Phosphate Rock In Colombia— A Preliminary Report

GEOLOGICAL SURVEY BULLETIN 1272-A

Prepared in cooperation with the Servicio Geologico Nacional of Colombia, under the auspices of the Government of Colombia and the Agency for International Development, U.S. Department of State

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By JAMES B. CATHCART *and* FRANCISCO ZAMBRANO O.

With a section on

THE PHOSPHATE OCCURRENCE AT TURMEQUÉ

By PEDRO E. MOJICA G.

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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By James B. Cathcart and Francisco Zambrano O.

ABSTRACT

Exploration for phosphate rock in Colombia was successfully carried out in 3½ months in 1966 by the U.S. Geological Survey and the Inventario Minero Nacional of the Ministry of Mines and Petroleum of the Government of Colombia; the investigation was financed through a technical assistance loan from the U.S. Agency for International Development. The theory of exploration, based on modern studies of phosphorite deposits, is that phosphate often is deposited in the miogeosyncline adjacent to the foreland or craton and in deeper parts of the ocean where deposition of clastic material is at a minimum and where upwelling currents deposit a suite of rocks characterized by chert, black shale, carbonate rock, and phosphorite. Previous work in Colombia had demonstrated that phosphate is present in rocks of Cretaceous age and is most abundant in rocks of Late Cretaceous age—La Luna Formation and Guadalupe Group—in the Eastern Cordillera.

INTRODUCTION

Minable concentrations of phosphate are found in nature in three principal environments—as guano or deposits derived from guano, as igneous apatite associated with alkalic rocks, and as marine phosphate deposits. Marine deposits account for about 75 percent of the world's production of phosphate.

The search for phosphate in Colombia began as early as 1942 (Hubach, 1952), and from 1944 to 1952 some work on guano deposits in caves and on the islands off the coast was done by the Colombia Servicio Geologico Nacional (Paba Silva, 1949; Sarmiento Alarcon and Sandoval, 1947; Suarez Hoyos, 1948). Some reconnaissance work was done during these years in the Cretaceous rocks of the Eastern Cordillera (Sarmiento Alarcon, 1947; Sarmiento Soto, 1942a, 1942b, 1943a; Wokittel, 1957). In a résumé, Wokittel (1960) concluded that there were no known economic deposits of phosphate in Colombia. In 1961, Bürgl began a study of phosphate in the Eastern Cordillera of Colombia (Bürgl and Botero G., 1962). The work showed that phosphorite is concentrated in rocks of Late Cretaceous age, particularly in the Senonian. Slansky (1963) conducted a study on phosphate and concluded that the Upper Cretaceous was the most favorable stratigraphic interval and that the western part of the Eastern Cordillera was the most favorable structural location for the development of possibly economic phosphate.

Accordingly, the work reported here was confined to the Eastern Cordillera and to rocks of Late Cretaceous age. Particular attention was paid to the facies changes in the miogeosyncline, and the field investigation pointed to the area in the Department of Norte de Santander, where the best phosphorite was found. Phosphate deposits were found in both the geosynclinal and the platform facies in Upper Cretaceous rocks spread through a large area of the Eastern Cordillera—from the Department of Huila in the south to Norte de Santander in the north, a distance of over 600 kilometers.

Phosphate has been mined from Upper Cretaceous rocks (La Luna Formation) at the Lobatera mine in Venezuela (Harrington and others, 1966), close to the town of Cúcuta in Colombia.

The U.S. Geological Survey program, sponsored by the U.S. Agency for International Development and undertaken in collaboration with the Servicio Geologico Nacional and the Inventario Minero Nacional, included a plan to search for phosphate in the Cretaceous rocks in the Eastern Cordilla in Zone IV, where Bürgl and Botero G. (1962) reported phosphate. The writers' part in this program was carried out from August to December 1966 and had as its objective the examination of previously found phosphate occurrences to decide whether phosphate could be mined or beneficiated and to determine future targets for exploration for possible economic deposits of phosphate.

ACKNOWLEDGMENTS

We wish to thank the members of the Inventario Minero Nacional and their director, Dr. Dario Suescun Gomez, for their complete cooperation and valuable assistance in all phases of the project. Dr. Marino Arce of the Inventario Minero Nacional accompanied us in the field; without the benefit of his detailed knowledge of the geology of Colombia and of the phosphate occurrences, the work could not have been accomplished. Drs. Pedro E. Mojica G., Gilberto Manjarres, Raul Perea, and Jaime Cruz, senior geologists of the Inventario Minero Nacional, also provided valuable assistance in the field. Personnel of the U.S. Geological Survey in the various zones were most helpful in guiding the writers to phosphatic outcrops and in pointing out details of structure and stratigraphy. It is a real pleasure to acknowledge the help of D. H. McLaughlin, Jr., Dwight E. Ward, and Charles M. Tschanz of the U.S. Geological Survey. Earl M. Irving, chief of the U.S. Geological Survey's cooperative project with the Inventario Minero Nacional, was extremely helpful in all aspects of the work.

REGIONAL GEOLOGY OF COLOMBIA

The dominant physiographic feature of Colombia is the Andes Mountain system, which forms a broad north-trending belt that extends the entire length of the country. In Colombia, the Andes chain consists of three high ranges separated by valleys (fig. 1). From west to east the principal tectonic features are the Pacific Coastal basin, the Western Cordillera, the Cauca basin, the Central Cordillera, the Magdalena basin, the Eastern Cordillera, the Llanos basin, and the Guayana shield.

The physiography controls transportation routes. East-west transport is difficult because of the high mountain ranges and deep valleys; most transportation is north-south.

The Western Cordillera and the Central Cordillera were part of a deep eugeosynclinal basin in the Cretaceous; the Llanos basin and the Guayana shield formed the craton or foreland of the Cretaceous miogeosyncline; and only the Eastern Cordillera contains rocks of the Cretaceous miogeosyncline. Tertiary rocks in the interior of the country are continental; marine Tertiary rocks are confined to the Pacific coast and the northern part of the country.

CRETACEOUS ROCKS

In Colombia, phosphate rock has been noted only in rocks of Cretaceous age in the Eastern Cordillera. The Cretaceous rocks in the Western and Central Cordilleras are in the eugeosynclinal facies and are composed of a thick series of clastic and volcanic rocks. This facies is not favorable for accumulation of phosphate in economic amounts. The discussion of the stratigraphy of the Cretaceous is therefore confined to the Eastern Cordillera—the only area favorable for phosphorites.

During Cretaceous time the floor of the miogeosyncline of the eastern Andean province oscillated, leading to repeated marine transgressions, which are marked in the stratigraphic record by a variety of facies. The stratigraphy of the Cretaceous of the Eastern Cordillera is shown in figure 2.

Phosphorite beds have been found only in the upper part of the Cretaceous section in the Guadalupe Group and La Luna Forma-

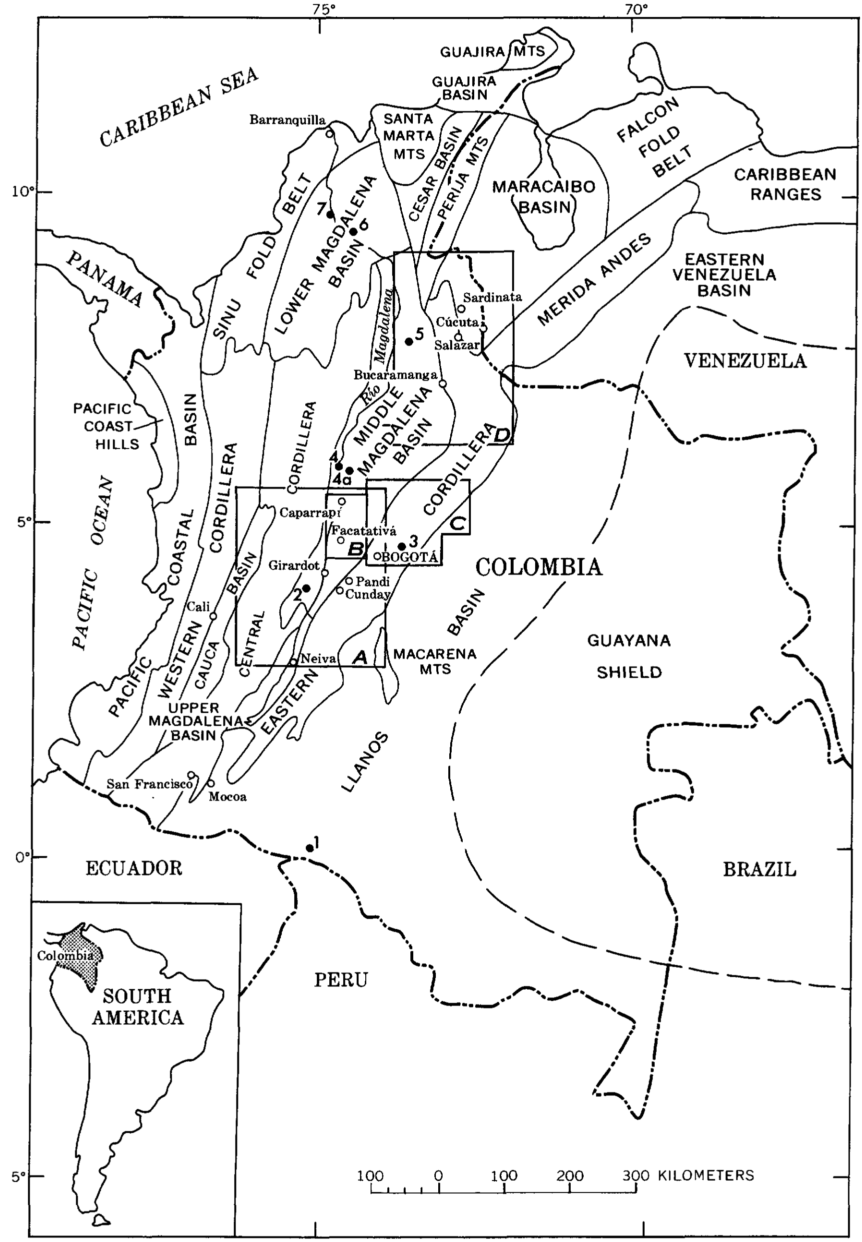

FIGURE 1.—Principal tectonic features of Colombia. Numbers indicate areas for which gamma-ray well logs were available (see fig. 6). Inset *A* shows area of figure 7; *B*, figure 8; *C*, plate 2; *D*, plate 3.

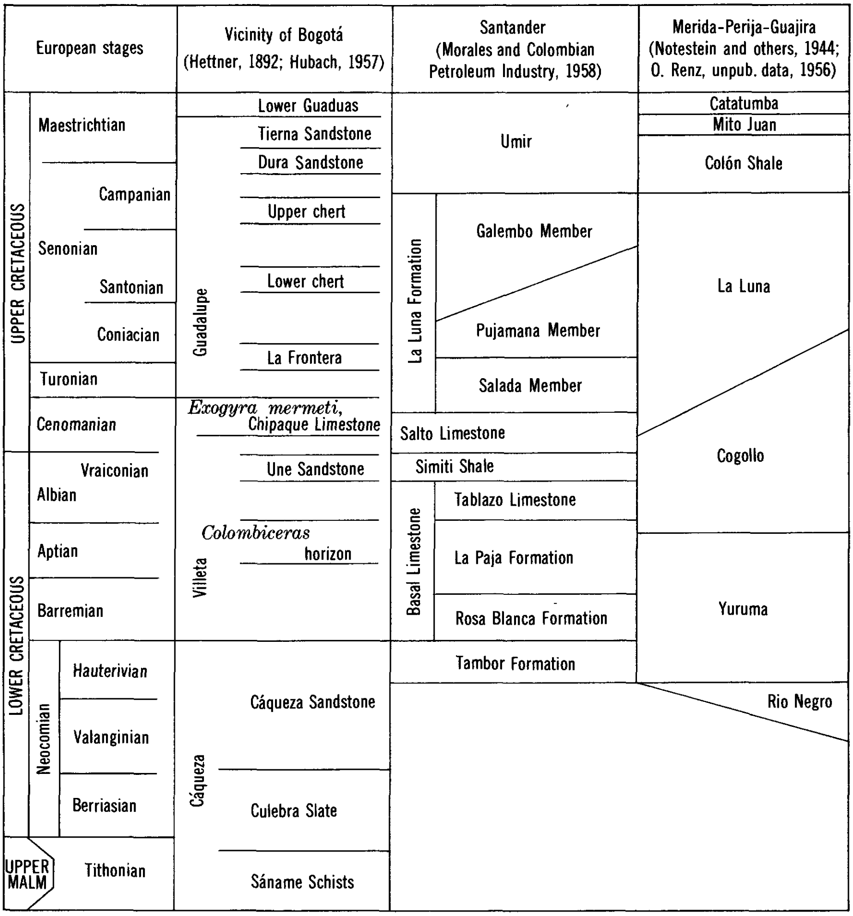

FIGURE 2.—Correlation chart of the Cretaceous of the Eastern Cordillera. From Bürgl (1961, table 2).

tion, but phosphatic beds containing minor amounts of P_2O_5 are also present in the Villeta Group (Barremian to Cenomanian). Bürgl (1961) pointed out that the lower part of the Guadalupe cannot be differentiated lithologically from the Villeta and that the boundary is arbitrary.

Facies changes in the upper part of the Cretaceous are well shown in the Department of Cundinamarca. East of Bogotá, the Guadalupe Group is a thick section of clastic material—light-colored to reddish-stained sandstone and siliceous claystone. This facies underlies much of the sabana and extends west of Facatativá. The salt deposits of Zipaquirá may be in or slightly below this facies (D. H. McLaughlin, Jr., oral commun., 1966).

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The Upper Cretaceous at Alto del Trigo west of Facatativá consists of limestone and calcareous shale and chert, and the section is much thinner than the clastic section to the east. At Alto del Trigo, Bürgl (cited in Thompson, 1966) called the phosphatic limestones the Galembo member of La Luna Formation (Santonian). The cherts in the section may be equivalent in age to the lower chert of the Guadalupe Group.

A similar facies variation occurs to the south, at the boundary of Cundinamarca and the Department of Tolima. There, the section at Pandi and Cunday is in the sand facies of the platform, and the section to the west at Ortega is in the chert-limestone-shale facies.

In the Departments of Santander and Norte de Santander the Upper Cretaceous (La Luna Formation) consists of chert, limestone, black shale, and phosphorite. Between Soata and Pamplona, rocks of equivalent age are chert-limestone-black shale, including some very thin beds of phosphatic sandy limestone, whereas to the north and west—the sections at Salazar, Sardinata, and San Vicente—the rocks consist of chert and phosphorite. These phosphorite beds are as much as 2 meters thick and have a high P_2O_5 content.

Farther north, on the Guajira Peninsula, La Luna Formation consists of thin-bedded limestone, calcareous shale, and minor chert and contains almost no phosphate. According to Bürgl (1961), the Upper Cretaceous rock on the Guajira Peninsula is a "limestone-arenaceous" facies which he considered to be a change from deep- to shallow-water facies. Rollins (1965) indicated that La Luna Formation on the southern part of the Guajira is on the shelf (possibly epicontinental), but that the section on the northern part of the peninsula thickens and is a deeper water basin facies.

The northward thinning of the Cretaceous and the change in lithology, from a dominantly clastic section in the Bogotá area to a more limy section in the Maracaibo basin, are shown in figure 3.

Cretaceous rocks underlying the Guadalupe Group in the Bogotá area are dominantly fine-grained clastics—black shale, fine-grained sandstone, and a few limestone beds of the Cáqueza and Villeta Groups (fig. 2). Black shale in the Villeta Group is radioactive, and thin beds of sandy limestone in the Villeta contain some phosphate (Bürgl and Botero G., 1962). In Santander, the Cretaceous rocks underlying La Luna Formation consist of radioactive black shale (Simiti Shale and La Paja Formation), limestone (Salto Limestone, Tablazo Limestone, and Rosa Blanca Formation), and a basal sandstone (Tambor Formation). No phosphate beds are known in these formations. Farther north (fig. 2), the Cogollo and Yuruma Formations consist of limestone and shale and contain no known phosphate.

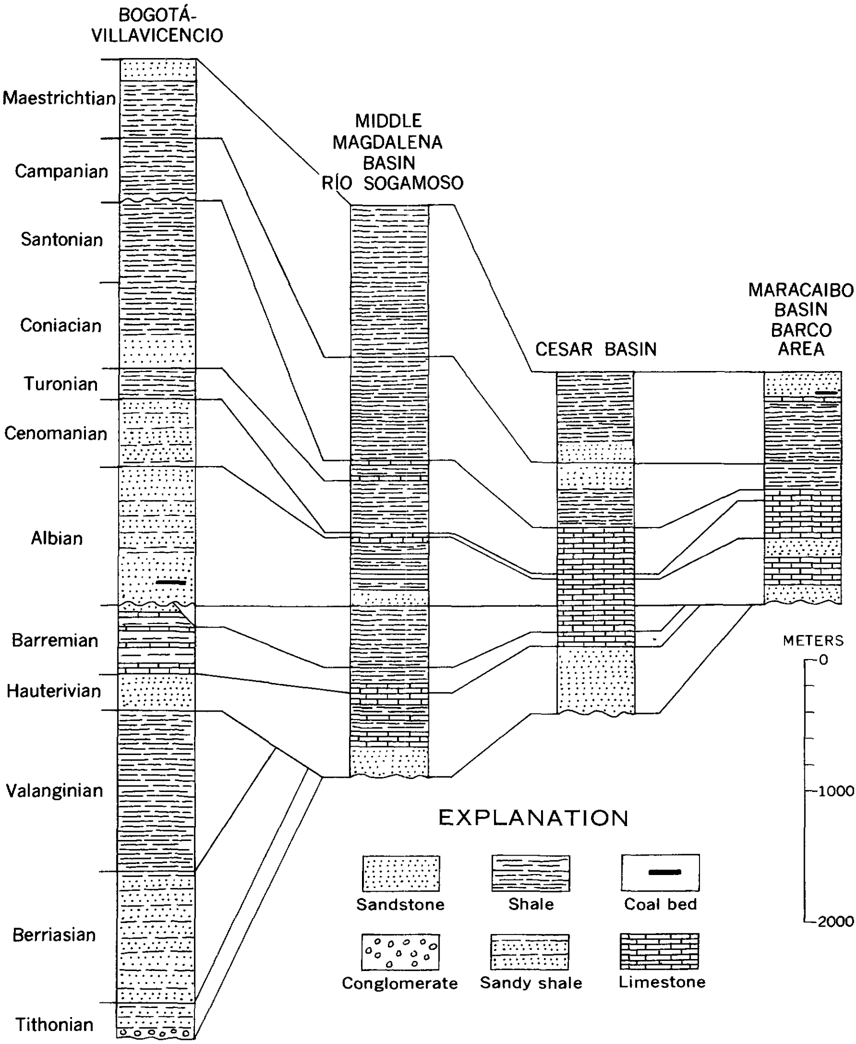

FIGURE 3.—Columnar sections of the Cretaceous in the Eastern Cordillera, showing northward thinning and changes in lithology. (From Campbell, 1964, fig. 4.)

In the Bogotá area, the rocks of the uppermost part of the Guadalupe Group are sandstones. The Guadaus Formation, overlying the Guadalupe, consists of claystone, minor sandstone, and some beds of coal; the Guaduas represents a transition between the marine formations of the Cretaceous and the continental formations of the Tertiary. The Umir Formation overlying La Luna consists of shale and fine-grained sandstone. The shale beds are radioactive and slightly phosphatic, but there are no known phosphate beds. The Colón Shale and Mito Juan and Catatumbo Formations of the Maracaibo basin area consist of shale and sandstone and are not known to be phosphatic.

TERTIARY ROCKS

Marine Tertiary rocks in Colombia are confined to the Pacific coast on the west and the Caribbean coast on the north. Tertiary rocks in the interior of the country are continental (Bürgl, 1961); gamma-ray logs show no radioactive anomalies in rocks of Tertiary age. Marine Tertiary rocks on the Pacific coast, from Buenaventura south to the Ecuador border, compose a series of clay, sand, and conglomerate as much as 5,000 m thick. In this region the Miocene section is about 3,000 m thick on the Río Guapi, but it thins to the north and south (Oppenheim, 1949). The upper and middle Miocene at the Gulf of Uraba is 1,300 m thick (Oppenheim, 1949). There is little chance of finding workable phosphate deposits in these thick sections of marine Tertiary rocks. Marine Miocene rocks of the northern coast and in the Guajira Peninsula contain sparse grains of phosphate.

Tertiary rocks in the intermontane basins are continental—fluvial, lacustrine, or alluvial fan deposits. They range in age from Eocene to Pliocene and consist of sand, shale, and conglomerate. No phosphate is known in any of these rocks, and gamma-ray logs show no anomalous radioactivity. Commercial deposits of phosphate are not likely to be found in the continental rocks of Tertiary age.

Marine Miocene rocks on the Guajira Peninsula were briefly examined. The rocks consist of brown sandy limestone and calcerous shale. The limestone is fossiliferous and contains only about 0.5 percent P_2O_5.

The Tertiary section on the Guajira Peninsula (after Rollins, 1965) is as follows:

Tucacas Formation—Clay shale and argillaceous limestone. The lower part of the formation is early Miocene. Rollins suggested that the formation may extend into the Pliocene.

Jimol Formation—Sandy limestone, clay shale interbeds. The basal part is middle Oligocene; the rest of the formation is late Oligocene.

Uitpa Formation—Gypsiferous clay shale. Middle Oligocene.

Sillimana Formation (Siamana Formation)—Limestone, clay shale interbeds, and a basal conglomerate. Middle Oligocene; the lower part may be early Oligocene.

Nazareth Formation—Sandy limestone; middle or late Eocene; correlative with the Macarao Formation.

