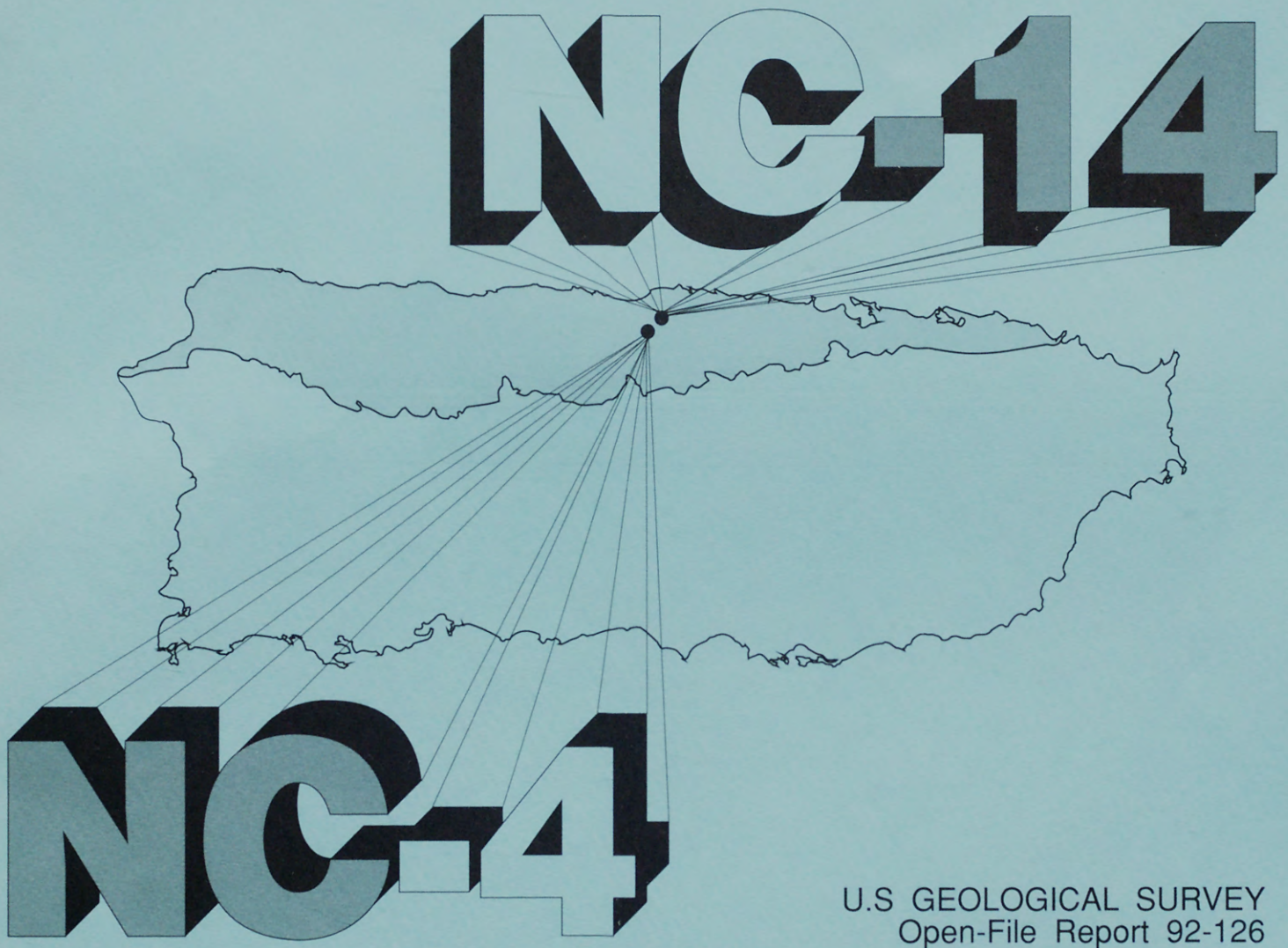
GEOLOGIC AND HYDROLOGIC DATA COLLECTED AT TEST HOLES NC-4 AND NC-14, MANATI AND VEGA BAJA, PUERTO RICO



U.S GEOLOGICAL SURVEY
Open-File Report 92-126

Prepared in cooperation with the
PUERTO RICO DEPARTMENT OF NATURAL RESOURCES

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San Juan, Puerto Rico
1992

U.S. DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, Jr., Secretary

U.S. GEOLOGICAL SURVEY
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CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Flow	
gallon per minute (gal/min)	0.06308	liter per second

Temperature: Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = 1.8 \times °C + 32$$

Abbreviated water-quality units used in report:

microsiemens per centimeter at 25 degrees Celsius (µS/cm)

GEOLOGIC AND HYDROLOGIC DATA COLLECTED AT TEST HOLES NC-4 AND NC-14, MANATI AND VEGA BAJA, PUERTO RICO

By Jesús Rodríguez-Martínez[1], Richard A. Scharlach[2], and Arturo Torres-González[1]

ABSTRACT

Test holes NC-4 and NC-14 were drilled in the municipalities of Manatí and Vega Baja, respectively, in northern Puerto Rico as part of a study of the ground-water resources in the Northern Coastal Province of Puerto Rico. This study was conducted from 1986 to 1988 by the U.S. Geological Survey in cooperation with the Puerto Rico Department of Natural Resources. Test holes NC-4 and NC-14 were drilled to depths of 1,898 and 1,837 feet below land surface, respectively. Geologic and hydrologic data collected during drilling included continuous core lithology, water-quality measurements, water levels, and estimates of aquifer yields from the water-bearing zones. Detailed petrological and microfaunal analyses of the cores were used to determine the mineralogical content, ages, and paleoenvironments of deposition.

Analysis of the core recovered from test hole NC-4 indicated that four geologic formations of middle Tertiary age were penetrated, these were in descending order: the Aymamón Limestone, the Los Puertos Limestone, the Cibao Formation, and the Lares Limestone. The Tertiary formations are capped by surficial deposits of Quaternary age. Test hole NC-14 penetrated rocks of middle Tertiary age that included three geologic formations, these were in descending order: the Aymamón Limestone, the Los Puertos Limestone, and the Cibao Formation. These formations are overlain by surficial deposits of Quaternary age. In both test holes the Cibao Formation consisted of the undifferentiated Quebrada Arenas and the Río Indio Limestone Members of the Cibao Formation and an unnamed mudstone unit.

Test hole NC-4 penetrated three water-bearing units: a water-table aquifer and two artesian aquifers. The specific conductance in the water-table aquifer ranged from 500 to 38,000 microsiemens per centimeter at 25 degrees Celsius. The specific conductance ranged from 740 to 800 microsiemens per centimeter at 25 degrees Celsius in the two artesian aquifers. The relative yield ranged from 120 to 195 gallons per minute in the water-table aquifer and from 60 to 195 gallons per minute in the artesian aquifers. The water level ranged from 81 to 89 feet below land surface in the water-table aquifer. In the artesian aquifers, water levels ranged from 22 feet below land surface to 88 feet above land surface.

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Test hole NC-14 penetrated four water-bearing units: a water-table aquifer and three artesian aquifers. The specific conductance in the water-table aquifer ranged from 590 microsiemens per centimeter at 25 degrees Celsius at a depth of 40 feet to 49,500 microsiemens per centimeter at 25 degrees Celsius at 1,010 feet below land surface. In the artesian aquifers specific conductance was about 700 microsiemens per centimeter at 25 degrees Celsius. The relative yield ranged from 58 to 370 gallons per minute in the water-table aquifer, and from 15 to 60 gallons per minute in the artesian aquifers. The water level in the water-table aquifer ranged from 20 to 32 feet below land surface. In the artesian aquifers the water levels ranged from 18 feet below land surface to 19 feet above land surface.

INTRODUCTION

The Northern Coastal Province of Puerto Rico is a coastward-thickening wedge of highly karstified platform carbonates and minor clastic rocks of Oligocene to Holocene age. It flanks the central mountains comprised of rocks of Cretaceous and early Tertiary age, and extends from near Aguada, in the western part of the Island, to Loíza, about 30 mi east of San Juan (fig. 1), and encompasses an area of approximately 700 mi^2 (Monroe, 1980).

Limited geologic and hydrologic data are available for the subsurface coastal areas of northern Puerto Rico. As part of a cooperative study between the U.S. Geological Survey and the Puerto Rico Department of Natural Resources, 15 test holes were drilled (fig. 1) between 1986 and 1988 in order to describe the geologic and hydrologic characteristics of the aquifers and confining units of the Northern Coastal Province (Torres-González and Wolansky, 1984). The findings resulting from the drilling of these test holes are being documented in a series of reports.

