Stratigraphy of the Lower Cretaceous Rosablanca and Cumbre Formations, Utica Sandstone and Murca Formation, West Flank, Eastern Cordillera, Colombia

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RESUMEN

Las Areniscas de Utica (Berriasiano), la Formación Murca (Valanginiano Superior), la Formación Cumbre (Berriasiano) y la Formación Rosablanca (Valanginiano), comprenden la sequencia sedimentaria del Cretácico Inferior en la parte central de la Cordillera Oriental.

Este trabajo presenta un posible ámbito de depósito para las unidades clásticas y calcáreas del Cretácico Inferior. Durante el Valanginiano Inferior la cuenca fue dividida en un depocentro donde se depositó la Formación Murca, una plataforma al sureste donde se depositaron las informalmente llamadas Areniscas de Utica, y una plataforma hacia el norte donde se depositaron las formaciones Cumbre y Rosablanca. Estas últimas unidades se depositaron en un ambiente marino somero en la subcuenca Tablazo-Magdalena, mientras que la Arenisca de Utica fue depositada en aguas someras y la Formación Murca fue depositada en aguas profundas por corrientes turbidíticas. Los sedimentos para las unidades aflorantes al sur provinierón del occidente, probablemente de la Paleocordillera Central, mientras que el área de aporte para las unidades del norte correspondio a los macizos de Santander y Floresta. El nombre de Formación Murca es propuesto para la unidad turbidítica basal que aflora en el núcleo del anticlinal de Murca y se propone una localidad tipo para esta unidad.

ABSTRACT

The Utica sandstone (Berriasian), Murca Formation (Upper Valanginian), Cumbre Formation (Berriasian) and Rosablanca Formation (Valanginian) comprise the Lower Cretaceous sedimentary sequence in the central part of the Cordillera Oriental.

This work presents a probable depositional setting for the Lower Cretaceous clastic and calcareous units. The Late Valanginian basin was divided into a central depocenter (Murca Formation), a southwestern shelf (Utica sandstone) and a northern platform (Cumbre and Rosablanca formations).

The Cumbre and Rosablanca formations were deposited in shallow marine environments in the Tablazo-Magdalena basin, while the Utica sandstone and Murca Formation were deposited in shallow water and deeper water respectively by turbiditic currents. The sediments for the southern units came from the west, probably from the Paleo-Central Cordillera. The sediments for the northern units came from the Santander-Floresta paleomassif. The name Murca Formation is proposed for the turbiditic basal unit that crops out in the core of the Murca anticline, and a type locality is proposed.

INTRODUCTION

The study area is located 100 km northwest of Bogotá, on the west side of the Cordillera Oriental, the easternmost range of the Northern Andes mountain chain. It occupies the region between 5°10'-5°50'N latitude and 73°50'-74°15'W longitude, on topographic sheets 169, 170, 189, 190, and 208, published by the Instituto Geográfico Agustín Codazzi (IGAC)(Figure 1).

The area is characterized by mountain ranges of deformed Cretaceous rocks with elevations that reach up to 2,800 m above sea level in the central part of the area and descend to 200 m above sea level in the Middle Magdalena valley in the northwestern portion of the area. There are several roads in the area, but access is principally by unpaved or partially paved roads such as the Bogotá-Pacho-La Palma, Chiquinquirá-Otanche, La

Belleza-Florián and Puerto Boyacá-Otanche roads. Access to many parts is by trails or old paths.

This paper deals only with exposures of the Lower Cretaceous sequences in the northeastern and southern parts of the area. In the northern portion of the area, the Lower Cretaceous succession is formed by the Cumbre and Rosablanca formations which extend from the Berriasian to Valanginian (Alfonso, 1985; Etayo & Rodríguez, 1985). In the southwestern part of the area, in the Villeta anticline, the Utica sandstone is dated as Upper Berriasian to Upper Valanginian (Etayo, writing comunication). In the central portion, in the Murca anticline, is the informally named Murca sandstone unit (Murca Formation), which has a Upper Valanginian age based on fossils collected where the type section was measured. This is overlain by the Villeta Group.

These latter units, the Utica sandstone and Murca sandstone (Murca Formation), have been recognized in previous works as the Cáqueza sandstone, the upper part of the Cáqueza Group which extends from the Tithonian to Hauterivian (Bürgl, 1961; Campbell & Bürgl, 1965; Thompson, 1966; Julivert, 1968; Gallo, 1977).

The purpose of this paper is to present a stratigraphic analysis of the lower Cretaceous clastic and calcareous basal units on the western margin of the Cordillera Oriental, and to establish the depositional setting of these units. The name Murca Formation is proposed for the basal unit informally called the Murca Sandstones, and a type locality is proposed.

The area is characterized by two structural styles. In the western part of the area major faults such as the La Salina Thrust, the La India Thrust, Cambrás and Canoas-La Peña Thrust, Dos Hermanos Fault, and La Honda Fault have a predominant N-NE trend (Moreno, 1989). In the eastern part of the area deformation is less intense. I would like to thank the staff of TENNECO-HOCOL S.A. and ESRI (University of South Carolina) whose continued support made this study possible.

REGIONAL GEOLOGICAL SETTING

The Cordillera Oriental of Colombia extends from Mocoa in the south to Cúcuta in the north. North of 8° Latitude, the Cordillera Oriental bifurcates to form the Serranía de Perijá along the Colombian-Venezuelan border and the Mérida Andes in Venezuela (Bürgl, 1961). The east and west verging crustal uplifts along the Cordillera Oriental are bounded by reverse faults (Campbell & Bürgl, 1965; Julivert, 1970; Irving, 1975). They are bounded in the western part by the La Salina and Cambao-Cambrás thrust along the Magdalena Valley and in the eastern part by the Guaicáramo fault system.

The Cordillera Oriental of Colombia, within the east Andean province, is built of Mesozoic and Tertiary strata deformed chiefly during Tertiary orogeny (Bürgl, 1961; Julivert, 1968; Fabre, 1983). These rocks form a sedimentary cover overlying a basement of lower Paleozoic and Precambrian metamorphic and igneous rocks, and little deformed and metamorphosed upper Paleozoic rocks (Julivert, 1970). The basement crops out within and near the chain in several massifs, including the Santander, Floresta, Quetame, Garzón and Serranía de la Macarena.

During the early Mesozoic the region was characterized by tensional fault movement with extrusion of alkaline magmas (Bürgl, 1967; Maze, 1984). In the east Andean Region, the early and middle Mesozoic were periods of essentially continental deposition and of erosion. The Triassic was initiated by block faulting and by extrusion of alkaline acid magmas (Bürgl, 1967). In Late Triassic time the southerwestern portion was invaded by a local marine transgression from the west Andean Sea. At the beginning of the Liassic, renewed fault movements took place accompanied by intrusions of initially acidic, and finally basic magmas. The intrusives were located on the eastern flank of the Cordillera Central and formed a volcanic swell (Bürgl, 1967, Aspden *et al.*, 1987). During Middle and Late Jurassic times the greater part of the East Andean region was a lowland without notable erosion or sedimentation.

From Tithonian to Albian times, the region progressively subsided and became a marine province in which a thick and extensive sequence accumulated, containing some intrusive bodies in the lower part (Bürgl, 1961, 1967; Julivert, 1968; Etayo, 1969; Fabre, 1983, among others). The Cretaceous section has been subdivided into four cycles or sequences separated by unconformities, which are recognized by different criteria such as distinct intervals or surfaces, paleontological hiata, marked changes in geographic distribution, onlap of sediments, and basins with marked changes in lithologies. These cycles began in the Tithonian and lasted until Maastrichtian times, (Bürgl, 1961; Campbell & Bürgl, 1965; Etayo *et al.*, 1969; Allen *et al.*, 1988). According to Bürgl (1961), the mid-Cretaceous depositional basin was bounded on the west by the Triassic-Jurassic uplift of the Cordillera Central and on the east by the Guyana Shield.

There are some stocks, dikes, and sills of gabbroic composition intruding the flanks of the central part of the Cordillera Oriental. Trümpy (1943) reported the youngest porphyries (the most basic ones) as possibly of Early Cretaceous age. In the Muzo emerald district, ultrabasic intrusions in Albian Rocks were found by Gannser (1945, *in* Trümpy 1943). Basic intrusions near the Guaguaquí River in the northwestern part of the area are recorded by Campbell & Bürgl (1965). All of these intrusive bodies found in the central part of the Cordillera were studied by Fabre & Delaloye (1983). They postulated that the presence of these bodies in the most subsident part of the basin, where the Cretaceous transgression began, shows that it was a possible zone of weakness of the continental crust in the area.

PREVIOUS WORK

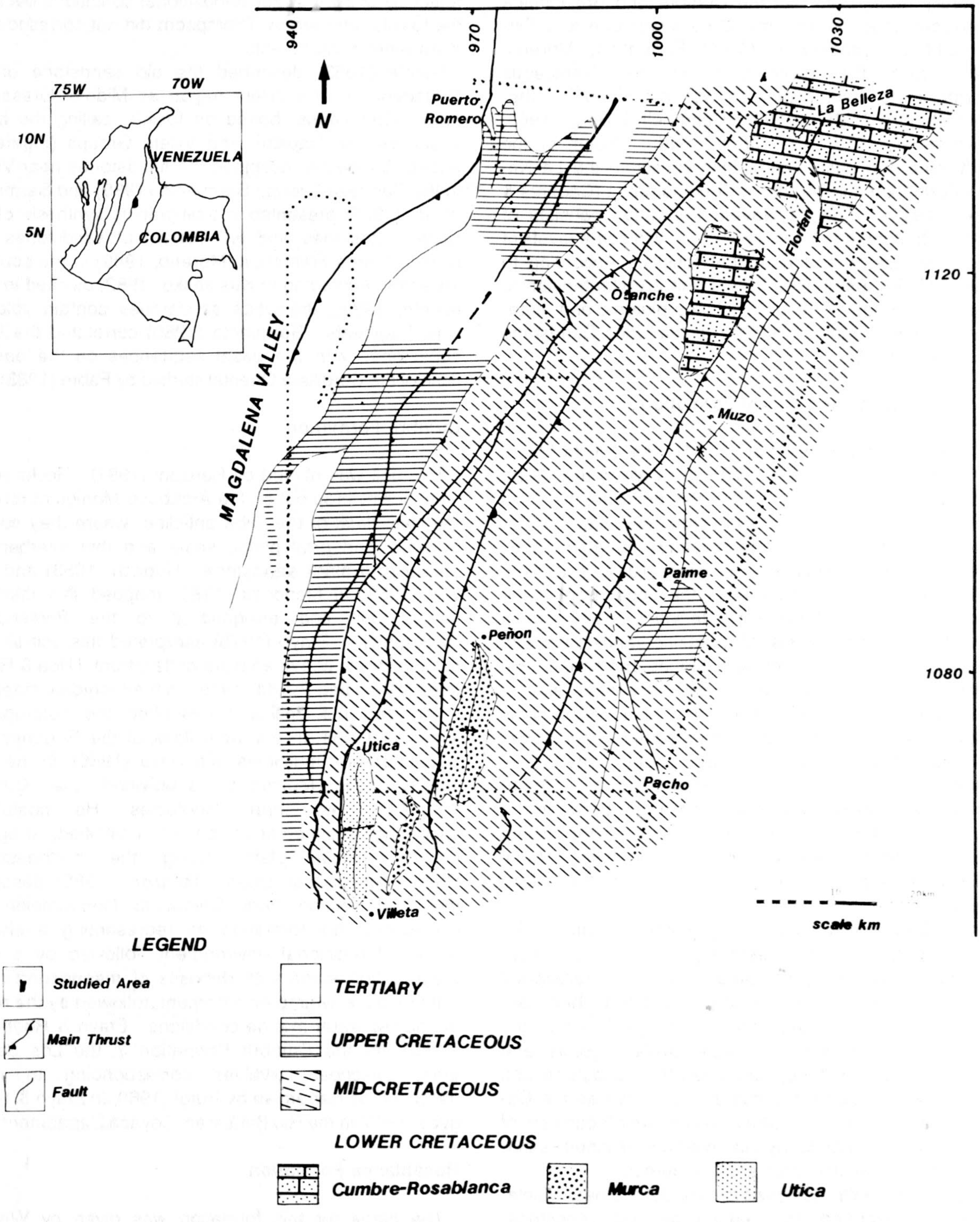

FIGURE 1- Location and geologic map of study area.

