PREPARED IN COOPERATION WITH
THE COMMONWEALTH OF PUERTO RICO
ECONOMIC DEVELOPMENT ADMINISTRATION
INDUSTRIAL RESEARCH DEPARTMENT

GENERAL CHARACTER AND AGE OF BEDROCK

Exposed bedrock in the Arecibo quadrangle and most of the strata penetrated in the only deep well in the area, the dry Kewanee Interamerican Oil Co. test well 4CPR (Briggs, 1961a), are marine sedimentary rocks, chiefly limestone. These are generally believed to range from middle Oligocene (Zapp, Bergquist, and Thomas, 1948) to middle Miocene (Monroe, 1963) in age, although some geologists believe that the sequence contains no Oligocene rocks (Gordon, 1961). This middle Tertiary sequence rests unconformably on deformed volcanic, and possibly plutonic, rocks of early Tertiary and (or) Cretaceous age.

ROCKS PENETRATED BY TEST WELL 4CPR BUT NOT EXPOSED IN THE ARECIBO QUADRANGLE

CRETACEOUS OR TERTIARY SYSTEM

Rocks of Cretaceous, Paleocene, or Eocene age.—Test well 4CPR, near the coast southeast of Punta Las Tunas, penetrated 1,961 m of strata. The bottom 263 m is composed chiefly of pale-olive, olive-gray, and pale-yellowish-brown volcanic sandstone and siltstone containing conspicuous pyrite crystals and blebs. Some zones in this section are calcareous; others are silicified. Slickensides noted on some of the drill cuttings indicate deformation, and cuttings from the top of the volcanic sandstone and siltstone interval have a bleached appearance (Briggs, 1961a).

Somewhat similar fine-grained volcanic rocks that crop out beneath the unconformity in the Utuado quadrangle about 18 km due south of the test well are considered to be Eocene in age by A. E. Nelson (written commun. 1964) on the basis of fossil identifications by E. A. Pessagno. The volcaniclastic strata in the test well also may be Eocene in age. However, the pre-Oligocene volcanic-plutonic terrane exposed in Puerto Rico is structurally and lithologically complex (Briggs, 1964), and it is probable that the concealed basement on which the San Sebastián Formation rests in the Arecibo quadrangle is equally complex. It appears likely that coarser volcaniclastic rocks, lavas, and plutonic rocks of Cretaceous and (or) early Tertiary age also may be present beneath the unconformity in this area.

TERTIARY SYSTEM

San Sebastián Formation.—Directly above the rocks of Eocene(?) age in test well 4CPR are about 30 m of strata chiefly composed of sandstone and conglomerate. These in turn are overlain by about 295 m of strata composed dominantly of olive-gray calcareous claystone interbedded with subordinate sandstone, clayey limestone, and some coal seams. Pyrite and (or) marcasite are conspicuous through most of this 325 m of section, but in some zones small iron oxide concretions occur instead of iron sulfides, and the claystone is pale yellowish brown rather than olive gray. These strata are correlated with the San Sebastián Formation that crops out south of the quadrangle at the base of the exposed middle Tertiary section.

According to Zapp, Bergquist, and Thomas (1948) the San Sebastián Formation of Oligocene age consists chiefly of gravel, sand, silt, clay, and marl, with some impure limestone beds and thin beds of lignite locally present. Its exposed thickness ranges from 0 to about 300 m. South of the Arecibo quadrangle, in the Utuado quadrangle, the San Sebastián is thin or absent in most exposures.

Lares Limestone.—The 504 m of strata above the San Sebastián in test well 4CPR are composed almost entirely of coarse- to very fine grained, pinkish-, orange-, and yellowish-gray to light-gray, pure limestone, but included in the lower 175 m of this section are a few beds of marl, calcareous claystone, and sandstone. Although the presence of such relatively impure layers in the lower part suggests a facies which may be equivalent in age to the San Sebastián Formation farther south, the overall aspect is more similar to the Lares Limestone in outcrop, so the entire 504 m are correlated with the Lares Limestone.

