizon. This horizon was reported in the upper part of the D section (Figure 3).

Palynological counts include 4308 spore grains, 2304 pollen grains, 637 fungal spores and fungal fruiting bodies and 158 Botryococcus fragments/specimens (raw counts in Appendix A, see supplementary
online material). Marine palynomorphs are absent. The upper 91.4 m (300 feet) of the section contains scattered *Botryococcus* which were dominant at 38.1 m (128 feet). There was no record of the colonial alga *Pediastrum* in the outcrop section, although they were recorded in some of the previously studied well sections. Table 2 lists the biostratigraphically important Eocene taxa identified in this study and all are illustrated in Plate 1 (figures 1–22). The other palynomorph taxa identified in this study are listed in Appendix B (see supplementary online material). One new pollen species, *Rhoipites? perprolatus*, is formally described. This grain had been called *Trilongicolpites perbonus* in several unpublished reports by Tropical Oil Company, Shell, Intercol and Ecopetrol (i.e. Rueda et al. 1996) and as *Rhoipites guianensis* var. ‘perbonus’ in internal Ecopetrol reports.

5.1. Systematic paleontology

Descriptive morphological terminology closely follows that of Jaramillo and Dilcher (2001) for exine architecture and tectal sculpturing. The Rules of the International Code of Botanical Nomenclature (McNeill et al. 2006) for species names are followed herein. All figured and type specimens are stored in the palynological collection of the Litoteca Nacional Bernardo Taborda, Instituto Colombiano del Petroleo, km 7 via Piedecuesta, Santander, Colombia. The Litoteca Nacional (National Core Library) of Colombia is a government institute and a public centre of

![Figure 3. Stratigraphic sections used to build the outcrop composite section of the Esmeraldas Formation in the Nuevo Mundo syncline (modified from GEMS LTDA 2009).](image)
information and research in geological sciences, which is officially responsible for managing and preserving the rock and microfossil collections in Colombia. The Library promotes use by scientists and consultants interested in global geological processes and exploration of oil, mining and energy resources. The inventory
includes public and confidential collections of cores, cuttings, outcrops, petrological rock samples and micropaleontological collections. Holotypes and paratypes can be freely consulted upon written request to the library manager.

**Rhoipites? perprolatus** sp. nov.
Plate 1, figures 15–19

**Holotype.** Lisama-10 well, 9850’, EF O23 (Plate 1, figure 15).
**Paratypes.** Vega de Pato Creek, 144 B, EF U18 (Plate 1, figure 16); Lisama-10 well, 9850’, EF G18/2 (Plate 1, figure 17).

**Ethymology.** After its perprolate shape.

**Diagnosis.** Tricolpate, mid-sized (22–42 μm long), ellipsoidal, perprolate, exine thick (1 μm), reticulate, heterobrochate, marginate, lumina distinctly elongated parallel to the colpi, slightly cristate and resembling a funnel.

**Description.** Single pollen grain, monad, radial symmetry, isopolar, perprolate; tricolpate, sometimes tricolporate, colpi slightly marginate, furrow long, reaching polar area and projecting deeply inwards, margo formed by slight decrease in size of the lumina toward the aperture; exine semitectate, columellae distinct, reticulate, heterobrochate, large in mesocolpium becoming smaller near colpi margins and apocolpium, reticula angular, elongated toward poles, slightly cristate, lumina 1–1.5 μm, decreasing gradually toward the base of the reticula resembling a funnel, muri thick (1–1.5 μm).

**Dimensions.** Equatorial diameter: range 9–22 μm, mean = 14 μm; polar diameter: range 22–42 μm, mean = 31 μm, SD = 10.3; polar/equatorial diameter: range 1.4–3.5, mean = 2.2 colpi margins 2 μm thick, exine 1 μm thick, lumina 3–4 μm wide, parallel to the polar axis. Specimens measured: 304 in several sections along the MMVB and the Catatumbo Basin (Appendix C, supplementary online material). Measurements are listed in Appendix D (see supplementary online material).

