Geology of the Florida Quadrangle Puerto Rico

By ARTHUR E. NELSON *and* W. H. MONROE

CONTRIBUTIONS TO GENERAL GEOLOGY

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By Arthur E. Nelson and W. H. Monroe

ABSTRACT

The Florida quadrangle is in north-central Puerto Rico, approximately 53 kilometers west-southwest of San Juan. Cretaceous and lower Tertiary rocks, consisting mostly of volcanically-derived epiclastic and pyroclastic deposits and lava flows, are exposed in the southern half of the quadrangle. These rocks, which have a total thickness of about 8,500 meters, are intruded, in places, by small bodies of gabbro, diorite, and granodiorite. Approximately 520 meters of middle Tertiary rocks are exposed in the northern half of the quadrangle; these consist mostly of limestone and rest unconformably on the Cretaceous and lower Tertiary rocks. In places, Recent unconsolidated landslide, alluvial, and blanket sand deposits cover the older rocks. Owing to tropical weathering, thick residual soils cover much of the area.

Most of the quadrangle is on the north flank of the principal fold of the west-trending Puerto Rico anticlinorium, and, in general, the strata strike westerly. Although the middle Tertiary rocks have been only gently warped, the Cretaceous and lower Tertiary rocks have been folded and extensively fractured. The folds plunge gently west to northwest, and the dominant trend of the main faults is also west to northwest. Numerous cross faults show diverse trends. Most faults dip steeply or are vertical, and the amount of stratigraphic displacement along them varies widely. Movement along some of the west-trending faults was transcurrent in a left-lateral sense. Graben and horst structures have formed along some faults. Joints are common and locally fracture and shear cleavages occur.

INTRODUCTION

The geology of the Florida quadrangle was studied as part of a program of preparing geologic maps and investigating the mineral resources of Puerto Rico. This program has been undertaken by the U.S. Geological Survey in cooperation with the Commonwealth of Puerto Rico Economic Development Administration.

The Florida quadrangle (pl. 1) is approximately 53 kilometers west-southwest of San Juan, in north-central Puerto Rico. It is north of the drainage divide between the Atlantic Ocean and the Caribbean

Sea. The quadrangle can be divided into two general areas, and each has a distinctive topographic expression. The northern half, underlain by a thick sequence of calcareous deposits, has a rugged karst topography in which many valleys are more than 100 meters deep. The topography is not as rugged in the southern half, but the hills commonly rise to higher altitudes.

Major surface drainage in the Florida quadrangle is limited to the southern half; the Río Toro Negro and Río Cialitos join the Rìo Grande de Manatí east of the quadrangle, and the Rìo Yunes and the Rìo Limon coalesce and flow west to the Rìo Grande de Arecibo. The karst area does not have a well-integrated surface drainage system; only minor streams are found, and many of these streams flow into sinks or caverns and are lost in a net of underground drainage.

Fieldwork began in October 1961 and was completed in June 1963. A. E. Nelson mapped the Cretaceous and Eocene rocks in the southern part of the quadrangle, and W. H. Monroe mapped the middle Tertiary rocks in the northern part.

Except as noted for the volcanic sandstone, grain-size determinations are based upon the following scale of grain diameters: coarse, greater than 5 millimeters; medium, 1–5 mm; fine, less than 1 mm. The proposed classification of Fisher (1961) is used for epiclastic and pyroclastic volcanic sandstone.

GENERAL GEOLOGY

Several varieties of rocks, ranging in age from Cretaceous to middle Tertiary, are exposed in the quadrangle. Most of the Cretaceous and lower Tertiary rocks are of volcanic derivation and consist of epiclastic and pyroclastic deposits and lava flows. Epiclastic rocks include siltstone, sandstone, conglomerate, and lahars; pyroclastic rocks include volcanic breccia, lapilli tuff, and tuff; lava flows comprise both andesite and basalt. Some of the epiclastic rocks contain pyroclastic material that has fallen directly into the depositional basin and has been incorporated in the sediments; some of the pyroclastic rocks contain detrital material. A few limestone units are also present. The Cretaceous rocks have been intruded in places by small bodies of diorite, gabbro, and granodiorite. A stratigraphic thickness of as much as 8,500 meters of Cretaceous and lower Tertiary rocks may be present, but some rock units may be repeated by faulting. Middle Tertiary rocks, about 520 meters thick, consist mostly of marine limestone that has subordinate amounts of marl, clay, and sand; these rocks rest unconformably on the older Cretaceous and lower Tertiary rocks. Recent unconsolidated landslide, alluvial, and blanket sand deposits cover the consolidated rocks locally. Pervasive tropical weathering has caused thick residual soils to form over much of the quadrangle.

Fossils dated as Late Cretaceous (Santonian to Maestrichtian) have been collected from the older rocks in the quadrangle (N. F. Sohl, written commun., 1963). The lower Tertiary rocks are continuous with rocks in the Utuado quadrangle to the west that locally contain upper Paleocene to middle Eocene microfossils.

The Florida quadrangle is on the north flank of the west-trending Puerto Rico anticlinorium. The axis of this anticlinorium, the main structural arch of the island, trends west to west-northwest across the central part of Puerto Rico. The axial zone of the anticlinorium coincides approximately with the southern boundary of the Florida quadrangle, but the precise location of the axial trace is obscured by minor folds and faulting. The Cretaceous and lower Tertiary rocks have been moderately folded and extensively fractured and faulted. The fold axes trend west to northwest. The middle Tertiary rocks have an almost uniform dip of 4°–5° N. and, in places, show gentle warping.

CRETACEOUS ROCKS

RÍO OROCOVIS FORMATION

The Avispa Lava Member of the Río Orocovis Formation of Late Cretaceous age crops out in a small area near the middle of the east border of the quadrangle. This member is mostly composed of andesite lava but has minor intercalations of lapilli tuff and volcanic sandstone. The Avispa Lava Member continues into the Florida quadrangle from the Ciales quadrangle where Berryhill (1965) mapped it. To the south the Avispa is in fault contact with the younger Cretaceous Pozas Formation. To the north the Avispa is overlain by rocks of middle Tertiary age and, in part, is mantled by slide materials derived from them. Less than 60 meters of the formation is exposed in the quadangle.