According to Zapp, Bergquist, and Thomas (1948), the outcropping Lares Limestone is of middle to late Oligocene age and is composed of beds of very finely to finely crystalline pure limestone and firm to friable open-textured limestone; its total thickness does not exceed 200 m along most of its line of outcrop. Due south of test well 4CPR, however, they included in the Lares Limestone a sequence of limestone about 400 m thick that embraced all strata above the San Sebastián Formation and below the Aguada Limestone. More recently, the Lares has been restricted to the lower part of this limestone sequence, and the upper part, which is exposed in the Arecibo quadrangle, has been named the Montebello Limestone Member of the Cibao Formation (Nelson and Monroe, 1966). In the northeastern part of the Utuado quadrangle, south of test well 4CPR, the restricted Lares Limestone ranges from less than 40 m to about 200 m thick (W. H. Monroe, oral commun. 1964).

PHYSIOGRAPHY

Northern Puerto Rico is characterized chiefly by striking and locally spectacular karst topography (Monroe, 1960). The principal types of tropical karst features are well displayed. Seven broad physiographic subdivisions are recognized. No sharp lines can be drawn between these subdivisions at most places on the map, but five of the seven subdivisions can be related to lithologic differences in underlying limestone bedrock and surficial deposits (Monroe, 1966).

Subdued karst.—In the southwestern part of the Arecibo quadrangle, south of La Esperanza and west of the Río Tanamá, is a small area characterized by moderate slopes, local relief rarely exceeding 60 m, and interior drainage. Broad shallow depressions, dome-shaped hills, irregular ridges, and rudimentary stream patterns (there are no perennial streams) are typical of such karst areas. Outcrops are largely chalk and marl of the Cibao Formation, but the area is underlain in part by the Montebello Limestone Member of the Cibao.

Sinkhole karst.—Extremely rugged, strongly developed sinkhole karst topography occurs in a band about 4 km wide across the southern part of the quadrangle. This subdivision is interrupted by the subdued karst area and the valleys of the Río Grande de Arecibo and the Río Tanamá. Steep-sided sinkholes are separated by serrate ridges and subpyramidal towers. Some sinkholes are as much as 50 m deep from the lowest point on the rim to the bottom; vertical distance from the bottom of a sinkhole to the top of an adjacent tower is as much as 125 m, although commonly it is less than 100 m. Some sinkholes have coalesced to form irregular karst valleys, most notably in the outcrop area of the Montebello Limestone Member and along the contact between the Montebello Member and the overlying Aguada Limestone. Sinkhole karst is generally restricted to rocks of the Montebello and the Aguada; in the Montebello, individual unconnected sinkholes are as much as 250 m across, whereas in the Aguada most sinkholes are less than 200 m across.

Mogote karst.—North of the sinkhole karst, and extending across the middle of the quadrangle, except in the valley of the Río Grande de Arecibo, is well-developed karst topography of a different type. The steep-sided subconical or dome-shaped hills are called mogotes, from which this type of karst topography takes its name. In the Arecibo quadrangle, mogotes rise as much as 50 m above extensive intrakarst blanket-deposit plains and are commonly 100 to 150 m in diameter at the base. They also are observed as peaks on irregular elongate bedrock ridges that have as much as 70 m of local relief. Some shallow sinkholes and some weak dendritic drainage patterns also are found. Mogote karst has developed only on the lower and middle parts of the Aymamón Limestone.