Purpose and Scope

This report presents the geologic and hydrologic data collected at test holes NC-4 and NC-14, drilled in 1986 and 1988 in the municipalities of Manatí and Vega Baja, respectively. The data include water levels, lithologic descriptions, and specific-conductance data collected at these test holes for water from the major aquifers identified at these two sites. Also, the gross mineralogy and estimates of porosity for the aquifers penetrated by test hole NC-4 are presented. These data will aid in the correlation of major geologic and hydrogeologic units and help quantify the direction and rate of ground-water flow in the Northern Coastal Province.

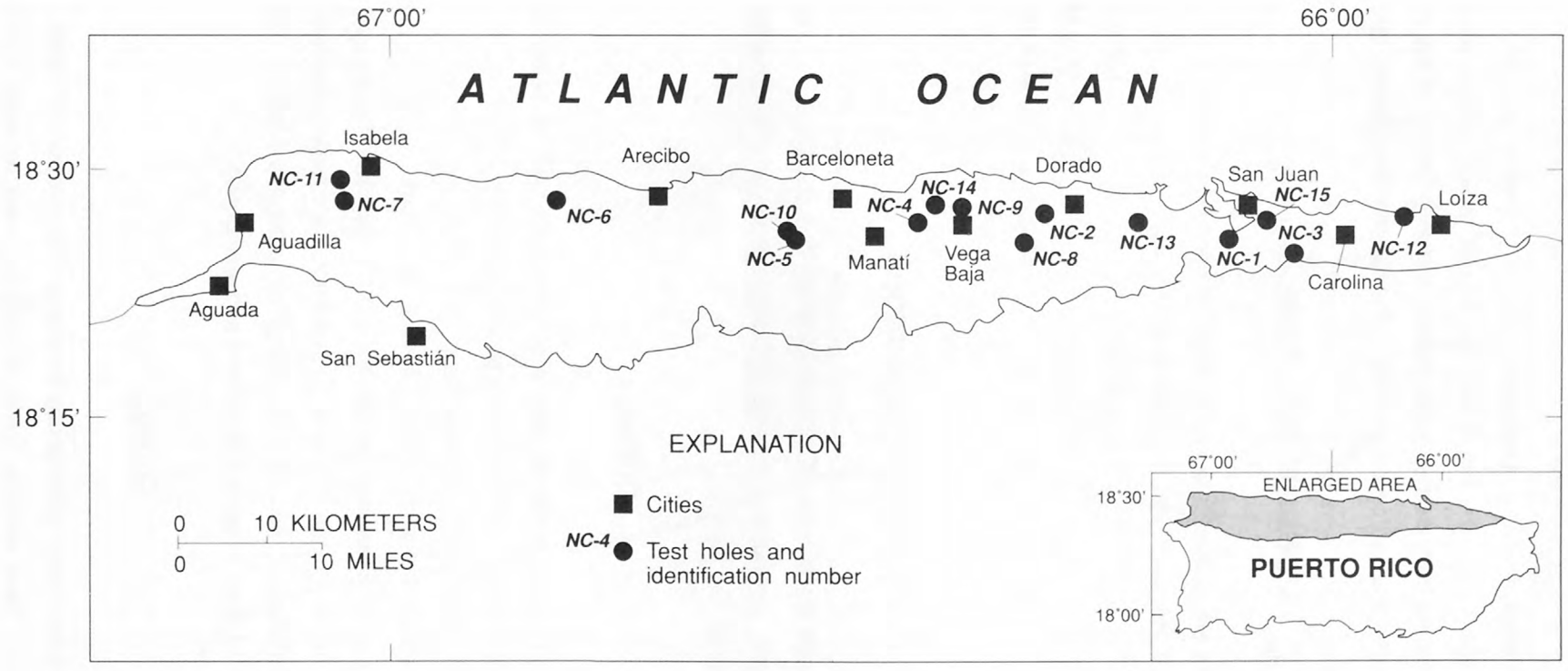

Figure 1.--Areal extent of the Northern Coastal Province of Puerto Rico and the location of test holes.

The drilling and coring program was designed to allow the collection of continuous core samples for geologic, hydrologic, and paleontologic analyses. Geophysical logs were used to describe and define the major geologic and hydrologic units at the two test holes. Water-level measurements were made and water-quality samples were collected from discrete water-bearing zones. Results of the paleontologic analysis were used to correlate the local hydrogeologic units to the regional stratigraphic units.

Location of Study Areas

Test holes NC-4 and NC-14 are located on the north coast of Puerto Rico. The site of test hole NC-4 is about 1.4 mi south of Laguna Tortuguero and 0.02 mi north of Highway 2 in the municipality of Manatí, 25 mi west of San Juan (fig. 2). The land surface altitude of the drilling site is 108 ft above sea level. The site of test hole NC-14 is about 0.1 mi east of Laguna Tortuguero and about 1.2 mi north of Highway 2 in the municipality of Vega Baja, 21 mi west of San Juan (fig. 2). The land surface altitude of the drilling site is 10 ft above sea level.

DATA-COLLECTION METHODS

Data-collection methods used at test holes NC-4 and NC-14 are described in this section. Included are descriptions of drilling methods, continuous collection of lithologic cores, and the collection of various hydrologic data such as water levels and yields.

Drilling

Test holes NC-4 and NC-14 were drilled to depths of 1,898 and 1,837 ft below land surface, respectively. The equipment used to drill the test holes was a hydraulically driven, reverse air system, which uses air under pressure to bring cuttings to the surface. The drill stem consisted of 20 ft sections of threaded, seamless, doubled-walled drill stem, 3 in. in diameter. As drilling progressed, air was forced under high pressure through the annulus between the two walls of the drill stem, forcing formation water and core samples up the center opening of the drill stem. Core samples and water were ejected from the drill stem into a large cyclone container that served as an energy dissipator and a sample collector. After drilling, test holes NC-4 and NC-14 were plugged with cement and abandoned.

Coring

Test holes NC-4 and NC-14 were cored continuously from land surface to the total depth of each hole (1,898 and 1,837 ft, respectively). Core samples, 2.5 in. in diameter, were retrieved from the cyclone

