The Upper Cretaceous and Lower Paleocene of the Eastern Bogotá Plateau and Llanos Thrustbelt, Colombia: Alternative Appraisal to the Nomenclature and Sequence Stratigraphy.

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VERGARA S., L.E. & RODRIGUEZ CH., G. (1997): The Upper Cretaceous and Lower Paleocene of the Eastern Bogotá Plateau and Llanos Thrustbelt, Colombia: Alternative Appraisal to the Nomenclature and Sequence Stratigraphy.- GEOLOGIA COLOMBIANA, 22, pgs. 51-79, 13 Figs., 2 Tablas, Santafé de Bogotá.

Abstract: The Upper Cretaceous stratigraphic record of the Eastern Bogotá Plateau and Llanos Thrustbelt of Colombia was studied in several outcrop sections and oil wells, leading to an alternative scheme of stratigraphic nomenclature and sequence stratigraphic interpretation. The Chipaque Formation (Cenomanian-Campanian) is overlain by the Guadalupe Group in the Bogotá Plateau and by the Palmichal Group in the Llanos Thrustbelt. From oldest to youngest, the correlation between the subdivisions of these two groups is as follows: The Arenisca Dura Formation (Campanian) of the Guadalupe Group, corresponds to the Arenitas de San Antonio Formation of the Palmichal Group; the Plaeners Formation (Campanian-Maastrichtian) to the Lodolitas de Aguacaliente Formation; the Arenisca de Labor, the so-called "Lutitas y areniscas finas" and the Arenisca Tierna Formations of the Guadalupe Group correspond to the Arenitas de San Luis de Gaceno Formation of the Palmichal Group. In turn, a lower part of the Guaduas Formation of the Bogotá Plateau is equivalent to the Guaduas Formation of the Palmichal Group. The Palmichal Group is redefined by excluding the overlying Socha Inferior Formation from it, mainly because the Socha Inferior's lower limit is represented in some places by an unconformity. Additionally, the above mentioned formations are included now in the Palmichal Group. Major depositional environments shift according to sea level fluctuations of second and third order. The Chipaque Formation of the Bogotá area is a second order (super)cycle where at least four third order sequences are circumscribed. Likewise, the Guadalupe Group and the Guaduas Formation are supersequences that bear higher frequency sequences. A major erosion period, documented here in the Medina-1 well, cannibalized part of the Maastrichtian of the Palmichal Group. The youngest sequence studied is represented in its lower portion by the lowstand deposits of the Socha Inferior Formation.

Key words: Upper Cretaceous, Paleocene, Stratigraphy, Sequence Stratigraphy, Stratigraphic Nomenclature, Palynology, Bogot· Plateau, Llanos Thrustbelt, Hydrocarbon Exploration

Resumen: El registro estratigráfico de la parte oriental de la Sabana de Bogotá y el Piedemonte Llanero ha sido estudiado con base en columnas estratigráficas y pozos petroleros, lo cual ha conducido a un esquema alternativo de nomenclatura estratigráfica y de estratigrafía secuencial. La Formación Chipaque (Cenomaniense-Campaniense) está suprayacida por el Grupo Guadalupe en la Sabana de Bogotá y por el Grupo Palmichal en la zona del Piedemonte Llanero. De base a tope la correlación entre las formaciones de estos grupos se propone así: La Formación Arenisca Dura (Campaniense) del Grupo Guadalupe corresponde a la Formación Arenitas de San Antonio del Grupo Palmichal; la Formación Plaeners (Campaniense-Maastrichtiense) a la Formación Lodolitas de Aguacaliente. La Formación Arenisca de Labor, el llamado nivel de "Lutitas y areniscas finas" y la Formación Arenisca Tierna del Grupo Guadalupe corresponden a la Formación Arenitas de San Luis de Gaceno del Grupo Palmichal. Una parte de la porción inferior de la Formación Guaduas de la Sabana de Bogotá es equivalente a la Formación Guaduas del Grupo Palmichal. El Grupo Palmichal se redefine excluyendo a la Formación Socha Inferior, principalmente por existir una discordancia en su límite inferior, y se incluyen en él las Formaciones anteriormente mencionadas. Los ambientes deposicionales varían de acuerdo a los cambios del nivel del mar, tanto de segundo como de tercer orden. La Formación Chipaque en la Sabana de Bogotá representa un (super)ciclo de segundo orden que comprende por lo menos cuatro secuencias de tercer orden. De manera similar, el Grupo Guadalupe y la Formación Guaduas son supersecuencias, en las cuales otras secuencias de mayor frecuencia se pueden delinear. Un período de erosión mayor, documentado aquí en el pozo Medina-1 ha causado pérdida parcial del registro del piso Maastrichtiense.

La siguiente secuencia está representada en su parte inferior por un sistema de nivel bajo, dentro de la Formación Socha Inferior.

Palabras claves: Cretáceo Superior, Paleoceno, Estratigrafía, Estratigrafía secuencial, Nomenclatura estratigráfica, Palinología, Sabana de Bogotá, Piedemonte llanero, Exploración de hidrocarburos.

INTRODUCTION

The Colombian Eastern Llanos Basin and the adjacent foothills of the Eastern Cordillera have been continuously explored for hydrocarbons in view of the successful results over the past few years and the enormous amount of reserves expected to be found. The discoveries of Cusiana and Cupiaga in the early nineties have become familiar to oil explorationists worldwide and have drawn much of the activities of the Colombian oil industry towards the Llanos Thrustbelt, commonly referred to as "Piedemonte Llanero". In spite of the large amounts of geological information gathered for the hydrocarbon projects, many aspects concerning the stratigraphy of the prospective Cretaceous and Tertiary systems are still a matter of uncertainty or debate. A great part of the problem derives from an informal treatment of the stratigraphic nomenclature. Only a few stratigraphic columns have been published and chronological data are scarce, hampering consensus as to nomenclature and sequences among stratigraphers. Therefore, new data on the stratigraphy of this particular area are imperative and of relevance to exploration geology.

In this work, formality in the stratigraphic nomenclature is attempted by following the regulations of the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature: NACSN 1983). One of the premises of the Code we stress here because it is relevant to the stability of the nomenclature states that "the decision not to use a newly proposed or a newly revised term requires a full discussion of its unsuitability" (Article 5a). We are aware that the only way to establish a standard and stable nomenclatural scheme is by following rigorously the rules of the stratigraphic codes designed for this purpose.

In addition, to reconcile conventional nomenclature with the increasing number of sequence stratigraphic models for eastern Colombia, this paper shall tie the stratigraphic successions expressed in terms of formations to the correlation parameters provided by sequence stratigraphy. A significant matter we will address is the correlation between the Upper Cretaceous and Lower Paleocene units of the Eastern Bogotá Plateau with those of the Llanos Thrustbelt. This interval contains major sandstone bodies that are potential or proved hydrocarbon reservoirs in these areas. Additionally, alternative interpretations to the proposed sequence stratigraphic schemes, supported by new stratigraphic and chronological information, are presented herein.

GEOLOGICAL FRAMEWORK

Paleogeographic reconstructions for the Upper Cretaceous of Colombia have been conveyed by Etayo-Serna *et al.* (1976) and Macellari & De Vries (1987). Fig. 1 shows the paleogeographic provinces outlined by Macellari & De Vries around the Guyana shield, revealing increasing water depth towards the W. During the Early Mesozoic the present Eastern Cordillera and Magdalena Valley experienced crustal extension generating a rift system that was filled with sediments mainly during the Cretaceous. Whether this rift system belonged to a back-arc (e.g. Cooper *et al.* 1995) or to a supracontinental setting (e.g. Macía *et al.* 1985) is a matter of controversy, whose resolution still requires a complete understanding of the setting and radiometric dating of plutons emplaced in the Central Cordillera.

The pelagic sedimentation that took place in the position of the present Magdalena Valley was interrupted towards the end of the Cretaceous with the uplift of the Central Cordillera, giving rise to a foreland basin that developed fully during the Tertiary (e.g. Van Houten & Travis 1968). The structural style present in the Cordillera includes high-angle, basement-involved thrusts as well as low-angle detachments. Different thickness of Cretaceous formations in the Llanos Foothills indicates differential subsidence through early activity of faults along the thrustbelt and inversion during Tertiary orogenic phases (Dengo & Covey 1993; Cooper *et al.* 1995).

Macellari (1988) denoted the Llanos basin as a domain of clastic sedimentation in a proximal pericratonic setting around the Guyana shield. The stratigraphic relations of the lithological units of the Eastern Cordillera and Llanos Basin as presented by Macellari (1988: Fig. 14) evidence a direct relationship between proximity to the continental craton of Guyana and decresing preservation of the stratigraphic record. The missing record in the Eastern Llanos basin is the product of erosion, of wedging out of the units by onlapping onto the basement, or of westward sediment bypassing.

STUDY AREA AND METHODS

The present work concerns mainly outcrop sections from the Eastern Cordillera and Llanos Thrustbelt at latitudes between 4° and 6° N (Fig. 1). Several stratigraphic sections were visited during field campaigns and detailed columns were described at scale 1:50 at the localities known as El

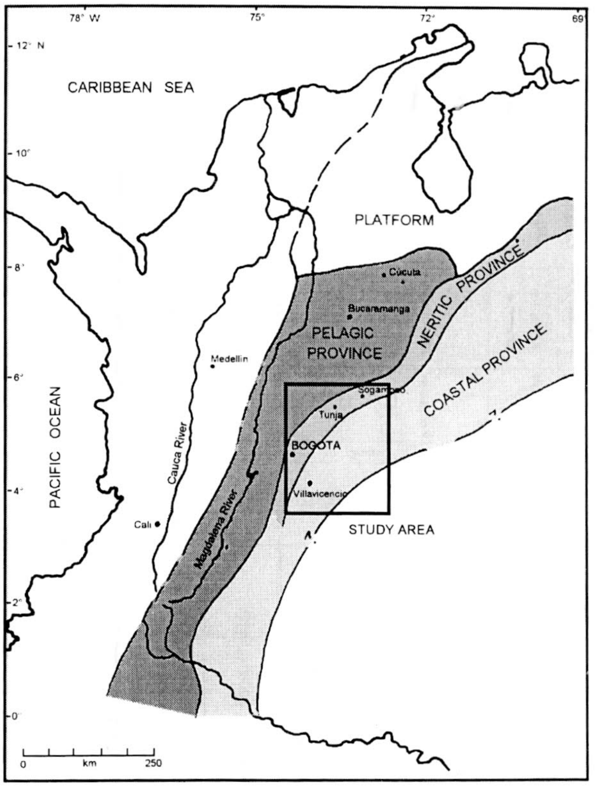

Fig. 1. Late Cretaceous (Turonian-Santonian) paleogeographic provinces in eastern Colombia (modified from Macellari & De Vries 1987), showing the study area.

Crucero, the Chinavita-Tibaná lower (northern) road, Páramo del Rajadero, Caño Blanco, Quebrada Playonera and Quebrada Palmichal (see Fig. 2). In the surroundings of the Quebrada Playonera and Caño Blanco, mapping the sections at a scale of 1:1000 was necessary to clarify the structural relations. Apart from outcrop information, we consulted the composite logs of a few oil wells, from which we include here those of Cusiana 2A, Medina-1 and Apiay 4P, provided by Ecopetrol-ICP and BPX Colombia.

Laboratory work included the study of 89 samples for foraminiferal study, the results of which are presented in detail by Vergara *et al.* (1997). The information from quantitative palynology and palynofacies analyses from 195 samples was incorporated; these studies were carried out by Bioss Ltda. and Bioestratigráfica Ltda. The list of the most relevant palynomorphs reported is given in Appendix 1 and 2. Samples taken for nannoplankton studies were barren. Petrographic characterization was undertaken for 70 thin sections; these results were presented by Vergara & Rodríguez (1996).

To establish the relations of the units defined in the eastern side of the Bogotá Plateau to those of the Llanos Thrustbelt, we have reviewed the history of stratigraphic nomenclature on the study area. However, this historical development of nomenclature will not be addressed in detail in the present paper. In Tables 1 and 2 we summarize the stratigraphic nomenclature of the Upper Cretaceous in both Eastern Bogotá Plateau and Llanos Foothills. We will return to this matter later.

CHIPAQUE FORMATION

A major problem of the Chipaque Formation, as introduced by Hubach (in Kehrer 1933), is that there is still no type section with sufficient information for re-examination purposes. Thus, it is necessary to establish a reference section. Following the stratigraphic code (NACSN 1983; Article 8e), a principal reference section can be assigned to a well established section lacking stratotype. We propose the El Crucero section along the highway from Sogamoso to Aguazul close to Lake Tota (coordinates: 1.113.300N/ 1.130.300E to 1.111.900N/1.130.800E of IGAC; see Fig. 2) as the principal reference section for the Chipaque Formation for the Eastern Bogotá Plateau area, which excludes the Llanos Foothills. The El Crucero secton is the most complete exposure of the Chipaque Formation that we found during our fieldwork. This section exhibits most of the unit, including its upper boundary. The succession is affected by faults and folds to a minor extent. The section is illustrated in Fig. 4. Further details are found in Vergara *et al.* (1997) and an overall view of the geology can be seen in the map of Ulloa *et al.* (1973).

In the Llanos Thrustbelt the Chipaque Formation has been referred to as the Gachetá Formation (Miller 1972), but it is a synonym of the Chipaque Formation. We follow here the proposal of Guerrero & Sarmiento (1996) to abandon the name Gachetá because the name Chipaque has priority.

Concerning the use of the Villeta Group for the Chipaque, Une and Fómeque Formations, we prefer to follow Julivert's (1968), proposal to restrict the Villeta Group to the western strip of the Eastern Cordillera. Certainly, Hettner (1892) defined the "Villetaschichten" in the area of Villeta (western flank of the Eastern Cordillera), where the Villeta Group is useful because diverse shale intervals have not received formal names and are difficult to map separately. In our view, Hubach's (1957) proposal of lumping together the Chipaque, Une and Fómeque Formations of the Eastern Bogotá Plateau into the Villeta Group was not justified because these formations have little affinity to each other and can be separated and mapped easily without the need of a unit of higher rank. The same holds for their correlation to units in other basins, for which the formations rather than the group are commonly utilized.

In the El Crucero section the uppermost 480 m of the Chipaque Formation are exposed, comprising Cenomanian

TABLE 1.
Upper Cretaceous lithostratigraphic nomenclature of the Eastern Bogotá Plateau.

