Cretaceous and Tertiary Rocks In the Corozal Quadrangle Northern Puerto Rico

By ARTHUR E. NELSON

CONTRIBUTIONS TO STRATIGRAPHY

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By ARTHUR E. NELSON

ABSTRACT

Approximately 11,600 meters of Cretaceous and lower Tertiary volcanogenic rocks are exposed in the Corozal quadrangle, and these rocks are unconformably overlain in the northern fifth of the quadrangle by about 470 meters of middle Tertiary marine deposits. Faulting has divided the Cretaceous and lower Tertiary rocks into three distinct stratified sequences. An unnamed Cretaceous volcanic sequence, probably the oldest group of rocks in the quadrangle, is in the northeast quadrant. The next youngest sequence is the Río Orocovis Formation of earlier workers and other Cretaceous rocks that are exposed in the south half of the quadrangle. Upper Cretaceous and lower Tertiary rocks, the youngest sequence, are exposed in a westerly to northwesterly trending band near the central part of the quadrangle. Stratigraphic relations between these rock sequences are obscure.

Detailed mapping and recognition of a greater number of units have made it necessary to raise the Río Orocovis Formation to group rank and its former members to formation rank. Two newly divided stratigraphic units in the group are herein named the Los Negros Formation and the Cuchillas Member (of the Avispa Formation).

In addition it is necessary to name and define or to adopt several formations in the Upper Cretaceous and lower Tertiary sequence: a unit of Late Cretaceous or early Tertiary age is named the Cibuco Formation; three lower Tertiary units are named the Palmarejo Formation, the Corozal Limestone, and the Ortiz Formation. A unit of middle Oligocene age is herein designated the Mucarabones Sand.

INTRODUCTION

This report presents changes in stratigraphic nomenclature in a succession of Cretaceous and Tertiary rocks in the Corozal quadrangle in northern Puerto Rico. Six stratigraphic units are formally named; one previously used unit is redefined and adopted for use by the U.S. Geological Survey and one previously named formation has been raised to group rank and its members to formation rank. Stratigraphic studies in the Corozal quadrangle (fig. 1) are part of a larger program of geologic mapping and mineral resource studies of Puerto

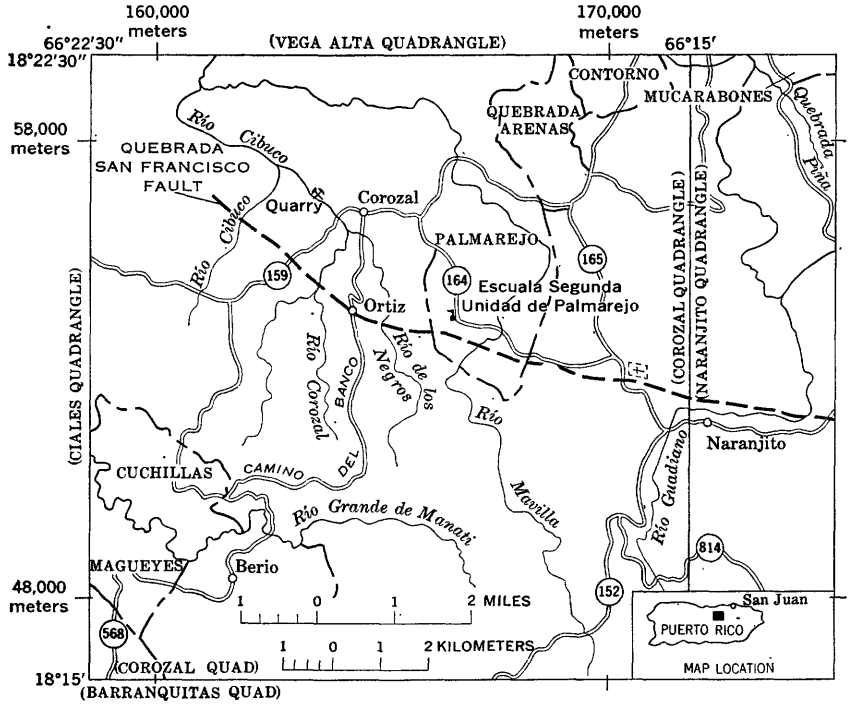

FIGURE 1.—Map of the Corozal quadrangle and part of the Naranjito quadrangle.

Rico by the U.S. Geological Survey in cooperation with the Economic Development Administration of Puerto Rico.

Many of the stratigraphic units occurring in the Corozal quadrangle are named herein. To present their relations to the other formations more clearly, all Cretaceous and Tertiary stratigraphic units in the quadrangle are described. Table 1 shows the stratigraphic succession of these rocks in the Corozal quadrangle.

The proposed classification of Fisher (1961) is used in the description of the volcanic rocks.

STRATIFIED ROCKS

The rocks of the Corozal quadrangle constitute a complex of Cretaceous to lower Tertiary volcanogenic deposits. These rocks have been intruded by diorite and gabbro and are unconformably overlain by middle Tertiary marine calcareous and related deposits in the northern fifth of the quadrangle. The complex, consisting of approximately 11,600 meters of marine volcanogenic rocks, has been divided by faulting into three distinct stratified sequences. The locations of these sequences are shown on figure 2. Area 1 is underlain

TABLE 1.—*Stratigraphic succession of consolidated rocks presently recognized in the Corozal quadrangle*

