Cretaceous and Lower Tertiary Stratigraphy in West-Central Puerto Rico

GEOLOGICAL SURVEY BULLETIN 1254-B

Prepared in cooperation with the Commonwealth of Puerto Rico Economic Development Administration, Industrial Research Department

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By PETER H. MATTSON

CONTRIBUTIONS TO STRATIGRAPHY

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CRETACEOUS AND LOWER TERTIARY STRATIGRAPHY IN WEST-CENTRAL PUERTO RICO

By PETER H. MATTSON

ABSTRACT

Volcanic rocks of Cretaceous and early Tertiary age underlie most of mountainous west-central Puerto Rico.

About 6,000 m of thin-bedded tuffaceous sandstone, siltstone, and mudstone and thick-bedded and massive lapilli tuff, coarse tuff, volcanic breccia, volcanic conglomerate, and lava of chiefly andesitic and basaltic compositions constitute the Cretaceous section in the eastern half of the area; in the western half the upper part of the section has been removed by erosion or faulted out. The oldest Cretaceous rocks exposed are probably Early Cretaceous, Albian, in age; the youngest are latest Cretaceous, Maestrichtian, in age. Except for possible local unconformities in the Albian interval and a probable disconformity or moderate unconformity in the Santonian (possibly Coniacian) interval, the record shows that deposition of fragmental volcanic rocks, accompanied by sporadic extrusion of lavas, was nearly continuous from the Albian to the Maestrichtian.

A profound unconformity separates the lower Tertiary sequence from the Cretaceous rocks; no strata yielded fossil collections referred to the Paleocene or lower Eocene, and middle Eocene rocks rest unconformably on rocks ranging from Albian to probably Campanian in age, as well as on some plutonic rocks. About 3,000 m of middle and perhaps upper Eocene volcanic and epiclastic rocks are exposed. The Eocene volcanic rocks are chiefly dacite tuffs and lavas, as opposed to the andesites and basalts that predominate in the Cretaceous sequence.

Widespread intrusive igneous activity occurred from latest Cretaceous to Eocene time, and resulting metamorphism affected strata of all volcanic units from place to place. Part of the Utuado batholith underlies much of the northern part of west-central Puerto Rico. In addition, large faults have broken the area into a complex geological pattern.

INTRODUCTION

As used in this report, west-central Puerto Rico comprises the Adjuntas and Jayuya quadrangles (fig. 1). The chief purpose of the report is to describe in some detail the volcanic stratigraphy of these

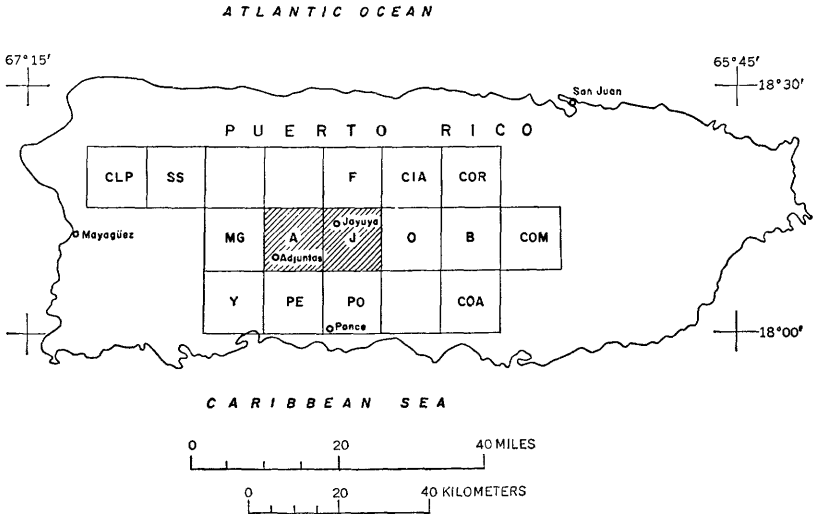


FIGURE 1.—Map showing location of west-central Puerto Rico. The following 7½-minute quadrangles referred to in the text are shown by abbreviations: CLP, Central La Plata; SS, San Sebastián; F, Florida; CIA, Ciales; COR, Corozal; MG, Monte Guilarte; A, Adjuntas; J, Jayuya; O, Orocovis; B, Barranquitas; COM, Comerio; Y, Yauco; PE, Peñuelas; PO, Ponce; COA, Coamo.

quadrangles, but reference also will be made to features in adjacent areas, and units in west-central Puerto Rico will be correlated with previously defined stratigraphic units elsewhere in Puerto Rico.

The geologic map (fig. 2) of this report is a simplified version of separately 1:20,000 scale geologic maps of the Adjuntas and Jayuya quadrangles (Mattson, 1967a and 1967b). Fossil and other data are keyed to localities shown on these maps, and most places referred to in this text are shown only on the 1:20,000 maps.

Places described in the text are located by means of the Puerto Rico Meter Grid System coordinates, tick marks for which are shown along the borders of the 1:20,000 scale geologic maps mentioned above. The east coordinate is given first and the entire coordinate is enclosed in parentheses for clarity, as (143,890 m E.; 34,780 m N.). Location generally are accurate to the nearest 10 meters.

Spanish words, other than place names, used in the text are: barrio, a political subdivision of a municipality; hacienda, estate, large farm, or plantation; lago, lake; quebrada, stream, río, river.

The only two towns in the area are Adjuntas, 77 km southwest of San Juan and 20 km north of Ponce, and Jayuya, 16 km east-northeast of Adjuntas.

The geology of west-central Puerto Rico is being studied as a program of geologic mapping and investigation of the mineral resources of Puerto Rico conducted by the U.S. Geological Survey in cooperation with the Economic Development Administration, Commonwealth of Puerto Rico. Field mapping for the report occupied 38 months in 1960, 1961, 1962, and 1963.

Previous geologic studies in the area were by Kaye (1957), Kaye and Dunlap (1960), Moneymaker (1947a, b), and Weaver (1958).

Fossil identifications by W. S. Cole, E. A. Pessagno, Jr., Otto Renz, K. N. Sachs, and N. F. Sohl are gratefully acknowledged. I am also grateful for permission to study unpublished reconnaissance and detailed geologic maps of A. D. Fraser, Inc., San Juan, P.R., and Ponce Mining Co., Utuado, P. R.; for stimulating discussions with W. R. Bergey, R. Reynoso, J. Sugden, J. D. Weaver, and G. K. Williams; and for access to unpublished geologic maps of the Garzas hydroelectric tunnel by B. C. Moneymaker.

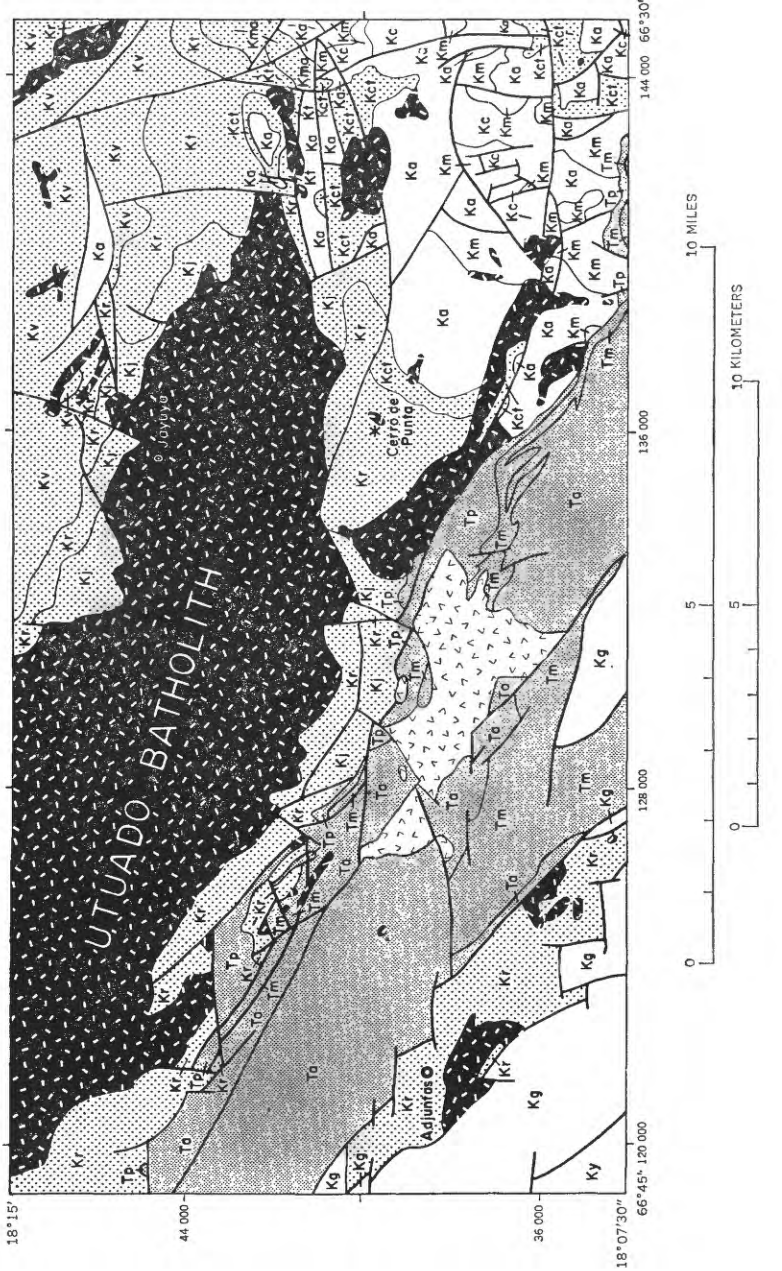
In descriptions of stratified rocks, bedding is described as thin if less than 5 cm, medium if between 5 and 50 cm, thick if between 50 and 100 cm, and massive if larger than 100 cm. Laminations or laminae are planar zones less than 1 cm thick distinguished from adjacent zones by differences in texture, grain size, or composition but are not necessarily parallel to bedding. Stratified rock generally breaks along bedding planes but not along laminae.

Clastic and pyroclastic rocks are named in terms of their predominant grain size, not the maximum size found. If significant, the maximum size may be shown by an adjective, as "conglomeratic" or "pebbly mudstone."

The adjectives "clastic" and "epiclastic" as used herein indicate that such materials have been derived from another rock or another area by erosion and transportation. They do not necessarily imply that the source materials were lithified or are more than slightly older than the level in which the reworked material is deposited.