There is no single comprehensive work which concerns the stratigraphy of the area of study. It is generally recognized that the Cumbre and Rosablanca formations together with the Utica sandstone and Pinzaima-Murca sandstone (Murca Formation, Moreno, 1989,) form the lower cycle of the Cretaceous (Berriasian to Hauterivian) as was described in other areas (Figure 2; Bürgl, 1961; Campbell & Bürgl, 1965; Etayo *et al.*, 1969; Allen *et al.*, 1988). South of the study area, the basal sandstones constitute the La Naveta Formation near Apulo, in Cundinamarca (Cáceres & Etayo, 1969). The La Naveta Formation consists of medium to coarse grained sandstone with some levels of limestone, corals and abundant fossils. According to Etayo (1969), ammonites in this unit are Hauterivian to Berriasian in age. This unit includes plutonic and metamorphic lithic fragments similar to the Utica Sandstone (Allen *et al.*, 1988).

Utica Sandstone and Murca Formation

According to Champertier (1961), the Villeta-Murca anticlinorium is asymmetric, with axes along the Villeta and Murca Rivers. In the core of this anticline, the Utica sandstone and Murca Formation crop out (called the Cáqueza sandstone) consisting of sandy conglomerates, sandstones and claystones. Hubach (1931, *in* Julivert, 1968) named the sandstones of the upper part of the Cáqueza Group (Tithonian-Hauterivian) the Cáqueza sandstones. They consist of quartzitic sandstones with interbedded black ferruginous siltstones and shales. He recognized the Cáqueza Group on the eastern side of the Sabana de Bogotá. According to a petrographic study by Aalto (1971, 1972), the Cáqueza sandstones are red, white or gray, inmature, poorly sorted, very angular to angular, orthoquartzitic sandstones. Champertier (1961) also recognized sandstones between the towns of Villeta and Utica in the core of the Villeta anticline, and between Nimaima and La Peña. These sandstones are overlain by the shales of the Villeta Group.

Later, Campbell & Bürgl (1965) described from the Rio Murca anticline in the western part of the Cordillera Oriental a sequence of sandstone and interbedded black shale, where the individual sandstone beds are thin (10-80 cm) and coarse grained with the characteristic presence of large pyrite crystals and convolute bedding. They compared this sandstone with the Hauterivian sequence commonly known as the Cáqueza Sandstone in the Ubalá region, which consists of hard, dark, quartzitic, pyritic, medium grained sandstone and interbedded black shale (Figure 2).

Thompson (1966) assigned the sandstone near Villeta, which is described as medium bedded sandstone, generally medium to coarse grained, probably deposited as turbidites in a deep Cretaceous basin, to the upper part of the Cáqueza Group. According to fossil control studied by Bürgl, Thompson (1966), assigned this sandstone to the Hauterivian. Gallo (1977) also described the sandstone near Utica as the Cáqueza sandstone, but differed from Thompson (1966) by suggesting relatively shallow water depositional conditions because the fossils reported by Thompsom did not correspond to deep water environments.

García (1983) described the old sandstone of the Cretaceous in the Villeta region as Middle Jurassic to Lower Cretaceous, based on fossils, calling the basal sequence the Trapiche and Villeta Groups (Figure 2). Acosta & Obando, assigned the sandstones near Villeta to the Cáqueza Group. Sarmiento (1985) and Sarmiento *et al.*. (1985) presented a stratigraphic synthesis of the Utica Sandstones and K1 interval of sandstones and shales (Murca Formation, Moreno, 1989) in the south of the area. According to Kuslanskg (1982, as cited in Sarmiento, 1985), the Utica sandstones contain volcanic lithic fragments. Sarmiento (1985) correlated the Utica sandstones with the basal sequences on the eastern flank of the Cordillera Oriental studied by Fabre (1983).

Cumbre Formation

This unit was named by Renzoni (1981). Rocks at the type locality crop out on the Arcabuco-Moniquirá road on the west flank of the Oiba anticline, where they consist of black and grey pyritic shale and thin interbeds of greenish to black sandstone. Hubach (1953) and Julivert (1958, *in* Mendoza, 1985) mapped this then unnamed unit and assigned it to the Portlandian(-Valanginian). Etayo (1978) interpreted this unit as tidal flat sediments above an older deltaic front. Ulloa & Rodríguez (1979) and Pulido (1979), in their regional mapping, recognized the unit and described the outcrops as lenticular forms on the west flank of the Portones and Sabanagrande anticlines. Mendoza (1985), in the type locality near Moniquirá, subdivided the Cumbre Formation into three lithofacies. He postulated oscillating sedimentation on an unlithified, irregular, coastal alluvial plain during the northeastward Cretaceous transgression. Renzoni (1985) described the road section from Chima to Contratación. He considered this formation as representing a shallow marine depositional environment, followed by a delta progradation stage with deposits of meandering rivers within a back swamp environment, followed by the return of shallow water marine conditions. Etayo & Rodríguez (1985), for the Cumbre Formation in the Los Santos area, described bivalves corresponding to types described as Barremian by Bürgl (1960, *in* Etayo & Rodríguez, 1985) in the Rio Batá area, Boyacá Department.

Rosablanca Formation

The name for this formation was given by Wheeler (1929, as reported in Morales, 1958). This unit has been mapped in the Mesas and Cuestas region. Its stratigraphy has been studied in detail in the Rio Sogamoso area by Zamarreño (1963, *in* Alfonso, 1985), who subdivided the formation into seven levels. The lower levels

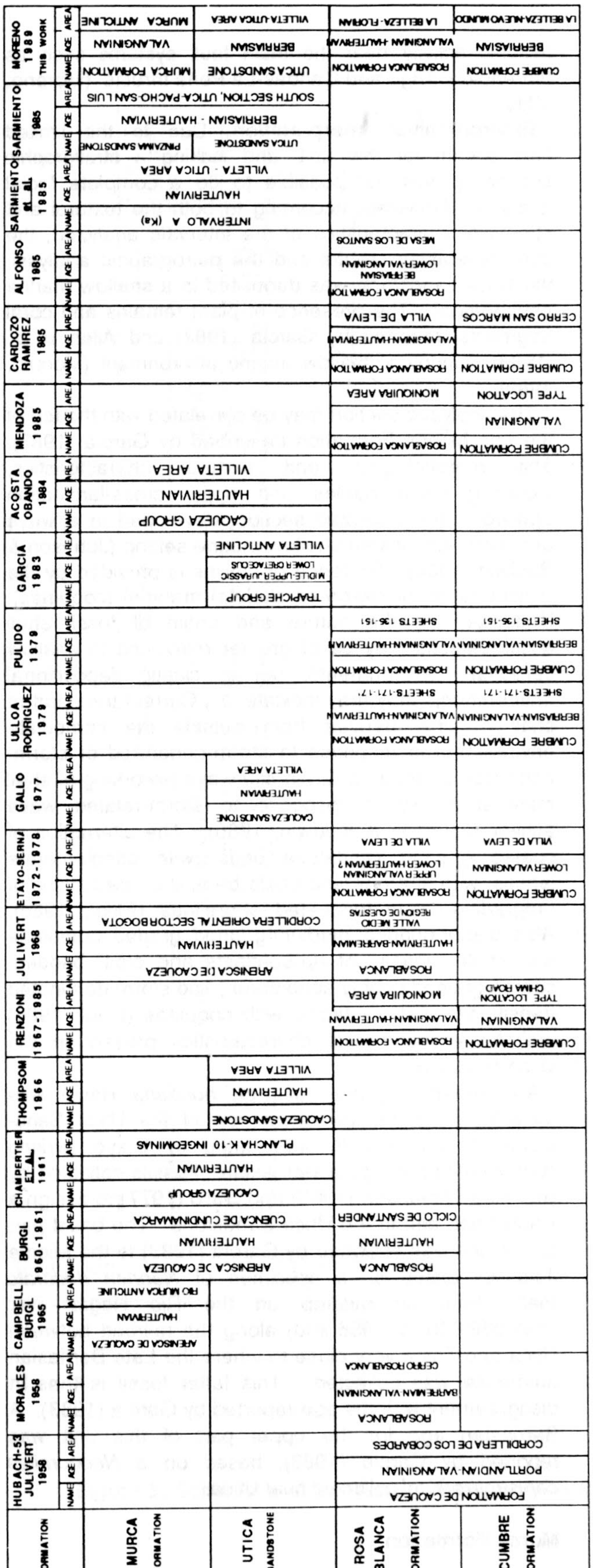

FIGURE - 2. Lithostratigraphic nomenclature of the Cretaceous basal units in the central part of the Eastern Cordillera, Colombia.

were deposited in evaporite facies in shallow-marine environments (Alfonso, 1985). According to the fossil control (Morales *et al.*, 1958; Julivert, 1968), this unit is Barremian in the northern part, Hauterivian in the Mesa San Gil region, and Valanginian age in the Villa de Leiva area (Julivert,1958; 1968). In the Villa de Leiva area, Miller & Etayo (1972) suggested a Late Valanginian to Early Hauterivian age for the formation. Etayo & Rodríguez (1985) suggested a Late Valanginian age for this formation based on ammonites. The lower part of the Rosablanca Formation has features of a modern sabkha (Alfonso, 1985). Cardozo & Ramírez (1985), in the Villa de Leiva area, described three local micro-sequences within the Rosablanca Formation, with typical facies in the form of interdigitated beds which reflect depositional continuity.

STRATIGRAPHY

The Utica sandstone (Berriasian-Valanginian), Murca Formation (Valanginian), Cumbre Formation (Berriasian), Rosablanca Formation (Valanginian-Hauterivian), and Villeta Group (Valanginian-Coniacian), comprise the Lower and mid-Cretaceous sedimentary sequence in the study area. Both the Utica Sandstone and the Murca Formation were referred to in early works as the Cáqueza sandstone, the upper part of the Cáqueza Group extending from Tithonian to Hauterivian times (Champertier *et al.*, 1961; Bürgl, 1961; Campbell & Bürgl, 1965; Thompson, 1966; Julivert, 1968; Gallo, 1977; Ulloa, 1988).