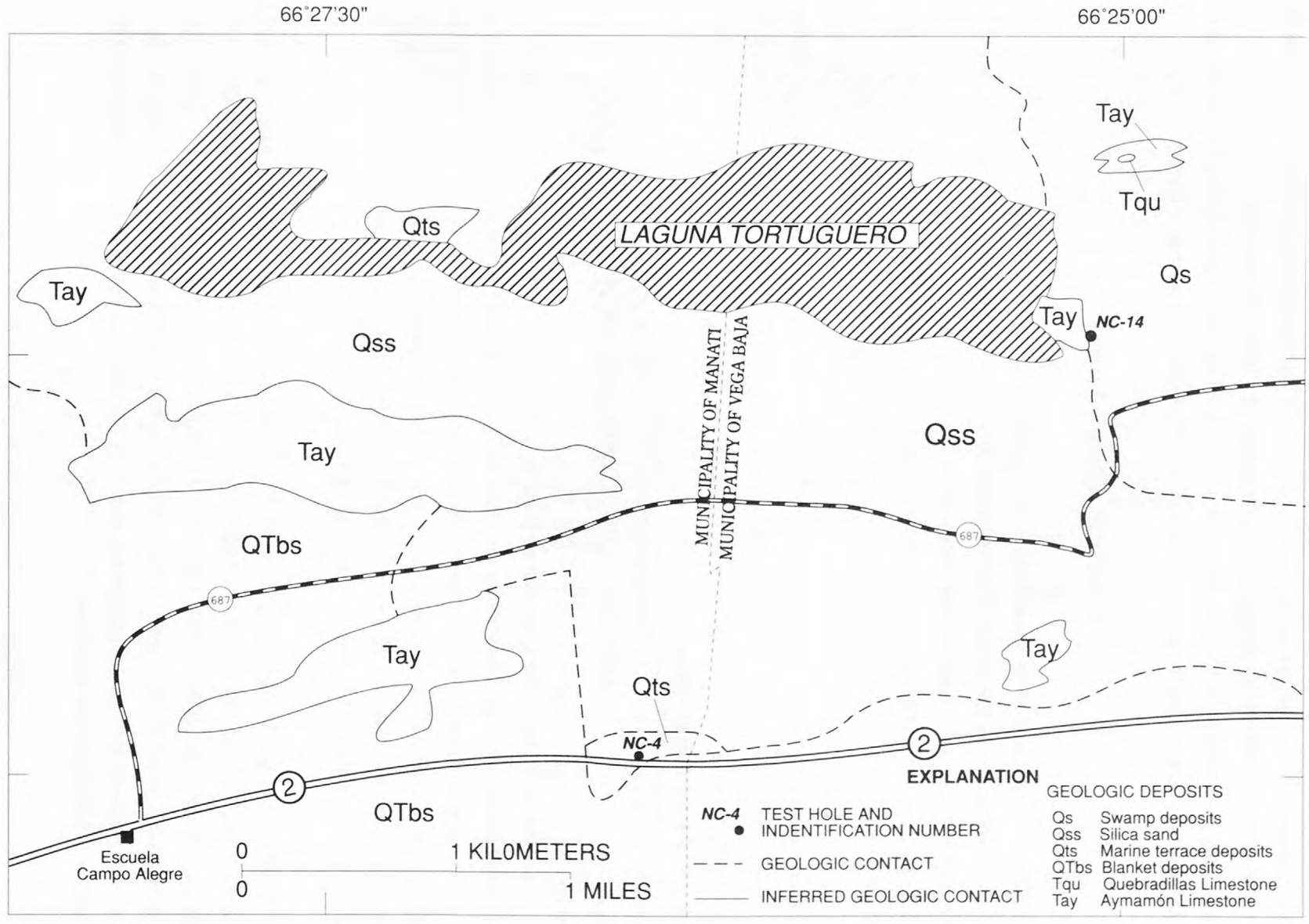

Figure 2.-- Surficial geology in the area of test holes NC-4 and NC-14, Manatí and Vega Baja, Puerto Rico.

sample collection devices, measured, described, and placed in wooden boxes for preservation and storage at the University of Puerto Rico at Mayagüez. Each core box holds the equivalent of one drill stem or approximately 20 ft of core. A representative split of core samples were also collected for storage at the U.S. Geological Survey office in San Juan. Core recovery ranged from poor to excellent.

Hydrologic Measurements

Water-level measurements were made at approximately 20 ft depth intervals during drilling, using either an electric sensor or steel tape. Time restrictions prohibited a full recovery of water levels; therefore, the measurements did not always represent static water-level conditions. Water-level measurements were made on the inside of the drill pipe prior to commencement of drilling each day and within selected intervals when there was a noticeable increase in water ejected from the discharge pipe.

Flow measurements were made at the discharge point of the cyclone collector as drilling proceeded. These flows represented water air-lifted to the surface from the test hole; thus providing data on the relative-aquifer yield. A minimum sustained flow of 20 gal/min and hydraulic continuity were the criteria for differentiating water-bearing units.

GEOLOGIC AND HYDROLOGIC DATA

The rocks of middle Tertiary age that crop out in the Northern Coastal Province have been divided and mapped as seven formational units by Monroe (1980). Seiglie and Moussa (1984) later modified the geologic framework described by Monroe on the basis of additional paleontologic data collected from borehole, hole cuttings, and outcrop samples (fig. 3). They also recognized that the lithologic character of these outcrop units changes as they extend into the subsurface. This report uses the Seiglie and Moussa (1984) modifications to the nomenclature of Monroe (1980).

A water-table aquifer has been known to exist in the Laguna Tortuguero area since the 1940's. However, it was not until the 1960's that large withdrawals from the water-table aquifer began. Local discharge from the water-table aquifer is primarily to Laguna Tortuguero (Giusti, 1978). A deep artesian aquifer was discovered in 1971, when a local industry drilled a production well 1.5 mi west of Laguna Tortuguero. However, the hydraulic properties, as well as the water quality of this aquifer, remained largely unknown until this study was completed.

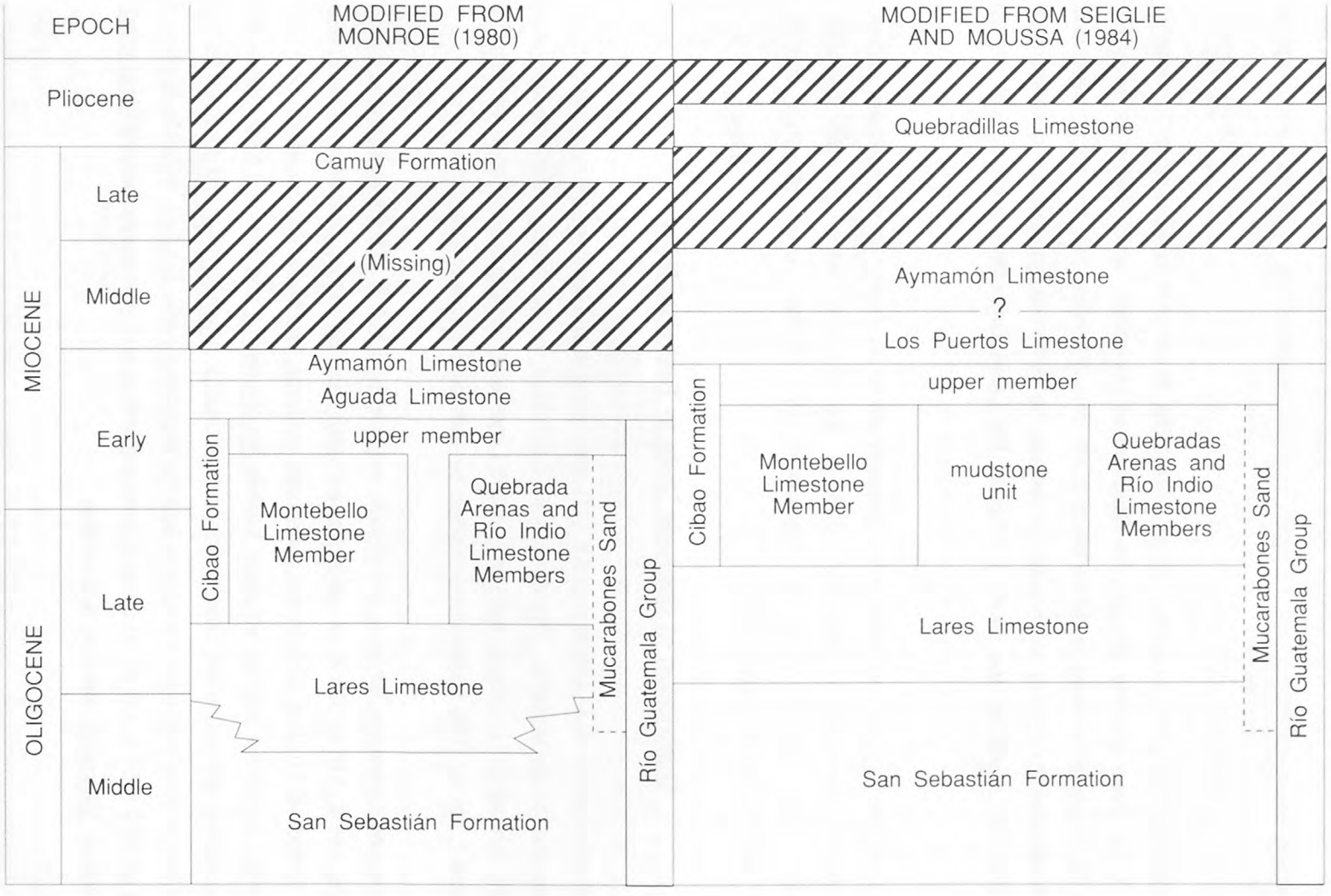

Figure 3.--A chart showing the stratigraphic units comprising the middle Tertiary sequence of the Northern Coastal Province of Puerto Rico.

Test holes NC-4 and NC-14 penetrated surficial deposits of Quaternary age and rocks of middle Tertiary age south and west of Laguna Tortuguero, in the municipalities of Manatí and Vega Baja, respectively.

The surficial geology of the Laguna Tortuguero area (fig. 2) consists of deposits of Quaternary and Tertiary age in the areas of lower altitude; the Quebradillas Limestone, which exists as an erosional remnant; and the Aymamón Limestone, which exists in the form of mogote hills and ridges separated by broad lowlands underlain by sand or sandy clay. Underlying the Aymamón Limestone in descending order are the Los Puertos Limestone, the Cibao Formation, the Lares Limestone, and the San Sebastián Formation.

The rocks in the Laguna Tortuguero area generally dip to the north. In the southern part of the carbonate platform, the dip is about 5°, and at the test-hole sites the dip generally is less than 2°. The northerly dip is interrupted by several small flexures having a generally north-south trend (Monroe, 1971).