**Comments.** The genus *Rhoipites* was defined by Wodehouse (1933) to include pollen grains that are ellipsoidal, tricolporate, reticulate with a long and pointed colpi; the colpi and pore have conspicuous thickenings that projects deeply inwards (Jansonius and Hills 1976, CARD 2421). *Rhoipites? perprolatus* has great similarity to *Rhoipites guianensis* (Van der Hammen and Wijmstra 1964) Jaramillo and Dilcher (2001) in having angular reticula elongated toward the poles and decreasing toward the aperture. However, *Rhoipites? perprolatus* is perprolate (polar diameter/equatorial diameter mean = 2.3 μm), slightly heterobrochate and tricolpate to occasionally tricolporate, whereas *R. guianensis* is prolate (polar diameter/equatorial diameter mean = 1.5 μm), strongly heterobrochate and always tricolporate.

### 5.2. Palynostratigraphy

The graphic correlation equations between the sections are shown in Appendix E (see supplementary online material), and the first appearance datums (FAD) and last appearance datums (LAD) in the composite section can be found in Appendix F (see supplementary online material). The most important events are illustrated in Figures 4 and 5. Most of the FADs and LADs in the composite section are strongly influenced by the edge effect (Foote 2000), which is an artificial increase in FAD and LAD at the limits of a studied section. The time represented by the Esmeraldas Formation is shorter compared to the biostratigraphic range of most of the recorded taxa; it would therefore be expected to have a strong edge effect in the sections. Nevertheless, there are some useful events for regional correlation purposes. The FAD of *Rhoipites guianensis*, the LAD of *Racemonocolpites facilis* and the LAD of *Rhoipites? perprolatus* appear to be useful as correlation elements and are not affected by edge effects. The Esmeraldas Formation can be divided into one interval zone and one assemblage zone that is subdivided into two subzones (Figure 5). The positions of the base and top of the zones are presented in composite units (cu). These units have the polarity of a well, being smaller toward younger rocks and higher toward older strata of the composite section.

#### 5.2.1. Interval zone (4061–3242 cu)

The lowest (oldest) 243.84 m (800 feet) of the section has very low recovery of pollen and spores. This zone is recognized by the presence of *Spirospyncolpites spiralis*, *Cyclusphaera scabrata*, *Psilatrites* spp. and *Leavigatosporites tibuensis*. *Botryococcus* spp. and fungal spores are also present.

#### 5.2.2. Rhoipites? perprolatus assemblage zone (3242–0 cu)

**Key Rhoipites guianensis and Rhoipites? perprolatus events define this assemblage zone. The base of the zone is defined by the top of the Interval Zone and the FAD of *Rhoipites? perprolatus*, *Rhoipites guianensis* and *Cicatriciosporites dorogensis*. The top of the zone is the LAD in the basin of *Rhoipites? perprolatus*. The assemblage comprises typical Eocene taxa, such as *Brevitricolpites microechinatus*, *Brevitricolpites macroexinatus*, *Corsinipollenites undulatus*, *Cricotriporites*...
minutiporus, Cyclusphaera scabrata, Foveotriporites hammenii, Lanagiopollis crassa, Luminidites colombianensis, Mauritiidites francisci var. francisci, Monocolpopollenites ovatus, Monoporopollenites annulatus, Perisyncolporites pokornyi, Polyvordioceoisporites spp., Pseudostephanocolpites perfectus, Retibrevitricolporites grandis, R. speciosus, Retistephanopora minutiporus, Retitricolpites simplex, Retisyncolporites angularis, Spirosyncolpites spiralis, Tetracolporopollenites maculosus, T. transversalis and Verrutriletes virueloides. The FAD of Perisyncolporites pokornyi and Luminidites colombianensis, the LAD of Cricotriporites minutiporus, L. colombianensis and Racemonocolpites facilis and the presence of Retisyncolporites angularis and Pseudostephanocolpites perfectus are also recorded in this zone. Fossil remains of molluscs were present in the upper part in the outcrop section and in the ditch-cuttings of some wells and are associated with high abundances of freshwater algae (Botryococcus spp. and Pediastrum spp.) and amorphous organic matter. These fossils likely correspond to the Los Corros Fossil Horizon.

The LAD of Racemonocolpites facilis and abundance of the freshwater algae divide the Rhoipites? perprolatus Zone into two informal subzones, A and B.

5.2.3. Subzone A (3242–223.04 cu)

This subzone is defined as a concurrent-range subzone, the top of which is defined by the LAD of
Figure 5. Palynostratigraphic distribution scheme of the Esmeraldas Formation in the Nuevo Mundo syncline area. The biostratigraphic ranges of the most important taxa are shown.
Racemonocolpites facilis. This LAD is located 140 cu below the Los Corros Fossil Horizon and has been recognized in five sections. The palynological assemblage is the same as that described for the Rhoipites? perprolatus Zone.

