Preliminary Geologic Map of the Naguabo and part of the Punta Puerca Quadrangles, Puerto Rico

TM
CM
twand

by

John W. M'Gonigle, 1934-

1977

U.S. Geological Survey
[Reports - Open file ser.]

Reproducible only in Map drawer

Introduction

The Naguabo and Punta Puerca quadrangles are underlain by a lower Cretaceous volcanic sequence of intrusive, extrusive, and volcaniclastic rocks and by intrusive bodies ranging in age from Cretaceous to as young as Eocene. Quaternary surficial deposits cover about a third of the land area, and soil or saprolite or both has formed on most of the upland areas. The major part of the area lies north of the left-lateral Cerro Mula fault, which trends west-northwest through the Humacao quadrangle (fig. 1) and which has offset stratigraphic units in the northeastern part of Puerto Rico from those of the central part by many kilometers. Volcanic units north or south of the Cerro Mula fault zone can be traced and correlated laterally but not across the fault zone.

Early references to the geology of the region are those by Lobeck (1922), Fettke (1924a), Meyerhoff (1933), and Meyerhoff and Smith (1931).

The terminology of volcaniclastic rocks used in this report is largely that of Fisher (1960, 1961, 1966), and for bedding thickness, that of Ingram (1954). The classification of plutonic rocks is principally that of the International Union of Geological Sciences (Streckeisen, 1973), modified as proposed by Lyons (1976).

Volcanic Rocks

At several places in the hills west and south of Ceiba and in a fault block north of Naguabo fine-grained lavas typical of the Figuera Lava are interlayered with breccias and lavas typical of the upper part of the Daguao Formation. These exposures (Kfld) are considered to be within the gradational zone that separates the Daguao from the overlying Figuera Lava. On Isla Piñeros the Figuera Lava apparently conformably overlies the Daguao Formation.

The Daguao intrusive breccias are interpreted to be remnants of some of the volcanic necks or conduits which supplied the andesitic material that makes up the tuff breccias and lavas of the Daguao Formation (M'Gonigle in press a). Some of the coarse autoclastic lavas that are interlayered with tuffs and breccias in the ridge on the west side on Ensenada Honda may be sills from the Daguao intrusive (Kdi) immediately to the northeast, rather than flows. The base of the Daguao Formation is not exposed, but the formation is perhaps the oldest unit exposed in northeastern Puerto Rico. No identifiable fossils were found in the formation, but it is considered to be entirely Early Cretaceous in age, as it lies stratigraphically below the Early Cretaceous Figuera Lava and Fajardo Formation.

The Figuera Lava and overlying Fajardo Formation are best examined in the Fajardo quadrangle to the north of the Naguabo quadrangle. The local occurrences of both pillow lavas and ash flow materials in the Figuera Lava within the Naguabo and Fajardo quadrangles indicate the Figuera is in part submarine and in part subaerial. In the Fajardo quadrangle Briggs (1973) found that the Fajardo Formation conformably overlies the Figuera, but in the Naguabo quadrangle the two units are found only in fault contact. The Figuera is considered to be Early Cretaceous in age by Briggs (1973).

In the northern half of the Fajardo quadrangle Briggs (1973) was able to subdivide the Fajardo Formation into four members. In the southern part of the Fajardo quadrangle and in the Naguabo quadrangle, exposures are too poor to permit a good subdivision of the Fajardo Formation. Paleontological studies show the Fajardo to be Early Cretaceous (Albian) in age (Briggs, 1973).

The age of the much altered Mambiche sequence is unknown. It has been tentatively correlated (M'Gonigle, in press b) with the Lomas Formation of the Humacao and El Yunque quadrangles, which is considered to be Upper Cretaceous in age (Seiders, 1971 a,b).

Laminated to thin-bedded sandstone and tuff sequences in the Daguao Formation closely resemble some members of the Fajardo Formation and cause some initial difficulty in mapping. In general, however, the Daguao tuffs do not consistently develop the yellowish brown color on weathered surfaces so characteristic of units in the Fajardo Formation, but mostly take on a grayer brown or brownish gray color. Also the thickness of well-bedded units is generally not as great in the Daguao Formation, nor is consistently fine stratification (or even prismatic jointing) so well developed across an exposure. Wispy laminations are much more common and better developed in the Fajardo tuffs and sandstones. In the Daguao Formation coarse-grained , thick-bedded tuffs commonly grade into a finer-grained thin-bedded tuff sequence, whereas in the Fajardo the transition is commonly more abrupt. Finally, breccias adjacent to tuff or sandstone beds in the Daguao are rather different from those in the Fajardo Formation, as explained under "Description of map units".

Stocks

Lithology and distribution--A variety of plutonic rocks are represented in six stocks exposed in the Naguabo quadrangle. Compositionally, four of them resemble most of the plutonic rocks in Puerto Rico in that they range from quartz diorite to granodiorite. The stock south of Daguao shows the greatest compositional variation. It is medium grained, (like the other stocks) throughout most of its area, but has masses of fine-grained (TKgdf) and darker dioritic (TKgdd) rock at its eastern end. The stock at the head of the Rio Daguao locally has a fine-grained allotriomorphic-granular quartz feldspar groundmass, which I think indicates a relatively rapid increase in the crystallization rate during the final stages of cooling- perhaps as the intrusive neared the surface.