Description of Geologic Units in Test Hole NC-4

Test hole NC-4 penetrated surficial deposits of Quaternary age and sedimentary rocks ranging in age from Late Oligocene to Late Miocene. These rocks are subdivided, in descending order, into four geologic formations: the Aymamón Limestone, the Los Puertos Limestone, the Cibao Formation, and the Lares Limestone (table 1, fig. 4). This sequence is overlain by surficial deposits of Quaternary age.

The Aymamón Limestone, which is 375 ft thick, extends from 110 to 485 ft below land surface and consists of: (a) 191 ft (110 to 301 ft) of red algae grainstone and packstone containing a diverse fossil assemblage: soritids, encrusting foraminifera, echinoids, molluscs, and branching corals; (b) 54 ft (301 to 355 ft) of dolomitic packstone bearing red algae, soritids, Amphistegina, and coral; (c) 85 ft (355 to 440 ft) of red algae packstone and grainstone bearing echinoids, molluscs, Amphistegina, and coral; (d) 25 ft (440 to 465 ft) of a quartz-sand red algae packstone bearing branching coral, Kuphus, miliolids, soritids, and molluscs; and (e) 20 ft (465 to 485 ft) of coarse-grained packstone and grainstones bearing Amphistegina, molluscs, echinoids, Halimeda, miliolids, and soritids.

The Los Puertos Limestone, which is 224 ft thick, extends from 485 to 709 ft below land surface and consists of: (a) 57 ft (485 to 542 ft) of packstone-rudstone bearing corals, molluscs, and foraminifera; (b) 58 ft (542 to 600 ft) of a slightly quartz-sand wackestone-packstone and grainstone bearing red algae, molluscs, foraminifera, Halimeda, Kuphus, and branching coral; (c) 43 ft (600 to 643 ft) of red algae

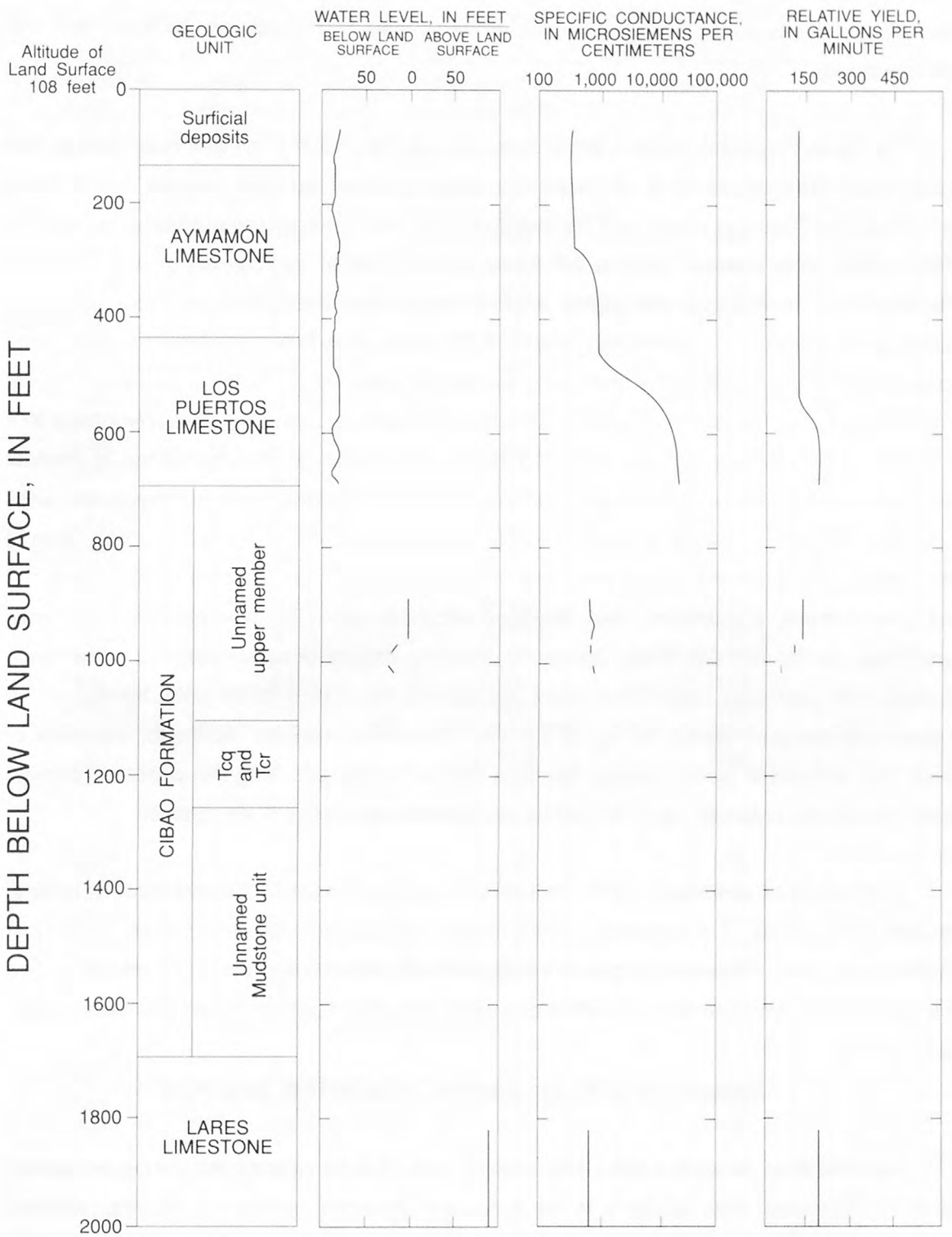

Figure 4.--Geologic units, water level, specific conductance of water, and relative yield at test hole NC-4, Manatí, Puerto Rico. Tcq and Tcr refer to the Undifferentiated Quebrada Arenas and Río Indio Limestone Members of the Cibao Formation.

packstones and grainstones bearing echinoids and molluscs; and (d) 66 ft (643 to 709 ft) of variable dolomitic and quartz-sand packstones bearing echinoids, soritids, miliolids, and molluscs, with scattered thin clay layers.

The Cibao Formation, which is 991 ft thick, extends from 709 ft to 1,700 ft below land surface and is subdivided into three members. In descending order these are: an upper member (typical Cibao), the undifferentiated Quebrada Arenas and Río Indio Limestone Members, and an mudstone member (table 1). The unnamed upper member, which is 449 ft thick (709 to 1,158 ft), and consists of (a) 239 ft of irregular interbedded claystone, clayey and slightly dolomitic wackestone, wackestone-packstone, and packstone bearing oysters and benthic foraminifera, and (b) 210 ft of irregularly interbedded marls and claystone, with minor beds of clayey wackestone and quartz sandstone, characterized by a poor to locally rich benthic foraminifera fauna. The undifferentiated Quebrada Arenas and Río Indio Limestone Members is 92 ft thick (1,158 to 1,250 ft), and consists of (a) 48 ft of slightly dolomitic wackestone-packstone interbedded with clays and marls bearing large benthic foraminifera, molluscs, branching corals and bryozoans, and (b) 44 ft (1,206 to 1,250 ft) of marl and slightly dolomitic clayey limestone bearing oysters, coral, large benthic foraminifera, Halimeda, and worm tubes. The unnamed mudstone unit is 450 ft thick (1,250 to 1,700 ft) and consists mostly of mudstone, marl, claystone and minor clayey-sandy wackestone-packstone. The carbonates are iron-rich and locally dolomitic. A diverse mixture of faunal elements characterizes this lithologic unit; planktonic foraminifera (most abundant in the middle of the unit), benthic foraminifera (increasingly abundant toward the top of the unit), thin-shelled molluscs, echinoids, and black organic matter with associated pyrite. Locally, flat large benthic foraminifera, long thin plates of Halimeda, red algae, cyclostome bryozoan, large encrusting foraminifera, and molluscs are common.

Test hole NC-4 penetrated 198 ft of the Lares Limestone, from 1,700 to total depth of 1,898 ft. This geologic unit consists of a sequence of alternating carbonate and siliciclastic rocks characterized by quartzlithic arenites, litharenites irregularly interbedded with calcareous siltstone and claystone, marls rich in planktonic and large benthic foraminifera and minor amounts of packstone and grainstone in the upper part.