Series or stage	Formation	Member
Upper Oligocene and lower Miocene	Cibao Formation	Upper member
		Miranda Sand Member
		Quebrada Arenas Limestone Member
		Río Indio Limestone Member
Middle and upper Oligocene	Lares Limestone	
Middle Oligocene	Mucarabones Sand*	
	San Sebastián Formation	
	—Unconformity—	
Paleocene or Eocene	Ortiz Formation*	
	Corozal Limestone*	
	Palmarejo Formation*	
Upper Cretaceous or lower Tertiary	Hornblende tuff	
	—Break in sequence—	
	Carreras Siltstone (equivalent? to Palmarejo Formation)	
	Cibuco Formation* (equivalent? to hornblende tuff)	
	—Break in sequence—	
Upper(?) and Upper Cretaceous	Pozas Formation (equivalent? to undivided rocks)	
	Undivided rocks	
	—Break in sequence—	
Lower and Upper Cretaceous	Río Orocovis Group*	Los Negros Formation*
		Avispa Formation* — Cuchillas Member*
		Perchas Formation*
		Magueyes Formation*
	—Break in sequence—	
Cretaceous	Volcanic sandstone	
	Andesite lava	
	Volcanic breccia	

*Redefined, adopted, or named and defined in this report.

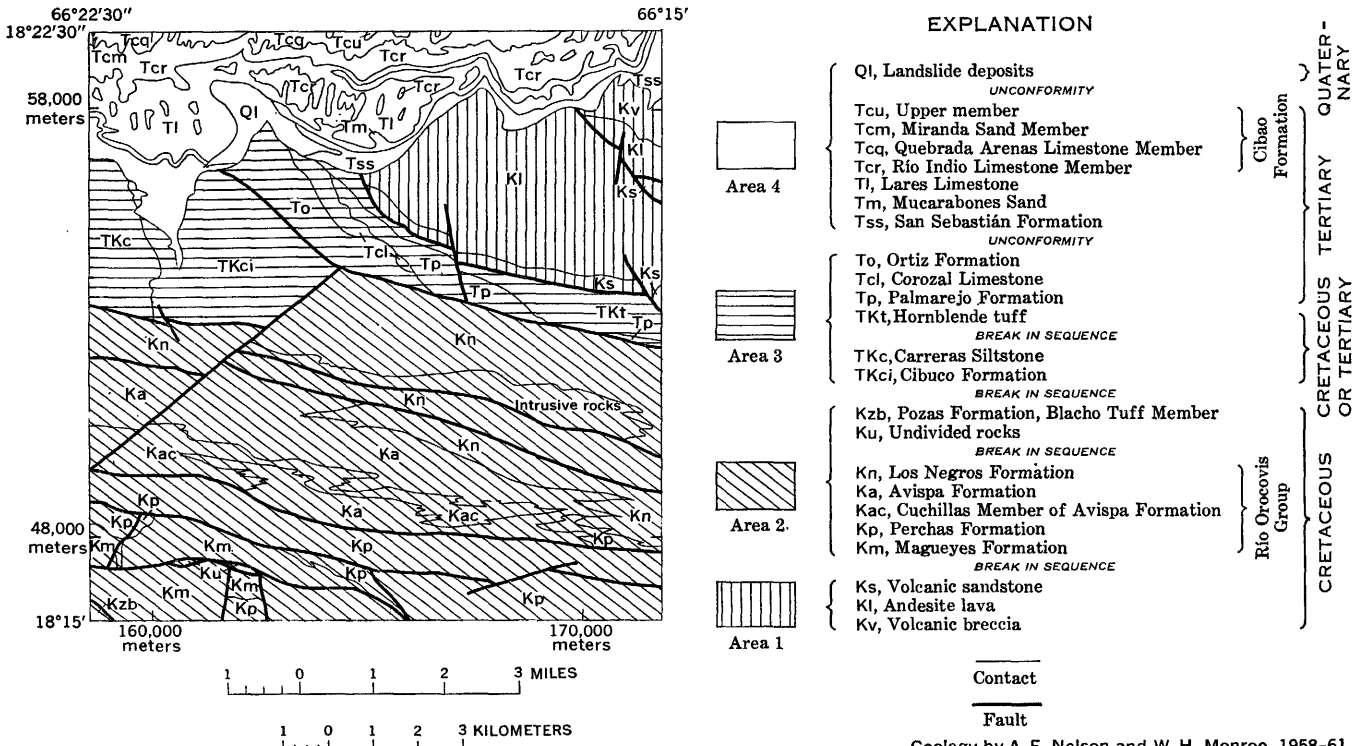

FIGURE 2.—Generalized geologic map of the Corozal quadrangle.

by an unnamed Cretaceous volcanic sequence, probably the oldest group of rocks in the quadrangle; area 2 is underlain mostly by the Río Orocovis Group, and area 3 by Upper Cretaceous and lower Tertiary rocks, the youngest sequence in the complex. Area 4 shows the distribution of middle Tertiary deposits that have a maximum thickness of 470 m and that unconformably overlie rock units in areas 1 and 3.

CRETACEOUS ROCKS

The oldest rocks in the Corozal quadrangle are probably those in the northeastern part (area 1, fig. 2). They include volcanic breccia, lava, and well-bedded volcanic sandstone and siltstone. Because this unnamed sequence is bounded by faults, its stratigraphic relations to the other stratified units in the quadrangle could not be determined. The stratigraphic units in this sequence are described but are not named; they are of Cretaceous age.

VOLCANIC BRECCIA

Volcanic breccia and associated rocks occupy a small area in the northeastern part of the quadrangle (fig. 2). In the Corozal quadrangle the unit consists mostly of volcanic breccia with some interstratified discontinuous beds of volcanic sandstone and a lava lens. The volcanic breccia, generally poorly exposed and partly weathered, is a characteristic reddish purple and contains numerous fragments of andesite. The rocks strike generally west-northwest and dip moderately to the south. Only the upper 300 m of the volcanic breccia is exposed, but in the adjacent Naranjito quadrangle this sequence is at least 2,000 m thick (M. H. Pease, Jr., written commun., 1964). On the north and northwest, the volcanic breccia is overlapped by middle Tertiary deposits; to the south and southwest, it is overlain by andesite, but because of poor exposures in this part of the Corozal quadrangle the nature of the contact could not be established.