The hornblende diorite stock (TKd) is more mafic than most plutonic rocks of eastern Puerto Rico; its nearest analog is located just south of Humacao (west of the Naguabo quadrangle), where a diorite-hornblende complex in the San Lorenzo batholith forms a curved ridge. In contrast the hornblende diorite in the Naguabo quadrangle weathers readily and the stock is deeply eroded, overlain in large measure by swamp deposits and probably the ocean in Ensenada Honda. Exposures in a small abondoned quarry off the road to the pier on the west side of the bay show that the dark diorite was broken into large angular blocks and intruded by a lighter, more felsic hornblende diorite. How large a part of the stock was affected by later stage fracturing and secondary intrusion is unknown, as so little of the stock is exposed.

The quartz keratophyre stock (TKk) is unusual, and similar intrusives have not been reported elsewhere in eastern Puerto Rico. It is similar in appearance to the Water Island Formation of the U.S. Virgin Islands (Donnelly, 1966), except that in Puerto Rico the keratophyre does not seem to include extrusive rocks.

Age--The quartz diorite Rio Blanco stock of the El Yunque quadrangle (Seiders, 1971a) has been radiometrically dated at 46 my (Eocene) (Cox and others, in press). Part of a hydrothermally altered stock of granodiorite (?) is present along the southwestern border of the Naguabo quadrangle; this stock is probably Cretaceous in age, as it appears to have intruded the Mambiche volcanic sequence of the Humacao quadrangle (M'Gonigle, in press b) prior to extensive Cretaceous hydrothermal alteration along the Cerro Mula fault. Farther west, in east-central Puerto Rico, alteration along the Cerro Mula fault zone was dated at 75 my (Cox and others, in press), and it is presumed that the alteration in the Humacao and Naguabo quadrangles is also Cretaceous. Whether the age of the other stocks in the area is Cretaceous or Tertiary is unknown. The quartz diorite at the head of the Rio Daguao probably intruded the keratophyre stock, as the keratophyre appears to have been silicified by the diorite adjacent to the contract, and a dike from the east side of the diorite cuts the keratophyre. The age relationships of the other stocks are unknown.

Structure

The major part of the Naguabo quadrangle lies north of the Cerro Mula fault zone, although most of the faults in the area probably formed in response to the same regional stresses that caused at least 33 km of left-lateral movement along the Cerro Mula fault (Briggs and Pease, 1968; oral comm. 1976), and lesser displacements along other strike-slip faults in northern Puerto Rico.

The left-lateral Peña Pobre fault, subsidiary to the Cerro Mula fault, is thought to trend eastward from the Humacao quadrangle, buried beneath Quaternary deposits in the valley south of Naguabo. A north-trending, largely buried normal fault forms the western boundary of an uplifted block of the Daguao Formation. The Peña Pobre fault has apparently offset the normal fault for a distance of 3 km between the Naguabo and Humacao quadrangles (see fig. 1). The part of the normal fault that lies in the Naguabo quadrangle (south of the Peña Pobre fault) is buried and approximately located on the map; it separates the Daguao Formation on the east from the Mambiche sequence on the west. North of the Peña Pobre fault the normal fault juxtaposes the Daguao against the Fajardo and Lomas Formations in the Humacao quadrangle to the west (see fig. 1). The left-lateral Maizales fault, which offsets the normal fault for a distance of about 500 m in the Humacao quadrangle (M'Gonigle, in press b), probably merges with the Peña Pobre fault in the vicinity of Naguabo.

The granodiorite stock south of Daguao lies across the projected trend of the Peña Pobre fault, and is elongate in an east-west direction. Exposed rocks of the intrusive are not sheared, and it is probable that the stock was emplaced after movement on the Peña Pobre fault had ceased. This interpretation was advanced for the granodiorite stock that lies along the Peña Pobre fault near the town of Río Blanco in the Humacao quadrangle to the west (M'Gonigle, in press b). There the volcanic strata along the fault are better exposed and are sheared, whereas the granodiorite is not. In any event, the elongation of both stocks suggests some structural control by the Peña Pobre fault during the emplacement of the stocks. Most of the hydrothermally altered rocks of the study area are concentrated along the projected trend of the Peña Pobre fault near Naguabo. This is similar to the situation in the Humacao quadrangle, where hydrothermally altered rocks are distributed along the trends of the Cerro Mula and Peña Pobre faults. Elsewhere in northern and central Puerto Rico hydrothermal alteration has affected rocks mainly along transcurrent fault zones (Pease, 1960; Hildebrand, 1961; Cox and Briggs, 1973).

North of Duque a northwest-trending fault forms the western boundary of an uplifted block of the Figuera Lava. The Duque fault probably extends to the southeast along the Río Santiago valley from Duque past Naguabo to the Peña Pobre fault. Whether the Duque fault had some strike slip movement in addition to a vertical component is not known. The movement sense is similar to that of the normal fault in the Humacao quadrangle (fig. 1) that bounds the uplifted block of the Daguao Formation west of the valley, but it is uncertain whether or not the Peña Pobre fault also offset the Duque fault.