HETTNER 1892	HUBACH 1931a	HUBACH 1931b	HUBACH in KEHRER 1933	STUTZER 1934	SCHEIBE 1938	ROYO Y GOMEZ 1941	HUBACH 1958 (written 1951)	HUBACH 1957	BÜRGL 1959	PRATT et al. (CSPGG) 1961	UJUETA 1962	JULIVERT 1962,1968	RENZONI 1962, 1968	Mc LAUGHLING & ARCE 1969	PEREZ & SALAZAR 1978	ULLOA & RODRIGUEZ 1979b	VERGARA & RODRIGUEZ (this work)
Guaduas Schichten	Formación de Guaduas	Piso del Guaduas	Piso del Guaduas	Formación Guaduas	Estratos del Guaduas	Formación de Guaduas	Formación de Guaduas	Grupo de Guaduas	Formación Guaduas	Guaduas Formation	Formación Guaduas	Formación Guaduas	Formación Guaduas	Formación Guaduas	Formación Guaduas	Formación Guaduas	Guaduas Formation
Stufe der Guadalupe Schichten	Formación de Guadalupe	Piso del Guadalupe: Guadalupe Superior: Arenisca Tierna Plaeners Arenisca Dura	Piso del Guadalupe: Conjunto Superior: Arenisca Tierna Plaeners Arenisca Dura	Formación Guadalupe	Estratos del Guadalupe	Formación Guadalupe: Conjunto Superior	Formación de Guadalupe: Conjunto Superior: Arenisca Tierna Plaener Arenisca Dura	Grupo de Guadalupe: Formación Guadalupe Superior: Miembro Arenisca Tierna Miembro Plaeners Miembro Arenisca Dura	Formación Guadalupe: Arenisca Tierna Plaeners Superiores Arenisca Dura Plaeners y Arcillas Arenisca no det. Plaeners y Areniscas Primera Lidita Plaeners y Areniscas	Guadalupe Formation: Tierna Member Upper Plaeners Dura Member Lower Plaeners Raizal Member	Formación Guadalupe Superior: Arenisca Tierna Nivel de Arenisca de Labor Nivel de Plaeners Arenisca Dura	Formación Guadalupe: Arenisca Tierna Lutitas y Arenitas finas Arenisca de Labor Plaeners Arenisca Dura	Grupo Guadalupe: Arenisca de Labor y Tierna Plaeners Arenisca Dura	Grupo Guadalupe: Formación Guadalupe Superior: Arenisca Tierna Arenisca de Labor Plaeners Arenisca Dura	Grupo Guadalupe: Formación Tierna Formación Arenisca de Labor Formación Plaeners Formación Arenisca Dura	Formación Guadalupe: Miembro Arenisca Tierna Miembro Los Pinos Miembro Plaeners y Arenisca de Labor Miembro Arenisca del Raizal	Guadalupe Group: Arenisca Tierna Formation Lutitas y areniscas finas Arenisca de Labor Formation Plaeners Formation Arenisca Dura Formation
		Piso del Villeta: Conjunto Superior	Conjunto Inferior Piso del Villeta: Conjunto de Chipaque			Conjunto Inferior Formación Villeta Superior	Conjunto Inferior Caliza de Chipaque	Formación Guadalupe Inferior Grupo de Villeta: Formación de Chhipaque	Grupo de Villeta: Segunda Lidita		Formación Guadalupe Inferior		Grupo Villeta: Formación Chhipaque	Formación Guadalupe Inferior Formación Chipaque	Formación Chipaque	Grupo Chipaque: Conjunto Superior Cto. interm. (La Frontera) Conjunto Inferior	Chipaque Formation
Stufe der Villeta Schichten	Formación de Villeta	Conjunto Medio	Conjunto de Une	Formación Villeta	Estratos del Villeta	Formación Villeta Medio	Formación de Villeta: Conjunto Superior Conjunto Medio (Arenisca de Une)	Formación de Une	Villeta Superior	Villeta Formation	Formación Villeta	Formación Villeta	Formación Une	Formación Une		Areniscas de Chiquinquirá	Une Formation
		Conjunto Inferior	Conjunto de Fómeque			Formación Villeta Inferior	Conjunto Inferior	Formación de Fómeque	Villeta Inferior				Formación Fómeque	Formación Fómeque			Fómeque Formation
Stufe der Giron Schichten	Formación de Cáqueza	Piso de Girón	Piso de Girón	Formación Cáqueza	Estratos del Girón	Formación Cáqueza	Formación de Cáqueza	Grupo de Cáqueza	Grupo de Cáqueza	Hauterivian Sandstones (not exposed)	Estratos de Girón	Formación Cáqueza	Grupo Cáqueza	Formación Cáqueza			

TABLE 2.
Upper Cretaceous and Lower Paleocene lithostratigraphic nomenclature of the Llanos Foothills.

van der HAMMEN 1958, 1961	MILLER 1972	ULLOA & RODRIGUEZ 1979 a	PEREZ 1985	PEREZ et al. 1985	BARTELS 1986	RENZONI 1991	COOPER et al. (1995)	CAZIER et al. (1995)	GUERRERO & SARMIENTO (1996)	VERGARA & RODRIGUEZ (1996)	VERGARA & RODRIGUEZ (this work)
Arcillas del Limbo	Los Cuervos Formation	Arcillas del Limbo	(hiatus)	El Limbo Claystones		Arcillas del Limbo	Los Cuervos Formation	Los Cuervos Formation	Grupo Socha: Formación Socha Superior		Socha Group: Socha Superior Formation
Arenisca de El Morro	Guadalupe Formation	Grupo Palmichal: Conjunto E	Guadalupe: K 1	Palmichal Group: E	Grupo Guadalupe: Arenisca Tierna	Grupo Palmichal: (five unnamed units)	Barco Formation	Barco Formation	Formación Socha Inferior	Formación Arenisca de El Morro	Socha Inferior Formation
		Conjunto D		D	Arenisca de Labor		Guaduas Formation	Upper Guadalupe shale	Formación Guaduas	Grupo Palmichal: Conjunto D	Guaduas Formation
		Conjunto C		C			Guadalupe Formation	Upper Guadalupe sandstone	Grupo Guadalupe: Formación Arenitas de San Luis de Gaceno	Arenita superior (C)	Palmichal Group: Arenitas de San Luis de Gaceno Formation
		Conjunto B	K 2	B	Plaeners			Guadalupe shale	Formación Lodolitas de Aguacaliente	Chert y lodolitas (B)	Lodolitas de Aguacaliente Formation
		Conjunto A		A	Arenisca Dura			Lower Guadalupe	Formación Arenitas de San Antonio	Arenita inferior (A)	Arenitas de San Antonio Formation
	Gachetá Formation	Formación Chipaque	(hiatus)	Chipaque Formation	Formación Chipaque	Grupo Villeta: Formación Chipaque	Gachetá Formation	Gachetá Formation	Grupo Villeta: Formación Chipaque	Formación Chipaque	Chipaque Formation
	Ubaque Formation	Formación Une				Formación Une	Une Formation	Basal Sandstone	Formación Une		Une Formation
	Fomeque Formation	Formación Fómeque				Formación Fómeque			Formación Fómeque		

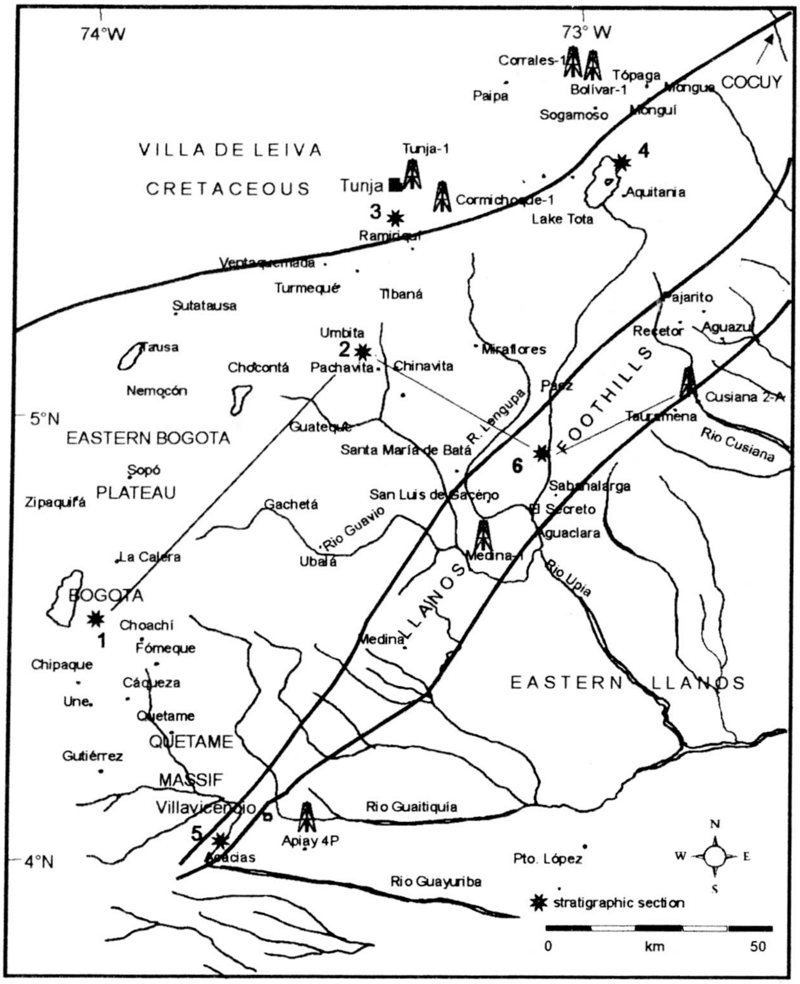

Fig. 2. Location of the stratigraphic columns and exploratory wells within the study area. Stratigraphic sections: 1. Páramo del Rajadero (Choachí); 2. Chinavita-Tibaná road section; 3. El Crucero; 4. Quebrada Playonera/Palmichal; 5. Caño Blanco. The line section from locality 1 to Cusiana is shown in Fig. 12.

to Campanian age (Vergara *et al.* 1997). The base of the Chipaque Formation was dated Early Cenomanian by Herngreen & Dueñas Jiménez (1990), in the Llanos Foothills. In the Caño Blanco section, strata below but very close to the lower limit contain palynomorphs of Coniacian to Santonian age (samples 200295-01 to 03; see Appendix 2), indicating that the lower boundary is younger there than close to San Luis de Gaceno, where Herngreen & Dueñas Jiménez (1990) obtained their samples. This means that the lower boundary of the Chipaque is diachronous (see Fig. 12b). Samples 030495-01 to 04 from the uppermost 10 m of the Chipaque Formation in the Quebrada Playonera section (see Fig. 7; Appendix 2) contain Late Santonian-Early Campanian palynomorphs, and all samples from the unit above are of Campanian age. From the Caño Blanco section, all samples above 210295-04 are also Campanian (see Fig. 8), supporting that the base of the Campanian occurs in the upper part of the Chipaque Formation. Except for the base of the Chipaque Formation in the Caño Blanco section, the age interval given here coincides approximately with that of Guerrero & Sarmiento (1996), who favored a time span from the Early Turonian to the Late Santonian for the Chipaque Formation exposed in the vicinity of San Luis de Gaceno.

Lithology consists mainly of gray to dark gray mudstones with even and wavy lamination, alternating with beds of fine to very fine sandstones. Bentonite layers in the lower part as well as an angular bed truncation at 138 m above the base are observed. In the Caño Blanco section of the Foothills, dark colored shales with sandstone interbeds ascribable to the Chipaque Formation attain 170 m of thickness and date Santonian to Campanian. The underlying succession at this locality is composed predominantly of sandstones with minor coal beds that we attribute to the Une Formation. These strata were dated Coniacian-Santonian and are underlain by further sandstones.

In the El Crucero section there are mainly two facies types represented by dark colored mudstones or shales, and very fine to fine grained sandstones. Based on the sand/shale ratio, we infer open sea deposits (outer shelf) and transition zone episodes (cf. Reinson 1992). The shales sometimes contain abundant plant remains that suggest the nearby presence of fluvial mouths. The sandstone interbeds correspond generally to shoreface environments. We attribute the nearly equal proportion of sandstones and shales in some intervals (e.g. m 230-285) as resulting from deposition in the lower shoreface and "distal lower shoreface" (*cf.* Van Wagoner *et al.* 1992: Fig. 3A), the latter denoted here as transition zone.

Vergara *et al.* (1997) ascribed the predominance of agglutinated foraminifera to calcium carbonate undersaturation in the water column due to a high input of fresh water from the nearby continent, hypothesis also supported by the lack of carbonate banks or concretions in this section.

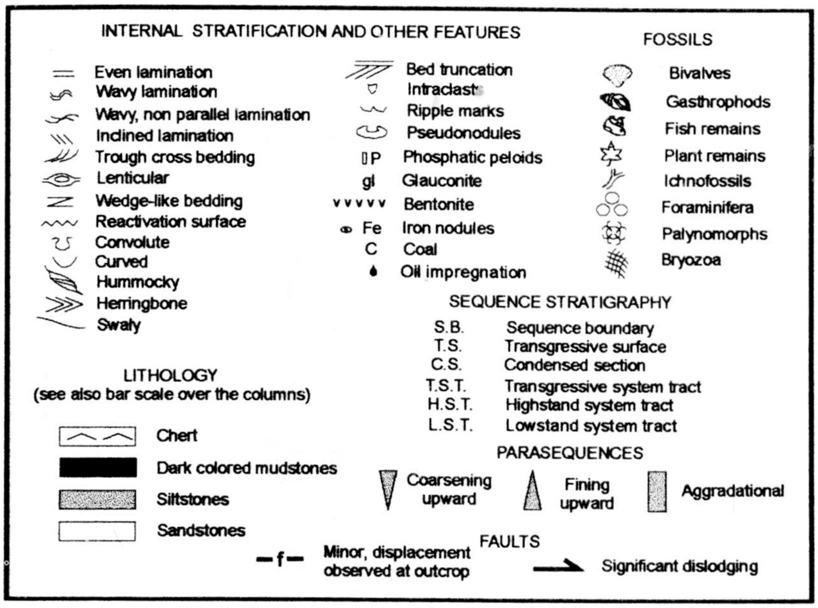

Fig. 3. Key to the stratigraphic columns.

The palynofacies are consistent with this interpretation, in that they show a predominance of spores and angiosperm pollen grains. In general, these considerations point towards an important lateral environmental change of the lower part (Cenomanian to probably Santonian) of the Chipaque Formation, from prodelta in the Eastern Bogotá Plateau to deltaic sandstones in the Llanos Thrustbelt, as visible at the Caño Blanco section. This paleogeographic scenario is similar to that postulated by Fabre (1985: Fig. 7) for the Chipaque Formation during the Turonian and Coniacian.

GUADALUPE GROUP

The first comprehensive descriptions of the Guadalupe Group were conducted by Hubach (1931, 1957, 1958). Here, we follow the nomenclatural divisions used by Julivert (1962) with the ranks given by Renzoni (1962), for the stratigraphy of the Guadalupe Group in the Eastern Bogotá Plateau (see Table 1).