ANDESITE LAVA

The next younger unit is composed of porphyritic andesite and associated rocks exposed in the northeastern part of the quadrangle (fig. 2). This unit contains lenticular flows of porphyritic andesite interstratified with andesitic volcanic breccia, volcanic sandstone and siltstone. The lava is dark greenish gray, weathers brownish gray, and commonly contains pillow structures and amygdules. Plagioclase phenocrysts, which characteristically have a glomeroporphyritic habit, compose about 18–24 percent of a sample, by volume, but the percentage varies greatly from bed to bed. The groundmass is usually minutely crystalline. Interstratified with the flows are massive layers of volcanic breccia and lenticular units of distinctly

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bedded volcanic sandstone and siltstone. The breccia contains angular to subrounded andesite fragments lithologically similar to the lava; the matrix contains fragments and crystals of plagioclase and pyroxene and tiny pumiceous particles. Hydrothermal alteration has affected much of the andesite unit so that in some areas the original texture and lithology cannot be determined.

In the Corozal quadrangle, the andesite unit has a maximum thickness of 1,800 m. Like the older volcanic breccia, this unit is bounded on the northwest by overlapping middle Tertiary deposits; to the south and southwest these rocks are conformably overlain by the volcanic sandstone and siltstone unit (fig. 2).

VOLCANIC SANDSTONE AND SILTSTONE

The next younger unit consists of interbedded volcanic sandstone and siltstone; the unit forms a narrow belt of south-dipping rocks that extends from near the middle of the east border of the quadrangle to a short distance east of the town of Corozal (figs. 1, 2). Part of this unit is also present in a fault wedge along the east edge of the quadrangle 3.5 kilometers south of the north border. The volcanic sandstone and siltstone are commonly tuffaceous and less commonly calcareous. The unit also contains some massive layers of conglomerate and several andesite flows. The cobbles and pebbles in the conglomerate are mostly andesite, and the flows are similar to those previously described in the underlying unit. Only about 500 m of the lower part of this clastic unit is present in the quadrangle, but in the Naranjito quadrangle, this sequence has a maximum thickness of 1,100 m (M. H. Pease, Jr., written commun., 1964). In the Corozal quadrangle, the upper part of the volcanic sandstone and siltstone has been removed by faulting, and the lower part rests conformably on the older andesite lava unit.

RÍO OROCOVIS GROUP

The term Río Orocovis Formation (Berryhill, 1965, p. 19) was first used for a sequence of volcanic rocks in the next quadrangle to the west, the Ciales quadrangle. Four members, comprising 4,500 m of rock, were included in the formation: the Magueyes Member at the base, the Perchas Lava Member, the Avispa Lava Member, and a basalt tuff member. Because some of these members were divided into additional mappable units in the Corozal quadrangle, the Río Orocovis Formation is here raised to the rank of group and the former members are here raised to formations. In addition, basaltic tuff that is contiguous with the basalt tuff member of the Río Orocovis Formation of Berryhill (1965) is here named the Los Negros Formation.

The Río Orocovis Group, a major stratigraphic division of the Cretaceous System in east-central Puerto Rico, occupies most of the south half of the quadrangle (fig. 2). It comprises a thick accumulation of basalt, andesite, basaltic tuff, sandstone, siltstone, and breccia primarily of volcanic origin. The Magueyes Formation is composed chiefly of epiclastic rock, the Perchas Formation of basalt, the Avispa Formation of andesite, and the Los Negros Formation of basaltic tuff. Although one lithologic type is the principal constituent in each formation, the Magueyes Formation, for example, contains, in addition to volcanic sandstone and siltstone, members of basalt and andesite and basaltic tuff that are similar to the Perchas, Avispa, and Los Negros Formations, respectively.

Owing to the complex depositional history, the stratigraphy of the Río Orocovis Group is characterized, as is the stratigraphy of the entire Cretaceous System in Puerto Rico, by abrupt lateral and vertical facies changes. In places, parts of one formation in the Río Orocovis Group are time equivalents of parts of another formation in the group. In general, however, most of the Perchas Formation is younger than the Magueyes Formation; most of the Avispa Formation is younger than the Perchas Formation; and the Los Negros Formation, which has the greatest stratigraphic range, is for the most part the youngest formation in the group.

Rocks of the Río Orocovis Group apparently accumulated in an active volcanic terrain where predominantly volcanic material of various types and chemical compositions was derived from several different sources. Although each formation represents an interval of fairly continuous deposition of one type of rock, there were repeated instances when, from different sources and for relatively short intervals, other lithologic types of this volcanic suite were simultaneously deposited. This volcanic material apparently erupted from vents and long fissures on the ocean floor. Thick lava and coarse pyroclastic debris probably accumulated near source areas; ash and reworked volcanic debris were deposited over a much broader area and interfingered with the near-vent deposits.

Approximately 3,000 m of the Río Orocovis Group is present in the Corozal quadrangle. Relations with older and younger rocks are not known, and the cumulative thickness of the group is uncertain. The base of the group is not exposed, the top is faulted out, and other parts may be repeated by folding and faulting.

Diagnostic fossils have not been found in the rocks of the Río Orocovis Group in the Corozal quadrangle. On the basis of stratigraphic relations to younger fossil-bearing rocks elsewhere in Puerto Rico, the Río Orocovis Formation was assigned to a probable Turo-

nian(?) to late Santonian(?) or early Campanian age by Berryhill (1965, p. 45). Fossils in rocks equivalent to the lower part of the Río Orocovis Group in the Barranquitas quadrangle, south of the Corozal quadrangle, have been dated by N. F. Sohl (written commun., 1963) as Albian. Hence, the lower part of the Río Orocovis Group is probably Early Cretaceous, and the upper part apparently is Late Cretaceous.

