The Tertiary Fusagasugá Succession; a record of the complex Latest Cretaceous-pre-Miocene deformation in an area between the Magdalena Valley and Sabana de Bogotá

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ABSTRACT
The Tertiary succession in the Fusagasugá syncline includes unconformities, thick marginal to alluvial deposits, and an upsection change in sandstone composition that constrain pre-Miocene deformation eastward of the present western flank of the Cordillera Oriental. Five informal units were mapped along the western flank of the syncline. Lower Paleocene fine-grained coastal plain deposits of Unit I (499 m) rest paraconformably upon upper Campanian shallow-marine sandstones and calcareous shales of the Guadalupe Group; palynological data document the absence of middle and upper Maastrichtian strata. The disconformity between paleosols at the top of Unit I and estuary sandstone and siltstones of Unit II (153 m) marks a second stratigraphic surface with a biostratigraphic gap that probably includes the Paleocene-Eocene boundary. The remaining successions (Units III to V; >1400 m) is not dated, and the lithofacies association of sandy siltstones and sandstones indicate deposition from coastal to alluvial plains. Mappeable sandstone intervals in Units II to V show lateral extent of several hundred of meters, intraformational gentle angular unconformities, and gentler dip of beds toward the axis of the syncline; these map patterns are similar to those predicted in growth strata in continental settings, suggesting accumulation during deformation. The upsection increase in population of lithic fragments and feldspars between the Guadalupe Group and Unit I, of metamorphic lithic fragments between Units I and II, and of volcanic lithic fragments between Units III and IV indicate the unroofing of source area(s) and volcanism during deposition of Units IV and V.

INTRODUCTION
In the Fusagasugá syncline, a structure 60 km west from Bogotá, the Late Cretaceous-Tertiary sedimentary succession differs abruptly with coeval successions in presently contiguous thrust sheets (Figure 1) (e.g. Cáceres et al, 1970; Acosta & Ulloa, 1997). This abrupt difference raises the question whether strata have been telescoped perpendicular, oblique or laterally along regional faults. On the other hand, models of syntectonic deposition, evidenced by the record of growth strata, could explain the differences in thickness and lithologies of coeval strata.

In the last years, several papers have documented pre-Miocene events of deformation along the Middle Magdalena Valley and the western flank of the Eastern Cordillera. North of the study area, folds and thrusts concealed below a regional Late Eocene unconformity document a Paleocene-Early Eocene event of west-verging thrusting along the Middle Magdalena Valley and the western flank of the Eastern Cordillera (Restrepo-Pace, 1999). Alternatively, deformation of the coarsening-upward Upper Cretaceous-Paleocene strata beneath the unconformity has been related to flexural tilting caused by the shift in locus of deformation from the Central Cordillera to the Eastern Cordillera (Gomez et al, 2003). Farther west in the Piedras-Girardot foldbelt, stratigraphic pinchouts of Upper Cretaceous lithic sandstones and eastward thickening of Paleocene growth strata indicate gentle deformation affecting the Piedras-Girardot foldbelt during Late Cretaceous time and west-vergent thrusting (Montes, 2001).

This paper summaries stratigraphic, petrographic, and palinological results of a comprehensive study carried out in 1996 in the western flank of the Fusagasugá syncline. The main purpose of this study was to document the stratigraphy, age, sandstone composition and surfaces of stratigraphic correlation in the Tertiary succession. Nowadays, these results may be integrated into regional studies addressed to attest different models of deformation proposed for the Central and Eastern Cordilleras, and to give sedimentary facies indicators for palinspastic reconstruction of the Magdalena Valley, western flank of the Eastern Cordillera, and the Sabana de Bogotá areas.

REGIONAL SETTING
The Fusagasugá syncline, a broad south-southwest-plunging structure, follows the regional structural trend of the Usme syncline to the east
and the San Bernando and San Juan synclines to the south (Figures 1 and 2). These synclines are bounded by west-vergent tight anticlines and thrust faults of the western flank of the Eastern Cordillera. West of the Fusagasugá syncline and between the Boqueron and Quinini faults, synclines axes has a non-linear northeast trend.