Description of Water-Bearing Units in Test Hole NC-4

Test hole NC-4 penetrated three water-bearing units: a water-table aquifer and two artesian aquifers (table 2). The water-table aquifer is in the Aymamón Limestone and the Los Puertos Limestone and extends from 83 ft below land surface to a depth of 695 ft. The water-table aquifer is underlain by a confining unit that extends to a depth of 900 ft and is in the upper part of the upper member of the Cibao Formation. Underlying this confining unit is a multi-zone artesian aquifer extending from 900 to 1,020 ft

Table 2.--*Selected hydrologic data from test hole NC-4*

Depth below land surface (feet)	Water level below or above (+) land surface (feet)	Specific conductance, (microsiemens per centimeter)	Relative yield, (gallon per minute)
	Water-Table Aquifer		
83	83.0	500	120
121	83.0	500	120
150	84.7	500	120
215	87.7	500	120
234	83.2	500	120
276	81.4	500	120
295	82.1	510	120
317	82.3	600	120
356	82.0	950	120
395	82.5	1,000	120
435	87.7	1,050	120
475	87.5	1,050	120
516	81.5	950	120
547	82.4	8,500	125
557	82.4	8,100	120
570	82.4	12,100	135
589	81.4	18,000	180
596	89.0	19,000	185
625	89.0	21,000	195
643	82.1	38,000	195
695	81.1	35,000	185
	First Artesian Aquifer		
900	4.8	750	135
957	4.8	760	135
970	12.5	740	102
987	22.0	740	102
1,020	10.0	800	60
	Second Artesian Aquifer		
1,837	+88.0	800	190
1,884	+85.0	800	190
1,898	+85.0	800	195

below land surface, located in the lower part of the upper member of the Cibao Formation. A 817 ft thick confining unit extends from 1,020 to 1,837 ft below land surface. It is located in the lower part of the upper member, the Quebrada Arenas and the Río Indio Limestone Members, the unnamed mudstone unit of the Cibao Formation and uppermost part of the Lares Limestone. An underlying artesian aquifer in the Lares Limestone extends to the bottom of the test hole at 1,898 ft below land surface.

The specific conductance of water in the water-table aquifer remained constant at about 500 µS/cm from 83 to 276 ft below land surface (table 2). The specific conductance of water increased to a maximum of 38,000 µS/cm at a depth of 643 ft and then decreased to 35,000 µS/cm at 695 ft below land surface. In the upper artesian aquifer the specific conductance ranged varied from 740 to 800 µS/cm and remained constant at about 800 µS/cm in the lower artesian aquifer (fig. 4, table 2).

The relative yield in the water-table aquifer remained constant at 120 gal/min to a depth of 547 ft, then gradually increased to 195 gal/min at a depth of 625 to 695 ft below land surface. This zone of maximum flow in the water-table aquifer coincides with the zone of maximum specific conductance. In the upper artesian aquifer, the relative yield ranged from 60 to 135 gal/min, generally decreasing with depth. In the lower artesian aquifer, the relative yield increased slightly with depth from 190 to 195 gal/min.

The water level in the water-table aquifer ranged from 81.1 to 89.0 ft below land surface (table 2, fig. 4). In the upper artesian aquifer, from 900 to 957 ft below land surface, water levels remained constant at 4.8 ft below land surface. At depths of 970 to 1,020 ft below land surface, water levels in test hole NC-4 fluctuated from 10.0 to 22 ft below land surface. In the lower artesian aquifer, water level ranged from 88 to 85 ft above land surface.

In test hole NC-4 the type and porosity of the retrieved core were estimated by using either hand samples or thin sections (table 3). In the top 540 ft of test hole NC-4, the estimated porosity generally ranged between 5 and 10 percent, with values greater than 10 percent occurring at depths of 125, 150, 315, 330, 355, 450, and 520 ft (table 3). In the upper 300 ft, recrystallization is significant, and the porosity is dominantly vuggy and less commonly moldic. From 301 ft to a depth of 540 ft below land surface, the porosity is dominantly moldic with lesser interparticle and vuggy porosity. Intercrystalline porosity is present locally in dolomitic zones. In the depth interval from 933 to 1,089 ft below land surface, the percent porosity generally ranged from less than 5 to 7 percent, with only one estimate higher than 10 percent, which was at a depth of 1,013 (table 3). This zone contains poorly cemented sandstones, and the porosity is dominantly interparticle with lesser moldic porosity. The zone is bounded above and below by fine grained siliciclastics and clayey limestones.

Table 3.--*Estimates of porosity in test hole NC-4*

[Types of porosity: Bp, between particles (interparticles); Wp, within particles (intraparticles); Mo, moldic; Vug, vuggy; Sh, shelter; Bc, between crystals (intercrystalline); Fr, fracture; >, more abundant than; :, about the same as; Method: Hand sample refers to microscopic examination of a polished piece of rock for type and percent of porosity]

Depth below land surface (feet)	Type(s) of porosity	Percent porosity	Methods
92	Vug:Mo:Sh	<5	Thin section
125	Vug:Sh:Mo	10	Hand sample
150	Vug:Mo	10	Hand sample
181	Vug>Mo	5-10	Thin section
186	Mo:Vug:Bp	5	Hand sample
200	Vug	<10	Hand sample
235	Vug>Bp:Mo	5-10	Thin section
273	Mo:Vug:Bp	<5	Hand sample
301	Mo:Bp:Vug	5-10	Hand sample
315	Mo:Bc	10	Hand sample
330	Mo>Bc	10	Thin section
342	Mo>Bc	5-10	Hand sample
355	Bp:Mo:Fr	10	Thin section
397	Bp:Bc:Mo	5-10	Hand sample
412	Mo:Bc	5-10	Hand sample
425	Mo:Vug	<5	Thin section
437	Bp>Mo:Vug	7-10	Hand sample
450	Mo	10	Thin section
481	Mo>Vug	<5	Hand sample
513	Mo>Bp	5-10	Hand sample
520	Mo>Fr	10	Thin section
540	Mo	5-10	Hand sample
933	Mo	5-7	Thin section
950	Bp	<5	Hand sample
998	Bp	5	Hand sample
1,013	Bp>Wp>Mo	10	Thin section
1,038	Wp:Vug	5-7	Thin section
1,089	Bp	<5	Hand sample

Description of Geologic Units in Test Hole NC-14

Test hole NC-14 penetrated surficial deposits of Quaternary age and sedimentary rocks ranging in age from early Miocene to middle Miocene. These rocks are subdivided in descending order into three geologic formations: the Aymamón Limestone, the Los Puertos Limestone, and the Cibao Formation (table 4, fig. 5). The surficial deposits consists of a 40 ft thick section of claystone and clayey quartz sand.