MAGUEYES FORMATION

The Magueyes Formation (Berryhill, 1965, p. 21) occupies most of the southwestern part of the quadrangle (fig. 2). There it consists chiefly of alternating beds of volcanic sandstone and siltstone and interstratified amygdaloidal pillow basalt, pillow andesite, basaltic flow breccia, basaltic tuff, volcanic breccia, and lapilli tuff.

Good exposures of volcanic sandstone and siltstone, basaltic tuff, and andesite can be seen in discontinuous outcrops on the westerly trending section of Route 568 west of Berio in barrios Magueyes and Palmarito. The best exposures of basalt are on Route 568 approximately 1.4 km north of the south boundary of the quadrangle.

The dark-greenish-gray volcanic sandstone and dark-gray volcanic siltstone are composed mostly of tuffaceous material. The sandstone ranges from massive and thick bedded to thin bedded; some beds are graded. It is fine to coarse grained and is characterized by crystals and fragments of dark-green clinopyroxene. Chlorite and epidote commonly are present, and in some places calcite has been introduced and has made the rock decidedly calcareous.

The volcanic breccia contains fragments of andesite in a matrix of small crystals and fragments of plagioclase and pyroxene. Lapilli tuff contains pale-green pumice fragments, some lithic fragments of lava, and small grains of pyroxene and plagioclase in a matrix of glass and microcrystalline material. The basaltic flow breccia is an accumulation of large fragments of basalt, and individual samples are similar in composition to basalt.

Some of the thicker basalt flows, andesite flows, and basaltic tuff deposits have been mapped locally in the Corozal quadrangle as unnamed members.

A maximum of 1,400 m of the Magueyes is exposed in the southwestern part of the quadrangle, but the formation thins to the east. Although a part of the Magueyes is conformably underlain by rocks equivalent to the Perchas, some of the lower part of the formation is faulted out in the adjoining Barranquitas quadrangle to the south (Briggs and Gelabert, 1962), and the lower contact relations are not known. The upper part of the formation is conformably overlain by the Perchas Formation. The Magueyes in the Corozal quadrangle was said to be contiguous with strata mapped as Cariblanco Forma-

tion in the northern Barranquitas quadrangle (Briggs and Gelabert, 1962). Later work, however, has shown that the strata mapped as Cariblanco Formation in the northern part of the Barranquitas quadrangle are a part of the Magueyes Formation (R. P. Briggs, written commun., 1965).

PERCHAS FORMATION

The Perchas Formation (Berryhill, 1965, p. 25), named for exposures in the Ciales quadrangle, extends in a narrow belt east-southeastward across the Corozal quadrangle into the adjoining Naranjito and Barranquitas quadrangles (fig. 2). The Perchas consists mostly of lenticular flows of dark-greenish-gray to dark-grayish-black pyroxene-rich basalt. Individual flows, ranging from 20 to 50 m in thickness, commonly are pillowed; some grade into highly vesicular flow breccia. Scattered discrete beds of volcanic sandstone and siltstone and lenses of basaltic tuff and andesite are also present. The sandstone and siltstone are simliar to the rocks composing most of the underlying Magueyes Formation. The tuff and andesite are similar to the rocks of the younger Los Negros and Avispa Formations. Some of the thicker units of volcanic sandstone and siltstone, andesite, and basaltic tuff have been mapped as unnamed members in the Perchas Formation.

Approximately 800 m of the formation is exposed in the Corozal quadrangle. Contacts with the underlying Magueyes and overlying Avispa and, locally, Los Negros Formations are conformable.

AVISPA FORMATION

The Avispa Formation (Berryhill, 1965, p. 28) occupies a crudely lenticular area north of the Perchas Formation in the southern part of the quadrangle (fig. 2). It extends westward into the Ciales quadrangle but thins abruptly toward the east and pinches out just west of the east edge of the Corozal quadrangle. The formation is a heterogeneous unit consisting primarily of lenticular pillow andesite interbedded with volcanic breccia, intraformational conglomerate, discrete beds of volcanic sandstone, siltstone, and tuff, and basalt flows. The lava ranges from greenish gray to dark gray and has a purplish cast locally; it weathers dull brown. Several unnamed members of the various lithologic types have been mapped. A distinctive lenticular unit of interbedded volcanic breccia and volcanic sandstone and siltstone is present near the top of the lower third of the formation. This unit, which separates the lava flows in the lower part from those in the upper part, is named the Cuchillas Member and is described in the following paragraph. The maximum thickness of the formation in the Corozal quadrangle is estimated to

be 1,800 m. Contacts with the underlying Perchas and overlying Los Negros Formations are conformable.

Cuchillas Member.—The Cuchillas Member of the Avispa Formation is exposed in the southern part of the Corozal quadrangle (fig. 2) and is here named after barrio Cuchillas in Municipio de Corozal where it is best exposed. The type locality is along the banks of the Río Grande de Manatí between coordinates 50,000–159,000 and 50,800–158,660 (reference to meter grid based on Puerto Rico coordinate system shown by ticks at margin of fig. 1). The Cuchillas Member consists of dark-grayish-green massive volcanic breccia and lapilli tuff interstratified with fine-grained dark-greenish-gray to dark-gray volcanic sandstone, siltstone, and crystal tuff. The breccia facies of the member occurs as large, discontinuous, somewhat lenticular bodies separated by the finer grained discretely bedded facies. The breccia and lapilli tuff, which are poorly sorted, are made up of andesite fragments in a fine-grained matrix of rock fragments, plagioclase and pyroxene crystals, some pumice, and some small unidentified mineral fragments. The Cuchillas Member is about 500 m thick in the type locality, but eastward along strike it is quite variable in thickness where it intertongues with andesite lava of the Avispa Formation. Contacts with the enclosing lava are poorly exposed. The Cuchillas Member is considered to be of Late Cretaceous age.