Utica Sandstone

In previous works, the informally named Utica Sandstone was referred to as the Cáqueza Sandstone, of the upper part of the Cáqueza Group (Champertier, 1961; Thompson, 1966; Gallo, 1977; Acosta & Obando, 1984; Ulloa, 1988). The Utica Sandstone was named the Trapiche Group by García (1983), who proposed subdivision into the Los Monos and Cuné formations with a total thickness of 600 m. Later Sarmiento *et al.* (1985) and Sar miento (1985) presented a stratigraphic synthesis of the informally named Utica sandstone (Figure 2). The Utica sandstone is exposed in the southwestern portion of the study area, and was recognized on the railroad between Utica and Tobia in the core of the Utica anticline (Figure 3). This basal sandstone is approximately 500 m in thickness and consists mainly of yellow gray, coarse to fine grained, graded sandstone with black shales interbedded, with some limestone at the top of the unit . The lowermost part of the unit consists of black shales (mudstone, Dott, 1964) interlayered with massive, parallel bedded, yellow-gray sandstones (arkosic wackes, Dott, 1964). Petrographic analysis of the mudstones shows 90% clay minerals, 3% quartz grains and 7% heavy minerals such as pyrite and mica sheets (Moreno, 1989). The petrographic analysis of the sandstones shows a large amount of siliceous material in the sense of Dott (1964), who included the chert fraction in the quartzose fraction . The sandstone contains igneous and sedimentary lithic fragments (Moreno, 1989). These petrographic characteristics and the high amount of matrix permit classification of these rocks as arkosic wackes (Dott, 1964, Figure 5a).

The coarse grained sandstones start with a sequence of coquina lenses and conglomeratic, fine grained sandstone with cobble sized clasts and intraclasts of black mudstone. The conglomeratic sandstones are present as lenses with quartz pebbles within parallel laminated beds 20-80 cm thick. Up-section the sandstones are more abundant, and grade to siltstone and mudstone. The upper part of this unit consists of conglomeratic sandstones and coarse to fine grained sandstones with abundant coquina lenses, and conglomeratic sandstone beds 12-20 cm thick (Moreno, 1989). The sandstone beds contain cross-bedding in sets 5-10 cm thick. The coquina lenses consist of small fragments of bivalve shells, which are interlayered each 2 meters. Sedimentary structures such as cross-bedded sandstone beds interlayered with very finely parallel laminated mudstone with assymetric ripples on the bedding planes were recognized and determined on the eastern flank of the Utica anticline on the railroad between Tobia and Utica. On the road between Villeta and Utica, near La Magdalena, the Utica sandstone also crops out. Here the unit consists of interlayered beds of mudstone, with lenses of gastropods and oysters, and calcareous sandstones with plant fragments, coral fragments, and low angle cross-stratification with symmetrical ripple marks. The sandstone beds exposed in that location contain coarse to fine grained, massive beds 1-2 m thick with some conglomeratic lenses. The upper part of the Utica sandstones was observed near Utica, where it consists of black limestone beds with intercalations of black shales. They present sigmoidal cleavage perpendicular to the stratification, indicating tectonic activity near the main fault systems such as the Alto del Trigo and Canoas-La Peña thrusts (Moreno, 1989).

Environmental Interpretation. Due to the limited field control for this unit, and lacking a stratigraphic section, it was not possible to do a complete facial analysis. However, according to both the textural and structural characteristics of the intervals analyzed, the clay mineralogy results and the petrographic analysis, the Utica sandstone was deposited in a shallow marine environment. The presence of plant remains and coral fragments, reported by García (1983) and Allen *et al.* (1988), support a shallow marine environment (Moreno, 1989).

The analyzed section may be correlated with the top of the Los Monos Formation described by García (1983). The morphological and textural characteristics, including wave ripples and ripple cross-lamination upward in the analyzed section, developed in a wave and storm-dominated shallow marine setting (Johnson & Baldwin, 1986). Evidence of storms is provided by the concentration of reworked skeletal material (coquinas). Understanding the nature and origin of fossil shell accumulations may be of greater relevance to shallow carbonate environments, but in clastic depositional environments they may indicate: 1-) Current transport of shell material derived from outside the immediate environment in response to storm-generated or storm-enhanced currents; or 2-) in-situ wave reworking of shell material mainly in response to storm-related wave activity (Johnson & Baldwin, 1986). The alternation of coarse grained sandstone beds, with conglomerate lenses, with siltstone and shale beds is characteristic of prograding wave-dominated shorelines (Elliot, 1986). Also, planar bedded, medium grained, graded sandstone and shale lenses of rip-up-clasts and cross-bedded, coarse grained pebbly sandstone , and storm dominated transitional offshore facies with coquinas (Elliot, 1986) are the environmental characteristics present in the Utica sandstones.

An ammonite (*Sarasinella* cf. *hondana* Hass) was collected from the lowermost part of the Utica Sandstone. This ammonite was dated by Etayo (writing comunication) as upper Berriasian. Fossils collected by Bürgl led Thompson (1966) and Gallo (1977) to assign a Hauterivian age to the Utica Sandstone. The basal part of this unit was assigned by García (1983) to the Middle Jurassic, based on a specimen of *Nerinea decorate* Piette from an outcrop on the Rio Negro river (X=1,058,600; Y= 956,900) along the railroad between Utica and Tobia very close to where the Late Berriasian ammonite was collected. This latter fossil is thus in disagreement with the age reported by García (1983). A Berriasian age for the upper part of this unit was reported by García (1983), based on a *Neocomites capistratus* Bürgl collected near Utica.

Murca Formation

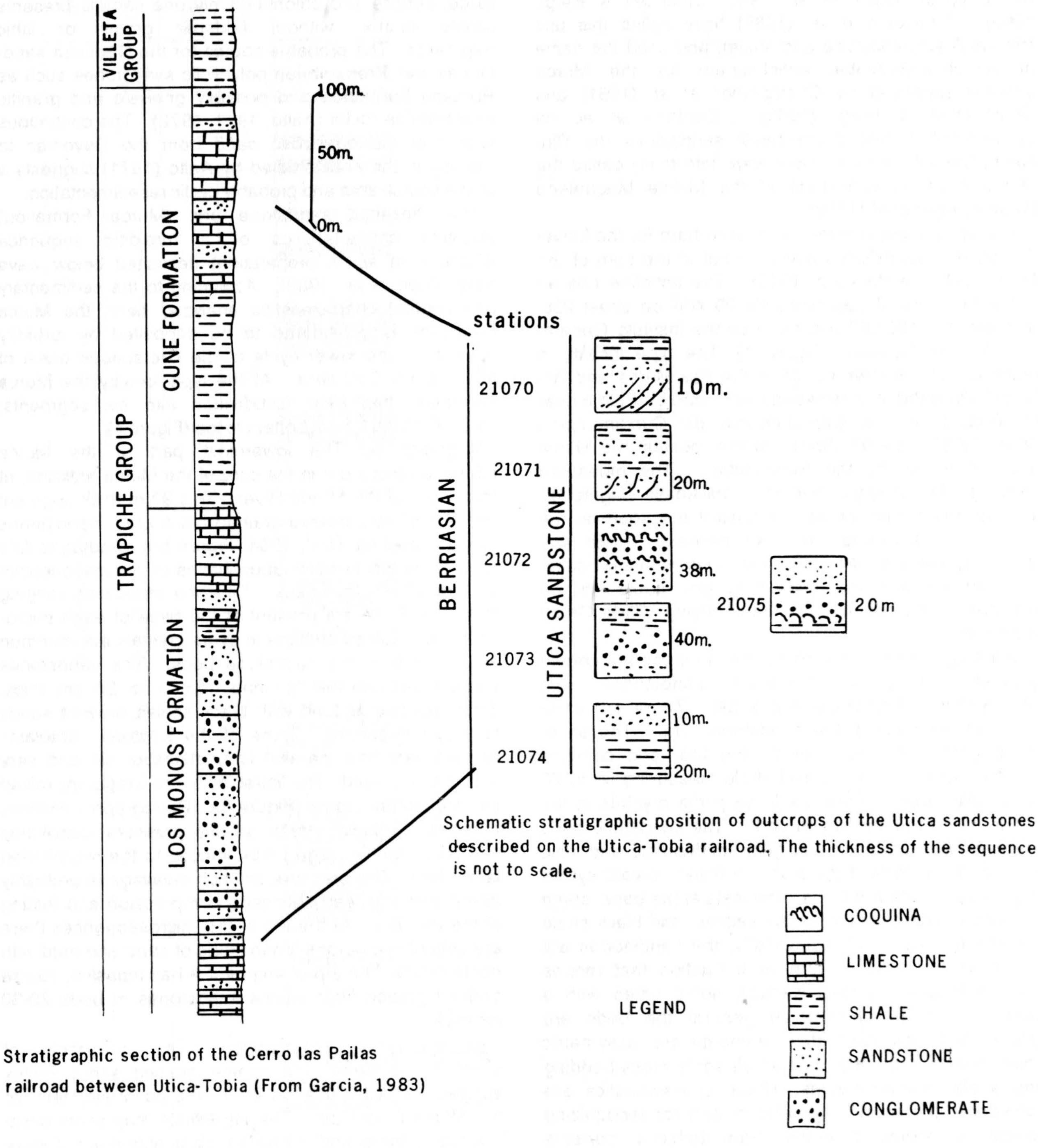

Figura 3. Schematic stratigraphic relation of the Utica sandstone from the Utica-Tobia railroad

The Murca Formation has been refered to as the Cáqueza sandstones, the upper part of the Cáqueza Group (Champertier *et al.*, 1961; Campbell & Bürgl, 1965). Sarmiento *et al.* (1985) have called this unit Interval A (of sandstone and shale), and used the name of Nimaima-Guayabal anticlinorium for the Murca anticline proposed by Champertier *et al.* (1961) and Champertier & Bürgl (1965). Cardozo *et al.* (in preparation) named these basal sandstones the Pinzaima Sandstone unit. They were informally called the Murca-Pinzaima sandstone in the Middle Magdalena Basin by Allen *et al.* (1988).

The name Murca Formation is used here for the Lower Cretaceous sandstones that crop out in the core of the Murca anticline (Moreno, 1989). The anticline has an aerial exposure of approximately 20 km^2 on sheet 208, at scale of 1:100,000 published by the Instituto Geográfico Agustin Codazzi, (Figure 1). The type locality is proposed at the intersection of the Rio Murca and Rio Negro along the road between Pacho and La Palma near to Talauta, in the Departamento de Cundinamarca (X=1,072,625, Y= 971,350). At this location the Murca anticline is cut by the Negro river. The measured stratigraphic section is 920 m in thickness (Figure 4). The formation also crops out toward the south in the Caquero area, along the road between Villeta and Nimaima, where the Murca Formation is intensely folded. The contact with the underlying unit could not be observed. The contact with the overlying Villeta Group is transitional.