Arenisca Dura Formation

The Arenisca Dura Formation is 450 m thick E of Bogotá (Pérez & Salazar 1978), but thins out northwards. The northermost outcrop we know of is the one at the El Crucero section, where the unit appears to be less than 200 m thick (Fig. 5). In the lower portion chert beds develop in some sections (Fig. 8). Normally, the Arenisca Dura is composed of fine-grained sandstones, sometimes bearing calcareous cement and chert or mudstone interbeds. Trace fossils, especially *Thalassinoides* burrows, are common.

Bürgl (1955), followed by Etayo Serna (1964) and Julivert (1968), favored a Campanian age for the base of the Guadalupe Group. From the Chinavita-Tibaná section, samples close to the lower limit of the Arenisca Dura Formation contain a palynomorph assemblage with a range of Late Campanian to Early Maastrichtian (see Appendix 1). Although all other samples were barren of microfossils, a Campanian age for the whole formation is in agreement with data from Pérez & Salazar (1978) and Föllmi *et al.* (1992), and from our own data for the equivalent unit in the Llanos Thrustbelt (see later).

At the Chinavita-Tibaná section, the lower part of the formation exhibits fine to very fine grained sandstones, wavy internal structures and abundant bioturbation that support a lower to middle shoreface environment (Davies *et al.* 1971). The predominance of large *Thalassinoides* burrows together with this lithology also suggests shoreface environments. A high concentration of phosphates in the upper part of the unit indicates episodes of high energy, typical of the inner shelf. At the El Crucero section there are intervals (e.g. between m 95 and 145) where an approximately equal proportion of sand and fine material favors the transitional zone as the depositional site (Elliot 1989). The uppermost beds were generated in environments that range between the middle shoreface and the transition zone.

Plaeners Formation

The Plaeners Formation is composed primarily of chert, porcelanites and dark shales. We observed outcrops of this formation in several localities, such as close to Lake Tota, Tunja or Ramiriquí. In most of them the occurrence of layered or nodular phosphates is a secondary but constant feature.

Pérez & Salazar (1978) supported an Early Maastrichtian age for the Plaeners Formation, whereas Föllmi *et al.* (1992) assigned to most of the unit in the Tausa section N of Bogotá a Late Campanian age, and to the uppermost part a Late Campanian-Early Maastrichtian range. As it will be discussed later, the equivalent unit of the Plaeners Formation in the Palmichal Group contains the Campanian/Maastrichtian boundary as indicated by palynological data.

Chert beds intercalated with organic matter bearing mudstones are commonly laid down under quiet, offshore conditions. It is generally believed that the genesis of such rock types is due to enhanced primary productivity in the water column. In

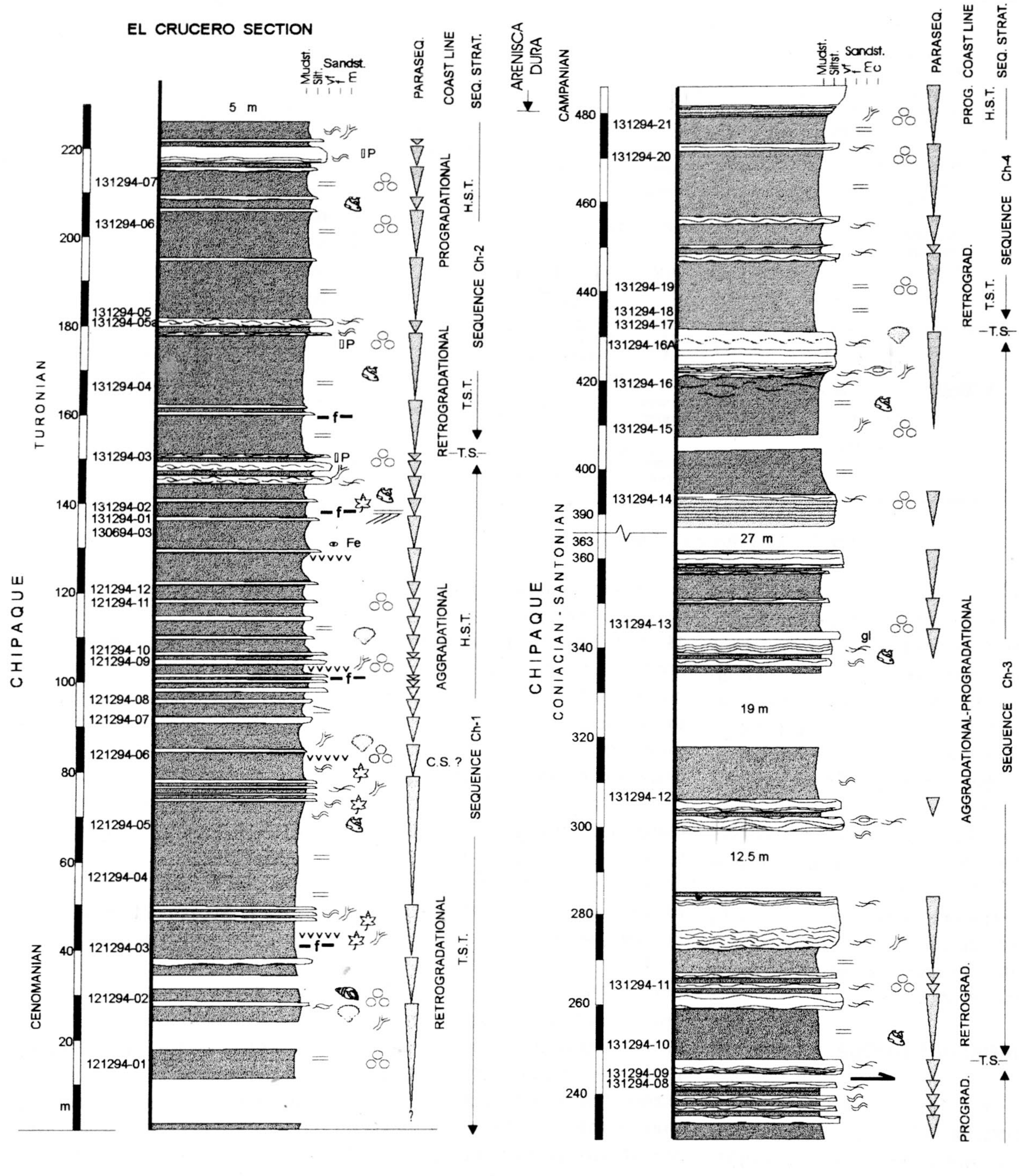

Fig. 4. Stratigraphic column and sequence stratigraphy of the Chipaque Formation, El Crucero section.

Colombia, the upwelling model has been also invoked to explain the large amounts of nutrients in the water column that enabled microorganism proliferation, and consequent deposition of organic rich shales and chert (Macellari & De Vries 1987; Föllmi *et al.* 1992; Vergara 1994). Phosphorite genesis has also been discussed, especially by Föllmi *et al* (1992), but Glenn *et al.* (1994) pointed out the lack of understanding of the processes that generate phosphatic pellets and phosphate availability in general. Within the Plaeners Formation, the occurrence of sandstone interbeds in many localities suggests that part of the deposition of this formation occurred in places shallower than the transition zone.

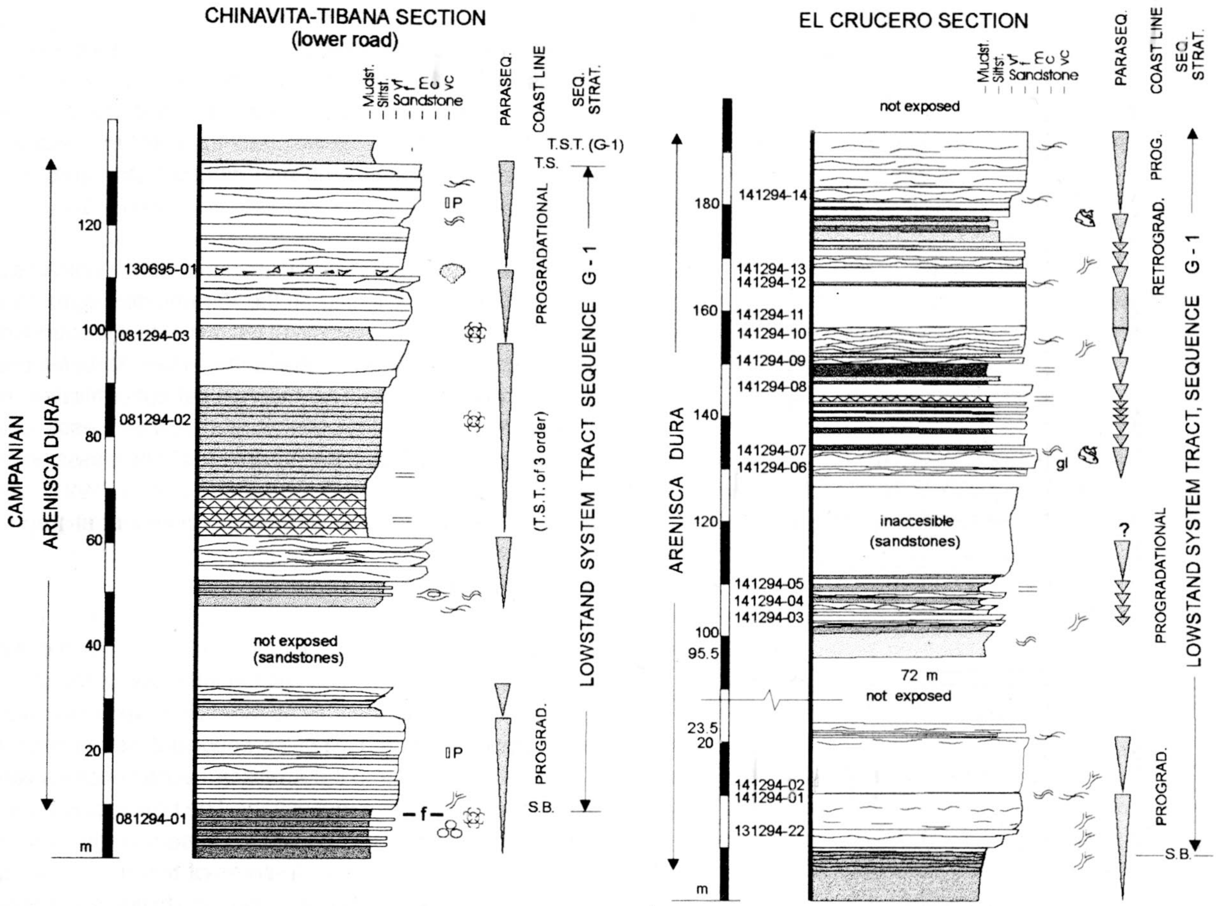

Fig. 5. Stratigraphic column and sequence stratigraphy of the Arenisca Dura Formation at the El Crucero and the Chinavita-Tibaná road section.

Arenisca de Labor Formation

The Arenisca de Labor varies in thickness from ca. 180 m NE from Bogotá (Ujueta 1962; Pérez & Salazar 1978) to 65 m at the Páramo del Rajadero (Julivert 1962). Ujueta included ca. 20 m of mudstones in the uppermost part, but we include this segment in the "Lutitas y areniscas finas" (see later), i.e. we excluded it from the Arenisca de Labor (see Fig. 6)

The nature of the lower boundary of the Arenisca de Labor seems to vary in places. We observed a transitional contact with the mudstones of the Plaeners Formation (e.g. Lake Tota close to Aquitania), but in other localities it seems to be rather sharp (Julivert 1962; Pérez & Salazar 1978). The reader is referred for further details to the description provided by Julivert (1962) for the Páramo del Rajadero section, and to its petrographical characterization by Zamarreño de Julivert (1962).

Ujueta (1962) reported ammonites and other fossils of probable Maastrichtian age, which is consistent with the data of Pérez & Salazar (1978), though the fossils in both of these studies come from the "Lutitas y areniscas finas" between the Arenisca de Labor and Tierna. However, taking into account a Campanian-Maastrichtian boundary within the Plaeners Formation, an Early Maastrichtian is the most probable age for the Arenisca de Labor.

The sandstones of this rock unit do not differ considerably from those of the Arenisca Dura Formation, except for containing fewer mudstone interbeds. The unit was deposited within the shoreface, as indicated by the large amount of fine sandstone in thick banks. There are also fewer internal structures in comparison to the Arenisca Tierna, where an upper shoreface paleobathymetry is favored (see below). A depositional environment within the shoreface, probably in the middle shoreface, is inferred for the Arenisca de Labor.

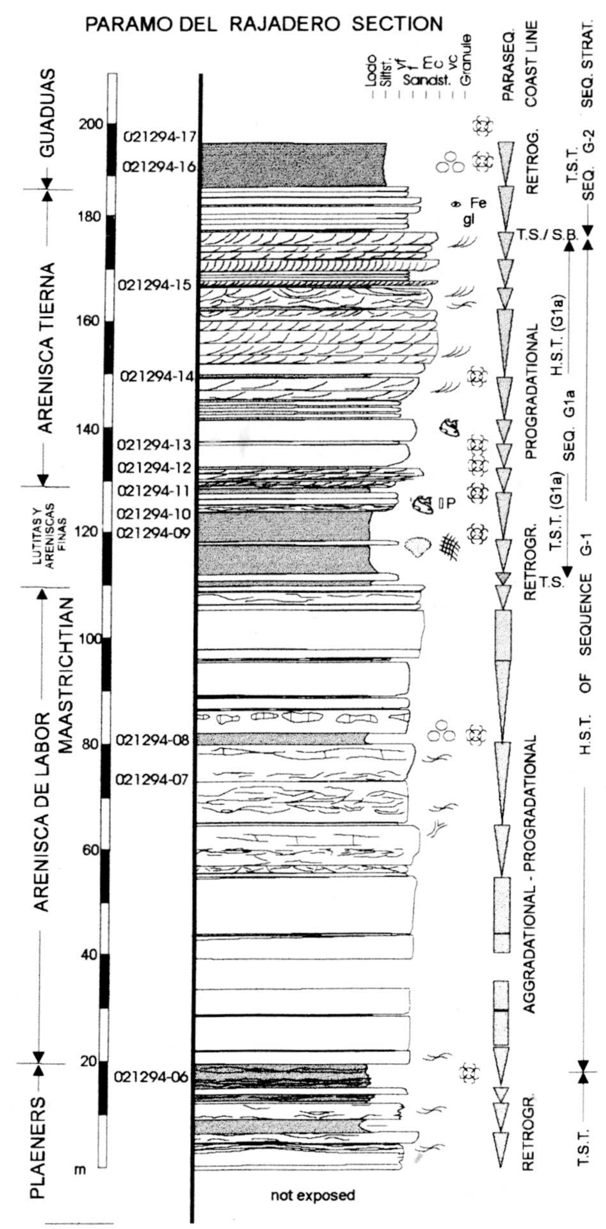

Fig. 6. Stratigraphic column and sequence stratigraphy of the upper portion of the Guadalupe Group at the Páramo del Rajadero section.