LOS NEGROS FORMATION

A unit of basaltic tuff trends eastward across the middle of the Corozal quadrangle (fig. 2). Berryhill (1965) mapped contiguous rocks in the Ciales quadrangle as the basalt tuff member of the Río Orocovis Formation. This pyroclastic unit is here named the Los Negros Formation after the Río Los Negros along which the formation is well exposed. The type area is along the Río Los Negros and the Camino Del Banco road between coordinate 51,680 and 53,710, and the type locality is in the Río Los Negros valley between coordinate 51,800 and 52,140. Excellent easily accessible exposures of the formation also occur along Route 814 from 200 m west of the bridge over the Río Guadiana to 500 m east of the bridge.

The Los Negros Formation consists predominantly of numerous layers of massive crystal-lithic basaltic tuff but includes some basalt flow breccia and lapilli tuff. In fresh exposures, the formation is mostly dark greenish gray to dark greenish black, but in weathered exposures it is characteristically light olive green. Rounded somewhat globular masses of basalt, averaging about 10 centimeters in diameter, are randomly scattered throughout the tuff. These globular masses are similar in lithology to the basalt of the Perchas Formation.

Several unnamed members and small lenses of basalt and andesite similar to those of the Perchas and Avispa Formations, respectively, are included in the formation. Lenses of volcanic sandstone and siltstone, ranging from less than 30 cm to more than 6 m in thickness, are also irregularly distributed throughout the massive tuff.

As much as 1,000 m of the formation is exposed in the Corozal quadrangle and 1,800 m in the Naranjito quadrangle (M. H. Pease, Jr., written commun., 1964). Throughout most of its extent in the Corozal quadrangle, the Los Negros conformably overlies the Avispa Formation. In the southeastern part of the quadrangle, however, it overlies the Perchas Formation. Because of faulting, the upper part of the Los Negros is not exposed in either the Corozal or adjacent quadrangles. The formation is considered to be of Late Cretaceous age.

STRATIGRAPHIC RELATIONS

The stratigraphy of the Río Orocovis Group is complicated by much and unusually abrupt interfingering of units; each formation contains interstratified units that are lithologically similar to the principal rock types of the other formations in the group (figs. 3, 4), and interpretation of the stratigraphy is further complicated by intense deformation. Generally, the upper parts of a formation intertongue with the lower parts of an overlying formation. Commonly, formations and members are lenticular; the formations thin abruptly and, in places, pinch out in other formations of the group. Thicknesses of stratigraphic units are, therefore, variable.

UNDIVIDED ROCKS

Unidentified rocks occur in the southern half of the quadrangle in several small slices in fault zones along the easterly trending faults (fig. 2). The rocks are weathered to a deep-reddish-purple saprolite whose texture resembles that of highly weathered volcanic breccia of the Upper Cretaceous Pozas Formation exposed in the Ciales quadrangle (Berryhill, 1965). Presumably these rocks are of Late Cretaceous age.

POZAS FORMATION

The Blacho Tuff Member of the Pozas Formation (Berryhill, 1965, p. 51) is present in a small area in the southwestern part of the quadrangle (fig. 2). It consists of partly welded tuff composed of pumice and dense lava fragments and is underlain by pillowed andesite. The tuff is reddish gray and on weathering turns to a characteristic deep reddish purple; the lava is a greenish gray to dark gray. Less than 50 m of the Blacho is present in the quadrangle.

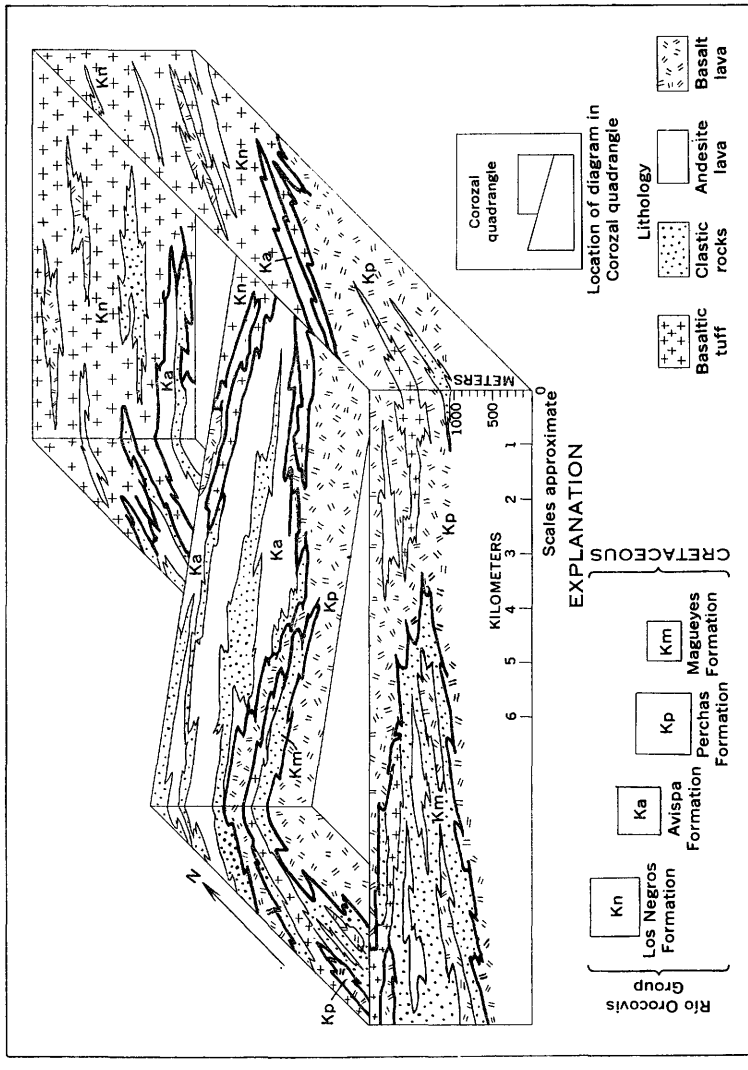

FIGURE 3.—Stratigraphic relations between formations of the Río Orocovis Group and rock types in each formation.