The lava of the Río Orocovis is greenish gray and is characterized by feldspar phenocrysts that are arranged to form a glomeroporphyritic texture in a fine-grained groundmass. This rock is similar lithologically to andesite lava of the Mameyes Formation in the southern part of the quadrangle.

VISTA ALEGRE FORMATION

Bedded pyroxene-rich tuff extends across the southern part of the Florida quadrangle into the Jayuya quadrangle; this tuff has many interbedded units of volcanic sandstone and siltstone, as well as minor amounts of volcanic breccia, lapilli tuff, and lava. These rocks, of Early(?) to Late Cretaceous age, are here named the Vista Alegre Formation from Cerro Vista Alegre in the southern part of the Florida quadrangle. The type exposures are along the road northwest of Cerro Vista Alegre in the southeast corner of the quadrangle, between coordinates 48,000–142,740 and 48,380–142,500 (P.R. meter grid). Good exposures of volcanic sandstone and siltstone can be seen along this road. The volcanic breccia, usually residual boulders in saprolite, can best be seen along the north-south stretch of the road Vereda Las Cruces west of Cerro Vista Alegre. Several good exposures of andesite lava can be seen in the valley of the Río Cialitos just north of the south boundary of the Florida quadrangle.

The lower part of the Vista Alegre Formation is not present in the quadrangle but is exposed in the adjacent Jayuya quadrangle, where it lies conformably on the finer grained and thinner bedded Robles Formation (P. H. Mattson, written commun., 1963). The Vista Alegre conformably underlies the Mameyes Formation; the contact is placed at the base of the lowest lava of the Mameyes. Because the Vista Alegre Formation is complexly faulted, the thickness in the Florida quadrangle is not exactly known but is at least 500 meters.

Most of the formation consists of volcanic sandstone and subordinate amounts of siltstone, some of which is calcareous. Included in the sandstone and siltstone are bedded crystal tuff, lithic tuff, and reworked tuff. Lenses of volcanic breccia, lapilli tuff, and basaltic tuff are distributed sporadically through the formation, and numerous beds of lava, principally andesite but including minor basalt, occur at various horizons.

Siltstone units are thinner, finer bedded, and finer grained than the sandstone units with which they are interlayered. Generally, the siltstone is dark bluish gray where fresh but a dull brown where weathered. The sandstone and tuff range in color from dark greenish gray to pale olive green and are fine to medium grained. Those volcanic rocks usually are well bedded, but some beds are massive; most commonly the thinner bedded units occur in the lower part of the formation. Graded bedding is present but is not readily apparent.

Volcanic sandstone, in places containing plagioclase fragments, is characterized by dark-green pyroxene grains scattered in a lighter and somewhat finer matrix. Associated with the sandstone are crystal tuff beds that are characterized by numerous fragments of pyroxene and fewer fragments of plagioclase and pumice in a matrix that contains some partly devitrified glass. Thin sections of the tuff show that the glass is commonly colorless to light green and has devitrified to a weakly birefringent material. The pyroxene is clinopyroxene (augite to diopside) and occurs as crystals or fragments that are, on the average, larger than the fragments and crystals of plagioclase. Plagioclase grains are seldom more than one-half millimeter in length, whereas pyroxene grains commonly are more than 1 mm in length. Opaque grains of magnetite(?) occur, and dust of the same material is common. Secondary minerals include chlorite, epidote, calcite, quartz and sericite. In some places veinlets of quartz, calcite, and epidote cut the tuff.

Deposits of volcanic breccia are, in general, rather massive and light greenish gray. The fragments are seldom more than 8 centimeters in diameter, Although these fragments are principally composed of lava, some of which is vesicular, siltstone and sandstone fragments also occur. Lithic fragments in the breccia commonly are subangular, but angular to subrounded fragments also are found. Much of the matrix is too fine to be identified but contains crystals and fragments of pyroxene and, in places, considerable feldspar.

The andesite lava contains well-formed pillow structures in some localities, is bluish gray to greenish gray, and is characterized, like other andesite lavas of north-central Puerto Rico, by phenocrysts of plagioclase in a fine-grained groundmass. The plagioclase phenocrysts, which range in length from 1 mm to almost 9 mm, have a glomeroporphyritic arrangement and are commonly sericitized. Clinopyroxene phenocrysts are commonly smaller and less abundant. Glass and cryptocrystalline material are important constituents in the groundmass which includes hyalo-ophitic, intersertal, and intergranular textures. Opaque grains and dust, probably magnetite, are common, and in some specimens small opaque needles, probably ilmenite, are present. Secondary minerals include epidote, calcite, chlorite, sericite, and pyrite.

Basalt flows are closely associated with the andesite lava. Fresh basalt is dark greenish gray to grayish black but changes on weathering to pale olive green. It is commonly pillowed and amygdaloidal. Dark-green clinopyroxene phenocrysts 3–4 mm in length in a fine-grained groundmass are characteristic; plagioclase phenocrysts are rare. More extensive and thicker basalt flows interlayered with the andesite lava are shown by a hachured overprint on the geologic map; thinner and less extensive basalt flows are not shown.

MAMEYES FORMATION

A sequence of Upper Cretaceous volcanic rocks, consisting mostly of andesite lava that conformably overlies and in places intertongues with part of the Vista Alegre Formation, is here named the Mameyes Formation for exposures in Barrio Mameyes Arriba. The type locality for the Mameyes is along a jeep trail heading west from Cerro Palo de Café between coordinates 46,800–135,620 and 46,920–135,080. Here, even though partly weathered, the rocks show best the textural variations and, in places, the pillow structures of the lava flows. The Mameyes Formation is mainly a thick unit of andesitic lava flows and subordinate intercalated beds of volcanic sandstone and siltstone. The sandstone beds are characterized by a moderate to abundant quantity of pyroxene. The lava beds of the Mameyes are lenticular and intertongue locally with the units above and below; therefore, although the contacts of this formation with the underlying Vista Alegre and the overlying Tetuán Formations are conformable and sharp, these contacts do not occupy the same stratigraphic positions at all localities on the map.