At the type locality, the rocks are composed of coarse grained, locally cross-bedded sandstones and intercalations of siltstone and shale. There are intraclasts at the base of the sandstone beds. The sandstone grades to fine towards the top, and contains intercalations of siltstone and shale measuring up to 20 cm in thickness. There are large pyrite crystals in the basal part of the sandstone beds. The sandstone beds are described as black and grey feldspathic and lithic wackes (Dott, 1964, Figure 5b), in fining-upward cycles (Figure 4). There are shale intraclasts at the base, some siltstone interbeds higher in the section, and black shale towards the top. Petrographically, the sandstones are immature and have a framework fraction that ranges from feldspathic to lithic wackes, some times with a calcareous matrix-cement. In general the beds are graded, with reworked lithic fragments and assymetric ripple-marks. Some contain small scale cross-bedding and shale interlaminations. These characteristics are considered the most diagnostic criteria for recognizing sandstone bodies deposited from turbiditic currents (Stanley, 1963; Potter, 1967).

The Cáqueza sandstones are red, white or gray, immature, poorly sorted, very angular to angular quartzarenite, coarse grained siltstone and very fine grained quartzarenite, with lamination and beds averaging 0.8-3.0 m in thickness (Aalto, 1971, 1972). The average sandstone composition for the Cáqueza sandstones was given by Aalto (1971, 1972) as 53% quartz grains and 47% matrix-cement (Moreno, 1989, Figure 5c). The matrix cement is essentially of iron oxide, sericite and chlorite. Only one sample presents calcite matrix, without feldspar grains or lithic fragments. The probable source for the Cáqueza sandstones was Precambrian polycyclic sandstones such as Roraima Formation and possibly gneissic and granitic Precambrian rocks (Aalto, 1971, 1972). The continuous supply of the quartzose sand from the Devonian to Tertiary in the area studied by Aalto (1971) suggests a stable source area and probably cyclic resedimentation.

The Pinzaima sandstone unit (Murca Formation) presents characteristics of a turbiditic sequence (Cardozo *et al.*, in preparation) deposited below wave base (Allen *et al.*, 1988). According to the sedimentary and textural characteristics analyzed here, the Murca Formation is considered to be deposited by turbidity currents in the lower cycle of the Cretaceous basin of the Eastern Cordillera. At the type locality the Murca Formation has been subdivided into six segments, called A trough F from bottom to top (Figure 4).

Segment A. The lowermost part of the Murca Formation crops out in the core of the Murca anticline, at the mouth of the Murca River. This 90 m thick segment consists of very coarse grained black-gray sandstones (arkosic wackes, Dott, 1964, Figure 5b), grading to fine toward the top in continuous cycles or microsequences of 1 to 20 cm thickness. Siltstone intraclasts ranging from 1 to 5 cm are present at the base of each microsequence. Large authigenic pyrite crystals are common at the base of the sandstone beds. The sandstones present bed parallel laminae from 1 to 20 cm thick. Siltstones interbedded with black shales present sandy lenticular channels. Some of the siltstone intraclasts contain very fine, parallel laminations of silt and very fine grained sand. The intraclasts are irregulary mixed into the coarse matrix (Figure 6a). Petrographic analysis of some of these clasts reveals pressure dissolution related to the cleavage perpendicular to the microfolded lamination. The pressure solution cleavage is problably associated with early Miocene compression and folding of the anticline. At the top of the microsequences there are sets of microcross-laminations of sand and mud with ripple marks. The top of segment A has massive, coarse grained graded lithic wacke sandstones in beds 20-30 cm thick.

Environmental Interpretation. The presence of siltstone intraclasts in a coarse grained sandy matrix suggests a debris flow facies for the basal segment of the Murca Formation. The intraclasts may show basal inverse grading and preferred clast alignment (Figure 6a). Subaqueous debris flows and slumps require greater slopes than classical turbidity currents (Walker, 1986). This segment may correspond to coarse interchannel layers such as those proposed by Nelson & Kulm (1973), or to channel turbidity currents of the upper fan such as those proposed by Shanmugam & Moiola (1988). Evidence of this type of facies is also provided by the basal geometry described in the basal

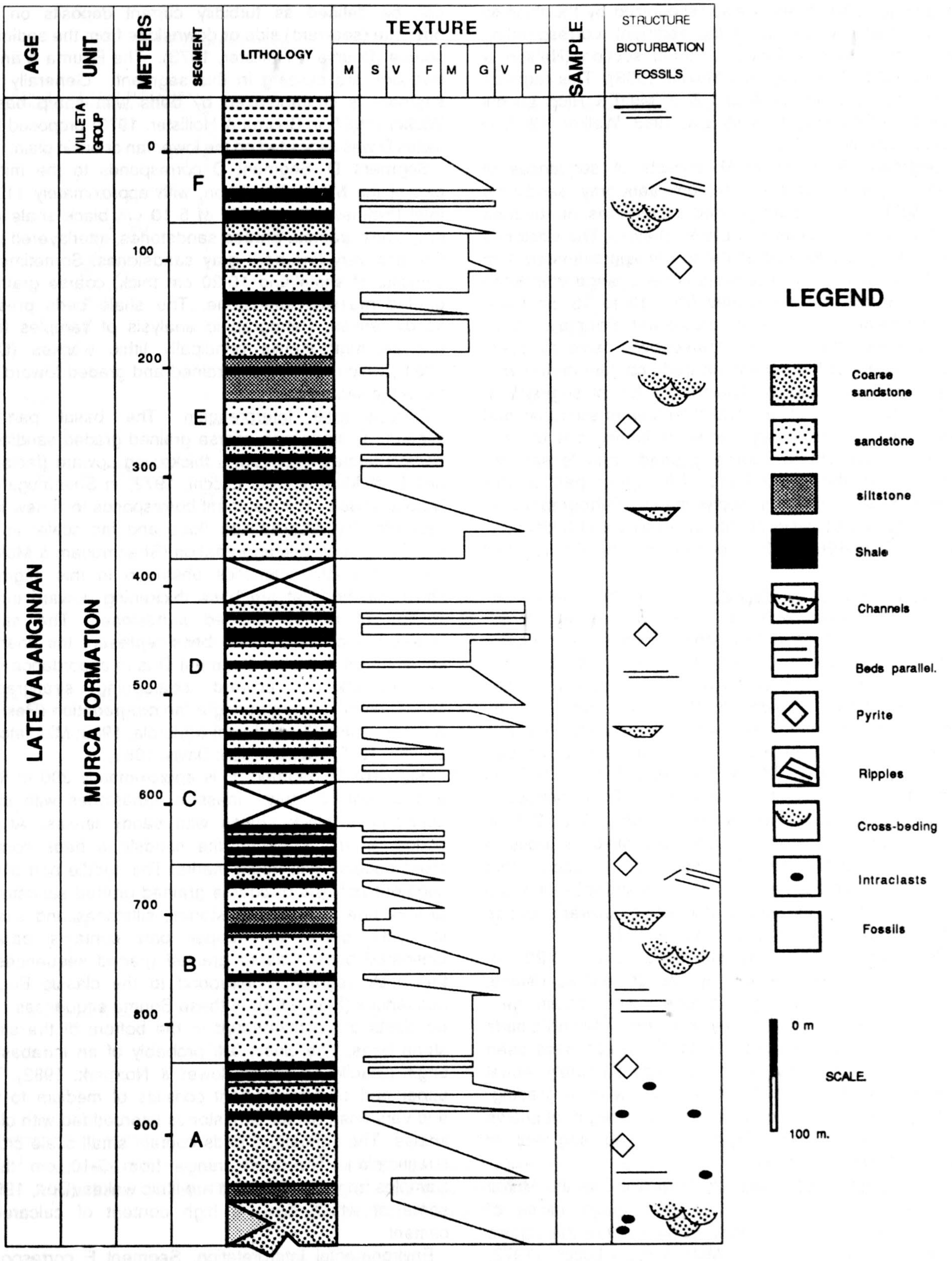

Figure 4. Stratigraphic column of the Murca Formation from the type locality, on the Murca anticline core, on the road between Pacho and La Palma towns, Departamento de Cundinamarca.

segment. This facies is also recognized by the thinning of the beds up section in the segment, corresponding with an upward widening channel section (Nelson & Kulm, 1983; Shanmugam & Moiola, 1988). This segment corresponds to facies A and B of Mutti & Ricci Lucchi (1972, *in* Shanmugam & Moiola, 1988; Walker, 1967, *in* Walker & Mutti, 1973).

Segment B. Segment B consists of sequences of coarse grained graded, medium dark-gray sandstone and light gray, medium grained sandstones interbedded with sets of siltstones and black shales. The siltstones and shales are located at the top of approximately 1 m thick sequences. The sandstone beds range from 80 to 90 cm thick, and the shales from 10 to 15 cm thick. These sequences are comparable with Bouma's classic sequences, which are separated by erosive surfaces. The majority of the sandstone beds contain large pyrite crystals at their bases. Toward the top of segment B, there are 5-10 cm thick parallel laminated siltstones and shales with internal very fine wave laminations of sand and silt. Medium to coarse grained sand lenses are common in the shale beds. The upper part of this segment also contains ripple marks. Petrographically, this segment consists mainly of arkosic and feldspathic wakes (Dott, 1964;). The segment is approximately 180 m thick.

Environmental Interpretation.The 1 m thick sequences can be correlated with the classic Bouma sequences. They start with rapid flow and deposition on erosive surfaces of massive graded sandstones. Muddy beds are deposited at the top by a fine grained, low density turbiditic current. Segment B is considered to be deposited in the middle fan, where the channel influence is less intense. These sequences are named suprafan lobes by Walker (1978, *in* Reineck & Singh, 1980), in thinning and fining upward sequences. They correspond to lobe facies C of Mutti & Ricci Licchi (1972-1975, *in* Shanmugam and Moiola, 1988), deposited as lobes in progradational turbidite sequences. They suggest that aggradation and progradation are responsible for the lobe formation, producing thickening upward cycles (Mutti, 1985, *in* Shanmugam & Moiloa, 1988).

Segment C. This segment consists of 10-20 cm thick beds of interlayered gray fine grained sandstone, black shale and black siltstone. The tabular geometries of segment C are very constant. The shale beds of this segment contain some fossils which were used for dating. This segment has approximately equal proportions of silty and sandy beds without grading. Petrographic analysis of samples of this segment shows mainly lithic wackes (Figure 5b). The segment is approximately 80 m thick.

Environmental Interpretation. Segment C of the Murca Formation corresponds to the lobe fringe facies of Shanmugam & Moiola (1988), or facies D of the classic distal turbidite proposed by Mutti & Ricci Lucchi (1972, *in* Walker & Mutti, 1973). It begins with Bouma's sequence C, and is described as a distal turbidite which can be defined as turbidity current deposits on the opposite (seaward) side or downslope from the sediment source (Bouma & Hollister, 1973). The Bouma A and B divisions are missing in this segment. Generally this segment is characterized by beds with sharp bases. Walker (1967, *in* Bouma & Hollister, 1973) proposed that facies D was deposited on the lower fan or basin plain.