Breccia in float along the contact between the Blacho Tuff Member and the Magueyes Formation suggests that the contact is a fault. The lower part of the Pozas Formation is not exposed in the Corozal quadrangle, but in the Ciales quadrangle (Berryhill, 1965, p. 49), the Pozas conformably overlies rocks that are underlain by the Río Orocovis Group.

Fossils have not been found in the Blacho Tuff Member in the Corozal quadrangle. In the Florida quadrangle (Nelson and Monroe, 1966), the Pozas Formation contains Campanian to Maestrichtian fossils (N. F. Sohl, written commun., 1963).

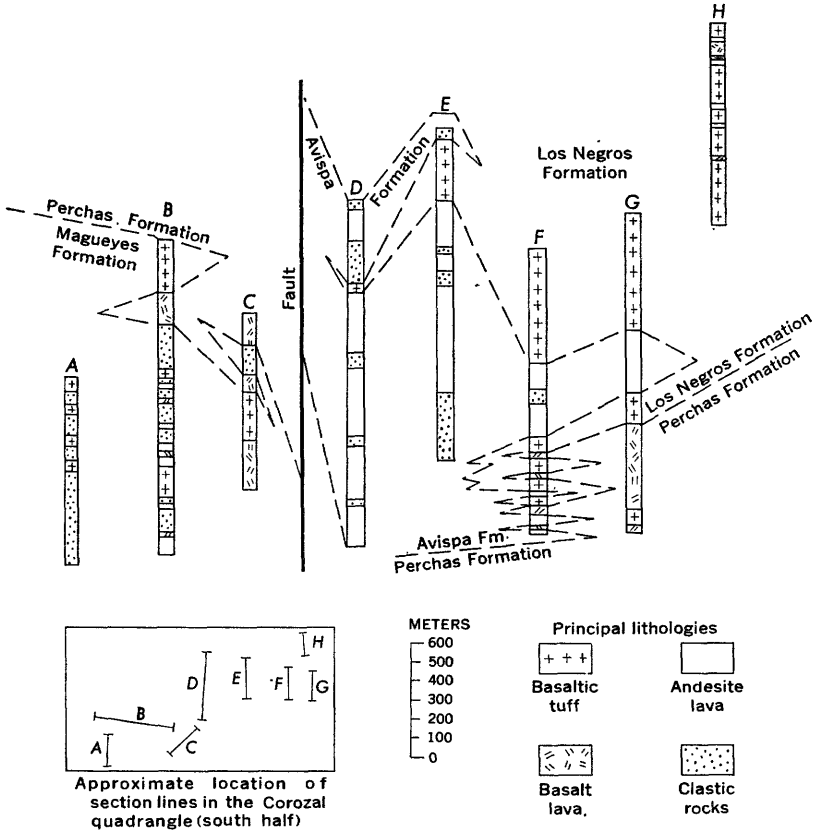

FIGURE 4.—Generalized correlation diagram of the Río Orocovis Group. Only major lithologic types are shown.

CRETACEOUS OR LOWER TERTIARY ROCKS

CIBUCO FORMATION

A conspicuous mappable unit of massive conglomerate and thinner bedded clastic rocks that is well exposed in the west-central part of the quadrangle (fig. 2) is here named the Cibuco Formation for exposures in the Río Cibuco. The type locality is in the valley of the Río Cibuco between coordinates 55,560 and 55,180, about 3 km west-southwest of Corozal. The Cibuco Formation is composed mostly of massive conglomerate or breccia-conglomerate. Pebbles and some angular fragments of porphyritic lava, tuff-breccia, tuff, and diorite are present; detrital quartz and plagioclase grains are common in the finely crystalline matrix. Massive conglomerate in the lower part of the formation grades upward into thinner bedded conglomerate interstratified with volcanic sandstone, siltstone, and bedded tuff, and in the upper part of the formation finer grained clastic rocks predominate. The conglomerate is dark gray where fresh, but where weathered it has a medium-reddish cast.

About 2,000 m of the Cibuco is exposed in the quadrangle, but because of faulting the lower contact is not exposed. The Cibuco is overlain by and interfingers with the lower strata of the Carreras Siltstone (Berryhill, 1965, p. 63–65). The Carreras as defined by Berryhill is Late Cretaceous or early Tertiary in age, and presumably so is the Cibuco.

CARRERAS SILTSTONE

The Carreras Siltstone is exposed in the west-central part of the Corozal quadrangle (fig. 2). It consists of thin-bedded dark-gray to olive-black locally calcareous volcanic siltstone and some thin beds of volcanic sandstone and tuff. A maximum thickness of about 600 m is exposed in the quadrangle. The contact with the underlying Cibuco Formation is placed at the top of the uppermost conglomerate bed. Overlapping middle Tertiary deposits conceal the upper part of the formation.

The Carreras Siltstone is Late Cretaceous or early Tertiary in age (Berryhill, 1965, p. 63–65).

