PALEONTOLOGIC AND STRATIGRAPHIC RELATIONS OF PHOSPHATE BEDS IN UPPER CRETACEOUS ROCKS OF THE CORDILLERA ORIENTAL, COLOMBIA

By

Edwin K. Maughan
U.S. Geological Survey

and

Francisco Zambrano O.

Pedro Mojica G.

Jacob Abozaglo M.

Fernando Pachón P., and

Raúl Durán R.,

Instituto Nacional de Investigaciones Geológico-Mineras

79-1525

CONTENTS

ILLUSTRATIONS

TABLES

PALEONTOLOGIC AND STRATIGRAPHIC RELATIONS
OF PHOSPHATE BEDS IN UPPER CRETACEOUS ROCKS OF THE
CORDILLERA ORIENTAL, COLOMBIA

By

Edwin K. Maughan
U.S. Geological Survey

and

Francisco Zambrano O., Pedro Mojica G., Jacob Abozaglo M.,
Fernando Pachón P., and Raúl Durán R.,
Instituto Nacional de Investigaciones Geológico-Mineras

ABSTRACT

Phosphorite crops out in the Cordillera Oriental of the Colombian Andes in rocks of Late Cretaceous age as strata composed mostly of pelletal carbonate fluorapatite. One stratum of Santonian age near the base of the Galembo Member of the La Luna Formation crops out at many places in the Departments of Santander and Norte de Santander and may be of commercial grade. This stratum is more than one meter thick at several places near Lebrija and near Sardinata, farther south it is locally one meter thick or more near the base of the Guadalupe Formation in the Department of Boyacá. Other phosphorite beds are found at higher stratigraphic levels in the Galembo Member and the Guadalupe Formation, and at some places these may be commercial also. A stratigraphically lower phosphorite occurs below the Galembo Member in the Capacho Formation (Cenomanian age) in at least one area near the town of San Andrés, Santander. A phosphorite or pebbly phosphate conglomerate derived from erosion of the Galembo Member forms the base of the Umir Shale and the equivalent Colón Shale at many places.

Deposition of the apatite took place upon the continental shelf in marine water of presumed moderate depth between the Andean geosyncline and near-shore detrital deposits adjacent to the Guayana shield. Preliminary calculations indicate phosphorite reserves of approximately 315 million metric tons in 9 areas, determined from measurements of thickness, length of the outcrop, and by projecting the reserves to a maximum of 1,000 meters down the dip of the strata into the subsurface. Two mines were producing phosphate rock in 1969; one near Turmequé, Boyacá, and the other near Tesalia, Huila.

INTRODUCTION

Phosphorite beds, some of which may be economic, have been found in strata of Late Cretaceous age at several localities in the Cordillera Oriental and in a few localities in the southern part of the Cordillera Central of the Colombian Andes (fig. 1). The present study has established elements of the paleographic and stratigraphic framework in which the phosphorite beds were formed. Several areas of possible exploitation are outlined and stratigraphic and paleogeographic guide lines for continued exploration of phosphate in Colombia have been established.

Previous work

Several unsuccessful searches were made for phosphorite in Colombia (Hubach, 1953; Wokittel, 1960, p. 323-4). Bürgl and Botero (1967) made the first attempt to locate economic phosphate resources on a regional scale and concluded that strata of Santonian (early Late Cretaceous) age would most likely contain phosphorite. Their work led to discovery and the opening of a mine near Tesalia in the Department of Huila, in beds of the

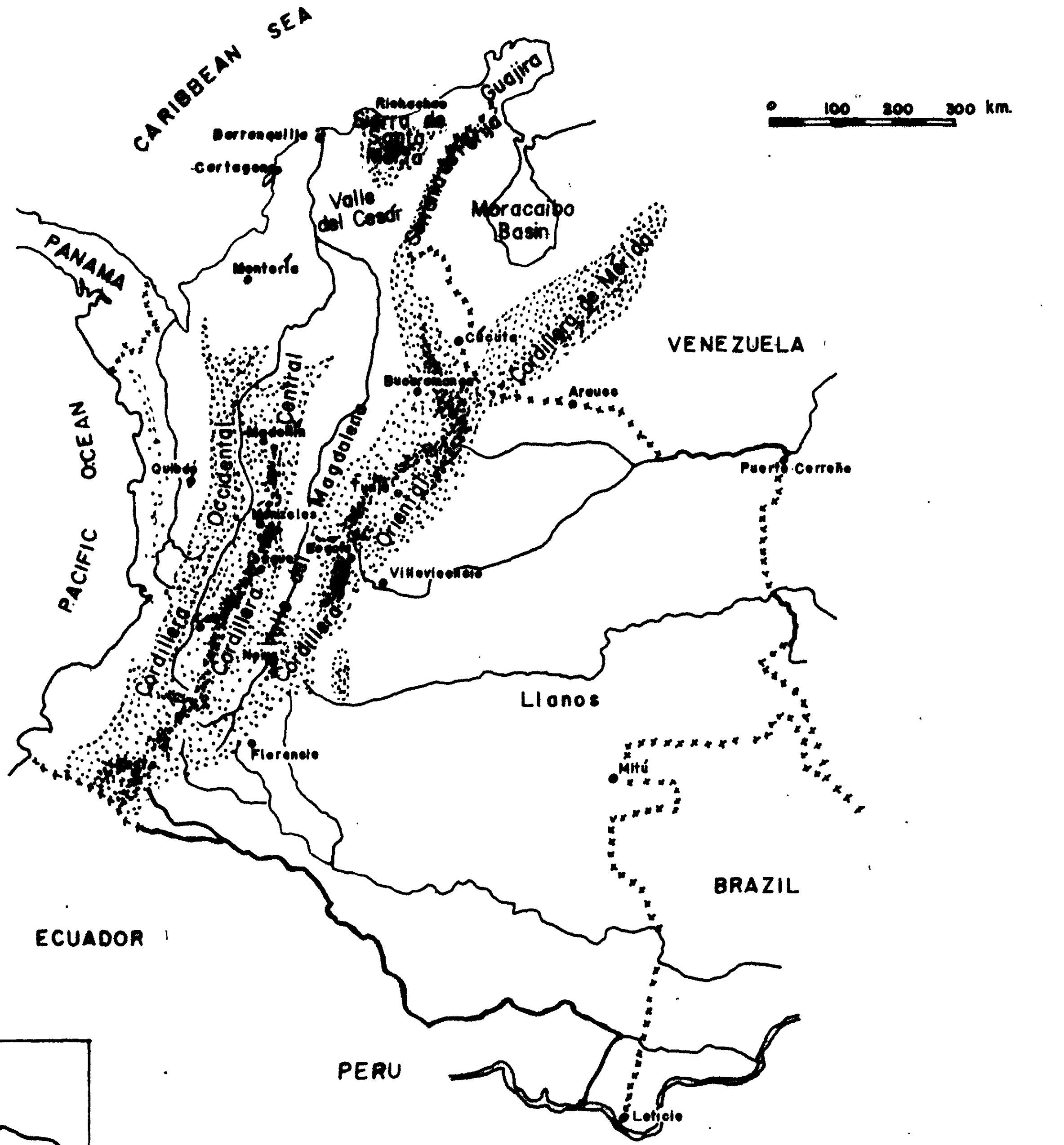

Figure I.

Informe Nº

Major physiographic provinces in Colombia and western Venezuela

Dibujó: Enid de Oggioni

Guadalupe Formations of Santonian age. Geological exploration for petroleum in western Venezuela and adjacent parts of Colombia resulted in the discovery of phosphate, also of Santonian age, in the La Luna Formation, and has led to the exploration and opening of a phosphate mine at Lobatera in the State of Táchira, Venezuela, about 25 km east of the Colombian border.

Work of the Inventario Minero Nacional (IMN), now incorporated into the Instituto Nacional de Investigaciones Geológico-Mineras (INGEOMINAS), was extended to the western part of the Sabana of Bogotá because of the indications of phosphorite in the vicinity of Alto del Trigo (fig. 2). Indications of phosphorite were found also in southern Cundinamarca and in Santander and Norte de Santander. Cathcart and Zambrano (1967) synthesized the existing data and established the existence of probable commercially exploitable deposits in the La Luna Formation in the Departments of Santander and Norte de Santander. They concluded that the apparent best deposits are near Sardinata, Norte de Santander. Studies of phosphorite near Turmequé in the Department of Boyacá were undertaken by Mojica (in Cathcart and Zambrano, 1967, p. 131-133).

Present studies

The present 2-year study, from February 1967 to February 1969, began as a separate program of IMN to study the phosphate resources of Colombia, some of which extended beyond the boundaries of the originally designated zones of the Inventario Project. Many of the areas recommended for more detailed study by Cathcart and Zambrano (1967) have been examined, and are reported here. The work included detailed mapping, measurement

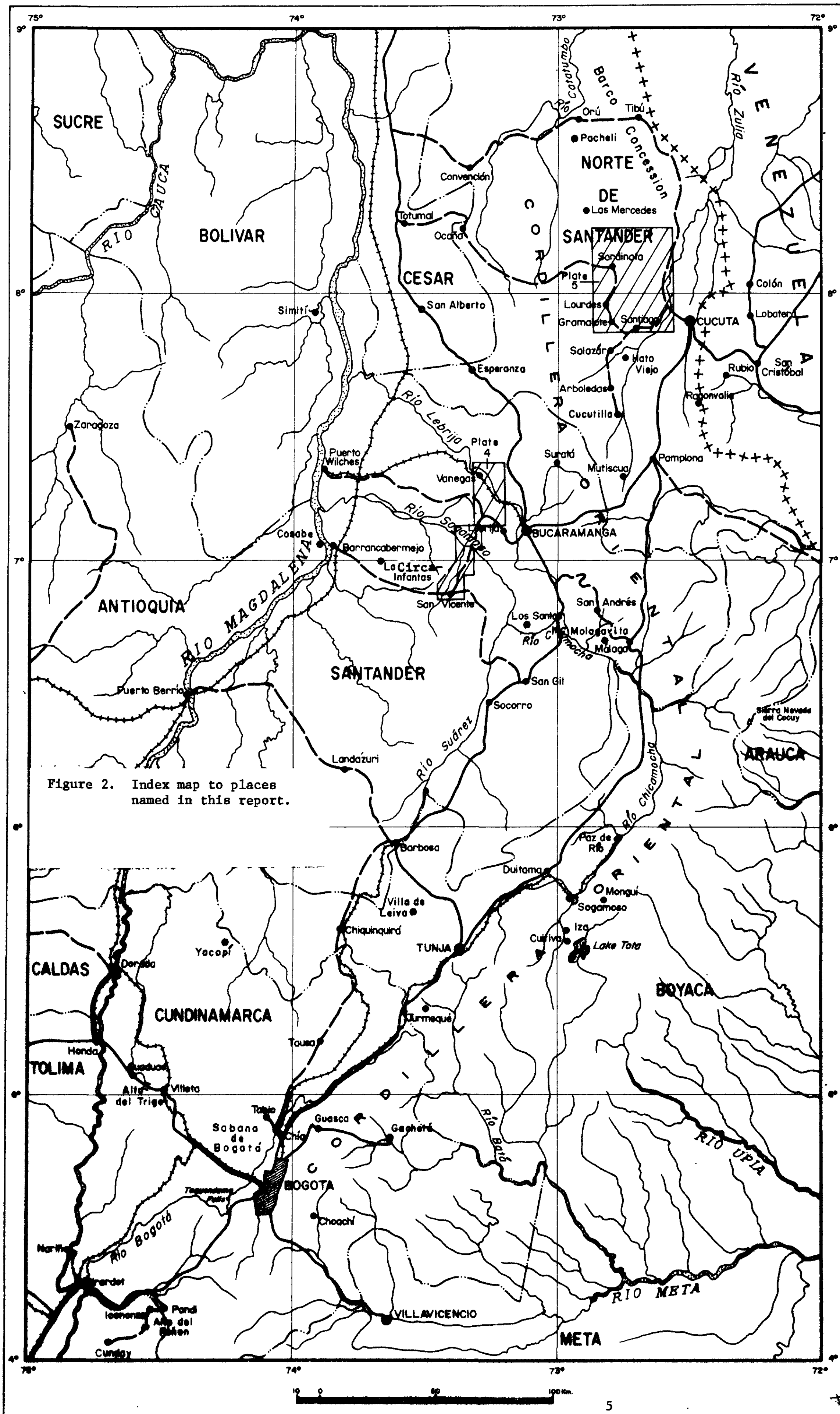

Figure 2. Index map to places named in this report.

of stratigraphic sections, sampling of phosphorite strata, and analysis of phosphorite for its P_2O_5 content.

Acknowledgments

Special thanks are due Dwight E. Ward of the U.S. Geological Survey who served as advisor to the IMN in the Departments of Santander and Norte de Santander. Many of his observations indicated areas favorable for the phosphorite resources. Donald H. McLaughlin, Jr., of the U.S. Geological Survey and advisor to the IMN in the vicinity of Bogotá, provided much information regarding the stratigraphy of that area. Patricio Saénz, Ecuadorian student trainee with the Inventario, assisted during part of the work.

Paleontological material collected as part of this study was examined by Edward B. Fritz of the U.S. Geological Survey and Diana Gutiérrez P., IMN, whose identifications aided in correlation of stratigraphic units.

Administrative support for this study was provided by Earl M. Irving of the U.S. Geological Survey, and Dario Suescún G., and Andrés Jimeno V., Directors of IMN during the time of the study. Marino Arce H. and Jaime Cruz of IMN also aided the progress of this work, as did many residents in the areas visited during the course of study who are to be thanked for their hospitality.

CRETACEOUS STRATIGRAPHY

The stratigraphic nomenclature of Cretaceous rocks in the Cordillera Oriental of the Andes was developed in the vicinity of Bogotá, in the

Oriental. West of the Sabana, the strata are composed mostly of finer grained clastic rocks, predominantly claystone and siltstone, and limestone.

Several stratigraphic names that are still used for the rocks in the vicinity of Bogotá were introduced by Hettner (1892, Spanish translation p. 44-48) who divided the upper part of the Cretaceous strata into the underlying Villeta Formation, which is dominantly siltstone and claystone; and the overlying Guadalupe Formation, which is dominantly sandstone. The Guadalupe is overlain by the Guaduas Formation of Late Cretaceous (Maestrichtian) and Tertiary (Paleocene) age, which comprises mostly soft, gray, and varicolored claystone and sandstone. Hettner, who described the stratigraphic units in only general terms, did not clearly define contacts between the Villeta, Guadalupe, and Guaduas.

Many names used to identify units in the Cretaceous rocks in the vicinity of the Sabana de Bogotá were introduced by Enrique Hubach; but most of the names he used were never established according to presently accepted standards of stratigraphic nomenclature. He attempted to establish and name time-stratigraphic, rather than rock-stratigraphic units and was not always consistent in the way he used the names. In table 1, the column attributed to Hubach is an attempt to codify and summarize his use of nomenclature derived principally from the two most complete reports (Hubach, in Kehrer, 1933; Hubach, 1957).

Table I NOMENCLATURE AND CORRELATION OF FORMATIONS FROM BOGOTA TO THE MARACAIBO BASIN. COLOMBIA AND WESTERN VENEZUELA

AGE		Approximate European Stage Equivalents	CENTRAL PERIJA: Hedberg and Sass 1937	CENTRAL PERIJA: Sutton, 1946	CENTRAL PERIJA: Rod & Maync, 1954	BARCO CONCESSION: Notestein, Hubman, & Bowler, 1944	MIDDLE MAGDALENA VALLEY: Morales & others, 1958	VICINITY OF BOGOTA: Hubach 1933, 1957	VICINITY OF BOGOTA: Renzoni, 1962; Etayo, 1964	VICINITY OF BOGOTA: This report	MIDDLE MAGDALENA VALLEY: This report	MARACAIBO BASIN: This report
CRETACEOUS	Upper	Maestrichtian	Lo Luna		Guasare Fm.; Mito Juan Fm.; Colón Shale	Catatumbo Fm.; Mito Juan Fm.; Colón Shale	Umir Fm.	Guaduas Fm; Guadalupe Group, Conjunto Superior: Tierna Sandstone; Labor Sandstone	Guaduas Fm; Guadalupe Formation: Tierna Sandstone; Labor Sandstone; Plaeners Fm.	Guaduas Formation; Guadalupe Formation, Upper Mbr.: "Tierna" Sandstone	Umir Shale	Colón Shale; Socuy Ls. Mbr.
		Campanian						Plaeners	Raizal Member	"Labor Ss"		
		Santonian			La Luna Formation	La Luna Formation	La Luna Fm.: Galemba Member	Dura Sandstone		Lower Mbr.: "Raizal"; "Dura Sandstone"	La Luna Formation: Galembo Member	La Luna Formation: Galembo Member
		Coniacian		La Luna				Conjunto Inferior	Villeta Group: Chipaque Formation	Villeta Group: Chipaque Formation		
		Turonian					Pujamana Mbr; Salada Mbr.	La Frontera Ss.			Pujamana Mbr.; Salada Mbr.	Pujamana Mbr; Salada Mbr.
		Cenomanian	Cogolla	Cogollo Group: Capacha	Cogollo Group: Maracá Fm.	Cogollo Formation	Salto Limestone	Villeta Group: Chipaque Fm.: Chipaque Ls.			Salto Ls.	Capacho Formation
	Lower	Albian		Aguardiente	Lisure Fm.	Uribante Formation: Aguardiente Mbr.	Simití Shale	Une Sandstone: Une Sandstone	Une Sandstone	Une Sandstone	Simití Shale	Uribante Formation: Aguardiente Ss Member
		Aptian		Apón Fm.	Apón Fm.	Mercedes Mbr.	Basal Limestone Group: Tablazo Limestone; Paja Formation	Fómeque Fm.: Colombiceras zone	Fómeque Formation	Fómeque Formation	Tablazo Limestone; Paja Shale	Mercedes Ls Member
		Barremian Neocomian	Río Negro	Río Negro Formation	Río Negro Formation	Tibú Member	Rosa Blanca Fm.; Tambor Formation				Rosa Blanca Limestone; Tambor Formation	Tibú Sandstone Member

Edwin K Maughan 1969

Application of much of Hubach's terminology has been made in studies by Renzoni (1962; table 1) and by several geologists associated with the petroleum industry, especially as summarized by Campbell (1962). Paleontological studies, helpful in establishing the correlation of strata, were made by Hans Bürgl, and although only a few of Burgl's reports are cited specifically in this report, most are included in the valuable summary of Cretaceous paleontological data compiled by Etayo (1964).

Opinions regarding the separation of the Villeta Group and the Guadalupe Formation and the correlation of strata within these units, especially the correlation of the more coarsely clastic facies east of the Sabana of Bogotá with the finer-grained facies to the west, have differed markedly and will not be resolved without additional careful study.

Villeta Group

The Villeta Group was defined by Hubach (in Kehrer, 1933) to include the Fómeque Formation, the Une Sandstone, and the Chipaque Formation. In this report, in agreement with Renzoni and Etayo, the Villeta Group includes these three formations (table 1), but the upper boundary of the group is higher than the boundary of Hubach because of the upward extension of the Chipaque Formation (Campbell, 1962, p. 21; Renzoni, 1962, p. 72) to include strata that Hubach has called lower Guadalupe (Conjunto Inferior).