5.2.4. Subzone B (223.04–0 cu)

This zone has the typical palynological assemblage of the Rhoipites? perprolatus zone and high abundances of the freshwater algae Botryococcus and Pediastrum. The mollusc layers of Los Corros Horizon are located within this subzone. It is worth noting that although the acmes of Botryococcus spp. and Pediastrum spp. are located within this subzone, they were not found co-occurring in the same locations. Botryococcus spp. acmes were found only in the outcrop section, whereas Pediastrum spp. acmes were found in three wells. The LAD of Rhoipites? perprolatus at the Esmeraldas–Mugrosa boundary defines the top of the subzone.

5.3. Correlation and age of the Esmeraldas Formation

The correlation points used for comparison with the biozonation of the Llanos Foothills of Colombia (Jaramillo et al. 2011a) were the FADs of Lanagioipollis crassa, Cicatricosisporites dorogensis, Perisyncolporites pokornyi and Luminidites colombianensis and the LADs of Cricotriporites minutiporus and Racemonocolpites facilis. Figures 4 and 5 illustrate the graphic correlation and the palynostratigraphic distribution scheme, respectively. Appendix E contains the correlation equations.

Cyclusphaera scabrata and Spirosyncolpites spiralis were present within the Interval Zone. The FADs of both palynomorphs are located in the Early Eocene T04-T05 zones of Jaramillo et al. (2011a), respectively. The FAD of Cicatricosisporites dorogensis (zone T06 of Jaramillo et al. (2011a), Middle Eocene) was located above, within an interval with good pollen and spore recovery, and was found in similar stratigraphic position across the MMVB. This suggests a probable Early Eocene age for the base of the Esmeraldas Formation (Interval Zone, Figure 4). Using the correlation equation, the top of the T06 Zone is tentatively placed at 764 cu in the Esmeralda composite section; the Rhoipites? perprolatus zone is therefore Middle to Late Eocene (T06-T07 Zones). The LAD of Racemonocolpites facilis is located between 703 cu and the Los Corros in the Esmeraldas composite section, and within the T07 Zone in the foothills. The Los Corros Fossil Horizon is Late Eocene (T07 Zone, Figure 4).

5.4. Similarities between the Nuevo Mundo syncline and the Medina sections

The Sorensen values show that the median of the Nuevo Mundo versus the Medina samples is 0.18, Nuevo Mundo within-samples is 0.51 and Medina within-samples is 0.48. For the Morisita-Horn Index, the median of the Nuevo Mundo versus the Medina samples is 0.27, Nuevo Mundo within-samples is 0.78.
and Medina within-samples is 0.6. The non-metric multidimensional (MDS) analysis (Figure 6) also shows that the samples from Nuevo Mundo and Medina section form two distinct groups. Using both similarity indices, the first axis explains the dissimilarity between Nuevo Mundo and Medina samples and the second axis the dissimilarities of Nuevo Mundo within samples and Medina within samples.

6. Discussion
6.1. Palynostratigraphy and age
The age of the base of the Rhoipites? perprolatus zone is uncertain. The Middle Magdalena Valley Unconformity (Gomez et al. 2005), a regional unconformity in the MMVB, places the Esmeraldas Formation above either the Paleocene Lisama Formation or Cretaceous rocks in the wells used for correlation. The base of the Esmeraldas Formation (Interval Zone) in these wells may not represent the true stratigraphic base of the formation compared to the most complete section of Esmeraldas in the Nuevo Mundo Syncline. However, despite low recovery, the Interval Zone is present in all wells below the FAD of R. guianensis, suggesting that the zone could be regionally extensive. It is associated with red to purple shales and paleosols, probably related to intense oxidation due to subaerial exposure.

In northern South America, the FAD of Cicatricosisporites dorogensis occurs during the earliest Middle Eocene (Germerraad et al. 1968; Muller et al. 1987; Jaramillo et al. 2011a). This FAD marks the base of the T06 Zone of Jaramillo et al. (2011a). Pardo-Trujillo et al. (2003) and Jaramillo and Dilcher (2001) did not record Cicatricosisporites dorogensis, Rhoipites guianensis and Rhoipites? perprolatus in the La Paz Formation in the Nuevo Mundo Syncline area.