THE SETTING

West-central Puerto Rico is very mountainous. Nine of the 10 highest peaks in Puerto Rico are in the eastern half of the report area, the Jayuya quadrangle; the highest elevation in Puerto Rico—Cerro de Punta (1,338 m)—is in the east-central part of the report area; the lowest elevation is about 130 m at the southeast corner. The average local relief (the maximum difference in elevation within 3.2-km circles centered on a 1¼-minute grid) is about 420 m.


UTUADO BATHOLITH
Cerro de Punta
Adjuntas
18°15'
18°07'30"
66°45'
66°30'
120 000
128 000
136 000
144 000
44 000
36 000
Kv
Ki
Kr
Ka
Kc
Km
Kcl
Kg
Ky
Tp
To
Tm
Tg
0
5
10 MILES
0
5
10 KILOMETERS

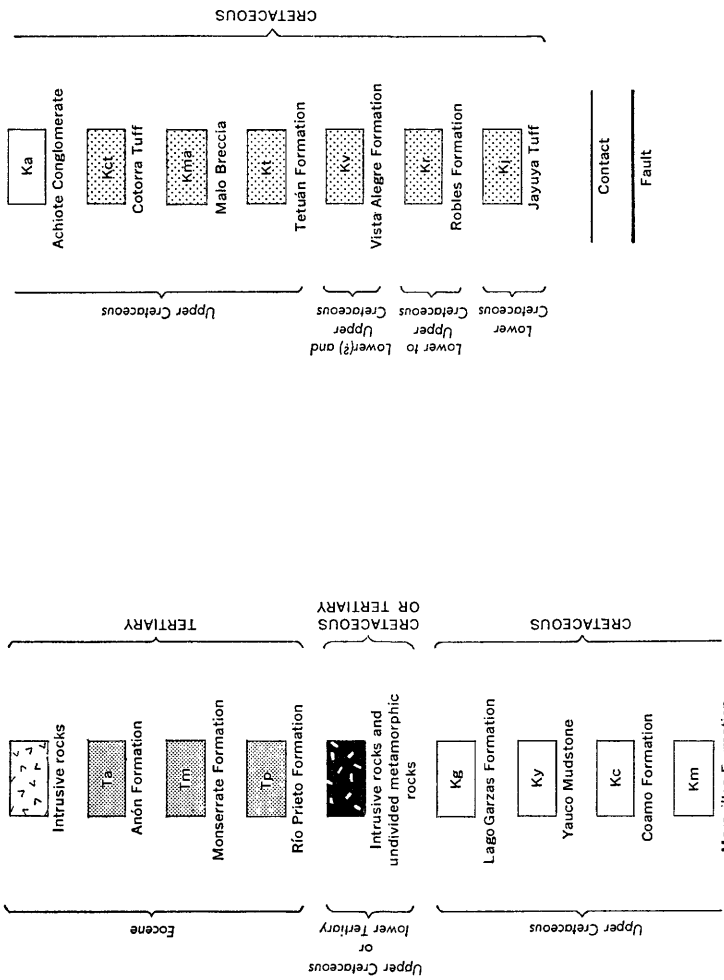


FIGURE 2.—Simplified geologic map of west-central Puerto Rico.

The west-trending Cordillera Central crosses the southern part of the area and separates north-flowing tributaries of two of the master streams of Puerto Rico, the Rìo Grande de Arecibo and Río Grande de Manatí, from the headwaters of the south-flowing Ríos Tallaboa, Cañas, Portugués, San Patricio, Cerrillos, Anón, and Guayo, and minor streams. Rugged topography in the southwestern and eastern parts of the area is developed on bedded and massive volcanic rocks and small bodies of intrusive rock. In the southwest this topography is dominated by long linear valleys that have formed along large northwest-trending faults; in the east the topography has a less well defined northerly trend. In the extreme southwestern corner of the area and on the west side of Cerro de Punta, gently rolling upland on and near the Cordillera Central, at elevations of 750–900 m, is perhaps due to rapid erosion of soft volcanic rocks in a tropical climate with heavy rainfall. The north-central to northwestern part of the area contains only moderately rugged terrain underlain by easily weathered plutonic rocks.

West-central Puerto Rico contains a complex sequence of volcanic and sedimentary rocks cut by large bodies of igneous rock. There has been some metamorphism near the borders of the igneous intrusions. The stratified rocks range in age from Albian(?) to middle Eocene. The composite maximum thickness of Creaceous strata is about 6,000 m, and the composite maximum stratigraphic thickness of lower Tertiary rocks is about 3,000 m. The rocks are folded and highly faulted, and Eocene strata rest unconformably on strata ranging in age from Albain to Campanian, as well as on plutonic rocks. Quartz monzonite, granodiorite, quartz diorite, and diorite were emplaced in Campanian time or later, before deposition of the Eocene sequence, and form the central part of the Utuado batholith. A dacite stock and small stocks of quartz diorite and diorite cut the Eocene sequence. Copper, gold, iron, molybdenum, and manganese minerals occur in pods, small veins, or disseminated grains; two "porphyry copper" bodies and other copper occurrences are found in areas of hydrothermally altered and mineralized rock.

Fresh rock is generally well indurated. Except on the steepest slopes and in some stream beds, all rocks have been deeply weathered and are mantled by thick saprolitic or lateritic clays. Alluvial flood-plain deposits, alluvial fans, and terrace deposits occur in the major river valleys.

CRETACEOUS SYSTEM

JAYUYA TUFF

A sequence of pyroclastic volcanic rocks with some lava and fine-grained sedimentary rocks is herein named the Jayuya Tuff, for exposures in the Jayuya quadrangle north and west of the town of Jayuya. The type locality is on a trail north from route 531 up the slope of Cerro Morales, from (132,730 m E.; 44,740 m N.) to (132,685 m E.; 45,190 m N.). Exposed at the type locality are massive dark-green coarse-grained crystal tuff and lapilli tuff with several lenses 5–10 m thick of greenish-gray laminated medium-bedded silicified mudstone and thin-bedded, graded tuffaceous sandstone. The tuff contains abundant pyroxene and feldspar, lapilli of basalt, and sparse larger crystals.

Mafic volcanic rocks in the Jayuya Tuff occur along the north and east sides of the batholith, and the formation is also present south of the batholith in fault blocks between Hacienda Jauca and Hacienda El Banco. In this area the rocks are highly pyritized, epiodotized, and in part hydrothermally altered. Original textures that are preserved suggest that these deeply weathered gray and grayish-green rocks were feldspathic tuff and lava. In most places within the contact aureole of the intrusion, the rocks are metamorphosed to feldspar-hornblende hornfels, gneiss, and schist; scattered exposures of less metamorphosed rocks occur in many of these areas and also to the south near Cerro Saliente. The less metamorphosed rocks are commonly massive coarse-grained dark pyroxene-rich crystal tuffs; pyroxene-rich lapilli tuffs; and uncommon basalt lavas. In some places, particularly north and northwest of Jayuya, feldspar predominates over pyroxene in the tuffs. The rocks generally form a knobby weathered surface decomposed to brownish-red soil and saprolite.

These mafic rocks are lithologically indistinguishable from rocks of the Cotorra Tuff and mafic volcanic rock lenses in the Vista Alegre Formation. They are also similar in lithology and stratigraphic position to pyroxene-feldspar crystal tuffs mapped to the east in Orocovis quadrangle as a lenticular unit at the top of pre-Robles rocks (Briggs, 1967).

East of Cerro Saliente, about 65 m of green to maroon medium- to thick-bedded laminated siltstone and mudstone, partly silicified, occurs as a lens between the mafic and feldspathic volcanic rocks. Maroon calcareous siltstone, partly bleached and silicified, also forms a small lens in the mafic volcanic rocks about 400 m southward at the north end of the small alluvial deposit in the Río Saliente.

In the valley of the Río Saliente, feldspathic volcanic rocks lie above the mafic volcanic rocks. These rocks are green and gray coarse-grained feldspar crystal tuffs and feldspar porphyry lavas, metamorphosed to hornfels or gneiss in almost all exposures. Small bodies of mafic volcanic rocks occur within the predominantly feldspathic terrain, and vice versa.

The lower part of the Jayuya Tuff is cut out by the Utuado batholith; the upper contact appears to be conformable with the Robles Formation. The rocks south of the batholith are in fault contact with the Robles on the north and west, are probably in fault contact with plutonic rocks on the southwest, and are unconformably overlain by Eocene rocks on the southeast. Massive pyroxene-rich tuff and lapilli tuff of the Jayuya are at least 900 m thick at Cerro Morales, and the feldspathic facies is as much as 600 m thick where it is exposed 2 km northwest of Cerro Saliente. No fossils have been found in the Jayuya Tuff.

ROBLES FORMATION

Bordering the eastern extension of the batholith and eastward in the Jayuya quadrangle, the Robles Formation (defined by Pease and Briggs, 1960) consists of 500–600 m of massive to medium-bedded laminated green, greenish-purple, and blue-gray mudstone with some volcanic siltstone and sandstone. Good exposures are on route 141 northwest of Jayuya. Scattered interbedded layers of fine-grained laminated dark pyroxene-bearing tuff and feldspathic tuff occur near the base of the unit, and there are occasional lenses of pryoxene-bearing lithic lapilli tuff. Within the batholith contact aureole the mudstone is metamorphosed to a fine-grained impure siliceous rock and the coarse-grained volcanic and epiclastic rocks to hornfels. The impure siliceous rock and to a lesser extent the hornfels are the ridge-forming rocks in the central and western parts of the quadrangle.

Near Cerro de Punta and in the east-central part of the report area, the Robles Formation is 2,100–2,500 m thick and also contains conspicuous laminated mudstone, but has a larger proportion of massive laminated tuffaceous siltstone and sandstone, laminated fine-grained pyroxene-bearing tuff, some fine-grained green sedimentary breccia, and basalt and andesite lava flows that are generally less than 10 m thick. Good exposures are on the dirt road from Hacienda Gripiñas to route 143 at Cerro de Punta. Crossbedding and channeling occur at a few localities; one such exposure indicates a current moving towards the northeast. Several lenses, generally less than 10 m thick, of friable coarsely crystalline pure white marble are interbedded with silicified siltstone northwest of Cerro de Punta near the lowest levels of the formation. Here, metamorphism has silici-

fied, epidotized, and pyritized the volcanic rocks and formed hornfels and gneiss near the batholith.