A fault with a northwest trend parallel to that of the Duque fault extends from the town of Limones. This fault, which apparently displaces a breccia zone (Kflb) in the Figuera Lava, may extend some distance to the southeast down the valley toward the town of El Banco, more or less bounding the western end of the keratophyre stock. Many of the remaining faults detected in the mapped area have northeast or northwest trends, as do many valleys and many of the dikes along the coast at Húcares. If the Figuera Lava and the Daguao Formation contained more mappable marker beds and/or were better exposed, geologic mapping would probably show the bedrock to be complexly faulted, with northeast and northwest trends predominating.

One or more faults may trend northeast under the alluviated low lands from the swamps near the east edge of the granodiorite stock south of Daguao through the Roosevelt Roads Naval Reservation and on past the town of Ceiba. This suggestion, however, is based mainly on physiography; there is no direct evidence of such faulting. Both the keratophyre and the diorite stocks have an east-west elongation, which hints at structural control during the intrusions, as in the case of the granodiorite stock south of Daguao.

The small exposure of quartz diorite on the west border of the map north of Duque is the end of an offshoot from the Rio Blanco stock, and it was probably intruded along a west-trending fracture (Seiders, 1971a).

Briggs (written comm. 1977) mapped three north-trending folds in the Cretaceous volcanic rocks in the Fajardo quadrangle north of the Naguabo quadrangle. These folds are offset by west-trending strike-slip faults, and hence are considered by Briggs to predate the faulting.

Attitudes in the Daguao Formation peripheral to Ensenada Honda in the Naguabo and Punta Puerca quadrangles have a rather uniform dip to the southwest, and in the ridges around Húcares to the northeast. The wide spacing between the bedding attitudes that were obtainable across the remainder of the Naguabo quadrangle makes it difficult to determine if folds are present. With the information available at this time, it is probably simpler to assume that bedding attitudes in the mapped area are a result of the tilting of fault blocks.

Economic Geology

There are no known metal-bearing deposits in the study area. Pyrite grains and crystals are ubiquitous in the volcanic rocks, as is magnetite in the plutonic rocks; chalcopyrite is scarce. A few small masses of pyrrhotite were found in an epidotized zone in the Daguao Formation on the north side of the hill that is just northwest of the old drydock off the Bahía de Puerca.

Volcanic rocks have been excavated from small borrow pits and quarries throughout the Naguabo and Punta Puerca quadrangles for use as fill, but large amounts of the fill used in the area comes from quarries in tuffs and sandstones of the Fajardo Formation in the Fajardo quadrangle to the north. The diorite stock and the keratophyre stock have been quarried as a source of crushed rock, as has the Daguao intrusive breccia which lies south of the airport on the Naval Reservation. These three types of rock are strong and tough and should provide superior material for road metal and other construction purposes. Alluvial materials can provide local sources of sand and gravel but quartz-rich sand for concrete is in short supply in the area.

References

Berryhill, H. L., Jr., and Glover, Lynn, 3d, 1960, Geology of the Cayey quadrangle, Puerto Rico: U. S. Geol. Survey Misc. Geol. Inv. Map I-319.

Briggs, R. P., 1964, Provisional geologic map of Puerto Rico and adjacent islands: U. S. Geol. Survey Misc. Geol. Inv. Map I-392.

______, 1969, Changes in stratigraphic nomenclature in the Cretaceous System, east-central Puerto Rico: U. S. Geol. Survey Bull. 12740-0, 31 p.

Briggs, R. P., 1973, The Lower Cretaceous Figuera Lava and Fajardo Formation in the stratigraphy of northeastern Puerto Rico: U.S. Geological Survey Bull. 1372-G, 10 p.

Briggs, R. P., and Akers, J. P., 1965, Hydrogeologic map of Puerto Rico and adjacent islands: U. S. Geol. Survey Hydro. Inv. Atlas HA-197.

Briggs, R. P., and Pease, M. H., Jr., 1968, Large- and small-scale wrench faulting in an island-are segment, Puerto Rico [abs.]: Geol. Soc. America Spec. Paper 115, p. 24.

Broadel, C. H., 1961, Preliminary geologic map showing iron and copper prospects in the Juncos quadrangle, Puerto Rico: U. S. Geol. Survey Misc. Geol. Inv. Map I-326.

Cadilla, J. F., 1963, Geology of the Humacao titaniferous iron deposit: Caribbean Jour. Sci., v. 3, no. 4, p. 243-247.

Colony, R. J., and Meyerhoff, H. A., 1935, The magnetite deposit near Humacao, Puerto Rico: Am. Inst. Mining Metall. Eng. Trans., v. 115, p. 247-272.

Cox, D. P. and Briggs, R. P., 1973, Metallogenic map of Puerto Rico: U. S. Geol. Survey Misc. Geol. Inv. Map I-721.

Cox, D. P., Marvin, R. F., M'Gonigle, J. W., McIntyre, D. H., and Rogers, C. L., in press, Potassium-argon geochronology of some metamorphic, igneous, and hydrothermal events in Puerto Rico and the Virgin Islands: U. S. Geol. Survey Jour. Research.