STRUCTURE

The structure of the Eastern Cordillera is not well known. Bürgl (1961) pointed out that gentle folding of the miogeosynclines and eugeosynclines started in and continued through the Senonian and reached a maximum at its close. As a result of the folding, five synclinoria, or basins of subsidence, were present at the start of the Cenozoic. These basins received thick accumulations of Tertiary and Quaternary sediments derived from erosion of the associated anticlinoria, which were repeatedly uplifted throughout the Cenozoic.

The structure of the Eastern Cordillera is complex in detail. The beds are folded and broken by both thrust and normal faults; as a consequence, it is difficult to estimate phosphorite tonnage.

The possibility that phosphorite deposits of the platform facies are structurally controlled has been advanced by Bentor (1953) and Cathcart and Osterwald (1954). Phosphorite of the platform facies in the Eastern United States was deposited in basins formed on the flanks of anticlines or domes that were rising at the time of deposition; evidently the depth of the water is a critical factor in the precipitation of phosphorite.

Bürgl's isopach map (1961, fig. 25) of the Senonian shows a series of thick and thin deposits, alined in a northeast direction (fig. 4). Bürgl pointed out that the variation in thickness is due to the folding that started during the early Senonian. A correlation between the location of phosphate deposits and the thickness of sections is indicated: most phosphate was deposited during the Senonian, and the best deposits are in areas of thin Senonian sections. It is likely that the phosphate was deposited on or close to the flanks of rising anticlines (the thin sections) and that the depth of the water was a controlling factor. The distribution of the best phosphorite deposits in the Eastern Cordillera may be allied to the local structural picture, as well as to their original position in the deep parts of the miogeosyncline.

FACIES CONCEPT AND ITS BEARING ON PHOSPHATE PROSPECTING

Clues to the location of phosphorite facies in many parts of the world are provided by paleogeography and by the location of upwelling oceanic currents. Kazakov (1937) first proposed that phosphate was deposited in areas of oceanic upwelling, and his concept was used by McKelvey, Swanson, and Sheldon (1953) to explain the phosphorite deposition of the Phosphoria Formation of Permian age in the Northwestern United States. Later the theory was further developed and expanded to define the lateral and vertical sequence of facies that are common where phosphate-rich waters upwell onto a shoaling bottom (McKelvey, 1963; McKelvey and others, 1959; Sheldon, 1964a). The facies concept envisions deposition on a shoaling bottom of a suite of rocks ranging from black shales and phosphorites in the deep parts

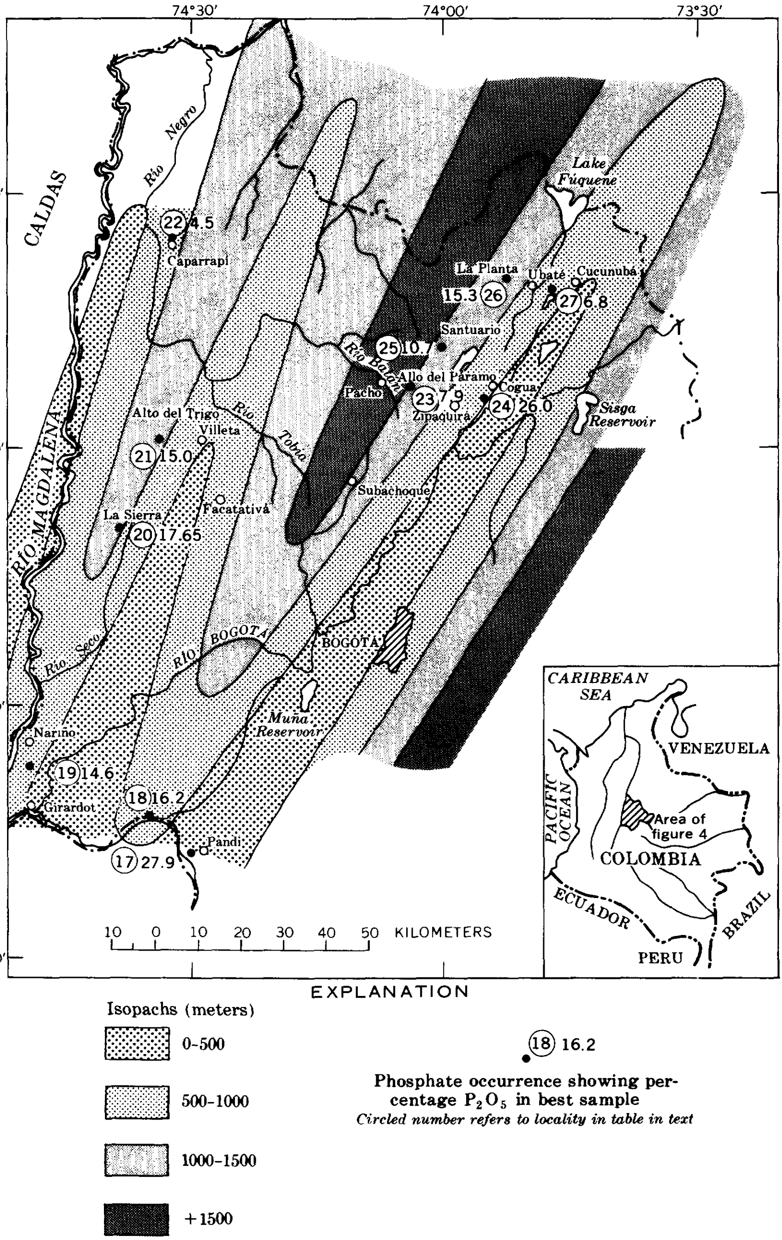

Figure 4.—Isopach map of the Senonian, Department of Cundinamarca, showing relation to phosphate occurrences. (Isopachs from Bürgl, 1961, fig. 25).

of the basin to limestone and chert facies that contain some phosphate at intermediate depths to a more sandy facies on the shelf. The sandy facies on the shelf may also contain phosphate beds, but they are generally not as high grade, abundant, or thick as the phosphorites deposited in the deep parts of the basin.

The upwelling currents from which the apatite mineral of marine phosphorites is precipitated are present in the modern oceans only between lat. 40° N. and 40° S. and on the west side of the major continents. A reconstruction of the paleogeography of the ancient phosphorites indicates that they, too, were deposited in the same locations (Sheldon, 1964b). The vast amount of phosphorus in ancient deposits indicates that the basin of deposition had to have been open to broad oceanic circulation for long periods of geologic time.

Chemical precipitation of phosphate is slow, and sections that contain economic phosphorite deposits are very thin. In thicker sections that contain large amounts of clastic or volcanic sedimentary rocks, phosphate, if it has been precipitated, is so dispersed in the large volume of nonphosphatic materials that it does not form an economic deposit.

The tectonic setting that meets the conditions of upwelling, oceanic circulation, and little clastic or volcanic deposition is the miogeosyncline, and studies of economic marine phosphorite deposits throughout the world indicate that many were deposited in a miogeosynclinal environment (McKelvey, 1963; Sheldon, 1964b).

PALEOGEOGRAPHY

CRETACEOUS MIOGEOSYNCLINE

At the end of the Paleozoic, deformation and uplift in the Colombian region resulted in the development of inland basins of deposition. During Triassic and Jurassic time the basins were the site of alluvial deposition. In the Early Cretaceous, however, the trough along the east side of the present Eastern Cordillera became the site of marine deposition, and black organic shale was deposited in it at the same time that coarser clastic material was deposited at the margin of the geosyncline (Belding, 1955). Marine conditions in the trough continued through the Late Cretaceous, but, as pointed out by Bürgl (1961), the Cretaceous of the Eastern Cordillera was marked by repeated marine transgressions and by oscillation of the floor of the miogeosyncline, resulting in deposition of a variety of facies.

In Colombia, at the time of this investigation, phosphate had been found only in rocks of Cretaceous age (Bürgl and Botero G., 1962; Slansky, 1963) in the Eastern Cordillera, and the best phosphate occurrences known were in the Guadalupe Group and La Luna Formation of Late Cretaceous (Santonian and Campanian) age. In August 1966, phosphate occurrences were know from near Neiva in the Department of Huila in the south to the area near the towns of California and Suratá in Santander in the north and at the Lobatera mine in the State of Táchira in western Venezuela.

As discussed above, a miogeosyncline formed in Colombia during Cretaceous time, and phosphatic sediments were deposited in the geosyncline during Late Cretaceous time. A paleogeographic map of Late Cretaceous time was made (fig. 5) from a compilation based on all available published data and new data derived from the present study. This compilation was modified further as fieldwork progressed.

Available published information and geologic maps indicate that the Cretaceous miogeosyncline in the latitude of Bogotá was narrow but that it widened both north, toward Cúcuta and the Maracaibo basin and south, toward the Ecuador border. This relation suggests that the upwelling currents in Late Cretaceous time may have come from the north or northwest and from the south or southwest, particularly because of the uplifted area (fig. 5) in the Central Cordillera indicated by Campbell (1964).

LITHOFACIES

The facies changes in the miogeosyncline, from clastic near the foreland to chert-limestone-black shale-phosphorite in the deeper water, are an important clue to the location of a possible economic phosporite deposit. East of Bogotá, toward the foreland, the Upper Cretaceous consists of a thick section of light-colored clastic rocks—fine- to medium-grained sandstone, gray shale, siliceous siltstone, and a few thin beds of phosphatic sandstone. This section is typical of the area near the foreland, where the clastic materials are thick, contain very little phosphate, and are not of economic interest. The section at Lake Tota, to the north, is similar to the section east of Bogotá. The phosphatic sandstone beds are about 0.2–0.3 m thick and contain only about 7 percent P_2O_5.

The sand facies west of the foreland and toward the basin contains good phosphorite beds such as those near Elias, Cunday, and Turmequé. Phosphorite beds are as much as 2 m thick and contain as much as 25-30 percent P_2O_5.

Still farther west, in the deeper part of the miogeosynclinal basin, the facies changes from sand to chert-limestone-black shale. This facies contains calcareous phosphorite beds that are about 0.1–0.2 m thick and contain as much as 17 percent P_2O_5. These beds are exposed at La Sierra, Alto del Trigo, and Caparrapí. From this lateral se-

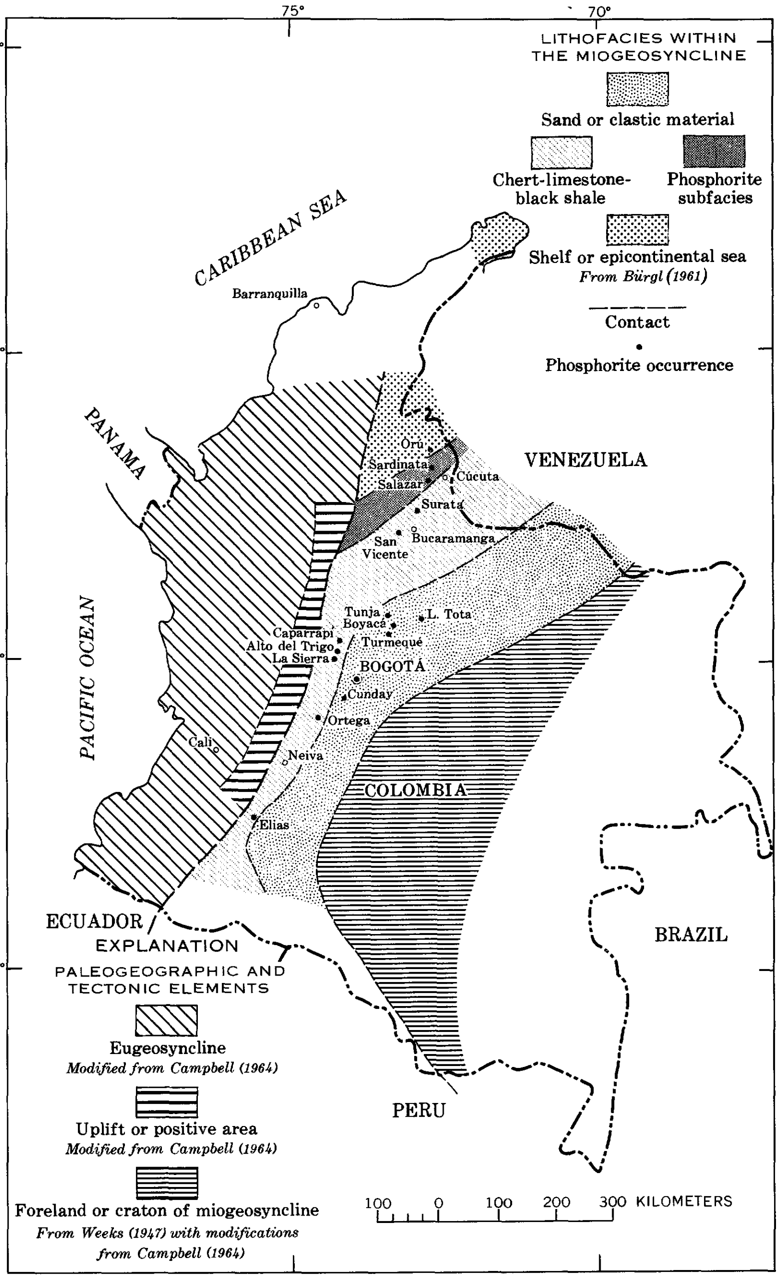

Figure 5.—Late Cretaceous paleogeographic (nonpalinspastic) and lithofacies map showing relation of phosphorite occurrences to facies in the miogeosyncline.

quence of facies, better deposits might have been expected to the west, toward the Magdalena River. A traverse there, however, showed coarse clastics that must have come from the west, possibly from the positive area identified by Campbell (1964) in the position of the Central Cordillera. Thus, the central part of the miogeosynclinal basin in Late Cretaceous time was too narrow for phosphorite to form.

The evidence that the miogeosyncline widens to the north and that the best area to look for phosphorite deposits is north of the California-Suratá area in Santander was confirmed by fieldwork. Phosphorite beds in the chert-limestone-black shale facies increase in thickness and in grade from south to north and also to the west. Thus, beds near Soatá (pl. 1) are only about 0.2 m thick, but near San Vicente (pl. 1), several phosphorite beds are as much as 1 m thick and contain more abundant phosphate pellets than the beds near Soatá.

Still farther north, in Norte de Santander, the phosphorite beds are thicker and higher in phosphate content. At Sardinata (pl. 1) a single bed of phosphorite is about 2 m thick and contains only apatite grains and minor quartz, cemented by clay and apatite. The beds in this area are in the chert-limestone-black shale facies, but the phosphorite beds are thick and high grade; these beds have been separated into a phosphorite subfacies of the chert-limestone-black shale facies.

There are enough data to indicate that the western part of the sand facies could possibly also be delineated as a phosphorite subfacies. As geologic work on the phosphate deposits of Colombia continues, an attempt should be made to map the phosphorite subfacies of the sand facies.

North of Sardinata, near the town of Orú (pl. 1), phosphate beds in the Upper Cretaceous are thinner, and the facies differs from that at Sardinata. The phosphate beds are calcareous and are associated with thin beds of limestone, calcareous shale, and some chert. The facies here may represent deposition in shallower water toward what Bürgl (1961) called an epicontinental sea facies. The Upper Cretaceous on the Guajira Peninsula (loc. 53, pl. 1) is thin and consists of thin-bedded gray calcareous shale, limestone, minor chert, and one thin bed that contains some grains of phosphate.

The miogeosyncline also widens to the south, but much of that area is covered with Tertiary sedimentary rocks, and little is known of the facies or their distribution. More phosphate may remain to be discovered in this area.

The paleogeographic and lithofacies map (fig. 5) is only an approximation based on available data. It should be refined and altered as detailed fieldwork is done so that phosphate deposits in unexplored areas and potential deposits in areas covered by rocks of Tertiary age may be outlined and examined.

EXPLORATION METHODS

FIELD PROCEDURES

The tectonic position and the stratigraphic horizon at which a phosphorite deposit is likely to be found were determined as outlined in the previous pages. Field procedures, after these determinations have been made, consist basically of examining all the roadcuts where the phosphorite horizon is likely to crop out. Therefore, an important part of the field examination of the known phosphorite outcrops included an attempt to relate each outcrop to its position in the miogeosyncline and to a facies within it. Because a phosphorite deposited by upwelling water is widely distributed geographically, examination of roadcuts is enough to determine the presence of such a unit, and it should be emphasized that this preliminary examination was all that was done in Colombia. Field examination indicated that there were at least two facies—a clastic or sand facies represented by the Guadalupe Group and a chert-limestone-black shale facies represented by La Luna Formation. Both facies contain phosphorite beds. A series of traverses were made across the miogeosyncline to determine more accurately the position of the facies. After discovery of the phosphorites, detailed mapping, followed by trenching and drilling, must be done to determine the grade and tonnage of the material and the possible economics of mining and processing the material.

Because phosphorite is an ordinary looking rock, it may be overlooked by the field geologist. Its common association with chert and black shale is a useful guide in locating a phosphorite bed.

The scintillation counter is a very useful tool in phosphate exploration. Marine phosphorites contain small amounts of uranium, and outcropping phosphorite beds show distinct anomalous radiation. Scintillation traverses of the areas of interest should be made, and each area of anomalous radiation should be carefully examined.

A semiquantitative estimate of the P_2O_5 content of a phosphorite bed can be made in the field with a Shapiro kit (Shapiro, 1952). The test should be used with caution, however, because the very small sample volume used in the test makes it difficult to obtain a representative sample of the phosphorite bed. Samples of the phosphorite bed should be taken to the laboratory for analysis.

GAMMA-RAY LOGS

More than 100 gamma-ray logs of oil wells were examined. The logs included much of the Tertiary and a part of the Cretaceous section. The Tertiary formations that were logged with the gamma ray are nonmarine and did not show any anomalous radiation. Almost all the formations shown on the chart (fig. 6) were logged with the gam-

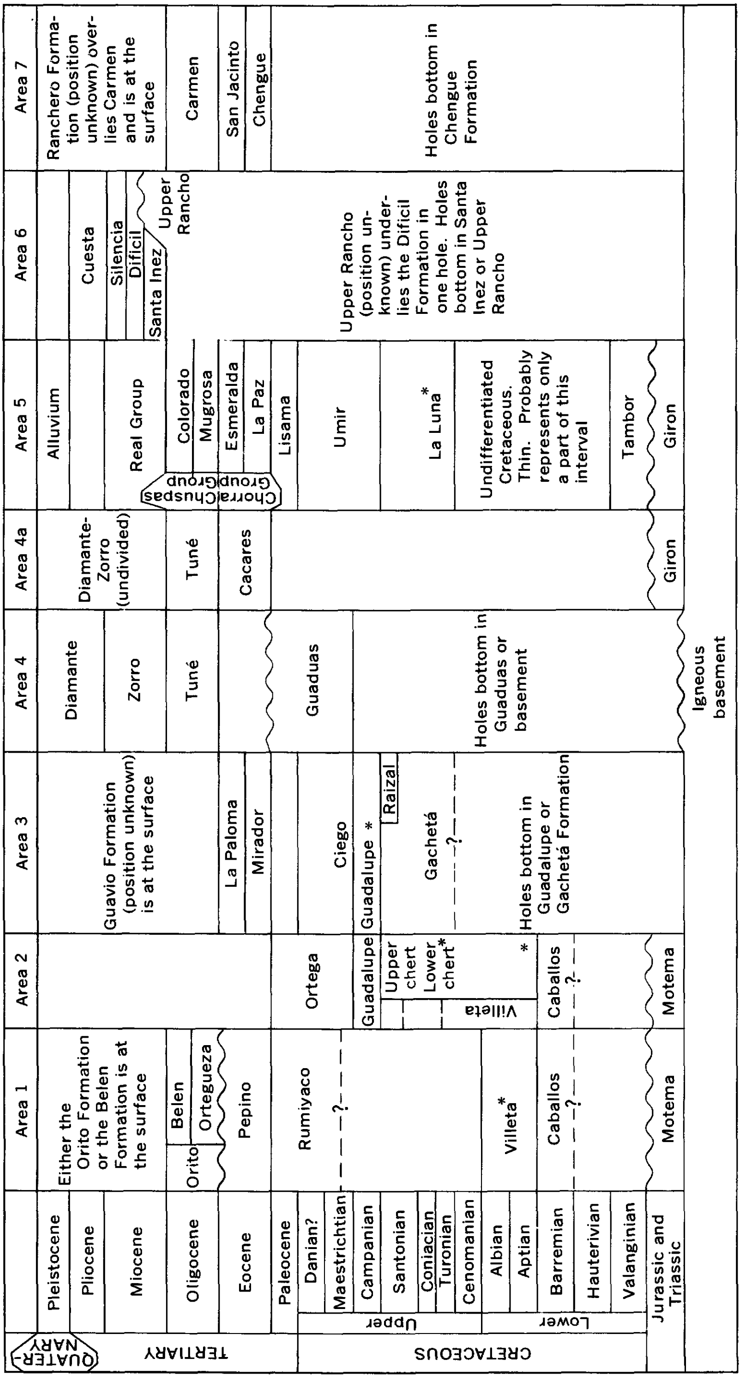

FIGURE 6.—Correlation chart based on gamma-ray well logs. Asterisk indicates anomalous radioactivity. Age assignments are those given by the oil companies that drilled the wells. Locations of areas are shown in figure 1.

ma-ray unit. The marine Tertiary section in the northern part of Colombia has been penetrated by oil wells, but no gamma-ray logs of these wells could be located. Anomalous peaks of radiation were found only in middle and upper Cretaceous rocks—the Guadalupe Group, La Luna Formation, and Villeta Group. High radiation peaks in the Villeta Group are probably due to black carbonaceous shale, as indicated by an examination of the surface outcrops of this group. Radiation peaks in the lower chert of the Guadalupe Group and in La Luna Formation may be due to thin beds of phosphatic material.

PHOSPHATE OCCURRENCES

All the known occurrences of phosphate are in rocks of Cretaceous age, and the only known phosphorite beds that have economic potential are in the Guadalupe Group and La Luna Formation of Late Cretaceous age. The investigation of phosphate (fig. 5) in Colombia was confined largely to the known outcrop areas of these formations, although the rest of the Cretaceous and the Tertiary were traversed in reconnaissance. All analytical and sample data from the literature and from the sampling in the current investigation are summarized in tables 1 and 2.