Figure 2 shows a cross-strike alignment of northwest-striking structures and termination of regional folds and faults described above. In thrust belts, transverse zones are identified in map view by abrupt along-strike changes in thrust-belt structures, including plunging ends of ramp anticlines, bends in strike of longitudinal thrust faults and associated folds, transverse faults and folds, changes in stratigraphic level of detachment, displacement transfer between frontal ramps, and boundaries between structural styles (Thomas, 1990). Therefore, the cross-strike alignment of structures shown in Figure 2 supports the identification of a transverse zone, named here as Fusagasugá transverse zone.

METHODS

Geological mapping of about 46 km$^2$ at a scale of 1: 25,000 at the western flank of the Fusagasugá syncline was carried out in order to map structures and the lateral continuity of units. The Cacho and Bogotá Formations (sensu Cáceres et al, 1970) were surveyed at a scale of 1: 100 and 1:500 respectively using the Jacob’s staff method. Samples of sandstones and mudstones were collected at different stratigraphic positions for petrographic analysis and palynological age determination.

Thirty sandstone samples were selected for petrographic analysis. One thousand points were counted for each thin section in order to identify composition of framework and accessory grains, as well as interstitial material. Detrital modes exclusive of carbonate grains, heavy minerals and micas were calculated from the point-count results and plotted in ternary diagrams. Although we used the traditional method of point-counting (polymineralic, coarsely crystalline grains are counted as lithic fragments; e.g., Ingersoll et al, 1984), most of the sandstones are fine-grained and allow the plot of modal compositions in ternary diagrams of Dickinson (1985) that relates sandstone composition with tectonic setting.

Fifteen palynological samples were analyzed for determination of age and interpretation of depositional environments. The samples were processed with 70% HF; centrifuged twice in ZnCl$_2$ solution. The float fraction was oxidized with KClO$_3$ plus HNO$_3$. At least two completed slides of each sample were scanned at about 20X. Counts were made to determine the relative frequency of each species in each sample. Five categories were defined: "Rare", 1-2 individuals per slide, "Present" 3-5 individuals, "Common" 6-10, "Abundant" 11-30 and "Dominant" >30 individuals per slide. The genera assignments were done according to the taxonomy in Muller et al (1987), Jansonius & Hills (1976), and Lentini & Williams (1993). The palynofacies classification is described in Jaramillo et al (1995). The TAI (thermal alteration index) is an scale based on color of spores and pollen measured by reflects light under oil (Traverse, 1988).

STRUCTURE OF THE WESTERN FLANK OF THE FUSAGASUGÁ SYNCLINE

Detailed mapping of the western flank of the Fusagasugá syncline exhibits a wide variety of structures (Figure 3). Mesoscopic, parallel and asymmetric folding is observed in laminated mudstones, claystones and siltstones at the base of Unit I (Figure 4A), suggesting that west-vergent thrusting of the Cretaceous sequence in the subsurface continue along the base of the Unit I. This thrust system is accompanied by folding associated to a ramp at the core of the Fusagasugá syncline. A local fault affects strata of Unit I. An imbricated array of northwest-striking left-lateral faults are characterized by narrow segments of brittle deformation accompanied by wedge-like, sub-vertical cleavage with horizontal displacement and cataclastic rocks affecting Cretaceous rocks. Neutral folding at mesoscopic scale was observed in sandstones of Units II and III. Seismic studies are needed to understand the geometry in depth and origin of these northwest-striking structures.

LITHOSTRATIGRAPHY OF THE FUSAGASUGÁ SYNCLINE

Five informal units, named Units I to V, were mapped in the Tertiary succession (Figures 3 and 6). Basal Tertiary beds rest upon sub-tabular thick beds of fine-grained quartzarenites, phosphatic sandstones, and calcareous black mudstones and wackestones of the undifferentiated Guadalupe Group. Important lithological characteristics of each Tertiary unit are described below.