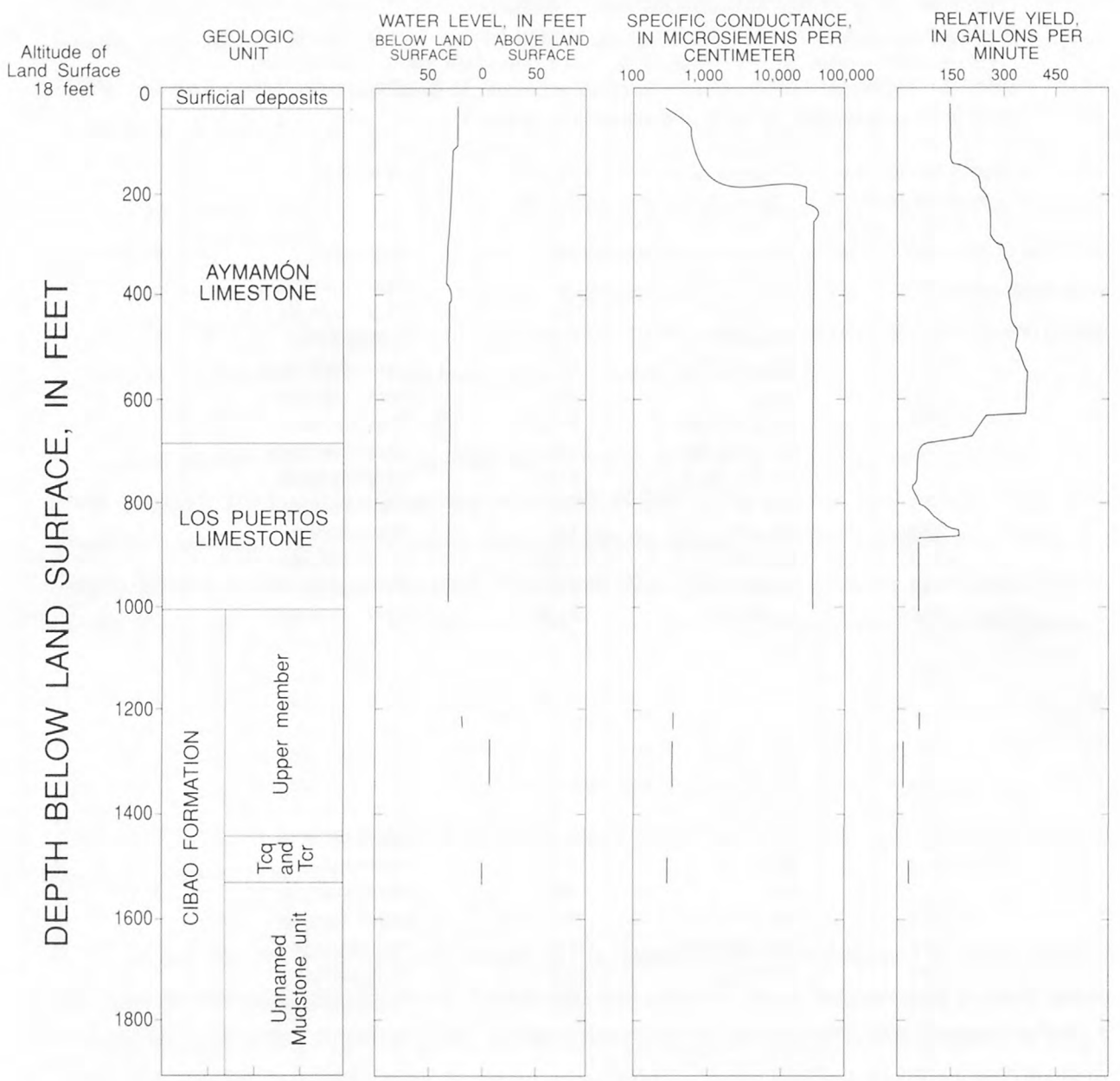

Figure 5.--Geologic units, water level, specific conductance of water, and relative yield at test hole NC-14, Vega Baja, Puerto Rico. Tcq and Tcr refer to the Undifferentiated Quebrada Arenas and Río Indio Limestone Members of the Cibao Formation.

The Aymamón Limestone, which is 635 ft thick, extends from 40 to 675 ft below land surface and consists of: (a) 226 ft (40 to 266 ft) of red algae-clayey wackestone and packstone bearing encrusting foraminifera, corals, and molluscs; (b) 176 ft (266 to 442 ft) of packstone-grainstone and minor wackestone bearing red algae, echinoids, Amphistegina, and coral; (c) 76 ft (442 to 518 ft) of dolomitic-chalky skeletal wackestone-packstone; (d) 110 ft (518 to 628 ft) of molluscan wackestone-packstone bearing echinoids, corals, and Halimeda; and (e) 47 ft (628 to 675 ft) of slightly clayey wackestone-packstone, bearing molluscs, encrusting foraminifera, and minor echinoids.

The Los Puertos Limestone, which is 325 ft thick, extends from 675 ft down to 1,000 ft below land surface and is subdivided into (a) 91 ft (675 to 766 ft) of skeletal wackestone bearing red algae, molluscs, and soritids; (b) 77 ft (766 to 843 ft) of slightly quartz-sand red algae dolomitic wackestone-packstone bearing reef and molluscs; (c) 61 ft (843 to 904 ft) of red-algae packstones and packstone-grainstone, bearing molluscs and coral, dolomitic in part; and (d) 96 ft (904 to 1,000 ft) of red algae (crustose and branching) wackestone-packstone and wackestone and minor grainstone bearing molluscs, soritids, miliolids, and echinoids.

The Cibao Formation, which is 837 ft thick, extends from 1,000 to 1,837 ft below land surface and is subdivided in descending order into three members: an upper member (typical Cibao lithology), the undifferentiated Quebrada Arenas and the Río Indio Limestone Members, and an unnamed mudstone unit. The upper member, which is 440 ft thick, extends from 1,000 to 1,440 ft below land surface and consists of a sequence of terrigenous (clay, silt, and sand) wackestone and wackestone-packstone, claystone, marl, and minor clayey-quartz sandstone with a diverse molluscan and foraminifera fauna.

Test hole NC-14 penetrated 100 ft thick of the undifferentiated Quebrada Arenas and Río Indio Limestone Members, from 1,440 to 1,540 ft below land surface. This geologic unit consists of Miogypsina and oyster-bearing quartz sandy limestone, quartz sandstone, and minor claystone and marls. The unnamed mudstone unit, which is 297 ft thick (depth of 1,540 to 1,837 ft), is a sequence of carbonate mudstone, minor sandstone, marl, claystone, siltstone, minor wackestone, and rarely packstone.

Description of Water-Bearing Units in Test Hole NC-14

Test hole NC-14 penetrated four water-bearing units: a water-table aquifer and three artesian aquifers. The water-table aquifer is in the Aymamón Limestone and the Los Puertos Limestone and extends from 40 ft below land surface to a depth of 1,010 ft (table 5) and into the uppermost 10 ft of the upper member of the Cibao Formation. The water-table aquifer is underlain by a confining unit in the upper member of the Cibao Formation that extends to 1,210 ft below land surface. The upper artesian aquifer,

Table 5.--*Selected hydrologic data from test hole NC-14*

Depth below land surface (feet)	Water level below or above (+) land surface (feet)	Specific conductance, (microsiemens per centimeter)	Relative yield, (gallon per minute)
	Water-Table Aquifer		
83	83.0	500	120
40	20.0	590	150
54	20.0	800	150
75	20.0	800	150
116	20.0	850	150
135	20.0	850	150
140	21.0	1,200	150
148	21.0	1,600	165
153	21.0	2,400	170
156	24.0	2,800	190
161	24.0	3,000	200
168	24.0	6,000	225
174	24.0	14,000	230
176	24.0	17,000	230
180	24.0	19,000	230
185	24.0	22,000	230
196	24.0	34,000	230
214	24.0	38,000	260
236	24.0	47,500	260
314	32.0	49,000	300
334	32.0	49,000	310
397	25.0	49,000	320
415	28.0	49,000	320
436	26.0	49,000	320
576	29.0	49,000	370
630	29.0	49,000	360
675	30.0	49,000	135
690	30.0	49,000	60
720	30.0	49,500	60
821	30.0	49,500	90
865	30.0	49,500	180
875	30.0	49,000	140
957	30.0	49,500	58
1,010	30.0	49,500	58
	First Artesian Aquifer		
1,216	19.0	700	60
1,240	19.0	700	60
	Second Artesian Aquifer		
1,261	+9.0	700	15
1,350	+9.0	700	10
	Third Artesian Aquifer		
1,495	+3.0	700	30
1,540	+3.0	700	30

also within the upper member of the Cibao Formation, extends to a depth of 1,240 ft below land surface. The upper artesian aquifer is underlain by a 20 ft thick (depth 1,240 to 1,260 ft below land surface) confining layer which is, in turn, underlain by the middle artesian aquifer that extends to 1,350 ft below land surface. Both of these zones are within the upper member of the Cibao Formation. A third confining unit, which is 145 ft thick (depth of 1,350 ft to 1,493 ft below land surface), is in the upper member and the undifferentiated Quebrada Arenas and the Río Indio Limestone Members of the Cibao Formation. The lower artesian aquifer, which is 45 ft thick (depth of 1,495 to 1,540 ft below land surface), lies beneath this confining unit and is in the undifferentiated Quebrada Arenas and the Río Indio Limestone Members.

The specific conductance of water in the water-table aquifer increased from 590 µS/cm at a depth of 40 ft to 49,000 µS/cm at 314 ft below land surface. The specific conductance remained relatively constant at 49,000 to 49,500 µS/cm from a depth of 314 ft to a depth of 1,010 ft. The specific conductance remained constant at 700 µS/cm in the three artesian aquifers (fig. 5, table 5).

The relative yield remained constant at 150 gal/min from 40 to 140 ft below land surface (table 5). The relative yield gradually increased to 370 gal/min at a depth of 576 ft below land surface. A decrease to 60 gal/min occurred from 576 to 690 ft below land surface, and then the yield gradually increased to 180 gal/min at a depth of 865 ft below land surface. Near the base of the water-table aquifer, the relative yield decreased to 58 gal/min at a depth of 957 ft below land surface and remained relatively constant to a depth of 1,010 ft below land surface. In the upper artesian aquifer, the relative yield remained constant at 60 gal/min. In the middle and lower artesian aquifers, the relative yield was 15 gal/min at a depth of 1,261 ft below land surface and 30 gal/min at the depth of 1,493 to 1,540 ft below land surface, respectively (fig. 5, table 5).

The water level in the water-table aquifer, ranged from 20 to 32 ft below land surface. In the upper artesian aquifer it was 19 ft below land surface. In the middle and lower artesian aquifers, water level was 9 and 3 ft above land surface, respectively.