TABLE 1.—*Analytical and sample data for phosphate rock in Colombia*

[Analysts: Bernardo Fajardo Pinzón, Alvaro Mondragón, Alberto Diaz, Rosalia Medina, Inés Coronado, and Doris Cabal de Chaya, of the Laboratorio Quimico Nacional, Ministerio de Minas y Petroleos. Dashes (--) indicate not analyzed; N.D., not determined; IMN, Inventario Minero Nacional]

Locality	Sample	IMN No.	Age and unit	Lithology	P_2O_5 (percent)	Thickness (meters)	Reference
1 (pl. 1)	FZ-479		Upper Cretaceous.	Chert, phosphate.	16.76	0.20	Zambrano O. (1966).
2 (pl. 1)	HB-4081A		do	Chert, phosphate sand, shale.	7.0	.33	Do.
	4081		do	do	8.7	.40	Do.
3 (pl. 1)	FZ-315H		Upper Cretaceous—Coniacian to Campanian.	do	8.88	.10	Do.
	315E		do	do	22.36	.38	Do.
	315D		do	do	19.24	.48	Do.
	315C		do	do	18.77	.80	Do.
4 (pl. 1)	517		Upper Cretaceous.	do	16.18	.60	Do.
	519		do	do	12.56	.13	Do.
	521		do	do	19.31	.65	Do.
	522		do	do	17.88	.12	Do.
5 (pl. 1)	303		do	Phosphate sand, chert.	15.76	.20	Do.
6 (pl. 1)	348A		do	Phosphate sand, shale, chert.	14.48	.20	Do.
	348B		do	do	14.37	.25	Do.
	348C		do	do	24.33	.60	Do.
7 (pl. 1)	637		Upper Cretaceous.	Sand, shale, marl.	12.57	.20	Do.
	638A		do	do	7.41	.20	Do.
	638B		do	do	19.35	.20	Do.
8 (pl. 1)	No sample		do	Same bed as loc. 7	--	N.D.	

See footnote at end of table.

TABLE 1.—*Analytical and sample data for phosphate rock in Colombia*—Continued

Locality	Sample	IMN No.	Age and unit	Lithology	P_2O_5 (percent)	Thickness (meters)	Reference
9 (pl. 1)	Slansky		do	Chert, shale, phosphate rock.	19.0	N.D.	Slansky (1963).
10 (pl. 1)	do		do	do	27.4	1.0+	Do.
11 (pl. 1)	do		Upper Cretaceous—Campanian.	Chert, phosphate rock.	25.0	N.D.	Do.
12 (pl. 1, fig. 7)	Bürgl and Botero G.		do	Chert, phosphate sand.	10 samples, 0.1–17.59	N.D.	Bürgl and Botero G. (1962).
12 (pl. 1, fig. 7)	do		Lower Cretaceous—Albian.	Limestone, black shale.	6.0	N.D.	Zambrano O. (unpub. data).
13 (pl 1, fig. 7)	do		Upper Cretaceous—Santonian.	Chert, shale, phosphate.	26 samples, 0.1–23.48.	N.D.	Bürgl and Botero G. (1962).
	do		Upper Cretaceous—Turonian.	Limestone	12.52	3.0	Do.
14 (pl. 1, fig. 7)	Zambrano O., Bürgl and Botero G.		Upper Cretaceous—Campanian.	Chert, phosphate rock, shale.	44 samples, 0.6–26.0.	1.0 (max)	Bürgl and Botero G. (1962); Zambrano O. (unpub. data).
15 (pl. 1, fig. 7).	do		Upper Cretaceous, Campanian.	Chert, phosphate.	20 samples, 0.4–21.72.	.6 (max)	Do.
16 (pl. 1, fig. 7).	FZ-808	15794	Upper Cretaceous, Guadalupe.	Sand, minor phosphate.	0.19	1.50	Collected by Cathcart and Zambrano, O. in 1966.
	809A	15795	do	Shale	5.34	2.00	Do.
	809B	15796	do	Siltstone	0.22	1.20	Do.
	809C	15797	do	Shale	6.21	1.20	Do.
	FZ-809D =JBC-117.	15798	do	Phosphorite sand.	20.84	1.00	Do.
	FZ-811A	15799	do	Sand	7.42	.35	Collected by Zambrano, O., in 1965.
	811B	15800	do	do	16.34	.40	Do.
	811C	15801	do	do	11.40	.45	Do.
	811D	15802	do	do	12.26	.15	Do.
	812A	15803	do	do	2.69	.20	Do.
	812B	15804	do	do	20.26	.25	Do.
16a (fig. 7)	813A	15805	do	Shale	1.11	1.20	Do.
	813B	15806	do	do	1.00	3.70	Do.
	813C	15807	do	do	8.37	.10	Do.
	813D	15808	do	Phosphorite	14.9	.20	Do.
	813E	15809	do	Sandstone	12.2	5.00	Do.
17 (pl. 1, figs. 4, 7).	FZ		do	Phosphorite, sandy.	27.96	.27	Collected by Zambrano O. and Cathcart in 1966.
	FZ		do	do	27.54	.18	Do.
	JBC-1A	15703	do	do		.27	Do.
	-1B		do	do		.10	Do.
	-1C	15704	do	Weathered phosphorite, sandy.		.50	Do.
18 (pl. 1, figs. 4, 7).	FZ-724A	15351	do	Gray shale	1.56	1.00	Collected by Zambrano O. in 1965.
	724B	15352	do	Chert	1.04	.40	Dc.
	724C	15353	do	do	1.21	.60	Do.
	724D	15354	do	Phosphatic sandstone.	11.13	1.30	Do.
	724E	15355	do	Shaly sandstone.	6.45	.33	Do.
	724F	15356	do	Phosphatic sandstone.	15.20	.50	Do.
	724G	15357	do	Shaly sandstone.	2.20	.60	Do.
	724H	15358	do	Phosphatic sandstone.	8.58	.25	Do.
	724I	15359	do	do	9.33	.33	Do.
	FZ-724J= JBC-2.	15360	do	Phosphatic "fish-bone" sandstone.	16.16	.25	Do.

See footnote at end of table.

TABLE 1.—*Analytical and sample data for phosphate rock in Colombia*—Continued

Locality	Sample	IMN No.	Age and unit	Lithology	P_2O_5 (percent)	Thickness (meters)	Reference
19 (pl. 1, figs. 4, 7).	Bürgl and Botero G.	-------	Campanian, upper chert.	Chert, phosphate, limestone.	24 samples, 0.18–7.03.	N.D.	Bürgl and Botero G. (1962).
	do		Santonian, lower chert.	do	16 samples, 0.06–14.64.	N.D.	Do.
	do		Coniacian	N.D	9 samples, 0.04–1.20.	N.D.	Do.
	do		Turonian, La Frontera.	Limestone	5 samples, 0.07–0.28.	N.D.	Do.
19a (fig. 7)	do		Maestrichtian		8 samples, 0.08–2.35.	N.D.	Do.
20 (pl. 1, fig. 4) =14–17 (fig. 8).	JBC-14		La Luna, Galembo member.	Black chert		N.D.	Collected by Cathcart and Zambrano O. in 1966.
	15	15716	do	Gray phosphatic limestone.	2.84	0.3	Do.
	16	15717	do	Calcitic phosphorite.	17.65	.3	Do.
	17	15718	do	Weathered clayey sand.	0.39	N.D.	Do.
21 (pl. 1) =12, 13 (fig. 8).	12		do	Limestone, black shale, chert.	Many samples, <5.0–14.98.	0.08–1.30.	Section by Mojica G., (p. 46).
	13	15712	Umir Formation.	Black shale		N.D.	Collected by Cathcart in 1966.
18 [1]	18	-------	La Luna(?)	do			Collected by Cathcart and Zambrano O. in 1966.
19 [1]	19	15756	Turonian, La Frontera.	do	0.25	N.D.	Do.
20 [1]	20	15757	Villeta	do		N.D.	Do.
21 [1]	21	15758	Albian(?), Villeta.	do	0.19	N.D.	Do.
22 [1]	22	15759	Berremian(?), Villeta.	do		N.D.	Do.
23 [1]	23	15760	Villeta	do	0.16	N.D.	Do.
24 [1]	24	15761	do	do	0.22	N.D.	Do.
29 [1]	29	15767	do	do	0.10	N.D.	Do.
30 [1]	30	15768	do	do	0.05	N.D.	Do.
22 (pl. 1, fig. 4) =31, 32 (fig. 8).	31A	15769	La Luna	Phosphatic sand.	4.24	.30	Do.
	31B	15770	do	Phosphatic limestone.	1.62	.35	Do.
	31C	15771	do	Phosphatic sand.	3.86	1.00±	Do.
	31D	15772	do	Weathered phosphatic sand.	4.51	.50±	Do.
	32	15773	do	Phosphatic limestone.	0.58	N.D.	Do.
23 (pls. 1, 2, fig. 4).	FZ-601-1	15260	Guadalupe	Chert, phosphate sand.	3.19	.25	Zambrano O. (unpub. data); samples collected in 1965.
	2	15261	do	do	1.43	.20	Do.
	3	15262	do	do	6.99	.25	Do.
	4	15263	do	do	5.84	.15	Do.
	5	15264	do	do	2.21	.35	Do.
	6	15265	do	do	3.94	.45	Do.
	7	15266	do	do	7.91	.70	Do.
	8	15267	do	do	6.53	.20	Do.

See footnote at end of table.

TABLE 1.—*Analytical and sample data for phosphate rock in Colombia*—Continued

Locality	Sample	IMN No.	Age and unit	Lithology	P_2O_5 (percent)	Thickness (meters)	Reference
24 (pls. 1, 2, fig. 4).	LC-32	15634	do	do	26.0	N.D.	D. H. McLaughlin (unpub. data).
25 (pls. 1, 2, fig. 4).	JBC-10A	15835	do	Phosphate sand, shale.	10.70	0.3	Collected by Cathcart and Zambrano O. in 1966.
	10B		do	do		.2	Do.
	10C		do	do		.2	Do.
	11		Villeta(?)	Sandy black shale.		N.D.	Do.
26 (pls. 1, 2, fig. 4).	PM-U65		Chipaque(?)	Limestone, phosphorite.	15.3	N.D.	Mojica G. (unpub. data).
27 (pls. 1, 2, fig. 4).)	150	15362	Upper Guadalupe.	Siltstone, phosphate sand.	6.8	2.00	Do.
28 (pls. 1, 2)	JBC-34	15776	Guadalupe	Phosphatic sandstone, chert.	7.25	.3	Collected by Cathcart and Zambrano O. in 1966.
	35	15777	do	Siliceous shale, phosphate sand.	14.20	.5	Do.
	36	15778	do	Sandstone, minor phosphate.	1.56	.3	Do.
28A (pl. 2)	37	15779	do	Phosphorite, sandy.	19.62	.4	Do.
	38	15780	do	Weathered phosphate sand.	1.60	.2	Do.
	39	15781	do	Gray silty shale	1.06	N.D.	Do.
	40	15782	Villeta	Black shale	0.50	N.D.	Do.
29 (pls. 1, 2)	41A	15783	Guadalupe	Phosphate sand	17.94	.35	Do.
	41B	15784	do	do	22.55	.25	Do.
	42A	15785	do	do	17.74	.20	Do.
	42B	15786	do	do	16.20	.20	Do.
	42C	15787	do	do	22.10	1.00 (42C–42D)	Do.
	42D	15788	do	Sand, minor phosphate.	5.66		
30 (pls. 1, 2)	43	15789	do	Chert, phosphate sand.	21.05	.25	Do.
31 (pls. 1, 2)	45A	15791	do	Phosphatic sandstone.	6.60	.3±	Do.
	45B	15792	do	Weathered phosphate sand.	0.76	.3±	Do.
	45C	15793	do	Chert, phosphate sand.	7.28	.3±	Do.
32 (pl. 1)	44	15790	Villeta	Black shale	0.16	N.D.	Do.
33 (pl. 1)	HB-3375		Santonian, Guadalupe.	Chert, phosphate sand.	23 samples, 0–20.93.	N.D.	Bürgl and Botero G. (1962).
34 (pls. 1, 3)	JBC-114	10821	La Luna, Galembo member.	Chert, phosphate limestone.	6.72	.1+	Collected by Cathcart in 1966.
35 (pls. 1, 3)	115	10822	do	Silty, phosphatic limestone.	15.38	.10+	Collected by Cathcart and Zambrano O. in 1966.
	116	10823	do	Phosphatic shale (bone bed).	15.00	.20	Do.
36 (pls. 1, 3)	56	10394	La Luna, Pujamana member.	Shale, black	0.55	N.D.	Do.
	57	10395	do	Phosphatic, limy sandstone.	2.24	.50	Do.
	58	10396	do	do	0.54	.25	Do.
	59	10397	do	do	0.54	.50	Do.

See footnote at end of table.

TABLE 1.—*Analytical and sample data for phosphate rock in Colombia*—Continued

Locality	Sample	IMN No.	Age and unit	Lithology	P_2O_5 (percent)	Thickness (meters)	Reference
	60	10398	La Luna, Galembo member.	Limestone, some phosphate.	0.47	0.50±	Collected by Cathcart and Zambrano O. in 1966.
	61	10399	do	Phosphatic shale.	0.98	.75	Do.
	62	10400	do	Limestone, phosphatic.	1.02	.30±	Do.
	63	10401	do	Phosphatic shale (bone bed).	2.56	.30±	Do.
	64	10402	do	do	19.35	.45	Do.
	65	10403	do	Phosphatic shale (composite).	17.42	N.D.	Do.
	66	10404	do	Phosphatic shale (bone bed).	5.10	.20	Do.
37 (pls. 1, 3)	52	10390	do	Calcareous shale, minor phosphate.	0.31	N.D.	Do.
	53	10391	do	Shaly limestone	0.77	N.D.	Do.
	54	10392	do	Calcareous shale, phosphate.	0.46	N.D.	Do.
	55	10393	do	Shaly limestone	0.23	N.D.	Do.
	67	10405	do	Phosphate shale (bone bed).	12.16	1.80±	Do.
	68	10406	do	Weathered phosphate sand.	21.82	.30±	Do.
38 (pl. 1)	113	10820	do	Phosphatic shale (bone bed).	14.21	.31	Do.
39 (pls. 1, 3)	107	10814	do	do	14.10	.30±	Do.
	108	10815	do	Phosphatic limestone.	12.32	.20	Do.
	109	10816	do	Arkosic sandstone.	19.78	.08	Do.
	110	10817	do	Phosphatic limestone.	4.37	N.D.	Do.
	111	10818	do	Black limestone	0.84	.20±	Do.
40 (pls. 1, 3)	105	10812	do	Phosphatic sandstone (float).	8.61	N.D.	Do.
	106	10813	do	Phosphatic shale (bone bed).	15.33	.40	Do.
	112	10819	do	Phosphatic shale.	3.45	.20±	Do.
41 (pls. 1, 3)	69	10776	do	do	0.70	.30±	Do.
	70	10777	do	Phosphatic shale (bone bed).	13.52	.30±	Do.
	71	10778	do	Black limestone	0.23	N.D.	Do.
42 (pls. 1, 3)	97	10804	Cogollo	Black shale	0.35	N.D.	Do.
	98	10805	La Luna, Galembo member.	Phosphatic limestone (float).		N.D.	Do.
	99	10806	do	Phosphate shale.	5.98	.20	Do.
	100	10807	do	Phosphate shale (bone bed); not in place.	13.10	N.D.	Do.
	101	10808	do	do	17.84	N.D.	Do.
43 (pls. 1, 3)	102	10809	do	Phosphorite sand.	25.03	1.0±	Do.
44 (pls. 1, 3)	104	10811	do	Phosphatic shale (float).	10.77	N.D.	Do.
45 (pls. 1, 3)	103	10810	do	do	0.35	N.D.	Do.

See footnote at end of table.

TABLE 1.—*Analytical and sample data for phosphate rock in Colombia*—Continued

Locality	Sample	IMN No.	Age and unit	Lithology	P_2O_5 (percent)	Thickness (meters)	Reference
46 (pls. 1, 3)	73	10780	La Luna, Galembo member	Phosphatic limy shale ("bone bed").	4.98	0.20	Collected by Cathcart and Zambrano O. in 1966.
47 (pls. 1, 3)	72	10779	do	Calcareous phosphorite.	14.98	1.0±	Do.
48 (pls. 1, 3)	94	10801	do	Phosphatic shale.	20.00	.10	Do.
	95	10802	do	Calcareous phosphatic shale.	6.75	N.D.	Do.
	96	10803	do	Phosphatic shale ("bone bed").	18.15	.20±	Do.
49 (pls. 1, 3)	80	10787	do	Sandy shale, some phosphate.	1.20	.10	Do.
	81	10788	Cogollo	Phosphatic limestone.	0.31	.20±	Do.
	82	10789	do	Black shale	0.23	N.D.	Do.
	83	10790	La Luna, Galembo member.	Phosphatic limestone.	4.44	.15	Do.
	84	10791	do	Phosphorite sand.	31.83	2.00	Do.
	85	10792	do	Phosphatic limestone.	16.53	.16	Do.
	86	10793	do	Phosphorite sand.	17.76	1.50±	Do.
	87	10794	do	Weathered siliceous shale.		.50±	Do.
	88	10795	do	Phosphorite sand.	26.22	1.50±	Do.
	89	10796	do	Glauconitic, phosphate sand.	6.68	.50±	Do.
	90	10797	do	Glauconitic limestone.	5.79	N.D.	Do.
	91	10798	do	Phosphorite sand (float).	30.05	N.D.	Do.
	92	10799	do	Phosphatic shale (bone bed)—float.	12.28	N.D.	Do.
	93	10800	do	Phosphatic sand and shale.	1.00	.30±	Do.
50 (pls. 1, 3)	74	10781	do	Phosphatic sandy shale.	3.05	.20±	Do.
	75	10782	do	Black chert	0.07	N.D.	Do.
51 (pls. 1, 3)	76	10783	do	Weathered shale.	1.54	N.D.	Do.
	77	10784	do	Phosphorite sand, calcareous.	3.32	.30±	Do.
	78	10785	Colón shale	do	9.15	.50±	Do.
	79	10786	do	Calcareous shale, phosphatic.	1.62	.30±	Do.
52 (pl. 1)	118	15814	La Luna	Phosphatic limestone.		.10	Do.
53 (pl. 1)	119	15815	Miocene	Sandy limestone, trace, phosphate.	0.54	N.D.	Do.
54 (pl. 1)	120	15816	Recent	Surficial limonite pebbles.		N.D.	Do.
55 (pls. 1, 2)	PM-4A	15812	Guadalupe	Phosphate sand	21.24	1.40	Mojica G. (unpub. data).
	4B	15813	do	do	18.10	2.20	Do.
	55F	15817	do	do	30.74	.60	Do.
	55E	15818	do	do	15.30	.60	Do.
	55C(A)	15819	do	do	15.15	.60	Do.
	55C(B)	15820	do	do	15.32	1.00	Do.
	55G	15821	do	do	28.73	1.50	Do.
	55B	15822	do	do	27.61	.50	Do.

See footnote at end of table.

TABLE 1.—*Analytical and sample data for phosphate rock in Colombia*—Continued

Locality	Sample	IMN No.	Age and unit	Lithology	P_2O_5 (percent)	Thickness (meters)	Reference
56 (pls. 1, 3)	JBC-46	10384	Rosa Blanca Limestone.	Limestone	0.31	N.D.	Collected by Cathcart and and Zambrano O. in 1966.
	47	10385	La Paja Shale.	Black shale	0.19	N.D.	Do.
	48	10386	La Luna, Galembo member.	Phosphatic shale (bone bed).	20.70	0.80	Do.
	49	10387	do	Phosphatic shale coarse phosphate.	6.95	.20	Do.
	50	10388	do	Phosphatic shale (bone bed).	7.15	.50±	Do.
	51	10389	do	Phosphatic limestone.	1.81	1.50+	Do.

[1] Grab sample of shale. Locality number is for figure 8.

TABLE 2.—*Analytical and sample data for phosphate rock in drill-hole cores in Quebrada Santibanez*

[Analysts: Bernado Fajardo Pinzón, Alvaro Mondragón, Alberto Diaz, Rosalia Medina, Inés Coronado, and Doris Cabal de Chava, of the Laboratorio Quimico Nacional, Ministerio de Minas y Petroleos. IMN=Inventario Minero Nacional. See fig. 8 for location of drill holes. Depth below surface is range in depth below drill-hole collar. Cores sampled bv Cathcart and Zambrano O. in 1966]

IMN No.	Age and unit	Lithology	P_2O_5 (percent)	Depth below surface (feet)
Drill hole 1				
15719	Cimarrona, Umir.	Black shale	0.08	30–73
15720	do	Conglomerate	.12	73–82
15721	do	Black shale	.76	82–129
15722	do	Conglomerate	.47	89–89.67
15723	do	Black shale	1.86	129–312
Drill hole 2				
15724	Cimarrona, Umir.	Black shale	0.88	20–151
15725	do	do	.28	151–313.5
Drill hole 3				
15726	La Luna(?)	Black calcareous shale	0.18	20–141
15727	La Luna	do	.47	141–259
15728	do	do	.19	259–281.5

TABLE 2.—*Analytical and sample data for phosphate rock in drill-hole cores in Quebrada Santibanez*—Continued

IMN No.	Age and unit	Lithology	P_2O_5 (percent)	Depth below surface (feet)
Drill hole 4				
15729	La Luna	Black, calcareous shale; alternating beds are more and less phosphatic.	0. 34	24–43. 33
15730	do	do	2. 89	43. 33–48. 33
15731	do	do	. 25	48. 33–74
15732	do	do	1. 26	74–79. 5
15733	do	do	. 63	79. 5–81. 5
15734	do	do	1. 82	81. 5–82
15735	do	do	. 60	82–92. 5
15736	do	do	. 88	92. 5–95. 5
15737	do	do	. 59	95. 5–167
Drill hole 5				
15738	La Luna	Black shale	0. 46	3–87
15739	do	Chert	. 23	87–88. 5
15740	do	Black shale	. 49	88. 5–116
15741	do	Siliceous shale	. 56	116–130
15742	do	Black shale	. 80	130–134
15743	do	Phosphatic shale	2. 72	134–136. 5
17544	do	Black shale	2. 03	136. 5–147
15745	do	Chert	1. 15	147–283
Drill hole 6				
15746	La Luna	Black siliceous shales and chert; alternating beds are more and less phosphatic.	1. 03	2–104
15747	do	do	3. 27	104–106
15748	do	do	2. 32	106–116
15749	do	do	1. 02	116–145
15750	do	do	3. 60	145–150
15751	do	do	4. 11	150–156
15752	do	do	5. 02	156–157. 25
15753	do	do	. 62	157. 25–161. 5
15754	do	do	2. 85	161. 5 –164. 25
15755	do	do	1. 09	164. 25–200

HUILA AND OTHER LOCALITIES IN SOUTHERN COLOMBIA

Localities in Huila and in the southern part of the country were not visited by Cathcart but were sampled by Zambrano O. in 1966. Rocks of Late Cretaceous age, sampled near the towns of Timaná and Elias in Huila, contained 9–22.4 percent P_2O_5. Near the town of La Plata, a phosphate bed containing an average of 20 percent P_2O_5 was sampled, and minor shows of phosphate were found near Mocoa and San Francisco in Putumayo (pl. 1).