The Mameyes Formation ranges in thickness from 750 to 1,100 meters and extends from the west edge of the map eastward in an arcuate pattern to the Damián Arriba fault where it is in juxtaposition with the younger Pozas Formation. The road southwest from Hacienda Marqués traverses the greatest area of exposure of the formation from a point approximately 900 meters north of the south border of the map northward to its upper contact about 800 meters southeast of Hacienda Marqués. The formation is repeated by faulting, however, and the true thickness is not represented along this traverse.

The greenish-gray andesite lava is pillowed and amygdaloidal in places. This lava is generally similar to the andesite lava of the Río Orocovis Formation in the Ciales quadrangle (Berryhill, 1965) and Corozal quadrangle (A. E. Nelson, written commun., 1963). The andesite lava contains pyroxene phenocrysts in places but is characterized by clusters of plagioclase phenocrysts in a fine-grained groundmass. Intersertal, intergranular, hyalo-ophitic, and felted groundmass textures occur. The size of the constituents of the fine-grained groundmass varies from outcrop to outcrop. Plagioclase in the groundmass and as phenocrysts is commonly sericitized, and some clinopyroxene is altered to chlorite. An opaque mineral, presumably magnetite, is abundant in the groundmass of some of the lava. Potassium feldspar is present in the groundmass of some lava, as indicated by staining with cobaltinitrite using the method described by Bailey and Irwin (1959). In a few places, pyrite is disseminated through the rock.

The volcanic sandstone and siltstone in the Mameyes Formation are similar lithologically to the sandstone and siltstone in the Vista Alegre Formation.

TETUÁN FORMATION

The Upper Cretaceous Tetuán Formation, consisting mostly of bedded tuff, is here named after Barrio Tetuán. Exposures on the east side of Route 140 just north of the bridge where the highway crosses the Río Limón and approximately 1 kilometer east of the west edge of the quadrangle are designated the type locality. The formation is estimated to be 1,200–1,500 meters thick and extends from the western part of the map to the northwest-trending Damián Arriba fault where it is in juxtaposition with the Yunes Formation. The lower and upper contacts of the formation are conformable. The contact between the Mameyes and the Tetuán is placed at the contact of the uppermost lava unit of the Mameyes Formation with the lowermost volcanic sandstone unit of the Tetuán Formation. The contact between the Tetuán Formation and the overlying Alonso Formation is placed at the top of the uppermost thin-bedded tuff of the Tetuán Formation that underlies the massive red to reddish-gray volcanic breccia of the Alonso Formation.

Stratified reworked tuff, some of which is calcareous, makes up most of the formation, but thin, mostly lenticular beds of volcanic breccia, lapilli tuff, and lavas of both andesite and basalt occur at numerous horizons within the formation; some of the thicker beds of andesite lava are shown separately on the map (pl. 1).

The tuff is fine grained and pale greenish gray to olive green. It is generally well bedded; however, some beds are massive. Although graded bedding occurs locally, this type of bedding is not recognized at most outcrops. Thin sections indicate that graded bedding is perhaps more common in the strata of the Tetuán than most observations of these strata in the quadrangle readily indicate.

The tuff of the Tetuán Formation includes vitric, crystal, and lithic-crystal varieties. Pyroxene and plagioclase fragments and tiny pieces of pumice are the principal megascopic constituents of these rocks. Pyroxene and plagioclase occur as crystals and crystal fragments; pumice occurs as tiny pale-greenish-gray fragments that are irregularly distributed throughout the rock. Opaque magnetite(?) grains and dust are also common. Shards in the vitric tuff are, in general, colorless to pale green and have devitrified in part to a weakly birefringent material. The matrix is largely a mixture of glass dust and tiny ash particles. Some of the matrix material is almost submicroscopic but possesses faint polarization tints. In the vicinity of intrusive rocks, pyrite occurs as disseminated grains throughout the tuff. Secondary chlorite, calcite, epidote, quartz, and sericite are noted in some thin sections.

Some pyroxene-rich crystal tuff of the Tetuán Formation is, in many respects, similar in lithology to that of the Vista Alegre Formation. In fact, some thin sections from each formation, if compared, look almost identical. The crystal tuff of the Tetuán Formation, however, generally contains more plagioclase, glass, and pumice and less pyroxene than does the Vista Alegre crystal tuff, and the rocks of the Tetuán Formation are generally finer grained than those of the Vista Alegre Formation. Tuff beds in the Tetuán Formation that appear similar to those in the Vista Alegre Formation are not present in as large volumes as are the other lithologic types. The lava flows, volcanic breccia, and lapilli tuff deposits are also similar to the corresponding rock types in the Vista Alegre and Mameyes Formations.

The age of the Tetuán Formation is Late Cretaceous (Santonian to Campanian), and this dating is based upon a fragmentary ammonite that belongs possibly to either *Kossmaticeras* or *Kitchenites* (W. A. Cobban, written commun., 1963). The range of these two genera is Santonian to Campanian, (N. F. Sohl, written commun., 1963).

ANDESITE LAVA

A small body of andesite lava occurs in a fault zone near the central part of the map. It is similar lithologically to the andesite lava in the Mameyes Formation.

ALONSO FORMATION

A sequence of brownish-red welded tuff and associated volcanic rocks of Late Cretaceous age is here named the Alonso Formation from Barrio Don Alonso. The formation crops out in two areas at the west edge of the map; the smaller outcrop area is just south of the Río Limón. The larger area is south of the Marqués fault and extends about 2 kilometers into the quadrangle; in this area the maximum exposed thickness of the Alonso is about 500 meters. Exposures extending 100 meters southeast along a dirt road from Puerto Rico Route 140 (coordinates 51,340–132,260) are designated the type locality. The formation conformably overlies the Tetuán Formation, but its top is not exposed in the quadrangle.

The Alonso Formation is a mixed sequence of welded tuff, nonwelded tuff, lava breccia, and volcanic breccia which contains mainly andesite lava fragments. The formation also contains minor amounts of lapilli tuff, lithified mudflow deposits, volcanic sandstone, and some thin beds of andesite(?) lava containing a high percentage of plagioclase crystals. The Alonso Formation weathers to a characteristic purplish gray.