Segment D. Segment D corresponds to the middle part of the Murca Formation, with approximately 110 m total thickness. It consists of 5-10 cm black shale and gray , fine grained, graded sandstones, interlayered with fine and very fine dark gray sandstones. Sometimes it consists of shale and 10-20 cm thick, coarse grained, graded massive sandstone. The shale beds present sandy lenses. Petrographic analysis of samples from this segment shows principally lithic wackes (Dott, 1964), which are coarse grained and graded toward the top of the segment.

Environmental Interpretation. The basal part of segment D starts with coarse grained graded sandstone beds (Bouma's A division), thickening upward (facies C and D of Mutti & Ricci Lucchi, 1972, *in* Shanmugam & Moiola, 1988). This segment corresponds to a new lobe deposited by progradation (lobe and fan scale) in the basin and bed scale aggradation (Shanmugam & Moiola, 1988). The characteristics observed in this segment show thin beds at the base thickening upward in the section of coarse grained sandstones. The sandy lenses found in the shale beds represent the channel influence on the lobe. Segment D is in accordance with the hypothetical upward coarsening stratigraphic sequence developed during a fan progradation (Reineck & Singh, 1980; Shanmugam & Moiola, 1988; Middleton & Bouma, 1973; Walker, 1986; Davis, 1983).

Segment E. Segment E is approximately 300 m thick and consists of gray massive sandstones with intercalations of black shales with sandy lenses. At the bottom of this segment the sandstone beds contain cross-bedding and ripple marks. The middle part of the segment consists of coarse grained graded sandstones to very fine grained sandstones, siltstones and shales in cyclic beds. The upper part contains parallel laminated beds. Coarse grained graded sequences in this thick segment correspond to the classic Bouma sequences (Figure 6b). In these Bouma sequences , rip-up clasts are concentrated in the bottom of the sandstone beds. The clasts are probably of an intrabasinal origin (Stauller, 1967, *in* Howell & Normark, 1982). The upper part of this segment consists of medium to fine and very fine grained sandstones interbedded with black shales. The sandstone beds contain small scale cross-stratification. The beds range from 5-10 cm thick. Samples from this segment are lithic wakes (Dott, 1964), some of which have a high content of calcareous cement.

Environmental Interpretation. Segment E corresponds to a thinning upward sequence of a new lobe in the middle fan. It represents a regradational deposit. Where

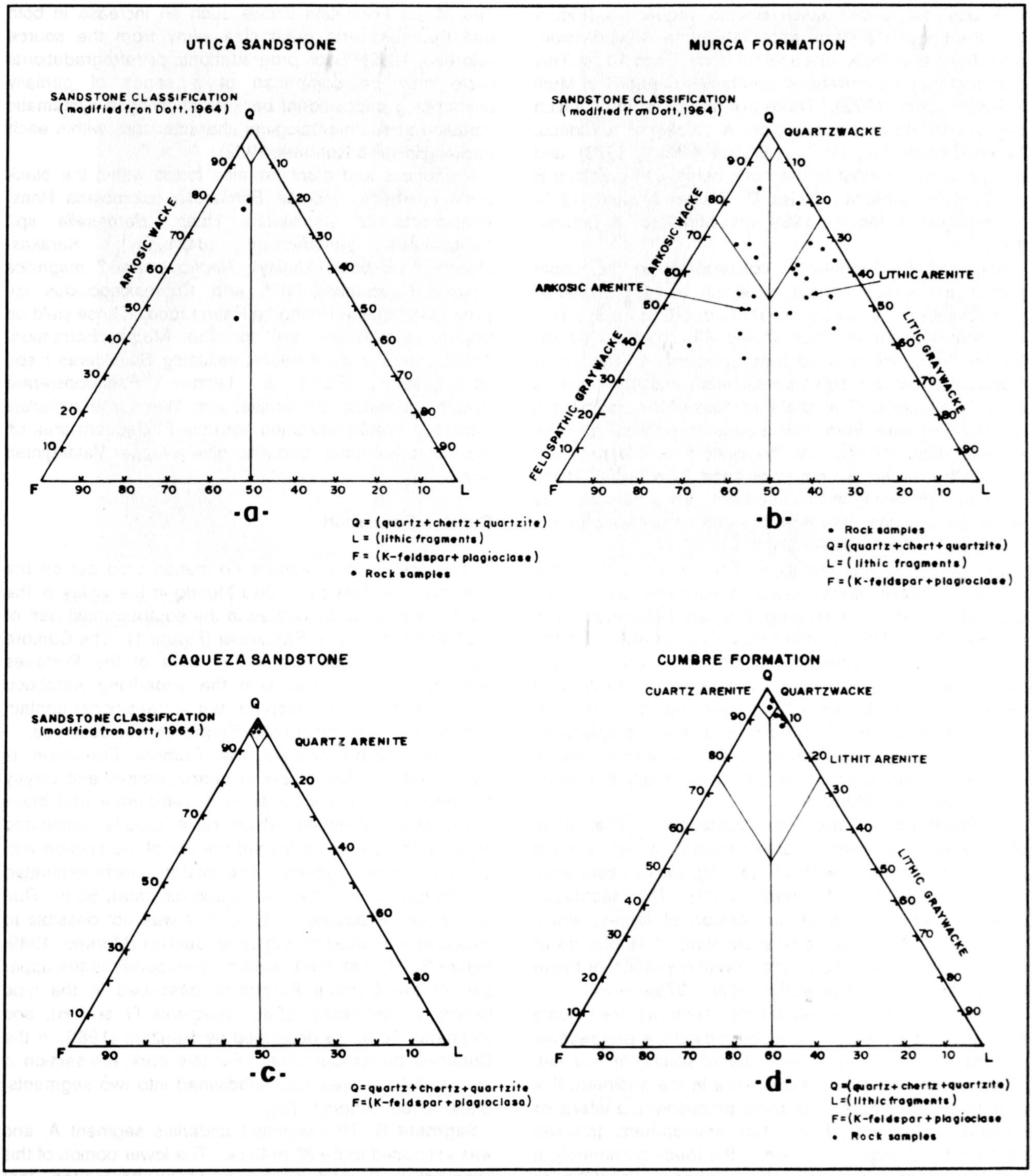

Figure 5. Triangular QFL plot showing mean sandstone classification of the Murca Formation, Utica Sandstones, Cumbre Formation and Cáqueza Sandstone (recalculated from data of Aalto (1971, 1972). Modified from Dott, 1964.

it is possible to distinguish Bouma sequences (Figure 6b), the sequence starts with the Bouma A subdivision, and changes in thickness upward from 1 m to 10 cm. This segment may be correlated with facies C and D of Mutti & Ricci Lucchi (1972). There are groups of beds which begin with Bouma subdivision A (proximal turbidites, facies C of Walker, 1967, *in* Walker & Mutti, 1973), and groups in which most of the beds begin with divisions B or C (distal turbidites, facies D; Walker & Mutti, 1973; Shanmugam & Moiola, 1988; and Middleton & Bouma, 1973).

Segment F. Segment F corresponds to the upper part of the Murca Formation, which has a transitional contact with the overlying Villeta Group (Figure 3). This segment consists of black shales with interbedded 20-30 cm thick, fine grained gray sandstones. The sandstone beds contain cross-stratification and ripple marks in the shale beds. The total thickness of this segment is 80 m. Samples from this segment consist of lithic wackes (Dott, 1964). At the bottom of the segment there are massive 60 cm thick sandstone beds. Black shales predominate in this segment. These shales may represent the transition from the coarse turbiditic Murca Formation to the Villeta Group.

Environmental Interpretation. The upper part of the Murca Formation corresponds to noncyclic basin plain deposits in an area fringing the fan (Shanmugam & Moiola, 1988). This segment may also correspond to the Bouma E subdivision, consisting of a turbiditic and hemipelagic mud with some sandstone interbeds, and facies G of Mutti & Lucchi (1972), with pelagic and hemipelagic shales deposited from very dilute suspension. The process of deposition includes the normal pelagic rain of sediments onto the sea floor (Mutti & Lucchi, 1972, *in* Walker & Mutti, 1973).

Progradation and Retrogradation. The sense of migration is readily determinated in an ancient sequence through vertical (stratigraphic) sequence analysis (Howell & Normark, 1982). This technique applies Walther`s law of succession of facies, which states simply that the vertical stacking of lithofacies at any given location reflects the lateral migration of these facies over a period of time (Blatt *et al.*, 1973).

In a retrogradational sequence, such as the Murca Formation, ascending lithofacies indicate a progressive change to a more distal depositional setting on the fan. This may be caused by a decrease in the sediment flux (due to either climatic or tectonic processes), a lateral or forward movement of the fan environment (caused perhaps by change in location of the feeding channel), a subsidence of the continental freeboard (isostatic or tectonic), or eustatic sea-level rise (Howell & Normark, 1982). The morphology and distribution of young sedimentary deposits on modern fans show that detrital deposition generally is not uniformly distributed. Few turbidite currents are capable of spreading across the entire basin or fan. Within each active depositional sector, turbidites show a general decrease in both bed thickness and grain size away from the source (Fig. 7). The Murca Formation shows such an increase in both bed thickness and grain size away from the source (Moreno, 1989). Each progradational or retrogradational cycle may be composed of a series of partially overlapping depositional packets showing a systematic variation of sedimentological characteristics within each packet (Howell & Normark, 1982).

Ammonites and plant remains found within the black shale interbeds include *Berriasella colombiana* Haas; *Pseudoosterella ubalaensis* Haas; *Berriasella* sp.; *Santafecites santafecinus* (d'Orbigny); *Karakaschiceras*? cf. *bakeri* (Imlay); *Neohoploceras*? *magnifica* (Imlay); *Neocomites* sp.?, and *Cupressinocladus* sp. (land plant) on the Pacho-La Palma road. These yield an Upper Valanginian age for the Murca Formation. Ammonites and plant debris, including *Sainoceras* n.sp., aff. *hirsutum* Fallot & Termier; *Pseudoosterella ubalaensis* Haas; fish scales; and *Weichselia reticulata* (Stokes & Webb), collected from the El Caquero area on the Villeta-Nimaima road also give a Upper Valanginian age.

Cumbre Formation

The rocks of the Cumbre Formation crop out on the road from La Belleza to Otro Mundo in the valley of the Rio Minero, an area located in the southernmost part of the Departamento de Santander (Figure 1). The Cumbre Formation outcrops are in the core of the Portones anticline. The contact with the underlying Arcabuco Formation was not observed, but a transitional contact with the overlying Rosablanca Formation was observed.

In the section studied, the Cumbre Formation is composed of a few layers of quartzarenites and clayey sandstones with intercalations of red-purple and black argillaceous siltstones which have parallel laminated layers with wavy beds toward the top of the section with 15-20 cm thick segments. The total thickness estimated for this formation in the area is approximately 50 m. Due to the poor exposure of the unit, it was not possible to measure a detailed stratigraphic section (Moreno, 1989, Figure 8). The studied section corresponds to the upper part of the Cumbre Formation described in the type locality by Mendoza (1985; segments G and H), and segments 56 to 83 described by Renzoni (1985) in the Cordillera de los Cobardes. For this work, the section in the La Belleza area was subdivided into two segments, B and A from bottom to top.