"Lutitas y areniscas finas"

This name was used by Julivert (1962) to refer to the dark-colored mudstones confined between the Arenisca de Labor and Arenisca Dura Formation at the Páramo del Rajadero, where they attain a thickness of 16 m. In other localities close to Bogotá 20 m are reported, although included into the Arenisca de Labor (*cf.* Ujueta 1962). As mentioned above, fossils ascribed to the Maastrichtian have been reported. This level was already treated independently from the other Formations of the Group by Pratt *et al.* (1961), who called it Upper Plaeners. In our opinion this is an unfortunate name because it introduces confusion with the "real" Plaeners. Additionally, the "Lutitas and areniscas finas" is sometimes denoted also as "Los Pinos Formation", a name we prefer to avoid here because of its ambiguous definition and different stratigraphical connotations in the Cocuy area (see Guerrero & Sarmiento 1996).

The onset of dark laminated shales evidently indicates a period of water deepening. In the Páramo del Rajadero a phosphatic layer in the middle of the unit contains abundant biogenic remains, among others the oyster *Abruptalopha abrupta* and bryozoa. The mechanical concentration of fossils allows this bed to be envisaged as a tempestite or a gravity flow deposit, and the phosphates to be classified as allochtonous, according to Föllmi & Garrison (1991). We will come back to this in the section on sequence stratigraphy.

Arenisca Tierna Formation

The Arenisca Tierna is the uppermost Formation of the Guadalupe Group. The unit lies transitionally on top of the "Lutitas y areniscas finas" as observed in several localities. In the places where these shales wedge out, separating the Arenisca de Labor from the Arenisca Tierna becomes very difficult and perhaps unnecessary. The best exposure we found is the one at the Páramo del Rajadero (see Julivert 1962). Typical, well-known features of this unit are large scale trough cross-bedding and medium- to coarse-grained sandstones.

As mentioned above, fossils of Maastrichtian age have been reported from the mudstones below. A Maastrichtian age for the Arenisca Tierna is supported by fossils from the Cocuy area reported by Etayo-Serna (1985). Sarmiento (1992) assigned spores and pollen from rocks of the uppermost portion of the Guadalupe Group, evidently from the Arenisca Tierna Formation to a palynological zone of Maastrichtian age. Our palynological data reveal an age range of Late Campanian-Early Maastrichtian (see Appendix 1), which permit to precise the early datings of Maastrichtian to the Early Maastrichtian.

The sandstones contain marine elements such as glauconite and minor shale interbeds with dinoflagellates. In several localities (e.g. Páramo del Rajadero, Tausa) we observed flaser and lenticular structures that indicate tidal environments, and probably some sand shoals too (Reinson 1992: Fig. 8). The type of trough cross bedding observed is thought to develop preferably in the upper shoreface (*cf.* Reinson 1992; Elliot 1989). Beach environments may also be represented in the uppermost portion. A regressive sedimentation pattern upsection is evident in the parasequence stacking (see later).

PALMICHAL GROUP

The Palmichal Group, as defined by ULLOA & RODRÍGUEZ (1979a) was composed of five informal units of formational rank, three dominantly of sandstones (A, C and E) and two of mudstones (B and D), all confined between the Chipaque Formation and the Arcillas de El Limbo. However, in this paper we exclude the uppest sandstone unit (E) from the Palmichal Group, here denoted as Socha Inferior Formation, because it lies upon an unconformity, to be discussed later. This constitutes a revision in the sense of the NASC (1983: Article 17a).

Units A, B and C of the Palmichal Group have recently received the formal names of Arenitas de San Antonio, Lodolitas de Aguacaliente and Arenitas de San Luis de Gaceno, respectively, all of them with formational rank (GUERRERO & SARMIENTO 1996). We regard this proposal as formal, sufficiently documented and necessary for naming these units, previously handled informally. Although we retain these units here, we include them in the Palmichal and not in the Guadalupe Group for reasons we will discuss below.

As noted by BARTELS (1986), the type section chosen by ULLOA & RODRÍGUEZ (1979a) at the Quebrada Palmichal (sheet K-12, Guateque) is decapitated by a fault that dislodged the upper part of the group (their units D and E). Therefore, the exposure of the Palmichal Group and Socha Inferior Formation is more suitable for study at the adjacent Quebrada Playonera. In this section the Arenitas de San Antonio, Arenitas de San Luis de Gaceno and Socha Inferior Formations are well exposed between coordinates 1.040.100N/1.018.400E (base of section) to 1.040.500N/ 1.016.000E (top of section) of IGAC (National Geographical Institute) and serve as a reference section of the revised Palmichal Group and of the Socha Inferior Formation. The Lodolitas de Aguacaliente, in turn, were studied at the adjacent ravine to the S of the Quebrada Playonera, known as Quebrada Palmichal (Palmichala in sheet K-12), between coordinates 1038700N/1115600E (lower limit) and 1038700N/1115500E (upper limit) of the IGAC.

Palmichal vs. Guadalupe

In accordance with the stratigraphic code, our preference for the Palmichal Group has to be supported. We argue that the three upper formations of the Guadalupe Group known as Arenisca de Labor, "Lutitas y areniscas finas" and Arenisca Tierna (see Fig. 9), are not recognizable or mappable in the area of the Llanos Foothills (see Figs. 6, 8), therefore constituting a single and quite homogeneous rock body. Additionally, a further sandstone unit (the Socha Inferior) was able to be grouped easily to the underlying units because of the extremely reduced thickness (or absence) of the Guaduas Formation, facilitating geologic mapping of the three sandstone units (A, B and C) as a Group, with a conspicuos geomorphologic expression. Taking these points into account, we consider valid the procedure of ULLOA & RODRÍGUEZ (1979a) of creating the Palmichal Group, instead of bringing the name Guadalupe from the Eastern Bogotá Plateau.

The only publication that existed in 1975, prior to elaboration of sheet K-12 (ULLOA *et al.* 1975), was the one of VAN DER HAMMEN (1958), introducing the Arenisca de El Morro. However, the stratigraphic relation of the Arenisca de El Morro to the underlying succession was undefined by VAN DER HAMMEN (1958: Plate II). ULLOA & RODRÍGUEZ (1979a) illustrated the complete succession below the Arenisca de El Morro, which comprises the A and B units of the Palmichal Group. Although it was not imperative for ULLOA & RODRÍGUEZ (1979a) to adopt the name Arenisca de El Morro, they correlated it with an undefined (upper) portion of the Palmichal Group, creating confusion.

We prefer here the use of the name Palmichal Group, mainly because of the following reasons, that we review as follows:

1. As remarked above, the three uppermost units of the Guadalupe Group are impracticable in the Llanos Foothills because they cannot be separated from each other. This constitutes a reason to abandon the Arenisca de Labor, the "Lutitas y areniscas finas" and the Arenisca Tierna, but only in the Llanos Foothills (see NASC 1983: Article 20a)

2. The name Palmichal has priority over the Guadalupe in the Llanos Foothills. Although it has been sparsely mentioned in congress memoirs or unpublished thesis, the Guadalupe in the Llanos Foothills was used in publications only until COOPER *et al.* (1995) and CAZIER *et al.* (1995).

3. The abandonment of the Palmichal Group proposed by GUERRERO & SARMIENTO (1996: 4) claiming synonymy to the Guadalupe, the Guaduas, the Socha Inferior, and the Arenisca de El Morro is not actually justified because neither of these units is synonym of the Palmichal Group, they are merely *equivalent* to parts of it (see Fig. 10).

4. Following Article 7c of the Code (NASC 1983), we preferred to redefine (or revise according to Article 17a of the Code) the upper boundary of the Palmichal Group, to its abandonment. We believe this is more practical and avoids the extension of the Guadalupe Group eastwards, beyond its type area (Fig. 2).

5. The condition of mappability is sufficiently fulfilled. Ingeominas, the Colombian Geological Survey, has mapped it extensively in sheets K-12 and K-13 (ULLOA *et al.* 1975; ULLOA & RODRÍGUEZ 1981), 211 (ULLOA & RODRÍGUEZ 1976), 230 (ULLOA *et al.* 1976), 193 (RENZONI 1991) and 266 (PULIDO *et al.* 1993), all of them of public domain. According to them, the unit can be followed along the Llanos Thrustbelt, as outlined in Fig. 2, from the Yopal area in the northern

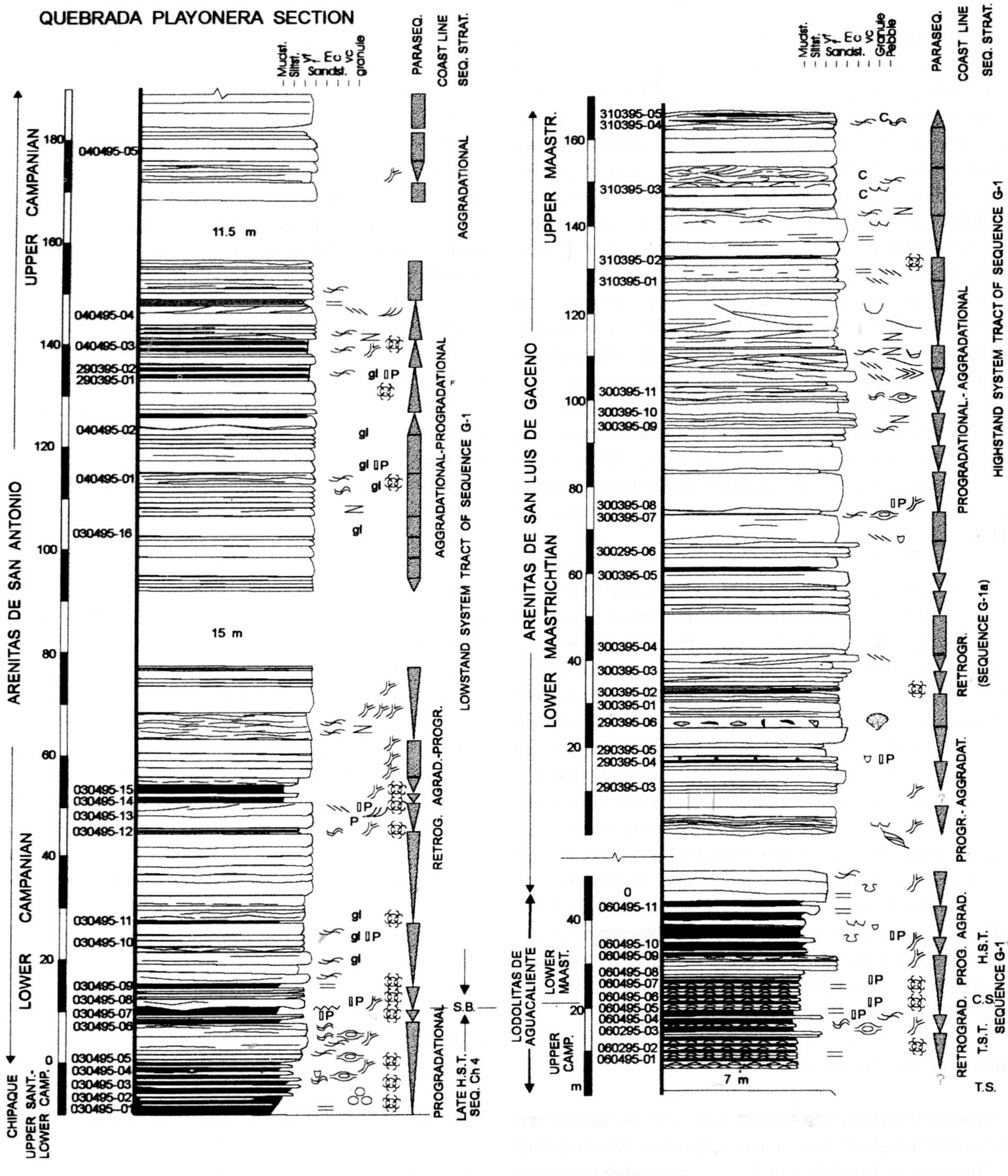

Fig. 7. Stratigraphic column and sequence stratigraphy of the Palmichal Group in the section of the Quebradas Playonera and Palmichal.

Foothills southwards to the Villavicencio-Acacías area (see also Ulloa & Caro 1985). Abandonment of the Palmichal Group would practically render Ingeominas' maps ill-equipped or in the worst case invalid. Instead, the maps can be improved by separating the Socha Inferior Formation from the Palmichal Group with the aid of the mentioned unconformity, where present.

Based on these factors, we restrict the Guadalupe Group to the eastern part of the Bogotá Plateau and the Palmichal Group for the Llanos Thrustbelt E of Santa María de Batá.

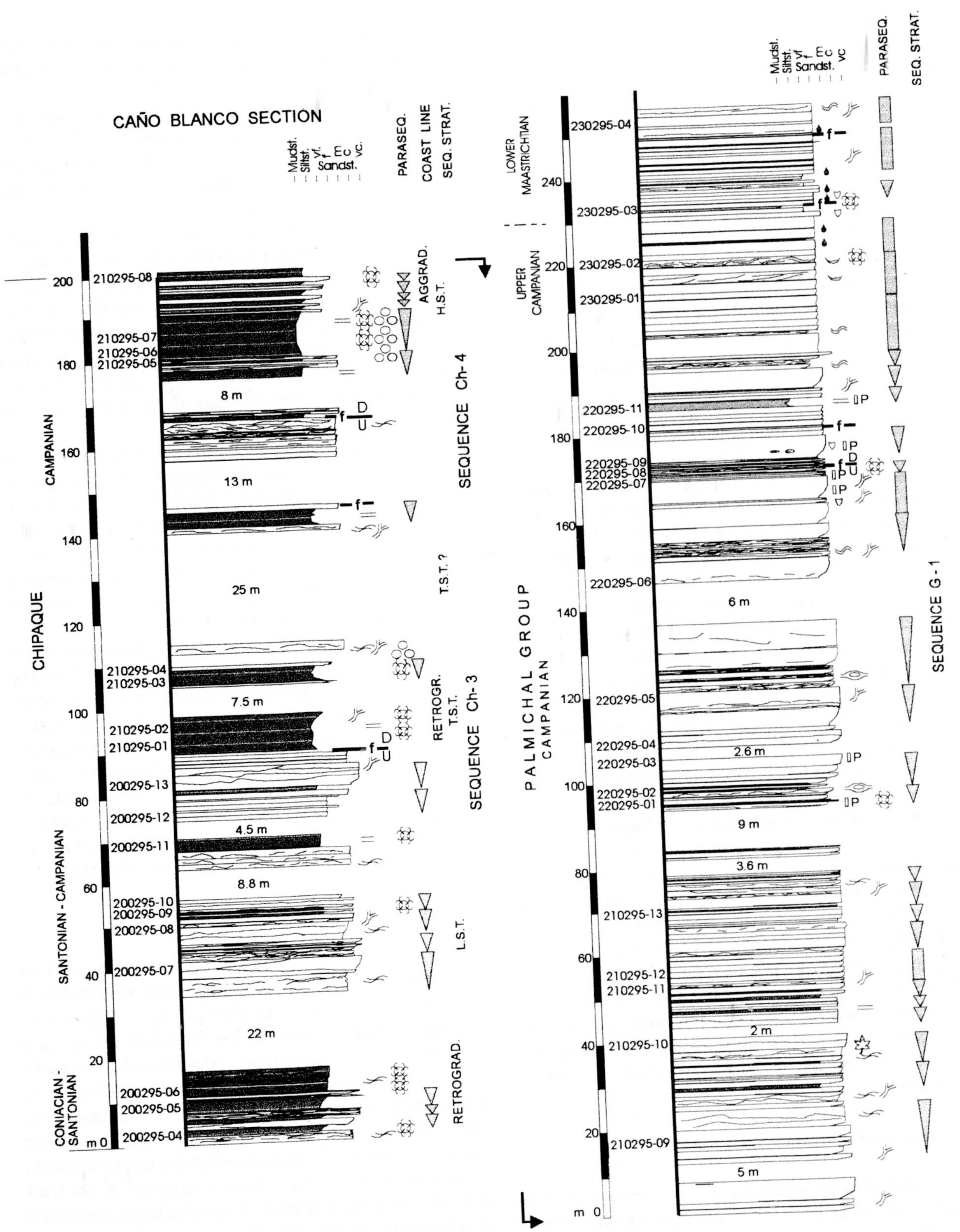

Fig. 8. Stratigraphic column and sequence stratigraphy of the Chipaque Formation and Palmichal Group, Caño Blanco section.