SECTION AT ELIAS

Phosphate beds at Elias are associated with chert, minor shale, and medium-grained sandstone. The phosphate grains are oval or cylindrical and are cemented by microcrystalline silica. Accessory minerals include quartz, iron oxides, minor glauconite, and angular fragments of questionable volcanic material. Fossils from the section, identified by Hans Bürgl, indicate a Coniacian-Campanian age. The beds are nearly vertical and strike northeast.

Partial section at Elias

[Loc. 3, pl. 1. Measured by Francisco Zambrano O. in 1966]

	Thickness (meters)
Upper Cretaceous (Coniacian-Campanian):	
1. Sandstone, medium grained	5.00
2. Shale, siliceous (porcellanite)	.60
3. Phosphorite; contains 8.88 percent P_2O_5	.10
4. Shale, yellow	.08
5. Chert	1.10
6. Phosphorite; similar to bed 3	.15
7. Chert	6.60
8. Sandstone	.52
9. Chert	1.75
10. Sandstone; contains a few phosphate grains	.60
11. Chert	.15
12. Phosphorite; contains 22.36 percent P_2O_5	.38
13. Shale; contains a few phosphate grains	.15
14. Chert	.55
15. Phosphorite; contains 19.24 percent P_2O_5	.48
16. Shale	.02
17. Phosphorite; contains 18.77 percent P_2O_5	.80
18. Chert; contains thin beds of shale	1.50
19. Sandstone; contains a few phosphate grains	.14
20. Chert	.72
21. Phosphorite; not sampled	.13
22. Chert	.35
23. Phosphorite; not sampled	.28
24. Shale	.29
25. Phosphorite; contains fish remains	.29
26. Chert	3.00
Base of section.	

Two samples (beds 15 and 17) that contained 19.2 and 18.8 percent P_2O_5 were crushed, and the heavy and light fractions were separated with bromoform. The heavy separates contained 32.5 and 34.9 percent P_2O_5, the light fractions 9.1 and 8.3 percent P_2O_5 (Zambrano O., 1966), but no data are available on the amounts of the light and heavy fractions or of the losses in grinding. Indications, however, are that grinding followed by flotation would give a good concentrate, and the process of flotation might be economic, provided enough tonnage of this grade of phosphate rock is present. The total thickness of beds 15 through 17 is 1.30 m, and bed 16, separating the phosphorite beds, is only 0.02 m thick. Because the beds are nearly vertical, mining would have to be by underground methods.

A phosphorite bed, 0.30 m thick, containing 21.2 percent P_2O_5, and associated with chert, was sampled about 500 m north of the abovementioned section. The bed dips about 30° W. It was not visible farther north because of vegetation cover along the Magdalena River.

SECTION NEAR TIMANÁ (QUEBRADA EL TOBO)

About 5 km southwest of Timaná dark-colored phosphate beds are associated with chert and limestone. The beds strike northeast and dip steeply east.

Partial section at Timaná (Quebrada El Tobo)

[Loc. 4, pl. 1. Measured by Francisco Zambrano O. in 1966]

	Thickness (meters)
Upper Cretaceous:	
1. Limestone, fossilferous; contains 0.50 percent P_2O_5	20.00
2. Phosphorite, sandy; contains 16.18 percent P_2O_5	.60
3. Shale, black	.12
4. Phosphorite; contains 12.56 percent P_2O_5	.13
5. Chert, black; contains thin black shale interbeds and a bed of phosphorite 0.07 m thick	5.78
6. Phosphorite; contains 19.31 percent P_2O_5	.65
7. Shale, black	.17
8. Phosphorite; contains 17.88 percent P_2O_5	.12
9. Chert, black	2.20
10. Shale, gray to black	6.00
11. Limestone, black	1.30
Base of section.	

The sections at Elias and Timaná are similar, except for the limestone beds in the Timaná area. Beds 6–8 in the Timaná section are similar to beds 15–17 in the Elias section in thickness, P_2O_5 content, and in the separation of the two phosphate beds by a thin shale bed.

A phosphate bed 0.20 m thick, containing 15.8 percent P_2O_5, was found associated with chert in rocks of Late Cretaceous age along the Petal–La Plata road (loc. 5, pl. 1).

Along the La Plata-Puracé road, a bed of sandy phosphorite dipping about 30° W. is associated with chert, shale, and limestone. The phosphorite bed is 1.05 m thick and contains 24.33 percent P_2O_5 (loc. 6, pl. 1).

On the road between San Antonio and Vegalarga, 37 km from Neiva in Quebrada Fortalecillas, three beds of phosphorite alternate with shale (loc. 7, pl. 1); a partial section of the Upper Cretaceous rocks (Zambrano O., 1966) is as follows:

	Thickness (meters)
Phosphorite; contains 19.35 percent P_2O_5	0.20
Shale; contains limestone intercalations	9.20
Phosphorite; contains 7.41 percent P_2O_5	.20
Shale, black, calcareous (or shaly marl); contains a phosphorite bed 0.20 m thick that has 12.57 percent P_2O_5	50.00
Shale, black	100.00
Base of section.	

A bed 1.2 m thick, containing 4.1 percent P_2O_5, was found on the road from Neiva to San Antonio at the Rio La Ciebas. The bed is Albian (Early Cretaceous) in age.

SECTION NEAR SAN FRANCISCO, PUTUMAYO

Beds of phosphate rock associated with chert, shale, sandstone, and limestone of probable Late Cretaceous age crop out on the road between Pasto and Mocoa, about 6 km south of San Francisco. The beds strike nearly north-south and dip steeply west (loc. 2, pl. 1). The section measured by Zambrano O. (1966) is as follows:

	Thickness (meters)
Shale and chert interbedded	48.50
Phosphorite; contains 8.70 percent P_2O_5	.40
Chert, black	3.34
Shale, black	.58
Phosphorite; contains 7.00 percent P_2O_5	.33
Sandstone	.32
Shale, gray	5.00
Sandstone	3.50
Shale, red	30.00+
Base of section.	

An outcrop of chert, about 5 m thick, on the road between Mocoa and Urcusique (loc. 1, fig. 5) has a bed of phosphorite 0.20 m thick in its lower part. The phosphorite bed contains 16.8 percent P_2O_5.

SUMMARY

The sandy phosphorite beds in the area are associated with chert, shale, sandstone, and minor limestone and are in the sandy facies close to the platform. The age of the best phosphorite is Late Cretaceous (Coniacian to Campanian). Generally, the beds are steeply dipping and are structurally complex. Mining would have to be done by underground methods. The sandy phosphorite beds can be upgraded by flotation, as indicated by the bromoform separation, to a high-grade phosphate product, but large tonnages must be proved before capital investment in a grinding and flotation plant can be justified. The material can be ground and used for direct application as fertilizer, and it is possible that grinding followed by screening to remove the harder quartz grains would upgrade the product. Some grinding and flotation tests should be done on representative samples to indicate recovery of phosphate. The tonnage is completely unknown, and detailed geologic maps should be made of the areas near Elias and Timaná to determine the extent of the phosphorite. This work should be supplemented by further sampling, perhaps including drilling, to determine the extent, grade, and tonnage of the phosphorite in these areas. The Elias and Timaná areas should be given low priority for further work, but they should not be overlooked.

GIRARDOT-ORTEGA AREA

The phosphate occurrences in the Girardot-Ortega area were not seen by Cathcart, but the area was sampled by Bürgl (Bürgl and Botero G., 1962) and by Zambrano O., whose maps and sections have been used in the compilation of this section of the report. The initial sampling by Bürgl and Botero G. (1962) established that the only phosphate beds of economic interest are in rocks of Late Cretaceous (Santonian and Campanian) age—in general, the upper part of the Guadalupe Group, although a phosphatic limestone of Turonian age in the lower Guadalupe contains 12.5 percent P_2O_5 in a bed 3 m thick.

Bürgl and Botero G. (1962) sampled beds from Turonian through Campanian age on the road between Girardot and Nariño and the Late Cretaceous (Maestrichtian) on the road east of Girardot (loc. 19 and 19a, fig. 7 and table 1). The most phosphatic sample contains 14.6 percent P_2O_5 and is of Santonian age. Rock descriptions are not given, but the bed is possibly in the chert-limestone-shale facies.

Near Ortega, samples were taken of beds ranging in age from Turonian through Maestrichtian. Phosphate beds from the lower chert (Santonian) contain as much as 23.5 percent P_2O_5, and those from the upper chert (Campanian) contain as much as 17.5 percent P_2O_5. The beds are in the chert-limestone-shale facies.

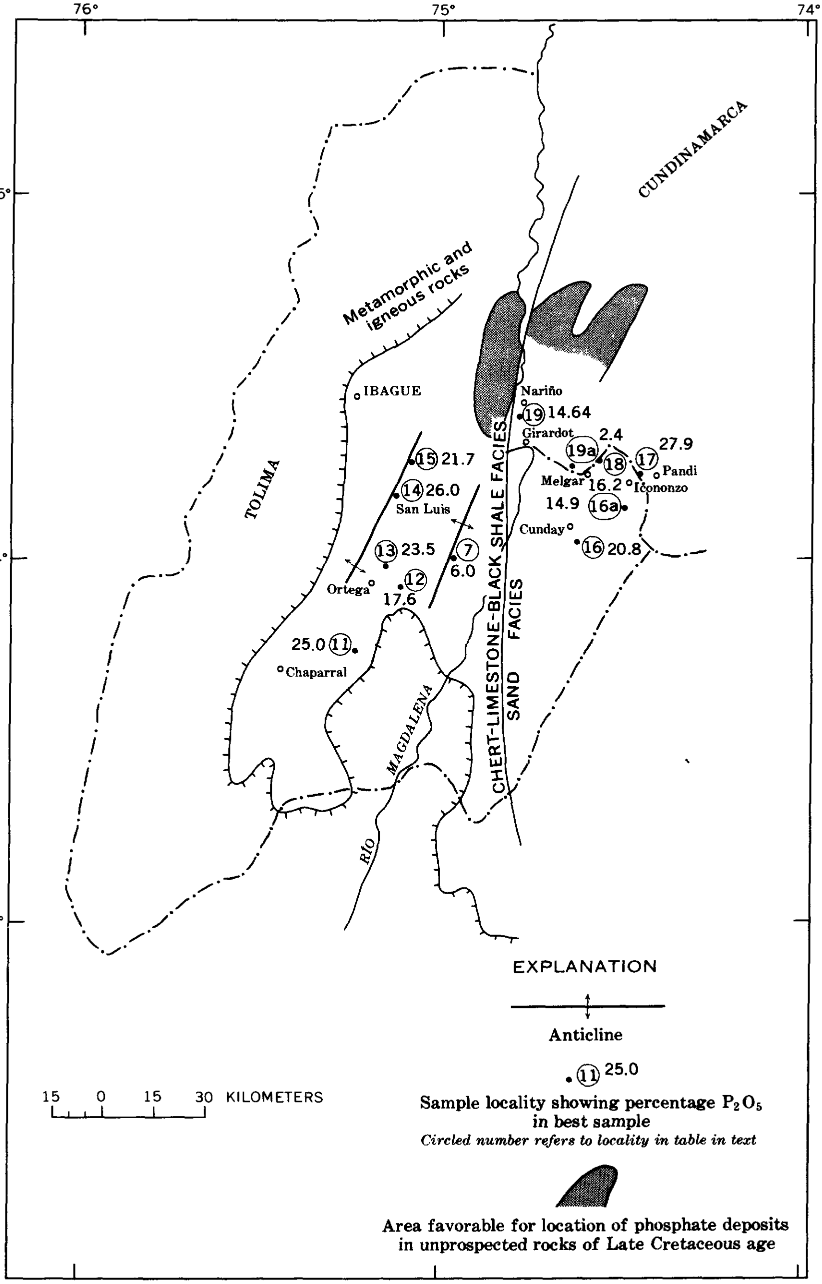

Figure 7.—Geologic sketch map of the Girardot-Ortega and Pandi-Cunday areas. See figure 1 for location of map area.

Zambrano O. sampled one limb of an anticlinal structure from Payande toward the southwest. This structure is west of the structure at Girardot-Ortega (fig. 7). Samples were taken of phosphate beds in the upper chert member of the Guadalupe Group close to the base of the Campanian (fig. 6). These samples contain a maximum of almost 28 percent P_2O_5 (table 1).

Partial sections of the upper chert member of the Guadalupe Group (Upper Cretaceous)

[Loc. 12–14, pl. 1, fig. 7. From Francisco Zambrano O., unpub. data, 1962]

Section at Quebranda La Bañadera

	Thickness (meters)
Chert	-----
Phosphate rock; contains 3.48 percent P_2O_5	0.45
Phosphate rock; contains 3.63 percent P_2O_5	.37
Phosphate rock; contains 23.64 percent P_2O_5	.60
Chert	-----
Base of exposed section.	

Section between Quebradas Guayabo and Mogollón

Chert	-----
Phosphate rock; contains 14.17 percent P_2O_5	.60
Chert	2.00
Phosphate rock; contains 27.96 percent P_2O_5	.40
Base of exposed section.	

Section between Quebradas Alcaparrosa and Guayabo

Chert	-----
Phosphate rock; contains 3.82 percent P_2O_5	.40
Phosphate rock; contains 26.96 percent P_2O_5	.40
Chert	-----
Base of exposed section.	

Section between Quebrada La Cieba and Los Caracolies

Chert	----
Phosphate rock; contains 7.11 percent P_2O_5	.85
Chert	2.50
Phosphate rock; contains 7.11 percent P_2O_5	.60
Chert	1.50
Phosphate rock; contains 7.49 percent P_2O_5	1.00
Chert	----
Base of exposed section.	

Partial sections of the upper chert member of the Guadalupe Group (Upper Cretaceous)—Continued

Section in Quebrada Mata de Guadua

	Thickness (meters)
Chert	----
Phosphate rock; contains 6.02 percent P_2O_5	0.40
Chert	.60
Phosphate rock; contains 24.87 percent P_2O_5	.50
Chert	----
Base of exposed section.	

Section between Quebradas La Bañadera and Mata de Guadua

Chert	----
Phosphate rock; contains 13.83 percent P_2O_5	.50
Chert	.70
Phosphate rock; contains 5.48 percent P_2O_5	.40
Phosphate rock; contains 1.58 percent P_2O_5	.30
Chert	.30
Phosphate rock; contains 8.34 percent P_2O_5	.50
Chert	.40
Phosphate rock; contains 26.80 percent P_2O_5	.40
Chert	----
Based of exposed section.	

Section at Cerro Chaquirco on the El Guavio-Ortega road

Chert	1.60
Phosphate rock; contains 6.37 percent P_2O_5	----
Chert	.25
Phosphate rock; contains 9.62 percent P_2O_5	.30
Chert	.20
Phosphate rock; contains 22.39 percent P_2O_5	.60
Chert	6.00
Phosphate rock; contains 17.74 percent P_2O_5	.25
Chert	----
Base of exposed section.	

Section at Quebrada La Irene

Chert	4.00
Phosphate rock; contains 22.44 percent P_2O_5	.50
Chert	8.00
Phosphate rock; contains 19.64 percent P_2O_5	.40
Chert	1.00
Phosphate rock; contains 12.32 percent P_2O_5	.45
Base of exposed section.	

Partial section of the Guadalupe Group (Upper Cretaceous) at Los Cerros

[Loc. 15, pl. 1, fig. 7. From Dario Botero, unpub. data, 1966]

	Thickness (meters)
Chert, gray; contains 0.4 percent P_2O_5	0.20
Shale, gray; contains 0.4 percent P_2O_5	.80
Shale, yellow; contains 0.4 percent P_2O_5	.10
Phosphate rock; contains 7.82 percent P_2O_5	.38
Phosphate rock; contains 4.67 percent P_2O_5	.10
Phosphate rock; contains 8.42 percent P_2O_5	.17
Phosphate rock; contains 10.74 percent P_2O_5	.24
Phosphate rock; contains 3.16 percent P_2O_5	.19
Shale, siliceous; contains 0.60 percent P_2O_5	.19
Phosphate rock; contains 4.90 percent P_2O_5	.27
Chert, gray; contains 0.60 percent P_2O_5	.12
Phosphate rock; contains 12.25 percent P_2O_5	.47
Calcareous chert, some phosphate at base; contains 0.60 percent P_2O_5	.20
Phosphate rock; contains 21.72 percent P_2O_5	.69
Chert; contains 0.60 percent P_2O_5	.30
Chert, some phosphate; contains 6.21 percent P_2O_5	.30
Chert, calcareous; contains 0.60 percent P_2O_5	.33
Chert; contains 0.60 percent P_2O_5	.83
Chert and shale; contains 1.80 percent P_2O_5	1.00+
Base of measured section.	

The partial sections of the phosphorite beds in the upper chert member of the Guadalupe Group indicate the continuity of the beds in the part of the area sampled. The approximate distance between the northernmost and southernmost samples is about 15 km, and the bed that has the highest P_2O_5 content in each section ranges in thickness from 0.40 to 0.69 m and averages about 0.50 m. The P_2O_5 content ranges from 21 to 27 percent and averages about 24 percent. The interbedded cherts, analyzed only in the section sampled by Botero, contain less than 1 percent P_2O_5.

The material is sufficiently high grade to be used for direct acidulation without beneficiation, provided the tonnage is great enough; it also would be a valuable material for direct application to the acid soils of the immediate area. Mining, however, would have to be by underground methods and would be costly, particularly because mining width would have to be greater than the half-meter thickness of the phosphate bed, and the chert would have to be separated from the phosphate rock.

Further work should be done in the Girardot-Ortega area to determine the extent, tonnage, and grade of the phosphate beds. Also, a promising but as yet unprospected area west of Girardot (shown in fig. 7) should be examined. The beds in this area, according to the geologic map of Girardot (Colombia Servicio Geologico Nacional, 1956), are Late Cretaceous in age and dip gently east. The low dips in the area indicate the possibility of an open-pit mining operation, provided the phosphate beds are under light overburden.

PANDI-CUNDAY AREA

Phosphate at the Pandi-Cunday area (loc. 16–18, pl. 1) was first located by Zambrano O. at a roadcut near Pandi (loc. 17, pl. 1) and in a roadcut on the Boqueron-Melgar road (loc. 18, pl. 1). The section was examined by the writers in September 1966, and further work in the area was recommended. Zambrano O. then located the outcrop on the Cunday-Villarica road (loc. 16, pl. 1).

The phosphate beds are apatite and quartz sand, loosely cemented by a mixture of clay and apatite. X-ray diffractometer patterns of two samples from Pandi (JBC–1A and JBC–1C, loc. 17, pl. 1 and table 1) show that the only mineral phases are apatite and quartz. Sample JBC–1A is relatively unweathered and contains more apatite than quartz and a trace amount of a clay mineral. Sample JBC–1C is bleached and whitened by weathering and contains much more quartz than apatite and also contains a trace amount of the aluminum phosphate mineral, wavellite.

The beds at Pandi (loc. 17, fig. 7) dip less than 20° N. and strike nearly east-west. The phosphorite beds are thin (avg about 0.5

Partial section of the upper Guadalupe Group near Pandi

[Loc. 17, fig. 7. Measured by Francisco Zambrano O.]

	Thickness (meters)
Recent:	
Slide material, very poorly sorted, contains various-sized blocks of sandstone in a fine sandy matrix	4.00
Cretaceous, Guadalupe Group:	
Phosphorite, gray; not sampled	.30
Covered interval	.50
Phosphorite, gray, sandy; contains 27.96 percent P_2O_5	.27
Shale, gray, laminated; contains a few phosphate grains	.15
Chert, gray, stratified; abundant foraminifers	.18
Phosphorite, gray; abundant foraminifers; contains 27.54 percent P_2O_5	.18
Chert, dark-gray to black, stratified	1.20
Sandstone, fine-grained; some phosphate grains in the upper part of the bed (gradational contact with bed below)	1.50
Phosphorite, sandy; irregular contact, unconformable with bed below; contains rounded shale fragments	.10
Shale, dark-gray, compact	6.00
Limestone, bedded; slightly phosphatic	3.00
Limestone, phosphatic; not sampled	.40
Sandstone, fine-grained, dark; few grains of phosphate	.80
Sandstone, fine-grained; very few grains of phosphate	2.50
Base of measured section.	

m) and contain as much as 27.9 percent P_2O_5 (table 1). Slightly to the south, near Icononzo, the phosphate bed is again exposed in the road, but here the strike is N. 45° W., and the dip is about 26° N. At this locality, the phosphate bed is nearly a meter thick and contains 21.4 percent P_2O_5. The phosphorite sand bed at Icononzo is the same horizon as the bed at Pandi, but at Icononzo, the bed (sample JBC–1C) is weathered and phosphate has been leached from it.