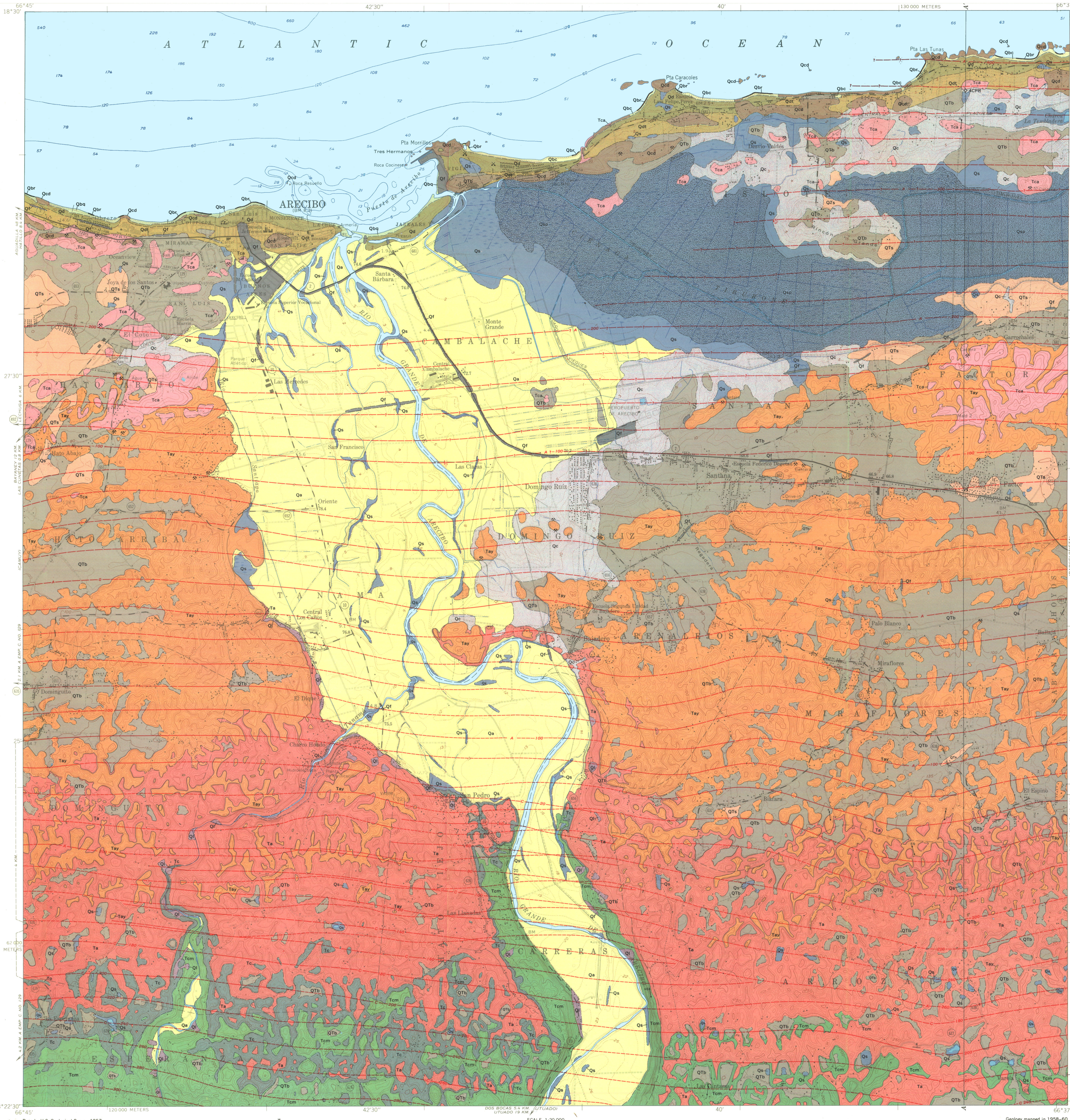
Rolling hills and irregular plains with minor karst features.—This subdivision also extends across the Arecibo quadrangle, with the exception of the area occupied by the flood plain of the Río Grande de Arecibo. To the south the subdivision grades into mogote karst. On the east side of the quadrangle it is limited to the north by the Ciénaga Tiburones; on the west it extends northward to include the scarp just south of Highway No. 2, west of Arecibo. Hills in this subdivision have moderate to gentle slopes, and local relief is generally less than 60 m. Mogotes and irregular ridges are also present, but these are less striking than in the more pronounced mogote karst to the south, generally having less local relief and more gentle slopes. Irregular blanket-deposit plains occur in parts of this subdivision, but depressions are shallow and interior drainage is rare. On some slopes dendritic drainage patterns have developed, although there are no perennial streams. The rolling hills and irregular plains are chiefly on the Camuy Limestone, but the southern part of the subdivision contains areas underlain by the upper part of the Aymamón Limestone and in the northwest part contains areas underlain by cemented dunes.