The Fómeque Formation, composed predominantly of dark-gray siltstone and claystone, and some thin beds and lenses of dark-gray limestone, lies above the Cáqueza Sandstone and is Hauterivian to Aptian, according to paleontological data summarized by Etayo (1964, p. 32-34). The Une Sandstone, composed mostly of fine-grained sandstone and interbedded siltstone, is Albian to Cenomanian age (Etayo, 1964, p. 34-35).

The strata between the Une Sandstone and the Guadalupe were named the Chipaque Formation by Hubach (*in* Kehrer, 1933); but later, he changed the name of this unit to the Upper Formation (Conjunto Superior, not shown on table 1) of the Villeta Group, and designated the Chipaque Limestone a "lithological guide member" at the top of this formation (Hubach, 1957). Hubach placed the contact between the Chipaque and the Guadalupe above limestone which contains *Exogyra squamata* d'Orbigny (called by its synonym *Exogyra mermeti* Coquand by Hubach); this limestone is not continuous, however, and the highest limestone containing *E. squamata* may be at a stratigraphic level above or below (Campbell, 1962, p. 20; D. H. McLaughlin, Jr., oral commun., 1968). The boundary between the Chipaque and the Guadalupe as defined by Hubach is not definitive and cannot be mapped; therefore, Campbell (1962, p. 21) and Renzoni (1962, p. 72) extended the Chipaque upward to include the prodominantly black shaly claystone of the Lower Guadalupe (Conjunto Inferior) of Hubach, and they placed the contact between the Guadalupe and the Chipaque at the base of the thick white sandstone and interbedded siliceous shale that corresponds to Hubach's Dura Sandstone. This better defined and more consistent contact between dominantly sandstone strata above and dominantly claystone strata below was used by geologists of IMN in their geologic mapping of the Cordillera Oriental near Bogotá (D. H. McLaughlin, Jr., oral commun., 1968).

Guadalupe Formation

The Guadalupe Formation is dominantly sandstone, composed of moderately to well-sorted, fine- to medium-grained quartz; but it is coarse grained and finely conglomeratic near the top. The sandstone is white to light yellowish-gray and commonly stained dark yellow, dark orange, and brown. The sandstone units in the Guadalupe Formation are separated by several thick claystone units. In the lower part of the formation, the strata are generally well cemented, being siliceous and very compact. In the upper part, they are moderately to poorly cemented, being slightly calcareous to noncalcareous; commonly the sandstone is friable and the claystone is very soft. Basinward, northwestward of the principal ranges of the Cordillera Oriental, the Guadalupe is composed of increasingly finer grained quartz sand and silt and grades into argillaceous and calcareous strata of the middle Magdalena Valley facies. Beds comprise thin to thick sets of wedge-planar, low angle cross-strata (classification of McKee and Weir, 1953). Sets are commonly separated by dark-gray, thinly laminated claystone and siltstone--especially in the lower part. Cross-stratification is more pronounced in the upper part of the formation and diminishes northwestward away from the Guayana shield into parallel-bedded and laminated strata deposited on the continental shelf.

The Guadalupe Formation, originally named by Hettner (1892) for the predominantly sandstone upper part of the Cretaceous, was later interpreted by Hubach (_in_ Kehrer, 1933) to include the underlying siltstone and claystone strata in the lower part of the formation. Hubach (_in_ Kehrer, 1933; 1957) elevated his Guadalupe to a group (table 1) and divided it into a lower and an upper formation (Conjunto Inferior and Conjunto Superior). His Lower Guadalupe Formation, mostly siltstone and claystone, is now included in the Chipaque Formation, and the Guadalupe Formation (Group of some authors) is restricted to a section of predominant sandstone (Campbell, 1962, p. 21; Renzoni, 1962, p. 72). The Upper Guadalupe Formation of Hubach, mostly sandstone, was divided by him (Hubach, 1957) into three "lithogical guide members," which are, from base to top, the Dura Sandstone, the Plaeners Formation, and the Tierna Sandstone. The Tierna was subsequently subdivided into the Labor Sandstone below, and the name Tierna was restricted to the upper part.

The subdivision by Renzoni (1962) follows that of Hubach (1933, 1957); in ascending order it includes the Dura Sandstone, the Plaeners Formation, the Labor Sandstone, and the Tierna Sandstone. Other workers (Julivert, 1962b; Etayo, 1964) have called the Dura Sandstone the Raizal Member. The Guadalupe Formation has been divided into a lower and an upper member for purposes of mapping in the IMN program in the vicinity of Bogotá (D. H. McLaughlin, Jr., oral commun., 1968). The Lower Guadalupe of McLaughlin is represented by a thick section of fine- to medium-grained, well-indurated, thin-bedded, cliff-forming sandstone which is the Dura of Hubach and Renzoni, and moderately to well-indurated very fine-grained sandstone to argillite and claystone of the so-called "Plaeners" Formation. Raizal Member is used in this report for the lower member of the Guadalupe Formation of McLaughlin to avoid possible confusion with the Lower Guadalupe of Hubach. The upper member of the

Guadalupe of McLaughlin is the upper cliff-forming sandstone which Hubach and Renzoni called the Labor and Tierna Sandstones. The Labor Sandstone is lithologically similar to sandstone in the Raizal Member of the Guadalupe, but the uppermost Tierna Sandstone is poorly sorted, finely conglomeratic, and strongly crossbedded. This uppermost sandstone lies unconformably upon the Labor Sandstone or the Raizal Member where the Labor is absent.

"Plaeners" is a German word descriptive of the thin and regular bedding of some strata, and it has been used to refer to at least three distinct stratigraphic levels. An upper, or first plaeners, and a lower, or second plaeners are commonly recognized along the western margin of the Sabana de Bogotá and in adjacent parts of the upper Magdalena Valley. These units were called "liditas" rather than plaeners by Bürgl (Bürgl and Dumit, 1954; and Burgl, 1955). The "Plaeners Formation" east of Bogotá forms a recessive unit of somewhat siliceous, very fine-grained sandstone, siltstone, and claystone lying between more prominent cliff-forming sandstone units, and is at a stratigraphic level higher than the lower and upper plaeners west of Bogotá. A similar lithotope is common at several levels in the Guadalupe Formation east of Bogotá, and the Raizal Member includes several thick-bedded sandstone beds as well as plaener units up to the prominent sandstone beds of the upper member.

The "Tierna Sandstone" lies unconformably upon the "Labor Sandstone" and the Raizal Member. Bevelling along the unconformable surface below the Tierna is evident along the road from Guasca to Gachetá in Cundinamarca, where the Labor Sandstone is locally absent (E. B. Fritz, oral commun., 1968). McLaughlin (oral commun., 1969) reports that near Guasca the sandstone of the Raizal Member of the Guadalupe is only a few tens of meters thick, but he attributes the thinning here to change of facies rather than to bevelling. Bevelling is evident in southern Cundinamarca near Pandi and in adjacent parts of Tolima near Icononzo and Cunday. Near Pandi, the Labor Sandstone is composed of about 100 meters of very light gray and yellowish-gray, fine- and medium-grained, moderately well sorted sandstone. This sandstone is well cemented, calcareous, and slightly siliceous, and forms prominent cliffs. It is composed mostly of parallel, thin and thick beds of low-angle, cross-laminated sandstone. Most beds are separated by thin fissile claystone partings that generally do not exceed 10 cm in thickness. The contact at the top of this sandstone unit is very sharp, and many ravines of the region have been eroded through the softer, overlying strata, with the result that the streams flow on the relatively smooth surface formed on the top of this sandstone. Overlying the sandstone is thin-bedded and laminated, light orange-brown, argillaceous sandy siltstone of variable thickness. It may have a maximum thickness of about 40 meters, but locally it is absent. A coal bed in the upper part of this unit is mined near Icononzo, but the lateral extent of this bed is limited to a few hundred meters. The overlying conglomeratic sandstone, correlated with the Tierna, is unconformable upon the underlying strata. In the Pandi area this conglomeratic sandstone rests either upon the coal, the siltstone below the coal, or locally upon the Labor Sandstone. At Alto del Peñón on the road between Icononzo and Cunday, the conglomeratic sandstone rests directly on the fine- to medium-grained sandstone of the Labor, which at that place is reduced in thickness to only 40 meters.

Further loss of section is indicated farther west, where, a few kilometers north of Cunday, the Labor is entirely absent, and the base of the conglomeratic sandstone lies about 65 meters stratigraphically lower than it does at Alto del Peñón. In this section near Cunday, the base of the conglomerate is about 5 meters above a phosphorite bed that is equivalent to a bed 30 meters below the base of the Labor Sandstone in the section at Alto del Peñón. A western source for this conglomerate is suggested by the thicker bed and larger pebbles near Cunday, compared with the thinner bed and smaller pebbles at Also del Peñón and even thinner bed and smaller pebbles near Pandi.

The conglomeratic aspect of the Tierna Sandstone, and the unconformable relation to underlying strata suggest that the Tierna is the initial deposit of a new cycle of sedimentation that includes the overlying Guaduas Formation. Rather than to include the Tierna at the top of the Guadalupe Formation, it would seem logical to map this sandstone as a separate formation or as the basal member of the Guaduas in future studies.

The age of the Guadalupe Formation ranges from Santonian to Maestrichtian. Fossils from the lower Guadalupe are very scarce in the mountains east of Bogotá, and Campbell (1962, p. 21) placed a provisional Campanian age on this unit. Hubach (1957, p. 102) reports *Ostrea nicaisei* Coquand from the base of the Dura Sandstone but makes no definite age designation other than to place these strata in the Senonian. He also states that ammonites and lamellibranchs from the plaeners near Usaquén, in the north of Bogotá, are probably Santonian.

The Santonian age for the lower part of the Guadalupe is indicated by Foraminifera of that age at several places where thin porcellanite beds replace sandstone beds near the base of the formation. Bürgl and Dumit (1954, p. 33-34) report Globigerina cretacea d'Orbigny, Guembelina glabulosa Ehrenberg, Texanites, aff. T. serratomarginatus Redtenbacher, and Anomalina redmondi Petters from the lower porcellanite (lidita inferior) in the section between Girardot and Nariño. In their plate 7, Bürgl and Dumit correlate these porcellanite beds with sandstone and porcellanite near the base of the Guadalupe Formation in the section exposed between Tabio and Chía. They had considered these strata as upper Coniacian; however, Bürgl and Botero (1967, p. 24) revised the age of these strata (lidita inferior) to Santonian. Collections from the lowermost of the porcellanite beds near Turmequé, Boyacá (pl. 1), include Anomalina redmondi and Orthokarstenia revoluta (Stone) (identified by E. B. Fritz, written commun., 1968), and indicate a Santonian age for the lower part of the Guadalupe Formation in another area where thin porcellanite beds locally grade into sandstone beds near the base of the formation. Anomalina redmondi (identified by E. B. Fritz, written commun., 1968) was found in strata near the base of the Raizal Member of the Guadalupe Formation in the Alto del Peñón between Icononzo and Cunday, Tolima. This foraminiferid also is common in higher strata of the Raizal Member or its equivalents at other places (Bürgl and Dumit, 1954; Fritz and Gutiérrez, unpub. data).

The upper porcellanite (primera lidita), equivalent to the upper part of the Raizal Member, contains Siphogeneroides ewaldi (Karsten) and is considered early Campanian in age by Bürgl and Dumit (1954) in the sections between Girardot and Nariño and between Tabio and Chía, and also by Fritz and Gutiérrez (unpub. data) near Tausa, near Turmequé, and between Iza and Cuitiva. Above the upper porcellanite, or equivalent sandstone beds in the upper part of the Raizal Member, soft calcareous siltstone and clayey siltstone beds are of middle Campanian age, according to Bürgl and Dumit (1954). From yet higher beds, they note Siphogeneroides ewaldi Karsten and Orthokarstenia (Siphogeneroides) clarki (Cushman and Campbell) from sandy and calcareous beds equivalent to the Labor Sandstone. Near Tequendama Falls a Campanian age for the upper sandstone of the Guadalupe is indicated by Foraminifera, according to Hubach (1957, p. 101), but on the stratigraphic column which accompanies Hubach's report, the upper sandstone is named Tierna, and an early Maestrichtian age is indicated. Van der Hammen (1954, p. 58) divides this sandstone by an unconformity and suggests that the Campanian age applies only to the lower part (Labor equivalent) and presents evidence of a Maestrichtian age for the upper, Tierna sandstone. Between Tabio and Chía, rocks of Maestrichtian age, which include a claystone unit and an overlying sandstone, probably the Tierna, lie unconformably upon older strata and contain Siphogeneroides plummeri, Orthokarstenia clarki, and Siphogeneroides cretacea (Bürgl and Dumit, 1954).

Middle Magdalena Valley

Stratigraphic nomenclature used in this report for the upper part of the Cretaceous rocks in the middle Magdalena Valley follows that of Morales and others (1958, p. 643-656), with some modifications (table 1). The Cretaceous in the middle Magdalena Valley can be divided into a lower sequence of Berriasian to Hauterivian, and possibly as young as early Barremian age rocks, and an upper sequence of Aptian, possibly as old as late Barremian, to Maestrichtian age rocks. Remnants of the lower sequence form a thick unit of sandstone, limestone, and interbedded shale at many places along the valley of Río Suárez, in the vicinity of Villa de Leiva, Boyacá, and locally in the subsurface of the Magdalena Valley. The lower sequence is not considered in this report, except to note that it has been incorrectly correlated by Morales and others (1958, p. 643-650) from outcrops near Villa de Leiva and near San Gil with the lower part of the younger sequence that crops out along the western flank of the Cordillera Oriental in the vicinity of Río Lebrija and Río Sogamoso.

Deposition of the Cretaceous upper sequence began unconformably on beveled strata of the lower sequence and older rocks in Barremian or Aptian time with the Tambor Formation as the basal unit of a limestone and shale group. The group is overlain by the La Luna Formation of Turonian to possibly Campanian age, and the uppermost Cretaceous formation, lying above the La Luna, is the Umir Shale of Maestrichtian age. Many of the formation and member names applied in the middle Magdalena Valley to the Cretaceous upper sequence are taken from features along the west flank of the Cordillera Oriental in the vicinity of Río Lebrija and Río Sogamoso (pl. 2).

Limestone and shale group

In the middle Magdalena Valley, a group of limestone and shale formations, probably equivalent to the Cogollo Group of the Maracaibo Basin and to all but the uppermost part of the Villeta Group in the vicinity of Bogotá (table 1), consists of the upper part of the Tambor Formation, the Rosa Blanca Limestone, Paja Shale, Tablazo Limestone, Simiti Shale, and possibly the Salto Limestone. These formations comprise a sequence of dark-gray siltstone and claystone alternating with dark-gray, commonly fossiliferous limestone.

These formations, except for the Salto Limestone, are well exposed along the west flank of the Cordillera Oriental in the vicinity of Río Sogamoso and Río Lebrija, where they are approximately 1,700 meters thick (fig. 3). A considerably greater thickness of supposedly equivalent strata in the lower part of the Cretaceous in the valley of Río Suárez, near Villa de Leiva, Boyaca, and in the subsurface of the middle Magdalena Valley (Morales and others, 1958, fig. 20, and fig. 22), as well as the considerable range of age given for these formations, suggest that exposures at the type sections have been miscorrelated with strata in these other areas. Additional stratigraphic and paleontologic studies are needed to determine better the age and probable unconformable relationship of the units within the limestone and shale group to strata of the older Cretaceous sequence. A suggested correlation of the upper sequence with the Cretaceous rocks described near Villa de Leiva by Etayo is shown in figure 3. An apparent northward increase in limestone and thinning of shale units within the limestone and shale

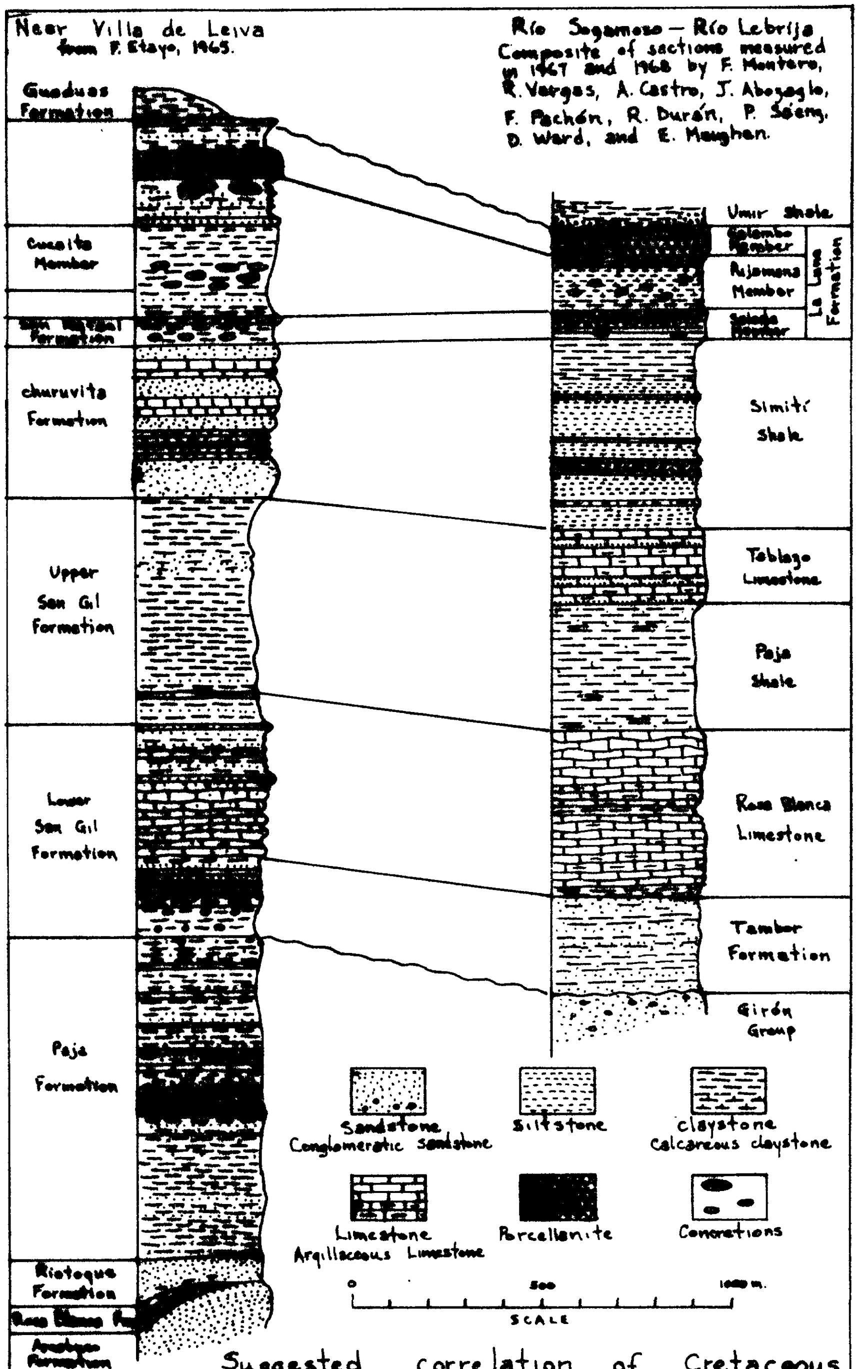

Figure 3 — Suggested correlation of Cretaceous rocks exposed between Río Sogamoso and Río Lebrija to those exposed near Villa de Leiva.

group in this area (Patricio Saénz, oral commun., 1968) suggests correlation of these strata, exclusive of the Simití and Salto, with the "Basal Limestone Group" in the Buturama and Totumal fields (Morales and others, 1958, fig. 12 and fig. 14), the "upper Bolivar Limestone" of the Casabe field (Morales and others, 1958, fig. 20), and the "Tablazo Limestone" of the La Cira-Infantas field (Morales and others, 1958, fig. 22).