Donnelly, T. W., 1966, Geology of St. Thomas and St. John, U.S. Virgin Islands, in Caribbean Geological Investigations, H. H. Hess, ed.: Geol. Soc. America Memoir 98, p. 85-176, 7 pl., 32 figs., 4 tables.

Fettke, C. R., 1924a, The geology of the Humacao district, Porto Rico: New York Acad. Sci., Sci. Survey Porto Rico and Virgin Islands, v. 2, pt. 2, p. 117-197.

______ 1924b, Magnetite deposits of eastern Porto Rico: Am. Inst. Mining Metall. Eng. Trans., v. 70, p. 1024-1042.

Fisher, R. V., 1960, Classification of volcanic breccias: Geol. Soc. America Bull., v. 71, no. 7, p. 973-982.

______ 1961, Proposed classification of volcaniclastic sediments and rocks: Geol. Soc. America Bull., v. 72, no. 9, p. 1409-1414.

______ 1966, Rocks composed of volcanic fragments and their classification: Earth-Sci. Rev., v. 1, no. 4, p. 287-298.

Hildebrand, F. A., 1961, Hydrothermally altered rocks in eastern Puerto Rico: U. S. Geol. Survey Prof. Paper 424-B, p. B219-B221.

Ingram, R. L., 1954, Terminology for the thickness of stratification and parting units in sedimentary rocks: Geol. Soc. America Bull., v. 65.

Knoerr, A. W., 1952, Minnesota mining men open up rick Puerto Rico iron mine: Eng. Mining Jour., v. 152, no. 8, p. 74-79.

Lobeck, A. K., 1922, Physiography of Porto Rico: Sci. Survey of Porto Rico and the Virgin Islands, v. 1, pt. 4.

Lyons, P. C., 1976, IUGS classification of granitic rocks - a critique: Geology, v. 4, p. 425-426.

Meyerhoff, H. A., 1933, Geology of Puerto Rico: Puerto Rico Univ. Mon., ser. B., no. 1, 306 p.

Meyerhoff, H. A., and Smith, I. F., 1931, The geology of the Fajardo district, Porto Rico: New York Acad. Sci., Sci. Survey Porto Rico and Virgin Islands, V. 2, pt. 3, p. 201-360.

M'Gonigle, J. W., in press a, The Rio Abajo, Pitahaya, and Dagua Formations in eastern Puerto Rico: U. S. Geol. Survey Bull. 1435-B.

M'Gonigle, J. W., in press b, Geologic map of the Humacao quadrangle, Puerto Rico: U. S. Geol. Survey Misc. Geol. Inv. Map I-1070.

Pease, M. H., Jr., 1960, Structural control of hydrothermal alteration in some volcanic rocks in Puerto Rico: U. S. Geol. Survey Prof. Paper 400-B, p. B360-B363.

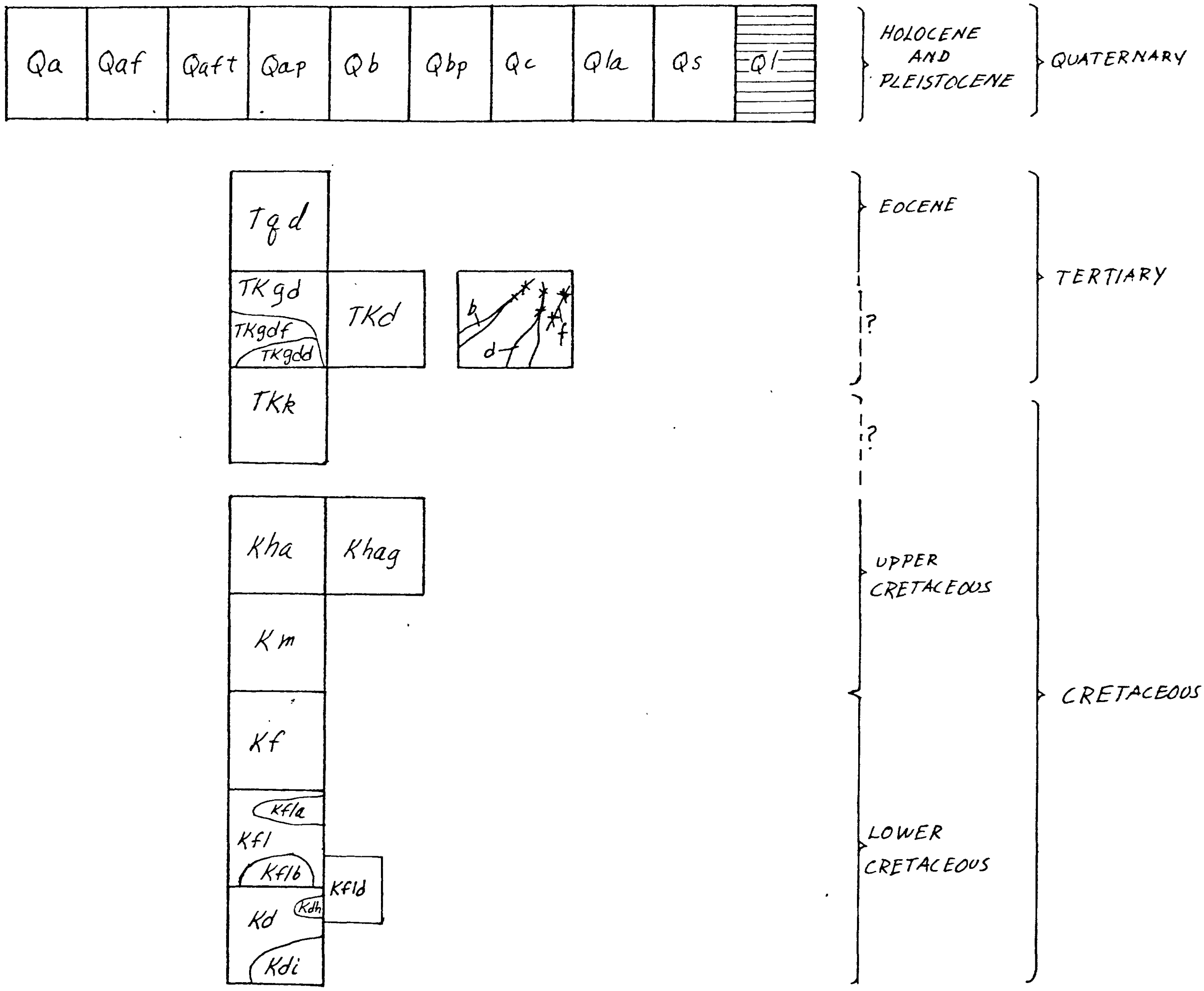
Pease, M. H., Jr., and Briggs, R. P., 1960, Geology of the Comerio quadrangle, Puerto Rico: U. S. Geol. Survey Misc. Geol. Inv. Map I-320.