Ciénaga Tiburones.—The vast marsh called the Ciénaga Tiburones extends from the flood plain of the Río Grande de Arecibo eastward beyond the edge of the Arecibo quadrangle, a total length of about 15 km. The marsh averages 1.5 km in width, is virtually flat, and consists of marshy ground and peaty swamp at or near sea level.

Coastal rolling lowlands.—All the area of low to moderate relief between the shoreline and the Ciénaga Tiburones, the flood plain of the Río Grande de Arecibo, and the rolling hills and irregular plains subdivision to the south is part of the coastal rolling lowlands. This subdivision is characterized by east-west oriented ridges, headlands, and dunes with altitudes less than 20 m above sea level at most places. Most of the slopes are gentle, but some low cliffs are found, chiefly at the shore. Broad flat areas and swales commonly occur between the higher points, and occasional depressions mark minor karst development and deflation topography. The Camuy Limestone crops out at some localities in this belt, but at most places it is concealed by surficial deposits. Cemented dunes and dune sands form most of the areas of moderate relief at and near the shore.

River valleys and flood plains.—The most prominent single physiographic feature in the quadrangle is the valley of the Río Grande de Arecibo. Almost vertical walls rise as much as 180 m above the flood plain near the south edge of the quadrangle where total local relief is about 250 m. The sides of the valley become progressively less steep and lower to the north; to the northeast the flood plain coalesces with the Ciénaga Tiburones. Irregular benches with moderate karst development occur on the valley sides, representing transitions from adjacent physiographic divisions. The river meanders across a flood plain that is 1.2 km wide at the south edge of the map, narrows to 0.6 km at San Pedro, and widens in its lower reaches to more than 5 km.

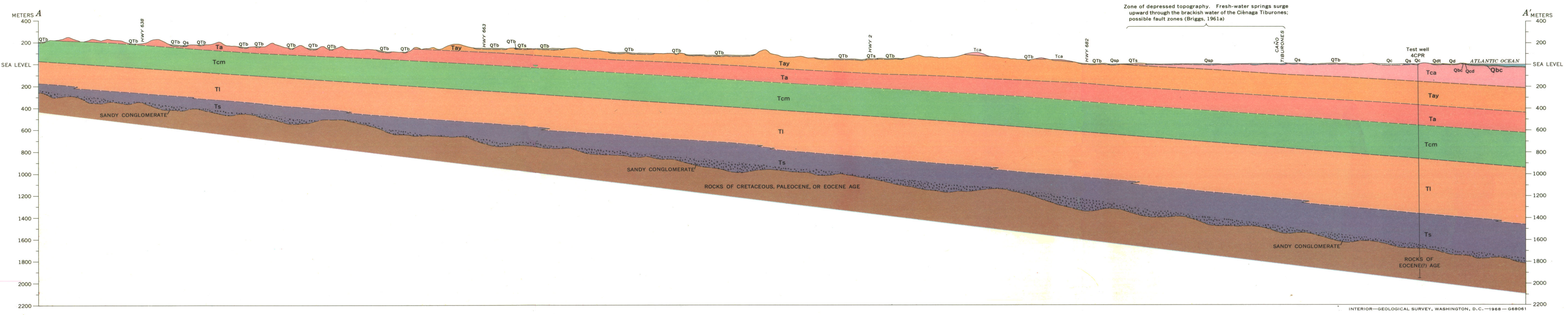
The Río Tanamá, which enters the Río Grande de Arecibo from the southwest, has very steep walls, vertical in places, with local relief at some points more than 125 m. The river has formed flood plains at some places along its course; the largest plain, about 150 m wide, is about 1.5 km east of La Esperanza.