Unit I (or Guaduas Formation sensu Cáceres et al, 1970) is 499 m thick at the Tibacuy-Cumaca road and consists of green, wavy-laminated mudstones with excellent record of plant remains. Thin to medium beds of ripple-laminated, fine-grained iron-rich quartzarenites dominates at the bottom (Figures 4A and 7A). In the middle and top, sublitharenites and subarkoses (Figure 7B) are present in coarsening-upward sequences or interbedded with mudstones. The lithology in the
upper 100 m consists of massive, light gray, red mottled mudstones (Figure 4B).

A disconformable contact between Units I and II is defined by thick to medium beds of sublitharenites (Figure 7C) to litharenites interbedded with sandy siltstones and mudstones. The basal contact of the uppermost and thickest sandstone ridge truncates with a very low angle lower beds of Unit II north of Tibacuy, (Figure 3) and upper beds of Unit I south of Tibacuy (Figure 4C). A thickness of 153 m was measured along an unpaved road south of Tibacuy. Unit II (or Cacho Formation sensu Cáceres et al, 1970) consists of thick fining-upward successions of green to gray, fine- to medium-grained sandstones interbedded with light gray, massive and sandy mudstones. Sedimentary structures of sandstone beds are dominantly massive, and ripple- to wavy-laminated at the bottom changing upsection to sets of planar and trough cross beds (Figure 4D). Bidirectional cross-bedding was identified in isolated cosets, and isolated remains of leaves and intraclasts are common in massive sandstones.

An increase of fine-grained lithologies marks the transitional contact between Units II and III. A thickness of 1217 m was measured along the Tibacuy-Silvania road. Farther south in the San Bernando syncline, intraformational gentle angular unconformities place strata of Unit II and III in contact with Unit I and Cretaceous beds (Cáceres et al, 1970). Unit III (or Bogotá Formation sensu Cáceres et al, 1970) is composed mostly by decametric sequences of massive, sandy light gray to red mottled mudstones interbedded with metric sequences of medium to thick beds of fine- to medium-grained sublitharenites, litharenites (Figure 7D), and subarkoses to the top. Map patterns show sandy ridges embedded in muddy lithologies, with lateral extension varying from a few hundred of meters to four kilometers, and with dip angles decreasing toward the core of the syncline. Minor dark gray, green and black mudstones with plant remains are present in lower to middle beds of Unit III. Sedimentary structures in sandstone beds varies from massive to large-scale planar to trough cross bedding. Ripple lamination occurs at the top of some fining-upward successions. Unit III contains both fining-upward and coarsening-upward successions (Figures 4E and 4F).

Decrease of mudstone beds, presence of medium- to coarse-grained sandstones with gravel-size clasts, and the increasing content of volcanic lithic fragments (Figure 7E) define the transitional contacts between Units III and IV, and between Units IV and V. The thickness of Units IV and V (upper part of the Bogotá Formation sensu Cáceres et al, 1970) was not established in this study. Large-scale trough cross-bedding with coarse-grained grains interposed along trough planes (Figure 5A) is the most important sedimentary structure in sandstone beds of Unit IV. Moderate angle of cutbank slopes define the basal geometry of channel-like medium to very thick sandstone beds, which composition varies from lithic arkoses to litharenites (Figure 5B). Basal conglomerates and fining-upward trends in grain size dominate in channel-like beds. Unit V consists of massive, reddish and sandy mudstone interbedded with thin to medium sub-tabular beds of medium-grained lithic arkoses with crude horizontal and trough cross-bedding (Figures 5C and 7F). A thin bed of mudstones with flow structures was also identified (Figure 5C).

INTERPRETATION OF DEPOSITIONAL ENVIRONMENTS

Lithologies and sedimentary structures of Tertiary strata are grouped into 6 lithofacies associations. The conformable vertical stacking pattern of lithofacies is the basis for our interpretation of environments of accumulation (IN UPPER CASE) (Figure 6).

1. Cross-bedded, fine- to medium-grained sandstones and conglomeratic sandstones in channel-like and cuneiform beds overlying by very fine sandstones with ripple lamination and light-colored (gray and red mottled) massive claystones to sandy siltstones (Figure 4F). Sand-bed channels are the result of accretion (downstream and lateral, Figures 4D and 5B) within sand bar complexes (SAND BARS FILLING CHANNEL BEDS), whereas fine-grained lithologies accumlated by aggradational processes (Figure 4B; OXIC FLOOD PLAINS IN CONTINENTAL SETTINGS). This lithofacies association is observed in the upper segment of Unit I, and in Units II, III, IV and V.