Rogers, C. L., in press, Geologic map of the Punta Gayanes quadrangle, Puerto Rico: U. S. Geol. Survey Misc. Inv. Map I-998.

Seiders, V. M., 1971a, Geologic map of the El Yunque quadrangle, Puerto Rico: U. S. Geol. Survey Misc. Geol. Inv. Map I-658.

_____ 1971b, Geologic map of the Gurabo quadrangle, Puerto Rico: U. S. Geol. Survey Misc. Geol. Inv. Map I-567.

Strecheisen, A. L., Chairman, 1973, International Union of Geological Sciences Subcommission on the Systematics of Igneous Rocks, Plutonic Rocks. Classification and nomenclature recommended by the IUGS Subcommission on the Systematics of Igneous Rocks: Geotimes, v. 18, no. 10, p. 26-30.


Qa
Qaf
Qaft
Qap
Qb
Qbp
Qc
Qla
Qs
Ql
HOLOCENE AND PLEISTOCENE
QUATERNARY
Tqd
TKgd
TKgdf
TKgdd
TKd
b
d
f
TKk
EOCENE
?
TERTIARY
?
Kha
Khag
Km
Kf
Kfla
Kfl
Kflb
Kfld
Kd
Kdh
Kdi
UPPER CRETACEOUS
LOWER CRETACEOUS
CRETACEOUS

DESCRIPTION OF MAP UNITS

Qa ALLUVIUM (HOLOCENE AND PLEISTOCENE)--Unconsolidated clay- to boulder-sized material in stream-channel deposits along major streams. Locally includes fans and terraces; gradational into alluvial plain deposits. Thickness locally exceeds 10 m

Qaf ALLUVIUM AND FANGLOMERATE (HOLOCENE AND PLEISTOCENE)--Unconsolidated to weakly consolidated, poorly-to well-sorted, clay- to boulder-sized material in fans and in stratified alluvial valley-fill deposits. Locally terraced; includes slope wash, small landslides and channel-fill deposits. Gradational into units mapped as predominantly alluvium, alluvial plain, and terraced deposits. Thickness locally more than 25 m

Qaft TERRACED DEPOSITS--Terraced alluvium and fanglomerate

Qap ALLUVIAL-PLAIN DEPOSITS (HOLOCENE AND PLEISTOCENE)--Unconsolidated to consolidated stratified alluvial deposits underlying broad, seaward-sloping plains. Composed of clay- to boulder-sized detrital material; interfingered with and overlying Holocene (surficial) beach deposits, and may include older beach and other marine materials at depth. Gradational into units mapped as alluvium and as alluvium and fanglomerate. Thickness probably more then 30 m locally

Qb BEACH DEPOSITS (HOLOCENE AND PLEISTOCENE ?),Unconsolidated fine- to coarse-grained sand and pebble deposits. South of Ensenada Honda composed of quartz and feldspar grains and plutonic and volcanic rock fragments, with considerable amounts of sand (shell, algal, and coral fragments) locally. From Ensenada Honda northward quartz grains are rare and plutonic rock fragments uncommon; deposits are principally of calcium carbonate grains with local admixtures of volcanic rock fragments and pebble clasts. Gradational into, and partly overlain by, alluvial and swamp deposits. Thickness probably more than 10 m locally

Qbp BEACH DEPOSITS OF PEBBLES AND COBBLES (HOLOCENE)--Moderately sorted, generally well-rounded local pebble and cobble deposits. Composed mainly of volcanic rock fragments from lavas and dikes, coral fragments, and calcereous sand. Gradational into sandy beach deposits. Thickness ranges from 2 m to 4 m or more