Tambor Formation.--The Tambor Formation was named by H. D. Hedberg in an unpublished report, according to Morales and others (1958, p. 643), for strata exposed along the railroad between Bucaramanga and Puerto Wilches in the Lebrija gorge between kilometers 92 and 95 near the village (Hacienda) of El Tambor (pl. 2). The lithology at the type section is described "to consist in its lower part of pebbles and cobbles (maximum diameter 45 cm) of fine-grained, red sandstone, quartzitic sandstone and shale, which have the aspect of Girón rocks (Morales and others, 1958, p. 644). The upper part of the formation is not described except to indicate that there are scarce limestone beds, which contain Lower Cretaceous fossils. The cobble conglomerate has been interpreted as a basal conglomerate of the formation representing the initial deposit of the Cretaceous transgression (Morales and others, 1958, p. 645-647). Outcrops of purplish-red cobble conglomerate between kilometers 93 and 95 in the canyon of Río Lebrija (conglomerado rojo of Cediel, 1968, p. 59) probably are the beds believed to be the basal conglomerate. However, this conglomerate must be excluded from the Tambor Formation because it is fanglomerate of probable late Tertiary or Pleistocene age. The conglomerate shows indistinct, but approximately horizontal stratification, which contrasts with the adjacent steeply dipping Mesozoic strata; it is only locally present within the Lebrija gorge; and it is related to neither the Jurassic (?) Girón nor the Cretaceous Tambor Formation.

A two part division of the Tambor has been used in maps by geologists of the Inventario Minero Nacional (D. E. Ward, oral commun., 1968). No rocks of Girón aspect are included on the geologic map of the Bucaramonga quadrangle (Ward and others, 1969) in the Tambor Formation in the vicinity of the type section. In the vicinity of Río Lebrija and southward for about 10 km, the Tambor, as mapped, consists of thin beds of pebbly, slightly conglomeratic sandstone and interbedded red and varicolored shales in the lower part, and gray lutites and a few thin beds of dark-gray limestone in the upper part. At other places, a lower part of pebbly conglomeratic sandstone and mudstone is mapped as part of the Tambor Formation, although it is lithologically the same as the Girón Formation, and it is in depositional continuity and is not readily separated from the underlying Girón. This sandstone forms prominent cliffs and ridges composed mostly of poorly sorted medium- to coarse-grained cross-bedded reddish-colored, arkosic sandstone to pebble conglomerate and includes beds of claystone and siltstone. Were it not for the mistaken concepts that the fanglomerate in the Lebrija gorge represents a basal conglomerate of the Cretaceous sequence, and that these strata are equivalent to that fanglomerate, these conglomeratic strata of the Girón Formation would not have been mapped as part of the Tambor Formation.

The Tambor, as restricted by excluding the fanglomerate and conglomeratic sandstone, mostly comprises lutites and is generally poorly exposed in valleys and swales. It is composed of moderately well sorted, parallel-bedded siltstone, very fine grained sandstone, and a few thin beds of limestone. These rocks ar commonly reddish to yellowish in the lower part of the formation, but mostly they are dark gray, weather to light brown, and are lithologically similar to the strata of the younger Paja Shale and Simití Shale and to argillaceous and silty beds within the Rosa Blanca and Tablazo limestones.

An unconformity, indicated by an erosional contact well exposed 5-1/2 km northwest of Asufrada along the road to Hacienda San Joaquín (pl. 4), separates the restricted Tambor from the underlying Girón. The unconformable contact is marked by a few thin beds of sandstone, grit, shale, and lithic pebbles reworked from the underlying strata which have been anciently weathered to a paleosol. A few siderite (?) and phosphate(?) nodules are scattered along the unconformable contact. This unconformity is believed to represent an important hiatus preceding deposition of the younger Cretaceous sequence of this ared to a paleosol. A few siderite (?) and phosphate(?) nodules are scattered along the unconformable contact. This unconformity is believed to represent an important hiatus preceding deposition of the younger Cretaceous sequence of this area, and may have formed after deposition of an older Cretaceous dequence that is locally absent. The Tambor is considered to be the initial unit of a younger sequence composed of alternating argillaceous and calcareous beds that includes formations through the Simití Shale.

Age of the Tambor Formation is uncertain. The upper part contains marine fossils, but no age determinations are known to have been made from collections in the vicinity of the type section. According to Etayo (1964, p. 39), the faunal assemblage that includes Choffatella decipiens Schlumberger cited by Morales and others (1958, p. 647) indicates an age that could be as young as Aptian. This collection is from the upper part of the Tambor near the Totumal field, about 125 km north of the type section. An age significantly greater than Aptian does not seem likely for the Tambor at its type section and along the western flank of the Cordillera Oriental between Río Lebrija and Río Sogamoso (fig. 2 and pl. 4), but the age could be as old as Barremian. Older ages, Valanginian and Hauterivian given by Morales and others (1958, p. 647-648), are questionable. A Hauterivian age determination is invalidated by assigning an Aptian age to the Choffatella decipiens fauna on which the Hauterivian age had been based (Etayo, 1964, p. 39); and a correlation with the Tambor in Boyacá considered to be Valanginian, is probably erroneous, according to Julivert (written commun., cited by Etayo, 1964, p. 39).

Strata in the canyon of Río Chicamocha near its confluence with Río Suárez are named the Los Santos Formation (Cediel, 1968, p. 54 and 58-60) and are correlated with the Tambor exposed along the mountain front between Río Sogamoso and Río Lebrija. However, Cediel tentatively assigns a Berriasian age to the Los Santos Formation because it underlies limestone of Valanginian and Hauterivian ages in the type area. Because the Los Santos Formation is much older than Aptian, the age established for the upper part of the Tambor near Totumal, the two formations probably are not equivalent; but the Los Santos Formation does seem to be equivalent to the Arcabuco Sandstone near Villa de Leiva.

Transgression of the sea from south to north is invoked by Morales and others (1958, p. 647-648) to explain the different ages reported for strata they correlate with the Tambor. Very slow transgression starting from about the beginning of Cretaceous time until Aptian time, and only crossing approximately 200 km between the Rio Chicamocha to Totumal seems unlikely. Even large-scale tectonic movements that could have greatly shortened the distance and juxtaposed the site of older deposition near to the site of younger seem inadequate to estalish the equivalency of these rocks.

Rather than being equivalent formations, the Tambor and the Los Santos are similar in lithology because they each represent the initial deposit of separate depositional sequences. The Los Santos is the initial deposit of the older Cretaceous sequence, and the Tambor is the initial deposit of a younger sequence. Limestone and shale strata that were deposited after the Los Santos Formation as part of the older sequence form a thick wedge of Early Cretaceous rocks exposed from the Río Chicamocha southward along the valley of Río Suárez and beyond to the vicinity of Villa de Leiva, Boyacá, but rocks of this age are absent where the Tambor Formation and succeeding strata of the younger sequence are exposed in the canyon of Río Sogamoso, about 20 km northwest of Los Santos. Gypsum beds that are part of this older sequence terminate abruptly in the area northwest of Los Santos (Darío Suescún G., oral commun., 1968), probably by erosional bevelling of the older sequence prior to deposition of the younger. The relationship of these strata suggest faulting or folding with uplift to the west; movement, approximately during Barremian time, may have been along the Suárez fault shown by Cediel (1968, pl. 2) on the geologic map of the pre-Cretaceous west of the Santander massif. These speculations, however, remain unresolved until detailed study of these strata can be undertaken.

Rosa Blanca Limestone.--The Rosa Blanca Limestone is composed of thin beds of medium- to dark-gray, fine- to medium-crystalline and fossiliferous limestone interstratified with shale partings and thin to medium-thick beds of dark-gray siltstone and claystone. The formation contains some coquina beds that are composed of abundant white, thick-shelled lamellibranchs in a matrix of dark-gray limestone. The formation was named by Wheeler, according to Morales and others (1958, p. 648), who suggest that the generally accepted type section is on the Río Sogamoso about 1 to 1-1/2 km upstream from the village of El Tablazo (pl. 4).

The age of the Rosa Blanca Formation in the type area is not known with certainty. The paleontological data from other areas are from strata that are questionably correlated with the type section near Tablazo. The formation may range from Hauterivian to Aptian although most fossil collections cited by Etayo (1958, p. 648; 1964, p. 39-41), indicate a Barremian age. On the other hand, only near Totumal does the Rosa Blanca physically compare in thickness and most lithological details with the Rosa Blanca in the type area near Tablazo. The fauna from the lower part of the Rosa Blanca near Totumal, which includes Choffatella decipiens Schlumberger, indicates an Aptian age for this formation (Etayo, 1964, p. 39), which is the only age that can be confidently extended to this formation along the Lebrija front.

Paja Shale.--Dark-gray, silty, micaceous, slightly calcareous claystone between the underlying Rosa Blanca and the overlying Tablazo Limestone is named the Paja Shale. A few thin beds of limestone are interbedded in the claystone. This formation was first described by O. C. Wheeler, according to Morales and others (1958, p. 649-650), and is named for Quebrada La Paja, a tributary of the Río Sogamoso, about 1 km upstream from El Tablazo (pl. 4). The age of the Paja in the type area is Aptian (Etayo, 1964, p. 46).

Many fossil collections from strata similar to the Paja in areas east of the Suárez fault, from the vicinity of Los Santos to the vicinity of Villa de Leiva, indicate a Barremian age for these rocks (Etayo, 1964 p. 41-46). However, these strata are not the Paja Shale, but are correctly correlated with the Tambor Formation at its type area.

Tablazo Limestone.--Tablazo Limestone is similar to the Rosa Blanca Limestone. This formation is named for the village of Ep Tablazo on the Río Sogamoso where it is crossed by the road between Lebrija and San Vicente. The type section is exposed along the north side of Río Sogamoso eastward from the village, according to O. C. Wheeler (as cited in Morales and others, 1968, p. 651), and the age is late Aptian to early Albian (Etayo, 1964, p. 46).

Simití Shale.--The Simití Shale (Morales and others, 1958, p. 651-652) is composed mostly of very dark-gray claystone and micaceous siltstone and interstratified thin- to medium-thick-bedded, very dark gray, finely crystalline, fossiliferous limestone in the exposures along the west flank of the Cordillera Oriental between Vanegas and San Vicente. These rocks are petroliferous and contain some apatite pellets and sparse to abundant glauconite grains in some strata, especially in the upper part of the formation. The name is taken from Ciénega Simití and the village where these strata are well exposed (fig. 2), and it is used for the soft-weathering, swale-forming beds between the Tablazo Limestone and the La Luna Formation.

The Simití may be divided into two parts. Approximately the lower two-thirds of the formation is composed mostly of siltstone that grades to sandstone in areas lying eastward and southward. The upper part, composed mostly of claystone and a few thin beds of limestone, correlates with similar clayey strata in the southern part of the Maracaibo Basin and in the vicinity of Bogotá, and with calcareous strata in the northern part of the Maracaibo Basin. The Simití is of Albian age, according to Morales and others (1958, p. 652). Exogyra squamata in the upper part of the Simití at exposures between San Vicente and Vanegas indicates a Cenomanian age for these strata.

Salto Limestone.--The Salto Limestone, said to be of formational rank and lying between the Simití and La Luna Formations (Morales and others, 1958, p. 652-655) is named for Quebrada El Salto near Totumal (fig. 2). This formation could not be identified by the writers on the west flank of the Cordillera Oriental in the vicinity of Vanegas nor as far south as San Vicente. Possible the limestone at this stratigraphic position is locally absent because of nondeposition or by erosional bevelling prior to deposition of the overlying La Luna Formation. An alternative possibility is that the Salada Member of the La Luna Formation or at least the limestone in the lower part of this member has been identified as the Salto Limestone in the Totumal area. The description by Morales of the Salto Limestone in the type area is like the limestone in the Salada Member. If the Salto is not a mappable unit distinct from the Salada Member of the La Luna Formation, its recognition as a distinct formation should be discontinued. A third possibility is that there may be a southward change of facies from limestone in the Totumal area into predominantly claystone and thin, fossiliferous, crystalline limestone beds which occur in the upper part of the Simití Shale in the Vanegas area and farther south. This latter possibility is supported by a similar southward change of facies for equivalent strata in the Maracaibo Basin where the Maraca Limestone grades into the Capacho Formation (Rod and Maync, 1954, p. 210). Comparison and reinterpretation of subsurface data in the middle Magdalena Valley presented by Morales and others (1958, fig. 20, fig. 22, fig. 12), also indicates a southward change from limestone to claystone.

La Luna Formation

The La Luna Formation was named (Garner, 1926, p. 679) in the Perijá area of western Venezuela near the Colombian border west of Lake Maracaibo. The use of this formation name to identify equivalent strata has been extended into the middle Magdalena Valley by Morales and others (1958, p. 653). The La Luna Formation generally is divisible into three members, but low-angle unconformities, facies changes, and intertonguing make complex stratigraphic relationships so that separation of these members is difficult in some areas. In the vicinity of Río Sogamoso, between San

Vicente and Lebrija in the Department of Santander, these three members were originally recognized and named in an unpublished report by O. C. Wheeler (Morales and others, 1958, p. 653-654).

The members of the La Luna, in ascending order, are the Salada, the Pujamana, and the Galembo. The section in Quebrada La Sorda near Azufrada (pl. 4) is one of the most readily accessible and completely exposed sections of this formation in the region and is used herein as the reference section for the western flank of the Cordillera Oriental. The columnar section measured at this location by geologists of the Inventario Minero is shown in column 5 on plate 1.

Salada Member.--Typical exposures of the Salada Member are indicated by Morales and others (1958, p. 653) as those on the north bank of the Río Sogamoso opposite the mouth of Quebrada Salada. The type locality is in question because there is no Quebrada Salada named on the 1:25,000-scale topographic map, Ríos Chucurí-Sogamoso, (Inst. Geogr. Col. Plancha 120-I-B, 1954). However, very good exposures of the Salada Member form a prominent hill on the north bank of the river opposite the mouth of Quebrada La Azufrada. These outcrops, 0.7 km northwest of El Tablazo, are probably those intended for the type section. The La Luna Formation is not exposed elsewhere along Río Sogamoso.

The Salada Member is also well exposed in Quebrada Hedionda, a tributary of Quebrada La Azufrada that is crossed by the road from Lebrija to San Vicente about halfway between El Tablazo and Quebrada del Ramo. The lower part of the Pujamana Member is also well to moderately well exposed in this quebrada and in the road cuts along its sides. The Salada Member is also moderately well exposed along the railroad immediately east of Vanegas (pl. 4).

The Salada Member consists of medium to dark-gray argillaceous limestone and calcareous claystone that is generally parallel laminated to parallel thin-bedded. Some strata are slightly to moderately siliceous and are better described as porcellanite (siliceous and possibly slightly calcareous claystone or siltstone; Krumbein and Sloss, 1963, p. 153-154). Laminae and thin beds of chert are commonly interstratified with the porcellanite in the upper part of the member. In these aspects, this member resembles the Galembo and is easily confused with it. Calcareous concretions ranging in diameter from a few centimeters to as much as 2 meters are common in the Salada Member, but are not common in the Galembo. Some concretions are spherical and range to 50 cm in diameter ("cannon-ball") and others are oblate and range to 3 meters in diameter by about one-third meter in thickness (so-called "cartwheels" or "ruedas de carretas"). Many of the concretions are pyritiferous, and pyrite crystals and nodules are common in the claystone beds. Foraminifera of small size are abundant in some layers; many concretions contain ammonites. A few thin beds as much as 40 cm thick of soft unctuous clay composed of kaolinite and mixed layered illite-montmorillonite (S. H. Patterson, written commun., 1970) are interstratified with porcellanite in the upper part of the Salada Member.

The contact between the Salada and the underlying Simití Shale appears to be well defined and marks a distinct lithologic change. The hard and considerably more resistant beds of the Salada contrast with the soft, poorly exposed arenaceous siltstone and claystone of the underlying strata. Bleaching of the dark-gray color of the uppermost few decimeters of the underlying strata, iron staining along the contact, and the fact that the basal strata of the La Luna that overlie this bleached zone consist of ripple-laminated siltstone suggest a disconformity at this contact. Variation in the apparent thickness of the Simití between El Tablazo and Conchal as observed on aerial photographs and geologic maps suggests a low-angle unconformity below the Salada Member.

Pujamana Member.--The name Pujamana is said to have been "first used by Wheeler in an unpublished report to designate the strata exposed in the Quebrada of the same name, a tributary of the Río Sogamoso" (Morales and others, 1958, p. 654). A typed copy of Morales' report in the library of the Servicio Geológico Nacional at Bogotá differs from the published version and states that the type section is "in the Galembo Ridge opposite the mouth of Quebrada Pujamana." In neither the Quebrada Pujamana nor the Galembo Ridge opposite its mouth are exposures adequate for a type section. The Quebrada Pujamana joins the Quebrada Aguablanca, and the only strata well exposed above the junction with Quebrada Aguablanca are part of the Simití Shale. The uppermost beds of the Pujamana Member and its contact with the overlying Galembo Member are well exposed along the west bank of Quebrada Aguablanca opposite the mouth of Quebrada Pujamana and at several places nearby. The most complete section is in Quebrada La Sorda, and it is presented here as the principal reference section (column 5, pl. 1). The lowermost 31 meters of the Pujamana is very poorly exposed, and unfortunately, the 13 meters that includes the contact with the Galembo is poorly exposed in this quebrada. Approximately the lower 30 meters of this member is well exposed in a roadcut at Quebrada Hedionda, about 3 km southwest of El Tablazo, and comprise soft, moderately fissile, mostly noncalcareous, dark-gray claystone. The upper part of the Pujamana is well exposed at many places to the north and south of Quebrada La Sorda. The section nearest to Quebrada La Sorda that is well exposed is 5 km south at the mouth of Quebrada Los Altos where the latter empties into Quebrada Aguablanca. The Pujamana Member is well exposed there, but the lowermost strata and the contact with the underlying Salada Member are displaced by a fault (R. Durán, oral commun., 1967).