In palinspastic restoration these areas could have been separated by more than 100 km, which is the eastward-directed shortening across the Eastern Cordillera estimated by Dengo & Covey (1993). The extension of the latter Group in N-S direction goes from the Yopal area in the N to the Acacías area in the S, as shown by the geological maps mentioned earlier.

Arenitas de San Antonio Formation

The unit herein referred to as Arenitas de San Antonio (Guerrero & Sarmiento 1996) of the Palmichal Group is in the Quebrada Playonera a 190 m thick rock body of fine-grained sandstones deposited on top of the Chipaque Formation (Fig. 7), which was formerly denoted as unit A of the Palmichal Group. Petrographic categories are predominantly quartz sandstones (Vergara & Rodríguez 1996). The most common structures are wavy and inclined lamination in medium thick beds. Bioturbation structures are well preserved in the lower part of the unit, composed mainly of the ichnogenera *Diplocraterion*, *Rhizocorallium*, *Thalassinoides*, *Skolithos* and *Planolites*.

In the present work a Campanian age is established for samples 030495-05, 07, 08, 09, 11, 12, 14 and 15 coming from the lower part, and a Late Campanian age is valid for samples 060495-01, 03 and 05 from the upper part of the formation at the Quebrada Playonera (see Appendix 2). As mentioned above, the base of the Campanian is inferred in the uppermost Chipaque Formation. Guerrero & Sarmiento (1996) confered an Early Campanian age to the unit close to San Luis de Gaceno.

The unit is composed basically of sandstones with a high degree of compositional and textural maturity, which, together with the sedimentary structures, authigenic minerals (glauconite, phosphates) and ichnofossils, indicate a shallow marine origin. Burrows may belong to the *Cruziana* as well as to the *Skolithos* ichnofacies, whose habitat oscillates between the foreshore and the lower offshore (Pemberton *et al.* 1992). The abundance of *Thalassinoides* and the apparent absence of *Ophiomorpha* suggests the former ichnofacies. Large amounts of sand were deposited almost continuously above the wave base-level within the shoreface. Close to the lower limit we observed reactivation surfaces and a large intraclast, all of which indicate an agitated environment.

Lodolitas de Aguacaliente Formation

The Lodolitas de Aguacaliente Formation defined by Guerrero & Sarmiento (1996), correspond to the B unit of the Palmichal Group. At the Quebrada Palmichal this unit is a 40 m thick succession of siliceous rocks, mainly chert and mudstone interbeds, that in places is bioturbated (Fig. 7). Finning upward beds of grain supported phosphatic rocks occur associated with the chert beds. Towards the middle of the unit a conspicuous level of highly phosphatic sandstones with coarse sand sized peloids and phospholitoclasts occurs. *Thalassinoides* and undetermined spreitened burrows were observed. Well preserved phosphatic ichtyoliths were identified in thin sections (see Vergara & Rodríguez 1996).

The dinoflagellate assemblages found in samples 060495-01, 03 and 05 are diagnostic of the Late Campanian, whereas those of samples 060495-06 through 290395-04 (5 samples included) were dated as Early Maastrichtian (see Appendix 2). This means the Campanian-Maastrichtian palynological boundary can be picked precisely, between samples 060495-05 and 060495-06, i.e. some 21 m above the base of the Lodolitas de Aguacaliente at the Quebrada Playonera.

In the Caño Blanco section a similarly precise age constraint of the Campanian-Maastrichtian boundary is confirmed between samples 230295-02 and 230295-03. However, cherts are absent from this interval in this locality. Instead, this time equivalent interval exhibits only medium bedded fine sandstones (see Fig. 8), illustrating the wedging out of the Lodolitas de Aguacaliente unit southeastward, from the Quebrada Palmichal to Caño Blanco.

The palynofacies of the Lodolitas de Aguacaliente are dominated by woody over herbaceous material, followed by marine derived amorphous and structured remains, which suggests a more proximal paleoenvironment than that of the equivalent Plaeners Formation. This is also indicated by the presence of sandstones ascribable to the lower shoreface. These sandstones may represent storms because of the variable granulometric content and fining upward array of components, and also because they are secondary to fine-grained rocks laid down offshore.

Arenitas de San Luis de Gaceno Formation

The rock unit herein denoted as the Arenitas de San Luis de Gaceno (Guerrero & Sarmiento 1996) corresponds to the C unit of the Palmichal Group (Ulloa & Rodríguez 1979a). The lower contact in the Quebrada Palmichal is transitional with the underlying Lodolitas de Aguacaliente. In the Quebrada Playonera the unit is 168 m thick (Fig. 7), and is composed primarily of medium to thick beds of rocks classified as quartz sandstones and sublithoarenites (Vergara & Rodríguez 1996). Towards the base hummocky and swaly structures have been recognized. A 1-m-thick shell lag containing abundant *Ostrea* deposited randomly to bedding occurs in the lower part at both of the aforementioned ravines. Higher in the section the internal structures include diverse types of cross bedding, namely swaly, festooned and inclined laminae, and also herringbone structures.

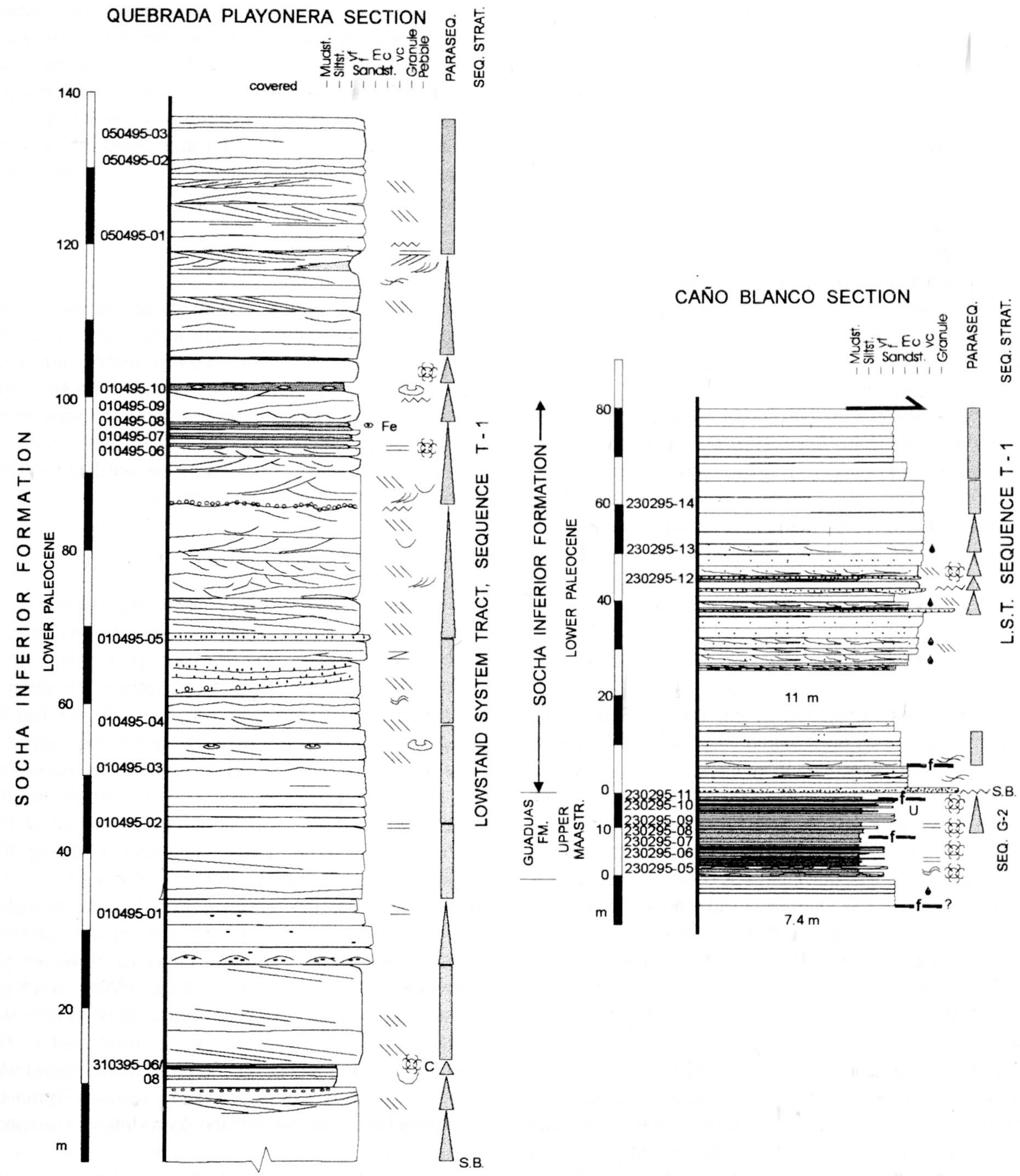

Fig. 9. Stratigraphic column and sequence stratigraphy of the Socha Inferior Formation at the Quebrada Playonera and Caño Blanco sections.

Close to the top the unit is densely laminated, and minor coal laminae and fragments appear.

Sample 290395-04 from the lower portion of this unit contains a fossil assemblage that belongs to the Early Maastrichtian (Appendix 2). In the upper part of the unit there are three samples (310395-02,04, 05) that yielded Late Maastrichtian palynomorphs. Guerrero & Sarmiento (1996) favored an early Maastrichtian age for the whole unit in their study area.

Several features point to a marine environment: marine fossils, phosphate occurrences, ichnofauna and sedimentary structures. In the lower part hummocky cross stratification commonly interpreted as storm related event beds (see e.g. Bourgeois 1980 and other references therein) as well as tempestites restrict the paleobathymetry to the inner shelf above the storm base level, i.e. approximately between 10 and 20 m (EINSELE 1992). In the lower 30 m of the succession, the sandstones have been deposited in the lower shoreface, where mudstone accumulation was hampered by water agitation (EINSELE 1992; WALKER & PLINT 1992).

In the middle part features such as bed geometry, high-amplitude curved lamination and cross bedding, suggest sedimentation in sand shoals that developed in the shoreface. Preservation of burrows may have been hindered by erosion and redepositional processes typical of the upper shoreface (*cf.* EINSELE 1992). Towards the top, swaly cross stratification and herringbone structures are developed. The former is usually generated in agitated bottoms of the shoreface, controlled by storms (WALKER & PLINT 1992; LECKIE & WALKER 1982) and the latter are associated with the foreshore (REINECK & SINGH 1980; REINSON 1992). Upsection, above m 150, large forward-stepping ripples are recognized among the very dense internal structures. Fine-grained sandstones with discontinuous wavy laminae of coal are found towards the top of the unit, and they resemble the lower unit of an estuarine deposit, as characterized by van Beck & Koster (cited in REINECK & SINGH 1980: Fig. 442).

Guaduas Formation

The Guaduas Formation in the Llanos Foothills is represented by mudstones with a very reduced thickness (less than 70 m), compared to its thickness in the Bogotá Plateau, where it attains over 1000 m (SARMIENTO 1992). ULLOA & RODRÍGUEZ (1979a; 1981), referred to this unit within the Palmichal Group (D) as a 40 m thick succession of dark mudstones with thin interbeds of siliceous siltstones and limestones. In the Quebrada Playonera the covered interval that corresponds to this unit is 62 m thick. An exposure of this unit was studied at the Caño Blanco section (Fig. 9), where some 15 m of dark gray mudstones with very fine sandstones are well exposed, despite minor disturbances at outcrop level.

A Late Maastrichtian age was established by means of palynomorphs (see Appendix 2; samples 230295-05 to 230295-10; also GUERRERO & SARMIENTO 1996). This age determination was helpful in identifying and avoiding miscorrelation of this unit to the Lodolitas de Aguacaliente, whose lack of chert beds in this section was already pointed out.

The palynofacies at the Caño Blanco section reveal an overwhelming predominance of terrestrial elements: pollen, spores, material derived from wood, herbs and coal, whereas marine phytoplankton is virtually absent. The average organic composition in 7 samples is 75 % woody, 7.8% herbaceous and 17.1% coal derived material. Although the sedimentary structures alone are here not clearly indicative of any environment in particular, in conjunction with the palynofacies a tidal depositional environment, probably of the sand-mud flat type (REINECK & SINGH 1980), rather than a normal shelf environment is favored. The presence of a thin chert layer can be ascribed to diagenetic silica redeposition (DECKER 1991; MURRAY *et al.* 1992) or to diatom proliferation in the tidal realm, as suggested by PÉREZ & SALAZAR (1978) for the Plaeners Formation close to Bogotá.

SOCHA GROUP

GUERRERO & SARMIENTO (1996) proposed the Socha Allogroup represented by the Socha Inferior and the Socha Superior Alloformations. Since we are dealing here with lithostratigraphic units, the equivalent to the Socha Allogroup is the Socha Group, which retains the same limits and main features of the Socha Allogroup as defined by GUERRERO & SARMIENTO (1996). In the present work, we will deal only with the Socha Inferior Formation, as follows.