HORNBLENDE TUFF

A distinctive unit of hornblende-bearing tuff and associated epiclastic rocks in the east-central part of the quadrangle extends northwestward to the town of Corozal (figs. 1, 2), where it is concealed by overlying middle Tertiary rocks. These reddish-brown to grayish-purple hornblende-bearing rocks include beds of massive hornblende crystal tuff, tuffaceous conglomerate with some diorite fragments,

laharic deposits, and volcanic sandstone. This hornblende tuff ranges in thickness from 50 to 450 m.

Owing to faulting, the lower part of this unit is not exposed in the quadrangle. Massive crystal tuff at the top of the sequence is conformably overlain by fine-grained volcanic sandstone of the Palmarejo Formation. Lithologic similarities and stratigraphic position suggest that the hornblende tuff and associated rocks may be equivalent to the Cibuco Formation in the western part of the quadrangle, and they are, therefore, also probably Late Cretaceous or early Tertiary in age.

LOWER TERTIARY ROCKS

PALMAREJO FORMATION

An alternating sequence of thin-bedded volcanic sandstone and siltstone is here named the Palmarejo Formation for exposures in barrio Palmarejo (figs. 1, 2). The type locality is designated as the valley of the Río Mavilla between coordinates 166,960 and 167,220 about 750 m south-southeast of Escuela Segunda Unidad de Palmarejo. The formation is exposed almost continuously from the middle of the east border of the quadrangle westward to the town of Corozal, where it pinches out between the hornblende tuff and the Corozal Limestone. Both sandstone and siltstone are gray to dark gray. The sandstone is medium to fine grained and in places calcareous. Its maximum thickness is almost 370 m in the area near Escuela Segunda Unidad de Palmarejo. In the eastern part of the outcrop belt, much of the upper part of the formation is faulted out along the Quebrada San Francisco fault. The Palmarejo conformably overlies the hornblende tuff, and a fine-grained sandstone at the top of the formation is conformably overlain by a fairly thick bed of buff limestone in the base of the Corozal Limestone.

Because of lithologic similarities and stratigraphic position, the Palmarejo Formation may be equivalent to the Carreras Siltstone of Cretaceous or Tertiary age in the western part of the quadrangle. The Palmarejo Formation contains fossils that range from Paleocene to Eocene in age (E. A. Pessagno, written commun., 1965). Pessagno identified Foraminifera collected by V. M. Seiders as *Pseudophragmina* sp.; the specimens were from an outcrop across the road from the cemetery on Route 164 in the eastern part of the Corozal quadrangle.

PROBABLE STRATIGRAPHIC RELATIONS OF CIBUCO FORMATION, CARRERAS SILTSTONE, HORNBLENDE TUFF, AND PALMAREJO FORMATION

The Cibuco Formation and the Carreras Siltstone in the west-central part of the Corozal quadrangle may be equivalent in age to the horn-

blende tuff and Palmarejo Formation, respectively, in the east-central part. Although these two pairs of formations are separated from each other by a fault, they are similar in several respects. They occupy the same relative stratigraphic position, and in both sets of formations the older units are coarse clastics, whereas the younger rocks are fine well-bedded volcanic siltstone and sandstone. In addition, fragments of diorite occur in both the Cibuco Formation and parts of the hornblende tuff.

It may be significant that fragments of intrusive rock, even though they are common in the Cibuco and only rarely occur in the hornblende tuff, are present in both formations. Dioritic intrusive rocks were not emplaced in rocks of the Corozal quadrangle until the later part of the Cretaceous Period, and dioritic fragments have not been observed in the older rocks of the Corozal quadrangle. It is suggested, therefore, that both the Cibuco Formation and hornblende tuff were deposited after the emplacement of dioritic intrusive rocks, possibly about the same time. If the Cibuco Formation and the hornblende tuff are correlative, then the Carreras Siltstone might well be equivalent to the Palmarejo Formation.

COROZAL LIMESTONE

A conspicuous unit of limestone exposed near the town of Corozal is here adopted as the Corozal Limestone (figs. 1, 2), as originally proposed by Berkey (1915, p. 23). The type locality is in the area from coordinates 54,620–165,720 north to coordinate 54,750. Northwest of the town of Corozal, the formation is overlapped by middle Tertiary rocks; 2 km southeast of Corozal the formation pinches out between the Palmarejo and Ortiz Formations, but a small lens reappears a little farther southeast along strike.

The formation is made up mostly of lenticular beds of light-gray limestone and grayish-red limestone breccia. In the lower part, above a basal limestone bed, thin beds of fine-grained calcareous sandstone, siltstone, and a bentonitic clay bed are interstratified with lenses of limestone. Higher in the section the limestone is more massive, commonly fluted and pitted, and in places weathers to a rubbly mass. A nodular limestone underlies a fragmental limestone in the upper part of the formation. Massive coarse breccia is well exposed in a quarry just west of the town of Corozal. Fragments consist mostly of limestone, but small amounts of volcanic rocks are also present. The matrix is somewhat calcareous and consists mostly of grayish-red shale and sandy material. Thin interbeds of shale and limestone are also present in the breccia. The thickness of the formation is variable; it has a maximum thickness of 150 m, and its average thickness is about 80 m.

The Corozal Limestone rests on the Palmarejo Formation and is conformably overlain by the Ortiz Formation. The contact with the Ortiz is locally indistinct; it is placed at the base of a highly calcareous coarse sandstone at the base of the Ortiz.

Kaye (1956, p. 115–117) listed fossils collected from the Corozal quarry and elsewhere in the Corozal Limestone; on the basis of these fossils he considered the formation to be Paleocene or Eocene in age.