The Pujamana is moderately well exposed in Quebrada La Sorda (pl. 1, sec. 5), except the lowermost 31 meters in the lower part of the member which is very poorly exposed. The member is moderately well exposed in the Vanegas area, especially the section along the railroad east of the village, and in the river bank and along a foottrail on the north side of Río Lebrija opposite the railroad. Excellent exposures of the Pujamana are in the canyon of Quebrada Cútiga east of Hacienda El Naranjo, at the junction of Quebrada Aguablanca with Quebrada Los Altos 3 km south of Azufrada, along the road 5 km west of San Vicente near Hacienda Palmira where the road traverses the La Luna Formation, in Quebrada Las Indias approximately 8 km west-southwest of San Vicente, immediately south of the bridge over Río Chucurí to Peña Negra, 1 km southwest of the mouth of Quebrada del Ramo, and in roadcuts in Quebrada Hedionda (pl. 4). All these, however, include covered intervals that obscure either the upper contact with the Galembo, or the lower contact with the Salada.

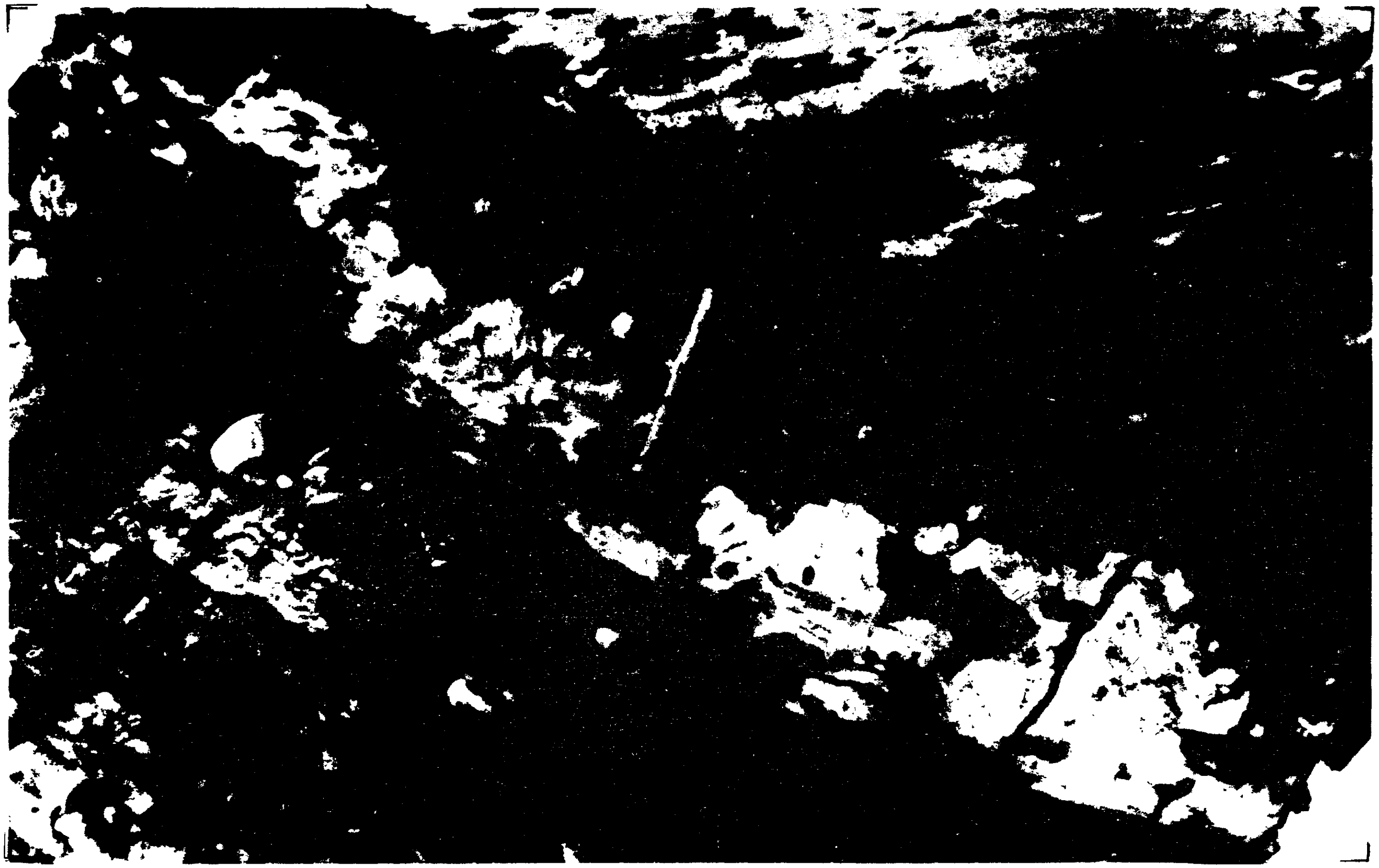

Fig. 4 Unconformable contact of Galembo Member with Pujamana Member at Vanegas, Santander.

The Pujamana Member consists mostly of very hard, dark-gray, calcareous and noncalcareous silty laminated claystone. It includes some thin beds of argillaceous and very finely crystalline limestone and abundant limestone concretions as in the Salada Member. Pyrite is common in this member in both the claystone and the concretions. The unit is generally less resistant to weathering than the Salada and Galembo members and commonly forms a valley or swale between them. The upper part of the member is somewhat siliceous; more resistant strata that are similar to the Galembo Member occur locally within these siliceous strata. Abundant thin beds of black chert are also common in the upper part. Foraminifera are scarce, but many concretions contain ammonites.

Thickness of the Pujamana varies greatly (D. E. Ward, oral commun., 1968). The member is 285 meters thick in Quebrada La Sorda. Differences in thickness may be due to changes of facies at the base from the more resistant, calcareous, and siliceous facies of the Salada; but variation is due mostly to bevelling of the member along the unconformable contact with the Galembo Member.

The contact with the overlying Galembo Member is an unconformity. Angular blocks of limestone as much as 1/2 meter long derived from uppermost strata of the Pujamana are incorporated into the basal phosphatic stratum of the Galembo in excellent exposures of the contact at the bend of the Río Lebrija, 1/2 kilometer west of Vanegas (fig. 4 and plate 3, column 16). An irregular contact probably due to partial erosion of the Pujamana is evident at other exposures in the Vanegas area and at Quebrada Los Altos (pl. 3, and pl. 2, column 6). Variable thickness of the Pujamana Member, and a slightly variable thickness between the base of the Galembo Member and the principal phosphorite bed, as if by in-filling of a slightly irregular surface (pls. 2 and 3), are also suggestive of an unconformity. Paleontological data suggest that this is also the contact between the Coniacian and Santonian substages of the Senonian, but in a few places the Galembo of Santonian age rests on Turonian or older rock.

A persistent zone of cartwheel concretions like those of the Salada lies in the Pujamana Member within two to three meters of the base of the overlying Galembo. This concretion zone probably is related to the unconformable surface rather than being a depositional feature near the top of the member. This zone of cartwheel concretions occurs throughout the region and may indicate a nearly time-stratigraphic horizon, but the concretions may have formed as secondary, rather than primary, features along an erosional surface on the Pujamana Member. It is suggested that these concretions formed by diagenetic migration and concentration of calcium carbonate along a horizon or in a thin zone parallel to a probable ancient erosion surface that formed after deposition of the Pujamana, rather than having been primarily formed by deposition and syngenetic concentration at a uniform stratigraphic horizon above the base of the member. These cartwheel concretions are useful as a guide to the boundary between the Pujamana and Galembo Members as well as to locate the principal phosphorite zone that lies approximately 7 to 10 meters above these concretions in the basal part of the Galembo.

Galembo Member.--The Galembo Member is a sequence composed dominantly of thin, planar-bedded porcellanite (fig. 5). Many layers of laminated to thin-bedded calcareous claystone, similar to the nonsiliceous claystone that dominates the lithology of the Pujamana, occur within this unit, especially in the middle part of the member. Apatite is common throughout these strata, generally as pellets or phosphatized Foraminifera and skeletal fragments. Apatite pellets and phosphatized forams are concentrated into individual beds as much as 2 meters thick, which make the Galembo Member the most important stratigraphic unit currently known for its phosphorite resources. Limestone concretions, characteristic of most horizons of the Salada and Pujamana Members, are scarce in the Galembo Member. No megafossils were found in the Galembo.

The thickness of the Galembo Member ranges from zero to as much as 120 meters. Near Hacienda Capitanejos (pl. 4) between El Tablazo and Azufrada and at several places between Azufrada and El Conchal, the Galembo is absent from the La Luna Formation, having been removed by erosion prior to deposition of the overlying Umir Formation (fig. 6; Maughan, 1969, pl. 1). The Galembo Member is 120 meters thick at Hacienda Mirabel, but it thins to 50 meters where it is exposed along the bank of the Río Sogamoso, 2-1/2 km north of the hacienda, and at another place along Cerro Galembo 2 km south of the hacienda. The member is only 25 meters thick, 6 km south of Hacienda Mirabel at the bridge near El Ramo across the Río Chucurí to Peña Negra; however, at Hacienda Palmira, 15 km farther south, the thickness is 112 meters.

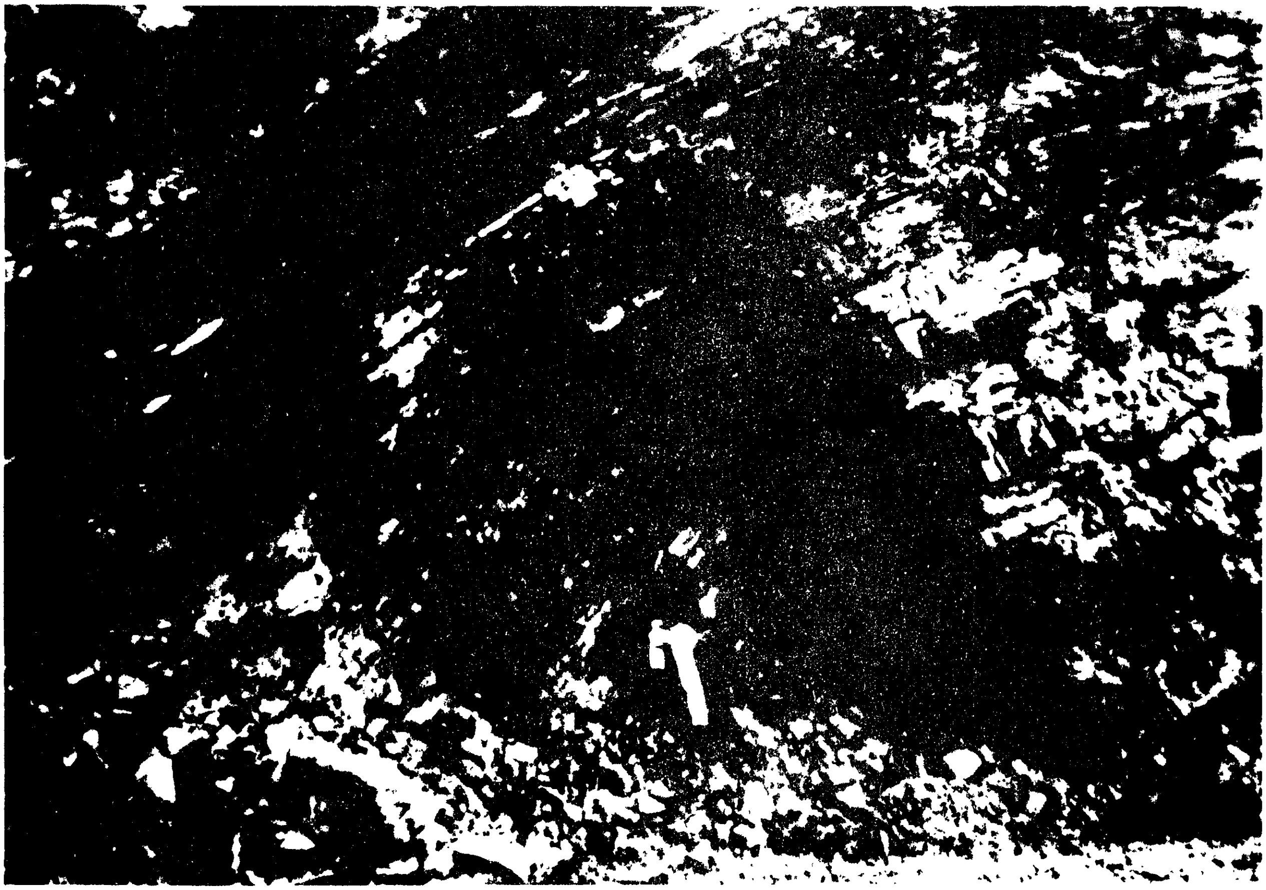

Figure 5. Exposure of typical thin-bedded porcellanite of Galembo Member of La Luna Formation near El Ramo on the road between Lebrija and San Vicente, Santander. The geologist is pointing to the intermediate phosphorite bed.

A pebble conglomerate at the base of the Umir Shale overlies the Galembo at many places and indicates the formation of an unconformable erosion surface prior to deposition of the Umir. Bürgl and Botero (1967, p. 27) note the absence in some parts of the Cordillera Oriental of upper Santonian and Campanian strata, which are equivalent to the Galembo, and suggest an unconformity. The unconformity accounts for most of the variation in thickness of the Galembo Member. Probably the Galembo strata were deposited more-or-less uniformly thick throughout most of the region of the middle Magdalena Valley and adjacent parts of the Cordillera Oriental as part of a wedge of sediments gradually increasing in thickness easterly into a trough marginal to the Guyana shield, but these sediments were subsequently warped and beveled as a consequence of regional tectonic disturbance. Figure 6 illustrates the folding with warping and erosion surface on which the conglomerate at the base of the Umir was deposited between Quebrada Las Indias and Conchal in the Department of Santander. This diagram is constructed from points of measured thickness and interpolations between these points based largely upon physiographic expression. Similar variations in thickness occur in the other areas of this study.

The Galembo, where it is thick in exposures along the east side of the middle Magdalena Valley, consists of a tripartite sequence that seems to be more siliceous to the south and more clayey to the north. Porcellanite is dominant in the lower and upper parts of the member, and these are separated by nonsiliceous to slightly siliceous calcareous claystone. However, the intermediate unit is siliceous in the exposures in the section at Palmira near San Vicente, indicating a local change of facies into porcellanite, whereas, farther north in the vicinity of Vanegas the lower part of the Galembo includes more soft claystone beds than are found in equivalent strata to the south.

This member includes thin to medium-thick beds of phosphorite composed mostly of pelletal and oolitic carbonate fluorapatite. These strata seem to extend across most of the area where the Galembo is present, and a zone composed of several beds near the base is the most persistent. These phosphorite beds are assumed to have been formed by upwelling currents over a stable shelf, as has been proposed for the origin of phosphorite beds of the Phosphoria Formation in the western United States (McKelvey and others, 1953).

Age of the formation.--The age of the La Luna Formation ranges from Turonian to Santonian, and possibly Campanian. An early Turonian age is indicated for the Salada Member in the middle Magdalena Valley, according to Morales and others (1958, p. 653), who report *Inoceramus labiatus* Schlotheim collected from the type section on the Río Sogamoso and the ammonites *Eagesia*, *Mamites*, and *Metoicoceras* from exposures in Quebrada

Aguablanca, 8 km northeast of the Totumal oil field in the Department of Cesár. *Inoceramus labiatus* were also collected by the writers from strata that are either the very upper part of the Salada or the lower part of the Pujamana in Quebrada Hedionda, and from the section on the Río Sogamoso opposite the mouth of Quebrada Azufrada (Quebrada Salada of Wheeler). Ammonites collected from the Salada Member in the Quebrada La Sorda and age assignments made from them by Fernando Etayo (oral commun., March, 1968) of the Servicio Geológico Nacional in Bogotá confirm an early Turonian age for these strata.

The assemblage of Foraminifera, consisting of *Heterohelix* sp., *Globigerina* sp., *Globigenerella* sp., and *Radiolaria* sp., collected from strata in Quebrada La Sorda indicate a Turonian to Coniacian age for the Salada (Edward Fritz, written commun., 1968).

The age of the Pujamana is upper Turonian to lower Coniacian, as indicated by Morales. This age is confirmed by Etayo from ammonites collected in Quebrada La Sorda.

Anomalina redmondi Petters was originally indicated to have a Coniacian age (Petters, 1955, p. 214) because it was thought to have been closely associated with ammonites of that age. According to Petters (1955, p. 214), "The ammonites *Bariosiceras* spp., *Peroniceras* spp., *Prionocycloceras* spp.(?), and *Texanites* sp. which were found a few meters beneath the top of the *Anomalina redmondi* zonule of the Barrancabermeja-San Vicente road, establish a Coniacian (early Austin) age." However, stratigraphic studies and samples from this locality (Hacienda Palmira, 0.5 km west of San Vicente) indicate the Anomalina redmondi is found within the lower 50 meters of the Galembo Member and that the underlying ammonite-bearing beds, apparently barren of microfossils, are part of the Pujamana Member. The Pumamana and Galembo contact at this place presents evidence of an unconformity and probable hiatus. Therefore, A Coniacian age is not established. The association of A. redmondi and Orthokarstenia revoluta, the latter generally considered restricted to the Campanian, in nearly all the collections of the present study from the Galembo Member, give these strata closer affinity to Campanian rather than to Coniacian, and the opinion of Bürgl and Botero (1967) that the age is Santonian seems more likely. Bürgl (1961, p. 27), who correlated the Galembo with the porcellanite beds in the Magdalena Valley in the Departments of Tolima and Cundinamarca, placed the lower porcellanite in the Santonian, in which he included the strata between the base of this porcellanite unit and the base of the upper porcellanite, but he gave no paleontological data for this change of opinion. However, according to Diana Gutiérrez (oral commun., 1969), this change was based upon unpublished data linking Anomalina redmondi with ammonites of Santonian age collected from the lower porcellanite unit.

An age for the Galembo as old as Turonian, as indicated by Morales (1958, p. 654-655), is probably erroneous. Based upon his lithologic description for this member of "numerous discoidal ammonite-bearing limestone concretions which reach eight meters in their maximum dimension" it seems likely that the Metoicoceras in Quebrada Aguablanca near Totumal did not come from the Galembo, but probably came instead from strata equivalent to the Salada or Pujamana. In the area of the present studies somewhat to the south of the Totumal area, abundant concretions in the two lower members and few concretions in the upper member were found to be among the distinguishing characteristics useful in recognizing the members of the La Luna. A northward increase of Galembo-like porcellanite was also found in the Salada and Pujamana equivalent, which makes differentiation of the three members more difficult toward the north, but little change in the relative abundance of concretions within each of the three members was also observed.

Umir Shale

The Umir Shale, which overlies the La Luna Formation, forms the uppermost Cretaceous unit on the west flank of the Cordillera Oriental. It is composed of a great thickness of soft, dark-gray claystone and is characterized by abundant concretions and very thin, lenticular beds of sideritic ironstone. The ironstone probably once contained pyrite, now altered to hematite, goethite, and limonite as the result of recent weathering. Abundant selenite crystals within these strata suggest that the siderite and pyrite were broken down by acidic waters and reconstituted into iron oxides and gypsum. Weathered exposures of the formation are light gray, mottled by the dark red to yellow color of the iron oxides; but the Umir as a whole presents a jumbled topographic surface of yellowish to reddish-gray soil with abundant large erratic blocks generally derived from sandstone strata of Tertiary age.