SUMMARY

This report contains geologic and hydrologic data collected from test holes NC-4 and NC-14, drilled in the municipalities of Manatí and Vega Baja, respectively, during 1986 and 1988. These test holes were drilled to determine the depths, thicknesses, and hydraulic properties of the local water-bearing units, as part of a study of the aquifers and confining units of the Northern Coastal Province of Puerto Rico. Test hole NC-4, drilled to a depth of 1,898 ft below land surface, penetrated surficial deposits of Quaternary age and four geologic units ranging in age from Late Oligocene to middle Miocene: the Aymamón Limestone,

the Los Puertos Limestone, the Cibao Formation, and the Lares Limestone. These units are overlain by surficial deposits of Quaternary age. Test hole NC-14, drilled to a depth of 1,837 ft below land surface, penetrated surficial deposits of Quaternary age and three geologic units that ranged in age from early Miocene to middle Miocene: the Aymamón Limestone, the Los Puertos Limestone, and the Cibao Formation. Both test holes were plugged and abandoned at the conclusion of the study.

Test hole NC-4 penetrated three water-bearing units: a water-table aquifer and two artesian aquifers. The specific conductance in the water-table aquifer ranged from 500 to 38,000 µS/cm. The specific conductance ranged from 740 to 800 µS/cm in the two artesian aquifers. The relative yield in the water-table aquifer ranged from 120 to 195 gal/min. In the upper artesian aquifer the relative yield ranged from 60 to 135 gal/min and in the lower artesian aquifer the yield ranged from 190 to 195 gal/min. The water level ranged from 81 to 89 ft below land surface in the water-table aquifer. In the upper artesian aquifer, water levels ranged from 4.8 to 22 ft below land surface. In the lower artesian aquifer, the water level ranged from 85 to 88 ft above land surface.

Test hole NC-14 penetrated four water-bearing units: a water-table aquifer and three artesian aquifers. The specific conductance in the water-table aquifer ranged from 590 to 49,000 µS/cm. In the artesian aquifers it was 700 µS/cm. The relative yield in the water-table aquifer ranged from 58 to 370 gal/min. In the upper artesian aquifer, the relative yield was 60 gal/min. In the middle and lower artesian aquifers, the relative yields were 10 to 15 and 30 gal/min, respectively. The water level in the water-table aquifer ranged from 20 to 32 ft below land surface. In the upper aquifer, the water level was 19 ft below land surface. In the middle and lower artesian aquifers, the water level was 9 and 3 ft above land surface, respectively.

SELECTED REFERENCES

Briggs, R.P., and Akers, J.P., 1965, Hydrogeologic map of Puerto Rico and adjacent islands: U.S. Geological Survey Hydrologic Investigations Atlas HA-197, 1 sheet, scale 1:240,000.

Giusti, E.V., 1978, Hydrogeology of the karst of Puerto Rico: U.S. Geological Survey Professional Paper 1012, 67 p.

Giusti, E.V., and Bennet, G.D., 1976, Water Resources of the North Coast Limestone area, Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 42-75, 42 p.

Goddard, E.N., and others, 1948, Rock-color chart: Washington, D.C., National Research Council, 6 p. (Republished by Geological Society of America, 1951; reprinted, 1963, 1970, 1975, 1979, 1980, 1984).

Monroe, W.H., 1971, Geology of the Manatí quadrangle, Puerto Rico: U.S. Geological Survey Miscellaneous Geological Investigations Map I-671, scale 1:20,000.

_____1980, Geology of the middle Tertiary formations of Puerto Rico: U.S. Geological Survey Professional Paper 80-953, 93 p.

Moussa, M.T., and Seiglie, G.A., 1975, Stratigraphy and petroleum possibilities of middle Tertiary rocks in Puerto Rico-Discussion: American Association of Petroleum Geologists, v. 59, p. 163-168.

Seiglie, G.A., and Moussa, M.T., 1984, Late Oligocene-Pliocene transgressive-regressive cycles of sedimentation in northwestern Puerto Rico, in Schlee, J.S., ed., Interregional unconformities and hydrocarbon accumulation: American Association Petroleum of Geologists Memoir 36, p. 89-95.

Torres-González, Arturo, and Wolansky, R.M., 1984, Planning report for the comprehensive appraisal of the ground-water resources of the North Coast Limestone area of Puerto Rico: U.S. Geological Survey Open-File Report 84-427, 32 p.

Table 1.--*Description of lithologic core from test hole NC-4*

[(5YR7/2), color code according to the Rock-Color Chart of the Geological Society of America (Goddard and others, 1984)]

Description	Depth, in feet below land surface
Quaternary Series **Surficial Deposits**	
Soil, clayey, red-brown. Claystone, silty, red-brown.	1 - 10
Silt, clayey, red-brown. Sand, fine, quartzose with scattered fragments of dense limestone near bottom.	10 - 90
Limestone, crystalline, hard, dense, fragmental, within red-brown silty claystone.	90 - 110
Miocene Series **Aymamón Limestone**	
Limestone, grayish-orange, pink and very pale orange (5YR7/2 and 10YR8/2), crystalline (lesser amount chalky), with the fabric generally obscured by effects of karstification. Packstone-grainstone, with a diverse faunal assemblage: red algae, foraminifera, molluscs, echinoid, and branching coral.	110 - 200
Grainstone, very pale orange (10YR8/2), well indurated, crystalline vuggy. Fossils include red algae, miliolid, Amphistegina, soritid, encrusting and miscellaneous foraminifera, echinoid, molluscs, bearing occasional branching-coral molds. Porosity: low to locally high vuggy calcareous rock.	200 - 250
Grainstone, light brown, very pale orange (10YR6/4 and 10YR8/2), fine grained, locally dolomitic, often well-sorted. Fossils include articulate red algae, foraminifera, molluscs. Other clasts include pelloids. Porosity: low moldic, vuggy, and interparticle.	250 - 276
Grainstone, dominantly chalky, poorly indurated with lesser amounts of hard, dense crystalline limestone, with a diverse faunal assemblage: red algae, foraminifera, echinoids, and molluscs. Mud filled vugs at 276 to 280 ft. Porosity: medium-high; interparticle, moldic, and intraparticle.	276 - 301
Mud filled vug?	301 - 305
Packstone, yellowish-gray (5Y7/2), coarse-grained, dolomitic. Fossils include red algae (robust branching forms), soritid, Amphistegina, coral and molluscs. Porosity: medium-high; moldic and interparticle.	305 - 355

Table 1.--*Description of lithologic core from test hole NC-4*--Continued

Description	Depth, in feet below land surface
Grainstone-packstone, very pale orange (10YR8/2), poorly indurated, slightly dolomitic. Fossils include Amphistegina, coral, and crustose red algae. Porosity: high, moldic, and interparticle.	355 - 390
Packstone, yellowish-gray and very pale orange (5Y7/2 and 10YR8/2), dolomitic. Fossils include red algae, Amphistegina, encrusting foraminifera, coral?, and molluscs. Porosity: low-medium; intracrystalline, and moldic.	390 - 430
Packstone-grainstone, grayish-orange (10YR7/4), friable, not well cemented. Fossils include red algae (branching and crustose forms), Amphistegina, encrusting foraminifera, Gypsina-Spherogypsina, echinoids, and molluscs. Porosity: medium-high; interparticle, moldic, and intraparticle.	430 - 440
Packstone, very pale orange (10YR8/2), slightly quartz sand, scattered dark organic? matter filling molds, chalky and poorly cemented. Fossils include branching coral, Kuphus, miliolid, soritid, molluscs (commonly large and whole), and red algae. Porosity: medium-high; moldic and interparticle.	440 - 465
Packstone-grainstone, yellowish-gray (5Y7/2), coarse-grained. Fossils include branching coral, Kuphus, Amphistegina, molluscs, echinoids, Halimeda, bryozoans, miliolids, and soritids.	465 - 485
Los Puertos Limestone	
Packstone-rudstone, very pale orange (10YR8/2). Fossils include massive and branching corals, large molluscs, rhodolites in a matrix of molluscs (including oysters), foraminifera (including encrusting forms). Wackestone and grainstone, in lesser amounts. Top 10 ft dominated by branching coral thicket. Porosity: medium-high moldic, interparticle and fracture.	485 - 542
Wackestone-packstone, grayish-orange-pink (5YR7/2), slightly quartz sand. Fossils include molluscs, red algae, foraminifera, Kuphus, and branching coral. Molluscs commonly large and whole. Porosity: low-medium, moldic.	542 - 565
Grainstone, grayish-orange and grayish-orange-pink (10YR8/4 and 10YR7/2), slightly quartz sand. Fossils include soritids, penneropolids, miliolids and red algae. Wackestone-packstone, with Halimeda, molluscs, coral, and soritids. Porosity: medium-high; interparticle and moldic intraparticle.	565 - 600