Qla LAGOON DEPOSITS (HOLOCENE)--Mud and calcareous sand deposits periodically innundated by very shallow marine waters. Gradational into swamp deposits. Found on western side of Ensenada Honda. Thickness uncertain

9.1267

Qc CORAL AND SHELL DEPOSITS (HOLOCENE AND PLEISTOCENE ?)--Local subareal banks of cemented coral and pelecypod shells on southwestern side of Ensenada Honda. Thickness about one meter

Qs SWAMP DEPOSITS (HOLOCENE)--Black to dark brown organic-rich soil and muck in poorly drained part of alluvial plains. In large part covered with mangrove. Thickness probably as much as 5 m locally

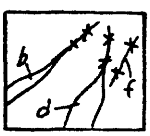
Ql LANDSLIDE DEPOSITS (HOLOCENE and PLEISTOCENE(?) --Slumps and earthflows on weathered slopes involving masses of soil and rock fragments of varied sizes, including boulders and blocks. Many small slides not mapped. Thickness locally more than 3 m

Tqd QUARTZ DIORITE (TERTIARY)--Light gray, medium- to coarse-grained unfoliated rock in a small exposure along the western border of the quadrangle, a part of the Rio Blanco stock which is centered in the El Yunque quadrangle. Seiders (1971 a) reports the stock to be 26.0 percent quartz, 5.0 percent orthoclase, 55.8 percent plagioclase, 7.3 percent hornblende, 3.6 percent biotite, 0.7 percent iorn oxides, 0.2 percent apatite, and 1.4 percent fine-grained alteration products and accessory minerals

TKgd QUARTZ DIORITE AND GRANODIORITE (TERTIARY(?) AND UPPER CRETACEOUS(?)--Light gray to light olive gray stocks of medium- to fine-grained unfoliated rock with hypidiomorphic-granular texture. Composition ranges from quartz diorite to granodiorite. Hornblende is the predominant mafic mineral; only minor amounts of biotite are present. Rounded metavolcanic xenoliths are locally present. A sample from the stock at the head of the Río Daguao exhibits a peculiar fine-grained allotrimorphic-granular quartz and feldspar groundmass for the otherwise normally developed medium-grained minerals in the quartz diorite.

TKgdf Fine-grained granodiorite facies

TKgdd Medium-grained dark dioritic facies



DIKES (TERTIARY(?) AND UPPER CRETACEOUS(?))--(b), Dark gray fine-grained andesitic dikes, locally porphyritic with plagioclase and/or pyroxene pheonocrysts; (f) light-gray, fine- to medium-grained aplite dikes and associated quartz veins; (d), light to medium light gray and brown medium-grained hornblende quartz diorite and hornblende granodiorite dikes locally bearing bipyramidal quartz phenocrysts, and fine-grained quartz-bearing dacite dikes. Bipyramidal quartz phenocrysts are especially prevalent along the coast near Húcares

Tkd DIORITE (TERTIARY(?) AND UPPER CRETACEOUS(?)--Stock of gray to medium dark gray, medium-grained to coarse-grained rock with hypidiomorphic-granular texture. Composition is that of a hornblende diorite with as much as 10 percent quartz locally. Plagioclase feldspar is mostly calcic andesine, with some oligoclase. About 5% of the feldspar is orthoclase and much of this is poikilitic, enclosing plagioclase and hornblende crystals. The hornblende, which, on the average, makes up about 20 percent of the rock, occurs both as stubby crystals 1 cm across and as crystals 5 to 10 mm long which locally are aligned, giving a lineation to the rock. About 3 to 4 percent clinopyroxene is present mostly as unreplaced remnants within the hornblende crystals. In a few places hornblende crystals as long as 6 cm were noted. Most exposures of the rock appear fairly homogeneous, although gradations in the mafic content are noticeable over a distance of a few meters.

Tkk QUARTZ KERATOPHYRE (TERTIARY(?) AND UPPER CRETACEOUS?)--Stocks of medium-dark-gray to medium-bluish-gray pophyritic rock with an aphanitic matrix in north-central part of mapped area. Contains oligoclase and bipyramidal quartz phenocrysts. Weathers to grayish yellow, dusky yellow and light brown. The quartz phenocrysts and the light colors are distinctive. Interior parts of the intrusive are massive in aspect, although the rock is commonly much jointed and locally shattered. Borders of the intrusive are often irregular, with numerous apophyses and dikes extending into the county rock. Groundmass is an intricate intergrowth of quartz albite and oligioclase. X-ray diffraction indicates that somewhat more than 10 percent of the rock is potassium feldspar, but this could not be confirmed optically. Phenocrysts of plagioclase are albite and oligioclase in crystals about 1-4 mm in length. The 3 mm long quartz phenocrysts tend to be resorbed and rounded, although a bipyramidal shape is plainly evident in many of them. Epidote is common as patches and stringers throughout the rock

Kha
Khag

HYDROTHERMALLY ALTERED ROCK (UPPER CRETACEOUS)--Kha-Hydrothermally altered volcaniclastic rocks and lavas. Light gray to white to yellowish-gray rock; ranges from very siliceous and hard to locally earthy, clay-rich and soft. Where more intensely altered original textures are destroyed. Contacts vary from fairly sharp and well-defined to gradational. Khag-light yellowish gray hydrothermally altered granodiorite(?) in a stock along the western border of the mapped area.