The Umir rests disconformably upon the La Luna Formation and generally includes a basal pebbly microconglomerate. This conglomerate consists of dark-gray to dark-greenish-gray, dolomitic, clayey siltstone matrix with abundant muscovite, detrital apatite pellets, and nodules of crystalline dark-brown apatite as much as 5 cm in diameter. Generally the conglomerate bed is about 40 cm thick, but locally, near Suratá, it is as much as 15 meters thick. The pelletal apatite grains are probably reworked from the underlying La Luna Formation. The crystalline apatite nodules probably are pebbles derived from sygenetically formed apatite crusts. Freas and Riggs (1968, p. 126-127) suggest that phosphate pebbles in the Miocene phosphate beds of Florida were derived from storm and wave action on phosphorite substrate that had formed in areas near the depositional site of the pebbles. The phosphatic pebbles at the base of the Umir Formation in Santander probably were derived in a similar way from crusts of crystalline apatite that had formed locally by precipitation from water enriched with phosphate; the phosphate came from apatite weathered and eroded from the underlying phosphatic beds in the Galembo Member. Decrease of phosphate upward within a few meters of the base of the Umir indicates termination of favorable conditions for the formation of phosphorite because favorable upwelling that prevailed during deposition of the Galembo Member probably no longer existed.

On the west flank of the Cordillera Oriental, the basal Umir conglomerate is thicker and richer in apatite in some places where the Galembo Member is thick, and it is thin and poor in apatite, and even locally absent, at other places where the Galembo is thin or absent. There seems to be a direct relationship between the thickness of the Galembo and the thickness of the phosphatic conglomerate at the base of the Umir. Places where the Galembo Member is thick are believed to indicate downwarped areas where the La Luna was subject to minimal removal by erosion; and places where the Galembo is thin or absent indicate upwarped areas that formed submarine highs, and possibly islands, where erosion of the La Luna was greatest. Thus, thicker conglomerate accumulated in downwarped areas that had formed shallow troughs and basins, and thin conglomerate, or none at all, accumulated on upwarped areas. The thicker (2.8 meters) and richer (27 percent P_2O_5) phosphorite found in the conglomerate in the San Vicente area suggests that similar richly phosphatic conglomerates may be found in other areas where thick sections of the La Luna are preserved such as along the Cerro Galembo in the vicinity of Mirabel (pl. 4, column 5).

The age of the Umir Formation is Maestrichtian, according to palynological studies by Van der Hammen (1954, p. 72). Foraminifera confirm this age. Some samples from the basal stratum of the Umir include Anomalina redmondi, believed restricted to the Santonian, and Orthokarstenia revoluta, probably Santonian and Campanian; however, some of these fossils are abraded and probably reworked from the erosion of the underlying Galembo Member and incorporated into the basal microconglomerate of the Umir. At Palmira, west of San Vicente, this basal Umir microconglomerate contains Orthokarstenia clarki, O. cretacea, O. clarki costifera(?), Siphogeneroides bramlettei, Bula sp., Cibicides sp., Robulùs sp., Anomalina sp. (redmondi reworked?), Globigerina cretacea(?) (Edward Fritz, written commun., 1968). The lower Maestrichtian age is based upon Siphogeneroides bramlettei, which is restricted to the lower Maestrichtian.

Maracaibo Basin

Cogollo Group

The Uribante Formation and the Capacho Formation, the lower part of the Cretaceous sequence in the Maracaibo Basin, form the Cogollo Group. The strata that comprise this group are a sequence of sandstone, limestone, and shale of Aptian, Albian, and Cenomanian age to which Garner (1926) had applied the name, Cogollo Formation. They lie above the Río Negro Formation and below the La Luna Formation. Notestein and others (1944) restricted Cogollo in the Barco Concession to the upper part of this sequence, assuming that the lower part, to which they had applied the name Uribante, was correlative with the Río Negro. The Cogollo, as originally constituted, was elevated to a group in western Venezuela by Sutton (1947), who divided the sequence into the Apôn, Aguardiente, and Capacho Formations. The name Cogollo Group was retained by Rod and Maync (1954), although different formation names, Apôn, Lisure, and Maracá Formations, were applied. The Cogollo generally has been used in the Colombian part of the Maracaibo Basin in the same restricted sense as introducted into the Barco Concession by Notestein and others (1944). In this report

Cogollo Group is used for the first time in Colombia to apply to the same stratigraphic sequence as that to which the name is applied in adjacent parts of Venezuela.

Uribante Formation.--The Uribante Formation, the name given by Sievers (1888) to a predominantly sandstone sequence exposed along the Río Uribante in the State of Táchira, Venezuela, was employed in the Barco Concession in Colombia by Notestein and others (1944), for equivalent, although less sandy, strata, and divided by them into the Tibú, Mercedes, and Aguardiente Members. The Tibú Member is predominantly limestone, but includes some arenaceous beds and conglomeratic sandstone at the base. The Mercedes Member is composed of interbedded limestone, shale, and subordinate amounts of sandstone. Shale predominates in the lower part of the member and limestone predominates in the upper part. The Aguardiente Member is composed predominantly of glauconitic sandstone. The limestone and shale in all three members give way to sandstone southward from the Barco Concession to exposures in the vicinity of Sardinata, Gramalote, and Pamplona where the Uribante Formation has little limestone and shale, and more closely resembles the Uribante of the type area in Táchira State.

In the Perijá region of western Venezuela, the predominantly limestone strata equivalent to the Tibú and Mercedes Members of the Uribante Formation are designated the Apón Formation (Sutton, 1964, p. 1645; Rod and Maync, 1954, p. 203-204). The predominantly sandstone strata equivalent to the Aguardiente Member are designated the Aguardiente Formation (Sutton, 1946, p. 1645) or Lisure Formation (Rod and Maync, 1954, p. 210).

Age of the Uribante Formation is considered Aptian and Albian. An Aptian age is given by Notestein and others (1944, p. 1178) for the entire Uribante. Upper Aptian to middle Albian is indicated by Sutton (1946, p. 1643) for the Apón Formation, the equivalent to the lower part of the Uribante; and a tentative Cenomanian age (Sutton, 1946, p. 1646) for the Aguardiente Formation, the equivalent to the upper part of the Uribante. A late Aptian and early Albian age for the middle part of the Apón Formation and a middle to late Albian age for the Lisure (Aguardiente equivalent) are suggested by Rod (in Rod and Maync, 1954, p. 208-210).

Notestein and others (1944, p. 1178) suggested correlation of the Uribante with the Río Negro Formation of the Perijá region; but the Río Negro underlies probable Barremian rocks in the type area (Sutton, 1946, p. 1641) and upper Aptian rocks at other places in the Maracaibo Basin. The base of the Uribante lies unconformably upon older rocks, generally metamorphic and crystalline intrusive rocks, but older sedimentary strata occur in some areas and these may be of Early Cretaceous age as young as Barremian.

Capacho Formation.--The Capacho Formation forms the upper part of the Cogollo Group in the southwestern part of the Maracaibo Basin. The name Capacho was introduced by W. Sievers (1888, p. 24; Sutton, 1946, p. 1647; Maync, in Schwarck and others, 1956, p. 104-105) for exposures near Independencia (formerly Capacho) in the State of Táchira in western Venezuela. In this report it is proposed that this name be applied to equivalent strata along the east flank of the Cordillera Oriental in Colombia. Equivalent strata of similar facies in the vicinity of San Andrés, Santander, are also designated Capacho Formation in this report (fig. 7), although these strata have previously been called the Cogollo Shale, following the use of Notestein and others (1944) in the Barco Concession of Norte de Santander (fig. 2). However, the Cogollo as originally used (Garner, 1929, p. 679; Maync, in Schwarck and others, 1956, p. 152-154) was far more inclusive and was applied to all strata between the Río Negro Formation (early Barremian age) and the La Luna Formation (Turonian and Suronian age). The Cogollo is now recognized as a group and the Capacho is the upper formation within that group (Sutton, 1944, p. 1641-1642). Rod and Maync (1954, p. 210) have named equivalent predominantly limestone facies the Maracá Formation in the central Perijá.

The Capacho Formation is composed mostly of very dark-gray to black claystone, micaceous siltstone, and interstratified thin to medium-thick-bedded, dark-gray, finely crystalline, fossiliferous limestone. These rocks are petroliferous and contain a few apatite pellets, and sparse to abundant glauconite grains in some strata. The formation was divided by Sutton (1946, p. 1647) into a lower predominantly shale member and an upper predominantly limestone member. A similar sequence was noted in the Petrólea area of the Barco Concession by Notestein and others (1944, p. 1179), who divided these strata (their Cogollo Formation) into three members, a lower thin-bedded claystone and interbedded limestone member, a middle predominantly claystone member, and an upper member, the Guayacán, composed predominantly of limestone interbedded with micaceous claystone and siltstone. A predominantly limestone unit in the upper part of the Capacho Formation is not evident in exposures near Sardinata nor farther south in Norte de Santander where the Capacho is composed mostly of claystone.

Age of the Capacho Formation is Cenomanian, according to Sutton (1946, p. 1648) as indicated by *Exogyra africana* Coquand var. *peruana* known to occur in the Cenomanian of Peru, *Ostrea scyphax* Coquand, and *Neithea aequicostata* d'Orbigny. A late Albian to Cenomanian age is given for the Capacho Formation by Rod (*in* Rod and Maync, 1954, p. 213) based upon "a tentative determination of ammonites."

La Luna Formation

Details of the La Luna Formation are given in the foregoing description of the stratigraphy of the middle Magdalena Valley. The use of this formation name was extended into Colombia by Notestein and others (1944), and is applied to exposures of these strata in the eastern part of the Cordillera Oriental adjacent to the Maracaibo Basin. The three members recognized and named by Wheeler (*in* Morales and others, 1958, p. 653-654) in the vicinity of Río Sogamoso on the west flank of the Cordillera Oriental in the Department of Santander have not previously been separately identified in the Maracaibo Basin.

Salada Member.--On the east flank of the Cordillera Oriental, strata in the lower part of the La Luna Formation are lithologically similar and correlate with the Salada Member. The member is composed mostly of thin, parallel-bedded porcellanite and contains abundant pyritic limestone concretions. The most accessible exposures are those along the lower part of the trail to the cemetery at Gramalote (fig. 2) and along the road east of Sardinata in the vicinity of Hacienda La Florida where the road traverses the La Luna Formation (pl. 5). The Salada Member is also well exposed along the highway about 3 km northeast of Pamplona toward Cúcuta (fig. 2).

The base of the La Luna Formation on the east flank of the Cordillera Oriental, like the contact with the underlying Simití on the west flank, is well defined by a distinct lithologic change. The formation contact in this area may be unconformable also, as suggested by alteration, probably due to ancient weathering of a few decimeters of the uppermost strata of the Capacho where they are overlain by the La Luna at La Florida near Sardinata (fig. 2; pl. 5).

Pujamana Member.--The soft and readily weathered strata of the Pujamana Member lie between the hard and resistant Salada and Galembo Members in the eastern part of the Cordillera Oriental. The Pujamana is poorly exposed and consists of thin-bedded argillaceous limestone and calcareous claystone and contains abundant limestone concretions. It can be seen in exposures near Pamplona, Hato Viejo, and Gramalote. The Pujamana is also exposed between Salazar and Gramalote where the Galembo Member is absent and the Pujamana is overlain by the Colón Shale.

At Ragonvalia, Salazar, Lourdes, and Hacienda La Florida near Sardinata, the Pujamana Member is absent, and the Galembo Member rests unconformably upon the Salada. The considerable variation of thickness of the Pujamana in these exposures of the eastern flank further suggest an unconformity above the member.

Galembo Member.--The Galembo Member in the Maracaibo Basin is composed mostly of thin parallel-bedded porcellanite, lithologically similar to the Salada Member except that limestone concretions are sparse and scattered apatite pellets are abundant, and several beds of phosphorite are included in the member. Thickness of the Galembo Member at exposures along the eastern flank of the Cordillera Oriental in the Department of Norte de Santander varies considerably as it does to the southwest on the west flank of the Cordillera in the Department of Santander.

At Hacienda La Florida near Sardinata, the Galembo Member is 17-1/2 meters thick, whereas in Quebrada La Chacona, 3 km west, the member is absent and the overlying Colón Shale rests upon the lower part of the La Luna Formation, probably the Salada Member. At La Florida and eastward for 9 km to San Miguel, the Colón Shale rests upon the principal phosphorite bed, and the Galembo Member is only about 17 meters thick. East of San Miguel, however, the Colón rests upon an eastward-thickening unit of porcellanite above the principal phosphorite bed. In Caño Los Novios, about 2 km east of San Miguel, the porcellanite between the phosphorite bed and the base of the Colón is 15 meters thick. Similar variations in thickness of the Galembo Member are evident in the vicinity of Gramalote. At the cemetery in Gramalote the Galembo above the phosphorite bed is 20 meters thick. In Quebrada Caldedero, 3 km north, this thickness is only 7 meters; and on the Lomo El Pantano, 1-1/2 km southeast of the cemetery, the Colon rests directly on the phosphorite bed. South of this place the phosphorite bed is beveled; studies as far south as the town of Arboledas have been unsuccessful in definitely locating additional exposures of the Galembo Member, except near the village of Hato Viejo and possibly in the vicinity of Salazar. At Hato Viejo, strata lithologically similar to the Pujamana Member are overlain by a few meters of porcellanite and two thin beds of phosphorite which presumably are the lowermost beds of the Galembo Member. In the vicinity of Salazar, the La Luna Formation is only 30 meters thick. The lithology of these strata is suggestive of the Galembo Member, and there are two thin phosphorite beds near the top of this sequence. Similar strata made up of thin-bedded, black, flinty porcellanite and thin intercalated soft, plastic, yellowish- and orange-gray claystone near Mutiscua contain fossils which indicate these strata to be the same age as the Galembo, but additional study is needed to establish the correlation of these strata at Mutiscua with those at Salazar. The La Luna Formation in the vicinity of Salazar lies upon the Capacho Formation and if these strata are Galembo, the Salada and Pujamana members are absent at this place.

The Galembo Member is about 200 meters thick near Ragonvalia, 48 km southeast of Gramalote (pl. 1, column 6). This thickness includes 38 meters of flinty porcellanite at the base of the member similar to that found near Mutiscua and Salazar. F. Montero of the Inventario Minero measured 243 meters of La Luna that includes Galembo on the road to Chitagá about 2 km southeast of Pamplona but did not differentiate any members (D. E. Ward, written commun., 1969). North of Sardinata the Galembo Member is absent from the La Luna Formation in exposures along the flank of the Cordillera Oriental between Las Mercedes and Orú (F. Pachón, oral commun., 1968).

Age of the formation.--The La Luna Formation in the type area east of the Perijá in western Venezuela is of Turonian and Coniacian age (Sutton, 1946). Farther south in Táchira State of western Venezuela, the La Luna Formation has been extended to include the Táchira Chert of Santonian age, and consequently the La Luna of the Maracaibo Basin and of the middle Magdalena Valley are equivalent. Microfossils collected from the lower part of the La Luna Formation at Hacienda La Florida include *Heterohelix* sp. and *Globigerina* sp., an assemblage indicative of Turonian age according to E. B. Fritz (oral commun., 1968) who identified the microfossils. Ammonites collected from the La Luna by Gerhardt in 1897 (*in* Sellier de Civrieaux, 1952, p. 244-245) near Rubio, Táchira State, Venezuela, include *Texanites texanum* (Roemer), *Texanites canaense* (Gerhardt), and *Paralenticeros sieversi* (Gerhardt), of which *T. texanum* is considered restricted to the Santonian, and the other two forms are known from the Santonian of Haiti. Microfossils from the Galembo Member of the La Luna Formation at the phosphate mine near Lobatera, Táchira, and at Hacienda La Florida near Sardinata, Norte de Santander, include Anomalina redmondi Petters, which is believed restricted to the Santonian Stage.

Colón Shale and younger Cretaceous formations

The Colón Shale is named from western Venezuela, and exposures along Río Lobaterita immediately north of the town of Cólon, Táchira, is the recommended type section (Sutton, 1946, p. 1651). This formation is composed of as much as 900 meters of dark-gray claystone and includes abundant small concretions and very thin lenticular beds of siderite. It is lithologically similar to the Umir Shale of the middle Magdalena Valley. At the base in many places is a pebbly microconglomerate composed of glauconite and apatite pellets and nodules in a dolomitic and calcareous siltstone matrix. This bed is as much as 7 meters thick and has been named the Socuy Limestone Member.

The Colón Shale has generally been considered Campanian and Maestrichtian (Notestein and others, 1944; Sutton, 1946; Cushman and Hedberg, 1941), although in a more recent report by Sellier de Civrieux (1952, p. 233), the age of the basal strata, the Socuy Limestone Member, is indicated to be late Campanian to early Maestrichtian, the early Maestrichtian age being considered more likely. If the base of the Colón Shale and the Umir Shale are transgressive over the continental shelf toward the Guayana shield, then the age of the lowermost strata of these formations may reflect deposition in late Campanian time on the shelf away from the shield, whereas closer to the shield, deposition may have commenced later in early Maestrichtian time. On the other hand, reworking of fossils, as near San Vicente, Santander, may have led earlier workers to assign a deceptively greater age to the lower strata of this unit. Cushman and Hedberg (1941, p. 79-80) divided the Colon into two zones; the Pullenia cretacea zone for the lower 300 m (1,000 feet) and the Siphogeneroides bramlettei zone for the upper 150 m (500 feet). Both Pullenia (Orthokarstenia) cretacea and Siphogeneroides bramlettei were found in the basal stratum of the Umir at San Vicente.

The Mito Juan and Catatumbo Formations complete the Cretaceous sequence in the western part of the Maracaibo Basin. These strata are somewhat similar to the underlying Colon Shale, but also include siltstone, sandstone, and coal and are believed to represent shallow marine and brackish-water deposits (Notestein and others, 1944, p. 1184-1189; Sutton, 1946, p. 1653-1656). Further details of these uppermost Cretaceous formations were not considered in this study.

CORRELATION OF STRATA

Correlation of strata is based in part on paleontological data and in part on physical comparison of strata from one area to another. These correlations take into account that facies changes dependent upon grain size are related to source areas, distance from source, energy transport levels, and environment of deposition. Transgression and regression of the sea are also important factors in attempting to correlate individual strata, although in general the length of time involved and the relatively sparse paleontological data based on slowly evolving species does not permit much precision in recognizing and correlating on-lapping and off-lapping strata.

Physical comparison of strata reveals several regional unconformities which extend from one part to another of the Cordillera Oriental. These unconformities are indicated by 1) abrupt changes in lithology, 2) hiatuses in the paleontological record, 3) continuity of superjacent strata contrasted with intermittent continuity of subjacent beds, indicating generally low-angle bevelling of the strata, and 4) lithological variations associated with the unconformable surface such as weathering and corrosion of strata below the unconformity and deposition of conglomerate, usually microconglomerate, above.