A section of the upper Guadalupe Group on the road between Cunday and Icononzo (loc. 16, pl. 1) was measured by Zambrano O. in 1966. The section, shown below, is in the sand facies, and the sandy phosphate beds contain as much as 14.9 percent P_2O_5 and are interbedded with chert. The material could be upgraded by removal of quartz by flotation methods, but the thick sandstone bed at the base of the section (the only bed that is thick enough to be mined) contains only 12.2 percent P_2O_5. Beneficiation tests have not been made on samples from this area, but the grade is just about at the lower limit of material that can be beneficiated economically. This bed is thick enough to warrant further work to determine its extent and phosphate content.

Section, part of the upper Guadalupe Group (Upper Cretaceous), on the road between Cunday and Icononzo

[Loc. 16a, fig. 7. Measured by Francisco Zambrano O., 1966]

	Thickness (meters)
Sandstone, coarse-grained; crossbedded in the top; contains some conglomerate layers	200.00+
Siltstone, light-colored	2.00
Sandstone, fine-grained	15.00
Sandstone, calcareous, fine-grained	5.00
Shale, black	.50
Shale, black; abundant foraminifers; contains 1.11 percent P_2O_5 (sample FZ–813A)	1.20
Shale, black, similar to above; not analyzed	1.20
Shale, black; contains a few phosphate grains; contains 1.00 percent P_2O_5 (sample FZ–813B)	3.70
Shale, black, phosphatic; contains 8.37 percent P_2O_5 (sample FZ–813C)	.10
Shale, black; abundant foraminifers	2.20
Shale, phosphatic; not sampled; similar to sample FZ–813C	.15
Chert, black	1.00
Phosphorite, sandy; contains 14.9 percent P_2O_5 (sample FZ–813D)	.20
Chert, light-colored	.35
Sandstone, light-colored; contains minor phosphate grains	1.00
Shale, black	3.00
Sandstone, light-colored; contains phosphate grains that are more abundant at the top of the unit; the unit contains 12.2 percent P_2O_5 (sample FZ–813E)	5.00

Base of section. Fault.

At the section in the road from Boqueron to Melgar (loc. 18, pl. 1), the beds lie on the west flank of an anticline, dip 45° W., and strike N. 14° E. The phosphorite sand beds are only about 0.5 m thick and contain as much as 16 percent P_2O_5. The beds are weathered but seem to correlate with those at Pandi; the lower grade may be due to removal of P_2O_5 by surficial weathering. A section, measured by Zambrano O., is given on p. A36.

The phosphorite on the road from Cunday to Villarica (section, p. A37) is nearly identical in lithology with the bed at Pandi. At the outcrop the beds are overturned, apparently owing to faulting, but a short distance to the north the section is in a normal position, forming a ridge capped by sandstone of the upper part of the Guadalupe Group. The ridge strikes northward and dips steeply west. Drilling normal to the bedding will be necessary to determine the thickness, grade, and extent of the phosphate bed.

The phosphorite sand beds are in the Guadalupe Group, are associated with the chert beds, and are in the sand facies closer to the shelf than to the deeper parts of the miogeosyncline. There is some evidence of reworking of phosphate nodules at the outcrop at Pandi, which may possibly account for the high grade of the material.

More work in the Pandi-Cunday area is needed, starting with detailed geologic mapping. In the Pandi area, the low dips and thin overburden indicate the possibility of open-pit mining, but drilling will be necessary to determine tonnage and grade of material that is amenable to open-pit mining. The area is partly covered by a landslide that obscures the bedrock geology.

The phosphorite sand is amenable to beneficiation. Grinding followed by flotation to remove quartz would probably make a high-grade concentrate, but large tonnages of material are necessary to amortize the large capital investment required. Only the area around Pandi-Icononzo is amenable to open-pit mining; the other outcrops are steeply dipping and would have to be mined by underground methods.

The grade of the phosphate rocks at Pandi and Cunday is high enough (about 28 percent P_2O_5) to allow its direct acidulation to make superphosphate, provided that the material, where it is fresh and unweathered, does not contain calcite. The beds at the surface are weathered to some extent, and at least one of the beds (sample JBC–1C, table 1) shows evidence of removal of phosphate by weathering. The mineral composition of the phosphorite bed in the subsurface can be determined only by analyzing drilling samples.

Section of part of the upper Guadalupe Group, on the road from Boqueron to Melgar

[JBC loc. 2; loc. 18, fig. 7. Measured by Francisco Zambrano O.]

	Thickness (meters)
Sandstone, white, fine-grained	40. +
Sandstone, fine-grained, bedded	5.00
Shale, gray, compact	8.00
Chert, shaly, gray; abundant foraminifers; minor phosphate	.45
Shale, gray; abundant foraminifers; contains some phosphate and 1.56 percent P_2O_5	1.00
Chert, shaly; many foraminifers; contains some phosphate and 1.04 percent P_2O_5	.40
Chert, shaly, phosphatic; contains 1.21 percent P_2O_5	.60
Sandstone, shaly, phosphatic; contains 11.13 percent P_2O_5	1.30
Shale, dark-gray, compact; minor phosphate	.25
Sandstone, shaly, gray, phosphatic; rich in foraminifers, contains 6.45 percent P_2O_5	.33
Shale, yellow, ferruginous	.12
Sandstone, shaly, gray; some foraminifers; contains phosphate and 15.20 percent P_2O_5	.50
Sandstone, shaly, gray; contains minor phosphate and 2.20 percent P_2O_5	.60
Sandstone, gray, fine-grained	.95
Chert, gray, shaly	4.60
Sandstone, gray, phosphatic; foraminifers and fishbones; contains 8.58 percent P_2O_5	.25
Chert, shaly, gray	.95
Sandstone, white, fine-grained; sparse phosphate	7.50
Sandstone, gray, very fine grained	11.30
Sandstone, fine-grained; contains some phosphate and 9.33 percent P_2O_5	.33
Shale, gray	.14
Chert, gray	.80
Sandstone, fine-grained; minor phosphate at top	9.00
Chert, shaly, gray; rich in foraminifers	7.80
Sandstone, phosphatic; foraminifers and fishbones; contains 16.16 percent P_2O_5	.25
Chert, shaly	1.05
Sandstone, fine-grained; abundant phosphate	.30
Chert	.80

Base of measured section.

Section of part of the Guadalupe Group, on the road from Cunday to Villarica

[Loc. 16, fig. 7. Measured by Francisco Zambrano O.]

	Thickness (meters)
Shale, gray, phosphatic; contains foraminifers; contains 5.34 percent P_2O_5 (sample FZ-809A)	2.00
Siltstone; contains foraminifers; contains 0.22 percent P_2O_5 (sample FZ-809B)	1.20
Shale, sandy, about the same as sample FZ-809A; not sampled	.80
Siltstone, compact; not sampled	.75
Shale, gray, phosphatic; contains intercalations of sand; contains 6.21 percent P_2O_5 (sample FZ-809C)	1.20
Sandstone; contains minor phosphate; not sampled	.60
Chert, clear	3.30
Phosphorite, sandy, gray; contains 20.84 percent P_2O_5 (sample FZ-809D)	1.00
Chert; not sampled	15.00
Base of measured section.	

If the tonnage proves insufficient to warrant the expense of an acid plant or a flotation plant, the material might still be of considerable benefit if ground for use as a soil additive, provided the mining costs are not too high. There is no question that this material would be of benefit, particularly when added to acid soils.

LA SIERRA-ALTO DEL TRIGO-CAPARRAPÍ AREA

Phosphatic limestone beds at Alto del Trigo (fig. 8) were first sampled by Bürgl (in Bürgl and Botero G., 1962), who noted that the beds are of Santonian age. The highest grade sample reported by Bürgl was of a phosphatic limestone that contains 16.53 percent P_2O_5. In a subsequent report Bürgel (cited in Thompson, 1966) noted that the phosphatic limestone at Alto del Trigo is in the Galembo member of the La Luna Formation. In the following detailed section, measured by Pedro E. Mojica G. in 1965, the P_2O_5 content of the individual beds ranges from less than 5 percent to 12.74 percent. The phosphatic limestone unit containing 12.74 percent P_2O_5 consists of two beds 8 and 10 centimeters in thickness that contain 14.98 and 10.95 percent P_2O_5.

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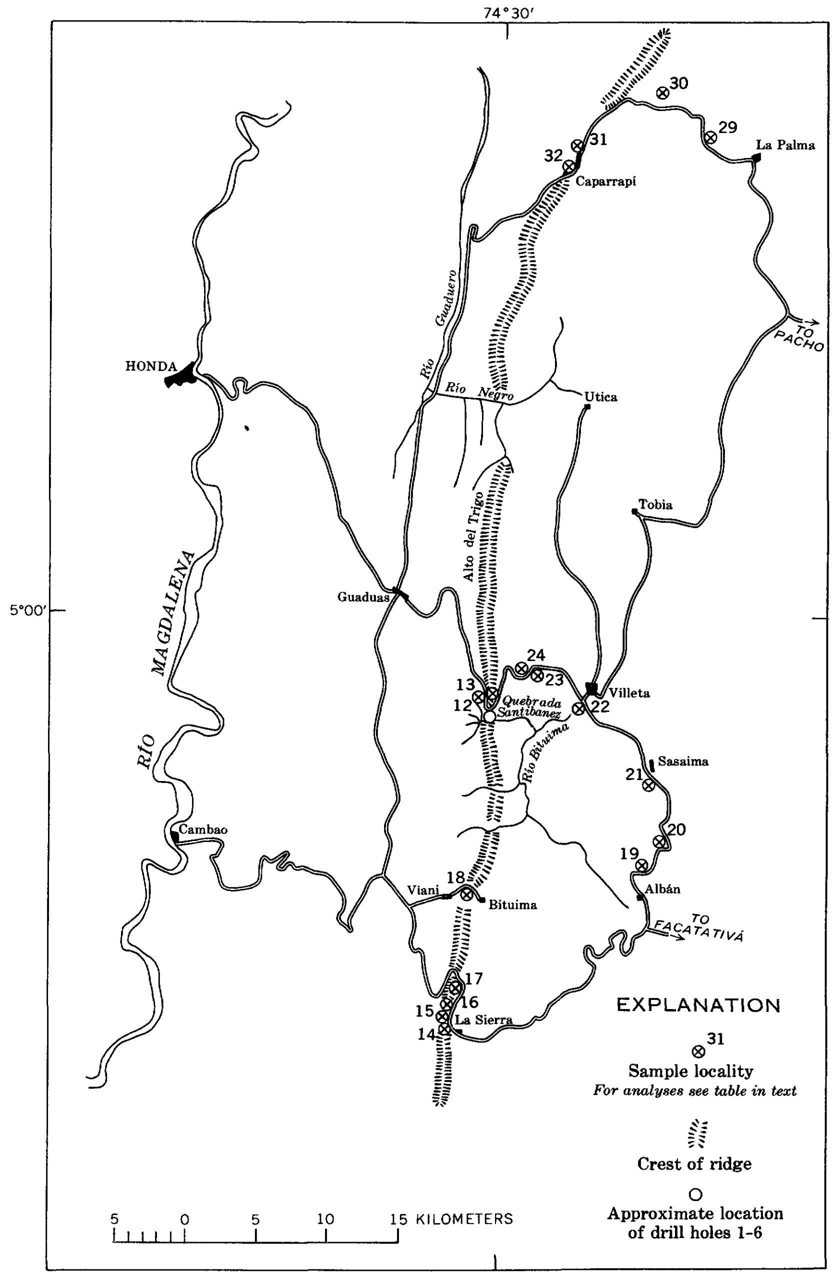

FIGURE 8.—Sketch map of the La Sierra–Alto del Trigo–Caparrapí area showing sample localities. See figure 1 for location of map area. For drill-hole descriptions see table 2 and pages A40–A41.

Section of La Luna Formation (Upper Cretaceous) along the road at Alto del Trigo

[Loc. 12, fig. 8. Measured by Pedro E. Mojica G. in 1965; modified slightly by James B. Cathcart and Francisco Zambrano O.]

	Thickness (meters)
Chert, black, fractured; contains a few phosphate grains and less than 5 percent P_2O_5	4.60
Limestone, sandy, black; few shale intercalations; contains less than 5 percent P_2O_5	1.35
Chert, black; contains phosphate grains and 12.25 percent P_2O_5	.40
Sandstone, friable; contains less than 5 percent P_2O_5	.30
Chert, calcareous, black; contains beds of sandy limestone and a few beds of ferruginous shale; contains few phosphate grains and less than 5 percent P_2O_5	10.25
Limestone, gray; contains few phosphate grains and 5.17 percent P_2O_5	.11
Limestone, shaly; contains a few phosphate grains and less than 5 percent P_2O_5	.50
Limestone, gray; contains a few phosphate grains and 5.56 percent P_2O_5	.14
Limestone, black; contains phosphate grains and 6.59 percent P_2O_5	.26
Limestone, black; interbedded with sandstone beds; contains few phosphate grains and less than 5 percent P_2O_5	1.70
Limestone, black; interbedded with black chert and a few thin shale beds; contains less than 5 percent P_2O_5	10.50
Chert, black, calcarous; contains veins of calcite and calcite nodules; contains less than 5 percent P_2O_5	5.60
Chert, calcareous, clear; contains grains of phosphate and 6.41 percent P_2O_5	.75
Limestone, black, shaly	.80
Limestone, black, hard; contains foraminifers	7.30
Shale, calcareous, thin-bedded, fractured	17.00
Limestone, black; contains sand beds and a few phosphate grains	2.10
Limestone, sandy; contains foraminifers, a few phosphate grains, and 5.83 percent P_2O_5	1.30
Limestone, sandy, gray; alternates with shale; few phosphate grains	11.44
Shale, black, laminated; few phosphate grains and less than 5 percent P_2O_5	2.95
Limestone, black; contains foraminifers and a few calcareous nodules in the lower part; contains less than 5 percent P_2O_5	7.95
Shale, calcareous, black; contains calcareous nodules	.87
Limestone, black; contains grains of fine phosphate and less than 5 percent P_2O_5	.52
Shale, black; contains foraminifers and less than 5 percent P_2O_5	1.70
Limestone, black; contains a few phosphate grains and less than 5 percent P_2O_5	4.25
Limestone, sandy, compact; contains phosphate grains and 8.65 percent P_2O_5	.30
Limestone, black; interbedded with calcareous shale; contains few grains of phosphate and less than 5 percent P_2O_5	12.00
Shale, gray; contains calcareous beds, a few phosphate grains, and less than 5 percent P_2O_5	4.20

Section of La Luna Formation (Upper Cretaceous) along the road at Alto del Trigo—Continued

	Thickness (meters)
Sandstone, fine-grained; contains a few phosphate grains and less than 5 percent P_2O_5	0.92
Limestone, sandy, gray; contains fine grains of phosphate and 5.37 percent P_2O_5	.30
Limestone, black; interbedded with shale; contains few phosphate grains and less than 5 percent P_2O_5	6.10
Limestone, black; contains phosphate grains and 7.07 percent P_2O_5	.25
Limestone, black, compact; contains fine quartz, a few phosphate grains, and less than 5 percent P_2O_5	8.30
Limestone, sandy, gray; contains phosphate grains and 7.46 percent P_2O_5	.46
Limestone, black; contains phosphate grains and 2.40 percent P_2O_5	.67
Limestone, black; contains abundant phosphate grains and 12.74 percent P_2O_5	.18
Shale, calcareous, thin-bedded; contains sparse phosphate grains and 1.95 percent P_2O_5	.17
Limestone, black, compact; contains some phosphate and 8.77 percent P_2O_5	.35
Limestone, black; contains coarse phosphate grains and 1.28 percent P_2O_5	.09
Limestone, black, massive; contains phosphate grains and 8.00 percent P_2O_5	.11
Limestone, black, massive; contains thin interbeds of pyritiferous shale; contains few phosphate grains and less than 5 percent P_2O_5	16.00
Limestone, black, massive; contains pyrite, foraminifers, a few phosphote grains, and 6.10 percent P_2O_5	.65
Limestone, black, laminated; calcite veins; contains less than 5 percent P_2O_5	.50
Limestone, gray; contains some phosphate grains and 7.36 percent P_2O_5	.32
Limestone, well-stratified; contains pyrite, sparse phosphate grains, and less than 5 percent P_2O_5	1.25
Limestone, black; contains grains of quartz and pyrite in the top	18.00

Base of measured section.

Logs of drill holes in Quebrada Santibanez, Alto del Trigo

[Depth given in feet below drill-hole collar. Location of drill holes given in fig. 8. See also loc. 21, pl. 1. Analytical and sample data given in table 2]

Drill hole 1

[Simplified from Marino Arce (unpub. data, 1966)]

	Depth (feet)
Soil zone; not sampled	0–30
Black shale, Cimarrona Formation(?)	30–73
Conglomerate (top of Umir Formation), fine-grained, quartz; veined with calcite; finer grained, sandy at base; lower contact is gradational	73–82
Black calcareous shale, very slightly phosphatic; Umir Formation; a fine, sandy quartz conglomerate between 89 and 89.67 ft contains a few phosphate grains	82–312

Logs of drill holes in Quebrada Santibanez, Alto del Trigo—Continued

Drill hole 2

	Depth (feet)
Soil zone; not sampled	0–20
Black calcareous shale, contains foraminifers that are very abundant at depth; Umir Formation	20–313.5

Drill hole 3

Poor recovery; core consists of calcareous black shale; contains foraminifers and is slightly phosphatic	0–20
Black calcareous phosphatic shale; La Luna Formation (?)	20–259
Black siliceous shale (chert), calcareous and phosphatic; La Luna Formation, Galembo member	259–281.5

Drill hole 4

Recovered only 2 in. of gray and brown clayey sandstone, leached and altered	0–13
Recovered 3 ft; top 1 in. is like the above; bottom 2 ft 11 in. is black calcareous shale	13–27
Black calcareous shale, phosphatic, pyritic; contains foraminifers	27–43.33
Black calcareous shale; contains a few grains of phosphate	43.33–48.33
Black calcareous shale; contains a few calcite veinlets	48.33–74
Black calcareous shale; contains a few phosphate grains	74–79.5
Black calcareous shale	79.5–81.5
Black calcareous shale; contains phosphate grains	81.5–82
Black calcareous shale	82–92.5
Black calcareous shale; contains some phosphate grains	92.5–95.5
Black calcareous shale; contains pyrite seams and grains, calcite veinlets, and abundant foraminifers	95.5–162

Drill hole 5

Soil zone; not sampled	0–3
Black calcareous shale; contains foraminifers and calcite veinlets and is weakly phosphatic; chert at 87–88.5 ft; hard saliceous shale (chert) at 116–130 ft; calcareous shale, containing a few phosphate grains, at 134–136.5 ft	3–147
Black siliceous shale or chert; contains calcite veinlets and pyrite and is texturally the same as the calcareous shale above	147–283

Drill hole 6

No sample	0–2
Black siliceous shale or chert; contains foraminifers, calcite veinlets, and pyrite and is slightly phosphatic	2–104
Black calcareous shale; contains a few phosphate grains	104–106
Black siliceous shale; contains phosphate grains	106-116
Black chert or siliceous shale; no visible phosphate	116–145
Same as at 106–116 ft	145–150
Same as at 116–145 ft	150–156
Same as at 106–116 ft	156–157.25
Same as at 116–145 ft	157.25–161.5
Same as at 106–116 ft	161.5–164.25
Black chert or siliceous shale; contains a few thin seams (1–2 in. thick) that contain phosphate grains	164.25–200

Six core holes were drilled in the Quebrada Santibanez, just south of Alto del Trigo, in late 1965 and early 1966. The drill holes penetrated the section from the Umir Formation into La Luna Formation. Brief summary logs of the drill holes were made by the writers and Marino Arce (p. A40–A41). Data on samples are shown in table 2. The drill holes are in the bottom of the quebrada, several hundred meters below the section at Alto del Trigo. The beds at this locality dip about 60° west and strike northeast. The beds are on the west flank of the Villeta anticlinorum.

The ridge crest on which the Alto del Trigo section crops out extends north and south for many kilometers (fig. 8). The section to the south at La Sierra (loc. 14–17, fig. 8) was first examined by Marino Arce and Francisco Zambrano O. and was later sampled by the writers. The section was not measured in detail, and only spot samples were taken. At La Sierra and to the north, the beds strike northeast and dip 40° W. Lithologically, the section is almost identical with the section at Alto del Trigo. The beds are black chert or siliceous shale, black calcareous shale, limestone, and phosphatic limestone. The most phosphatic bed is about 30 cm thick and consists of rounded black pellets of phosphate, ranging in size from a few millimeters to about a centimeter in diameter, in a matrix of calcite and quartz. The bed contains 17.7 percent P_2O_5. A black limestone bed, stratigraphically below the phosphatic limestone, contains 2.8 percent P_2O_5.

The ridge crest between La Sierra and Alto del Trigo is crossed only by the road between Viani and Bituima. A phosphatic limestone bed a few inches thick was noted in this section, but it consists mostly of black shale (loc. 18, fig. 8). La Luna Formation is very thin at this locality, and the section, being very close to the Bituima fault, is structurally disturbed. The section is not typical of La Luna Formation and may be entirely in the Villeta Group. The phosphatic limestone beds at La Sierra and Alto del Trigo are not present in the road between Viani and Bituima.