The Robles as mapped in the Cerro de Punta area may include parts or all of the Vista Alegre and Tetuán Formations, as it is overlain in that area by the Cotorra Tuff. This would account for the great difference in thickness between the Robles in this area and the Robles to the north and northeast. Poor exposures, deep weathering, and a probable westward decrease in the pyroclastic Vista Alegre component prevented further division of the Robles in the Cerro de Punta area.

The Robles Formation is also exposed in a northwest-trending horst near Adjuntas, in a belt along the southwest edge of the Utuado batholith, and in a small area northeast of the batholith. In the horst near Adjuntas are greenish-gray medium-bedded volcanic sandstone and some green and blue-gray laminated mudstone with interbedded feldspathic tuff and some andesite(?) lava. The relative amount of epiclastic and sedimentary rocks is greater, and the pyroclastic rocks are finer grained in the horst than in Robles areas to the north. Epidotization, chloritization, and pyritization are more pronounced near the two small plutons than elsewhere in the horst, and some hornfels is exposed near the plutons.

Within the horst, near Guaraguao, are several exposures of a lenticular biostrome as much as 10 m thick that contains abundant oysters and sparse calcareous algae. The matrix of the biostrome is generally dark limestone or limy mudstone, but in some places is a cream-colored lutite. Shale interbeds, in some places containing gastropod molds, are exposed within and bordering the biostrome.

Along the southwestern border of the batholith, the Robles Formation is more volcanic in character than in the horst. Dark-green basalt lava with pyroxene phenocrysts is common andesite(?) lava is less common, and there are some pyroxene-bearing coarse-grained tuffs and lapilli tuffs. Medium-bedded volcanic sandstone and mudstone are interbedded with the extrusive rocks and underlie a large part of the area west of the Río Grande de Arecibo, but the epiclastic facies could not be shown separately from the extrusive facies on the geologic map (Mattson, 1967a). Near the batholith the epiclastic rocks are epidotized and pyritized, the matrix of the effusive rocks is recrystallized to hornfels, and amphibole replaces some of the pyroxene phenocrysts in the lavas. Along the southwestern edge of the batholith, the Robles is about 650 m thick, thickening westward to at least 1,300 m, whereas it is approximately 1,000–2,000 m thick in the horst near Adjuntas.

The Robles overlies the Jayuya Tuff, and in the eastern half of the area it underlies the Vista Alegre Formation and Cotorra Tuff.

Map relations indicate that both lower and upper contacts are gradational in the east, but in the west the Robles is overlain unconformably by Eocene rocks along the south edge of the exposures that border the batholith. The only evidence for the unconformity in the west is the absence of the Achiote Conglomerate and other Cretaceous formations that overlie the Robles in the east.

In the Adjuntas quadrangle the Robles may be stratigraphically equivalent to the Jayuya, Vista Alegre, Tetuán, or Cotorra Formations in the Jayuya quadrangle and farther east, but rock units that could be correlated with these formations were not discovered. The Robles and Tetuán are more epiclastic and contain less effusive volcanic material than the Jayuya, Vista Alegre, and Cotorra, which are dominantly pyroclastic and effusive volcanic rocks. The five formations are lithologically similar to each other and are gradational into or interfinger with each other in part; hence it is difficult or impossible to map them across major structural breaks. Therefore, from Cerro de Punta westward, the entire stratigraphic unit is called the Robles Formation.

The Robles Formation is composed of sedimentary and volcanic rocks, probably largely deposited under shallow to moderately deep water marine conditions. This is shown by the interbedding of lavas with marine deposits, the presence of graded bedding, an oyster biostrome and other limestone lentils, and marine sedimentary directional features seen near Cerro de Punta and at three localities in the horst near Adjuntas. Crossbedding at (126,435 m E.; 32,550 m N.) in the Río Cañas shows a north-northwest-directed current. Load casts at (123,635 m E.; 36,170 m N.) on the north side of Río Saltillo show a northward-dipping slope, but fold axes of slumped beds at (125,370 m E.; 33,900 m N.) on route 10 show a west-southwest-dipping slope.

The only fossils found in the Robles Formation in west-central Puerto Rico are abundant specimens identified by N. F. Sohl (written commun., 1963) as a new species of the oyster *Crassostrea*, and compressed unidentifiable internal molds of turriculate snails. The fossils are in an oyster bank and surrounding shales at USGS locality 28752 (127,040 m E., 32,410 m N.) and USGS locality 28753 (126,710 m E., 32,490 m N.) in the southern Adjuntas quadrangle, and at USGS locality 28754 (128,000 m E., 31,090 m N.) in northern Peñuelas quadrangle about 1,200 m south of Adjuntas quadrangle on route 10. Foraminifera of Albian, Cenomanian, and possibly Santonian age have been described in the Robles Formation about 25 km to the east (Douglass, 1961; Otalora, 1961).

VISTA ALEGRE FORMATION

Massive to medium-bedded crystal-lithic tuffs and subordinate volcanic sediments and lava are continuous with the Vista Alegre Formation (Nelson and Monroe, 1966) of the Florida quadrangle to the north. A reference locality within the Jayuya quadrangle is on the west bank of the Río Toro Negro on route 149, from (143,530 m. E.; 43,020 m. N.) to (142,870 m. E.; 44,510 m. N.). The Vista Alegre is extensively exposed in the north-central to northeastern parts of the report area.

The formation at the reference locality consists predominantly of coarse-grained dark-green pyroxene-feldspar crystal tuff interbedded with coarse-grained greenish gray feldspar crystal-lithic tuff. There are also minor amounts of lapilli tuff and volcanic sandstone, siltstone, and mudstone. The rocks are medium bedded to massive, and there are some massive laminated mudstones similar to those in the Robles Formation. Pyroxene, plagioclase, and volcanic rock fragments are abundant in the tuffs; hornblende, biotite, and quartz are sparse. In some places red volcanic scoria gives the rock a variegated appearance. Lenses of greenish-gray epiclastic breccia are exposed at a few localities; fragments are generally lavas and aphanitic volcanic rocks as much as 3 cm in size.

Crossbedding occurs at two localities in the tuff (Mattson, 1967b); one shows east- and the other northwest-directed current. These current directions, common regular bedding, and interbedded marine sedimentary rocks indicate that the formation was formed under marine conditions.

One large lens of mafic volcanic rocks was mapped north of Jayuya; another, in the northeast corner of the area. The lenses contain basalt and massive coarse-grained basaltic tuff. Some samples of the basalt contain pseudomorphs after olivine, but generally only pyroxene and plagioclase occur as phenocrysts. In the north-central part of the map area (Mattson, 1967b) andesite (?) lava forms at least one flow or series of flows. The basalt, basalt tuff, and andesite(?) are petrographically similar to rocks of the Río Orocovis Group (Nelson, 1966) exposed northeast of the Jayuya quadrangle.

The Vista Alegre Formation is estimated to be 1,000–1,700 m thick in the eastern part of the Jayuya guadrangle, but thins to about 950 m in the western part of the Jayuya and in the southern part of the Florida quadrangles. Near Cerro de Punta the Vista Alegre, if present, is included in the Robles Formation for reasons given above. Contacts of the Vista Alegre with the overlying Tetuán Formation and the underlying Robles Formation are both gradational. No identifiable fossils were found in the formation.

TETUÁN FORMATION

Rocks assigned to the Tetuán Formation (Nelson and Monroe, 1966) are exposed on both sides of the valley of the Río Toro Negro in the eastern part of the area; the Tetuán was not recognized in the Adjuntas quadrangle. Good exposures are on a jeep road from Hacienda Ralate toward Los Tres Picachos, and also on the lower part of another jeep road extending up the next spur to the south.

The Tetuán Formation contains thin- to medium-bedded, laminated volcanic mudstone and sandstone interbedded with medium-bedded to massive coarse-grained feldspar crystal-lithic tuff. The rocks are greenish gray, gray and lavender. Graded bedding was rarely observed. Conglomeratic volcanic sandstone layers are common in the upper part of the formation west of the Río Toro Negro and may be equivalent to the Malo Breccia to the east. Two thin andesite(?) flows were mapped; one olivine basalt flow was seen but not mapped about 800 m north of Hacienda Figueroa.

The formation overlies the Vista Alegre Formation gradationally and is overlain, probably conformably, by the Cotorra Tuff west of the Río Toro Negro. East of the river, stratigraphic relations and thicknesses are approximate because of difficult access.

The Tetuán Formation is approximately 1,200 m thick west of the Río Toro Negro, but only about 460 m thick east of the river where the upper part of the Tetuán apparently interfingers with the Malo Breccia. No fossils have been found in the formation.

MALO BRECCIA

The Malo Breccia (Briggs, 1967) occurs only on the east-central boundary of the report area east of the Río Toro Negro. It is composed of green and gray volcanic breccia, lapilli tuff, and coarse-grained tuff with sparse volcanic sandstone, siltstone, and conglomerate. The tuffs and breccias contain fragments of volcanic porphyries, pumice, common feldspar, some pyroxene, and sparse hornblende and biotite, in a matrix of secondary chlorite, zeolite, and small pyroclastic or epiclastic feldspar crystals. Rocks are commonly epidotized, pyritized, and calcified, particularly in the westernmost exposures.

The Malo is very poorly exposed in the report area. It overlies the Tetuán Formation gradationally and is overlain by the Achiote Conglomerate. The contact with the Achiote is only known approximately; it could be either conformable or unconformable with small angular discordance. The Malo is 250–600 m thick in this area, thinning abruptly westward until it disappears at the Río Toro Negro. No fossils were found in the formation.

COTORRA TUFF

Pyroclastic rocks and basalt lava, in part continuous with the Cotorra Tuff of the Orocovis quadrangle (Briggs, 1967), are exposed in the southeastern part of the report area and east and south of Cerro de Punta. It was not recognized in the Adjuntas quadrangle. Good exposures are in the Río Toro Negro at Toro Negro Central Hidroelectrica Num. 2 and in and near Quebrada Achiote.

In the Jayuya quadrangle the Cotorra Tuff consists largely of dark-green and greenish-black coarse-grained tuff and lapilli tuff with minor volcanic breccia and basalt lava. The rocks are rudely bedded or sheeted in some places but are massive, sparsely laminated, at most localities. Pyroclastic components of the tuff are predominantly monoclinic pyroxene and fragments of pyroxene porphyries. Feldspar and hornblende crystals, fragments of hornblende porphyries, and fragments of hornblende-pyroxene porphyries are less common. Fragments are cemented by calcite, chlorite, and zeolite; some chlorite bodies probably represent altered volcanic glass.