Table 1 summarizes the ages of the stratigraphic units and their correlation between the three principal areas of this report, the Maracaibo Basin, the middle Magdalena Valley, and the vicinity of Bogotá, and shows also the nomenclature used by earlier writers. The span shown by the formations in the columns of table 1 indicate the ages assigned by earlier authors, rather than the previously presumed lateral correlation, but the span shown by the formations discussed in this report are intended to approximate the correlation of stratigraphic units between the three areas. Lower Cretaceous rocks were not studied in detail, and correlations presented here are opinions based upon random observations, and probably will be modified.

The Cogollo Group of the Maracaibo Basin, the limestone and shale group of the middle Magdalena Valley, and the Villeta Group below the La Frontera Member of the Chipaque Formation are approximately equivalent. These groups and the individual formacions and members within them exhibit similar lithological sequence and paleontologically determined ages. They represent the deposits of Aptian, possibly Barremian, to Cenomanian time in each of the three areas. Lithology of each of the correlated units is similar in these three areas, although there are slight facies differences because of the change from predominantly carbonate and fine-grained detrital sediments deposited on the shelf away from the craton to predominantly sand deposited southeastward toward the source of detritus on the shield.

The Capacho Formation, the upper part of the Simití Shale, and the lower part of the Chipaque Formation are similar in lithology, consisting of dark-gray silty claystone and thin interbedded dark-gray finely crystalline, fossiliferous limestone. Exogyra squamata, Ostrea, and other lamellibranchs are common in these limestone strata in all areas.

The Salada Member of the La Luna Formation is equivalent to the La Frontera Member of the Chipaque Formation. The siliceous and argillaceous limestone that is characteristic of the Salada Member grades into limestone, sandy limestone, and calcareous sandstone that are characteristic of the La Frontera. In all areas these strata contain fossils of Turonian age.

The Pujamana Member of the La Luna Formation is equivalent to the upper part of the Chipaque Formation. In all areas, these strata are composed of dark-gray claystone and siltstone, but they are more calcareous where they are recognized as the Pujamana Member and more sandy where they are included in the Chipaque. These strata are absent from some areas owing to erosion prior to deposition of the overlying beds of probable Santonian age.

The Galembo Member of the La Luna Formation is equivalent to the Raizal Member of the Guadalupe Formation (pl. 1) as indicated by the gradation from the thin-bedded porcellanite of the former into the fine-grained siliceous sandstone of the latter. This gradation is evident where porcellanite and sandstone intertongue in the vicinty of Sogamoso and Lake Tota in Boyacá, west of the Sabana de Bogotá in Cundinamarca, and in the vicinity of Pandi, Icononzo, and Cunday in southern Cundinamarca and adjacent parts of Tolima. The Santonian age of the lower part of the Raizal and the Galembo further establishes their lateral relation. Rocks of this unit were beveled northward, and strata of Campanian age are absent in most parts of Santander and Norte de Santander where strata equivalent to the upper part of the Raizal and the upper porcellanite are entirely missing (pl. 1). Still farther north, the entire Galembo Member is generally absent, as for instance, north of Sardinata from the vicinity of Mercedes at least as far as Orú; it is doubtful whether these strata have been preserved in most of the area of the Cesár Valley and the Guajira Peninsula (fig. 1).

The lower part of the Umir or Colón Shale grades laterally into the upper member of the Guadalupe Formation, and the upper part of the Umir is equivalent to the Guaduas Formation that overlies the Guadalupe (table 1). These formations rest unconformably upon La Luna and the unconformity extends into the upper member of the Guadalupe Formation where the Tierna Sandstone lies unconformably upon the Labor Sandstone. The Colón, Umir, Guaduas, and Tierna strata seem to represent transgressive deposition from north to south. This transgression may have begun in late Campanian time in the region of the present Maracaibo Basin, as indicated by the paleontological data of Cushman and Hedberg (1941). The lower 300 m of the Colón Shale in the Maracaibo Basin is characterized by a microfauna that includes Pullenia cretacea. However, farther south the Pullenia cretacea zone seems to be absent, and strata containing Siphogeneroides bramellettei, representing the upper 150 m thick zone in the Maracaibo Basin, lie directly above the unconformity. Another observation indicative of this transgression is southerly thinning of shale at the base of the Maestrichtian sequence. The section at Tausa in Cundinamarca has about 100 meters of this shale. The Shale is 40 meters thick in the section between Tabio and Chía (Bürgl and Dumit, 1954; Bürgl, 1955) and 15 meters thick between Bogotá and Coachí (Julivert, 1962a, fig. 2), whereas in the vicinity of Pandi and Icononzo there is no shale, and the overlying Tierna Sandstone, that lies directly above the unconformity, is thinner and coaser grained than in the sections farther north.

HISTORICAL INTERPRETATION

The area that is now the Cordillera Oriental of the Colombian Andes lay as part of the continental shelf between the Guayana shield and the Andean geosyncline from Aptian time until the end of the Cretaceous Period. Sedimentary rocks deposited during this time record a transgression and regression of marine water on the shelf. The Andean geosyncline trended north-northeast in Colombia, and elements of this ancient depositional trough are found in the Cordilleras Central and Occidental. The exact position of the edge of the Guayana shield is unknown because of the dearth of geological data from east of the Cordillera Oriental. The approximate positions of the shield, the continental shelf, and the geosyncline are shown in figure 8. The shield served as the principal source of detrital sediements, but some sediments and possible volcanic debris came from the west onto the shelf and suggest that a volcanic island arc existed in the geosyncline. The boundary between the cratonic source area and the depositional area of the shelf may have fluctuated considerably from the boundary of the craton shown in figure 8 as the sea transgressed and regressed in Cretaceous time.

Lower Cretaceous rocks deposited through at least early Barremian time were involved in tectonic activity and removed from many areas of Colombia prior to deposition of the later Cretaceous sequence. This later Cretaceous sequence began in Aptian time or possibly slightly earlier as the sea transgressed across the continental shelf onto the edge of the shield. The shelf deposits indicate that shallow-water environment prevailed for a considerable period of time through the Aptian, Albian, and Cenomanian. The shallow-water depositional environment is indicated by abundant neritic and shallow-water benthonic faunas that are found at several stratigraphic levels within this sequence. Thin to medium-thick limestone beds and abundant pelecypods such as Exogyra in the lower part of the Chipaque, the Capacho, and the upper part of the Simití Formations suggest shallow-water deposition in Cenomanian time.

A change to a deeper-water depositional environment about the beginning of Turonian time is indicated by a change of deposition at the base of the La Luna Formation. Sediments of the La Luna and Guadalupe Formations were deposited in moderately deep water. The deep water environment is suggested by the dominantly planktonic fauna composed mostly of Foraminifera and ammonities, by the fetid and pyritiferous claystone and limestone that are indicative of deposition in an euxinic environment below the oxygenated zone, by the thin, planar bedding of dark-colored, siliceous limestone that is believed to indicate sedimentation in deep water (Wilson, J. L., 1969), and by the pelletal apatite (Kazakov, 1950) that is especially abundant in the upper member of the La Luna.

The Salada Member grades in the direction of the Guayana shield from deep-water limestone into shallow-water limestone and thin sandstone beds of the La Frontera Member of the Chipaque Formation. The Galembo

Member also changes facies toward the shield where it grades into sandstone of the Guadalupe Formation; but the sandstone of the Guadalupe is thick and the bedding indicates subaqueous deposition in moderately deep water where the sediment may have been laid down as bottom-set and fore-set beds of deltas and offshore bars in a subsiding trough adjacent to the edge of the craton. The boundary between predomintly clay deposition and predominantly sand deposition shown in figure 8 is the approximate boundary between the predominantly porcellanite facies of the Galembo Member and the predominantly sandstone facies of the Guadalupe Formation.

Sediments of the Pujamana Member slowly accumulated and the shelf seems to have remained quiescent through Coniacian time until another tectonic disturbance initiated a change in depositon early in Santonian time. Epeirogenic uplift affected the craton and may have elevated the continental shelf also. An abundance of detritus eroded from the elevated craton accumulated on the shelf and formed the sandstone of the Guadalupe Formation and was the source of the finer grained clay and silt incorporated into the Galembo Member of the La Luna Formation. Most of the detritus eroded from the craton was quartz that probably was derived from previously deposited quartzose sediments near the margins of the shield. The depositional environment on the continental shelf which previously had been euxinic was replaced by freely circulating water and upwelling currents favorable to the formation of apatite. The Pujamana Member was eroded and locally

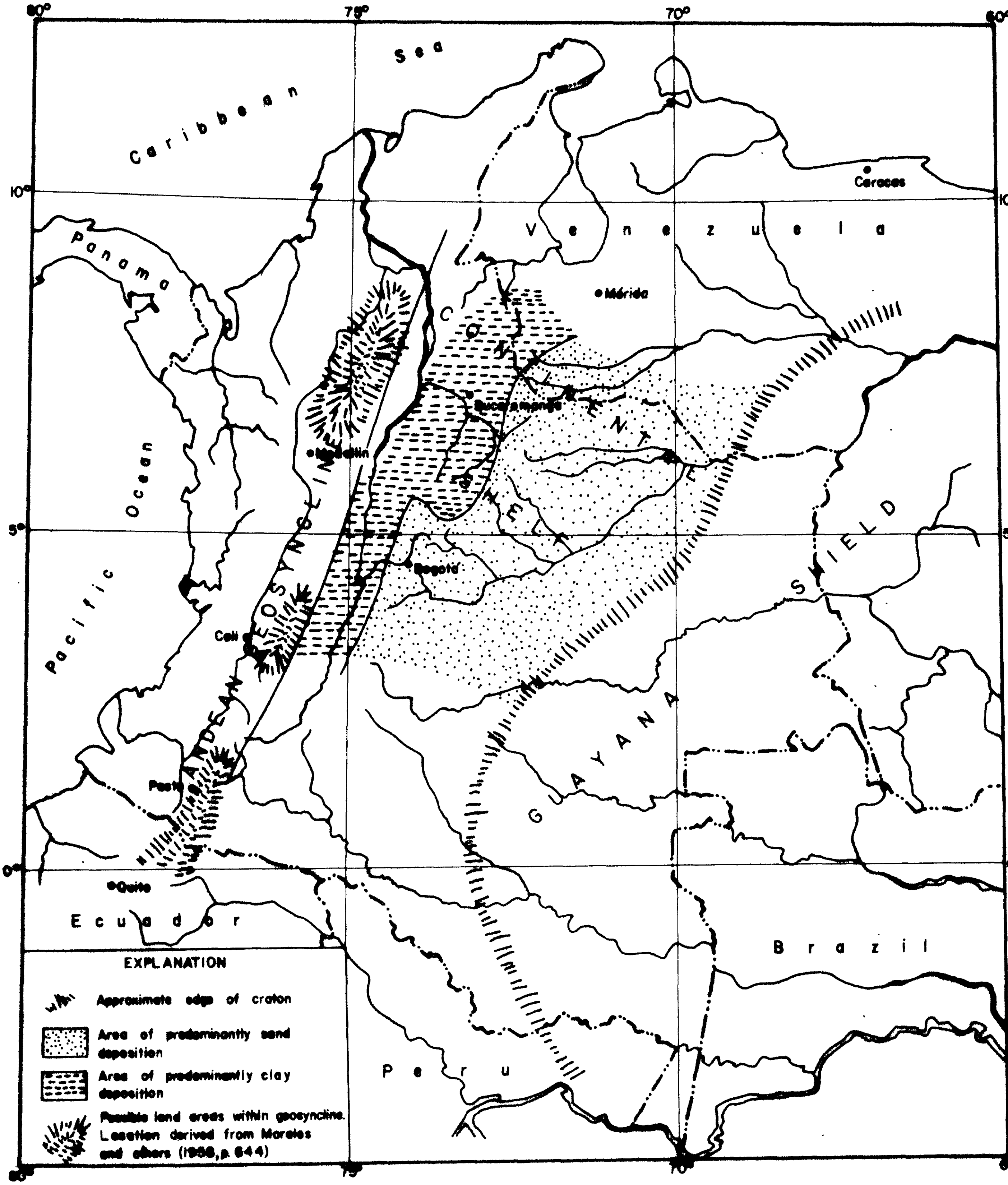

Figure 8. Generalized location of Late Cretaceous paleogeographic elements in Colombia.

removed, indicating that some warping of the shelf resulted from this tectonism.

Sedimentation probably continued well into Campanian time but was interrupted by uplift in the vicinity of the geosyncline in late Campanian or early Maestrichtian time. This uplift titled the shelf away from the geosyncline and toward the craton. The yet unconsolidated and probably still plastic sediments of the Galembo may have slid toward the shield, and low-amplitude folds (fig. 6) formed as these strata encountered resistance to further movement against the shield and its flanking mass of sand of the Guadalupe. Uplift along the geosyncline is indicated by bevelling of the Galembo toward the geosynclinal axis and its absence from areas adjacent to the geosyncline (Tomas Feininger, oral commun., 1967). The thickest sediments of Santonian and Campanian age are those of the Guadalupe Formation that lie near the margin of the shield in the vicinity of Bogotá and parallel with the geosynclinal axis. The Santonian and Campanian sediments in this area were little affected by the tilting and bevelling, there was very little or no erosion, and sedimentation may have continued in this area while erosion of the Galembo Member progressed in areas to the west and north.

Uplift in the geosyncline provided sufficient topographic relief near the geosynclinal axis in early Maestrichtian time that pebble conglomerate was deposited eastward as far as Cunday and Icononzo, and cobble conglomerate may have been deposited in the vicinity of Gualanday, about 60 km west, near the geosynclinal axis. Marine sedimentation continued in progressively shallower water during the remainder of Maestrichtian time and was succeeded by continental deposits.

The tectonic events that affected the sedimentary sequence in Late Cretaceous time may have been related to emplacement of the Antioquian batholith. Radiometric ages from the batholith, extracted from an unpublished map of the batholith compiled by Gerardo Botero, Professor at the National University of Colombia School of Mines, Medellín, indicate that emplacement was contemporary with the tectonic events described above. These radiometric ages are summarized in table 2. The radiometric ages determined for rocks of the batholith are scattered from a maximum of 83 million years to a minimum of 55 million years; but ages cluster from 72 to 68 million years (late Campanian to early Maestrichtian, according to Casey, 1964, p. 199), and the median for all 12 determinations is 70 million years, which is the probable age of the Campanian-Maestrichtian boundary. Therefore, emplacement of the batholith does seem to coincide well with the presumed uplift along the geosynclinal axis and contemporaneous tilting away from the geosyncline of the continental shelf in late Campanian to early Maestrichtian time.

PHOSPHATE DEPOSITS

Stratigraphic relations

Phosphorite beds within strata of Late Cretaceous age occur principally in Santonian strata. The occurrence of phosphate in minor

Table 2.--Summary of radiometric ages determined for the Antioquian batholith. Data extracted from an unpublished map of the batholith compiled by Gerardo Botero, National University of Colombia School of Mines, Medellín.

Location	Age in million years	Geologic age according to R. Casey, 1964, p. 199.
Northwest of Bello, about 4 kilometers	55	Tertiary
Northwest of Bello, about 4 kilometers	58	Tertiary
Northwest of Bello, about 4 kilometers	65	Late Maestrichtian
Midway between Cisneros and Puerto Berrio	68	Early Maestrichtian
East of Sonsón, 4 kilometers	69	Early Maestrichtian
Northwest of Bello, 4 kilometers	70	Maestrichtian-Campanian
Between San Rafaél and Guatape, 8 kilometers southwest of San Rafaél	71	Late Campanian
On Río Grande, 17 kilometers north of Entrerios	72	Late Campanian
Río Guadalupe, 7 kilometers north of Carolina	74	Early Campanian
Río Grande, 5 kilometers north of D. Matias	79	Middle Santonian
West of San Luis, 3 kilometers	80	Early Santonian
West of San Luis, 3 kilometers	83	Late Coniacian

amounts throughout much of the Upper Cretaceous section in the Cordillera Oriental has been shown by Bürgl and Botero (1967); their statistical analysis (p. 27-30; fig. 1, p. 37) indicates the Santonian as the most likely strata for further phosphate exploration. Most of the several favorable phosphorite beds located by Cathcart and Zambrano (1967), although only generally placed in their stratigraphic context, are in strata of Santonian age. Some phosphorite has been found in strata of Campanian age, especially near Sogamoso and near Pandi. One phosphorite bed is now known from strata of approximately Cenomanian, or possibly Albian, age.

The stratigraphically lowest known phosphorite bed in Colombia is in the Capacho Formation at San Andrés, Santander, where a thin bed of phosphorite having a thin sandstone parting occurs 145 meters above the base of the Capacho (fig. 7). This bed occurs about in the middle of a cliff-forming sandy limestone about 25 meters thick. Another phosphorite bed 15 meters above the top of this cliff is 2.5 meters thick and a single channel sample from it contains 25 percent P_2O_5. This bed of phosphorite is slightly calcareous and probably slightly siliceous and forms a ledge within the enclosing shale. The bed is exposed along two sides of a roughly triangular area beneath El Hato, a high bench about 500 meters above the town of San Andrés.

Phosphorite beds in the Capacho Formation near Molagavita and Cucutilla are believed to be at the same stratigraphic position as the beds at San Andrés (Raúl Durán R., oral and written commun., 1968). The phosphorite in these areas has not been evaluated but it may be an extension of the horizon near San Andrés. Phosphorite was not found at an equivalent position in the Simití Shale in the vicinity of the Río Sogamoso between San Vicente and Lebrija, nor in the Capacho Formation near Sardinata and Gramalote. A phosphatic glauconitic sandstone that could be the approximate equivalent of these units occurs about 100 to 150 meters above the base of the Capacho Formation about 4 km west of Orú on the road between Tibú and Convención. Bürgl and Botero (1967, p. 20-21), reported 21.78 percent P_2O_5 collected from about this same stratigraphic level near Ortega, Tolima; however, Zambrano could not confirm this report (Cathcart, J. B., written commun., 1969).

The Galembo Member of the La Luna Formation has three principal phosphorite zones identified herein as the lower, intermediate, and upper. Only the lower zone is known to contain phosphorite beds thick enough to be exploited. The phosphorite being developed at Turmequé in the Department of Boyaca is in the lower zone, the phosphorite being mined at Tesalia, Huila, probably is in this lower zone also. The intermediate phosphorite zone is composed of a single bed which averages about 0.6 meter in thickness and is 1 meter thick only in one small area near Vanegas. The upper zone is absent throughout most of Santander and Norte de Santander either because of post-Galembo erosion or nondeposition. Phosphorite beds equivalent to the upper zone occur more generally in the Galembo Member or the equivalent Raizal Member of the Guadalupe Formation in the Department of Boyacá. In this region the beds appear to be more variable in thickness than elsewhere, and phosphorite in the upper zone may be locally exploitable in the vicinity of Sogamoso.