2. Green, dark gray and black mudstone and claysstones with wavy and lenticular lamination of siltstones and sandstones (Figures 4A and 4C). Minor lenticular beds of arenites have lenticular, wavy, flaser and/or ripple lamination. The main type of dispersed organic matter is well-preserved herbaceous material (ANOXIC COASTAL PLAINS; TOP OF ANOXIC OXBOWS; TIDAL FLATS). This lithofacies association is observed in Units I, base of Unit II and in a thin interval of Unit III.

3. Coarsening-upward successions from massive light-colored mudstones grading to fine to medium beds of fine-grained sandstones. (Figure 4E; CREVASSE SPRAW). This lithofacies association is observed in the lower segment of Unit I and in Unit III.

4. Sandstones with bidirectional cross bedding (CHANNEL-FILL DEPOSITS INFLUENCED BY
TIDAL PROCESSES). This lithofacies association is observed in Unit II.

5. Massive sandstones with excellent remains of leaves and often presence of gravel-size muddy intraclast fragments. (SLUMPING OF CHANNEL WALLS, TRANSPORTED IN SUSPENSION AND ACCUMULATED BY AGGREGATIONAL PROCESS). This lithofacies association is observed in Units II and III.

6. Mudstones with flow-like lamination (DISTAL PYROCLASTIC FLOWS?). This lithofacies is only observed at Unit V.

The vertical stacking of the six lithofacies described above (Figure 6) suggests that Tertiary strata of the Fusagasugá syncline accumulated in environments encompassing from tidal flats and estuarine settings, which dominated during deposition of Units I and II, respectively. Coastal and alluvial plain environments dominated during deposition of Units III and IV. Proximity to continental volcanic settings is documented by distal pyroclastic flows and an increase of feldspars and volcanic lithic clasts in sandstones of Unit V (Figure 7F).

SANDSTONE PETROLOGY

All of the studied macroscopic samples and selected thin sections are compositionally and texturally submature. The high diversity of framework grains in sandstones of Units I to IV contrasts with the homogeneity of quartzarenites in the undifferentiated Guadalupe Group and basal sandstones of Unit I.

Comparison of composition (QFL) and provenance (QmFLt) ternary diagrams show a considerable amount of polycrystalline quartz (e.g., quartzite and chert) grains, even though monocrystalline quartz (Qm) is the most common grain type. The abundance of the total lithic (Lt) grains is quite similar to Qm fraction through the entire section (Figure 8).

The total lithic fraction is composed mainly of sedimentary (chert, claystone, siltstone, and minor quartz arenites) and metamorphic (foliated polycrystalline quartz, quartz-micaceous, and micaceous schist and phyllite) clasts (Figures 7A to 7E). Sedimentary lithic fragments are usually oxidized and have angular and irregular shapes. Input of volcanic clasts is evident close to the top of Unit III and in Units IV and V (Figures 7D to 7F). Lathwork and microlitic textures with feldspar crystals (Figure 7E) allow the identification of those grains as volcanic. Questioned volcanic rock fragments (e.g., devitrified glass looks alike to chert, Figure 7D) are found in the middle of Unit III, and in one sample of Unit II. Feldspar fragments are more altered in samples of Units I and II, and are easier to recognize in Units III to V. At the top of Unit IV and in Unit V plagioclase dominates over potassium feldspar (Figure 7F). Distorted muscovite and biotite flakes constitute up 12% of the entire thin section in the Tertiary succession. An abrupt increase in content of pyroclastic fragments and volcanic minerals (amphiboles, feldspars and volcanic lithics) is reported in sandstones of Unit V.

Two types of diagenesis were recognized. Physical compaction produces bending and fracturing of micas and other weak lithic fragments. Chemical diagenesis produces an initial event of quartz overgrowth followed by a later event of pore-filling by ferruginous oxides. Glauconite is present in samples at the base of Unit I and Unit II (Figure 7C). Chemical diagenesis highly reduced the primary porosity to values below 8%. Two samples closed to the boundary between Units III and IV show sparite cement.