Base by U.S. Geological Survey, 1957
2000-meter grid based on Puerto Rico coordinate system

SCALE 1:20 000

CONTOUR INTERVAL 10 METERS
DASHED LINES REPRESENT 5-METER CONTOURS
DOTTED LINES REPRESENT 1-METER CONTOURS
DATUM IS MEAN SEA LEVEL
DEPTH CURVES AND SOUNDINGS IN FEET—DATUM IS MEAN LOW WATER
SHORELINE SHOWN REPRESENTS THE APPROXIMATE LINE OF MEAN HIGH WATER
THE MEAN RANGE OF TIDE IS APPROXIMATELY 0.3 METERS



EXPLANATION

Thickness of units estimated from outcrops in and south of the Arecibo quadrangle. Asterisk (*) indicates thickness assigned to strata in test well 4CPR (Briggs, 1961a)

QUATERNARY

Recent

Fill and made-land (Qf)
Chiefly poorly sorted limestone rubble, sand, and clay. Breakwater and bulkhead pier west of Punta Morrillos contain large blocks of volcanic breccia (Briggs, 1961b, p. 29). Thickness 2–8? m

Beach deposits (Qbq, Qbr, Qbc)
Qbc, *chiefly calcium carbonate sand, coarse, well sorted, pale-orange to pale-grayish-orange; composed of calcite and aragonite fragments of shells and skeletons of marine organisms and calcite fragments reworked from cemented dunes. Minor quantities of quartz and volcanic-rock fragment grains. Thickness 1–6? m*
Qbq, *chiefly quartz sand, coarse to medium, well sorted, very pale orange to yellowish-gray and light-gray; minor feldspar, plutonic-rock fragment, magnetite (Guillou and Glass, 1957), and calcium carbonate grains; locally magnetite is concentrated in layers 1–4 cm thick. Thickness 1–6? m*
Qbr, *beach rock, beach sand cemented by calcite; in thin beds commonly parallel to beach surface, terminated by low scarps landward and dipping seaward. In most exposures of beach rock the grains are the same as in adjacent beach sands, but near the west edge of the area, eroded and possibly elevated beach rock adjacent to a quartz sand beach contains numerous pebbles of silicified volcanic and plutonic rock and appreciable magnetite. Thickness 0.5–1.5 m*

Dune sand (Qd, Qdt)
Qd, *sand, generally medium-grained; composition and color similar to adjacent beach sands; locally slightly indurated. Thickness 0–10 m*
Qdt, *transitional deposits; wind-blown sand from dunes and beaches mixed by natural agencies or by cultivation with blanket, alluvial, lagoonal, or swamp deposits; or sand forming thin and discontinuous veneers on these deposits, cemented dunes, or the Camuy Limestone. Thickness 0–2? m*

Floodplain alluvium (Qa)
Moderately well sorted, gradationally stratified sand, gravel, silt, and clay. Largely composed of quartz, feldspar, and plutonic-rock fragment sand grains, but silicified plutonic-rock and volcanic-rock pebbles and cobbles are common; some large blocks of limestone are found near valley margins. Thickness 0–70+ m

Swamp deposits (Qs, Qsp)
Qs, *clay, sandy clay, and silty clay, black, gray, and bluish-gray; water saturated; commonly with a high content of organic material. Thickness 0–3+ m*
Qsp, *peat and peaty muck, black to grayish-black where saturated; when drained commonly oxidized to medium gray. Thickness 0–3+ m*