A phosphorite zone higher than those in the Galembo Member is in the upper part of the Guadalupe Formation in the Pandi area of southern Cundinamarca and adjacent parts of Tolima. None of these beds in the upper Guadalupe are known to reach a thickness of as much as 1 meter; they probably are too thin to be commercial.

The lower phosphorite zone of the Galembo in Santander consists principally of two phosphate beds having a combined thickness that varies between 1.3 and 2.3 meters (pls. 2 and 3). Barren rock one-half to 1 meter thick between the two beds is composed of porcellanite. The phosphate in the lower zone at most places in Norte de Santander and Boyacá (pl. 1) comprises only a single bed of phosphorite that varies in thickness between 1 and 3 meters. Phosporite beds a few centimeters to a few decimeters thick are common in strata of this zone within a few meters above and below these principal beds. Strata underlying the lower phosphorite zone consist of porcellanite in Santander and Norte de Santander, but they consist of sandstone in most parts of Boyacá. Strata above this lower phosphorite zone are porcellanite in all areas. Correlation and thickness of the two phosphorite beds in Santander is illustrated in plates 2 and 3 and the stratigraphic relations of the lower phosphorite zone and the Galembo Member of the La Luna Formation between Santander, Norte de Santander, and Boyacá are shown in plate 1.

The phosphorite of the lower zone consists of pellets of carbonate fluorapatite in a matrix of clay, silt-size to very fine-grained quartz, and calcite. Locally this phosphorite is moderately siliceous, and at some localities such as Ragonvalia, Iza-Cuitiva, and Alto del Peñón, it contains abundant fine- to medium-grained quartz. Near Gramalote the phosphorite is very calcareous; it is believed that at most localities the fresh rock, when recovered, will be calcareous. Phosphatized Foraminifera are abundant, and fish bones and teeth are common. The thinner phosphorite beds within this zone contain fish bones, teeth, and Foraminifera more abundantly than the thicker beds.

The intermediate phosphorite zone of the Galembo Member generally lies 15 to 25 meters above the lower zone. It is composed generally of a single bed about half a meter thick, which is enclosed in strata of porcellanite. The thickness of the bed is relatively constant and ranges between 40 and 80 cm. Analyses of the bed consistently yielded high P_2O_5 ranging between 20 and 30 percent. The phosphorite is lithologically similar to that of the lower zone and is composed of apatite pellets in a matrix of clay, very fine-grained quartz, and calcite, but bones, teeth, and Foraminifera are not common.

In the vicinity of the mine at Turmequé this intermediate bed varies in thickness and texture. Near the mine entrance it consists of 4.6 meters of phosphatic sandstone where it is exposed 17-1/2 meters stratigraphically above the principal bed in the lower zone. In Quebrada Rosal, 2 km south of the mine, the intermediate bed is 1.5 meters thick and contains 28 percent P_2O_5 (Pedro Mojica, written commun., 1967). About 375 meters north of the mine, the bed is 2-1/2 meters thick, but exploration trenches and a tunnel in that area show that the bed thins to less than a meter and becomes sandy within a short distance.

The upper phosphorite zone of the Galembo Member is known from only two places in Santander, at Hacienda Palmira near San Vicente and Hacienda Mirabel near El Tablazo. At Hacienda Palmira the phosphorite zone is comprized of a single bed, 40 cm thick, overlain by 1 meter of porcellanite which is overlain unconformably by the Umir Formation. At Hacienda Mirabel several phosphorite beds are between 20 and 60 cm thick in this upper zone, which is separated from the Umir by a few meters of porcellanite. Elsewhere in the region, these strata are missing owing to erosion. However, farther south, in Boyacá where erosion was not as intense, equivalent strata are probably present.

Phosphorite believed to be the equivalent of the upper zone is present at several places in Boyacá in the area where the Galembo intertongues with the Raizal Member of the Guadalupe Formation. In Boyacá, as indicated by exposures along the road between the villages of Iza and Cuitiva, this phosphorite, between 60 cm and 2 meters thick, is near the top of the Raizal Member of the Guadalupe Formation and lies above a thick sequence of porcellanite, intercalated with beds of sandstone, siltstone, or claystone. It is overlain by 5 meters of porcellanite and a phosphatic sandstone which may be a part of the same phosphatic zone.

A fourth phosphorite zone, higher than the upper phosphate, is known from two areas, Monquirá near Sogamoso, and the Pandi-Icononzo area. In both areas the phosphorite units occur in a similar stratigraphic sequence of Campanian age and were probably formed nearly contemporaneously. This phosphorite zone is within porcellanite beds stratigraphically higher than porcellanite beds known from any other area and is within a generally less indurated sequence included in the upper part of the lower Guadalupe by McLaughlin. This uppermost part that contains the fourth phosphorite zone of the lower Guadalupe seems to be locally preserved remnants of the member that occurs near Sogamoso, Bogotá, and Pandi. The fourth phosphorite zone is absent toward the northwest of these places because erosional bevelling beneath the sandstone and shale of the upper Guadalupe has removed this part of the formation. This bed may continue for a considerable distance in a northeast to southwest direction, but it apparently does not extend far northwest of the exposures near Sogamoso and Pandi. At Monquirá the phosphorite bed is 1.6 meters thick and is composed of pelletal apatite in a slightly sandy and siliceous matrix. At Pandi there are three thin beds, one meter, one-half meter, and one-quarter meter thick, separated by a total of 2 meters of slightly phosphatic to barren claystone. The phosphorite beds are composed of pellets of apatite in a sandy and siliceous matrix.

The conglomerate at the base of the Colón Shale and the equivalent conglomerate at the base of the Umir Shale is composed of nodules and weathered apatite pellets in a matrix of dolomitic siltstone. Although the bed is generally low in P_2O_5, individual samples contain as much as 28 percent. This unit differs from all other phosphorite beds in that the apatite is derived by erosion and reworking of phosphate in the underlying La Luna Formation, and it was deposited in discontinuous pockets or lenses upon an irregular, unconformable surface.

The thickness and phosphate content of the bed vary considerably. Generally the bed is between one-half and 2 meters thick, although locally it is absent; its maximum known thickness is 11 meters. At Hacienda Palmira near San Vicente this bed is 2.8 meters thick, is composed chiefly of apatite pellets, and has a P_2O_5 content of 28 percent. At other localities between San Vicente and Vanegas on the west flank of the Cordillera Oriental, the bed is less than 1 meter thick and the P_2O_5 content is less than 10 percent. At Suratá, the bed is 11 meters thick, but the P_2O_5 content is low except at the base of the bed where it is about 15 percent. At Orú in Norte de Santander the bed is 2 meters thick and has an average P_2O_5 content of 11 percent. At Pacheli, 10 km south of Orú, the bed is 7 meters thick and has an average of 10.4 percent P_2O_5, although at this locality the lower 35 cm contain 21 percent P_2O_5.

The basal conglomerate occurs widely in Santander and Norte de Santander, and is the basal bed of the Socuy Limestone Member of the Colón Shale in western Venezuela. However, outside of these areas, this unit has been located only at Alto del Trigo (F. Zambrano, oral commun., 1969) west of Bogotá between Villeta and Guaduas

Summary of potential phosphorite reserves

The principal phosphorite bed is in the lower part of the Galembo Member of the La Luna Formation and the equivalent strata that are part of the Raizal Member of the Guadelupe Formation. The bed may contain minable deposits near Sardinata and Gramalote, Department of Norte de Santander, between San Vicente and Vanegas, Department of Santander, and between Iza and Cuitiva, Department of Boyacá. Deposits near Turmequé in Boyacá, and Tesalia in the Department of Huila were being mined in 1969. The Capacho Formation contains a bed of phosphorite near the village of San Andrés, Santander. The phosphorite bed at the base of the Umir Shale and the equivalent Colón Shale, varies markedly in thickness and P_2O_5 content, but it could contain some of the thickest phosphorite deposits in Colombia. Areas for which reserves have been calculated are listed, and reserves are summarized in table 3.

Criteria employed in computation of reserves

Estimates of economically minable phosphorite reported here fall within the classification of inferred reserves. Data to calculate

Table 3.--Summary of reserves of phosphate rock in (millions of metric tons).

A. Reserves of > 25 percent P_2O_5, probable low CaO material	
Sardinata, Norte de Santander	51 1/
Turmequé, Boyacá	5
Iza-Tota, Boyacá	35
Tesalia, Huila	9
Total	100
B. Reserves of 20-25 percent P_2O_5, high CaO material	
Municipio de Lebrija, Santander	40
Gramalote, Norte de Santander	10
San Andrés, Santander	7
Total	57
C. Reserves of 15- < 20 percent P_2O_5, and high carbonate material	
San Vicente, Santander	18
Orú, Norte de Santander	140
Total	158

1/ Recent investigations show high CaO in the subsurface, therefore much of this reserve should be included in category B (J. B. Cathcart, written commun., 1971).

measured reserves are available only for a small volume of rock in the immediate vicinity of the adits and raises of the mine at Turmeque. The data at some places would permit classification as indicated reserves except that chemical analyses are generally too incomplete to adequately establish the tenor of the phosphate rock, or that drill hole information to confirm subsurface projections of the phosphate-bearing strata are lacking. Because investigations are yet in progress (1969), all calculations are preliminary and are intended only as a guide for further work.

Strike length of the phosphorite beds is measured from geologic maps prepared at the scale of 1:25,000. Plates 4 and 5 are simplifed versions of these maps at a scale of 1:50,000. Thickness was determined by measured sections and some of these measured sections are shown in the correlations of sections, plates 1, 2, and 3. The strata have been projected into the subsurface below the local drainage level for 100 meters down the incline of the strata. In most areas the phosphorite beds probably extend to a considerably greater depth. The reserves have been estimated in two separate calculations; the amount of phosphorite lying above the local drainage level and the amount lying below the drainage level to the arbitrarily chosen depth of 100 meters. Additional reserves below 100 meters occur in most places but calculation of the amount available in these reserves would depend upon drill-hole data confirming the extension of the phosphorite, its thickness, and tenor.

A specific gravity of 2.5 has been used to obtain the weight from the volume determined by measurements of thickness and areal extent. The 2.5 specific gravity is an approximate value slightly higher than values determined by the National Chemical Laboratory, Bogotá.

The term, indicated reserves, is used to identify those reserves for which strike length, thickness, and tenor are reasonably well established, and all known data point favorably to the existence of the quantity and quality of rock as specificed. Generally the strike length of the phosphorite deposits assigned to this category in this report are known from more or less continuous exposures, but thickness and tenor are known only at widely separated locations, and there are no subsurface data. However, the continuity and uniformity of surface exposures generally suggest a similar continuity and uniformity where the strata are not exposed, and their projection into the subsurface is adequate to determine the approximate volume of the rock. Trenches to expose the phosphorite stratum between established points of control are needed to confirm the extension, thickness, and grade. Drill holes to establish the extension of the bed into the subsurface and to obtain thickness measurements and unweathered samples for mineralogy and analysis of grade are needed also.

Inferred reserves are those for which there are not yet sufficient data by which to accurately estimate quantity or quality. These are possible economic phosphorite bodies for which additional data ought to be obtained, but which could prove to be unexploitable. In some cases, the thickness, and possibly the tenor of a phosphorite bed is known in at least one locality, and other data suggest that areal extension may be large. On the other hand, factors such as variability in thickess or tenor, known to occur in the bed at other places, do not permit extrapolation of known data into unknown areas and an otherwise favorable appearing rock may be unexploitable. Numerous borings are needed to prove the extent, thickness, and grade in these areas. Unknown and unexpected structural complications may also reduce the size of the inferred reserves.

Phosphorite in areas where data have been obtained only by brief reconnaissance and limited observation are referred to as resources.

Description of deposits

Azufrada to Vanegas (Municipio de Lebrija), Santander

Phosphorite beds crop out near the base of the Galembo Member of the La Luna Formation (pls. 2 and 3) south of San Vicente to north of Vanegas in the Department of Santander (fig. 2). From Quebrada Los Altos (sec. 6, pl. 2) north to Conchal and Vanegas, the phosphorite strata are thick and continuous enough to be potentially economic; but south of Quebrada Los Altos, they are thin or low grade and their economic potential is not promising. The beds are probably nearly continuous between Azufrada and Conchal, a distance of 21 km, but in the vicinity of Vanegas they occur along shorter fault block ridges (pl. 4).

Two beds of phosphorite with combined thickness that ranges between 1.3 and 2.2 meters are separated by one-half to one meter of rock that contains from 0 to 5 percent P_2O_5. Channel samples show that the P_2O_5 content of each bed is between 20 and 25 percent. About 40 million tons of phosphate are present at or close to the surface in the area between Azufrada and Vanegas (table 4).

The phosphate reserves in this area (pl. 4) are readily accessible on the south by the highway from Bucaramanga to Barrancabermeja and on the north by the railroad from Bucaramanga to Puerto Wilches.

San Vicente, Santander

A bed of phosphorite 2.8 meters thick, composed of nodules and broken pellets of apatite and some quartz and dolomite in a matrix of clay, is exposed 5 km west of San Vicente on the road to Barrancabermeja. A single channel sample contained 28 percent P_2O_5. This phosphate bed unconformably overlies the Galembo Member of the La Luna Formation and forms a basal microconglomerate in the Umir Shale. This basal Umir stratum is known at several places in Santander and Norte De Santander but varies considerably in thickness and lithology. For example, near Hacienda La Unión, about 5 km south of Hacienda Palmira, 12 meters of slightly phosphatic sandstone, which is probably equivalent to this unit, contains less than 5 percent P_2O_5 (Gilberto Manjarrés, written commun., 1968). In the opposite direction, 2 km north of Hacienda Palmira, the thickness is about 2 meters (Fernando Pachón, written commun., 1968) and the quality is similar to the thicker exposure near Hacienda Palmira.

An inferred reserve of about 18 million tons may be present in this area. From the three exposures in this general area, a lenticular body 3 km long by one km wide and an average of 2.5 meters thick is assumed.

Table 4.--Phosphorite reserves in the Municipio of Lebrija in the area of Azufrada, Conchal, and Vanegas, Santander. Location of Blocks shown in plate 4.

Block 1/	Area in square meters	Average Thickness	Reserves in millions of metric tons
		Above drainage	
A	443,000	1.6m	1.8
B	None	-	-
C	132,000	2.1	0.7
D	148,000	1.3	0.5
E	518,000	1.6	2.1
F	5,200	1.6	<0.1
G	686,000	2.2	3.8
H	289,500	1.4	1.0
I	641,200	1.8	2.9
J	1,375,600	2.2	7.6
K	880,750	1.5	3.3
		Total	23.7

1/ Data for calculations in blocks A through G were supplied by Jacob Abozaglo M.; blocks H, I, and J, by Patricio Saénz; and block K by Raúl Durán of the Inventario Minero Nacional, July 1968.

Table 4.--Phosphorite reserves in the Municipio of Lebrija in the area of Azufrada, Conchal, and Vanegas, Santander. Location of blocks shown in plate 4.--(Continued).

		Drainage level to 100 m below	
A	305,000	1.6	1.2
B	120,000	1.8	0.5
C	145,000	2.1	0.8
D	170,000	1.3	0.6
E	414,000	1.6	1.7
F	130,000	1.6	0.5
G	427,000	2.2	2.3
H	534,000	1.4	1.4
I	716,000	1.8	3.2
J	833,000	2.2	4.6
K	400,000	1.5	1.5
		Total	18.3

An extensive exploration program of trenches and drill holes will be needed to confirm this preliminary calculation and to establish the chemical composition.

Sardinata, Norte de Santander

The principal phosphorite bed in the Sardinata area consists of pelletal apatite, minor quartz, and a trace of clay in a bed ranging between 1.0 and 2.0 meters and averaging 1.5 meters in thickness. This phosphorite bed is in the lower part of the Galembo Member of the La Luna Formation. The strata dip between 10° and 25° to the north where phosphorite is exposed along the road that leads east from Sardinata and connects with the road from Cúcuta to Tibú, and in ravines adjacent to the road. These exposures suggest that the bed extends continuously for a distance of about 13 km (pl. 5). The bed is exposed at the surface or lies beneath less than 15 meters of overburden in an area 4 km long that has a maximum width of 1,000 meters and an average width of about 500 meters (block A, pl. 5). The bed is exposed also at the surface or is overlain by thin cover in a band about 50 meters wide that extends west for an additional 4 km to the vicinity of Haciends La Florida. The phosphorite bed is exposed over about 3 km eastward from San Miguel, but in this area the bed is overlain by more than 15 meters of overburden that includes porcellanite beds of the Galembo Member, the Colón Shale, or alluvium and detritus.

The phosphorite bed probably continues northward beneath the Colón Shale from the exposures between Hacienda La Florida and Quebrada Los

Novios, but it could be absent in the subsurface in part of this area. The Galembo Member and the phosphorite bed are absent from exposures of the La Luna Formation between Quebrada La Chacona southwestward to about 3 km south of Sardinata; they seem to be absent from about 1 km east of Quebrada Los Novios to the easternmost exposure of the La Luna shown on plate 5. From 3 to 7 km south of Sardinata the phosphorite bed lies near the top of the La Luna, and as far south as Lourdes the bed probably occurs at most places in the narrow band of the La Luna where the formation is in fault contact with Precambrian crystalline rocks.

Reserves in the Sardinata area are summarized in table 5.

Orú, Norte de Santander

A large volume of phosphatic rock is present near Orú in the Department of Norte de Santander. This phosphatic material is a micro-conglomerate that forms the base of the Colón Shale and is equivalent to similar rocks at the base of the Umir Shale. Channel samples from Orú and from Pacheli, 10 km south of Orú, indicate a P_2O_5 content of 11 percent at Orú and 10.4 percent at Pacheli. The bed is lenticular and has a probable average thickness of about 4 meters. It is 2.5 meters thick at Orú, 4 meters thick 5 km to the south, and 7 meters thick 10 km south at Pacheli. South of Pacheli this bed thins, and 14 km south of Orú it is 2 meters thick. Assuming a lenticular body having an average thickness of 4 meters and a length of 14 km exploitable for 1,000 meters into the subsurface, there is a reserve of 140,000,000 tons of potential but low-grade phosphate rock in this area.

Table 5.--Phosphorite reserves in the vicinity of Sardinata, Norte de Santander. (Location of blocks shown in plate 5.)

Block	Area in square meters	Average thickness	Reserves in million metric tons
A	2,000,000	1.5	7-1/2 1/
B	11,000,000	1.5	40 2/
C	1,000,000	1.5	3-3/4 3/
		Total	51-1/4

1/ May be recoverable by open-pit mining.

2/ If phosphorite extends 1,000 meters in the subsurface at the average thickness of 1.5 meters.

3/ Part may be recoverable by open-pit mining.