Socha Inferior Formation

The Socha Inferior Formation, initially described from the Paz del Rio area, bears sandstones and conglomerates of Paleocene age (VAN DER HAMMEN 1961) that in the Llanos Thrustbelt lie unconformably on the Guaduas Formation of the Palmichal Grup. This unit was formerly referred by ULLOA & RODRÍGUEZ (1979a) to the "E" unit of the Palmichal Group. In a previous publication (VERGARA & RODRÍGUEZ 1996), we used the name Arenisca de El Morro for this unit to separate it from the Palmichal Group in view of the unconformity between them, basically following the procedure proposed by SARMIENTO (1994:170). As a consequence of this, the Palmichal Group became restricted to two sandy units (A and C) and two fine-grained, soft units (B and D) (see Table 2 for equivalencies). However, we acknowledge here that the Arenisca de El Morro is not the most suitable name for this unit, because, as defined by VAN DER HAMMEN (1958), it comprises a great part of the Maastrichtian and Paleocene, therefore being coeval with the Arenitas de San Luis de Gaceno and Guaduas Formation of the Palmichal Group, and with the Socha Inferior Formation (see Fig. 10).

GUERRERO & SARMIENTO (1996) discussed and extended the use of the name Socha Inferior to the Llanos Thrustbelt area for rocks commonly referred to the Barco Formation by the petroleum industry (e.g. COOPER *et al.* 1995: Figs. 4, 6). We adopt such proposal and stress differences in age with VAN DER HAMMEN's (1958) Arenisca de El Morro (Maastrichtian-Paleocene), whose uppermost sandstone unit corresponds to the Socha Inferior Formation (see Fig. 10).

The lithological succession of the Quebrada Playonera

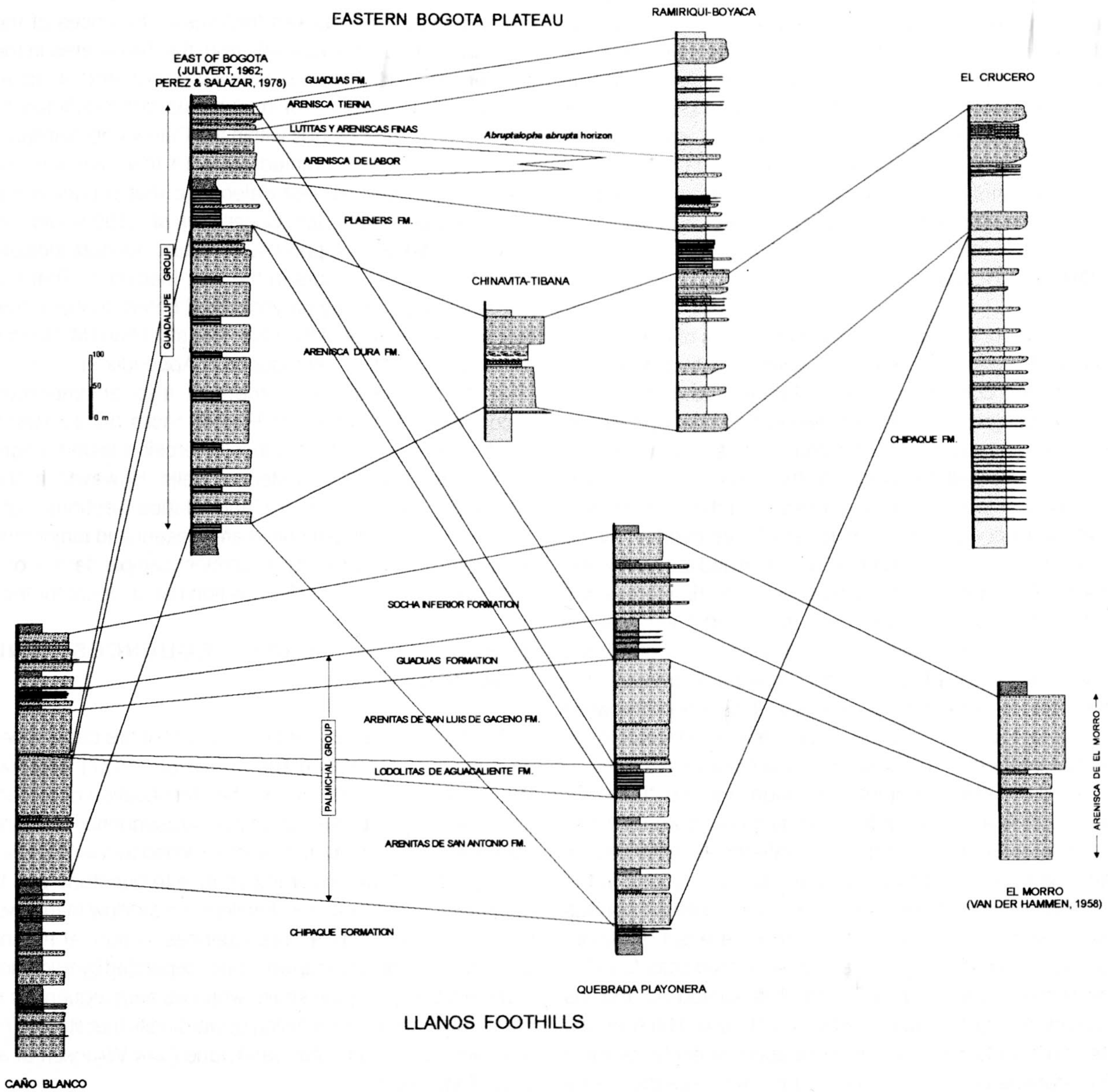

Fig. 10. Correlation of selected columnar sections along the eastern side of the Bogotá Plateau and the Llanos Foothills.

shows fine to medium grained sandstones that contain subangular shaped pebbles (Fig. 9). Black mudstone interbeds in sandstones and thin coal beds are present in the lower portion. Bi-directional curved lamination is well developed in the sandstones, and farther above dark laminated mudstones with iron nodules occur. In the upper portion of the unit a few bed truncations are worth mentioning because they may represent significant time gaps. At the Caño Blanco section some 80 m of the unit are exposed (Fig. 9). There, it is coarser grained than at the Quebrada Playonera, and conglomerates as well as conglomeratic sandstones are more frequent.

All samples from the Quebrada Playonera that were analysed for palynology have Early Paleocene assemblages, listed in Appendix 2 (see also BARTELS 1986). In the Caño Blanco section, samples 230295-12 and 240295-01 confirmed this age assessment (see Appendix 2).

The lower portion of the unit exhibits conglomeratic beds formed in distributary channels. At the Quebrada Playonera associated fine mudstone-sandstone intercalations appear to be of tidal origin. A few coal beds within very thick sandstone layers attest to the presence of swamps or marshes. In the middle part of the unit fining upward layers upon erosive surfaces correspond to channel fills. The aforementioned iron nodules in mudstones may represent well oxygenated swamps (Coleman 1966 cited in WRIGHT 1985). Between m 60 and 120 the general sedimentation pattern is attributable to sand bodies of an estuarine distributary channel (GALLOWAY & HOBDAY 1983: Fig. 5-19). Bed truncations and irregular surfaces were caused by bottom scouring of reactivated distributary channels.

CORRELATIONS

Fig. 10 shows the correlation of the units of the Eastern Bogotá Plateau to those of the Llanos Thrustbelt according to selected columnar sections. Figure 12b displays the chronostratigraphic relations between the Upper Cretaceous and Paleocene units of the Eastern Bogotá Plateau and the Llanos Thrustbelt. In addition to the sections correlated in Figure 12, it is important to stress that in the Caño Blanco section, Cenomanian-Coniacian strata are overlain by the typical shales of the Chipaque Formation and are composed mainly of sandstones. This sandstone interval is intermediate between the Une and the Arenitas de San Antonio of the Palmichal Group (Guadalupe according to Fig. 4 of COOPER *et al.*), coetaneous to part of the Chipaque Formation. It is illustrated in Fig. 4 of COOPER *et al.* (1995), where the wells La María-1 and La Cabaña-1 have penetrated sandstones placed by them in the Santonian and Coniacian stages.

Similarly, the Plaeners Formation and the "Lutitas y areniscas finas", also undergo wedging out towards the E. Consequently, it is difficult to separate the Arenitas de San Antonio from the Arenitas de San Luis de Gaceno in the most proximal sections due to the absence of the Lodolitas de Aguacaliente, equivalent to the Plaeners Formation. Similarly, the absence of the "Lutitas y areniscas finas" in the sections of the Llanos Thrustbelt is pointed out and has nomenclature implications discussed already. The Arenisca de Labor and Arenisca Tierna are approximately coeval to the Arenitas de San Luis de Gaceno, whereas the Socha Inferior Formation is coeval with the upper portion of the Guaduas Formation (VAN DER HAMMEN 1961).

The corresponding depth diagram to the chronological relations is shown in Fig. 12a. We stress important lithological differences between the Guadalupe and Palmichal Groups in their upper half. As pointed out above, the Arenisca de Labor and Arenisca Tierna Formations as characterized in the Eastern Bogotá Plateau do not maintain in the Llanos Thrustbelt their petrographic and sedimentologic diagnostic features, and cannot be separated by an intervening shale interval in between, thus merging in a single unit: the Arenitas de San Luis de Gaceno.

The presence of a hiatus in the Maastrichtian is relevant to the stratigraphic nomenclature. It was inferred by MACELLARI (1988: Fig. 14) and pointed out by SARMIENTO (1994) based upon marked thickness differences of the Guaduas Formation eastwards from the Tausa area in the northern Bogotá Plateau. SARMIENTO denoted it as an eastwards increasing erosional hiatus and predicted its occurrence in the Foothills within the Paleocene. Similarly, COOPER *et al.* (1995) pointed out a 14 m.y. hiatus in the Maastrichtian and earliest Paleocene that occurs in the Cusiana wells. Although COOPER *et al.* (1995) did not provide evidence to support such hiatus, our data indicate something similar occurs in the well Medina-1. There, a hiatus is supported by palynological determinations that indicate the absence of the Late Maastrichtian (M. Rueda, written comm., 1995, reproduced in Appendix 2).

In the well Apiay 4-P, there is also an important unconformity at the base of Eocene rocks (PÉREZ 1985), which suggests that at this locality erosion lasted longer than at the Cusiana and Medina wells. However, in the Quebrada Playonera and Caño Blanco sections both substages of the Maastrichtian are present and major time gaps were not detected. An insufficient sample density or a correlative conformity at this position can account for this.

DEPOSITIONAL SUPERSEQUENCES AND SEQUENCES

The sequence stratigraphic appraisal of this paper relies on the principles stated by VAIL *et al.* (1977) and VAN WAGONER *et al.* (1988, 1992). The identification of system tracts was eased by analyzing the parasequence stacking pattern according to the guidelines provided by VAN WAGONER *et al.* (1992). Of particular importance to our study was to distinguish parasequences developed in shallow marine vs. paralic environments. Parasequences in normal marine deposits are coarsening upward units separated by a flooding surface below a marine shale, whereas parasequences in paralic environments are fining upward units that start at the base with a transgressive sandstone (VAN WAGONER *et al.* 1992: Figs. 3a-3d).

Concerning sequence ranking, we will use here the denomination of supersequences for those of second order and sequences for those of third order (HAQ *et al.* 1988), essentially according to the time comprised they represent. A second order cycle spans 10-100 m.y. and a third order cycle 1-10 m.y., typically being shorter than 3 m.y. (PLINT *et al.* 1992). This allowed us to consider of second order the cycles with an estimated duration close or slightly less than 10 m.y., for practical reasons.

A few sequence stratigraphic models for study areas in Colombia have been published, focusing mainly on the Cretaceous system (MACELLARI 1988; FÖLLMI *et al.* 1992; VERGARA 1997; COOPER *et al.* 1995; GUERRERO & SARMIENTO 1996). Authors such as MACELLARI (1988) and COOPER *et al.*

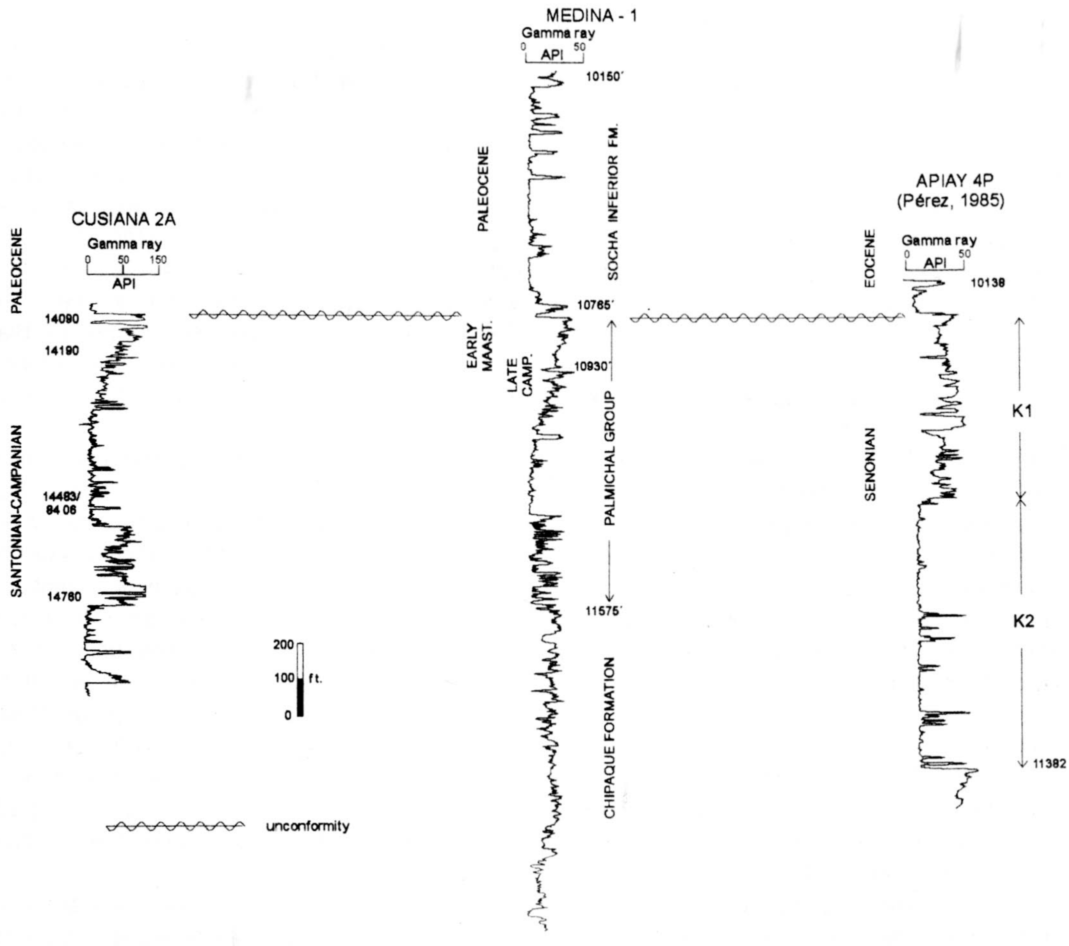

Fig. 11. Correlation of Cusiana 2A, Medina-1 and Apiay-4P oil wells showing the supra-Cretaceous unconformity. See text for explanation and Fig. 2 for localization of the wells.

(1995) presented regional stratigraphic frameworks, that leave much room for alternative interpretations, mainly because of the lack of supporting data. In this paper we prefer to focus on depicting the main elements and correlating the sequences we observed in each of our sections measured at the field.