Basalt lava and pyroclastic rocks containing fragments of basalt lava predominate in the Quebrada Achiote area. The lava commonly has pillow structures averaging 1 meter in longest dimension. It contains phenocrysts of augite and altered olivine(?) in a felty or trachytic matrix of feldspar, chlorite, and pyroxene. The presence of pillow structures and calcareous cement suggests that the Cotorra is a marine deposit.

Rock types in the Cotorra Tuff are similar to those found in lenses of volcanic rock in the Vista Alegre Formation, in the Jayuya Tuff, and in the Los Negros and Perchas Formations exposed to the northeast (Nelson, 1966). North of Quebrada La Mina in the Jayuya quadrangle the Cotorra overlies the Tetuán Formation, probably conformably; it overlies the Robles Formation gradationally near Cerro de Punta. The formation is overlain by the Achiote Conglomerate conformably or by an angular discordance too small to be measured by available data. North of Quebrada La Mina the Cotorra is about 90 m thick; it thickens to more than 250 m to the south and to about 460 m to the west near Cerro de Punta. No fossils have been found in the formation.

ACHIOTE CONGLOMERATE

Distinctive red and purple tuffaceous conglomerate and associated sandstone are herein named the Achiote Conglomerate after good exposures on the west side of the valley of Quebrada Achiote in the southeastern part of the Jayuya quadrangle. The type locality is on route 149 from (144,220 m E.; 35,200 m N.) to (144,145 m E.; 34,060 m

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N.). The Achiote is extensively exposed near the type locality; it is also exposed on and north of the Cordillera Central, in several areas a few kilometers north of the southern border of the quadrangle, and in a graben in the northeastern part of the quadrangle. It does not crop out in the Adjuntas quadrangle.

At the type locality the Achiote consists of massive red volcanic conglomerate with well-rounded clasts as large as 150 cm in diameter but generally no larger than 10–20 cm. The clasts are red and green andesites and some chert; the matrix contains feldspar and red hematitic pellets in a red mudstone. Interbedded with the red conglomerate are green tuffaceous conglomeratic sandstones and conglomerate. The green rocks contain the same clasts as the red conglomerate but have a feldspar-chlorite matrix. There also are interbeds of thin- and medium-bedded red and greenish-gray tuffaceous sandstone and red mudstone. Graded bedding and channeling are present in the red conglomerate, and the exposures are cut by thin dikes and sills of blue-green pyroxene-feldspar porphyry.

Greenish-gray tuffaceous conglomerate and finer grained clastic and tuffaceous rocks are found throughout the exposure area in the Jayuya quadrangle, but are less common than the red more epiclastic tuffaceous conglomerate in most areas. In the extreme southeast corner of the quadrangle east of El Semil, however, green rocks are common at all exposed levels of the formation.

The clasts in both conglomerates are generally well rounded but in some places are elongate and alined parallel to bedding; they are as large as 150 cm in diameter but the maximum size in a single locality is about 12 cm. The larger cobbles and boulders in many places "float" in the matrix, not touching each other. Volcanic porphyries are the most common clasts; these include basalt and andesite similar to lavas in the Jayuya, Vista Algre, Cotorra, and other formations in the area, and less commonly feldspar-quartz, feldspar-hornblende, and feldspar-pyroxene-biotite porphyries, not common in the older rocks. The porphyries are red, purple, or greenish gray. Other less common clasts are tuff, siltstone, limestone, sparse fossils, and red chert.

The matrix of the conglomerates is tuffaceous sandstone and mudstone; similar sandstone and mudstone are interbedded in the formation. It is largely pyroclastic but is sorted and reworked at some levels, particularly in the red facies. Feldspar and small chloritized porphyritic volcanic rock grains are most common; pyroxene, hornblende, and magnetite crystals and fresh porphyritic volcanic rocks form a minor part of the matrix. These clastic and pyroclastic grains are cemented by chlorite, zeolite, and calcite. The red facies commonly contains more calcite cement than the green facies.

Common oxidized clasts and matrix, common calcite cement, good sorting and reworking, some graded bedding and channeling, large size of the clasts, and the abrupt variation in stratigraphic thickness (Mattson, 1967b, section *E–E'*) suggest a shallow marine or fluviatile, deltaic environment for the red conglomerate and sandstone facies of the Achiote.

The Achiote Conglomerate is 200–400 m thick in the southeastern part of the Jayuya quadrangle but thickens westward to perhaps as much as 1,800 m between Cerro Maravillas and Monte Jayuya on the Cordillera Central, where the obscure structure of the Achiote prevents accurate measurement. It overlies the Cotorra Tuff except east of the Río Toro Negro, where it overlies the Malo Breccia. As the Cotorra is present again a few kilometers to the east, where it occurs between the Achiote and the Malo, it may have been removed by pre-Achiote erosion in the area east of the Río Toro Negro. The Achiote contact is conformable on the Cotorra or, at most, unconformable with slight angular discordance; contact relations with the Malo are obscured by tropical weathering and lack of outcrops. The Achiote grades upward into the Maravillas Formation, and the contact is defined as the top of the highest massive conglomerate.

The Achiote is the approximate stratigraphic equivalent of the massive conglomerate facies of the Cariblanco Formation of the northeastern part of Coamo quadrangle (Glover, 1961): the green facies of the Achiote is similar to marine volcanic conglomerates of the Cariblanco. A minimum thickness of 400 m of weathered conglomerate and sandstone, exposed in a graben near the Río Cialitos in the northeastern corner of the report area, is correlated with the Achiote on the basis of lithologic similarity. The rocks are red and purple tuffaceous conglomerates and sandstones, are moderately well sorted, and contain clasts of andesites and red and gray chert. Red volcanic sandstone and conglomeratic sandstone on route 157 in the Damian Abajo area of northwestern Orocovis quadrangle at (146,680 m E.; 45,070 m N.) and (147,165 m E.; 45,070 m N.) are also similar to rock types in the Achiote Conglomerate.

Fossil collection USGS 28761 (143,890 m E.; 34,780 m N.) in greenish-gray tuffaceous conglomerate in the upper part of the Achiote contains the pelecypods *Cymella bella* Conrad, *Cardium* (*Granocardium*) sp., and *Veniella* sp., and the gastropods *Pugnellus* sp. and *Cantharulus* sp. (N. F. Sohl, written commun., 1963). Sohl considers the collection Late Cretaceous, Santonian to Maestrichtian, in age. Otalora (1961) reports Coniacian or Santonian Foraminifera from the base of his Ildefonso Formation stratigraphically equivalent to the Cariblanco Formation of Glover (1961) and hence also to the Achiote

Conglomerate. However, Briggs and Gelabert (1962) consider the Ildefonso fossil locality to lie in the Robles Formation. Pessagno (1962, 1963, and written commun., 1961–64) has described numerous Santonian and Campanian assemblages from the overlying Maravillas Formation. Thus the Achiote conglomerate is of Late Cretaceous age, probably Santonian and perhaps in part as old as Coniacian.

MARAVILLAS FORMATION

The Maravillas Formation is here defined as a unit of well-bedded volcanic sandstone and siltstone, with some pyroclastic rocks, lying above poorly bedded Achiote Conglomerate and below poorly bedded coarse volcanic rocks of the Coamo Formation. It is named after Cerro Maravillas on the Cordillera Central, and its type locality is on route 143 east from Cerro Maravillas between (139,450 m E.; 35,360 m N.) and (140,530 m E.; 35,180 m N.). It is also exposed near Lago El Guineo, in the valley of Quebrada Doña Juana, and near the southern border of the quadrangle.

The type locality contains about 80 m of massive brownish-gray coarse-grained lithic tuff, overlain by about 300 m of medium- to thick-bedded volcanic siltstone and sandstone with common hornblende-feldspar porphyry dikes and sills. The bedded rocks are dark-gray and brown laminated tuffaceous siltstones and sandstones with some beds of crystal-lithic tuff similar to the tuff member at the base of the formation Channeling, slump structures, and graded bedding exposed at (140,320 m E.; 35,300 m N). indicate a south-southeast-facing depositional slope. Foraminifera and calcite cement, in addition to current features, suggest a marine environment for both the basal coarse-grained lithic tuff and the overylying well-bedded rocks.

Rock types common in the well-bedded part of the Maravillas Formation are muddy dark feldspathic sandstone, siltstone, and mudstone; green crystal-lithic coarse-grained tuff; and silty brown coarse-grained crystal tuff. Beds range from less than 5 cm to as much as 100 cm in thickness, but are generally less than 50 cm thick. Pyroclastic fragments include crystals of feldspar, amphibole, pyroxene, and sparse quartz, and green finely trachytic- and felty-textured volcanic rocks. The green fragments, probably largely chloritized, devitrified glassy rocks, give the coarse-grained green tuff its color. The matrix of the pyroclastic rocks is calcite, chlorite, and zeolite, with some compressed perlitic material. The green tuff contains less reworked material than the other rock types and is more common near the base of the formation than elsewhere.

A thick lens of brownish-gray lapilli tuff and coarse-grained tuff occurs at the base of the formation in several areas and may be continu-

ous; however it could not be mapped south of the Cerro de Punta fault. It contains crystals and crystal fragments of feldspar, hornblende, and pyroxene, and fragments of green, gray-green, and brown volcanic rocks set in coarse-grained feldspathic tuff. The coarse-grained tuff matrix is well sorted and cemented by calcite in some localities but is poorly sorted and muddy in other places. Common green and brown aphanitic and sparsely porphyritic volcanic rock fragments produce a similarity to tuffs of the Eocene Anón Formation. East of the Quebrada Achiote, the lens is a well-sorted crystal-lithic coarse-grained tuff and lapilli tuff resembling the salt-and-pepper facies of the Coamo Formation (see below).

The sandstone, siltstone, and mudstone have a smaller proportion of pyroclastic fragments, similar to these described above, in a matrix of carbonate and mud. Both pyroclastic and sedimentary rocks contain scattered Foraminifera and occasional Radiolaria. Thin lenses of medium- to dark-gray fragmental limestone occur at several levels generally in the lower parts of the formation; one lens is shown on the geologic map (Mattson, 1967b). Some reworked blocks of similar limestone occur near limestone lenses just above the coarse-grained tuff and lapilli tuff lens near route 149 and eastward.

South of Cerro Maravillas near a pluton of the Utuado batholith, strata of the Maravillas Formation have been metamorphosed to a moderate degree with the formation of epidote. Near the Río Guayo and the Quebrada Chiquita, the formation has been silicified and pyritized.