Landslide deposits (Ql)
Chiefly composed of limestone rubble, marl, and clay; some limestone blocks exceed 5 m in longest dimension. Thickness 0–10? m

Pleistocene

Cemented dunes (Qcd)
Medium-grained, grayish-orange to pale-yellowish-brown, nonfossiliferous, friable to well indurated, calcite-cemented, thin-bedded, commonly crossbedded eolian sandstone in units 5–15 m thick; some interbeds of pale-orange, fossiliferous, locally conglomeratic, friable to well indurated, calcite-cemented, thick-bedded marine sandstone in units 1–5 m thick; some paleosols, about 1 m thick, herein interpreted as tongues of blanket deposits (Kaye, 1959, p. B79–B96, B123–B126). Grains in sandstones are chiefly calcite, but subordinate quartz grains are conspicuous west of the mouth of the Río Grande de Arecibo. Thickness 0–25+ m

Lagoonal deposits (Qc)
Dark-brown, dark-gray, medium-gray, and bluish-gray clay, sandy and silty clay, and silt, commonly containing some organic material; water free to locally water saturated; essentially old lagoon-margin and swamp deposits in areas of low relief near sea level. Thickness 0–2+ m

Miocene to Recent

Blanket deposits (QTb, QTs)
QTb, *clayey quartz sand and sandy clay, moderate-reddish-brown, moderate-yellowish-brown, light-brown, and pinkish-gray cohesive even-textured mixtures of medium and fine quartz grains, kaolinitic clay, and hydrous iron oxides; generally friable, but locally well cemented by iron oxides. Quartz to clay ratios commonly range from 90:10 to 30:70. Blanket deposits are stranded sands that have been laterized concurrently with the solution of underlying limestone (Briggs, 1966). Thickness 0–30+ m*
QTs, *quartz sand, medium and fine, light-gray to white; commonly contains less than 2 percent clay and other impurities (Vázquez, 1968). Thickness 0–2+ m*

UNCONFORMITY

TERTIARY

Middle Miocene

Camuy Limestone (Tca)
Medium- to fine-grained, very pale orange, grayish-orange, yellowish-gray, and light-brown pure to somewhat clayey limestone interbedded with pale-yellowish-orange, grayish-orange, and light-gray chalk, clayey chalk, and marl; commonly thick-bedded; rare beds of quartz sandstone. East of the Río Grande de Arecibo, Camuy strata less than 30 m above sea level have commonly been recrystallized, forming rocks containing veins and blebs of clear calcite. This recrystallization locally obscures the contact between the somewhat clayey Camuy Limestone and the underlying pure Aymamón Limestone. In the Camuy quadrangle, west of the Arecibo quadrangle, three members have been defined in the Camuy Formation (Monroe, 1963). These are not recognized in the Arecibo quadrangle. Thickness 171 m*

DISCONFORMITY

Miocene

Aymamón Limestone (Tay)
Very fine and fine-grained, white to pale-gray and moderate shades of orange, yellow, and pink, essentially pure limestone, at many localities mottled and streaked light brown, light gray, and pale reddish brown; commonly thick-bedded; commonly chalky; locally coarsely fragmental. In test well 4CPR, about 67 m of calcitic dolomite occurs in the top of the Aymamón Limestone, but no dolomite is known to crop out in the Arecibo quadrangle. In most outcrops a hard carapace has formed over the commonly soft chalky limestone by surficial solution and reprecipitation of calcite. This "case-hardened" aspect has misled observers into assuming that the limestone is equally indurated at depth. Thickness 190–205 m; 216 m*