Km MAMBICHE SEQUENCE (UPPER(?) CRETACEOUS)--Shown only in cross section. Medium dark gray to moderate brown, medium- to thick-bedded altered volcaniclastic tuff, breccia, sandstone, conglomerate, and lava flows. These rocks crop out in the Humacao quadrangle in the zone of extensive hydrothermal alteration between the Cerro Mula and Peña Pobre faults, but are overlain by Quaternary deposits in the Naguabo quadrangle. Rocks are commonly much sheared and locally foliated, with calcite veinlets common along shear planes. Epidote, chlorite, carbonate, and probable zeolites replace some original constituents in most units of the sequence; extensive hydrothermally altered areas are grayish yellow to white, and have a soft, clayey to a hard siliceous aspect. Thickness uncertain

Kf FAJARDO FORMATION (LOWER CRETACEOUS)--Volcanic sandstone, tuff, volcaniclastic breccia, and minor lava flows. Medium-gray to grayish-brown sandstones and tuffs weather yellowish-brown, and are mostly fine grained, show graded bedding, and are laminated to thinly bedded. The clastic rocks are composed mainly of plagioclase and clinopyroxene grains, and minor volcanic rock fragments. Magnetite grains are usually present, and scattered small quartz grains are not uncommon. Breccias are medium gray to grayish brown, thick to very thick-bedded, and have a clinopyroxene-bearing sandstone or tuff matrix. Clasts are commonly rounded, although some are subangular, and generally 2 cm to 20 cm in diameter although a few boulder-size clasts are found locally. The composition of the clasts appears to be about evenly divided between fine-grained tuffs and lavas. Lava clasts are fine-grained, commonly amygdaloidal, with scattered feldspar and pyroxene phenocrysts locally. Some breccia beds contain small pumice clasts. A rather common type of clast in many Fajardo breccias is a light-colored, aphanitic, almost cherty-looking silicified tuff (?), sometimes bearinga thin white border resembling an alteration or weathering rind. Aphanitic lavas are dark gray, fine-grained, sparsely porphyritic, sometimes amygdaloidal, and resemble those of the underlying Figuera Lava.

The sandstones and tuffs generally occur in sequences some tens of meters thick, that alternate with equally thick units of breccia; although interbedding of units a meter or so thick is not uncommon.

Chlorite and epidote are common in rocks of the Fajardo. Near the Rio Blanco stock, along the western border of the quadrangle, many of the tuffs and sandstones are pyritized and silicified. About 1000 meters of the formation are exposed in the Naguabo quadrangle

Kfl FIGUERA LAVA (LOWER CRETACEOUS)--Andesitic lava sequence with intercalations of volcaniclastic breccia and tuff. Exposures generally confined to artificial cuts; most slopes show only float of lava fragments in soil. Medium dark gray to dark gray, reddish-brown weathering lavas are generally fine grained, medium bedded to massive, and locally autobrecciated. The lava contains small, scattered andesine phenocrysts and sparse pyroxene phenocrysts. Quartz is fairly common in veinlets, stringers, and blebs ranging from 3 to 9 cm in length. The original composition of the groundmass appears to have been largely andesine and clinopyroxene with minor magnetite, but in most places the groundmass is altered, to epidote, chlorite, tremolite-actinolite, quartz, and clay. Local amygdaloidal lavas have quartz, epidote, and calcite as vesicle fillings. Some lenticular zones of pillow lava are scattered through the section; the pillows range from 1 to 2 meters in diameter, and generally a light-colored, aphanitic, silicified (?) material occupies the interstices between the pillows. One thin light gray tuff bed (Kfla) crossed by highway 975 along the ridge crest west of Ceiba appears in thin section to contain devitrified pumice fragments and glass shards in a brown cryptocrystalline groundmass containing scattered broken plagioclase and pyroxene crystals. A planar texture (flowage?) is readily discernable in the rock, and it is interpreted as a nonwelded andesitic ash flow tuff, relatively rich in crystal fragments. Volcaniclastic rocks occur in units a few meters thick as interbeds within the main lava sequence. These rocks include some graded tuffs in layers 2 to 8 cm thick, but are mainly medium- to thick-bedded coarse tuff to lapilli tuff and tuff breccia. Clasts include some cherty-looking material (silicified tuff?) as well as minor pumaceous fragments, but are generally fine-grained lava and amygdaloidal lava, like that of the main part of the Figuera. An especially thick massive breccia (Kflb) underlying pillow lavas can be found along route 975 (extended) east of its intersection with route 972 on the ridge in the northwest corner of the Naguabo quadrangle. The breccia is made up of angular to rounded pebble-sized clasts of pumice, amygdaloidal fine-grained lavas, and locally, silicified tuff in a calcareous clinopyroxene-bearing tuff matrix. As much as 2000 meters of Figuera Lava may be exposed in the area