The Maravillas Formation is at least 380 m thick at the type locality and thickens to at least 560 m, a few kilometers to the south. The lapilli tuff and coarse-grained tuff lens is generally 50–80 m thick but is at least 200 m thick east of the Quebrada Achiote.

The Maravillas Formation interfingers with and grades downward into the Achiote Conglomerate; it is overlain conformably by the Coamo Formation. It is a mappable unit in the Jayuya quadrangle and is stratigraphically equivalent to the upper bedded part of the Cariblanco Formation and the lower bedded part of the Coamo Formation, as defined in the Coamo quadrangle (Glover, 1961). Limestone blocks and lenses in the Maravillas near route 149, just above the coarse-grained tuff and lapilli tuff lens, may be correlative with the Santa Ana Limestone Member of the Coamo Formation (Glover, 1961). If so, the lapilli tuff and coarse-grained tuff lens of Jayuya quadrangle may be correlative with the San Diego Lapilli Tuff Member of the Coamo Formation; the discontinuous bedded part of the Maravillas that occurs below the lapilli tuff and coarse-grained tuff lens would then correlate with the Sabana Hoyos Limestone Member and perhaps

the unnamed siltstone and sandstone member of the Cariblanco Formation (Glover, 1961). As none of these thin units are mappable across the area of Maravillas exposures, no names are applied to the members in west-central Puerto Rico.

Three of the four fossil collections from the Maravillas Formation give useful age information (table 1). These data indicate that the Maravillas Formation is Late Cretaceous in age, probably late Santonian and Campanian and possibly as young as Maestrichtian in the upper parts. This age agrees with that of numerous Santonian, Campanian, and Maestrichtian assemblages in the Maravillas in the adjacent quadrangle to the east and in correlative rocks to the southeast in the Coamo and Rio Descalabrado quadrangles (Pessagno, 1962, 1963; N. F. Sohl, written commun., 1957–1963).

TABLE 1.—*Fossil collections in the Maravillas Formation, west-central Puerto Rico*

	USGS locality			
	28758	J45-317	J47-347	J47-358
Turritella trilira Conrad	×			
Pseudoaulophacus floresensis(?)		×		
P. sp		×		
Globigerinelloides sp		×		×
Globotruncana bulloides		×		×
G. stuartiformis(?)		×		
G. fornicata		×		?
G. lapparenti s.s		?		×
G. sp.(?)			×	

USGS 28758. (142,925 m E.; 32,880 m N.); N. F. Sohl, written commun., 1963: Late Cretaceous—Campanian-Maestrichtian.
J45-317. (141,990 m E.; 34,660 m N.); E. A. Pessagno, written commun., 1963: Late Cretaceous—late Santonian-early Campanian.
J47-347. (140,870 m E.; 33,335 m N.); E. A. Pessagno, written commun., 1963—Late Cretaceous(?).
J47-358. (140,625 m E.; 33,350 m N.); E. A. Pessagno, written commun., 1963: Late Cretaceous—late Santonian.

COAMO FORMATION

Glover (1961) defined the Coamo Formation in Coamo quadrangle stating that "tuff-breccia, lapilli tuff, and tuffaceous conglomerate make up the bulk of the Coamo Formation in the Coamo quadrangle." However, he included within the Coamo Formation several bedded units that lie below the massive volcanic rocks. These are the San Diego Lapilli Tuff Member, the Santa Ana Limestone Member, an unnamed conglomerate unit, and unnamed sandstone and siltstone units. In west-central Puerto Rico, the Coamo Formation has been restricted to the massive volcanic rocks, and the Maravillas Formation (see above) has been defined to include the sequence below the restricted Coamo and above the Achiote Conglomerate.

In the Jayuya quadrangle the Coamo Formation is exposed in a trapezoidal fault block on the Cordillera Central near Lago Guineo,

on both sides of the valley of Quebrada Doña Juana, and in a small area at the extreme southeast corner of the quadrangle. The Coamo does not report out in the Adjuntas quadrangle. It is deeply weathered almost everywhere; in the area south of Quebrada Doña Juana, the only fresh rocks generally exposed are porphyry dikes cutting the formation.

The Coamo Formation in west-central Puerto Rico consists of coarse-grained tuff, lapilli tuff, and fine-grained volcanic breccia with a small amount of limestone and lava or intrusive rock. The largest fragment seen in the breccia was 30 cm. The rock is generally massive, but some coarse-grained crystal tuffs show layering and graded bedding, as near Misión Noel on route 143. Three pyroclastic rock types are common in the formation: salt-and-pepper tuff, green tuff, and muddy tuff. All occur in the size range from coarse-grained tuff to fine-grained volcanic breccia. The salt-and-pepper tuff facies is generally a crystal-lithic coarse-grained tuff and lapilli tuff, containing fragments of common to abundant feldspar, common hornblende, scarce quartz, sparse corroded and altered biotite(?), and common porphyritic and aphanitic volcanic rocks. There is a minor amount of chlorite, zeolite, and calcite cement. Sorting is generally good, but some localities show graded beds. The rock presents a green and white or black and white speckled appearance, in places resembling hornblende diorite. Saprolitic soils formed on this facies are yellow-brown to white and resemble soils derived from plutonic rocks. The salt-and-pepper facies generally occurs in the lower part of the formation in this quadrangle. It is quite similar to rocks of the San Diego Lapilli Tuff Member (Glover, 1961) and its correlative, the unnamed lapilli tuff lens of the Maravillas Formation, but is at a higher stratigraphic level than those units.

The green tuff facies in general contains fewer crystals, less hornblende, and more green lithic fragments than the salt-and-pepper facies. Quartz was not seen; some samples contain fragmental pyroxene. The color of the rock is caused by common green chloritized porphyritic and aphanitic volcanic rock fragments. This facies is generally a lapilli tuff or fine-grained volcanic breccia; it is similar to but generally coarser grained than the green tuff facies of the Maravillas Formation. The facies occurs throughout the Coamo but is more common in the upper portions.

The muddy tuff facies contains as much as 40 percent chloritic clay and silt matrix. Pyroclastic fragments are of volcanic rocks and some feldspar. The facies occurs at various levels within the formation and is also similar to pyroclastic rocks in the underlying Maravillas Formation.

One lava or sill is exposed at (142,600 m, E.; 34,360 m, N.). It is a dark bluish-gray pyroxene andesite(?) having an intergranular porphyritic texture, and contains chlorite pseudomorphs perhaps after a second type of pyroxene. Volcanic breccias in the formation contain fragments of similar rocks.

A lens of dark fragmental limestone as much as 5 m thick is exposed east of Hacienda San Clemente, and another thicker lens forms a dip slope west of the hacienda. The eastern lens has wavy bedding and contains fragments of rudists, bryozoa, and Foraminifera; the western lens is recrystallized and epidotized. The stratigraphic relation of the two lenses could not be determined because of an intervening igneous intrusion.

The Coamo Formation overlies the Maravillas Formation conformably; its upper contact has been removed by faulting and erosion. It has an exposed thickness of about 300 m in west-central Puerto Rico. Only one fossil locality has been discovered within the formation in this area. In a collection from (140,990 m E.; 34,500 m N.), in the eastern limestone lens near Hacienda San Clemente, E. A. Pessagno, Jr. (written commun., 1963), identified *Globotruncana stuartiformis* and *Sulcoperculina dickersoni*(?). His age assignment of the collection is Late Cretaceous, Campanian or Maestrichtian. The collection is probably from near the middle of the part of the formation exposed in the Juyuya quadrangle. As the underlying Maravillas Formation is Santonian and Campanian in age, possibly as young as Maestrichtian, the Coamo Formation is therefore Campanian or Maestrichtian in age. No fossils younger than Maestrichtian have been found in the Coamo in Puerto Rico.

YAUCO MUDSTONE

The Yauco Mudstone (Mattson, 1960) is exposed only southwest of the Garzas fault in the Adjuntas quadrangle in west-central Puerto Rico. Mitchell (1922, p. 249) named the formation for exposures along route 128 north of Yauco along the Río Yauco, but did not specify a type locality. Slodowski (1956, p. 62 ff.) mentioned good exposures of the Yauco in the same area but did not describe a type locality either. For the purposes of reference, one of the localities mentioned by Slodowski is herein described as the type locality and two others as reference localities.

Exposures at (106,930 m E.; 31,220 m N.) on route 128 north of Escuela Arturo Lluberas in northwestern Yauco quadrangle are herein designated as the type locality for the Yauco Mudstone. About 5 m of rhythmically bedded calcareous mudstone and mudstone occurs in paired beds composed of a bed of fissile mudstone that grades upward

into a bed of more calcareous mudstone. The calcareous mudstone is dark gray and forms 5- to 60-cm beds; the fissile mudstone is also dark gray and forms layers ranging from thin partings to beds as much as 15 cm in thickness. There are a few beds of dark-brownish-gray fragmental limestone that contain some Foraminifera. The beds dip about 20° ENE. and are gently deformed into folds of about 0.5 m amplitude and 2 or 3 m half wavelength; a small thrust fault dips 45° NE. and has an apparent throw of about 20 cm.

One reference locality is defined as the exposures in a quarry at (107,220 m E.; 30,970 m N.), on route 373 about 300 m east of the intersection with route 128, in northwestern Yauco quadrangle. Here about 40 m of thick to massively and evenly bedded mudstone is exposed in beds 0.5–7 m thick, cut by joints and calcite veins. The mudstone here is a dark-bluish-gray feldspathic calcareous siltstone that, above the quarry, weathers to thin- or medium-bedded brown rock. There are some beds of light-gray feldspathic coarse-grained tuff with calcareous cement. In nearby areas on routes 128 and 373, a massive grayish-tan rock that forms abundant pencil-fractured chips is probably the weathering product of this rock type.

Another reference locality is at (106,730 m E.; 31,470 m N.), in the Yauco quadrangle on route 128 north of the type locality. Here about 8 m of pencil-fractured calcareous mudstone, thin- to medium-bedded and blue gray, is interbedded with thin beds of black mudstone or argillaceous limestone, and with 20- to 50-cm beds of feldspathic coarse-grained tuff. Also present are a 1-m bed and a 70-cm bed of brownish-tan fragmental foraminiferal limestone that grades upward into calcareous mudstone.

In the Adjuntas quadrangle the Yauco Mudstone is thin- to medium-bedded calcareous mudstone and feldspathic sandstone, blue-gray or brownish-gray; it weathers to brick-red saprolite and soil. There are some beds of brown and red-brown feldspathic coarse-grained tuff and lapilli tuff. Scattered glauconite(?) flakes and glauconitic(?) worm trails occur locally, and there is some graded bedding. One fault-bounded area of massive purple-weathering crystal-lithic coarse-grained tuff is herein included in the Yauco because similar rocks intertongue with the Yauco to the southwest.