Lower Miocene

Aguada Limestone (Ta)
Medium- and fine-grained, locally very fine grained, very pale gray to gray and pale-yellowish-orange, yellowish-brown, grayish-yellow, and dark-gray limestone interbedded with subordinate grayish-orange and light-gray chalk and marl that increase in incidence downward; commonly thick-bedded, but uppermost 2–5 m is thin bedded at most localities and near the west edge of the Arecibo quadrangle the upper 30 m is composed of interlayered thick beds and thin-bedded units about 3 m thick. At the base 2–3 m of porcelaneous limestone commonly occurs. Quartz grains are rare in most of the Aguada Limestone, but commonly are minor constituents of thin beds. In test well 4CPR, chalk and marl form only a very small part of strata assigned to the Aguada Limestone. Thickness 90–150 m; 177 m*

Oligocene and Miocene

Cibao Formation (Tc, Tcm)
Tc, *chalk and marl, light-gray to pale-grayish-orange, commonly thick-bedded and massive; some quartz-bearing beds; some thick lenses of very pale orange to yellowish-gray, very fine grained limestone. Chalk and marl typical of the Cibao Formation in most of northern Puerto Rico (Zapp, Bergquist, and Thomas, 1948; Monroe, 1963) grade and interfinger progressively eastward into the Montebello Limestone Member (Nelson and Monroe, 1966) to a point on the east side of the canyon of the Río Grande de Arecibo where less than 10 m of the typical Cibao remain between the underlying Montebello Member and the overlying Aguada Limestone. From this point eastward all Cibao strata in the Arecibo quadrangle are assigned to the Montebello Limestone Member. Thickness 0–50 m*
Tcm, *Montebello Limestone Member; fine- to very fine grained, white, very pale orange, grayish-orange, and grayish-yellow nearly pure limestone, most commonly thick-bedded or massive, locally highly fossiliferous. Most of the Cibao Formation in test well 4CPR, where it is 305 m thick, is similar to the Montebello Limestone Member, but some marl, clay, and sandstone also are present. In the Barceloneta quadrangle to the east, strata now assigned to the Montebello Member were referred to as limestone of Cibao age (Briggs, 1965). Thickness 200–260 m*

Middle and upper Oligocene

Lares Limestone (Tl)
Shown in section only

Middle Oligocene

San Sebastián Formation (Ts)
Shown in section only

Contact
Dashed where approximately located or gradational

Strike and dip of beds

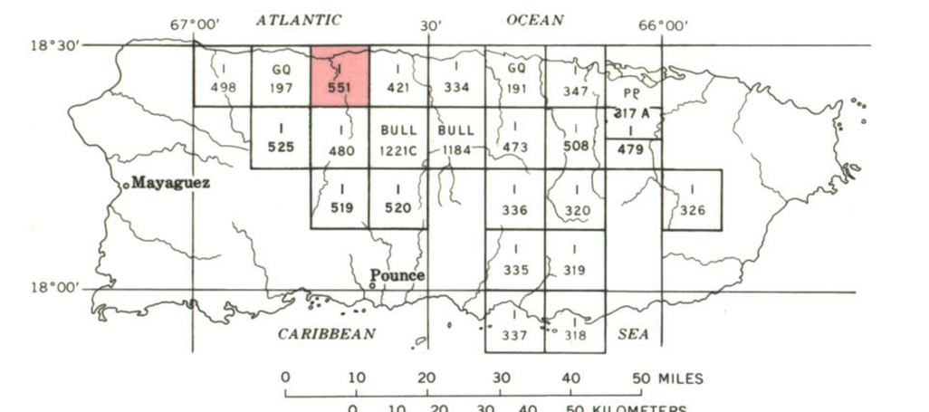
Apparent dip of beds where accurate strike information unobtainable

Structure contours
A, *drawn on top of the Aguada Limestone*
C, *drawn on top of the Cibao Formation*
Dashed where approximately located or where projected from another horizon; short dashed where reference plane projects above the ground surface; queried where probable. Contour interval 20 meters

Limestone quarry

Sand pit

4CPR
Oil test well (dry hole)



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GEOLOGIC MAP OF THE ARECIBO QUADRANGLE, PUERTO RICO

By
Reginald P. Briggs
1968