Segment B. This segment underlies segment A, and was estimated to be 30 m thick. The lower portion of this segment is formed principally of quartzarenites, that vary from medium to very fine grained, with intercalations of clayey siltstones. Colors range from brown-yellow to white, with a large amount of pyrite crystals and micas sheets. Some samples indicate apparently more silica cement. This phenomena was observed in diferents places with quartz dikes 2-5 cm in thickness. This may explain the recrystallization observed in thin section analysis (Moreno, 1989).

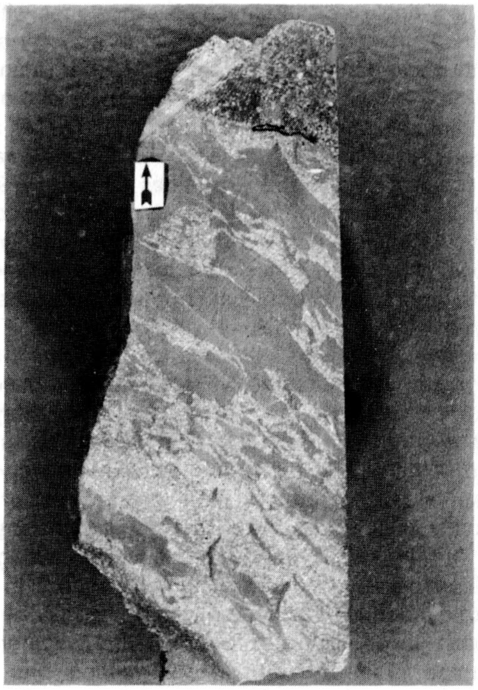

Figure 6A. Debris flow of channel deposit from segment A of the Murca Formation. The arrow length is 1 cm.

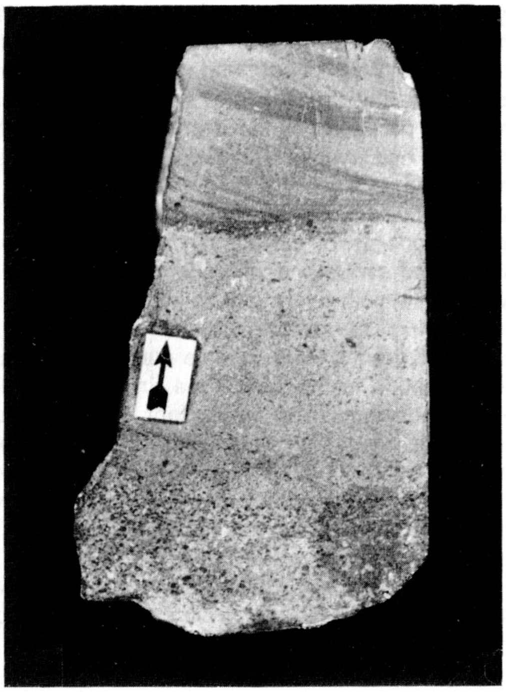

Figure 6B. Typical Bouma's sequence from segment E from the Murca Formation. The arrow length is 1 cm.

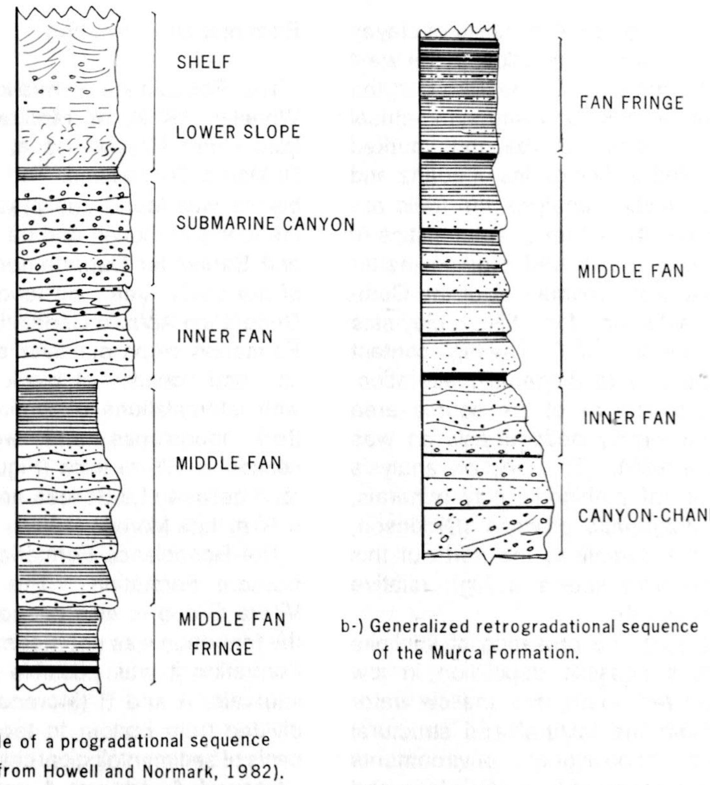

Figure 7. Comparison between a hypothetical progradational sequence, Figure a), and the retrogradational sequence from the Murca Formation, Figure b)

In general, the sandstone bodies of the lower part of segment B consist of parallel laminated beds of 15-20 cm thickness. Wavy beds and faint cross-lamination occur toward the top of the segment. This cross-lamination is produced by the distribution of the medium sized grains and pyrite crystals on the bottom of some sandstone beds.

The upper portion of segment B of approximately 10 m thickness, consists of clayey sandstone and very fine to fine grained sandstone with colors ranging from light yellow to white, with a ferruginous crust probably formed by weathering of pyrite present as crystals and disseminated grains. Mica crystals are generally parallel to the lamination in the sandstone. In some parts it is possible to distinguish a very slight cross-lamination. These sandstones are micaceous quartzarenites in composition (Moreno, 1989, Figure 5d). A sample of this portion collected at another place toward the top of the section consists of fine quartzarenite with an argillaceous matrix with rippled beds 10-15 cm thick.

Segment A. Segment A was observed on the road at Otro Mundo , and on the road from La Belleza to Florián, Santander. It consists of red-purple claystones and argillaceous siltstones, with some very fine to fine grained, yellow , micaceous clayey sandstone. This segment has parallel laminated beds of 10-15 cm thickness. The segment is about 20 m thick, with many wavy beds. It is possible to distinguish low angle cross-bedding in the sandstones, which is marked by heavy minerals.

The upper portion of the segment A consists of clayey siltstones, which change in color from yellow in the west to black in the east of the area. In the eastern part the siltstone consists of very parallel beds with symmetrical ripple mark sets. In some areas, bioturbation is marked by trails that have been filled by fine grains of quartz and mica. According to thin section analysis the trails are orientated similar to borrowing. Other characteristics of segment A are ferruginous crusts and organic matter concentrations. A sample, from segment A of the Cumbre Formation, was selected for XRD clay-size mineralogical analysis (Moreno, 1989). The high content of clay minerals may be due to diagenetic alteration, lithology, or weathering conditions of the source area (Reading, 1986) and not simply pedogenesis as was suggested by Mendoza (1985). Thin section analysis also shows high amounts of authigenic clay minerals, probably produced by diagenetic process (Dickinson, 1970). XRD analysis of a sample to the north of this area (Ballesteros, 1989) also shows a high relative amount of illite and some kaolinite.

Environmental Interpretation. The presence of kaolinite in segment A suggests a possible deposition in low salinity waters near to a river mouth, in a shallow water marine environment. Both the textural and structural characteristics suggest depositional environments ranging from foreshore for segment B to shoreface and transitional offshore in the upper segment (Elliot, 1986).

The foreshore environment for segment B is indicated by low angle sets of laminated sandstones with medium to fine grained sand beds. These may be associated with wave-dominated, microtidal barrier islands (Elliot, 1986; Pettijohn *et al.*, 1972). The lower part of segment A represents shoreface facies, with parallel and small ripple laminations in fine sands and clayey sandstones associated with mixed wave-tides (Hayes,1979, *in* Elliot, 1986). The upper part of segment A consists of siltstones and mudstones, with laminae and symmetrical ripple sets in well-sorted medium to fine grained siltstone with abundant bioturbation. The upper part of segment A represents the transitional offshore facies. The facial analysis suggests that the Cumbre Formation represents a transgressive sequence produced by the first advance of the Cretaceous Sea (Etayo, 1978; Mendoza, 1985; Renzoni, 1985, 1985a; Laverde & Clavijo, 1985). Pyrite occurs as euhedral crystals and disseminated grains in the sandstones and clayey sandstones. This is the product of diagenetic processes in the rocks, as is the presence of authigenic clay minerals such as chlorite within the matrix. In the upper part of segment B, quartz overgrowths may be related to quartz dikes that also occur in the segment. In Los Santos area, the Cumbre Formation has abundant bivalves, similar to Berriasian bivalves described by Bürgl (1960, *in* Etayo & Rodríguez, 1985). A fossil ammonite dated by Dr. Etayo (*Sarsinella* cf. *hondana* Haas; Ballesteros, 1989) gave a Berriasian age for the upper part of the Cumbre Formation.

Rosablanca Formation

The Rosablanca Formation was originally named by Wheeler (1929), as reported in Morales *et al.* (1958), from Cerro Rosablanca at the northeast corner of the DeMares Concession. The best exposure of the Rosablanca was found and measured on the road between the towns of Florian and La Venta (limit between Boyacá and Santander Departaments) in the northeast section of the study area, on topographic sheet 170 (Instituto Geográfico Agustin Codazzi, Figure 1). The Rosablanca Formation crops out over an area of approximately 80 km, and consists of black to greenish-gray limestone with intercalations of laminated calcareous shale and thick mudstones and wackestones. The exposed section is 175 m thick (Figure 8). The outcrops on the road between La Belleza and Pueblo Nuevo range up to 5-10 m thick Moreno (1989).

The Rosablanca Formation lies concordantly over the Cumbre Formation. The contact with the overlying Villeta Group is also concordant, but the upper part of the formation was not measured. Within the Rosablanca Formation it was possible to recognized two principal intervals, A and B (Moreno, 1989), which were further divided from bottom to top into four segments on the basis of sedimentological characteristics.