The Yauco Mudstone crops out more or less continuously westward, to the west coast of Puerto Rico. Slodowski (1956) estimated a minimum thickness of 1,500 m for the formation in the quadrangles adjacent to the present map area, and Mattson (1960) estimated a thickness of 2,400–2,800 m, thinning southward, about 30 km to the west. No thickness for the Yauco could be measured in the Adjuntas quadrangle because of structural complexity; the only contacts seen are faults. To

the west, the Yauco is the northern and eastern component of the Mayagüez Group of Mattson (1960). Mattson's Mayagüez Group overlies the Albian(?) Río Loco Formation of Otalora (1961) and is overlain by the Maestrichtian San Germán Formation of Mattson (1960). The Yauco Mudstone is equivalent to the Río Yauco Formation of Slodowski (1956) in the Yauco quadrangle, the Peñuelas and Río Yauco Shales of Mitchell (1922), and the Río Yauco Series of Hubbard (1923).

No fossil collections have been made from the Yauco in west-central Puerto Rico. To the west, many Foraminifera of Late Cretaceous (Campanian and Maestrichtian) age have been reported by Slodowski (1956), Pessagno (1960, 1962), and Mattson (1960). A few foraminiferal age ranges permit the existence of rocks as old as Turonian or Santonian within the formation, but no collections contain forms definitely older than Campanian. Therefore, the Yauco is considered of Campanian or Maestrichtian age in the Adjuntas quadrangle.

LAGO GARZAS FORMATION

Highly amygdaloidal purple lava and associated volcanic rocks are exposed in the graben between the Garzas and Ciénaga faults in the southwestern part of west-central Puerto Rico, in a horst south of the San Patricio fault in the south-central part, and in a fault block on route 10 along the Cerrillos fault. These rocks are herein named the Lago Garzas Formation for good exposures in the vicinity of Lago Garzas and eastward from the lake along route 518.

The type locality is at (122,300 m E.; 33,980 m N.), at kilometer post 5.0 on route 518 on the east side of Cerro El Gigante. Exposed here is a 5- to 8-m thick lava that is dark purplish blue, granular, fine grained, and highly amygdular. The lava is andesite or dacite having sparse small feldspar phenocrysts and common calcite and chlorite amygdules, calcite viens, and some epidote veins. The lava is overlain and underlain by purple lapilli tuff and volcanic breccia that contain fragments of rock similar to the lava. Within 200 m west of the exposure there are several dikes of andesite or dacite containing crowded feldspar and hornblende phenocrysts.

The formation consists of a basal member predominantly of mudstone and volcanic sandstone, a middle member of tuff, and an upper member of lava.

Lava and autobreccia in the formation are sparsely to extremely amygdaloidal purple, red, or greenish-gray andesite or dacite. Phenocrysts are of feldspar and small monoclinic pyroxene; some lava contain few or no phenocrysts. The groundmass of the lava is composed of felty plagioclase microlites and glass. Amygdules of chlorite, calcite,

quartz, chalcedony, and epidote are sparse to abundant. At (120,550 m E.; 35,020 m N.), north of Cerro El Gigante, imbricate elongated amygdules in purple aphanitic lava suggest a northerly source for the lava.

The pyroclastic rocks include purple, red, and green coarse-grained tuff, lapilli tuff, and some volcanic breccia. Common ejecta are red and purple aphanitic volcanic rocks, feldspar porphyries, crystals of feldspar and pyroxene, and chloritized fragments that are probably devitrified glass. Some shard structures were seen. The fragments are cemented by calcite and zeolite.

The epiclastic rocks are mudstone, volcanic sandstone, and siltstone. They are purple, red, and greenish gray, in part thin to medium bedded, and in part massive and laminated. Fragments, where identifiable, are similar to those in the pyroclastic rocks and contain grains of magnetite and quartz.

The three members of the formation intertongue or interfinger with each other in the central part of the exposure area. In general the stratigraphic sequence is, from older to younger, epiclastic rocks, pyroclastic rocks, and lava. A minimum thickness of 1,700 m of the formation was measured near Lago Garzas. The lava member is restricted to the graben between the Garzas and Ciénaga faults. The eastern horst and the fault block at the Cerrillos fault are composed predominantly of red and purple conglomeratic tuff and tuffaceous sandstone, thin-bedded or laminated volcanic sandstone and siltstone, and red and purple mudstone. In west-central Puerto Rico all contacts of the Lago Garzas are faults.

The Lago Garzas outcrop is part of a broad band of rocks that are exposed from Ponce to the west coast of Puerto Rico near Aguada. Hubbard (1923) called these rocks the "Río Blanco Series," and several reports (Slodowski, 1956; Turner, 1958; Pessagno, 1960; Mattson, 1960) use the same name for parts of the exposure band. However, M. D. Turner (oral commun., 1963) and Rigoberto Reynoso (Bear Creek Mining Co., oral commun., 1964) recently discovered that the band of exposures can be divided in most places into a northern zone of pyroclastic rocks and lava probably correlative with the Eocene Anón Formation (see below), and a complex southern zone that contains several mappable units. One of these mappable units correlates with the Lago Garzas, another with the Anón, and others perhaps with the Robles Formation or with the Mayagüez Group. Unfortunately, Hubbard's typical exposures of the "Río Blanco," as well as most of the modern Río Blanco river, are in the area of rocks probably at least in part correlative with the Anón. Therefore, it is herein suggested that

the name "Río Blanco" be abandoned in favor of Lago Garzas, Anón, or other names as appropriate to the specific areas.

One fossil collection has been described from the Lago Garzas Formation in west-central Puerto Rico. From locality AM 2–7 at (129,365 m E.; 33,530 m N.), on the dirt-road extension of route 503 in the horst near the San Patricio fault, Pessagno (written commun., 1962) has identified the following Foraminifera: *Globotruncana* (*G.*) *lapparenti lapparenti* Bolli; *G.* (*G.*) *stuarti stuartiformis* Dalbiez; *G.* (*R.*) *tilevi* (Bronnimann and Brown); *G.* (*R.*) *gansseri dicarinata* Pessagno, two new(?) species of *Globigerinelloides; Heterohelix striata* (Ehrenberg), *H.* sp.; and *Praeglobotruncana* (*H.*) *havanensis* Voorwijk. His stratigraphic detrmination is "early Maestrichtian, *Globotruncana* (*R.*) *tilevi* subzone. Probably upper part of *G. lapparenti ss.* zonule." The locality is in dark medium-bedded calcareous siltstone. Thus the Lago Garzas is at least in part of Late Cretaceous (Maestrichtian) age, but may extend somewhat older or younger.

TERTIARY SYSTEM

RÍO PRIETO FORMATION

The Río Prieto Formation is herein named for exposures in and near the Río Prieto in the southwestern part of the Jayuya quadrangle. It extends westward into the Adjuntas quadrangle near the Río Jauca and continues westward to Hacienda El Banco. Two small exposures of the formation are in Barrio Tanamá in the northwest part of the report area. The formation is an interfingering complex of several members: lapilli tuff and volcanic sandstone, volcanic sandstone and mudstone, algal limestone, and red conglomerate and conglomeratic mudstone. Because of the heterogeneity of the formation, type localities are described for each of the members.

The red conglomerate and conglomeratic mudstone is the herein adopted Miramar Conglomerate Member (Pessagno, 1960; Mattson, 1966). At its type locality south of Hacienda Miramar at (141,530 m E.; 32,520 m N.) in the southeast part of the report area, it is a red well-rounded poorly sorted conglomerate. Clasts are red and purple andesites derived from the underlying Achiote Conglomerate, in a soft red siltstone matrix. Lenses and beds of light reddish gray and pink algal limestone are exposed at the base of the unit. From Hacienda Miramar, the Miramar Conglomerate Member crops out discontinuously along a west-northwest strike almost as far west as Hacienda El Banco in the Adjuntas quadrangle, and the small Río Prieto outcrops in Barrio Tanamá are composed of the Miramar.

The Miramar Conglomerate Member is generally at the base of the

Río Prieto Formation and is as much as 130 m thick in the east. In the Barrio Tanamá and Hacienda El Banco exposures, it is probably less than 20 m thick. It contains clasts that are derived from the nearby underlying rock formations and that are generally angular except where derived from the well-rounded clasts of the Achiote Conglomerate. The matrix is sparse to common red siltstone and mudstone, containing fragments of calcareous algae and grading into a pink algal limestone in some places.

The algal limestone member is as thick as 70 m where it occurs above the Miramar Conglomerate Member at and near the type locality for the limestone, at (141,590 m E.; 32,150 m N.) on route 512 in Ponce quadrangle, about 130 m south of the report area. At the type locality it is a massive light-gray calcarenite and calcirudite with abundant fragments of calcareous algae and scattered corals in a calcarenite matrix. It is gradational downward with the Miramar Member with the appearance of fragments of volcanic rocks and a change in color to pinkish-white and pink, due to small amounts of manganese (Ponce Cement Co., oral commun., 1963). Thin lenses of limestone in the Miramar Member are generally of this pinkish transitional facies. Included in the algal limestone member are small massive lenses, perhaps 10 m thick, of white or grayish-white fragmental limestone containing abundant fragments of calcareous algae. These lenses occur below the Miramar Member just east of the Río Jauca but overlie the Miramar in the exposures west of the river. In most of these exposure areas, the limestone contains common manganese dendrites and is finely recrystallized owing to its proximity to the Jauca stock.

A limestone lens about 20 m thick exposed in the Río Guayo also is included in the algal limestone member, although the lens contains volcanic debris and is not as rich in algal fragments as the rest of the member. This gray limestone contains common shell fragments, algal fragments, and Foraminifera; crystals and crystal fragments of feldspar, quartz, and hornblende; and fragments of chloritized volcanic rocks. It is medium to thick bedded near the contacts of the lens but massive in the center.