BIOSтратIGRAPHY

In general, palynological samples yielded moderate recovery of organic matter and low recovery of palynomorphs. The determined TAI varies from immature (2) at the top of the section to mature (2+) at the base. Most of the samples are gas prone.

Palynological data indicate that at least two unconformities are present in the study area (Figure 6). The sample from the top of the undifferentiated Guadalupe Group has the occurrence of Dinoflagellates C. leptodermum, A. euclaense and Andalusieilla sp, and date the rock as Late Campanian to Early Maastrichtian. The concurrence of palynoflora S. baculatus and P. Humbertooides indicates a Latest Maastrichtian to Early Paleocene age for lowermost beds of Unit I. A paraconformity is recorded by the absence of palynomorphs of Maastrichtian age. In sample FA-5, the dinoflagellate Cerodinium sp. could be reworked, however it is not clear.

Samples from Unit I and lower Unit III yield an age Middle to probably Late Eocene on the basis of the occurrence of B. Bellus, P. Pokornyi, P. digitatus and the absence of Late Eocene markers. Strata recording the Paleocene-Eocene boundary are probably eroded by the disconformity at the base of Unit II. Sample FM 36 in Unit II yielded reworked palynoflora of Aptian-albian age.

Dates and interpreted environments are summarized in Figure 9, and a complete list of palynoflora and dinoflagellates is in the appendix.

DISCUSSION AND CONCLUSIONS

In the Fusagasugá syncline, a > 2070 m thick coarsening-upward Tertiary succession records an upsection change in environments of deposition from coastal to alluvial plains, as well as an
upsection increase in influx of sedimentary, metamorphic and volcanic lithic fragments in sandstone beds.

Lithological associations, sandstone composition, palynomorphs and dinoflagellates indicate an unconformity at the contact between the undifferentiated Guadalupe Group and Unit I. Although a structural conformity between Cretaceous and Unit I beds exists, a paraconformity is recorded by absence of Maastrichtian palynological data. A forced regression is suggested by the abrupt change from mixed siliciclastic and carbonate shallow-marine strata of the Guadalupe Group to fine-grained coastal plain deposits of Unit I. In addition, the presence of foliated polycrystalline quartz and chert fragments in basal sandstone beds of Unit I (Figures 4A and 7A) marks the initiation of the influx of unstable detrital sediments, which are more evident in sandstones at the middle of Unit I (Figure 7B). Eventhough the abrupt increase of the lithic fraction, lithofacies association between lower and middle beds of Unit I remain alike, suggesting no change in conditions of deposition but a change in exposed rocks in source areas.

Absence of Maastrichtian strata in the study area indicate either erosional truncation or nondeposition (e.g., bypass of sediments). Campanian to earliest Maastrichtian calcareous shales and phosphatic sandstones at the top of undifferentiated Guadalupe Group records the last Cretaceous marine transgression recorded in the Eastern Cordillera (e.g., Villamil, 1999) and eastern Magdalena Valley. Mixed siliciclastic and carbonate strata recording this transgression is also reported to the south in the upper Magdalena Valley (e.g., Ramirez & Ramirez, 1994) and in the southern Middle Magdalena Valley (e.g., Alzate, 2002). The paraconformity at the top of the Cretaceous does not record neither the westward progradation of littoral quartzarenites of the Arenisca Tierna Formation from the Sabana de Bogotá area (e.g., Diaz, 1994) nor the eastward progradation of fan- and braided-delta systems from the eastern margin of the Central Cordillera (i.e., La Tabla and Cimarrona formations; e.g., Montes, 2001; Gomez et al, 2003). Because of the structural conformity between Cretaceous and Tertiary strata and the distal location of the study area to prograding depositional systems, we favor the hypothesis of sediment bypassing combined with flexural effects caused by uplift of the Central Cordillera and Quetame massif(?) to explain the paraconformity.