North of Alto del Trigo, the ridge crest was crossed on the road from La Palma to Caparrapí. D. H. McLaughlin, Jr. (written commun., 1965), first suggested that the section along the road from La Palma to Caparrapí be examined for phosphate. The section at Caparrapí (loc. 30, 31, fig. 8) is structurally complex; a partial section, examined by the writers and by D. H. McLaughlin, Jr., and Marino Arce, is as follows:

Section of La Funa Formation(?) (Upper Cretaceous) at Capparrapi

[Loc. 31, fig. 8; see also loc. 22, pl. 1, table 1]

	Thickness (meters)
Sandstone, phosphatic, brown, weathered (sample JBC–31D); contains 4.5 percent P_2O_5	0.3
Phosphorite, sandy, brown-gray (sample JBC–31C); phosphate pellets are rounded but irregular in shape, gray, brown, and black; contains 3.9 percent P_2O_5	1.0
Limestone, thin-bedded, black; not sampled	2.0
Limestone, black, phosphatic (sample JBC–31B); contains 1.6 percent P_2O_5	.6
Phosphorite, sandy (sample JBC–31A); very similar to sample JBC–31C; contains 4.2 percent P_2O_5	.3
Limestone, black; not sampled	.6+
Base of measured section.	

Sample JBC–32 (fig. 8; loc. 22, pl. 1, table 1) was taken along the road, just south of the town of Caparrapí. It consists of black phosphatic limestone and contains 0.6 percent P_2O_5. The phosphatic sandstones sampled at locality 31 do not crop out at locality 32.

No work has been done north of Caparrapí on the topographic extension of the ridge. Between Caparrapí and Alto del Trigo, the section has been examined along the railroad line; no phosphate beds were found, and the section is extremely complex structurally (D. H. McLaughlin, Jr., oral commun., 1966). The photogeologic map of Villeta (Colombia Servicio Geologico Nacional, 1961) shows that the Upper Cretaceous section has been eliminated by structural complications between Caparrapí and Alto del Trigo.

The phosphatic limestone bed at Alto del Trigo and La Sierra can be used only as ground rock for direct application to the soil. Very large tonnages of this type of material are present in the area, but the grade within a realistic mining width is low, probably less than 10 percent P_2O_5. Further work is necessary to indicate the grade and the tonnage of material available.

The phosphorite beds at Caparrapí contain less calcite and more quartz than the phosphorite beds at Alto del Trigo, but mining might be very difficult because of structural complications. No data on tonnage are available, and this section should be studied in detail, particularly toward the north, to determine the extent, tonnage, and grade of the phosphorite. The phosphorite sand beds probably could be upgraded by grinding and flotation, but costs would be high, and a flotation plant could only be installed if large tonnages of easily minable material are present. Even if the tonnage is not large enough to supply a flotation plant, the material may be valuable as rock for direct application to the soil, and some upgrading might be accomplished by differential grinding. Further detailed geologic mapping in the Caparrapí area and to the north is recommended, and, if the results warrant, some drilling may be necessary to determine tonnage and grade.

GUADALUPE GROUP, BOGOTÁ TO DUITAMA

Phosphate occurrences from Bogotá to Duitama (pl. 2) are in the Guadalupe Group and are associated with the upper and lower cherts of Santonian and Campanian ages (fig. 2). The phosphate beds are sandy and are associated with chert or siliceous shale or silt, sandstone, black shale, and minor amounts of calcareous material. The area is in the sand facies (fig. 5) and ranges from the edge of the platform (as in the area east of Bogotá) almost to the junction with the deeper water chert-limestone-shale facies (as in the area near Tunja).

The section east of Bogotá (samples JBC–3 to JBC–7, pl. 2) is close to the platform. The Guadalupe Group is thick and is composed of fine-grained sandstone, siliceous siltstone, and black and gray shales. Except for the shales, the clastic rocks are light colored—white, gray, and brown, and some are stained red with iron oxide. Phosphatic beds are generally less than 0.3 m thick and contain only minor amounts of phosphate grains. For example, at the locality of sample JBC–3 (pl. 2) the section is structurally very complex; the only bed that contains phosphate is about 0.2 m thick, is composed of medium- to fine-grained quartz sand, and contains a few grains of brown phosphate. There are no known phosphate beds of economic value in the area east of Bogotá.

The section north of Bogotá toward Duitama is in the sand facies, but is farther from the platform than the section east of Bogotá, and some of the samples of phosphate rock were taken close to the chert-limestone-black shale facies. In general, the phosphate beds become thicker and contain more phosphate in a northerly direction from Bogotá to about Tunja. For example, near Turmequé (loc. 29, 55, pl. 2) sandy phosphorite beds are as much as 3.5 m thick (see section measured by Pedro E. Mojica G., p. A46) and contain as much as 30 percent P_2O_5 (sample PM–55F, table 1).

The Guadalupe Group on the road from Zipaquirá to Pacho (loc. 23, pl. 2) was sampled by Bürgl and Botero (1962) and by the writers (table 1). The best phosphate bed in this area is about 20 cm thick and contains 25.1 percent P_2O_5 (Bürgl and Botero G., 1962, p. 28). A sample, probably taken from the high-grade bed sampled by Bürgl, consists of rounded phosphate pellets in a matrix of quartz silt, clay, and organic material. The bed is in a sequence of steeply dipping black shale, siltstone, and fine-grained sandstone. Some of the shaly beds are calcareous.

Samples taken at El Santuario (loc. 25 and sample JBC–10, fig. 8) are of phosphatic sandstone. The phosphatic sandstone beds are 0.3 to 0.6 m thick and are interbedded with siliceous shale and massive nonphosphatic sandstone. The area is structurally complex. About 3 km north of locality 25, along strike, another outcrop of the Guadalupe Group consists of sandstone, siliceous shale or chert, and black shale. This outcrop (sample JBC–11) contains no phosphatic sandstone beds, and only one thin bed of sandstone contains a few phosphate nodules.

A thin bed of phosphatic sandstone was sampled by Pedro E. Mojica G. near Ubaté (loc. 26, pl. 2). The bed contains 15.3 percent P_2O_5 and is associated with sandstone, chert, shale, and minor limestone.

Beds of phosphorite sand of the Guadalupe Group were sampled at several localities between Tunja and Machetá (loc. 28, 28A, 29, and 55, pl. 2). The best phosphorite beds contain about 30 percent P_2O_5 (table 1), and although they are in a folded and faulted area, the folds are open, and bedding dips are moderate. At all the localities, the phosphorite sandstone beds are associated with light-colored siliceous shale, siltstone, and fine-grained sandstone. At the section south of Tunja (loc. 29, pl. 2), the beds dip gently; are covered by thin overburden; and could possibly be mined, at least locally, by open-pit methods. A partial section at this locality was measured by the writers.

Partial section of Guadalupe Group (Upper Cretaceous) south of Tunja

[Loc. 29, pl. 2]

	Thickness (meters)
Sandstone, phosphatic (sample JBC–42A); contains 17.7 percent P_2O_5	0.2
Shale, siliceous; not analyzed	.5
Sandstone, phosphatic (sample JBC–42B); contains 16.2 percent P_2O_5	.2
Shale; contains some phosphate grains; not analyzed	.3
Sandstone, phosphatic, massive; phosphate grains are much more abundant in the top 0.4 m (sample JBC–42C, 22.10 percent P_2O_5) than in the bottom 0.6 m (sample JBC–42D, 5.7 percent P_2O_5)	1.0
Base of measured section.	

A similar section was sampled on the Chocontá-Machetá road (loc. 28, pl. 2), where steeply dipping siliceous shale is interbedded with phosphatic sandstone. The total thickness of the shale–phosphatic sandstone sequence is about 2 m, and a sample of one of the phosphate beds contains 14.2 percent P_2O_5. On the road between Machetá and Guateque (loc. 28A, pl. 2), another outcrop of the Guadalupe Group is in the same siliceous shale–phosphatic sandstone sequence. There the best phosphate bed is about 0.5 m thick and contains 19.6 percent P_2O_5.

Near the town of Turmequé, Pedro E. Mojica G. discovered and sampled phosphatic sandstones in the same sequence of light-colored siliceous shale, sandstone, and siltstone. His report on the occurrence follows.

THE PHOSPHATE OCCURRENCE AT TURMEQUÉ

By Pedro E. Mojica G.

A bed of sandy phosphorite, probably in the lower part of the Guadalupe Group, crops out at several places near the town of Turmequé in the Department of Boyacá. The principal bed is in a quarry on the road between Turmequé and Ventaquemada, about 4 km southeast of Ventaquemada at Cascajera (loc. 55, pl. 2; loc. 55A, fig. 9). The phosphorite layer is well exposed in the roadcut and may extend about 3 km north and 6 km south. The phosphorite bed is on the east flank of a northeast-trending syncline. The phosphorite is a weakly cemented sandstone, consisting of grains of apatite and minor quartz. The phosphate bed at this locality is 3.60 m thick, but contains three intercalations of shale that total 30 cm in thickness. A detailed section of this outcrop is given below. The beds at the phosphorite outcrop strike N. 10° E. and dip 55° NW. Southwest of the roadcut three small streams (1–3, fig. 9) cut across the strike of the syncline. Outcrops along the streams have not yet been checked to determine the extent of the phosphorite bed.

Section of Guadalupe Group (Upper Cretaceous) near Ventaquemada in Bayacá

[Loc. 55A, fig. 9. Measured by Pedro E. Mojica G.]

	Thickness (meters)
Sandstone, light-colored, massive; contains some phosphate	1.8
Siltstone, calcareous	.6
Claystone, green	6.6
Sandstone; contains some phosphate	.4
Claystone, green	4.5
Sandstone, phosphatic	.3
Siltstone, green	.18
Phosphorite, sandy	.15
Siltstone, dark-gray	.60
Phosphorite, calcareous	.09
Siltstone, dark-gray	.15
Phosphorite, sandy	.22
Siltstone, light-colored	.70
Phosphorite, sandy	.06
Siltstone, light-colored	.20
Phosphorite, sandy; contains three thin claystone intercalations. Top part (about 1.2 m thick) contains 21.24 percent P_2O_5; bottom part (about 2.4 m thick) contains 18.10 percent P_2O_5	3.60
Siltstone and sandstone, interbedded	15.00
Base of measured section.	

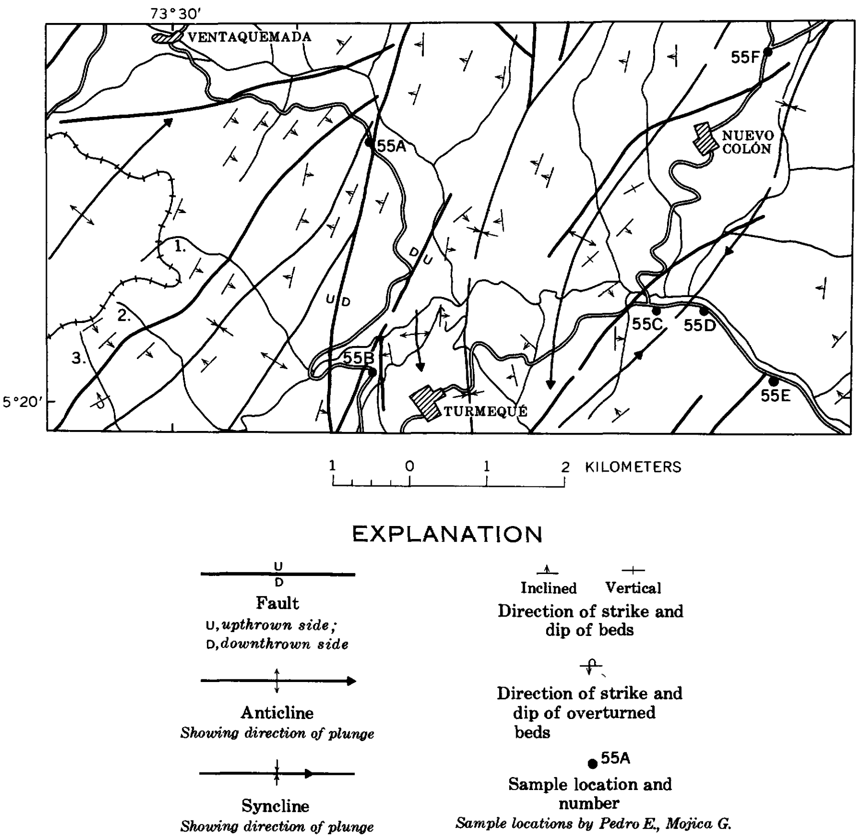

FIGURE 9.—Geologic map of the Turmequé area, showing location of samples. Modified from Geophoto, Inc., unpublished photogeologic map.

A second outcrop of the sandy phosphorite, about 1 m thick, is west of Turmequé on the road to Ventaquemada (loc. 55B, fig. 9). The phosphorite bed at this locality contains 27.6 percent P_2O_5, is overlain by massive white sandstone, and is underlain by claystone and laminated sandstone. Although the outcrop is between two faults (fig. 9), it indicates the continuation of the bed to the south, and at this locality, the phosphorite bed is on the east flank of a northeast-trending anticline.

The sandy phosphorite bed crops out at three localities on the road from Turmequé to Tibaná, south of Nuevo Colón (loc. 55C–55E, fig. 9). At locality 55C, beds of phosphorite, one 60 cm thick and the other 2 m thick, are interbedded with sandstone and siltstone. The beds contains 15.2 and 15.3 percent P_2O_5. At locality 55D a single bed of phosphorite, 60 cm thick, contains 15.3 percent P_2O_5. At locality 55E, the sandy phosphorite bed is also about 60 cm thick; contains 15.3 percent P_2O_5; and is interbedded with siltstone, claystone, and sandstone.

The phosphorite bed also crops out about 1.5 km north of Nuevo Colón on the road to Tunja. At this locality, the beds are folded and faulted, but there are two beds of phosphorite sand, 1.5 and 0.6 m thick, interbedded with claystone, siltstone, and sandstone. The beds contain 30.7 and 28.7 percent P_2O_5.

OTHER LOCALITIES IN BOYACÁ

The Guadalupe Group was sampled by the writers near Lake Tota (loc. 31, pl. 2). The beds are steeply dipping and structurally complex, and the phosphate sand beds are thin and low grade (7.3 percent P_2O_5, table 1).

North of Tunja (loc. 30, pl. 2) a sequence of steeply dipping light-colored siliceous shale, siltstone, and fine-grained sandstone of the Guadalupe Group contains a thin phosphate sand bed that has 21.1 percent P_2O_5, and east of Socha (loc. 33, pl. 1) Bürgl and Botero G. (1962) sampled the same sequence of siliceous shale, sandstone, and phosphate rock. At this locality, Bürgl (in Bürgl and Botero G., 1962) called the beds Santonian in age. The phosphate rock contains a maximum of 20.9 percent P_2O_5.

A traverse was made to the west of Tunja to examine the rocks of Early Cretaceous age. One sample of black shale of the Villeta Group taken near Vélez (loc. 32, pl. 1) contains only 0.2 percent P_2O_5. The traverse was ended near Vélez because of lack of time, but the section to the west should be investigated to test the possibility that rocks of La Luna Formation may be exposed in the hills west of Vélez.

LA LUNA FORMATION, SANTANDER AND NORTE DE SANTANDER

Phosphate localities in Santander and Norte de Santander in Colombia and Táchira in Venezuela were visited and sampled by the writers in October 1966, accompanied by Dwight E. Ward and Marino Arce, Gilberto Manjarres, and Raul Perea. The Galembo member of La Luna Formation was sampled throughout Santander and Norte de Santander and at two localities in Venezuela—the Lobatera mine (loc. 47, pl. 1; loc. 72, pl. 3) and on the road between San Antonio and Rubio (loc. 46, pl. 1; loc. 73, pl. 3). The base map showing the outcrop of the Galembo member was compiled by Ward (pl. 3). Many outcrop areas were sampled (pls. 1, 3, table 1), and one very good phosphorite sand that has the potential for being a large deposit was found near Sardinata (loc. 49, pl. 1; loc. 84–90, pl. 3). Areas near Orú (loc. 51, pl. 1; loc. 76–79, pl. 3), Salazar (loc. 43, pl. 1; loc. 102, pl. 3), Suratá (loc. 56, pl. 1; loc. 46–51, pl. 3), and San Vicente (loc. 36, pl. 1; loc. 56–66, pl. 3) also contain phosphorite beds that warrant further investigation. At all other areas where the Galembo member was sampled, the phosphorite beds are thin (usually less than 30 cm) and are in areas that are so structurally complex that mining would not be possible.

In a general way the phosphate beds are thicker, and more numerous and contain more phosphate pellets and less calcite in the northern and western parts of the area (in the deeper parts of the miogeosyncline) than in the southern and eastern parts, except that at Orú, north of Sardinata, the phosphorite beds are thin and contain more calcite.

The section at Orú is possibly a shallower water facies, probably the edge of the epicontinental sea facies of Bürgl (1961) that is typified by the Cretaceous section on the Guajira Peninsula. The phosphorite beds are associated with chert, limestone, and black shale.

The best phosphorite samples (table 1) contain 30 to 32 percent P_2O_5, and the grade, in percent P_2O_5, is higher in the phosphorite subfacies near Sardinata than in the chert-limestone-black shale facies and is lower in the epicontinental sea facies near Orú than in either of the other facies (table 1, pl. 3).

SARDINATA (loc. 49, pl. 1)

The phosphorite sand at Sardinata is along a cut in a road under construction from Sardinata east to a junction with the road from Cúcuta to Tibú. The first outcrop is about 1 km east of Quebrada La Chocona (samples JBC–84, JBC–85, pl. 3). The phosphorite bed is about 2 m thick, dips about 35° northwest and strikes northeast. The phosphate is at the surface, and the section exposed in the cut is about as follows:

Section of Galembo member of La Luna Formation (Cretaceous)

	Thickness (meters)
Phosphorite, sandy, black, brown, and gray; rounded but irregular-shaped phosphate pellets and quartz grains loosely cemented by a mixture of apatite and clay; sample JBC–84 contains 31.8 percent P_2O_5	2
Shale, siliceous, black, thin-bedded, contains some phosphate; not sampled	2
Limestone, black, sandy. phosphatic, sample JBC–85 contains 16.5 percent P_2O_5	.2
Base of exposure.	

Samples JBC–84 and JBC–85 were analyzed by X-ray diffractometer. Sample JBC–84 contains apatite as the major mineral phase, some quartz, and a trace of clay. The clay mineral is present in such small amounts that it could not be identified. Sample JBC–85 contains, in order of decreasing abundance, calcite, apatite, and quartz as the only identifiable mineral phases.

The phosphorite sand at the outcrop (sample JBC–84) is weathered, but the phosphatic limestone (sample JBC–85), only about 2 m below the sandstone, appears to be fresh.

The phosphorite is cut off to the east, perhaps by a fault, and the section that underlies the phosphate to the west (samples JBC–82 and JBC–83, pl. 3) is repeated along the road to the east. The section underlying the phosphate consists of black calcareous pyritic shale and thin beds of black limestone that contain a few phosphate grains.

About 5 km to the east, the phosphorite bed is again exposed along the roadcut (sample JBC–86, pl. 3), but here the beds dip gently north and strike east-northeast. The bed is exposed for at least 1 km along the road (to the location of sample JBC–88, pl. 3) and is covered by only a very thin veneer of overburden. The overburden consists of weathered silty material that contains chert fragments (sample JBC–87, pl. 3).

Samples JBC–86 and JBC–87 were analyzed by the X-ray diffractometer. Sample JBC–86 consists of quartz and apatite as the only major mineral phases, but there is a trace of a clay mineral that could not be positively identified. Quartz is more abundant in sample JBC–86 than in sample JBC–84.

Sample JBC–87, from the weathered material overlying the phosphorite, consists almost entirely of quartz, but it contains a trace of clay mineral, also in amounts too small to identify.

To the east, samples JBC–89 and JBC–90 (pl. 3) are of glauconitic sand and limestone and may represent the top of the Galembo member or the base of the overlying formation, both of which contain glauconite (Trump and Salvador, 1964; Morales and Colombian Petroleum Industry, 1958).

Samples JBC–80 and JBC–81 (pl. 3), still farther east, are from a brown sandy shale that contains some phosphate and a black sandy phosphatic limestone tentatively correlated with the Galembo member. The beds are steeply dipping and indicate either folding or faulting between this outcrop and the flat-lying outcrop to the west.

The flat-lying phosphorite sand at localities 86 and 88 (pl. 3) contains nothing but quartz sand and apatite. The bed, 1 to 2 m thick, is exposed along the road for at least a kilometer and extends to the south under light overburden for perhaps a kilometer. To the north, the bed is buried under thicker overburden that consists of both younger Cretaceous and Tertiary rocks, but the bed may extend for a long distance. Detailed geologic work followed by drilling will be necessary to determine the tonnage and grade.

The outcrop at locations 86 and 88 (pl. 3) is weathered and may differ in character from the bed in the subsurface. Calcite may have been leached from the weathered outcrop.

The phosphorite at Sardinata contains near-surface reserves of about 1.5 million tons, but the potential tonnage of the buried deposit to the north may be very large and could measure scores of millions of tons. Much of the material is buried too deeply to be mined by surface methods, and details of the structure are not known. Drilling or test pitting in areas where the bed is at shallow depths should be done to determine structure, tonnage, grade, and mineralogic character of the material in the subsurface.

The phosphorite exposed at the surface, on the basis of the X-ray examination of two samples, contains only apatite and quartz, and the grade, in percent P_2O_5, is high enough to permit acidulation to make superphosphate or triple superphosphate. Although the character of the unweathered rock in the subsurface is not known, the phosphorite there probably contains only small amounts of calcite.

South of Sardinata (samples JBC–91 to JBC–93, pl. 3) the outcrop of the Galembo member is slumped and structurally complex. The beds are steeply dipping and consist of thin-bedded siliceous shale or chert, limestone, black shale, and phosphorite. A sample of phosphorite sand (sample JBC–91), very similar in lithology to the samples from Sardinata, was not found in place, so its thickness and position in the section are not known.