A member of volcanic sandstone and mudstone overlies the Miramar Conglomerate Member in the central and western parts of the exposure area of the Río Prieto Formation. The type locality is on a trail from (133,660 m E.; 35,890 m N.) to route 143 at (133,640 m E.; 36,420 m N.); greenish- to purplish-gray laminated thin- to medium-bedded tuffaceous sandstone and siltstone, weathering to purple saprolite, occur with some layers of lapilli tuff and volcanic breccia. Graded bedding occurs in some beds. Elsewhere greenish- to purplish-gray mudstone beds are intercalated with the sandstone and siltstone. The

member is as much as 250 m thick in the Río Jauca area but is absent or less than 20 m thick elsewhere; contacts with the underlying Miramar Member and the overlying tuff member are gradational and, locally, the volcanic sandstone and mudstone member is interbedded with the tuff member.

A member of lapilli tuff, coarse-grained tuff, and volcanic sandstone is the youngest unit in the Río Prieto Formation. Exposures south of route 143 on a road from (133,160 m E.; 36,100 m N.) to (133,490 m E.; 35,710 m N.), designated the type locality, consist of massive blue-gray lapilli tuff, weathering purple, interbedded with a smaller amount of thin- to medium-bedded tuffaceous sandstone and coarse-grained tuff. Pyroclastic fragments in the tuffs and sandstone are crystals of hornblende, feldspar, and some quartz, porphyritic and aphanitic volcanic rocks, and some greenish-gray chloritized volcanic rocks; plutonic rock fragments are rarely seen. West of the type area, the member of lapilli tuff, coarse-grained tuff, and volcanic sandstone is gray-green and greenish-brown when fresh, weathers to purple, red, green, and brown, and contains sparse fragments of diorite and gabbro in addition to the more typical fragments and crystals. Some limestone fragments and calcite cement occur near the eastern limit of exposures of the unit.

The tuff member is as much as 120 m thick in the type area, but in the area west and south of the Río Jauca, where the Río Prieto Formation is 400 m thick, the member may be 150 m thick.

The entire Río Prieto Formation has a maximum thickness of 460 m in the central part of the report area, but is no thicker than 120 m in the southeastern part. It is apparently missing entirely for about a kilometer along strike between the Río Anón and the Río Guayo, in an area of poor exposures.

In the Jayuya quadrangle the Río Prieto Formation rests unconformably upon Cretaceous rocks and plutonic rocks, and is overlain conformably by the Monserrate Formation. Farther west, the Río Prieto rests unconformably on chloritized and epidotized rocks of the Jayuya Tuff, and grades laterally (westward) and vertically into the Monserrate Formation. The Jauca stock has intruded the Río Prieto Formation and has caused recrystallization of the algal limestone and shattering and small-scale contortions visible in the adjacent bedded rocks.

The Miramar Member and the algal limestone member extend to the southeast into Ponce and Río Descalabrado quadrangles, where Pessagno (1960) considered them a part of his Naranjo Formation. However, in the Jayuya quadrangle the two units are in a heterogeneous sequence below the Monserrate Formation and are best mapped

as a unit here called the Río Prieto Formation. The Río Prieto Formation is thus correlative with a part of the Naranjo Formation of Pessagno (1960).

The algal limestone member is the lithologic and approximate stratigraphic equivalent of the Cuevas Limestone (Glover, 1961), the Coamo Springs Limestone Member of the Naranjo Formation of Pessagno (1960), the Coamo Tuff Limestone of Berkey (1915), the Guayabal Limestone of Mitchell (1922), and the Coamo Springs Limestone of Hodge (1920). Coamo Springs Limestone may have priority, but it was not deemed necessary to name the limestone in west-central Puerto Rico.

Six fossil collections have been described from four different localities in the Río Prieto Formation (table 2). The last two collections listed are from the algal limestone member; the other collections are from the limestone matrix of the Miramar Conglomerate Member. The specimens in collection B are considered of poor quality by Otto Renz (written commun., 1961), so in the interpretation more significance is given to the middle Eocene collections A and E. As these middle Eocene collections are both from near the base of the formation, and the overlying Monserrate Formation is of probable middle Eocene age, the entire Río Prieto Formation is considered middle Eocene in age.

TABLE 2.—*Fossil collections from the Río Prieto Formation*

	A	B	C	D	E	F
Globorotalia densa Cushman	×					
G. velascoensis (Cushman)		×				
G. sp	×					
Amphistegina parvula (Cushman)					×	
Asterocyclina monticellensis (Cole and Ponton)					?	
A. aster Woodring					×	
Discocyclina sp		×				
Eoconuloides sp				?		
Fabiana cassis (Oppenheim)					×	
Lepidocyclina sp	?					
Pseudophragmina (*Proporocyclina*) *flintensis* Cushman						?
P. (*P.*) sp			×			
Archaeolithothamnion sp	×	×				

A. J34–63A (133,830 m E.; 36,550 m N.); E. A. Pessagno, written commun., 1963: middle Eocene.
B. 164 (same loc. as A); Otto Renz, Paleont. Lab., Bataafse Internationale Petroleum Mij. N.V., The Hague; written commun., 1961: late Paleocene or early Eocene.
C. f–35092 (same loc. as A); K. N. Sachs and W. S. Cole, written commun. 1963: Indeterminate.
D. f–35104 (139,130 m E.; 32,360 m N.); Sachs and Cole, written commun., 1963: Indeterminate.
E. f–35103 (139,130 m E.; 32,350 m N.); Sachs and Cole, written commun., 1963: middle Eocene.
F. f–35102 (140,630 m E.; 32,020 m N.); Sachs and Cole, written commun, 1963: middle(?) Eocene. This locality is in Ponce quadrangle, 260 m south of the Jayuya quadrangle border.

MONSERRATE FORMATION

The Monserrate Formation was named and described as the Monserrate Member of the Augustinillo Formation by Pessagno (1960). It is named after Hacienda Monserrate on the Río Cerillos in the Ponce quadrangle and has a type locality near kilometer post 6.9 on route 139 (135,910 m E.; 27,190 m N.). Pessagno (1960, p. 96) describes the unit as follows: "The Monserrate Member * * * consists principally of brownish black calcareous mudstones which alternate with medium gray calcilutites and occasional buff calcirudites. Apple green vitric tuffs are present at some horizons." The herein adopted Monserrate is considered a formation in west-central Puerto Rico because of its wide areal extent in the Jayuya and Adjuntas quadrangles. It trends west-northwest in almost continuous outcrop from the southeastern part of the report area almost as far as Hacienda El Banco, and it occurs in fault blocks along the same trend northwest beyond Pellejas in the northwestern Adjuntas quadrangle. The Monserrate also is exposed in a faulted Y-shaped area extending from the south-central Adjuntas quadrangle southeastward to the southwestern corner of the Jayuya quadrangle.

The Monserrate Formation is about 160 m thick and apparently interfingers with the Río Prieto Formation in the Río Jauca-Hacienda El Banco area, but detailed relations are obscure because intrusion of the Jauca stock and Tertiary plutonic rocks has left little of the Monserrate exposed in that area. West of Hacienda El Banco, and locally in its eastern outcrops, the Monserrate is exposed in probable depositional, unconformable contact with Cretaceous rocks; but over most of the outcrop area east of the Río Jauca, the Monserrate rests conformably on the Río Prieto Formation. The Anón Formation overlies the Monserrate, with some interlayering in the contact zone. In southeastern Adjuntas quadrangle, a thickness of perhaps 1,300 m of Monserrate is exposed in an area bounded by faults except on the northwest, where the Monserrate is overlain by the Anón.

In west-central Puerto Rico the Monserrate Formation is thin- to medium-bedded laminated reddish-gray, greenish-gray, and purplish-gray mudstone and tuffaceous sandstone, calcareous and foraminiferal in many places. Fine conglomerate, tuff, and lapilli tuff form a minor part of the unit. Feldspar, quartz, some pyroxene, and green chloritized rock fragments are the most common pyroclastic components; green and greenish-brown vitric tuff beds, similar to coarse-grained vitric tuff of the Anón Formation (see below), are present at most exposures. The Monserrate is silicified, pyritized, and hydrothermally altered in the central part of the Adjuntas quadrangle.

Four collections of Foraminifera have been described from the

Monserrate Formation in west-central Puerto Rico. Collection AM 2–6, at kilometer post 4.4, route 143 (127,290 m E., 35,650 m N.), contains the following silicified fauna: *Globigerina boweri* Bolli; *G.* sp. aff. *G. boweri* Bolli; *G.* sp. aff. *G. prolata* Bolli; *Globoratalia densa* (Cushman); common Radiolaria, mostly *Spumellina* (E. A. Pessagno, Jr., written commun., 1962). On the basis of these fossils, the collection is in the *Hantkenina aragonensis* zone (of Pessagno) and is early middle Eocene. Collection A49–39B, south of the Río San Patricio at (130,090 m E.; 33,845 m N.) contains fragments of coralline algae (cf. *Archaeolithothamnion*) and *Amphistegina* sp., giving an age determination of Tertiary, probably Eocene (E. A. Pessagno, Jr., written commun., 1963). Pessagno also identified *Globigerina* sp., keeled early Tertiary *Globorotalia* sp., and possibly *Globorotalia densa* (Cushman) in collection J39–195 from (134,800 m E.; 33,290 m N.), in a tongue of the Monserrate in the Anón Formation. He suggested an age of late Paleocene or Eocene, possibly middle Eocene, for the collection.

From the Ponce quadrangle, about 270 m south of the Jayuya quadrangle, K. N. Sachs and W. S. Cole (written commun., 1963) identified *Amphistegina parvula* (Cushman), *Asterocyclina monticellensis* (Cole and Ponton), and possibly *Eoconuloides* sp. in collection f–35101 from (140,640 m E.; 32,010 m N.); they suggest a middle Eocene age for that collection.

Weaver (1958, p. 1129) states that Pessagno collected poorly preserved *Globotruncana calcarata* (Cushman) and *G. lapparenti* (?) from a locality on route 143 that plots near kilometer post 1.6, at approximately (126,040 m E.; 35,420 m N.), and gives an age of Late Cretaceous, probably Campanian. The four Tertiary localities, lithologic similarity to lower Tertiary rocks, and mapping continuity with lower Tertiary rocks suggest that this Cretaceous determination be rejected, and an age of early Tertiary, probably middle Eocene, be accepted for the Monserrate in west-central Puerto Rico. This age is confirmed by several other Eocene localities in the formation in the Ponce quadrangle (Pessagno, 1960; Sachs and Cole, written commun., 1963).