Kfld MIXED ZONE (LOWER CRETACEOUS)-- Interstratified Figuera Lava and Daguao Formation

Kd DAGUAO FORMATION (LOWER CRETACEOUS)--Interbedded volcanic breccia, lava, and subordinate volcanic sandstone and crystal tuff. The volcanic breccia is medium gray, massive, and is composed of clasts of dark gray irregularly shaped subangular to subrounded granule- to cobble-size porphyritic andesite lava in a medium gray coarse-grained plagioclase and clinopyroxene crystal tuff matrix. The breccia units are commonly cut by fine-grained and by porphyritic lava dikes. Breccia beds are generally exposed only in artificial excavations, and float on natural slopes consists largely of lava clasts. Lavas are principally medium-dark gray andesites with a pilotaxitic texture and andesine and clinopyroxene phenocrysts; they are locally amygdaloidal. Some of these lavas are flow breccias, with porphyritic andesite clasts commonly more than 5 cm in diameter, either welded together or in a matrix of sheared andesite. Some dark greenish gray, very fine-grained flows are also autobrecciated.

Typical massive tuff breccia can be seen in housing excavations just northwest of Daguao; good breccia and lava exposures can be found along the coast southeast of Hucares. Coarse autoclastic lavas may be found throughout the section in the ridge directly west of Ensenada Honda and Langley Drive, on the Roosevelt Roads Naval Reservation.

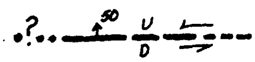
Dark to medium-gray volcanic sandstones and tuffs are usually laminated to thin-bedded and graded, and are locally crossbedded. A few crystal tuffs are hornblende-rich; most sandstones and tuffs are composed of plagioclase and clinopyroxene grains like the matrix of the massive volcanic breccias, and fairly commonly are calcareous. The sandstones and tuffs generally form units only a few meters thick in the western part of the mapped area. Notably thicker sequences in the east are shown by diagonal lines. Thick sequences of thin-bedded to laminated tuff are well exposed along the coast from Punta Algodones to Punta Cascajo, on the Roosevelt Roads Naval Reservation. Rocks of the Daguao Formation are commonly epidotized and chloritized in varying degrees. Volcaniclastic hornfels (h) occurs in a few places near the diorite and granodiorite stocks, and phyllitic to schistose rocks (s) occur in one area north of Daguao, south of the keratophyre intrusive (TKk). The formation interfingers with the overlying Figuera Lava in a few places (see text), its base is not exposed. The thickness of the Daguao is estimated to be on the order of 1000 to 1500 meters

Kdi DAGUAO INTRUSIVE BRECCIA (LOWER CRETACEOUS)--Hypabyssal intrusive of medium dark gray brecciated andesite. Contains subangular clasts of dark gray andesite with large plagioclase and clinopyroxene phenocrysts in a brecciated matrix of the same composition. The clasts seem to be lithologically identical to andesite clasts in the tuff breccias and autoclastic lavas of the Daguao Formation. The clasts of the two intrusives in the Naguabo quadrangle east of Daguao range from 3 to 15 cm in length; on Isla Piñeros in the Punta Puerca quadrangle blocks as large as 90 cm in length are found in a intrusive (?) making up a small hill on the northwest corner of the island. The intrusive rocks are locally much epidotized and silicified; the epidote and quartz occur in veins and in irregular patches. In a quarry in the intrusive body that is south of the Roosevelt Roads airfield some podshaped zones several meters long have been largely replaced by epidote and quartz, yet the original texture of the porphyritic andesite breccia is discernable.

An exposure of massive andesite lava about 100 m wide and 200 m long on the crest of the ridge to the northwest of Naguabo may also be an intrusive body. The lava is lithologically similar to the other intrusive breccias; although it is only partly brecciated, it does show some near vertical banding (flow lines),

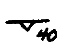
Symbols Used

CONTACT--moderately to well-exposed between arrows, dotted where concealed, queried where inferred. Quaternary-deposit contacts approximately located or gradational



FAULT--long dashed where approximately located; short dashed shere inferred; dotted where concealed; queried where uncertain. U, upthrown side; D, downthrown side; number and arrow shows dip of fault; wrench faults and relative directions of movement shown by parallel arrows on map, by T (toward) and A (away) in cross sections

Strike and dip of primary foliation in plutonic rocks. Shown by planar arrangement of mafic minerals and autoliths(?).



Inclined

Vertical

Strike and dip of foliation in metavolcaniclastic rocks

Inclined

Strike and dip of beds

Inclined

Overturned

Top determined from graded bedding or cross-bedding

Possibly slumped outcrop

Shear. Value shows dip where known

Vertical shear

EPIDOTIZED ROCKS--Yellowish-gray to pale olive altered volcaniclastic rocks and lavas. Tremolite-actinolite fibers seen in former vesicles; mafic minerals bleached light-colored; in general original rock textures visible. Many altered areas too small to plot on map occur throughout quadrangles.

PILLOW LAVAS--zones of locally pillowed lavas in the Figuera Lava

9-1367

ARTIFICIAL FILL

QUARRY OR BORROW PIT

Figure 1.-- Generalized geologic map of the Humacao, Naguabo, and Punta Puerca quadrangles, Puerto Rico.