Cicatricosisporites dorogensis is not very abundant in the Esmeraldas Formation. In the Cenozoic of northern South America, the FAD of C. dorogensis is well defined and the spore becomes frequent regionally following its FAD. We observed the same pattern in the Esmeraldas Formation, suggesting that the observed FAD of Cicatricosisporites dorogensis in the Esmeraldas Formation could be near the true origination event. The LADs of Spinizonocolpites grandis and Echitriporites trianguliformis var. orbicularis are useful to identify the upper Middle and Late Eocene (Jaramillo et al. 2011a). Unfortunately, they are not present in the Esmeraldas Formation. However, additional Middle to Late Eocene events are useful for correlation (Jaramillo et al. 2011a). These events are the FAD of Perisyncolporites pokornyi and Luminidites colombianensis and the LAD of Brevitricolpites macroexinatus, Cricotriporites minutiporus, Luminidites colombianensis and Racemonocolpites facilis.

There is also a Late Eocene marine flooding in the Central Llanos Foothills (Santos et al. 2008) that appears to be correlative with the Los Corros Fossil Horizon (Figure 4).

6.2. Regional stratigraphy: Middle Magdalena Valley to the Llanos Foothills
Cooper et al. (1995) and Bayona et al. (2008) suggested that the La Paz and Esmeraldas formations were correlative with the Mirador and the base of the Carbonera formations (sequences 3a-3b and sequence 4 of Bayona et al. 2008, respectively).

Figure 7 shows the depositional environments and correlation of the Eocene units across the MMVB to the Llanos Foothills. Santos et al. (2008) documented a marine transgression during the Late Eocene in northwestern South America. Using a Salinity Index, they established marine influence in the Central Llanos Foothills and Putumayo Basins within the T07 Zone of Jaramillo et al. (2011b). We have found that this Late
Eocene transgression is correlative with the lacustrine Los Corros Fossil Horizon (Figure 4). Santos et al. (2008) hypothesized that the sea transgressed through a corridor formed in the proto Lower Magdalena Valley Basin north of the MMVB, based on the tectonic reconstruction of the Northern Andes by Montes et al. (2005) (Figure 8). The Nuevo Mundo Syncline area was located very close to this marine corridor in the south (Figure 8). It seems plausible to interpret that both the marine flooding in the Llanos Foothills and the extensive lacustrine system developed in the MMVB are products of the same event. Both are coetaneous, short-lived and widespread. After the rotation of the Maracaibo block (Montes et al. 2005, red polygon in Figure 8, basins 1 and 2), the marine corridor was also rotated and placed farther northeast of Nuevo Mundo Syncline. Bayona et al. (2008) proposed that between the MMVB and the Eastern Cordillera, there has probably been a geographic barrier since the Eocene. Moreno (2010) reported paleocurrents with a predominant NW direction east of the Nuevo Mundo Syncline area, which suggest provenance of sediments from the east from a probable proto-Eastern Cordillera. It is possible that there was a barrier preventing the marine flooding from reaching the MMVB, where extensive lakes were developing. On the other hand, it is also possible that the inland expression of the marine flooding was a rapid increase in the accommodation space driving the development of extensive but short-lived lacustrine systems, such as those represented by the los Corros Fossil Horizon.

6.3. Similarities between sections

The MDS analysis shows that the floral compositions of Nuevo Mundo syncline section in the MMVB and the Medina section in the Llanos Foothills are different both in terms of presence-absence and abundance of
species (Figure 6). These differences could be the product of differences in depositional environments. The Nuevo Mundo Syncline was mainly alluvial, whereas coastal plain to slightly marine conditions prevailed in the Llanos Foothills at the same time. Alluvial plain sediments such as those found in the Nuevo Mundo Syncline tend to have lower recovery rates than other environments, as noted by Lorente (1986). She also found that richness in the pollen recovery in this environment is highly variable from barren to very rich, depending on taphonomic processes (oxidation) resulting from environmental fluctuations. Differences in taphonomy rather than differences in floristic provinces appear to be a more plausible explanation for the observed differences between MMVB and Medina.

7. Conclusions
The age of the Esmeraldas Formation ranges from late Early Eocene to Late Eocene. The Los Corros Fossil Horizon is dated as Late Eocene and it is coeval with the short-lived marine incursion recorded in the central Llanos Foothills. The Esmeraldas Formation correlates with the upper part of the Picacho Formation and the lower part of the Concentracion Formation in the Eastern Cordillera, the middle to upper part of the Mirador Formation and the lower part of the C8 member of the Carbonera Formation in the Llanos Foothills.

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