A disconformity is located at the contact between Units I and II. The truncation of this unconformity reaches Cretaceous and Unit I strata in the San Bernando syncline (Cáceres et al, 1970). A marine transgression is recorded at this contact because paleosols at the top of Unit I are overlain by mudstones and cross-bedded sandstones with glauconite; the latter lithofacies association is interpreted as the filling of subtidal estuarine channels (Figure 6). Sandstone composition in Unit II shows a slight increment of metamorphic lithic fragments (Lm), indicating unroofing of source areas composed of low-grade metamorphic rocks with a sedimentary cover. Rocks above the disconformity are Middle Eocene; however, a detailed palinological sampling is need to determine the gap in time at this surface in the study area.

Strata of the middle and top of the Unit III, and of Units IV and V dominantly accumulated in alluvial plains. Pyroclastic and epiclastics deposits reported here as Unit V could record Late Tertiary volcanic activity of the Central Cordillera. Therefore, these beds may be coeval with deposition of the Honda Formation in the Upper Magdalena Valley. However, we do not have biostratigraphic data to support this preliminary hypothesis.

Petrofacies of sandstones in the Fusagasugá syncline are more alike to the petrofacies of sandstones and conglomerates reported in the southern Middle Magdalena Valley (De Porta, 1965; De Porta, 1966; Gomez and Pedraza, 1994; Gomez et al, 2003), where they include Qm, Qp, Ls, and content of Lm and F increases above the Eocene unconformity (Gomez et al, 2003). Metamorphic lithic fragments in sandstones and conglomerates in the Upper Magdalena Valley are rare (Laverde, 1989; Duque & Perez, 1990; Caicedo & Roncancio, 1994). In contrast, sandstones in the Sabana de Bogotá are more quartzose with minor content of sedimentary and metamorphic lithic fragments (Cuervo & Ramirez, 1986; Hoorn, et al, 1987, Hoorn, 1988; Jaramillo et al, 1993; Cuervo, 1995).

Probable source areas are located toward the west (Central Cordillera) and southeast (Quetame massif) (Figure 10), where metamorphic rocks are overlain by a sedimentary cover consisting of Paleozoic and Cretaceous sedimentary rocks in addition to Triassic-Jurassic volcanioclastic strata and intrusives. Substrate sandstones indicate that source areas were at short distance away and sediments were buried rapidly. Reworking of dinoflagellate and palynomofa of Cretaceous age supports the interpretation of a nearby Cretaceous sedimentary cover. Unaltered volcanic lithic fragments at Units IV and V are supplied more likely from volcanic activity along the Central Cordillera.

The disconformity and map pattern of sandy ridges in Units II, III and IV support the
interpretation of pre-Miocene deformation west of the Sabana de Bogotá. Map patterns of sandstone intervals show the truncation of the unconformity and variations in the rate of accommodation space. A lower rate of generation of accommodation space is inferred for sandstones in Units II and IV, whereas the interbedding of sandstones and mudstones of Unit III suggests a higher rate of generation of accommodation space. Stratigraphic architecture of Units II, III and IV is similar to the geometry of growth strata in continental settings, indicating that deformation controlled the accumulation of alluvial and coastal plain deposits. This interpretation should be tested with seismic data, which also may document the vergence of subsurface deformation.

REFERENCES


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Colombia, in Etayo-Serna, F., ed., Estudios Geológicos del Valle Superior del Magdalena, Universidad Nacional de Colombia, Cap. VI.


**APPENDIX**

**PALYNOLOGICAL RESULTS**

**FA 7.2.**

Palynoflora:

<table>
<thead>
<tr>
<th>Palaeocystodinium golzowense</th>
<th>Rare</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psilamonocolpites medius</td>
<td>Rare</td>
</tr>
<tr>
<td>Perforatricolporites digitatus</td>
<td>Rare</td>
</tr>
<tr>
<td>Retritricolpites simplex</td>
<td>Rare</td>
</tr>
</tbody>
</table>

Remarks: Excellent recovery of aquatic organic matter and dinoflagellates.