ORÚ (loc. 51, pl. 1)

The Galembo member at Orú consists of calcareous phosphatic shale and sandstone, somewhat weathered, interbedded with cherts and calcareous shale. The beds dip gently east and are overlain at the road camp at Orú by thin-bedded black silty shale that contains no phosphate. The phosphate beds are exposed in the road, both east and west of Orú. The beds consist of phosphate pellets and fish remains in calcareous shale or sandstone. The phosphate beds are thin, but the section was not measured because of slumping and cover.

The gentle dips and the shallow overburden at this locality indicate the possibility of open-pit mining, but more work is necessary to determine the thickness, extent, grade, and tonnage of the phosphorite. The section at Orú is in the chert-limestone-black shale facies of the shelf or epicontinental sea rather than in the phosphorite as at Sardinata. The beds are more calcareous and contain fewer phosphate grains than the beds at Sardinata.

Only four samples were taken near Orú, two from the Galembo member of La Luna Formation and two from the Colón Shale. The beds range in thickness from 0.3 to 0.5 m and contain from 1.5 to 9.2 percent P_2O_5 (table 1).

SALAZAR (loc. 43, pl. 1)

The Galembo member crops out on the road, just northeast of Salazar (loc. 102, pl. 3). The best phosphorite at this locality is a bed of phosphate sand, very similar in lithology to the beds at Sardinata. The bed is about 1 m thick, dips about 30° southeast, and strikes northeast. The phosphorite is underlain by bedded siliceous shales and cherts. Nothing is known of the extent or tonnage of phosphorite material here; detailed geologic mapping should therefore be done in the area and between Salazar and Sardinata to determine the stratigraphic relations, tonnage, and grade of the phosphorite.

CALIFORNIA-SURATÁ (loc. 56, pl. 1)

A section of the Galembo member of La Luna Formation west of the town of California (loc. 48, 49, pl. 3) was sampled in some detail by Dwight E. Ward and Raul Perea. The most phosphatic bed is a calcareous phosphorite that contains abundant fish remains and phosphate pellets. The bed is about 0.8 m thick and contains about 20 percent P_2O_5. The sequence of beds is repeated south of the town of Suratá on the opposite limb of a syncline (loc. 50, pl. 3).

South of Suratá, the calcareous phosphorite is overlain by a sandy phosphatic limestone about 20 m thick (sample 51, pl. 3). The bed is more sandy and less phosphatic toward the top where it is in contact with the Umir Formation (Dwight E. Ward, written commun., 1967). The beds at this locality are vertical. The phosphatic limestone bed is thick enough to be mined but would be usable only as ground rock for direct application to the soil. The calcite content is too high for economic beneficiation.

SAN VICENTE (loc. 36, pl. 1)

North of the town of San Vicente, the outcrop of the Galembo member contains several beds of phosphatic sandstone and shale (samples 60–66, pl. 3). The beds range in thickness from 0.5 to 0.8 m and contain abundant phosphate pellets and fish remains. Faulting and folding, together with poor outcrops, make it impossible to be sure exactly how many phosphate beds are present, but there may be as many as six.

Several kilometers to the north (samples 67, 68, pl. 3), the section is again exposed along the road. At this locality there are three beds of phosphorite that also contain abundant fish remains and phosphate pellets in calcareous shale or sandstone. Two of the phosphate beds are separated by a shale bed only a few centimeters thick; these two beds total 1.8 m in thickness, including the shale parting.

This area, although structurally complex, probably contains a very large tonnage of phosphate, and is, therefore, worthy of further investigation. Many other areas in Santander and Norte de Santander were checked for phosphate (pl. 3), but none of them contain phosphate beds thick enough to be minable.

TÁCHIRA, VENEZUELA

A brief examination of the Lobatera phosphate mine (loc. 47, pl. 1), and of La Luna Formation in adjacent areas, in Táchira in westernmost Venezuela (loc. 46, pl. 1) showed that this area is in the chert-limestone-black shale facies. The phosphatic limestone bed at the Lobatera mine is 1 m thick, dips almost vertically, and contains an average of about 22 percent P_2O_5. The mined material is being finely ground and will be used for direct application to the soil.

On the road from San Cristobal to Rubio (loc. 46, pl. 1), an exposure of La Luna Formation consists of thin-bedded chert, limestone, black shale, and at least one bed of phosphatic shale. The phosphate bed contains abundant phosphate pellets and fishbones. The fishbone bed is found throughout Santander and Norte de Santander in the upper part of the Galembo member.

Several other localities in Táchira have been reported to contain "radioactive phosphatic limestone" (in Trump and Salvador, 1964, map). These areas are probably in La Luna Formation (pl. 3).

Thus, the chert-limestone-black shale facies extends into Venezuela in rocks of Late Cretaceous age. It is possible that the phosphorite subfacies near Sardinata also extends into Venezuela but may be buried by Tertiary rocks in the Maracaibo basin.

GUAJIRA PENINSULA

A reconnaissance trip was made to the Guajira Peninsula to check La Luna Formation of Late Cretaceous age and the marine Tertiary section. The trip was made during the rainy season, and the condition of the roads was such that only one outcrop of La Luna Formation was examined and one sample of fossiliferous limestone of possible Miocene age was taken. The part of the Tertiary section that was traversed by road with a scintillometer showed no abnormal radioactivity.

La Luna Formation consists of thin-bedded dark limestone, calcareous shale, and minor black chert. One sample of float contains some phosphate grains (loc. 52, pl. 1). The section of La Luna is thin, dips almost vertically, and strikes nearly east-west. The phosphate bed must be very thin, and only a thin section consisting of black chert and limestone is above background in radioactivity. La Luna Formation on the Guajira Peninsula does not contain enough phosphate to warrant further work, though a section of La Luna on the northern part of the peninsula was not seen.

The marine Tertiary section was sampled at only one place (loc. 53, pl. 1). At this locality, the geologic map (Colombia Servicio Geologico Nacional, 1963) indicates the age of the rocks as Miocene. The outcrop consists of thin-bedded brown sandy fossiliferous limestone and brown calcareous shale. The limestone contained a few grains of phosphate, but only 0.54 percent P_2O_5 (table 1).

Although the results of the brief traverse of the Guajira Peninsula were entirely negative, the area should not be completely abandoned in regard to phosphate possibilities. Only one outcrop of the marine Miocene was sampled, and others were traversed with the scintillometer, but several of the areas of outcrop shown on the geologic map (Colombia Servico Geologico National, 1963) could not be reached because of the condition of the roads. It is recommended that the other outcrops of the Miocene be briefly examined to determine if they are phosphatic. The beach sands on the northern coast of the Guajira Peninsula should be examined to determine if they contain any phosphate. This is an area of upwelling in the modern ocean (McKelvey, 1963), and some phosphate may be present here, as in Baja California and off the coast of Peru near the Sechura phosphorite deposits.

GUANO

The excreta of birds and bats, guano, is a valuable fertilizer material in many parts of the world; the material is at the surface or in shallow caves, and its content of nitrogen and phosphorus is water soluble and is immediately available to plants.

Cave deposits of bat guano are not large and, because of their size, have only local value as a source of fertilizer. The only known deposit of bat guano in Colombia is in the upper part of the Caca River (Wokittel, 1957). No data on reserves are given except that the deposit is small.

Because of its solubility the phosphate in guano is leached and combines with the material of the underlying rocks to form iron and aluminum phosphates, if the underlying rock is igneous, and calcium phosphate, if the rock is limestone. In Colombia, iron and aluminum phosphates are present on Malpelo Island (in the Pacific Ocean between lat 3°58′ N. and 3°59′ N. and long 81°35′ W. and 81°36′ W.), and the reserves of this material are estimated at 450,000 tons (Paba

Silvo, 1949; Suarez Hoyos, 1948; Sarmiento Alarcón, 1952; Hubach, 1952; Duncan McConnell in Hutchinson, 1950). Chemical analyses (Sarmiento Alarcón, 1952) show that the material is largely iron phosphate, and Duncan McConnell (in Hutchinson, 1950, p. 475–476) reported several iron and aluminum phosphate minerals—variscite. metavariscite, strengite, and phosphosiderite.

Although the tonnage of material is fairly large, iron phosphates are not useful in agriculture because of their insolubility. Malpelo Island is without an adequate port, and mining and transportation of the material would be almost impossible from a cost standpoint.

The islands of San Andrés (between lat 12°29′ N. and 12°35′ N. and long 81°41′ W. and 81°43′ W.) and Providencia (between lat 13°19′ N. and 13°23′ N. and long 81°21′ W. and 81°23′ W.) were examined for phosphate (Sarmiento Alarcón and Sandoval, 1947), but there is little or no guano and the P_2O_5 content of the underlying rocks ranges from a trace to 7.8 percent—far too low to be of any economic value.

Guano, or phosphatic material derived from guano, can therefore be eliminated as a possible source of phosphatic fertilizer in Colombia.

CONCLUSIONS AND RECOMMENDATIONS

Phosphorite deposits of potential economic interest have been discovered in Colombia in rocks of Late Cretaceous age in the Eastern Cordillera from Elias in the south to Orú in the north (pl. 1). Some of the deposits have potential for economic mining and chemical processing; others may be minable only for local use for direct application to the soil. All the deposits mentioned in this section of the report have some economic potential, and they range over such a wide area that production, even if limited to ground rock for direct application to the soil, would be of considerable value to Colombian agriculture.

The areas recommended for further exploration are presented in order of priority. For all, detailed geologic mapping is a necessary first step in determining the extent and tonnage of the phosphorite deposits, the structure, and the stratigraphy. Detailed mapping is also of value in providing a more detailed and accurate paleogeographic map, and this map, with the facies of the miogeosyncline carefully mapped, could lead to additional phosphorite discoveries.

In general, work should be concentrated on rocks of Late Cretaceous age, La Luna Formation and Guadalupe Group, because all the known potentially economic phosphate occurrences are in these formations. The work should also be confined to the Eastern Cordillera, where the miogeosyncline facies is present.

AREAS RECOMMENDED FOR FURTHER EXPLORATION

SARDINATA AND ADJACENT AREAS (SALAZAR AND ORÚ)

The phosphate sand bed exposed at Sardinata (loc. 49, pl. 1) could be mined directly for use in making chemical fertilizer. The tonnage of material at or close to the surface, about 1.5 million tons, is too small to warrant capital investment in a chemical plant. Detailed geologic mapping plus drilling (or test pitting in areas where phosphorite is at shallower depths) is the first step in determining the extent of this deposit. Further drilling should be done to the north, where the deposit is buried under younger rocks. Only this drilling will determine the tonnage of material that can be recovered by open-pit mining methods. The surface outcrop is weathered, and the mineralogy of the phosphate rock in the subsurface may be different from that at the surface; if calcite is present in the fresh rock, beneficiation and treatment of the rock will be considerably different from processes for the noncalcitic material.

The geologic mapping should eventually include the phosphate near Orú (loc. 51, pl. 1) and that near Salazar (loc. 43, pl. 1). Particular attention should be paid to the possible facies change between Sardinata and Orú.

The phosphorite sand at Salazar is similar lithologically to that at Sardinata; south of Sardinata (loc. 91–93, pl. 3) the phosphate sand bed is very thin, and between Sardinata and Salazar on the road between Santiago and Lourdes (loc. 94–96, pl. 3) the phosphorite bed is also thin and contains less phospate than the bed at either Sardinata or Salazar. These areas should be mapped in detail to determine the relations between them as well as the thickness, extent, and grade of the phosphorite bed or beds. Trenching in selected areas, plus drilling, probably will be necessary to determine the grade and tonnage of the phosphate bed.

At most localities there are several phosphate beds. Detailed sections have not measured, and the relations between the phosphate beds at different outcrops is not known. Detailed mapping is necessary to determine the stratigraphic relations between the outcrops.

TURMEQUÉ AND ADJACENT AREAS

The area around Turmequé (studied by Pedro E. Mojica G.) is in the sand facies but is close to the deeper water more limy facies. Much additional work is needed in this area, and the first step is to make a detailed geologic map to determine stratigraphy, structure, and the extent of the phosphate. The samples were taken only on the roads (fig. 9), and the phosphorite bed or beds should be traced throughout the area. At locality 55A (fig. 9) the phosphorite bed is 3.6 m thick and contains three clay partings with an aggregate thickness of about 30 cm. The bed contains an average of about 20 percent P_2O_5. The phosphorite bed dips 55° NW. and strikes N. 10° E. on the east flank of a syncline. The bed has not yet been located on the west flank of the syncline. Three quebradas cross the strike of the beds, southwest of the outcrop (1–3, fig. 9). These streambeds should be traversed to determine the extent of the phosphorite bed and the details of the synclinal structure. The bed should then be traced on the surface, and some trenching may be necessary to determine thickness and grade. The section on the west limb of the syncline should also be thoroughly investigated, and a series of detailed cross sections based on the detailed geologic mapping should be constructed to determine the depth of the phosphorite bed. A few holes must be drilled to confirm the cross sections. All the other outcrops should be traced and mapped in the same way.

Mapping should be extended to include the areas near Tunja (loc. 29, pls. 1, 2) and the beds to the south along the Chocontá-Machetá road (loc. 28, 28A, fig. 8). One or more beds of phosphate rock, which contain about 20 percent P_2O_5 and are as much as 1.5 m thick, occur at all these localities.

PANDI-CUNDAY AREA

The Pandi-Cunday area (loc. 16–18, and 57, pl. 1), southwest of Bogotá, is in the sand facies but is close to the deeper part of the basin where the limy facies was deposited. Beds of phosphate sand, as much as 1 m thick and containing as much as 27 percent P_2O_5, are present at several widely spaced localities. Only the beds along the roads have been sampled. Detailed geologic mapping followed by drilling is needed in this area.

At Pandi (loc. 17, pl. 1) the phosphorite bed dips gently and is covered by thin overburden. This area will have to be drilled or trenched, because the phosphorite is covered by a recent landslide. The area may be amenable to open-pit mining.

On the Cunday-Villarica road (loc. 16, pl. 1) the phosphorite bed is steeply dipping and is exposed along the road only because of local overturning, probably along a fault. A strike ridge of the Guadalupe Group extends for several kilometers to the north. The beds are in a normal position, dipping to the west. The ridge is about 200 m high, and drilling normal to the dip is necessary to determine the extent of the phosphorite bed. Mining in this area would have to be by underground methods. The outcrop is weathered, and the mineralogic character of the phosphate rock in the subsurface is not known; however, because this section is in the sand facies, it is thought that there will be little difference in the surface and subsurface material.

SAN VICENTE AND ADJACENT AREAS

The section near San Vicente (loc. 36, pl. 1) is in the chert-limestone-black shale facies, and there are several thin beds of phosphatic sand, phosphatic shale, and phosphatic limestone present. The section is structurally complex, and this may present problems in mining; however, a similar section is present several kilometers to the north (loc. 37, pl. 1), indicating the possibility of large reserves. Detailed geologic mapping is necessary to relate the stratigraphy of the outcrops to each other and to determine grade and tonnage of material present. Drilling after the geologic mapping is completed may be necessary to determine reserves accurately.

ORTEGA-GIRARDOT AREA

The area from Ortega to Girardot (loc. 11–15, pl. 1) is in the chert-limestone-black shale facies. Phosphate sand beds as much as 0.8 m thick contain as much as 26 percent P_2O_5. The beds are steeply dipping and would have to be mined by underground methods. The area is in the Magdalena River valley, and the phosphate occurrences are close enough to the agricultural area for use of finely ground phosphate rock in direct application to the soil.

Detailed geologic mapping is needed to determine the structure and stratigraphy and the extent, tonnage, and grade of the phosphate. An area north and west of Girardot (fig. 7) is underlain by rocks of Late Cretaceous age. In the part of the area west of the Magdalena River, bedding dips are low, and, if phosphorite is present, it might be minable by open-pit methods. The area has not been explored for phosphate.

ELIAS-TIMANÁ AREA

In this area (loc. 3, 4, fig. 5), phosphorite beds as much as 0.8 m thick contain as much as 22 percent P_2O_5. Similar beds have been sampled as far north as Yaguará (loc. 9, pl. 1) and Iquire (loc. 10, pl. 1). The area, investigated and sampled by Slansky (1963) and Zambrano O. (1966), is worthy of further work, and geologic mapping is needed to trace the phosphorite beds. Much of the area is covered by younger Tertiary rocks, and a drilling program might be necessary later to prospect favorable areas.

CAPARRAPÍ AREA

Phosphate sand beds as much as 1 m thick were found near Caparrapí (loc. 22, pl. 1). A large area limited by Caparrapí on the south, San Vicente on the north, and the Río Magdalena on the west is underlain by rocks of Cretaceous age, and has not been prospected, even in reconnaissance. Rocks of La Luna Formation may outcrop in this area, and these rocks are in a favorable position in the miogeosyncline for phosphorite.

CALIFORNIA-SURATÁ AREA

The California-Suratá area (loc. 56, pl. 1) was first prospected by Dwight E. Ward and Gilberto Manjarres. A phosphatic shale bed, 0.8 m thick and containing 20 percent P_2O_5, crops out near the town of California; the same bed crops out on the other limb of a syncline, near the town of Suratá. A phosphatic limestone bed overlies the phosphatic shale near Suratá. At this locality, the phosphatic limestone bed is about 2 m thick and is vertical. The material could be mined by underground methods and used for direct application to the soil. Detailed geologic mapping is necessary to determine the extent and tonnage of this bed.

ALTO DEL TRIGO-LA SIERRA AREA

Phosphatic limestone beds in this area (loc. 20, 21, pl. 1) are thin (about 30 cm) and low grade—the maximum content of P_2O_5 is only about 17 percent. The sections at La Sierra and Alto del Trigo are similar, and the most highly phosphatic beds in both sections are almost identical in thickness and grade. Structural complications have cut out La Luna Formation near Viani, between La Sierra and Alto del Trigo, but the potential resource of phosphatic limestone is large. The material can only be used for direct application of ground rock to the soil, but the area is close enough to the agricultural area of the Sabana that the transport costs might be within reason. Detailed mapping and sampling over a realistic mining width is necessary to determine the tonnage and grade of material having the highest phosphate content. The highest P_2O_5 content in the drill cores from Quebrada Santibanez (table 1) near Alto del Trigo is that of a 1-m sample near the middle of drill hole 4. The sample contains only 6.9 percent P_2O_5 and may include the 18-cm bed that at the surface contains about 13 percent P_2O_5. If the bed that contains 12.7 P_2O_5 at Alto del Trigo (section, p. A40) is combined with the two phosphatic limestone beds overlying it, the total thickness is 1.31 m, and the average P_2O_5 content is 5.7 percent. Thus, the combination of beds from the surface section matches very well the thickness, grade, and lithology of the bed from the drill hole.

Grades for a realistic mining width probably would only be about 5 percent P_2O_5, but this material might be useful as a soil additive in the immediate vicinity. Soil testing of large amounts of material from several of the potential deposits should be undertaken to find out whether the material would be beneficial for the local soils and which of the many deposits would provide the best material.

MARINE TERTIARY OF THE NORTHERN COAST

Marine sedimentary rocks of middle Miocene age contain phosphate at several places in the Western Hemisphere (Florida and North Carolina in the United States, and Sechura in Peru). All of these areas are close to upwelling currents in the modern oceans (McKelvey, 1963; Sheldon, 1964b), and other areas having similar conditions should be studied. One such area is the Guajira Peninsula, where Miocene rocks are present at the surface. A brief reconnaissance trip to the Guajira failed to uncover any phosphate, but one sample of sandy limestone of Miocene age contained a few phosphate grains. A more thorough reconnaissance of all the Miocene rocks of the Guajira Peninsula should be made. Marine Miocene sedimentary rocks also occur along the northern coast of Colombia in the Barranquilla area; this area should be studied for phosphate at least in reconnaissance by a scintillometer survey of the roads.

Phosphate is present on the modern beaches and just offshore in areas of upwelling oceanic currents, in such places as Baja California and off the coast of Peru. A concession to explore for phosphate deposits along the beaches and in the ocean immediately off the coast of Peru has been granted (Baker and Sprouse, 1967).

EXPLORATION PROGRAM

The phosphate investigations throughout Colombia dealt almost exclusively with exposures in roadcuts. The part of the section of the Guadalupe Group and La Luna Formation that was sampled depended on how much of the sample was exposed in the roadcuts. The phosphorite beds are present in the upper one-third of the Galembo member of La Luna Formation (Dwight E. Ward, written commun. 1967), and it is this part of the formation that is the most easily weathered and usually the least exposed. It is imperative that the upper part of the Galembo member of La Luna Formation be tested in the more favorable areas by drilling or by bulldozer cuts.

Each drill hole or test pit must be accurately located so that accurate tonnage and grade figures can be computed. Each drill hole should have a unique number, and this can be accomplished by tying each drill hole to the already existing land grid. For example, each quadrangle already has a number, and the drill holes can be numbered within the already existing system. A possible numbering system has been given by Cathcart (1966).

Tonnage computations can be made by computing the volume of phosphate rock in the ground and multiplying this known volume by the weight of the rock to get the tonnage. The volume of the rock in the ground can be determined by drilling, plus measurement at the outcrop, and should be reported in some standard unit of measurement, probably cubic meters. The weight per unit volume must be determined. The weight, in grams, of a measured volume of rock can be determined for each area and can then be easily converted to weight per cubic meter.

An alternative method can be used for each hole drilled. The volume and weight of the cored section can be measured, and the weight per unit volume can be calculated.

The weight per unit volume multiplied by the total volume will give the total tonnage of rock in the ground. If the rock is to be beneficiated, the tonnage of beneficiated material can be computed by multiplying the total tonnage times the percentage of concentrate, which will give the total tonnage of concentrate. The average grade can be determined using standard methods.

ECONOMIC CONSIDERATIONS

BENEFICIATION OF PHOSPHATE ROCK

Phosphate rock may be beneficiated in several ways, depending on the type of material, the grade (in percent P_2O_5), the type of diluting material, the coherence of the sample, the grain size of the material, and the amount of organic material present. Each deposit is different, and the details of the beneficiation vary from deposit to deposit, but certain generalizations regarding beneficiation can be made.