Sequences (Ch-1 to Ch-4) within the Chipaque Supersequence

At the El Crucero section the Chipaque Formation shows at least four retrogradational intervals used to delimit depositional sequences that correspond to third order sea level fluctuations. Their characteristics and relation of its elements to the microfauna are described by Vergara *et al.* (1997). The whole formation is considered to be a supersequence by Guerrero & Sarmiento (1996), in which the following sequences can be circumscribed.

Sequence Ch-1: On top the uppermost sandstones of the Une Formation, interpreted as lowstand deposits (Guerrero & Sarmiento 1996), a transgressive surface represented by the base of the Chipaque Formation occurs. The sequence covers Cenomanian to Turonian age. The transgressive system tract is clearly differentiated from its highstand system tract upon the parasequence stacking pattern, the latter being entirely aggradational in this case (Fig. 4). In this sequence the occurrence of several bentonite layers may be correlated to those reported close to the Cenomanian-Turonian boundary by Villamil & Arango-Pardo (in press), which were deposited during a regional maximum flooding period.

Sequence Ch-2: Between m 150 and 180 the sea bottom was deepened as indicated by retrogradational parasequence sets (see Fig. 4). The transgressive surface is associated to the occurrence of planktonic microfossils such as foraminifera and calcispheres, as well as other foraminifera and phosphate nodules. Above m 200 slightly increasing sandstone banks indicate progradation of the coast line, which becomes evident in the lower part of the right column of Fig. 4.

Sequence Ch-3: A third retrogradational interval observed upon m 250 corresponds to the basal part of sequence Ch-3. Clear parasequence stacking patterns can hardly be precised because of the uncertainty caused by the covered intervals in this part (250-430 m) of the Chipaque Formation (Fig. 4).

Sequence Ch-4: Above m 430 there is evidently another retrogradational interval that depicts the lower part of sequence Ch-4, of Campanian age. The maximum flooding of this sequence is probably associated with the increasing number of foraminifera found in sample 131294-21, close to the top of the unit, where the Chipaque Formation grades into the Arenisca Dura Formation. A similar foraminiferal assemblage occurs also in the upper Chipaque Formation at the Caño Blanco section (Fig. 8), where this sequence is represented by its uppermost 40 m.

Supersequence G-1

In the Guadalupe and Palmichal Groups sharper lithological contrasts eased the identification of sequences of third order within a supercycle that comprises practically the whole Guadalupe Group and part of the Palmichal Group as used here. This supercycle is represented by supersequence G-1, described as follows.

The Arenisca Dura and equivalent Arenitas de San Antonio of the Palmichal Group is viewed here as the lowstand system track of this sequence. A marked lithologic change occurs at the contact to the Chipaque shales, although note that in the Quebrada Playonera section the sequence boundary is picked above the formational contact at an erosion surface (Fig. 7). The lowermost portion of the Arenisca Dura is considered the late highstand system tract of sequence Ch-4. In the lower half of the unit sandstone beds increase rapidly up section revealing a progradational pattern. In the rest of the unit both progradational and aggradational parasequence stacking patterns seem to occur.

We interpret the cherts and mudstones of the Plaeners Formation and Lodolitas de Aguacaliente (Figs. 8 and 12) on top of the Arenisca Dura as a transgressive system tract that records a Late Campanian-Early Maastrichtian marine flooding event. This TST can be recognized in various localities of the Eastern Cordillera, but it is difficult to observe in the Llanos Thrustbelt because the Plaeners Formation wedges out towards the E . Nevertheless, the latter unit corresponds to the "Guadalupe shale" of sequence K70 of Cooper *et al.* (1995).

In sections such as in the Quebrada Palmichal the maximum flooding surface is inferred where chert beds achieved maximum clustering, sometimes coincident with phosphatic occurrences of probable condensed genesis (*cf.* Föllmi & Garrison 1991). Above this, an increase in the proportion of mudstone to chert beds is followed by progradational sandstones that we interpret to represent a HST. Within the Plaeners Formation, a similar interval of sandstones occurs in several other localities to the E of Bogotá. Note that at the proximal section of Caño Blanco the TST of this sequence is masked by sandstone deposits and was inferred only on the basis of a good chronological control (Fig. 8).

We interpret the HST of supersequence G-1 to be represented by the upper portion of the Plaeners Formation and the Arenisca de Labor and Tierna. We observed in several outcrops basin wide a transitional contact between the Arenisca de Labor and the Plaeners Formation. A slow transition at this limit is well developed in the Quebrada Palmichal section, meaning that both units can be linked genetically into a single sequence. Parasequences of the Arenisca de Labor are aggradational to progradational (e.g. at the Páramo del Rajadero, Fig. 6). The Arenisca de Labor is equivalent to the lower part of the Arenitas de San Luis de Gaceno, in which a progradational to aggradational parasequence stacking pattern is likewise observed at the Quebrada Playonera.

The Arenisca Tierna is envisaged here as the late HST of this supersequence and at the same time the HST of a sequence (G-1a) that will be discussed below. The unit is characterized by progradating parasequences and general coarsening upward lithology, deposited in transitional or very shallow marine environments. An equivalent sandstone in the Llanos sections is not mappable as a single body of rock, but based on the chronology and array of parasequences we infer that the interval above m 40 of the Arenitas de San Luis de Gaceno in the Quebrada Playonera correlates to the Arenisca Tierna of the Bogotá Plateau (Fig. 7). In the Quebrada Playonera, a HST is supported by a prograding succession of upper shoreface deposits that ends with intertidal, coal bearing sandstones. The thoroughly development of coal deposits in the Guaduas Formation of the Bogotá Plateau comes to mind because these occurrences may be genetically related, but in a different basin position.

Sequence K90 of Cooper *et al.* (1995), was defined in the Eastern Cordillera by the Arenisca Tierna Formation and a shale unit that corresponds to the Guaduas Formation of the Palmichal Group. In their scheme, the Arenisca Tierna is described as "a sand dominated transgressive system tract" (their pag. 1431). However, we observed in all

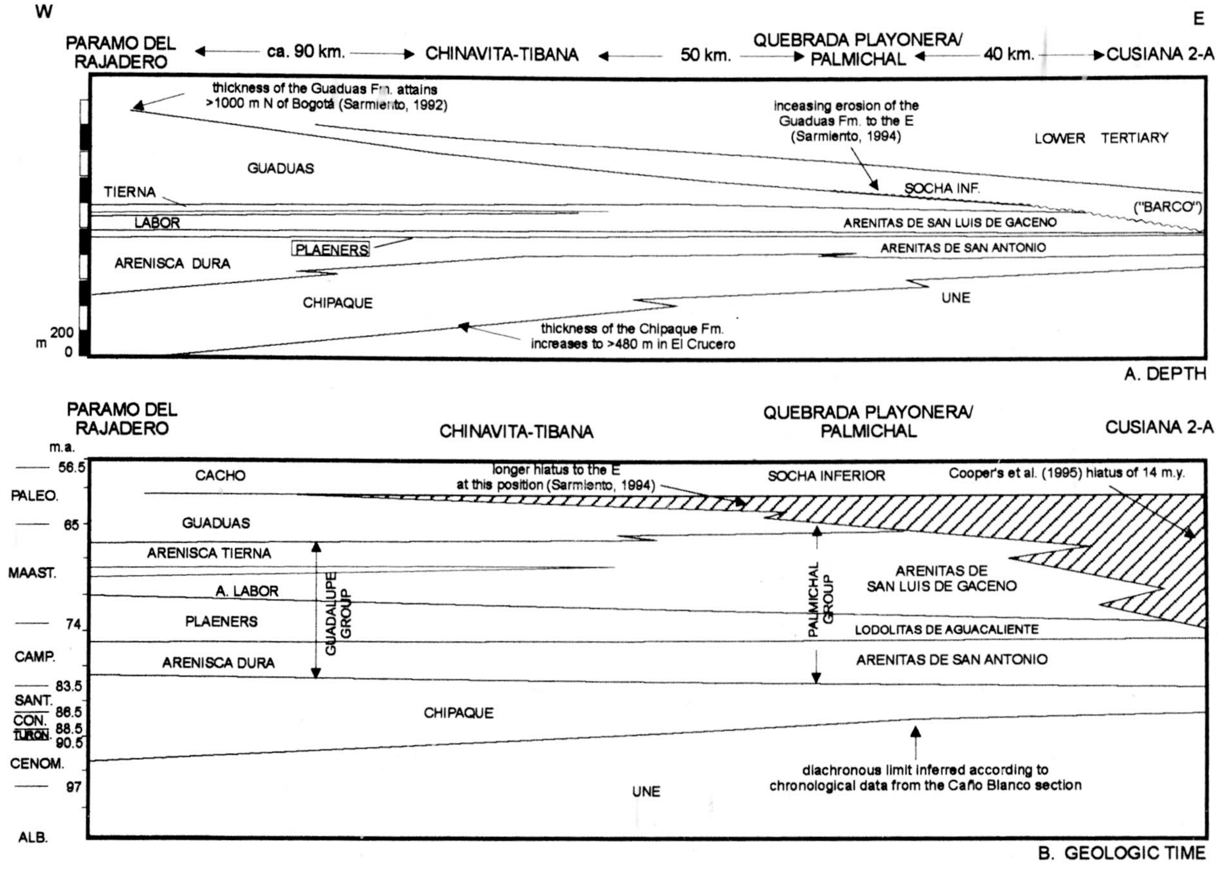

Fig. 12a. Distribution at depth of the Upper Cretaceous facies between the Páramo del Rajadero section and the Cusiana 2A well; b. chronostratigraphic diagram of the facies shown in a. Chronology after Harland *et al.* (1990). For location of the sections see Fig. 2.

sections a progradational parasequence stacking pattern and coarsening upward grain size, indicative of a regression (see also Sarmiento 1992).

Another opinion was presented by Guerrero & Sarmiento (1996), whose data indicate continental environments for the uppermost part of the Arenitas de San Luis de Gaceno. They interpreted this unit as the lowstand system tract of the superseding sequence. However, in our samples marine palynomorphs are present throughout the whole G-1 sequence, including the upper part of the Arenisca Tierna. As mentioned above, our field observations do not support a sequence boundary at the base of the Arenisca de Labor or of the Arenitas de San Luis de Gaceno.

It is interesting to note that the Arenisca Tierna (and equivalents) is a pretty constant unit of great areal extent in the Eastern Cordillera (see Díaz 1994). Indeed, HSTs are the best developed system tracts in areal extent, sometimes developing widespread fluvial deposits at the latest stage (Posamentier & Vail 1988). This would account for the continental deposits at the uppermost portion of the Arenitas de San Luis de Gaceno observed by Guerrero & Sarmiento (1996) or those present in the Maastrichtian La Tabla Formation of the Upper Magdalena Valley (Vergara 1994). Conversely, the preservation of a LST is dependent on its position in the basin and its development in very proximal sections is usually hindered or precluded by sediment bypass (*cf.* Haq *et al.* 1988).

Sequence G-1a: This is a sequence of third order that occurs in the upper portion of supersequence G-1. The "Lutitas y areniscas finas" between the Arenisca de Labor and Tierna reveals clearly a transgressive episode within the HST of supersequence G-1. These shales are well developed in the Páramo del Rajadero and other exposures to the E of Bogotá, attaining a thickness of 16 m, but in the sections of the Llanos Thrustbelt it is masked in a succession largely dominated by sandstone. However, it is likely that this system is represented by a retrogradational sandstone interval that occurs between 40-60 m in the section of the Quebrada Playonera (see Fig. 7).

A maximum flooding surface within the "Lutitas y areniscas finas" occurs close to the middle of the unit and may happen to coincide with a fossil concentration interpreted as a tempestite or a gravity flow deposit. Marine skeletal accumulations brought about by storm events can induce an apparent stratigraphic condensation because they can stir up buried fossils of different biozones or biotopes and concentrate them altogether in a single event-horizon (*cf.* KIDWELL 1993).

The Arenisca Tierna is considered here as the HST of sequence G-1a, and as discussed above, the late HST of sequence G-1, to where sequence G-1a is circumscribed. It exhibits a transitional contact to the underlying shales, and other features proper of a HST (see above).

We estimate the duration of this cycle was not longer than 3 m.y., mainly because sedimentation rates of the Arenisca Tierna may have been very high. The cycle probable took place during a part of the Early Maastrichtian, which lasted at most some 4,5 ma. (*cf.* HARLAND *et al.* 1990).

Supersequence G-2

The upper Maastrichtian mudstones of the Guaduas Formation are likely tidal flat deposits at the Caño Blanco section (see above). These rocks are coeval with the lower portion of the Guaduas Formation as described by SARMIENTO (1992). In the Páramo del Rajadero at the top of the Arenisca Tierna an interval of fine grained sandstones and mudstones with abundant glauconite are included here in the TST of this sequence. At the lowermost part of the Guaduas Formation of the Tausa section, MARTÍNEZ (1995) reported planktic foraminifera; this and the onset of deposits considered estuarine by GUERRERO & SARMIENTO (1996) allowed them to infer a transgressive surface at the base. Our data is not in disagreement to this, with the exception that this supersequence lacks a LST in our scheme, as discussed above. As pointed out by GUERRERO & SARMIENTO (1996), the Guaduas Formation at the Tausa section contains a maximum flooding followed by a HST, and probably another sequence (ST1), but these elements together with most of the sequence were obliterated by erosion in the Llanos Thrustbelt (see Fig. 12). It is our opinion that the whole Guaduas Formation represents a supersequence (G-2) which can be divided in further sequences such as those suggested by SARMIENTO (1994).

Supersequence T-1 (pars)

The Socha Inferior Formation represents the LST of supersequence T-1. It is composed mostly of coastal plain and estuarine deposits (Fig. 9) that developed regionally while the sea retreated. Within the Socha Inferior Formation, autocyclicity inherent to a probable deltaic system is responsible for local channel reactivation, as mentioned earlier. A base level drop was followed by the input of distributary channels draping and cannibalizing mudstones of the Guaduas Formation of the Palmichal Group. Thus, stream incision of the coastal plain and of other deposits occurred. In the Cusiana 2A well a type I unconformity appears to rest on top of shallow marine deposits of the Campanian (*cf.* COOPER *et al.* 1995). In the Medina-1 well the unconformity occurs above the Early Maastrichtian. The time gap of this sequence boundary is attenuated westward (see Fig. 12), to the point where the surface becomes a sharp contact on top of the Guaduas Formation, which becomes thicker in the same direction, i.e. basinward (*cf.* SARMIENTO 1994).