Interval A. Interval A corresponds to the basal part of the Rosablanca Formation in the La Belleza-Florián area. This interval consists of interlayered mudstone,

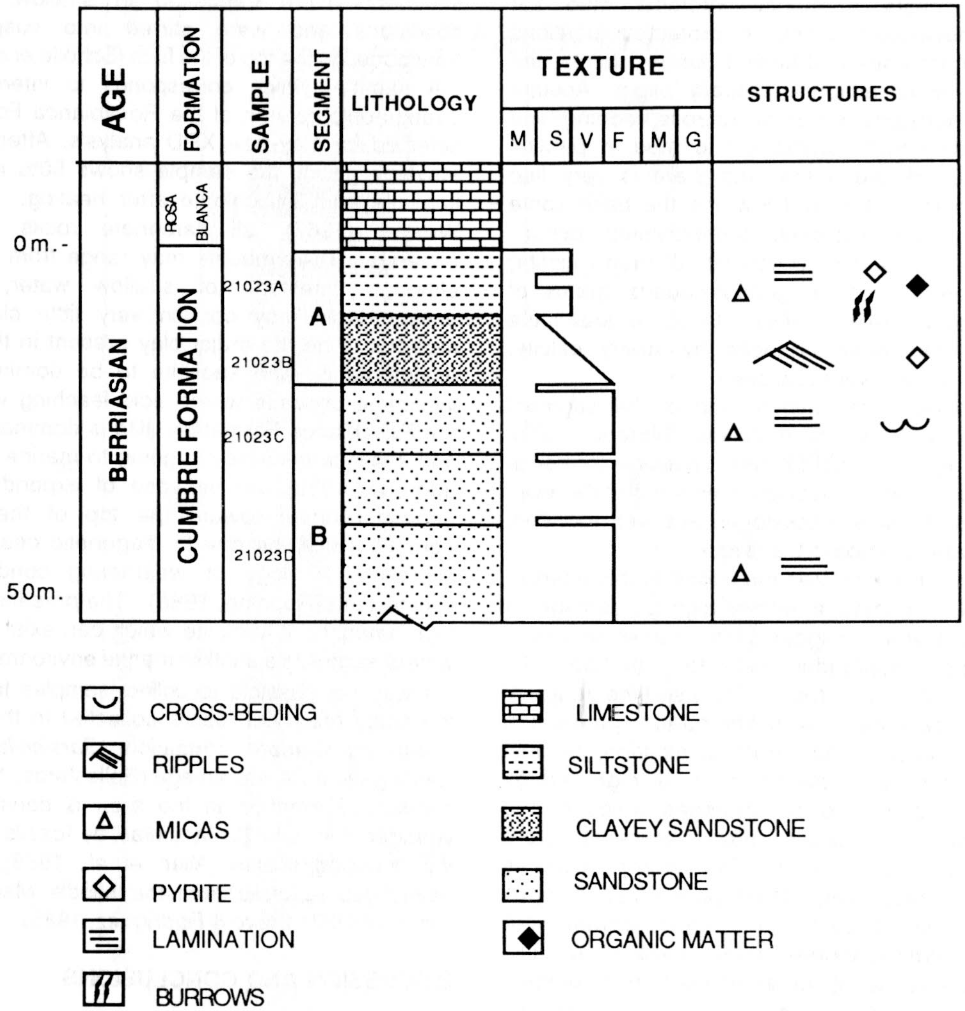

Figure 8. General stratigraphic column of the Cumbre Formation on the La Belleza-Otro Mundo road, Departamento de Santander

dolomitic mudstone, mudstone with terrigenous material, wackestone and boundstone. This interval was divided into three segments from bottom to top (Moreno, 1989). The most basal part of the section, with a thickness of approximately 15 m, consists of intercalations of black mudstone and black dolomitic mudstone with quartz clasts, interlayered with black shales. This segment presents parallel laminated, rippled, 5-10 cm thick beds with sharp contacts and fine internal lamination. The basal samples show microcross-bedding in thin section.

Petrographically, the dolomitic mudstone is comprised essentially of mud (micrite), which has been replaced in part by sparry calcite and dolomite (Moreno, 1989). Also, some fragments of echinoderm plates were found, probably the same as those described by Miller & Etayo (1972) and Cardozo & Ramírez (1985). Acetate peels of this interval show the presence of light bioturbation of indistinct mottled type (Moreno, 1989), together with some intraclasts of coarse sand size which were not observed in the thin section. The sample contains large pyrite crystals of probable authigenic origin. The facial characteristics of this segment suggest a shallow marine depositional environment, such as a supratidal marsh zone (Shinn, 1983). The alternation of mudstone and dolomitic mudstone with quartz grains toward the top, and mudstone with intraclasts that possibly indicate erosive events, suggest the action of high and low energy currents which deposited the mudstone. The terrigenous material may represent periods of high sediment supply to the basin (Moreno, 1989).

The presence of stromatolites in this interval, developed in continuous mats and algal-bound sediments, suggests a marine intertidal mud flat environment developed mainly in protected locations such as re-entrant bays and behind barrier islands and ridges, where wave action is usually slight. Acetate peels of the mudstone show microcross-bedding and graded lamination from coarse silt to mud in parallel laminated sets. Between the sets there is very fine laminated organic matter, and towards the base some synsedimentary structures such as microslumps occur . In thin section, the mudstone consists of mud (micrite) with a high amount of terrigenous quartz grains of coarse silt size (Moreno, 1989), In some areas the micritic matrix has been replaced by sparry calcite. Feldspar crystal clasts were also seen.

The wackstones of the middle part of the segment consist of fossil remains and intraclasts (Moreno, 1989), which are in a dolomitic micrite matrix, possibly formed in ponds and levee areas associated with high-tide level. The intraclasts in these wackstones are well rounded. Pyrite crystals are common in these rocks.

The presence of dolomitized mudstone in this interval, interlayered with mudstone with a high percentage of terrigenous material, suggests a transition zone between upper supratidal flat to intertidal flat environments at the top. The sedimentological characteristics described, including quartz grains in a micrite matrix and very fine parallel lamination, suggest that this segment was deposited in a high energy enviroment such as bars or beach ridges, which formed restricted areas to which the sediments were transported by suspension by low energy currents (Cardozo & Ramírez, 1985). These bars or beach ridges probably had their steepest slopes facing seaward, and merged with a tidal flat shoreward (Sellwood, 1986). The high percentage (20%) of quartz grains in this segment suggests periods with high supply of terrigenous sediments.

Interval B. This interval corresponds to the upper part of the Rosablanca Formation that crops out in the study area. The top of this interval was not measured because it forms a steep, inaccessible scarp. This interval corresponds to segment 4, and is approximately 40 m thick. Toward the bottom, this segment consist of intercalations of black calcareous shales with mudstone interlayers in parallel laminated beds 10-15 cm thick. The upper part of the segment consists of mudstones (dismicrite). Acetate peels show very fine laminae in the muds and shadowy bioturbation that appears to represent channels filled by very fine clastic sediments such as quartz and pyrite crystals. Petrographic analysis shows oolites and anhedral feldspar crystals (Moreno, 1989).

The sedimentary characteristics of interval B have been interpreted as due to deposition in a subtidal environment on a marine shelf (Shinn, 1983; Sellwood, 1986). This zone is characterized by the presence of muddy sediments interlayered with mudstones (micrite). The oolites in thin section provide evidence of this tide dominated environment. The adjacent muddy marine sediments were deposited in shallow, low energy conditions and were stirred into suspension and transported to the top of the flats (Scholle *et al.*, 1983).

A sample, which corresponds to interval B in the stratigraphic column of the Rosablanca Formation, was selected for clay-size XRD analysis. After treating with ethylene glycol, the sample shows 50% illite and 13% kaolinite and 3% chlorite after heating. According to Weaver (1967), all carbonate rocks contain clay minerals. The amounts may range from 0.01 to 40%, although limestone of shallow water, high-energy environments may contain very little clay. Illite was reported to be the major clay present in the majority of environments, and kaolinite to be dominant in fluvio-lacustrine deposits where acid leaching was active. In the Rosablanca Formation, illite is dominant but chlorite and kaolinite decrease in going to marine environments (Moreno, 1989). An increase of expandable minerals (montmorillonite) toward the top of the Rosablanca Formation may be due to diagenetic changes such as alteration, lithology or weathering conditions of the source area (Reading, 1986). The presence of relatively high amounts of kaolinite which can exist in low salinity waters suggests a shallow marine environment.

It was not possible to collect samples for dating from the study area, but fossils collected to the north in the underlying Cumbre Formation (*Sarsinella* cf. *hondana* Hass) gave a Berriasian age (Ballesteros, 1989). The Rosablanca Formation in the area is constrained as no younger than Late Valanginian by fossils of this age in the overlying shales (Allen *et al.*, 1988). Similar ages have been reported from the Middle Magdalena Basin (Alfonso, 1985; Etayo & Rodríguez, 1985).

DISCUSSION AND CONCLUSIONS

The Utica sandstone and Murca, Cumbre, and Rosablanca formations comprise the Lower Cretaceous sedimentary sequence in the study area and were deposited in depocenters in the Tablazo-Magdalena and Cundinamarca-Bogotá basins. Although these sedimentary units are partially time equivalent, they are lithologically distinct. Analysis of their petrographic composition and sedimentary environments shows that the units were deposited in distinct paleogeographic settings in the Early Cretaceous. Both the Utica sandstone and the Murca Formation, located in the southern part of the area, correspond to clastic sequences. To the north the basal sequences comprise the clastic unit of the Cumbre Formation and limestone of the Rosablanca Formation (Figure 1).

The initial Cretaceous transgression in the study area is marked by the shallow water marine Cumbre Formation to the north and possibly the prograding, wave dominated Utica sandstone, both of Berriasian age. The Cumbre Formation is overlain by Valanginian shallow marine limestone of the Rosablanca Formation,