**FA 8.2.**

Palynoflora:

<table>
<thead>
<tr>
<th>Psilatriletes sp.</th>
<th>Rare</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spiniferites sp.</td>
<td>Present</td>
</tr>
<tr>
<td>Microforam.</td>
<td>Present</td>
</tr>
<tr>
<td>Cribroperidinium sp.</td>
<td>Rare</td>
</tr>
<tr>
<td>Cerodinium leptodermum</td>
<td>Common</td>
</tr>
<tr>
<td>Cleistosphaeridium sp.</td>
<td>Present</td>
</tr>
<tr>
<td>Alisogynium eucaicis</td>
<td>Present</td>
</tr>
</tbody>
</table>

Remarks: Very poor recovery of organic matter and absence of palynomorphs.

**FA 19.1.**

Palynoflora:

<table>
<thead>
<tr>
<th>Bombacacidites bellus</th>
<th>Rare</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mauritiidites sp.</td>
<td>Present</td>
</tr>
<tr>
<td>Psilamonocolpites sp.</td>
<td>Rare</td>
</tr>
<tr>
<td>Jussitriporites sp.</td>
<td>Rare</td>
</tr>
</tbody>
</table>

Remarks: The recovered organic matter is characteristic of alluvial plain environments.

**FB 77.**

Palynoflora:

<table>
<thead>
<tr>
<th>Psilatriletes sp.</th>
<th>Rare</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conifer</td>
<td>Rare</td>
</tr>
</tbody>
</table>

Remarks: A high percentage of black debris organic matter and the absence of coastal plain phena are indicative of alluvial plains.

**FB 160.**

Palynoflora: Barren

Remarks: The recovered organic matter is characteristic of alluvial plain environments.

**FB 28.1.**

Very poor recovery of organic matter composed of fine-sized black debris

**FB 36.**

Fair recovery of organic matter composed of well sorted, medium-sized black debris. Absence of palynomorphs.

**FB 36.**

Palynoflora:

<table>
<thead>
<tr>
<th>Psilatriletes sp.</th>
<th>Abundant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psilamonocolpites medius</td>
<td>Abundant</td>
</tr>
<tr>
<td>Jussitriporites sp.</td>
<td>Rare</td>
</tr>
<tr>
<td>Bombacacidites bellus</td>
<td>Common</td>
</tr>
<tr>
<td>Perfotricolpites digitatus</td>
<td>Rare</td>
</tr>
<tr>
<td>Mauritiidites franciscoi</td>
<td>Present</td>
</tr>
</tbody>
</table>

Remarks: Abundant recovery of black debris organic matter and scarce recovery of sporomorphs. This type of palynomorphs is commonly found in alluvial plains.

**FB 63.**

Very poor recovery of organic matter and absence of palynomorphs.

**FB 8.2.**

Palynoflora:

<table>
<thead>
<tr>
<th>Psilatriletes sp.</th>
<th>Rare</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acritarcha</td>
<td>Present</td>
</tr>
</tbody>
</table>

Remarks: Excellent recovery of terrestrial-derived organic matter. The presence of dinoflagellates indicate a marine influence.

**FB 5.**

Palynoflora:

<table>
<thead>
<tr>
<th>Psilatriletes sp.</th>
<th>Rare</th>
</tr>
</thead>
</table>

Remarks: Good recovery of terrestrial organic matter and very low abundance of palynomorphs. This type of palynomorphs is commonly found in point bars in alluvial to coastal plains.

**FB 0**

Very poor recovery of organic matter and palynomorphs.
Figure 1.
Geologic map showing Tertiary outcrops between Bogota and Chaparral, the trace of major structures, and location of the geologic map in Fig. 3 (modified from Cediel and Caceres, 1988). Schematic stratigraphic columns I to IV illustrates the abrupt change in lithofacies and thickness of Paleogene strata between adjacent thrust sheets.
**Figure 2**
Definition of the Fusagasugá transverse zone (FTZ) by the cross-strike alignment of termination of the Usme syncline (US), the Fusagasugá syncline (FS), San Bernando syncline (SBS), and San Jose syncline (SJS). In addition, the trace of anticlines axes either ends or curves abruptly. The Quini (QF) and Boqueron thrust fault system and associated folds west of SBS terminate at the FTZ (regional structures modified from Cáceres et al. 1970).