ADDITIONAL COMMENTS

The stratigraphic relations and chronology of the Upper Cretaceous in the study area are of paramount importance in the reconstruction of the geologic history. We argue that conventional stratigraphic nomenclature is in no way incompatible with sequence stratigraphy, whose value in the prediction of facies is hardly questionable. However, both tools should be incorporated when studying the stratigraphy of the Eastern Cordillera because of the difficulty of correlating based on sequence stratigraphic elements alone. For instance, in the proximal sections of the Llanos Thrustbelt sea level oscillations produced only subtle changes in the sedimentology due to the huge amount of sand being deposited, making difficult the recognition of sequences.

The paleogeographic setting of the sequences comprising the Chipaque Formation is somewhere between POSAMENTIER & ALLEN's (1993) zone A and B of a passive continental margin, where subsidence rather than eustasy controls the quite subtle sedimentological changes we observed. Consequently, many sequences are delimited by marine flooding surfaces that coincide with the sequence boundary. In general, all transgressive deposits are more difficult to trace as one goes eastward due to the sparse development of flooding-related mudstones.

In contrast, the change in the paleogeographic setting to a foreland basin due to the emersion of the Central Cordillera during the Early Tertiary is currently accepted. In this new setting, zones A and B of POSAMENTIER & ALLEN (1993) are in a reversed position compared to the passive margin setting. Zone A is now at the foredeep and experiences the higher subsidence. The present Llanos corresponds to zone B, where lower subsidence rates, increased effect of eustatic changes, sediment bypassing and longer hiatuses are predicted. This is applicable to sequence T-1, where a forced regression accounts for the unconformity and the LST discussed already. Additionally, COOPER *et al.* (1995:

Fig. 14) introduced zone C for those areas such as the Eastern Llanos where subsidence is outpaced by eustatic falls but the sediment supply comes from the craton, in this case from the Guyana shield, and not from the orogenic belt. Between zones B and C a permanent marine strip is predicted. We acknowledge the importance of tectono-eustatic zone C in predicting stratal architecture, but a marine corridor appears to be theoretical, as no real marine sediments have been clearly documented in the Tertiary of the Eastern Cordillera.

As pointed out before, we do not aim to discuss the sequence stratigraphy at a regional scale, although we do believe that at least our proposed supersequences have an expression in vast areas. Further research is necessary to illustrate this properly. We present here alternative explanations to existing models, based on the interpretation of our sections. Moreover, we delineated third order sequences as those within the Chipaque Formation and the Guadalupe Group.

Finally, a few comments on the sequence stratigraphic models proposed so far for the Llanos Thrustbelt are deemed useful to draw the attention towards the questions that future work should tackle. Many of them were already discussed as they have nomenclatural implications. We were unable to correlate our outcrop data to those of many oil wells; this task was hampered by poor chronologic control or palynological resolution. The establishment of palynological biozonations for the Cretaceous of the study area still has to be pursued.

The sequence stratigraphic model of Cooper *et al.* (1996) deserves documentation of some aspects, especially concerning the chronologic framework and the incorporation of detailed columnar sections in areas such as the Eastern Cordillera. A specific discussion of this was furnished by Guerrero & Sarmiento (1996). Conversely, the stratigraphic scheme of Guerrero & Sarmiento (1996) relies too much on data from a single locality. Allostratigraphic units are indeed an alternative tool for correlation of broader scope, but most stratigraphers currently prefer a sequence stratigraphic approach to study the cyclicity of sea level changes and the basin evolution. In general, we regard both works as relevant contributions to the geology of the Llanos Thrustbelt and interestingly to us, they have many points of concurrence with the ideas presented herein.

CONCLUSIONS

The Chipaque Formation in the Eastern Cordillera was deposited during the Cenomanian to Campanian, but in the proximal section of Caño Blanco deposition of its typical platform mudstones began only until the Santonian. Between the Guadalupe (Campanian-Maastrichtian) and the revised Palmichal Group (Campanian-Late Maastrichtian) there are marked differences in lithological features and age, which led us to restrict the former Group to its type area close to the Bogotá plateau. We conclude that the Palmichal Group is the most suitable name for the Llanos Thrustbelt area, but its modification was necessary due to the presence of an unconformity at the base of the Socha Inferior Formation, which is excluded from the mentioned group. We endorse the use of the Palmichal Group and redefined it as comprising the formations known as Arenitas de San Antonio, Lodolitas de Aguacaliente and Arenitas de San Luis de Gaceno, retained here, and the Guaduas Formation. Mappability of the Palmichal Group is demostrated in published maps, whose validity is maintained here by preserving this name.

The correlation between the formations of both groups is stated as follows. The Arenisca Dura Formation correlates with the Arenitas de San Antonio, the Plaeners Formation with the Lodolitas de Aguacaliente, and the Arenisca de Labor and Arenisca Tierna are coeval with the Arenitas de San Luis de Gaceno. The Guaduas Formation of the Palmichal Group correspond to the lowermost part of the Guaduas Formation of the Bogotá Plateau, and the Socha Inferior Formation to the upper part of the Guaduas Formation and probably also to the Cacho Formation of the Bogotá Plateau.

The depositional sequences we have identified in outcrops are observed more easily in the Bogotá Plateau area than in the Llanos Thrustbelt due to the eastward wedging out of marker horizons such as the Plaeners and "Lutitas y areniscas finas" of the Guadalupe Group. We have identified third order sequences (Ch-1-4) circumscribed to a second order cycle represented by the supersequence Chipaque Formation. These sequences exhibit subtle sedimentological changes but marked changes in the parasequence stacking pattern. The supersequences generated during the closing phase of the basin (G1-2: Guadalupe Group + Guaduas Formation) bear also sequences that are more evident upon shifts of shoreface to offshore deposits. The last supersequence (T-1: Socha Inferior Formation) responds to a forced regression followed by the regional onset of continental deposition.

ACKNOWLEDGMENTS

This work resulted from an agreement between Ingeominas and Ecopetrol-ICP. We thank both institutions for logistic and financial support. Dr. Ignacio Martínez (Canberra) is gratefully acknowledged for his enthusiastic collaboration during the project. Bioss and Bioestratigráfica provided the palynological analyses. Special thanks to Milton Rueda for discussion of the palynological results. Carlos Arce (Esso) kindly furnished samples of the Medina-1 well. Thanks to BPX Colombia and Esso Colombiana for permission to publish the logs of the Cusiana- 2A and Medina-1 wells, respectively. Finally, Dr. Richard George contributed greatly to improve the paper by careful review of the text.

APPENDIX 1

(synthesized from the report of Bioss Ltda)

Páramo del Rajadero section

Sample 02.12.94.08

Andalusiella gabonense
Andalusiella mauthei
Senegalinium bicavatum
Andalusiella spp.
Palaeocystodinium spp.

Age: Late Campanian to Early Maastrichtian.

Sample 021204-09 to 10

Dinogymnium euclaensis
Dinogymnium acuminatum
Dinogymnium aff. acuminatum
Achomosphaera spp.
Dinogymnium spp.

Age: Santonian to early Maastrichtian.

Sample: 021294-11 to -12

Senegalinium bicavatum
Dinogymnium euclaensis
Achomosphaera sagena
Hystrichodinium pulchrum
Spiniferites ramosus
Senegalinium spp.
Achomosphaera spp.
Dinogymnium spp.
Cyclonephelium spp.

Age: Late Campanian to Early Maastrichtian

Sample 021294-13 and -14

Senegalinium bicavatum
Andalusiella spp.
Senegalinium spp.
Achomosphaera spp.
Achomosphaera sagena
Spiniferites spp.
Dinogymnium
Dinogymnium acuminatum
Odontochitina operculata
Andalusiella gabonense
Hystrichodinium spp

Age: Late Campanian to Early Maastrichtian

Sample 021294-17

Proxapertites humbertoides
Psilamonocolpites ciscudae
Psilatriletes guaduensis
Psilamonocolpites medius
Longapertites sp.
Dinogymnium aff. acuminatum

Age: Maastrichtian

Chinavita-Tibaná section

Sample: 081294-01 and -03

Dinogymnium euclaensis
Dinogymnium aff. heterocostatum
Andalusiella mauthei
Andalusiella gabonense
Senegalinium bicavatum
Cerodinium granulostriatum
Spiniferites ramosus
Senegalinium spp.
Achomosphaera spp.
Andalusiella spp.
Trithyrodinium (?) spp.
Dinogymnium spp.

Age: Late Campanian-Early Maastrichtian

Sample: 081294-19 (not illustrated)

Senegalinium bicavatum
Hystrichodinium pulchrum
Coronifera oceanica
Spiniferites ramosus
Achomosphaera spp.
Trithyrodinium (?) spp.

Age: Campanian

El Crucero section

Sample: 131294-17

Dinogymnium spp.
Hystrichodinium spp.
Senegalinium spp.

Age: Senonian

APPENDIX 2

(synthesized from the report of Bioestratigrafica Ltda.)

Quebrada Playonera section

Samples: 030495-01 to -04

Odontochitina operculata
Odontochitina costata
Oligosphaeridium complex
Dinogymnium heterocostatum
Sinidinium sverdrupianum
Xenasscus ceratioides
Retipollenites "afropollensis"
Tetradites "carolinensis"
Camarozonosporites "tenuis"
Araucariacites australis
Cyathidites minor
Cyathidites majaor

AGE: Late Santonian to Early Campanian

Samples: 030495-05 to 060495-05

Dinogymnium acuminatum
Dinogymnium nelsonense
Dinogymnium longicornis
Dinogymnium undulosum
Dinogymnium digitus
Dinogymnium vozzhennikovae
Alisogymnium euclaense
*Trichodinium castanea**
Circulodinium distinctum
Operculodinium ìluciitioidesî
Palaeohystrichophora infusoriodes
Alterbidinium sp.
Impaagidinium grandis
Trithyrodinium fragile
Subtilisphaera sp.
Hystrichodinium pulchrum

AGE: Campanian

Samples 060495-01,03,05

Andalusiella polymorpha
Andalusiella mauthei
Senegalinium bicavatum

AGE: Late Campanian

Samples: 060495-06 to 290395-04

Andalusiella mauthei
Andalusiella polymorpha
Senegalinium bicavatum
Senegalinium laevigatum
Cerodinium granulostriatum
Polykrikos ? sp.

AGE: Early Maastrichtian

Samples: 310395-02, 04 and 05

Spinizonocolpites baculatus
Araucariacites australis
Mauritiidites franciscoi
Retidiporites magdalenensis
Caamarozonosporites "tenuis"
Proxapertites operculatus
Synncolporites lisamae
Dinogymnium sp.
Senegalinium sp.
Alisogymnium aff. euclaense

AGE: Late Maastrichtian

Samples: 310395-06 to 010495-10

Foveotriletes margaritae
Ulmoideipites krempii
Spinizonocolpites sutae
Maauritiidites franciscoi
Bombacacidites cf. annaae
Longapertites vaneendenburgi
Proxapertites psilatus
Psilatriporites "cesarensis"
Retidiporites magdalenensis
Clavatriletes mutisii
Retitricolpites microreticulatus

AGE: Early Paleocene

Caño Blanco section

Sample 200295-01 to 200295-05

Droseridites senonicus
Dicolpites ìobtusipollusî
Foveomonoletes ìprofundusî
Retipollenites ìafropollensisî
Araucariacites australis
Palaeohystrichophora infusorioides
Circulodinium distinctum

AGE: Coniacian to Santonian

Samples 200295-06 to 210295-03

Oligosphaeridium complex
Coronifera oceanica
Trithyrodinium fragile
Isabelidinium acuminatum
Dinogymnium heterocostatum
Alisogymnium euclaense
Odontochitina sp.
Araucariacites australis
Dicolpites ìobtusipollusî
Cyathidites minor
Cyathidites major

AGE: late Santonian-early Campanian

Samples 210295-04 to 220295-11

Alisogymnium euclaense
Dinogymnium heterocostatum
Dinogymnium undulosum
Dinogymnium nelsonense
Dinogymnium vozzhennikovae
Dinogymnium longicornis
Dinogymnium acuminatum
Impagidinium grandis
Odontochitina operculata
Operculodinium "luciitioides"
Subtilisphaera sp.
Circulodinium distinctum
Cordosphaeridium sp.
Alterbidinium sp.
Trithyrodiniuim fragile
Palaeohystrichophora infusorioides
Leiosphaeridia sp.
Cyathidites minor
Araucariacites australis

AGE: Campanian

Sample 230295-02

Trichodinium castanea
Andalusiella mauthei
Andalusiella polymorpha
Senegalinium bicavatum

AGE: Late Campanian

Sample 230295-03

Andalusiella mauthei
Andalusiella polymorpha
Cerodinium granulostriatum
Senegalinium bicavatum
Leiosphaeridia sp.
Dinogymnium aff. nelsonense
Polykrikos ? sp.

AGE: Early Maastrichtian

Sample 230295-05 to 230295-10

Gabonisporites vigourouxi
Echimonocolpites grandispiniger
Zlivisporis blanensis
Ulmoideipites krempii
Proteacidites dehaani
Acanthotriles "ardilensis"
Clavatriletes mutisii
Echitriporites suescae
Dinogymnium acuminatum

AGE: Late Maastrichtian

Sample 230295-12 to 240295-02

Proxapertites psilatus
Scabradiporites ìlaurensisî
Clavatriletes mutisii
Psilatriporites "cesarensis"
Proxapertites humbertoides
Mauritiidites franciscoi
Psilamonocolpites medius
Bombacacidites sp.

AGE: Early Paleocene

Medina-1 well

depth 10420' - 10450' (cuttings)

Mauritiidites franciscoi
M. franciscoi var. *pachyexinatus*
Spirosyncolpites spiralis

Retitricolporites sp.
Retitricolporites gulanensis
Tetradites aff. magnus
Polyadites sp.
Bombacacidites annae
Proxapertites cursus
Psilatricolpites sp.
Psilamonocopites sp.
Psilatriletes group

AGE: Paleocene
(presence of Miocene-Paleocene cavings)

hiatus at approximately 10765'

depth 10870'-10900'

Achomosphaera sagena
Lejeunia sp.
Palaeohystrichophora infusoroides
Andalusiella polymorpha
Andalusiella mauthei
Andalusiella sp.
Senegalinium sp.
Senegalinium bicavatum
Trithyrodinium fragile
Spiniferites sp.
Operculodinium sp.
Paleocystodinium aff. australinum
Exochosphaeridium sp.
Spinidium sp.
Cordosphaeridium ? sp.
Circulodinium aff. distinctum
Polykrikos sp.

AGE: Early Maastrichtian

depth 10900í-10930

Andalusiella polymorpha
Andalusiella mauthei
Andalusiella sp.
Spinidium sp
Trithyrodinium fragile
Trichodinium castanea
Senegalinium bicavatum
Senegalinium laevigatum
Senegalinium sp.
Paleocystodinium ? sp.
Paleohystrichophora infusorioides
Cerodinium granulostriatum
Alterbidinium sp.
Spiniferites castanea
Isabelidinium sp.
Lanternosphaeridium sp.
Dinogymnium undulosum
Xenascus ceratioides
Polykrikos ? sp.

AGE: Late Campanian

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Manuscript submitted: April, 1997