At the type locality, volcanic breccia is overlain by about 60 meters of welded tuff characterized by crude columnar jointing. Overlying the welded tuff is lapilli tuff containing flattened fragments of pumice that are alined parallel to the planar structures in the underlying welded tuff. The lapilli tuff is at least 7.9 meters thick, and the upper contact is faulted The welded tuff is a relatively fresh, highly resistant rock, whereas the underlying breccia and overlying lapilli tuff are both highly weathered. Berryhill (1961) describes similar but thinner beds of welded tuff in the Pozas Formation in the Ciales quadrangle.

The most common constituent in the welded tuff is plagioclase, which occurs as crystal fragments, some of which are andesine. Other constituents include quartz, epidote, chlorite, zeolite(?), magnetite, and lithic fragments. The matrix of the tuff ranges from glassy to lithoidal, and in plane-polarized light much of the matrix material is clearly identified as shards which show compaction around fragments of plagioclase, quartz, and accidental lithic material. Locally, agglutinations of shards, some of which consist of streaks of secondary quartz, impart a planar structure to the rock which is parallel to that of the flattened pumice fragments. Some shards appear to have been squeezed between larger mineral grains. One thin section shows an area of shards and matrix where flow lines are truncated by another zone or sequence of the same material which also possesses flow lines. This relationship suggests that the tuff deposit was subjected to internal flowage after emplacement but prior to consolidation. Most of the nonwelded tuff is composed of the same material as the welded tuff and has a vitroclastic texture.

POZAS FORMATION

The Pozas Formation, named by Berryhill (1965) for a sequence of Upper Cretaceous volcanic rocks in the Ciales quadrangle, extends into the Florida quadrangle where a stratigraphic thickness of about 2,000 meters is present. Owing to faulting, however, neither the upper nor lower contact is exposed in the Florida quadrangle. The formation is in fault contact with the older Vista Alegre and Mameyes Formations to the south and the younger Yunes Formation to the northwest; to the north, the Pozas Formation is in fault contact with the Avispa Lava Member of the Río Orocovis Formation and is unconformably overlain elsewhere to the north by middle Tertiary deposits and landslide debris from middle Tertiary rocks. Although faulting prevents a positive correlation, similarities in rock types and relative stratigraphic position suggest that the Pozas correlates with the Alonso Formation which crops out in the western part of the quadrangle. As this correlation is not positive, the formations are separated by a break in sequence on the map explanation.

In the Ciales quadrangle, Berryhill divided the Pozas Formation into the Minguillo Lava Member, the Blacho Tuff Member, and an upper breccia member. These members are also present in the Florida quadrangle. The outcrop area of the Blacho Tuff Member is limited by the Damián Arriba fault, and most of the Minguillo Lava Member is concealed by younger deposits; thus, in the Florida quadrangle, most of the Pozas Formation is equivalent to Berryhill's upper breccia member.

In the Florida quadrangle the Pozas Formation consists primarily of a thick sequence of volcanic breccia and associated volcanic conglomerate; it also contains deposits of crystal tuff, volcanic sandstone and siltstone, lava flows and flow breccia, lahar deposits, and limestone. Several of these lithologic units have been mapped separately and include lava beds, limestone lenses, and a limestone body herein named the Flor de Alba Limestone Lentil. Except for the limestone and some volcanic sandstone and siltstone, the rocks of the Pozas Formation characteristically weather deep purple to reddish gray.

Volcanic breccia, including some lapilli tuff, is the most widely distributed rock type of the Pozas in the quadrangle. Fragments in the breccia, usually less than 4 cm long, are angular to subrounded and are composed of purplish-red andesite lava that is similar to the andesite lava occurring elsewhere in the formation. The matrix is largely tuffaceous and contains pumice particles, pyroxene and feldspar crystals, and crystal fragments. In places, volcanic breccia grades into crudely stratified volcanic conglomerate. Cobbles of the conglomerate consist mostly of andesite lava, and only a few limestone fragments are present. The matrix of the conglomerate is a purplish-red fine-grained material that in places contains abundant feldspar and less commonly pyroxene crystals and fragments. Good exposures of volcanic breccia and conglomerate occur in a small south-flowing stream 1.1 kilometer south of Escuela Segunda Unidad de Frontón and due west of the west-northwest-trending road from Hacienda Aldea.

Crystal tuff deposits are also widely dispersed throughout the Pozas Formation. They are deep reddish brown and fine grained and are characterized by numerous crystals and crystal fragments, seldom over 1 mm in length, of plagioclase and minor amounts of clinopyroxene. The matrix is a very fine grained material that is mainly devitrified glass. Sparse small lithic fragments can be observed.

Andesite lava and other rock types are commonly interstratified in the Pozas Formation. Generally, lava beds are confined to the eastern part of the outcrop area. Several of these lava beds cross Route 149 between the latitudes of Hacienda Flor de Alba and Hacienda Colon. In contrast to other lava in the quadrangle, pillow structures were not observed. Most of the lava is characterized by numerous grayish-white crystals of plagioclase in a dark-red aphanitic groundmass. Four lava types are in the Pozas. The most common variety contains numerous crystals of both plagioclase and clinopyroxene in an aphanitic groundmass. Plagioclase occurs as stubby crystals seldom more than 1 mm long. Clinopyroxene is less abundant and occurs as crystals which are commonly as much as 5 mm in diameter. A second lava variety is typified by a profusion of stubby plagioclase crystals in a fine-grained groundmass; clinopyroxene is rare or absent. In contrast, a third type is very fine grained, has only sparse plagioclase phenocrysts, and has little or no visible clinopyroxene. The fourth, and least common, variety of lava is highly scoriaceous and has few crystals of either plagioclase or clinopyroxene.

Some weathered outcrops of lava show a breccia texture, but generally the texture of the lava is hyalopilitic or hyalo-ophitic. The groundmass is a mixture of glass and microlites. The glass is commonly dark gray or black and in places has devitrified to a fine microcrystalline material. In some lava beds the plagioclase is albite; in others it ranges from oligoclase to andesine. Magnetite is present as discrete grains and dust in variable amounts in most of the lava. Secondary minerals include quartz, chlorite, zeolites, epidote, sericite and calcite.