**Figure 3**
Geologic map of the western flank of the Fusagasugá syncline. Dashed lines are the location of measured stratigraphic sections. A composite stratigraphic section is shown in Figure 6.
Figure 4

A. Asymmetric folding in thin to medium beds of mudstones and quartzarenites in lowermost strata of Unit I.  B. Massive light-colored sandy mudstone (paleosols) at the top of Unit I.  C. Abrupt contact between light-colored mudstones of Unit I and green mudstones interbedded with sandstones of Unit II showing thin sets of lateral accretion. Although the nature of the contact is regionally a disconformity (Caceres et al., 1970; Acosta & Ulloa, 1997), slight deformation affects the contact at this locality.  D. Planar cross beds in sandstones of Unit II forming macroforms of downward accretion. Note the presence of asymmetrical ripples at the top of planar cross beds.  E and F. Coarsening-upward and fining-upward successions in strata of Unit III, respectively.
Figure 5
A. Coarse-grained conglomeratic sandstones of Unit IV with trough cross beds. B. Moderate angle of cutbank slopes at the base of conglomeratic sandstones of Unit IV. C. Epiclastic sandstones of Unit V with sets of lateral accretion interbedded with mudstones that contain lamination reflecting flow structures (inset photo).
Figure 6. Composite stratigraphic column of the Tertiary succession at the western flank of the Fusagasuga syncline. Two major surfaces of correlation (base of Unit I and base of Unit II) are identified on the basis of palynological ages, interpretation of depositional environments, and change in sandstone composition (see text for discussion).
Characterstic variation in texture and composition of framework grains in Tertiary sandstones of the Fusagasuga syncline. 

**A.** Bimodal grain-size distribution between laminae in basal quartzarenites of Unit I; monocrystalline quartz (Qm) is the dominant grain type, whereas foliated polycrystalline quartz (Qpf) grains are in trace amounts. Cross nicols. 

**B.** Bimodal grain-size distribution between laminae and high diversity of grain types in subarkoses at the middle and top of Unit I; oxidized sedimentary lithic (Ls) and chert (Ch) fragments, feldspars (F) and metamorphic lithic (Lm) fragments. Parallel nicols. 

**C.** Bending of micas (M) by mechanical compaction and glauconite (glauc) filling primary porosity in a sublitharenite of Unit II. Framework grains includes: Ls= siltstones and sandy siltstones, Ch, Qm and Qpf. Cross nicols. 

**D.** Flow structure in a volcanic lithic (Lv) fragment in sandstones at the middle to top of Unit III. Note the difficulty to recognize the nature of the grain in cross nicols (inset upper left). 

**E.** Increase of Lv (note microlitic and spherulitic textures) and F (plagioclase and potassium feldspar) in a feldspathic arenite of Unit IV. Cross nicols. 

**F.** Dominance of feldspars (mainly plagioclase) and Lv in a lithic arkose of Unit V.
Ternary QFL diagram \( (Q=Qm+Qp+Ch; \ F=\text{plagioclase} + \text{potassium feldspar}; \ L=\text{Ls}+\text{Lm}+\text{Lv}) \) illustrates an upsection change in composition from subquartzose sandstones in Units I and II, to a more lithic sandstones in Unit III, and to feldspar-bearing sandstones in Units IV and V. Ternary QmFLt diagram \( (Lt=Qp+Ch+\text{Ls}+\text{Lm}+\text{Lv}) \) illustrates the tectonic setting of recycling an orogenic belt for Units II to IV, and erosion of a dissected arc during deposition of Unit V. The shift of points between QFL and QmFLt diagrams indicates the high content of polycrystalline quartz \( (Qp) \) and chert \( (Ch) \) fragments in all samples, with exception of the basal sandstone of Unit I.

**Figure 9**

Age and depositional environments determined by palynology. See Figure 6 for location of samples and appendix for a complete list of palynomorphs identified in each sample.

**Figure 10**

Location of probable source areas (present position) that could supply detrital sediments to the Tertiary succession of the Fusagasuga syncline.