ORTIZ FORMATION

A sequence of well-bedded volcanic sandstone, siltstone, and tuff exposed near the settlement of Ortiz (figs. 1, 2) is here named the Ortiz Formation. The type locality is in the Río Corozal between coordinates 55,320 and 55,720. The formation strikes northwest and dips southwest; it is present west, south, and southeast of the town of Corozal. To the southeast it is faulted out by the Quebrada San Francisco fault, and to the northwest it is unconformably overlain by middle Tertiary deposits.

Highly calcareous thick-bedded coarse sandstone with interbeds of dusky-red shale occurs at the base of the formation. This sandstone is overlain by a thin conglomerate bed containing many limestone pebbles. The upper part of the exposed section consists mostly of interstratified somewhat varicolored, red, green, and dark-gray volcanic sandstone and siltstone and pale-green tuff. A thin gray limestone lens is mapped in the upper part of the exposed formation. In places bentonitic clay occurs. The formation has a maximum thickness of 600 m.

The Ortiz overlies the Corozal Limestone conformably and is, therefore, presumed to be of Paleocene or Eocene age. The upper part of the Ortiz is not exposed because of faulting.

MIDDLE TERTIARY ROCKS

SAN SEBASTIÁN FORMATION

The San Sebastián Formation (Zapp and others, 1948) occurs in an irregular westerly trending band in the northern part of the quadrangle (fig. 2). It consists predominantly of reddish-brown and gray sandy carbonaceous clay, locally containing pebbles and cobbles derived from the underlying volcanic rocks. At some places it contains large lenses of clayey and silty fine to very fine sand and thin beds of calcareous sandy clay. Its thickness varies but is generally about 70 m. The San Sebastián rests with angular unconformity on the Cretaceous and lower Tertiary volcanic rocks and is of middle Oligocene age (Zapp and others, 1948).

MUCARABONES SAND

A distinctive unit of quartz sand extends across the northern part of the quadrangle (fig. 2). It is here named the Mucarabones Sand after barrio Mucarabones in the northwest corner of the adjacent Naranjito quadrangle where the formation is well exposed along the Quebrada Piña. The type locality is along Highway 861, 700–2,000 m northwest of its intersection with Highway 827, near the northwest corner of the Naranjito quadrangle. The formation is grayish-orange to grayish-yellow generally crossbedded quartz sand interbedded with glauconitic calcareous sandstone and thin beds of calcareous clay. Locally the sand contains a few persistent layers of hard sandy limestone. Although texture is varied, most of the sand is medium grained. The Mucarabones ranges from 5 to 50 m in thickness in the Corozal quadrangle.

The Mucarabones Sand clearly overlies the San Sebastián Formation in the eastern part of the quadrangle. Toward the west the formation grades laterally into the middle and upper Oligocene Lares Limestone. As far west as the longitude of Corozal, the sand is 40–50 m thick and is overlain by an increasingly thick sequence of Lares Limestone. West of Corozal, successively lower parts of the sand grade laterally into the Lares until near the western boundary of the quadrangle only 5 m of calcareous glauconitic sandstone separates the San Sebastián from the overlying Lares.

In barrio Quebrada Arenas near the northeast corner of the quadrangle, the sand contains at the top a persistent bed of very glauconitic sandy clay rich in tests of the Foraminifera *Lepidocyclina undosa*. The Mucarabones is of middle Oligocene age.

LARES LIMESTONE

The Lares Limestone (Zapp and others, 1948) crops out in a westerly trending band in the northern part of the quadrangle (fig. 2). It is mostly a pale-grayish-orange fairly pure limestone that is locally fragmental. Beds in the upper part are commonly about 20–30 cm thick. The limestone is about 130 m thick in the western part of the quadrangle but thins eastward and grades into the Mucarabones Sand. In barrio Quebrada Arenas and Contorno near the northeast corner of the quadrangle, only the upper 20 m of the Lares is present, and this part of the Lares consists of nontypical grayish-orange thin-bedded calcareous clay. The Lares has a sharp contact with the conformably overlying Cibao Formation.

The Lares Limestone is of Oligocene age (Zapp and others, 1948).

CIBAO FORMATION

The Cibao Formation (Monroe, 1962), which is present in a band across the northern part of the Corozal quadrangle (fig. 2), is divided into four members. At the base is the Río Indio Limestone Member, whose basal beds of dark-yellowish-orange fragmental limestone are in striking contrast to the underlying grayish-orange limestone of the Lares. Higher in the Río Indio Member are some thin beds of hard grayish-orange limestone that resemble the Lares closely and may be confused with it. The Río Indio, which is about 100 m thick west of the Río Cibuco, gradually thins eastward to about 50 m in the barrio Contorno and rests on the upper clay of the Lares Limestone.

The Río Indio Member grades upward into the overlying Quebrada Arenas Limestone Member, which consists of pale-orange to grayish-orange finely crystalline to granular limestone in beds ½–2 m thick interbedded with grayish-orange chalky limestone in beds averaging one-half meter in thickness. The member contains a local 6-m bed of sandy limestone 1 km east of Cerro Santa Bárbara. The Quebrada Arenas ranges from 60 to 70 m in thickness.

At two places in the quadrangle, channels about 10 m deep were eroded in the top of the Quebrada Arenas Limestone Member and filled with alluvium. In the extreme northwest corner, this alluvium, known as the Miranda Sand Member, consists of clayey red and gray mottled medium to coarse sand; in the area near Cerro Santa Bárbara, a similar sand contains a basal unit of coarse gravel.

Resting in sharp contact with the Quebrada Arenas Limestone Member and gradationally with the Miranda Sand Member, where it is present, is about 50 m of locally sandy calcareous clay and clayey sand mapped as an upper unnamed member of the Cibao Formation.

The Cibao Formation is of Oligocene and Miocene age (Monroe, 1962).

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