Minguillo Lava Member.—The Minguillo Lava Member, exposed in a small area adjacent to the east edge of the map, is dark-reddish-purple andesite lava. Short prismatic plagioclase crystals are abundantly distributed in a reddish aphanitic groundmass, and large pyroxene crystals are sporadically scattered throughout the rock.

Blacho Tuff Member.—Lahar deposits and associated lapilli tuff deposits make up the Blacho Tuff Member in the Florida quadrangle. The laharic deposits consist of a heterogeneous mixture of poorly sorted rock fragments, tiny pieces of pumice, and large crystals and crystal fragments of both plagioclase and pyroxene embedded in a deep-red fine-grained matrix. The matrix consists of small crystal fragments and very fine grained microcrystalline material containing some devitrified glass. The beds of welded tuff characteristic of the Blacho in the Ciales quadrangle were not observed in the Florida quadrangle. These subaerial units may have been destroyed after deposition or may not have been deposited in that part of the Blacho exposed in the Florida quadrangle.

Flor de Alba Limestone Lentil.—A somewhat lenticular body of light-gray generally crystalline limestone, here named the Flor de Alba Limestone Lentil, is exposed in the southeast quadrant of the quadrangle. It is named after Hacienda Flor de Alba which is about 500 meters east of the main part of the lentil. The limestone rests on and is overlain by beds of calcareous volcanic sandstone, some of which is also interbedded with the limestone at several horizons. The lentil is commonly well bedded, but in the upper part some of the limestone is massive. Parts of the lentil are fossiliferous, and a highly fossiliferous well-bedded outcrop on an improved trail at coordinates 144,260–51,560 is taken as the type locality.

Pelecypods, gastropods, and corals are common at some horizons in the Flor de Alba Limestone Lentil. An assemblage of these fossils, collected and identified by N. F. Sohl (written commun., 1963), were referred by him to the Late Cretaceous Campanian and Maestrichtian. A more precise designation of the age of the Flor de Alba Limestone Lentil is not possible at this time.

CRETACEOUS AND TERTIARY ROCKS

UNDIVIDED UPPER CRETACEOUS AND LOWER TERTIARY ROCKS

Several erosional inliers of Upper Cretaceous or lower Tertiary rocks, or both, occur within the southern part of the Lares Formation in the general area north of Escuela Segunda Unidad de Frontón. These inliers contain rocks that resemble both the Pozas Formation and Yunes Formation, but because of their limited extent it was not feasible to determine their structural relations to similar rocks farther south.

INTRUSIVE ROCKS

Granodiorite, diorite, gabbro, and andesite crop out as stocks, dikes, and sills in the Florida quadrangle, but only granodiorite and diorite-gabbro intrusive bodies are shown on plate 1. Small sills and dikes of andesite are closely associated with andesite lava of the Mameyes and Vista Alegre Formations and are not shown separately. An eastward extension of the gray to light-gray fine-grained hornblende granodiorite of the Utuado pluton (Weaver, 1958) is exposed in a small area along the west border in the southwestern part of the quadrangle. In places, granodiorite grades into quartz diorite, but the quartz diorite is not distinguished on plate 1. The textures of the intrusive rocks range from granitic to xenomorphic granular, but in places, phenocrysts of hornblende and plagioclase impart a porphyritic texture to the rock. Hornblende, plagioclase, and quartz are the principal minerals. Potassium feldspar and magnetite are common; accessory minerals include apatite, sphene and zircon. Secondary minerals include albite(?), sericite, biotite, chlorite, and calcite.

Plagioclase (An_{22-39}) is the most abundant mineral in the granodiorite and occurs both as phenocrysts and in the groundmass. Phenocrysts of plagioclase range between 1 and 4 mm in length; plagioclase in the groundmass ranges from 0.02 to 0.1 mm in length. The plagioclase is complexly twinned, normally zoned, and altered locally to sericite and chlorite. Hornblende occurs as lathlike crystals and as small neddlelike forms. The larger phenocrysts of hornblende are seldom longer than 5 mm. An opaque mineral, probably magnetite, occurs as small grains and dust throughout the groundmass. Trace amounts of microcline and biotite were observed. Quartz and potassium feldspar are anhedral and occur interstitially between larger minerals in the groundmass; in some thin sections potassium feldspar is graphically intergrown with quartz. This intergrowth suggests that the potassium feldspar may be of deuteric origin.

Numerous small dikes and stocks of diorite that in some places grade into gabbro are exposed in the southern part of the quadrangle. The diorite is fine grained, and the principal minerals are plagioclase, clinopyroxene, and hornblende. Magnetite, sphene, and apatite are the accessory minerals. Secondary minerals include chlorite, sericite, calcite, and epidote.

The texture of diorite in the Florida quadrangle ranges from granitic to xenomorphic and, locally, to porphyritic. Phenocrysts of hornblende, clinopyroxene, and plagioclase are locally as long as 2 cm but more commonly range between 3 and 5 mm in length. Minerals in the groundmass range from 0.02 to 0.1 mm in diameter. Plagioclase in the gabbro and in the more mafic diorite is as mafic as labradorite (An_{62}), but in most of the diorite it is in the calcic oligoclase to andesine range; some of the plagioclase is albite, but this mineral may be due to sodic metasomatism. The plagioclase is commonly normally zoned and polysynthetically twinned. Hornblende, locally poikilitic, replaced clinopyroxene in the diorite but not in the gabbro. Kelyphitic rims of magnetite and hornblende envelop some crystals of clinopyroxene; biotite is closely associated with hornblende and magnetite; uralite has formed in only a few places. Cobaltinitrite staining of three diorite samples showed that a trace of potassium feldspar is present in the groundmass. Quartz likewise is sparse.

Dioritic rocks cut all the Cretaceous rocks in the quadrangle except the Pozas; hence it is assumed that dioritic intrusion commenced after deposition of at least part of the Alonso Formation. The Paleocene and Eocene Yunes Formation is not known to have been intruded, but the hydrothermally altered rock in the Yunes suggests that magmatic activity may have continued after the deposition of the Yunes Formation. Thus, dioritic intrusion commenced toward the end of the Late Cretaceous and may have continued into the Eocene. The unmapped andesite sills and dikes are believed to be younger than or contemporaneous with associated lavas.