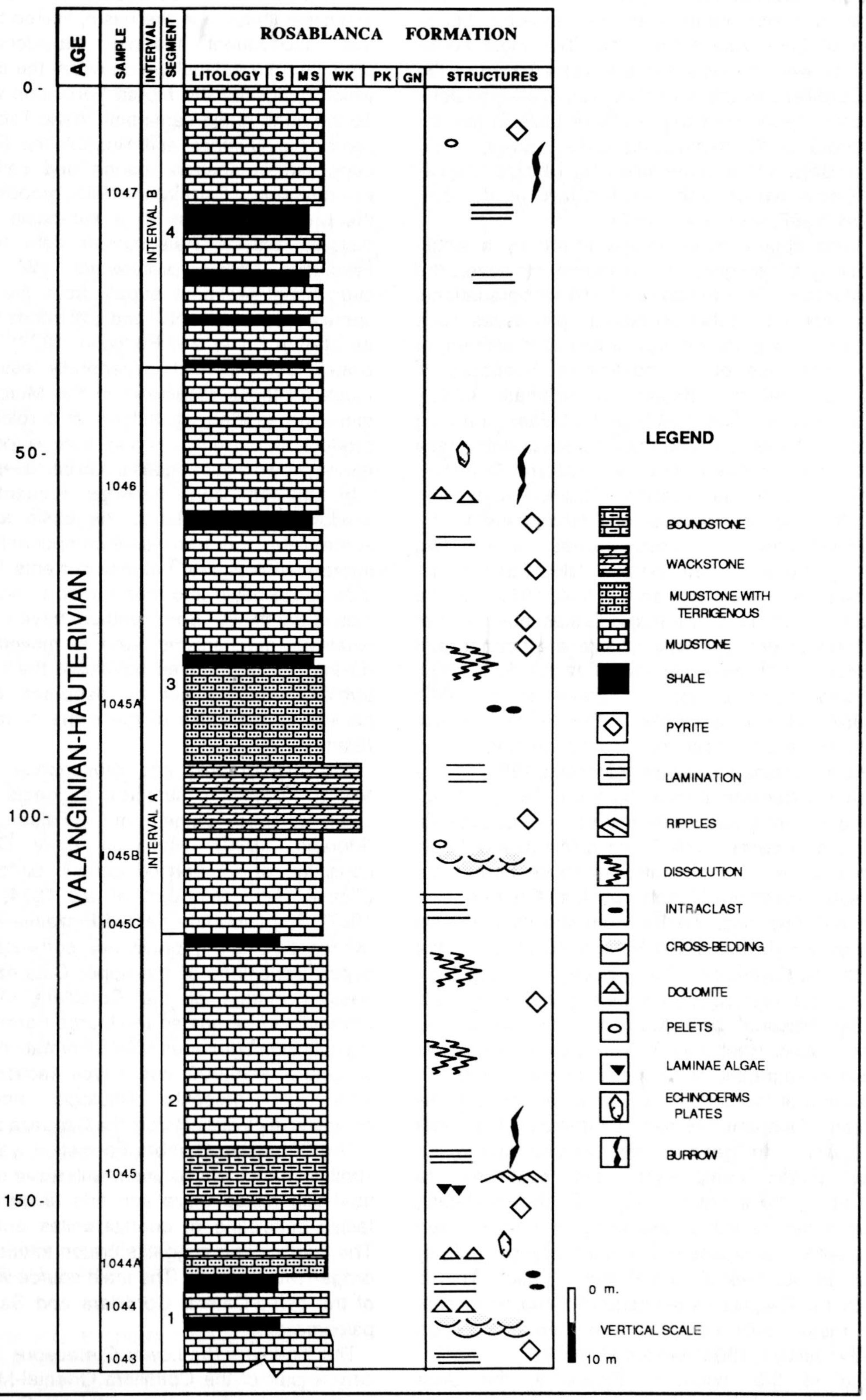

Figure 9. General stratigraphic column of the Rosablanca Formation in the northern part of the area

deposited in a shallow marine platform, while the Utica Sandstone is synchronous with the turbiditic Murca Formation of Late Valanginian age. The most northeastern units were deposited in the western part of the Eastern Cordillera in the so-called Tablazo-Magdalena Basin (Fabre, 1984), and the southern units in the so-called Bogotá or Cundinamarca Basin (Bürgl, 1957, 1959). The Bogotá Basin connected the Tablazo-Magdalena and Cocuy basins to the south (Etayo *et al.*, 1976; Fabre, 1984, 1987; Allen *et al.*, 1988).

These units appear to be characterized by a single cycle showing a transgressive sequence. However, the turbiditic Murca Formation shows a local retrogradational sequence, which probably represents processes such as decrease in the sediment flux, a lateral movement of the fan, subsidence of the continental freeboard or eustatic sea level rise (Howell & Normark, 1982). According to Fabre (1984, 1987), in the Upper Jurassic? or Berriasian times an important extensional phase affected the zone between the paleo-Central Cordillera and the Guaicáramo fault system. This E-W extension produced thinning of the crust and lithosphere in the Tablazo-Magdalena and Cocuy areas, where two subsident grabens formed with a NNE-SSW trend. These basins described by Fabre (1984, 1987) can be considered sub-basins of the major Cretaceous basin of the Cordillera Oriental, in which there are normal fault limited areas, which were separated by the Santander-Floresta paleomassif paleohighs (Etayo *et al.*, 1969; Fabre, 1987; Allen *et al.*, 1988). The Floresta massif plunges to the south under the Sabana de Bogotá into the Bogotá or Cundinamarca basin (Moreno, 1989).

During this extension phase, both the Tablazo-Magdalena and Cocuy grabens were filled with continental and marine sediments. The Tablazo-Magdalena basin filled with continental sediments (Arcabuco Formation) and shallow water sediments of the Cumbre and Rosablanca Formations. To the south, the Bogotá basin was filled by the shallow water Utica sandstone and the turbiditic Murca Formation. The Cocuy basin was filled by the Berriasian-Valanginian marine deltaic sediments (Lutitas del Macanal and Areniscas de Las Juntas formations; Fabre, 1984, 1987). A broadly similar Lower Cretaceous stratigraphic section can be seen along the eastern margin of the Cordillera Oriental as far south as the northern Quetame Massif, southeast of Bogotá (Fabre, 1987). In general, the section shows an increasing clastic component from southwest to northeast along the eastern margin. To the southeast, the sequence begins with a basal conglomerate followed by a thick section of shales of Tithonian (Bürgl, 1958) or Berriasian (Etayo, 1985a) to Valanginian age. This is followed by the Cáqueza sandstone of Hauterivian age. Together these units comprise the Cáqueza Group (Bürgl, 1959; Julivert, 1968; Allen *et al.*, 1988).

According to the model in Figure 9, the Utica sandstone was deposited in a shallow marine environment probably developed on a shelf and with a sediment supply from a Jurassic plutonic-volcanic arc in the Paleo-Central Cordillera. The activation of the extensional phase in the basin, limited by normal faults, and subsequent thermal subsidence may have produced the paleoslope on which the turbiditic currents which deposited the Murca Formation were developed. To the north at the same time in the Tablazo-Magdalena basin, the Cumbre and Rosablanca Formations were deposited in shallow marine and carbonate platform environments. Sarmiento (1985) proposed deposition of the Murca Formation in a sub-basin associated with tectonic activity. Paleocurrent data from the Murca Formation shows preferential SW to NE trends, suggesting sediment supply from the west, although some data presents NW and SW trends. Sallwold (1960, as cited in Potter and Pettijohn, 1977) interpreted small scale cross-stratification generally less to 10 cm high (such as those measured in the Murca Formation) in immature graded sandstone of turbidite origen as a product of currents issuing from a point source and moving down a subaquous slope into deeper water.

In turbidites, sole markings frequently indicate flow predominantly parallel to the basin axis, although in some cases with transverse components. The common interpretation is that turbidity currents flowed down the side of the basin and then turned to flow parallel to the axis of the basin. Some authors have suggested that by whatever mechanisms sand is moved down into the basin, it is then moved parallel to the basin axis not by turbidity currents but by deep-sea currents flowing parallel to the strike of the slope or to the basin axis (Blatt, 1972).

The petrographic and provenance analysis of the Murca Formation samples suggests that the main sediment supply came from the Paleo-Central Cordillera (Moreno, 1989), which in Early Cretaceous time consisted of an uplifted Jurasic plutonic-volcanic arc (Figure 16-17; McCourt *et al.*, 1984; Aspden *et al.*, 1987). The informally named Pinzaima-Murca sandstone (Murca Formation) previously correlated with the Cáqueza Sandstone of the upper Cáqueza Group on the eastern margin of the Cordillera Oriental, is here proposed to be named the Murca Formation. The lithologically homogeneous Murca Formation, was mapped at a scale of 1:25,000, and a type section was proposed. This unit presents lithologic and petrographic characteristics distinct from the Cáqueza sandstone.

The Berriasian Cumbre Formation was deposited in a shallow marine environment with wave-dominated microtidal and mixed wave and tide to transitional offshore facies consisting of quartzarenites and quartzwackes. The composition suggests craton interior and quartzose orogen provenance. The main source was probably part of the paleo-Central Cordillera and Santander-Floresta paleomassif.

The model for the Lower Cretaceous (Figure 9), of the central part of the Cordillera Oriental-Magdalena Valley is proposed, where the northeast Cumbre and Rosablanca Formations were deposited in shallow marine environments in the Tablazo-Magdalena basin, while to

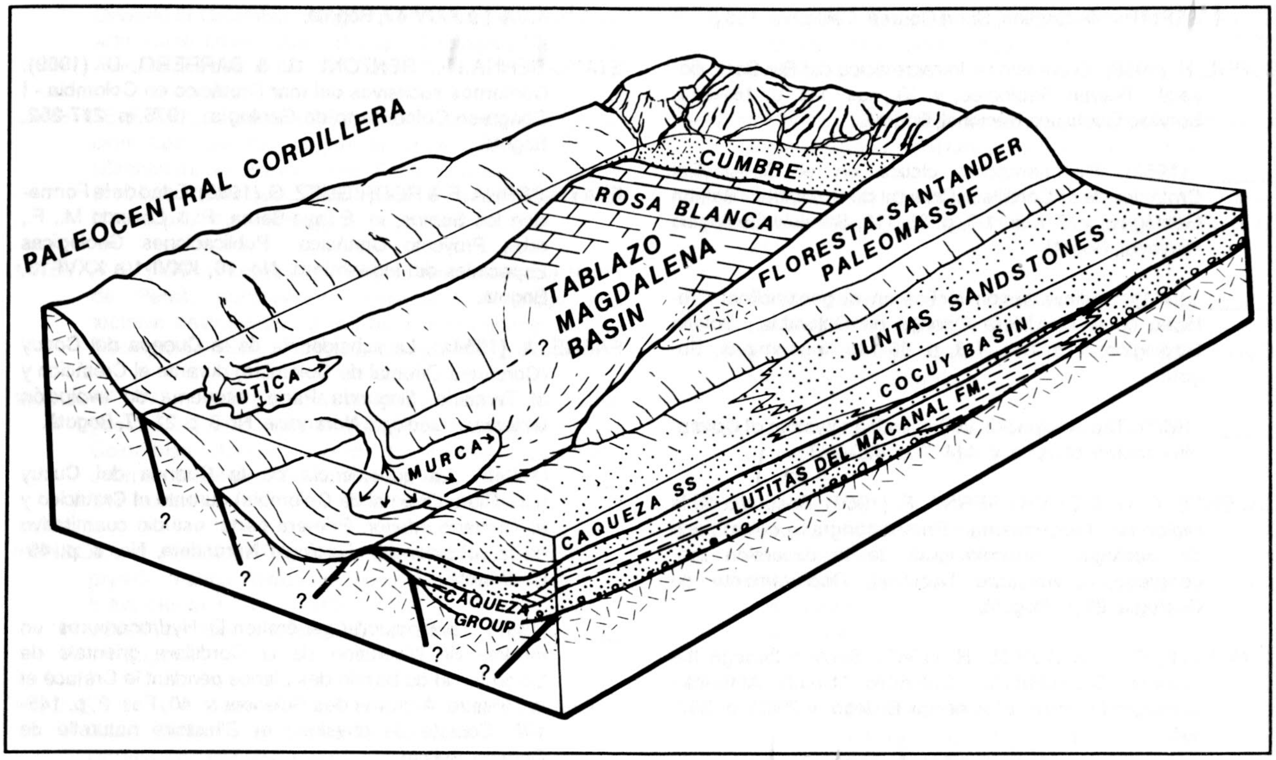

Figure 10. Diagrammatic model of the Lower Cretaceous basin of the Cordillera Oriental-Magdalena Valley

the south in the Cundinamarca-Bogotá basin the Utica sandstone was deposited in shallow marine environments and the Murca Formation was deposited in deeper water to the east of the Utica as a turbiditic deposit. The deposition of these latter units probably was associated with normal faults during an extensional phase in the Upper Jurassic? - Lower Cretaceous. Thus, the Late Valanginian basin was divided into a central depocenter (Murca Formation), a western or southwestern shelf (Utica sandstone) and a northern or northeastern platform (Rosablanca Formation).

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