PHOSPHORITE CONTAINING CLAY AND QUARTZ AS DILUTENTS

HARD WELL-CEMENTED ROCK

If the rock is high in P_2O_5 content (30 percent or more), the material can be acidulated directly to make either superphosphate or triple superphosphate. The only necessary treatment prior to acidulation is pulverizing.

If the rock is medium in P_2O_5 content (25–30 percent), it can be used as furnace charge to make elemental phosphorus.

If the rock is low in P_2O_5 content (less than 25 percent), upgrading is necessary to make a high-analysis fertilizer. One method is to grind the material fine enough to free the individual grains of phosphate and quartz, screen it to remove the clay particles, and treat it in flotation cells to separate quartz and phosphate particles.

UNCONSOLIDATED PHOSPHATE ROCK

If the rock is high grade, no beneficiation is necessary; the rock can be acidulated directly after grinding, can be used for direct application, or can be made into thermal phosphate by heat treatment. Prior to heat treatment, it is necessary to pelletize the unconsolidated materials, because fine-grained rock is not usable in a furnace.

If the rock is medium or low grade, beneficiation is necessary, but a grinding step is not needed; wet screening is usually sufficient to disaggregate the material. Because the grinding step is eliminated, lower grade material can often be economically upgraded.

PHOSPHORITE CONTAINING CALCITE OR DOLOMITE

HARD WELL-CEMENTED ROCK

If the P_2O_5 content is above 25 percent, the material can be upgraded by grinding and calcining at elevated temperature. Calcite breaks down to fine-grained CaO and CO_2. The CO_2 is given off as a gas, and wet screening to eliminate fine-grained material follows the calcining step.

Direct acidulation is not practical because of the high acid consumption, and known flotation processes do not separate calcite, dolomite, and apatite. If a flotation process is developed to separate apatite and carbonate minerals, grinding to free the particles would be necessary, and because phosphatic carbonate rocks also contain quartz, a two-step flotation process might be necessary to eliminate both quartz and carbonate minerals. A two-step flotation process might not be economic owing to the increased cost.

GROUND ROCK FOR DIRECT APPLICATION

The phosphate mineral of marine phosphorite deposits (carbonate fluorapatite) is rather insoluble in alkaline or neutral soils, but is slightly soluble in acid soils. The soils of Colombia are almost entirely acid and are in either the Latosolic or Podzolic great soil groups. Podzolic soils are formed in humid temperate climates in the higher latitudes in the northern hemisphere and in smaller areas in the southern hemisphere. Latosolic soils are formed in humid tropical or subtropical climates in the equatorial belt of South America. Both are acid soils that have been depleted of calcium, other bases, and organic materials. Both soil groups have low levels of fertility, but are responsive to scientific management.

Finely ground phosphate rock (80 percent to pass 200 mesh) can be of considerable long-term benefit to crops when applied to these acid soils. The phosphorus is slowly soluble, and although the increase in crop growth is not as dramatic as with the application of high-analysis fertilizer, the growth response over several years may approach the response to the high-analysis fertilizer. Application of finely ground phosphate rock should be of benefit to the crops in most of the arable lands in the country. Soil tests of the ground rock should be made to determine the crop benefits.

Calcareous phosphate rock, particularly material that contains less than 20 percent P_2O_5, cannot, under normal conditions, be economically concentrated to produce phosphate suitable for use in making one of the commercial fertilizer products. This type of raw material, however, may be of value as a source of ground rock for direct application. Large transportation costs would be prohibitive, and the material must therefore be used close to the mine area.

Calcining, at elevated temperature, of calcareous phosphate rock would increase the grade in terms of percent P_2O_5, perhaps by as much as several percent, and calcined material should be field tested along with uncalcined material to determine whether crop yields would be increased enough to warrant the additional cost of calcining. The agricultural testing to determine the crop response should be done in the area in which the material is to be used.

Soil pH is an important factor in the solubility and availability to plants of many of the important nutrients, but the effect of changing the pH from acid toward neutral or alkaline is not simple. For example, Allaway (1957, p. 71) pointed out, "Phosphate availability in many soils is highest when the soil is neutral or slightly acid, and it declines as the soil becomes either strongly acid or alkaline."

Thus, the addition of calcareous phosphate rock might change the pH of very acid soils sufficiently for the phosphorous to be available to plants or, conversely, might change the pH toward the alkaline side so that the phosphorus would not be available. Obviously, soil testing of calcareous phosphates is a necessity.

Sandy phosphate rock that is too low grade for conversion into superphosphate would also be of considerable benefit for use as ground rock for direct application. Because the phosphate grains are softer than the quartz grains, it is possible that grinding, followed by screening, would upgrade the material by removal of some of the quartz. Some tests on differential grinding should be made to determine whether upgrading is possible.

CHEMICAL TREATMENT OF PHOSPHATE ROCK

Carbonate fluorapatite, the phosphate mineral of marine phosphorites, is rather insoluble in neutral or alkaline soils, but is slightly soluble in acid soils. The phosphorus content of the apatite mineral is therefore slowly available to plants, and the resulting increases in plant yields may be delayed for two or more growing seasons. When phosphate rock is changed to monocalcium or dicalcium phosphate, however, the phosphate becomes water soluble and is immediately available to the plants, giving increased crop yields after the first application.

When ground phosphate rock is treated with sulfuric acid, the apatite is converted into water soluble monocalcium or dicalcium phosphate, and gypsum is formed. The reaction is about as follows:

$$Ca_{10}(PO_4)_6F_2+7H_2SO_4+3H_2O=3CaH_4(PO_4)_2H_2O+7CaSO_4+2HF \quad (1)$$

The hydrogen fluoride attacks quartz present in the phosphate rock and is liberated either as silicon tetrafluoride or as fluosilicic acid. The phosphate material is superphosphate, either ordinary superphosphate (OSP) or normal superphosphate (NSP). It contains from 18 to 20 percent available P_2O_5 if it is made from phosphate rock containing 31 percent P_2O_5 or more.

Wet process phosphoric acid is made by acidulating phosphate rock with sulfuric acid and separating phosphoric acid from gypsum by filtration. The reaction is:

$$Ca_{10}(PO_4)_6F_2+10H_2SO_4=6H_3PO_4+10CaSO_4+2HF \quad (2)$$

Triple superphosphate (TSP), also called treble or concentrated superphosphate, is made by acidulating ground phosphate rock with phosphoric acid. The principal reaction is:

$$Ca_{10}(PO_4)_6F_2+14H_3PO_4=10CaH_4(PO_4)_2+2HF \quad (3)$$

Triple superphosphate contains from 48 to 53 percent P_2O_5 that is available to plants. The capital investment for a plant to produce triple superphosphate is much greater than that for a plant to produce ordinary superphosphate; because of the higher available P_2O_5, however, triple superphosphate is a much more valuable product and may therefore be shipped much greater distances from the manufacturing plant.

Nitric acid could possibly be used as a substitute for sulfuric acid in these processes. Hydrochloric acid could be used to make phosphoric acid but could probably not be used in the manufacture of ordinary superphosphate because chlorine, which is deleterious in a fertilizer, would remain in the fertilizer product. Because of the lack of sulfur in Colombia, research on the use of nitric and hydrochloric acids as possible substitutes for sulfuric acid should be done.

THERMAL TREATMENT OF PHOSPHATE ROCK

Elemental phosphorus is made in an electric furnace using coke as a reducing agent. Quartz sand is added to combine with the calcium of the phosphate rock to form a calcium silicate that is removed as a molten slag. Phosphorus is given off as a gas and is condensed and collected as a solid. Elemental phosphorus can also be made in a blast furnace using coke rather than electricity as the source of power. Although phosphoric acid and triple superphosphate can be made from elemental phosphorus, most elemental phosphorus is used in the chemical industry.

Calcium magnesium phosphate is a fused product containing about 19 percent available P_2O_5. It is made by fusing two parts phosphate rock and one part olivine or serpentine in an electric furnace. The molten phosphate slag is quickly quenched, ground, and used for direct application to the soil. Because this product is alkaline, it is not suitable for mixing with ammonium salts.

Fused tricalcium phosphate is produced by fusing phosphate rock in an oil- or gas-fired furnace. Molten phosphate is quenched by high-velocity water jets. The product, while it is not completely water soluble, is more available to plants, particularly in acid soils, than is untreated phosphate rock.

The fuel, power, and raw-material requirements for making 1 ton of P_2O_5 equivalent, using 3.5 tons of phosphate rock, are about as follows (modified from table 25, Seims, 1951):

Wet-process triple superphosphate: 0.6 ton sulfur.
Electric-furnace triple superphosphate: 0.8 ton sicilia, 0.5 ton coke, 4,100 kilowatt hours of power.
Blast-furnace triple superphosphate: 0.8 ton silica, 1.8 tons coke.
Calcium magnesium phosphate: 1.8 tons magnesium silicate, 4,000 kilowatt hours of power.
Fused tricalcium phosphate: 0.4 ton silica, 240 gallons fuel oil or 33,000 cubic feet of gas.
Ordinary superphosphate: 0.6 ton sulfur.

TRANSPORTATION

Phosphate rock is a bulk product, and large tonnages of it must be moved from the mine to the consumer. Also, because phosphate is a fairly low value product (31 percent P_2O_5 rock from Florida is about $7.00 (U.S. currency) per ton at the mines), transport costs must be held to a minimum or the ultimate consumer, the farmer, will not be able to purchase the material.

Conventional methods used to transport large tonnage of material include railroads, barges, and trucks. The phosphate deposits in Colombia are not close to navigable rivers, and truck or rail transport would be difficult; railroads and (or) adequate roads would have to be built to the mine areas, and to some of the farming areas.

A possible alternative method of transport, brought to the writers' attention by Earl M. Irving, involves pumping the phosphate in a water slurry in large-diameter pipelines. The method might be attractive for moving phosphate from Turmequé (loc. 55, pl. 1) and Boyacá (loc. 29, pl. 1) to the Llanos or to the Magdalena River valley—potential large consuming areas for phosphate rock. The transport would be mostly downhill, and much of the work could be done by gravity. Other deposits might also be amenable to pipeline transport, providing total costs are sufficiently low; the method has enough promise to merit further investigation.

SULFUR

Sulfur is a critical raw material in chemical processing of phosphate rock to make triple or ordinary superphosphate. World production of sulfur is not able to completely satisfy demands, and at the present time sulfur is a critically short commodity.

Known sources of sulfur in Colombia are not sufficient to supply any large increases in demand. Sulfur is present in the volcanic tuffs of Puracé, but the total reserves are only about 1 million tons, computed as refined sulfur (Megyesi, 1962). Production of sulfur at the mines at the Puracé volcano is only enough to supply local demand, and it is not likely that production could be increased enough to supply a greatly increased demand, at least for any extended period of time.

Other possible sources of sulfur include pyrite from the black shales of the Cáqueza and Villeta Groups of Cretaceous age, but it would be impossible to mine these shales for their pyrite content alone. A few tons of pyrite per day goes onto the waste pile at the salt mine at Zipiquirá (D. H. McLaughlin, oral commun., 1966), and the pyrite could be recovered, but the tonnage is too small to be significant. Pyrite from metal mines has been used as a source of sulfur, but large tonnages of pyrite are not known in Colombia, and production from this source will probably remain small.

Sour gas is a source of sulfur in many parts of the world, but the gas fields of Colombia do not contain significant amounts of sulfur. However, the Quiriquire and Pedernales oil fields in eastern Venezuela do contain high-sulfur crude oil (Harrington and others, 1966, p. 58).

None of the known sources of sulfur within Colombia are thus likely to be able to supply the large tonnages that would be required to make phosphoric acid, superphosphate, and triple superphosphate by conventional methods. The most likely source for increased reserves and production of sulfur in Colombia is the volcanic rocks in the southern part of the country. Although the known reserves are small, a prospecting program in this part of the country might be valuable. Unless considerable additional reserves are found in this area, a plant to make chemical fertilizer probably would have to depend on imports of sulfur or be designed to use some other method. Thus the possibility of producing nitric acid by fixation, and using it for acidulation of phosphate rock, may be of considerable importance in Colombia.

AGRICULTURAL AREAS OF COLOMBIA AND THEIR RELATION TO PHOSPHATE OCCURRENCES

The principal large agricultural areas in Colombia are along the major river valleys (the Cauca, Cesar, Magdalena) in the Sabana near Bogotá and in the vast plains of the Llanos (fig. 10). However, small-scale farming in all parts of the well-populated mountain areas accounts for the bulk of the nation's crops. The principal undeveloped area suitable for large-scale agriculture is the Llanos.

The phosphate beds at Elias in the Magdalena River valley and vicinity (p. A25) could be used in the farm area of the upper Magdalena River valley and possibly in the Cauca River valley. Transportation to the Cauca River valley would be a problem because of the Central Cordillera, which is between the phosphorite deposits and the Cauca River valley.

Material from the phosphate occurrence in the Girardot-Ortega area (p. A28) could only be used in the upper Magdalena River valley, but transportation to the area of use would not be a serious problem.

The occurrence at Pandi-Cunday (p. A33) could be used in the Sabana near Bogotá or in the Magdalena River valley. This occurrence could be reasonably large, is known to be high grade, and contains silica as the principal diluent. If the deposit is large enough, it could be used to make high-grade chemical fertilizer and could be transported long distances to market areas—conceivably even into the Cauca River valley.

The phosphate at La Sierra–Alto del Trigo–Caparrapí is low grade and very calcareous (p. A37). The material is not suitable for benefication, but might make a good soil additive if finely ground and used for direct application. It might be possible to haul this material as far as the Sabana which is the closest agricultural area, but this area is about at the limit of transportation for the low-grade calcareous phosphorite.

The phosphate near Turmequé (p. A46) is very close to the paved road from Bogotá to Tunja. This material could be used in the Sabana. Also, if the deposit should prove large enough, the cost of a chemical fertilizer plant could be justified; it might then be possible to move the material to the Llanos through Bogotá and Villavicenio by truck or by gravity-flow pipeline.

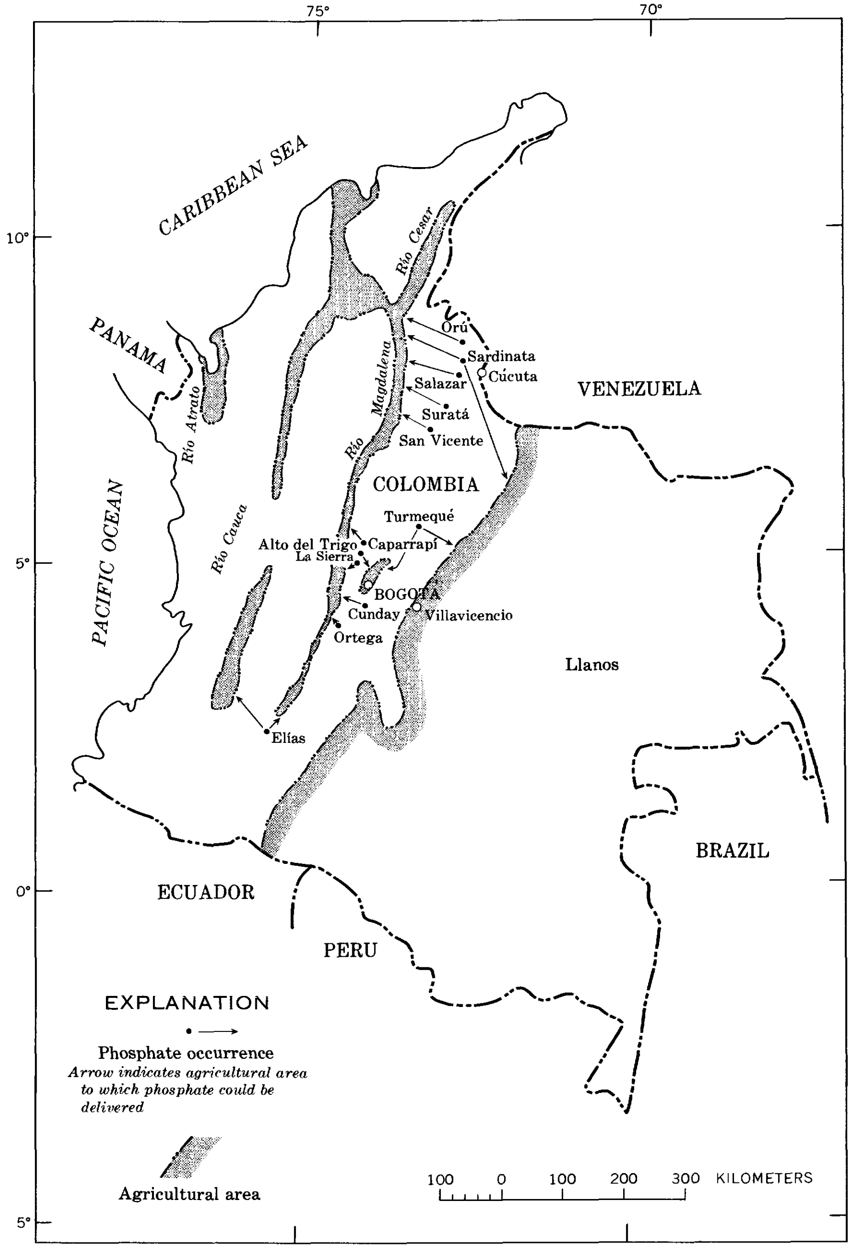

Figure 10.—Principal agricultural areas and phosphate occurrences of Colombia.

The phosphate from deposits in Santander and Norte de Santander could be trucked to the middle Magdalena River valley, made into chemical fertilizer (provided the tonnages are large enough to warrant the investment in a chemical plant), and then moved down river by barge to all the lower Magdalena River valley. If the deposits are large enough, export of phosphate material might be possible. Transport to the Llanos is possible through Cúcuta and across the Eastern Cordillera. However, material hauled this distance would have to be high-analysis fertilizer to support the transport costs.

OUTLOOK FOR MINING AND FERTILIZER PRODUCTION

The soils of Colombia, in the arable areas, are largely acid Latosols that have been depleted of much of the nutrient necessary for plant growth by natural leaching coupled with many years of intensive farming. Increased farm production, necessary to supply food for an expanding population, can be accomplished by the addition of fertilizer to the soil. Except for the small annual production of basic slag (about 28,000 tons per year) from the smelter at Pas del Rio, all phosphatic fertilizer has been imported. The amount of fertilizer imported (54,000 tons in 1963) is extremely small in terms of need.

The discovery of the potentially large phosphate deposits changes the situation considerably. Certain of these deposits may be sufficiently extensive and high grade to supply the fertilizer demands of the country at a cost that probably would be much less than the cost of imported fertilizers.

In addition to the potential high-grade deposits, there are several deposits spread throughout the Eastern Cordillera that might be mined for local use in areas close to the mine. Some of these deposits are probably too low grade to economically beneficiate to obtain a high-analysis chemical fertilizer, but these deposits might be very useful if mined and processed for direct application to the soil.

Whether these deposits are mined or not depends on economics—that is, the cost to the farmer of a delivered unit of P_2O_5. The local material must compete, in delivered cost, with phosphate rock from foreign sources or with phosphate rock from the potential high-grade deposits at Sardinata, in the northern part of the country. It is possible that a need to save on foreign payments might justify a higher cost for the commodity from a local source than from the foreign import, but the problem should be approached first from the point of view of strict economics to see if the local, probably low grade product can compete with the foreign import.

If the phosphorite at Sardinata is as high grade as the initial sampling indicates and if it turns out to be an extensive deposit that can be mined by open-cut methods, then the mined material would have about the same P_2O_5 content as phosphate rock imported to the Caribbean port of Barranquilla; there is no question but that this material can be delivered to Barranquilla at less cost than phosphate rock from a foreign source. However, the cost of the fertilizer to the farmer in the interior of the country would also have to include the internal transportation cost.

The actual cost of bulk transport of fertilizer material would depend on the area to which it is shipped. Bulk transport by barge up the Magdalena River is cheap, and all agricultural areas within reach of barge transport could get phosphate rock at a lower cost per unit P_2O_5 than from a local source. However, the costs of this barge-transported material to the farmer in the Sabana area near Bogotá, the Cauca River valley, the upper Magdalena River valley (above navigation), the Llanos area of eastern Colombia, and other areas in the southern part of the country might well be excessive, because additional transport would have to be by truck or rail over long distances and over one or more mountain ranges.

If the cost of road transportation is 1 cent per ton per kilometer, then the cost of transportation from Sardinata to Bogotá is about $4 per ton, and the total cost of phosphate rock from Sardinata delivered in Bogotá would be about the same as the cost of phosphate rock from a foreign source delivered in Barranquilla. Clearly then, phosphate rock imported from a foreign source cannot compete in cost with phosphate rock mined at Sardinata. However, phosphate rock from the occurrence at Ventaquemada could be transported to Bogotá for less than $2 per ton transportation cost. Mining in the Ventequemada area would probably have to be by underground methods; mining costs would thus be considerably more than those of the open-pit area near Sardinata, but the cost per unit of P_2O_5 would be about the same, if the grade at Ventaquemada is about half that at Sardinata. Preliminary sampling indicates that the phosphorite at Ventaquemada contains about two-thirds as much P_2O_5 as the phosphorite at Sardinata, so that the cost of delivered phosphate rock from Ventaquemada would be cheaper than that from Sardinata and without question would be cheaper than the cost of imported phosphate rock.

There is little question, then, that low-grade phosphate rock, even if it is only ground and used for direct application to the soil, would be far cheaper per unit P_2O_5 than would phosphate rock from an import source; in large parts of the country, local sources of low-grade rock might be cheaper than phosphate rock produced at Sardinata.

Probably all local sources of low-grade phosphate rock should be carefully investigated to determine their value to agriculture as ground rock for direct application to the soil. It seems likely that shipments of ground rock could be made economically to areas within about a 100-km radius.

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