TERTIARY ROCKS

YUNES FORMATION

A thick sequence of well-bedded lower Tertiary volcanic rocks in the west-central part of the quadrangle is here named the Yunes Formation from the Río Yunes along which a large part of the formation is exposed. Although measurement of its thickness is complicated by faulting, the formation is estimated to have a maximum thickness of 3,000 meters in the quadrangle. The formation is in fault contact with the Tetuán and the Mameyes Formations to the southwest and the Pozas Formation to the south; near the west edge of the map (pl. 1), the Yunes is also in fault contact with the Alonso Formation. To the north the Yunes is unconformably overlain by younger middle Tertiary rocks and associated landslide deposits. A section along Route 140 between coordinates 54,020–136,540 and 53,840–136,540, taken as the type locality, shows a sequence of thin beds of pale-green to brownish-green vitric tuff and associated volcanic sandstone and siltstone.

The formation consists mostly of fine-grained bedded tuff, volcanic sandstone, and siltstone. In places, volcanic breccia, conglomerate, and lenses of fragmental limestone occur. Weathered lava containing abundant plagioclase crystals occurs near the west edge of the quadrangle. The tuff beds are a very characteristic pale green to pale blue green and closely resemble Eocene tuff exposed in the Corozal quadrangle (A. E. Nelson, unpub. data) and in the Jayuya quadrangle (P. H. Mattson, written commun., 1963). Most of the volcanic sandstone, conglomerate, and breccia are dark gray to brownish gray. The limestone is light gray. Quartz grains, which are sparse in the older rocks, are common in the epiclastic rocks of the Yunes Formation.

Bedding in the Yunes Formation is variable. Generally, the tuff and siltstone are thin bedded; the volcanic sandstone ranges from thin to thick bedded, and the conglomerate, volcanic breccia, and limestone are massive and only faintly stratified. Graded bedding and associated slump structures are well formed in some of the coarser volcanic sandstone beds.

The tuffs range from crystal vitric to vitric. Plagioclase is the most common visible mineral; an opaque mineral (magnetite?) is sporadically distributed, and a few foreign rock fragments occur. The matrix consists mostly of pale greenish glass that is largely devitrified.

An area within the Yunes Formation centered around coordinates 54,120 and 134,540 contains numerous boulders of hydrothermally altered rock. These boulders occur as erratic masses as large as 4 meters in diameter. The rock that composes the boulders has not been observed in place, and whether this rock represents altered Yunes Formation is uncertain. The hydrothermally altered rock, which occurs in an area where vegetation conceals the bedrock, is highly siliceous, has a deep-red hematite stain, and locally contains some magnetite. Alteration has been such that the original nature of the rock cannot be determined.

The Yunes Formation is early Tertiary in age. It is continuous with rocks of late Paleocene to middle Eocene age exposed in the Utuado quadrangle (E. A. Pessagno, written commun., 1963). Pessagno identified fossils collected by Mattson in rocks equivalent to the Yunes Formation in the Utuado quadrangle to be *Globigerina* sp., *Globorotalia* sp. (keeled forms), and Radiolaria (spumellinids).

SAN SEBASTIÁN FORMATION

The San Sebastián Formation of Oligocene age rests with angular unconformity on a wide variety of volcanic rocks of Cretaceous and earlier Tertiary age. It consists mostly of pale-red clay containing black manganese stains and iron oxides, many calcareous concretions, and locally abundant pebbles of volcanic rocks. In the eastern part of the quadrangle, clay is overlain directly by the Lares Limestone, but in the western part about a meter of ferruginous quartz sand is present at the top of the San Sebastián Formation. Thickness of the formation ranges from 0 to 60 meters.

LARES LIMESTONE

The Lares Limestone of Oligocene age rests conformably and with a sharp contact on the San Sebastián Formation in most of the outcrop area of Lares, except on the buried hills in the central and western part of the quadrangle where the Lares rests unconformably on volcanic rocks. At these latter places, ancient hills of the middle Oligocene surface were not covered by the sea during San Sebastián time, and erosion continued into Lares time.

The basal 30–50 meters of the Lares consists of thin-bedded to flaky limestone that contains fine to medium grains (Wentworth scale) of limonitic rock that may represent weathered fragments of volcanic debris. The ferruginous grains are abundant in the basal 10 meters, but are sparse in higher beds. The flaky limestone is overlain by finely crystalline pink to yellowish-gray limestone that is massive to thin-bedded. In the eastern part of the quadrangle, very pure, white crystalline chalk is present from about 90 to 110 meters above the base of the formation. From about 140 to 150 meters above the base, the formation consists of rather coarse-grained fragmental limestone; above 150 meters, it consists of very fine grained crystalline limestone. In the eastern part of the quadrangle, the Lares appears to be about 250 meters thick; in the central part, about 230 meters thick; along Route 140 southwest of Florida, about 220 meters thick; and near the west edge of the quadrangle, about 180 meters thick. The westward thinning of the formation and the numerous buried hills where the Lares rests directly on pre-Oligocene rocks may reflect a rise in the basement.

Fossils are common in many parts of the formation and include Foraminifera, mollusks, echinoids, and algae; corals are present at some places but are rare in most parts of the formation. Foraminifera, especially *Lepidocyclina* sp., are very abundant in parts of the Lares, and apparently continuous foraminiferal beds have been observed 15–20 meters above the base in the eastern part of the quadrangle and about 50 meters above the base in other parts of the area.

CIBAO FORMATION

The Cibao Formation of Oligocene and Miocene age is a heterogeneous formation consisting predominantly of calcareous clay and very clayey limestone but including in places hard limestone, sand, and gravel. In the Florida quadrangle the formation rests sharply, perhaps disconformably, on the Lares Limestone.