ANÓN FORMATION

The Anón Andesite was named by Pessagno (1960) for Hacienda Anón on the Río Inabón in the Ponce quadrangle; the type locality is at kilometer post 9.0 on route 511 and below the road in the bed of the Río Inabón, at (137,185 m E.; 30,840 m N.). Pessagno considered the unit as a series of instrusive stocks, but further mapping north of his mapped area, extended in reconnaissance to his type locality, shows that the Anón is largely a complex of lava and pyroclastic rocks with only minor volcanic intrusive rocks. Stocks of rock

similar to the Anón do occur in west-central Puerto Rico but are shown separately on the geologic maps (Mattson, 1967a, 1967b). Ten chemical analyses of the Anón volcanic rocks and associated intrusive rocks range in silica content from 52 to 61 percent and show that, according to the classification of Rittmann (1952), the rocks are dacite (with minor andesite and rhyodacite) rather than andesite as was believed by Pessagno. For this reason, and because of its mixed lithologies, the name of the unit is here changed to Anón Formation.

The Anón Formation consists of interbedded pyroclastic and flow rocks with minor mudstone and volcanic sandstone. It is exposed in a northwest-trending zone across west-central Puerto Rico from the south-central border of the Jayuya quadrangle to the middle of the western border of the Adjuntas quadrangle.

Lava is more abundant than pyroclastic rock in the Anón in the Jayuya quadrangle, but is found less frequently farther west. The lava is a bluish- or greenish-gray porphyry, containing sparse to common phenocrysts of hornblende, plagioclase, some pyroxene, and more rarely quartz. The groundmass of most lavas contains felty or trachytic feldspar microlites, with interstitial chloritic or glassy material, and appears granular in hand specimen, but the groundmass of other lavas is a feldspar mosaic that appears cloudy in hand specimen. Amygdules of quartz, chalcedony, and chlorite are common at several levels in the formation and are in places elongated parallel to trachytic flow directions. Some lava, generally glassy and containing only sparse phenocrysts, forms flow breccias or autobreccias. Lavas are shown on the geologic maps in areas where they predominate over pyroclastic rocks, but they are also exposed though less abundantly, throughout the outcrop area of the Anón.

Pyroclastic rocks include lapilli tuff, coarse-grained tuff, and coarse-grained vitric tuff. The rocks are green, greenish-brown, and bluish-gray, are massive, and contain fragments as large as 30 cm in diameter in some exposures. The color of the rock is generally controlled by the percentages of green, greenish-brown, reddish-brown, and brown fragments of glass containing trachytic or felted feldspar microlites. A high percentage of these glassy fragments, from 20 to 40 percent, distinguishes the Anón pyroclastic rocks from most of the Cretaceous pyroclastic rocks. Other fragments in Anón rocks are andesites or dacites with phenocrysts of hornblende, pyroxene, feldspar, and sparse quartz; crystal fragments of feldspar, hornblende, and sparse pyroxene; and sparse diorite or gabbro. Shard structure is very uncommon; sparse cement is chlorite, zeolite, and chalcedony.

Tuffaceous mudstone and sandstone occur as scattered layers and thin lenses in the Anón, and conglomeratic tuff layers are exposed

at some places near the top of the formation. Three areas of medium-bedded tuffaceous mudstone and volcanic sandstone occur in the western part of the report area north of Lago Adjuntas. The rocks are gray or blue gray, generally calcareous, and contain common Foraminifera and Radiolaria. The westernmost body, exposed on both sides of route 526, is medium-bedded laminated tuffaceous sandstone and feldspathic tuff; the other two areas are fault blocks of well-bedded mudstone that might conceivably be segments of the underlying Monserrate Formation.

Highly altered green and greenish-gray volcanic rocks north of the San Patricio fault in the Adjuntas quadrangle orginally were feldspathic lavas and tuffs. They are now hydrothermally chloritized, epidotized, pyritized, silicified, and locally mineralized, and are here correlated with the Anón Formation. This correlation is based mainly on the fact that bedded cherts and silicified mudstones, stratigraphically below the volcanic rocks, have been correlated with the Monserrate Formation. The correlation is questionable because of the complex structure and the high degree of alteration of the volcanic rocks. Pyritization and alteration to calcite and epidote also are common near stocks and near some faults, and copper minerals locally are associated with the pyritized rocks.

The Anón overlies the Monserrate Formation gradationally; its upper contact has been removed by erosion. In the Jayuya quandrangle the Anón interfingers extensively with the Monserrate Formation, and near Hacienda Cortada it actually underlies the Monserrate, where the Monserrate formation pinches out.

A thickness of about 1,400 m of Anón is exposed in the Jayuya quadrangle. Complex structure in the Adjuntas quadrangle prevents accurate measurement of the thickness of the Anón.

Reconnaissance has established the presence of pyroclastic rocks similar to the Anón in a zone extending from the western Adjuntas exposures westward across the Monte Guilarte and San Sebastián quadrangles into Central La Plata quadrangle, a distance of about 30 km. In the San Sebastián and Central La Plata quadrangles, Turner (1958) and Hubbard (1923) have described these rocks as the Río Culebrinas "series," and Turner has estimated an exposed thickness of about 1,100 m.

Two foraminiferal collections from the Anón in west-central Puerto Rico have been described by Pessagno (written commun., 1963). He found *Globigerina* sp. and keeled *Globorotalia* sp. at locality A14–3, kilometer post 37.95 on route 10 (121,070 m E.; 41,940 m N.), and also at locality A15–31, kilometer post 38.05 on route 10 (121,210 m E.; 41,770 m N.). The former locality also has common Radiolaria of

probable Tertiary age. Pessagno considers the Foraminifera as probable of late Paleocene or Eocene age. In addition, Pessagno (written commun., 1963) has identified *Globigerina* sp. and questionably *Globorotalia densa* in a collection from the Ponce quadrangle, about 500 m south of the boundary of the Jayuya quadrangle at (134,470 m E.; 31,780 m N.). According to Pessagno, the age of the collection is late Paleocene or Eocene, possibly middle Eocene. The collection is from a lens of foraminiferal siltstone in the upper part of the formation, probably a faulted extension of the lens shown on the geologic map between Río San Patricio and Río Cerrillos, in the southwestern corner of the Jayuya quadrangle. To the west, in Central La Plata and San Sebastián quadrangles, Mattson (1960, p. 346) described two Eocene forminiferal collections, identified by Paul Bronimann in the Río Culebrinas "series" of Hubbard (1923), correlative with the Anón and perhaps a younger bedded unit.

The Anón Formation seems to be at about the same stratigraphic level across both the Adjuntas and Jayuya quadrangle, and the Monserrate Formation, of middle(?) Eocene age, interfingers with the Anón. The Anón can therefore be considered of middle to late Eocene age in west-central Puerto Rico; it cannot be as young as the early Oligocene post-orogenic deposits about 10 kilometers to the south in the Ponce and Peñuelas quadrangles (Ruth Todd, written commun., 1963).

STRATIGRAPHIC SUMMARY

The continuous Cretaceous sequence exposed in the eastern half of the report area may be divided into three broad parts.

The lowest of these parts contains only the Jayuya Tuff. In west-central Puerto Rico the contact of the Jayuya with the overlying Robles is gradational, but farther east the Robles rests with apparent unconformity on strata informally named pre-Robles rocks and here correlated, at least for the uppermost part, with the Jayuya Tuff (Berryhill and Glover, 1960; Pease and Briggs, 1960; Briggs and Gelabert, 1962). As basal Robles strata are Early Cretaceous, probably Albian, in age, then the Jayuya Tuff is probably Albian in age or older.

The Robles, Vista Alegre, Tetuán, Malo, and Cotorra Formations form a broadly homegeneous, vertically and laterally gradational sequence averaging more than 2,000 m in thickness over a large area. Mineralogically, these units are very similar, and lithologic types dominant in one unit are frequently found to be subordinate rock types in other units. This middle part of the Cretaceous sequence is directly correlative with the Robles Formation in the Comerío and Barranquitas quadrangles to the east (Pease and Briggs, 1960; Briggs and Gelabert, 1962) and is correlated, chiefly on mineralogic and litho-

logic grounds, with the Río Orocovis Group (formerly the Río Orocovis Formation) in the Ciales and Corozal quadrangles to the northeast (Berryhill, 1965; Nelson, 1966). This part of the sequence ranges from Early Cretaceous, probably Albian to Late Cretaceous, perhaps Santonian, in age.

The Achiote Conglomerate rests with apparent discomformity on strata of the middle part of the Cretaceous sequence. It grades upward into the well-stratified Maravillas Formation, which in turn grades upward into the massive Coamo Formation; these three form the upper part of the Cretaceous sequence. Their thicknesses vary from place to place, but in the south-central part of the Jayuya quadrangle, they may total more than 2,500 m in thickness. The top of the Coamo is not exposed. These formations are correlated with the Cariblanco and Coamo Formations of the Coamo quadrangle (Glover, 1961) and are Late Cretaceous in age, probably ranging from Santonian to Maestrichtian, but the Achiate may be in part as old as Coniacian.

The fault-separated Yauco Mudstone cannot be directly correlated with the continuous Cretaceous sequence in the eastern part of the report area. However, it is Late Cretaceous, probably Campanian or Maestrichtian, in age in western Puerto Rico and thus may be generally correlated with all or parts of the Maravillas and (or) the Coamo Formations.

The Lago Garzas Formation also cannot be directly correlated within west-central Puerto Rico. It is Late Cretaceous in age, probably Maestrichtian. A correlation with the Coamo Formation is reasonable, but the Lago Garzas may be younger than the Coamo and probably is younger than at least the lower part of the Yauco Mudstone.

A profound unconformity separates the Cretaceous rocks and the lower Tertiary rocks in west-central Puerto Rico (Mattson, 1966): lower Tertiary strata rest unconformably on plutonic rocks and Lower and Upper Cretaceous strata. If the assumption is made that the continuous Cretaceous sequence now present in the eastern part of the report area once was present where the Río Prieto Formation now overlies the Jayuya Tuff, then perhaps locally 5,000 m of section were removed by erosion prior to Río Prieto time. However, the missing Cretaceous section may not have been so thick in these areas.

The lower Tertiary Río Prieto, Monserrate, and Anón Formations are probably middle Eocene to perhaps late Eocene in age, so, on the basis of evidence in west-central Puerto Rico, the unconformity developed between latest Cretaceous, Maestrichtian, time and middle Eocene time; thus, erosion characterized Paleocene time in this area.

The volcanic sequence in west-central Puerto Rico thus represents perhaps four episodes of continuous deposition, separated by possible

local unconformities in Albian time (not seen in the report area but present elsewhere), a probable disconformity or moderate unconformity possibly in Coniacian but more probably in Santonian time, and a profound unconformity in the Maestrichtian to Eocene interval.

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