Gramalote, Norte de Santander

Phosphorite in the vicinity of Gramalote, Norte de Santander, is a southerly continuation of the bed near the base of the Galembo Member that occurs in the vicinity of Sardinata. It is exposed at several places extending from 1 km south of Gramalote to 3 km north (pl. 5). Exposures of the phosphorite bed are repeated by faults. The thickness of the stratum ranges between 1.3 and 3.0 meters, and the dip of the strata from 30° to 50°. The rock indicated by a channel sample from the exposure at the cemetery is 31 percent P_2O_5, and it is not calcareous. However, this rock is thoroughly weathered. In an exposure in Quebrada Caldedero, 3 km north of Gramalote, the bed is about twice as thick as at the cemetery, is very calcareous, and has a P_2O_5 content of 16 percent. The extent of the phosphorite in the fault blocks can only be approximated, and a total possible dip length of 500 meters divided into several segments by the faults is assumed for calculation of reserves in this area. A reserve of 10,000,000 tons is inferred.

San Andrés, Santander

Phosphorite near the town of San Andrés in the Garcia Rovira district, Department of Santander, crops out in a bed 2.5 meters thick in the Capacho Formation (fig. 7). It is composed of abundant apatite pellets in a limestone matrix, and is slightly siliceous. One channel sample contains 25 percent P_2O_5 and is very calcareous. The stratum has been traced by sporadic outcrops for 3 km along two sides of a high bench about 500 meters above the town and is believed to cover an area of 1,125,000 square meters. Beds dip between 5° and 10° in most of this area, but locally steepen to 18°. About 7 million tons of phosphorite are inferred at this location.

Iza-Tota, Boyacá

A phosphorite bed is exposed west of Lake Tota near the towns of Iza, Cuitiva, and Tota, 14 to 21 km south of Sogamoso in the Department of Boyacá. The phosphatic zone includes two adjacent beds having total thickness of 3.0 meters and a P_2O_5 content of 20 to 25 percent; the rock is composed of mostly pelletal apatite in a clayey and slightly calcareous matrix in the upper 2 meters. The matrix of the lower 1 meter is sandy and cherty, the phosphorite is of lower tenor than the upper, and laterally the phosphorite changes facies to phosphatic cherty sandstone.

A detailed study in the area (Ospina, 1968) indicates that this phosphorite horizon can be followed in exposures that extend northwestward on the west flank of a syncline from the town of Tota for 7 km to a point east of the town of Iza. Inferred reserves calculated from data presented by Ospina indicate about 35 million tons containing 20 to 25 percent P_2O_5. Work in 1970 and 1971 has substantially increased the reserves in this general area (J. M. Cathcart, written commun., 1971).

A third area considered as a possible phosphorite reserve in the same vicinity lies a short distance to the north where a stratigraphically higher phosphorite bed is exposed at a point about 5 km southeast of Sogamoso in the road to Lake Tota. The bed is 2 meters thick and is projected to extend 3.5 km south to where it is again exposed and is 2 meters thick. The upper phosphorite bed continues northward from the point where it is exposed in the road from Sogamoso to Lake Tota and has been identified in the vicinity of Monquirá, about 3 km north, but there it is less than 1 meter thick (Raúl Durán, oral commun., 1968).

Turmequé, Boyacá

The phosphorite bed being mined at Turmequé consists of pelletal apatite and phosphatized Foraminifera in a matrix of clay and silt-size quartz; noncalcareous at the surface, it contains some calcite at depth. Average P_2O_5 content is about 22 percent, and average thickness is 1.2 meters. The bed overlies sandstone at the base of the Guadalupe Formation and is overlain by thin-bedded porcellanite. This phosphate probably is equivalent to the phosphorite bed near the base of the Galémbo Member of the La Luna Formation in the Departments of Santander and Norte de Santander. The extent of this bed in the vicinity of the mine is indicated in a preliminary study of Mojica (1967, and in Cathcart and Zambrano, 1967) and subsequent studies of the Instituto de Fomento Industrial. A mine opened in March 1967, by the latter named agency was being operated by its subsidiary, Colminas, Ltda., in February 1969.

Tesalia, Huila

A phosphate mine developed by Fosfatos de Colombia Ltda. of Cali, has been in operation since 1966 at Tesalia in the Department of Huila. The phosphatic bed is in the Guadalupe Formation. Two beds of phosphorite are underlain by about 10 meters of porcellanite, and overlain by about 30 meters of similar porcellanite. The upper porcellanite sequence includes a thin phosphorite bed about 15 to 20 meters above the principal phosphorite horizon. The stratigraphic sequence, thickness, and the lithology of these beds are remarkably similar to the phosphatic sequence in the basal part of the Galembo Member.

The principal phosphorite bed is 1.4 meters thick. It is overlain by 1.0 meter of barren to slightly phosphatic porcellanite, and another 40 cm of high-grade phosphorite. Beds dip about 60° W. In June 1967, only the lower, thicker bed was being mined. It is reported to average 18 percent P_2O_5 and is slightly calcareous. The bed is estimated to extend at least 2,000 meters along the strike. The reserve inferred for the lower bed, if mined to a depth of 1,000 meters, is 7 million tons. An additional 2 million tons probably also exists in this same area and could be recovered by adjusting the mining procedure to simultaneously exploit the thinner, upper bed. This would yield a total inferred reserve of 9 million tons.

RECOMMENDATIONS FOR FURTHER EXPLORATION

The phosphorite beds located thus far (Cathcart and Zambrano, 1967) occur along a northeast- to southwest-trending belt that extends from the Venezuelan to the Ecuadorian border. The principal reserves are those in Santander and Norte de Santander, but reserves also are present in Boyacá. Several areas adjacent to the presently known reserves are unexplored, and additional phosphorite might be found in some areas farther south in Colombia.

Exposures of the La Luna Formation between the villages of Esperanza, Norte de Santander, and San Alberto, Department of Césár (fig. 2) were briefly studied. The lower phosphorite bed in the Galembo Member at one place near Esperanza was found to be 1 meter thick at the top of overturned La Luna Formation, structurally below the Pujamana Member. The area is structurally complex, but it should be mapped and the extent of the phosphorite bed determined. The Galembo Member is reported farther north in the vicinity of Totumal (Morales and others, 1958, p. 655), and that area should also be explored. Still farther north, the La Luna Formation in the vicinity of the Césár Valley probably does not include the Galembo Member and it is unlikely that phosphorite beds occur there.

Phosphorite beds may be present in the Galembo Member between San Vicente and Landázuri along the west flank of the Cordillera Oriental where the La Luna Formation forms hogback ridges that are similar to the ridges formed by these strata between San Vicente and Vanegas. Brief reconnaissance studies near Landázuri showed that phosphorite beds are present near the base of the Galembo Member (Fernando Pachón, oral commun., 1967). Additional study of these phosphorite beds in the Landázuri area is needed and any investigation of the Galembo ridges between San Vicente and Landázuri would probably locate phosphorite beds in that area. However, phosphorite beds are thinner and of lower grade in the vicinity of San Vicente than farther north, therefore, thickness and grade may continue to decrease southward to Landázuri.

Northwestern Cundinamarca seems a favorable phosphate province because this area lies near the edge of the Cretaceous continental shelf where upwelling currents from deeper waters in the adjacent geosyncline may have favored the formation of phosphate (McKelvey and others, 1953).

The Galembo Member in the vicinity of Yacopí and at least as far south as Alto del Trigo should be examined for beds of phosphorite, because these areas are in the favorable northwestern Cundinamarca province, and they lie along the southwesterly continuation of favorable phosphorite areas in Norte de Santander and Santander. An earlier study for phosphorite near Alto del Trigo, which is along this alignment, was concentrated on upper strata of the Guadalupe Formation;

lower strata equivalent to phosphorite zones near the base of the Galembo Member were not examined (Zambrano, oral commun., 1969).

Studies near Pandi, Icononzo, and Cunday in southwestern Cundinamarca and adjacent parts of Tolima showed that detrital sedimentation dominated in these areas and conditions for apatite accumulation apparently were only briefly favorable as indicated by the thin phosphorite beds there. The northeast to southwest trend of phosphate deposits in northern to central Colombia continues into Tolima and Huila where phosphorite has been noted at several places in the Cordillera Central in southern Colombia (Cathcart and Zambrano, 1967), although not studied yet in detail. The mine at Tesalia is along this trend, which suggests that there may also be additional economic phosphate resources in that area.

The phosphorite deposits in the Department of Boyacá should continue to be studied because of the reserves known near Turmequé and Iza, and the indications that additional reserves may be located near Sogamoso (Raúl Durán, oral commun., 1968). Paleogeographic relations suggest that these strata were deposited within an embayment upon the continental shelf similar to the paleogeographic environment of the phosphate deposits in the Phosphoria Formation of the western United States (Sheldon and others, 1967).

Most of the phosphorite deposits in Boyacá are lenticular bodies that diminish in thickness and apatite content because they intertongue over short distances with sandstone. The sandstone bodies were deposited probably as deltas and bars that formed on the shelf proximal to the Guayana shield. In prospecting for phosphorite in this area, it should be considered that, unlike other parts of the Cordillera Oriental where the phosphorite beds seem to have been deposited in nearly uniform thickness over a broad area, the phosphorite beds in Boyacá are lenticular; thus more trenches and drilling will be needed here than elsewhere to accurately determine bed geometry and the feasibility of mining.

The basal part of the Umir and Colón may contain local concentrations of detrital apatite. Additional large amounts of phosphatic rock at this stratigraphic level may occur between San Vicente and Landázuri and farther south of the reserve inferred near Orú. Other large amounts may occur at the base of the Colón Shale north of Orú, but search for additional phosphatic beds cannot be justified until the value and potential for use of the rock in the vicinity of Pacheli and Orú are established.

REFERENCES

Bürgl, Hans, 1955, La Formación Guadalupe entre Tabio y Chía en la Sabana de Bogotá, Departamento de Cundinamarca: Colombia Bol. Geol., v. 3, no. 2, p. 23-55.

________ 1961, Geologia histórica de Colombia: Rev. Acad. Colombiana de Ciencias Exactas, Fisicas y Naturales, v. 11, no. 43., p. 137-189.

Bürgl, Hans, and Botero G., Dario, 1967, Las capas fosfáticas de la Cordillera Oriental: Colombia Bol. Geol., v. 15, nos. 1-3, p. 7-44.

Bürgl, Hans, and Dumit Tobón, Yolanda, 1954, El Cretáceo Superior en la región de Girardot: Colombia Bol. Geol., v. 2, no. 1, p. 23-48.

Campbell, C. J., 1962, A section through the Cordillera Oriental of Colombia between Bogotá and Villavicencio: Colombian Soc. Petroleum Geol. and Geophys., Guidebook, 37 p.

Casey, R., 1974, in Harland, W. B., Smith, A. G., and Wilcock, B., eds., the Phanerozoic time scale, a symposium: London Geol. Soc. Quart. Jour., v. 1205.

Cathcart, J. B., and Zambrano O., Francisco, 1967, Roca fosfática en Colombia: Colombia Bol. Geol., v. 15, no. 1-3, p. 65-162.

Cediel, Fabio, 1968, El Grupo Girón, una molasa Mesozoica de la Cordillera Oriental: Colombia Bol. Geol., v. 16, nos. 1-3, p. 5-96.

Cushman, J. A., and Hedberg, H. D., 1941, Upper Cretaceous Foraminifera from Santander del Norte, Colombia: Cushman Lab. Foram. Res. Contr., v. 17, part no. 232, p. 79-100.

Etayo, S., Fernando, 1964, Posición de las faunas en los depósitos cretácicos colombianos y su valor en la subdivisión cronológica de los mismos: Bol. Geol., no. 16-17, Univ. Industrial de Santander, Bucaramanga, p. 5-142.

Etayo S., Fernando, 1965, Sinopsis estratigráfica de la región de Villa de Leiva y zonas próximas; Bol. Geol., no. 21, Univ. Industrial de Santander, Bucaramanga, p. 19-32.

Freas, D. H., and Riggs, S. R., 1968, Environments of deposition in the central Florida phosphate district, in Forum on Geology of Industrial Minerals, 4th, Austin, Tex., 1968, Proc.: Univ. Texas Bur. Econ. Geology, p. 117-128.

Garner, A. H., 1926, Suggested nomenclature and correlation of the geological formations in Venezuela: Am. Inst. Min. Metal. Eng. Trans., p. 677-684.

Hedberg, H. D., and Sass, L. C., 1937, Synopsis of the geologic formations of the western part of the Maracaibo basin, Venezuela: Venezuela Bol. Geol. y Min., v. 1, no. 2-4, p. 77-120.

Hettner, A., 1892, Die Kordillere von Bogotá: Petterman's Mitt., Band 22, Ergangzungshelf 104, 131 p. Gotha. Spanish translation by Ernesto Guhl, 1966, La Cordillera de Bogotá: Ediciones del Banco de le República, Bogotá, 351 p., Illus.

Hubach, Enrique, 1953, Estado actual de la exploración de fosfatos en Colombia: Colombia Bol. Geol. Año 1, no. 3, p. 1-6.

______1957, Estratigrafía de la Sabana de Bogotá y alrededores: Colombia Bol. Geol., v. 5, no. 2, p. 93-112.

Instituto Geográfico de Colombia (Agustín Codazzi), 1954, Carta Preliminar 120-I-B, Ríos Chucurí - Sogamoso, Scale 1:25,000: Ministerio de Hacienda y Crédito Público, Bogotá.

Julivert, M., 1962a, Estudio sedimentológico de la parte alto de la formación Guadalupe al E. de Bogotá (Cretácico Superior): Bol. Geol., Univ. Ind. de Santander, no. 10, p. 25-55.

______1962b, La estratigrafia de la Formación Guadalupe y las estructuras por gravedad en la Serrania de Chía (Sabana de Bogotá): Bol. Geol., Univ. Ind. de Santander, no. 11, p. 5-21.

Kazakov, A. V., 1950, Geotectonics and the formation of phosphorite deposits (translation): Izv. Akad. Nauk SSSR. Sen. Geol. no. 5, p. 42-68.

Kehrer, Guillermo, 1933, El carboniano del borde planero de la Cordillera Oriental: Minas y Petroleos, Bol., Bogota, v. 9, p. 105-121.

Krumbein, W. C., and Sloss, L. L., 1963, Stratigraphy and sedimentation: 2nd ed., W. H. Freeman and Co., San Francisco and London, 660 p.

Maughan, E. K., 1969, Destructive landslides and their geologic relations in the vicinity of Hacienda La Renta, west of Lebrija, Department of Santander: U.S. Geol. Survey Open-file report.

McKee, E. D., and Weir, G. W., 1953, Terminology for stratification and cross-stratification in sedimentary rocks: Geol. Soc. America Bull., v. 64, p. 881-889.

McKelvey, V. E., Swanson, R. W., and Sheldon, R. P., 1953, The Permian phosphorite deposits of western United States: Internat. Geol. Cong., 19th, Algiers, 1952, Comp. Rend., sec. 11, pt. 11, p. 45-64.

Mojica G., P. E., 1967, Estudio preliminar sobre un depósito de fosfato en la Cascajera (Turmequé, Boyacá), y geología general correspondiente a la plancha 191-III-C: Colombia Inventario Minero Nac., unpub. rept., 11 p., mimeo., 6 pl.

Morales, L. G., and others, 1958, General geology and oil occurrences of middle Magdalena Valley, Colombia, in L. G. Weeks, ed., Habitat of Oil: Am. Assoc. Petroleum Geologists, Tulsa, Oklahoma, p. 641-695.

Notestein, P. B., Hubman, C. W., and Bowler, J. W., 1944, Geology of the Barco Concession, Republic of Colombia, South America: Geol. Soc. America Bull., v. 55, p. 1165-1216.

Ospina, Carlos, 1968, Yacimiento de fosforita, Tota-Cuitiva, Iza (Boyacá): Colombia Serv. Geol. Nac., Informe 1537.

Petters, V., 1955, Development of Upper Cretaceous foraminiferal faunas in Colombia: Jour. Paleontology, v. 29, p. 212-225.

Renzoni, Giancarlo, 1962, Apuntes acerca de la litología y tectónica de la zona al este y sureste de Bogotá: Colombia Bol. Geol., v. 10, nos. 1-3, p. 59-79.

Rod, Emile, and Maync, Wolfe, 1954, Revision of Lower Cretaceous stratigraphy of Venezuela: Am. Assoc. Petroleum Geologists Bull., v. 88, no. 2, p. 193-293.

Schwarck A., Armando, and others, 1956, Stratigraphical lexicon of Venezuela (English edition): Venezuela Bol. Geol., Spec. Pub. 1, 664 p.

Sellier de Civrieux, J. M., 1952, Estudio de la microfauna de la sección-tipo del Miembro Socuy de la Formación Colón, Distrito Mara, Estado Zulia: Venezuela Bol. Geol., v. 2, no. 5, p. 231-310.

Sheldon, R. P., Maughan, E. K., and Cressman, E. R., 1967, Environment of Wyoming and adjacent states--Interval B (pl. 11), in Paleotectonic maps of the Permian System: U.S. Geol. Survey Misc. Geol. Inv. Map I-450, p. 48-54.

Sievers, W., 1888, Die Cordillere von Merida, hebst Bermerkungen Uber die Karibische Gebirge: Geog. Abhandl., v. 31, no. 1, 238 p.

Sutton, F. A., 1946, Geology of Maracaibo basin, Venezuela: Am. Assoc. Petroleum Geologists Bull., v. 30, no. 10, p. 1621-1741.

van der Hammen, Thomas, 1954, El desarrollo de la flora colombiana en los periodos geológicos...: Colombia Bol. Geol., v. 2, no. 1, p. 49-106.

Ward, D. E., Goldsmith, Richard, Cruz B., Jaime, and others, 1969, Mapa geológico del cuadrangulo H-12 (Bucaramanga), Colombia: Colombia Inst. Nal. de Investigaciones Geológico - Mineras, Ministerio de Minas y Petroleos, Bogotá.

Wilson, J. L., 1969, Microfacies and sedimentary structures in "deeper water" lime mudstones, in Depositional environments in carbonate rocks: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 14, p. 4-19.

Wokittel, Roberto, 1960, Recursos minerales de Colombia: Compilación de los estudios geológicos oficiales en Colombia, Tomo 10, 393 p.

Figure 7. Columnar Section of Capacho Formation and phosphorite beds, Lomo El Hato near San Andrés, Santander.

Scale
0 10 20 30 40 50m

by Jacob Abozaglo M. & Alonso Otero.

1967

U. S. Geological Survey
OPEN FILE REPORT 79-1525
This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards or nomenclature.

Dib. MHS.

U. S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

U. S. Geological Survey
OPEN FILE REPORT 79-1525
This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards or nomenclature.

PREPARED IN COOPERATION WITH THE INSTITUTO NACIONAL DE INVESTIGACIONES GEOLOGICO-MINERAS

OPEN FILE REPORT
(IR)CO-39

Plate 2. Correlation of measured sections of Galembo Member of La Luna Formation from the vicinity of San Vicente to the vicinity of Vanegas, Santander. Location of sections shown on Plate 4.

U. S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE INSTITUTO NACIONAL DE INVESTIGACIONES GEOLOGICO-MINERAS

OPEN FILE REPORT (IR) CO-39

Plate 3. Correlation of measured sections of Galembo Member of La Luna Formation in the vicinity of Vanegas and Conchal, Santander

by Jacob Abozaglo M. and Edwin K. Maughan