Throughout most of the Florida quadrangle, the Cibao Formation consists of friable pure limestone that is indurated on the surface at most places into a very finely crystalline texture. This unit is here named the Montebello Limestone Member from the village of Montebello, Barrio Río Arriba Poniente, Municipio de Manatí, which is surrounded by hills of the limestone. The specific type locality is in a cliff face on the east side of a trail 1,300 meters air line S. 33° E. of Montebello, coordinates 58,330–143,560, where about 20 meters of massive limestone rests on about 10 meters of thin-bedded and crossbedded limestone that is composed largely of medium to coarse grains, many of which are Foraminifera and shell fragments. The base of the unit is not exposed, but exposures updip toward the south and less than 5 meters stratigraphically lower are massive very fine grained white crystalline limestone of the Lares. In the central and western parts of the Florida quadrangle, the thickness of the Montebello Limestone Member is about 210 meters. This is more than the thickness of the entire Cibao Formation at the east edge of the quadrangle.

The Montebello Member is overlain in most of the quadrangle by calcareous clay or marl which is less than 10 meters thick in the west half of the quadrangle but which has not been mapped in that area.

Toward the east the Montebello Member intertongues with marl and limestone beds that have been recognized farther east. The Quebrada Arenas Limestone Member, consisting of 10–20 meters of alternating beds of hard and soft limestone, can be recognized from the east edge of the quadrangle to a point about a kilometer west of Montebello where it becomes indistinguishable from the limestone beds of the Montebello. In the northeast corner of the area, the Quebrada Arenas is overlain by about 50 meters of marl.

Southeast of Montebello successively lower parts of the Montebello Member grade laterally eastward into calcareous clay and earthy limestone, until at the east border of the area, the Cibao consists of the following units, in ascending order: About 50 meters of limestone of the Montebello Member; about 70 meters of calcareous clay and very clayey chalk or marl, characteristic of the Cibao in its type area in western Puerto Rico; about 20 meters of alternating hard and soft limestone of the Quebrada Arenas Member; and about 50 meters of calcareous clay and earthy, rubbly white to pink limestone of the upper member of the Cibao.

Fossils, especially *Lepidocyclina* sp., are present at many places in the lower two-thirds of the formation. The large echinoid *Echinolampus semiorbis* Guppy is abundant at many places in the marl below the Quebrada Arenas Member in the eastern part of the quadrangle. Mollusks and corals are locally abundant. A large part of the Montebello Limestone Member, however, contains few fossils.

AGUADA LIMESTONE

The Aguada Limestone of Miocene age rests conformably on the Cibao Formation. In the Florida quadrangle the contact is placed at the base of the first stratum of calcarenite, or granular limestone, that occurs above the few meters of marl and sporadic beds of very waxy limestone or calcilutite at the top of the Cibao Formation. In general, the contact has been placed as much as 0 to 15 meters higher than in the adjacent Barceloneta quadrangle (Briggs, 1965). The Aguada is only a cap of granular limestone and earthy concretionary limestone of a few high hills near the north border of the quadrangle. It is rich in molds of mollusks.

QUATERNARY DEPOSITS

Alluvium and terrace deposits.—Some of the large stream valleys contain thin deposits of alluvial sand and gravel. Some of the longer valleys of the limestone belt area in the north half of the quadrangle are floored with deposits of slightly sandy clay derived largely from weathering of the Lares Limestone but contaminated by a small amount of quartz sand. Such valleys as Quebrada del Pozo Azul and the valley due east of Quebrada Sumidero contain west-northwest-flowing streams that disappear in joints or caves. At the points where these streams disappear, a thick hummocky mantle of slightly sandy alluvial clay is present. A few streams flow in valleys that contain alluvial terrace deposits which are above the present alluvial plain, but to map these terrace deposits separately was impractical. The extensive flat plains between ridges in the extreme northern part of the quadrangle are underlain by reddish-brown sandy clay, a part of the blanket sand deposit of the adjacent Barceloneta quadrangle (Briggs, 1965). Briggs believes that this sand deposit is of both Tertiary and Quaternary age.

Landslides.—At places where the basal beds of the Lares Limestone are underlain on steep slopes by the San Sebastián Formation, clay beds of the San Sebastián have given way, causing blocks of limestone to drop and slide intermittently down the slopes. Some of these blocks are very large and reach lengths of as much as 10 meters. During the course of mapping, blocks of limestone as much as 3 meters in diameter slid onto Route 146 at two places just northeast of Hacienda Santa Elena. The blocks in the road had to be blasted before removal. At these places the road is cut into pale-red clay capped by slide blocks of limestone.

Two landslides have been mapped in the area near Escuela Unidad de Mameyes. The slide material consists of rock debris derived primarily from the Mameyes Formation and, in places, from dioritic intrusive bodies.

STRUCTURAL GEOLOGY

Most of the Florida quadrangle is on the north flank of the west to northwest-trending Puerto Rico anticlinorium and is characterized by a general northerly dip of the strata. The two most prominent structural features are the Damián Arriba fault and the unconformity between the lower Tertiary and middle Tertiary strata. Other less prominent structural features shown on the map include both faults and folds.

Several west- to northwest-plunging folds occur in the southern part of the quadrangle. One syncline, trending northwest from the southeastern part of the quadrangle, approximately parallels the Damián Arriba fault for almost 3 kilometers to where the trace of the axial plane is cut off by a fault. A synclinal remnant, possibly of the same fold, is exposed along the Marqués fault south of Hacienda Marqués. A northwest-trending anticline occurs between the Marqués and Damián Arriba faults and is best formed in the area north of Hacienda Marqués. The syncline occurring in the Pozas Formation is not well defined near the east edge of the quadrangle but is apparently the northwest continuation of a large fold mapped by Berryhill (1965) in the Ciales quadrangle. Small west-plunging folds, whose amplitude is seldom more than 5 meters, are common in some of the fine-grained volcanic sandstone and siltstone beds.

Although the Cretaceous and lower Tertiary strata in the quadrangle have been moderately folded, deformation by fracturing has had the more pronounced effect upon the rocks. Fault zones have formed, and very large movements have occurred along some of the faults. Joints are ubiquitous in the rocks, and fracture and shear cleavage are found in only a few places. Fracture cleavage is present in some of the fine-grained volcanic sandstone and siltstone, and in places where major faults cut these rocks, a shear cleavage has formed parallel or subparallel to the faulting.

The dominant trend of the faults is west-northwest, and subsidiary structures, local stratigraphic displacements, and regional relations indicate that the movement on the larger faults was transcurrent in a left lateral sense. Smaller cross faults formed in response to tension during the main faulting. The faults in the quadrangle are steeply dipping or vertical, and stratigraphic displacement along them varies widely. The Damián Arriba fault, one of the more important faults in Puerto Rico, crosses several quadrangles (Berryhill, 1965; Briggs, 1962; Briggs, written commun., 1963). Regional relationships suggest it has a left lateral displacement; the apparent stratigraphic displacement is considerable, as the entire section of the Vista Alegre, Mameyes, and Tetuán Formations, at least 2,450 meters in aggregate thickness, is not present north of the fault. The Limón fault trends east across the southern part of the quadrangle and has about 230 meters of displacement. The Marqués fault and the Garau fault have displacements estimated to be about 500 meters.

Outcrop relationships between the intrusive rocks and faults strongly suggest that some of the intrusives are faulted, but, because of the deep tropical weathering over much of the area, the time relationships between intrusive rocks and faulting could not be determined accurately.

Movement along faults in the quadrangle has produced graben and horst structures similar to those found elsewhere in Puerto Rico (Briggs and Pease, 1960). The largest graben is bounded on the south and southwest by the Damián Arriba fault and to the north by the fault separating the Río Orocovis Formation from the Pozas Formation; the horst is bounded on the northeast by the Damián Arriba fault and to the southwest by the Garau and Marqués faults.

Joints are very common in the Cretaceous and lower Tertiary rocks of the Florida quadrangle. The contour diagram of joints (fig. 1) indicates clearly that most of the joints are steeply dipping or vertical and that the strike directions form two principal maxima. The strike

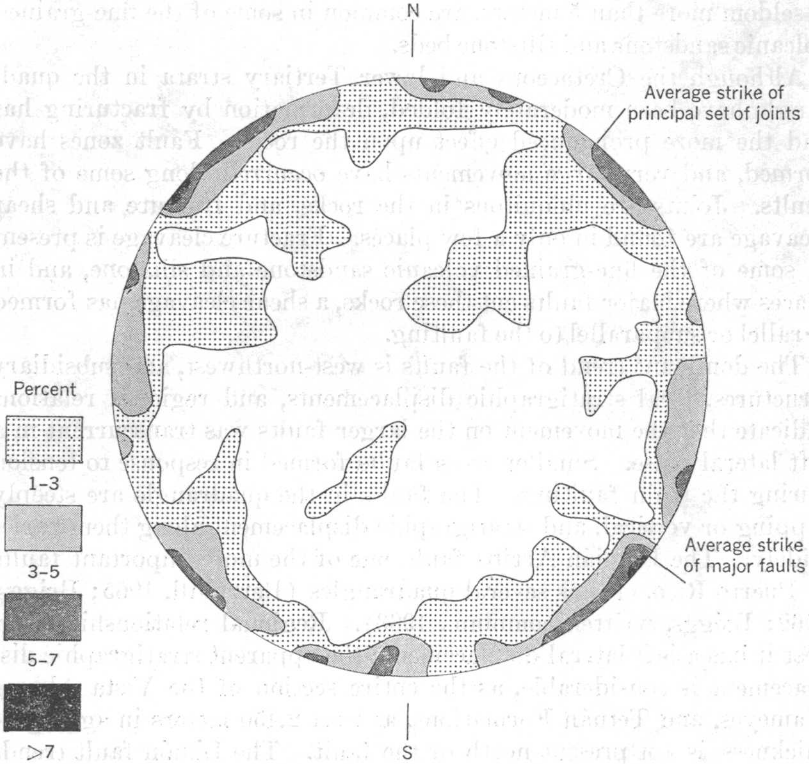

FIGURE 1.—Contour diagram of poles of 354 joints in Cretaceous and lower Tertiary rocks in the Florida quadrangle. Equal-area projection of lower hemisphere.

of one group of joints is approximately normal to the west-northwest strike of major faults, and the average strike of the other set is within 25° of being parallel to them.

ECONOMIC GEOLOGY

The principal mineral resources in the Florida quadrangle are limestone, sand, and gravel. The Lares Limestone and the Montebello and Quebrada Arenas Limestone Members of the Cibao Formation contain large quantities of very pure limestone. The rock is being extracted at present only in one quarry, on Route 140 about 3 kilometers due southwest of Florida. The limestone at this quarry is nearly pure $CaCO_3$ and is used for agricultural purposes. The Flor de Alba Limestone Lentil could also be a source of limestone.

River terrace and alluvial deposits of sand and gravel are local and of somewhat limited extent. The greatest source of sand and gravel in the quadrangle is in the valley of the Río Toro Negro near the east side of the quadrangle. Smaller deposits of sand and gravel occur locally in other streams.

Rocks suitable for use as highway aggregate, concrete aggregate, riprap, and dimension stone are available at many places in the quadrangle. The Cretaceous lavas, some lower Tertiary limestones, and the intrusive rocks could be sources of crushed stone for base course, coarse aggregate, and riprap. Some lavas, however, may contain deleterious minerals and might have to be examined to determine their suitability. Much of the volcanic sandstone and siltstone could be used as fill. Some of the Cretaceous limestone could be used as dimension stone.

Saprolite covers a large part of the south half of the quadrangle, and some of this material could probably be used for brick and ceramic clay.

Boehmite (the monohydrate of alumina) admixed with kaolinite was identified by S. S. Goldich (Thomas, Bergquist, and Zapp, written commun. 1945) by differential thermal analysis of several soil samples collected from sinkholes in the Lares Limestone. Hildebrand (1960, p. B368) confirms the presence of boehmite by use of X-ray powder diffraction methods. Extensive commercial drilling of the deposits has thus far not revealed bauxite in commercial grade or quantity.

Some mineralization is present in the quadrangle. Sulfides, mostly pyrite, occur principally in intrusive rocks but also in nearby volcanic rocks. Pyrite is also present in quartz veins in fracture zones. Barite occurs locally in small veins in the eastern part of the quadrangle. Although chalcopyrite was not seen in the quadrangle, copper carbonate has been found in float of siliceous vein material in some stream valleys. Native copper was found in float of lava from the Pozas Formation in the valley of the Río Toro Negro but was not observed in nearby outcrops.

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