Table 1.--*Description of lithologic core from test hole NC-4*--Continued

Description	Depth, in feet below land surface
Packstone-grainstone, yellowish-gray to light grayish-orange (5Y8/1 to 5GY7/1), with abundant branching coral, lesser amounts of echinoids, molluscs, miliolids, soritids and articulate red algae. Packstone, coarse-grained, with peloids. Fossils include molluscs, miliolids, soritids, and penneropolids. Porosity: high; moldic, interparticle, and intraparticle.	600 - 643
Packstone, yellowish-gray and light greenish gray (5Y8/1 and 5GY7/1), variable dolomitic, slightly quartz sand. Fossils include branching coral, echinoids, soritids, miliolids, penneropolids, molluscs, and articulate red algae. Locally contains quartz sand and scattered, thin clay layers. Branching coral is more abundant in top few feet - 'coral thicket'. Porosity: high; moldic, interparticle, and intraparticle.	643 - 709
Cibao Formation **upper member (typical Cibao)**	
Mudstone-wackestone, olive to light gray, clayey, and quartz sand. Fossils include foraminifera and molluscs (oysters). Near top, burrowed and dolomitic bearing articulate red algae. Porosity: low-medium; moldic intercrystalline.	709 - 719
Claystone, olive to light gray, with thin-shelled white pelecypods.	719 - 727
Wackestone, medium grey and yellowish-gray (N5 and 5Y8/1) to quartz-sand, skeletal, with black micritic intraclasts (pelloidal), calichified? texture. Clayey in the upper few feet. Porosity: low-medium; interparticle and vuggy.	727 - 744
Packstone, light grey (N7), with quartz sand, intraclastic (black micritic). Fossils include thin-shelled pelecypod, foraminifera, cyclostome bryozoan, and Halimeda. Porosity: medium; interparticle and interparticle.	744 - 760
Wackestone-packstone, light greenish-grey and yellowish-grey (5GY8/1 and 5Y8/1), chalky and poorly reduced with black micritic intraclasts common at 800 and at 817 ft, locally clayey. Fossils include miliolids, soritids, echinoids, red algae, ostracodes, molluscs, and unidentified benthic foraminifera. Porosity: medium; reduced, intraparticle, and interparticle.	760 - 850

Table 1.--*Description of lithologic core from test hole NC-4*--Continued

Description	Depth, in feet below land surface
Packstone-grainstone, very pale orange (10YR8/2). Fossils include articulate red algae, pelloids, miliolids, soritids, penneropolids, oysters, gastropods, echinoids, thin branching corals, and Kuphus. Wackestone, clayey at 855 to 865 ft. Porosity: medium-high; reduced moldic, interparticle, and intraparticle.	850 - 883
Wackestone-packstone, light gray (N7). Fossils include soritids, miliolids, and molluscs. Porosity: low-medium moldic.	883 - 893
Grainstone, medium light gray and light yellowish-gray (N7 and 5Y6/2). Fossils include soritids, miliolids, Amphistegina thin-shelled pelecypods and high-spired gastropods, articulate red algae and cyclostome bryozoans. Porosity: low-medium moldic, often reduced.	893 - 948
Clays, clayey sandstone and conglomerates. Some layers contain volcanic quartz sand and well-rounded lithic pebble-sized clasts.	948 - 970
Wackestone-packstone, grayish-yellow-green (5GY7/2), quartz sand, skeletal. Also quartz sandy clay.	970 - 993
Sandstone, grayish-yellow-green (5GY7/2), quartzose, non-calcareous, poorly fossiliferous, poorly cemented with clay matrix. Red-brown iron stains.	993 - 1,004
Clays and clayey marls.	1,004 - 1,012
Grainstone, white to yellowish-gray (N9 to 5Y8/1), quartz sandy. Fossils include miliolids, red algae, soritids, ostracodes, echinoids, bryozoans, oysters and peloids? Porosity: high; interparticle and intraparticle moldic.	1,012 - 1,017
Sandstone, quartzose. Marls, slightly sandy and silty.	1,017 - 1,036
Wackestone, yellowish-gray (5Y8/1), quartz sand with micritic intraclasts. Fossils include red algae, soritid-penneropolids and large gastropods. Porosity: low-medium; vuggy, interparticle, and microinterparticle.	1,036 - 1,055
Sandstone, quartzose and lesser amounts of clayey and quartz rich marls-limestone and poorly fossiliferous clay. Porosity: low interparticle.	1,055 - 1,097
Clays, red, brown, green, purple, quartz silty.	1,097 - 1,105

Table 1.--*Description of lithologic core from test hole NC-4*--Continued

Description	Depth, in feet below land surface
Sandstones, marls, and clays.	1,105 - 1,120
Clays, olive, purple, yellow-brown. Fossils include soritids and penneropolids.	1,120 - 1,131
Grainstone, medium light gray and light greenish grey (N6 and 5 GY8/1), fine-grained, quartz-rich, lithic sandy. Fossils include articulate red algae, miliolid, and other small benthonic foraminifera, peloids and molluscs. Porosity: low moldic.	1,131 - 1,146
Similar to above, without molluscs.	1,146 - 1,158
Cibao Formation **Quebrada Arenas and Río Indio Limestone Members**	
Wackestone-packstone, greenish-grey (5GY6/1), slightly dolomitic. Fossils include large benthic foraminifera, molluscs, bryozoans, and branching corals. Molluscs are commonly large and whole pelecypods including oysters and gastropods. Porosity: medium-high; moldic, intraparticle, and intracrystalline.	1,158 - 1,166
Wackestone-Packstone, pale yellow-green (5GY7/2), interbedded with thin layers of clays and marls, slightly dolomitic. Fossils include molluscs, branching corals, and bryozoans. Molluscs are commonly large and whole gastropods and oysters. Porosity: (limestone) low-medium; moldic.	1,166 - 1,206
Marls-clayey limestone, medium light grey (N6), slightly dolomitic, quartz silty. Fauna include oysters, coral, large benthic foraminifera, Halimeda, and worm tubes. Porosity: low-medium; interparticle and intraparticle.	1,206 - 1,250
Cibao Formation **unnamed mudstone unit**	
Wackestone-packstone, pale olive, (10Y6/2), dolomitic, clayey, with large benthic foraminifera, Amphistegina, lesser bryozoans and echinoids. Porosity: low-medium; interparticle and intraparticle.	1,250 - 1,268
Clays, olive (10 Y 6/2).	1,268 - 1,276

Table 1.--*Description of lithologic core from test hole NC-4*--Continued

Description	Depth, in feet below land surface
Wackestone-packstone, pale olive (10Y6/2), fine quartz sandy, clay-rich, dolomitic. Fossils include large benthonic and planktonic foraminifera and bryozoans. Porosity: low-medium; interparticle and intraparticle.	1,276 - 1,282
Claystone, olive, with scattered small pelecypods.	1,282 - 1,292
Wackestone-packstone, pale yellow-green (5GY7/2), clayey. Fossils include large benthic foraminifera (Lepidocyclina, Amphistegina, and Heterostegina), planktonic foraminifera, oyster, red algae, coral, and rhodolites. Porosity: medium; moldic interparticle.	1,292 - 1,303
Clays, with small scattered pelecypods.	1,303 - 1,313
Wackestone-packstone, grayish-olive (10Y5/2), clayey, fine-quartz sandy. Fossils include large benthic and planktonic foraminifera, molluscs, lesser oysters and pectens. Glauconite and pyrite as cement and/or replacement. Porosity: low; microinterparticle.	1,313 - 1,326
Marls, clays, and thin clayey limestone beds. Fossils include large benthic foraminifera, small gastropods and pelecypods.	1,326 - 1,375
Clays, with pectens and bryozoans.	1,375 - 1,398
Marls, quartz silty, with thin shelled molluscs.	1,398 - 1,415
Interbedded clayey siltstones and limestone, grayish-yellow-green (5GY7/2). Limestones are packstones, clayey, fine-quartz sandy, with Lepidocyclina, planktonic foraminifera and minor coral fragments. Porosity: low; microinterparticle moldic and fracture.	1,415 - 1,455
Siltstone and claystone, grayish-green (5GY6/1), calcareous. Fossils include foraminifera, echinoid spines, and other skeletal grains. Porosity: low; interparticle.	1,455 - 1,480
Clays, calcareous, with few molluscan fragments.	1,480 - 1,500
Siltstone and lesser clays, grayish-green (5GY6/1), calcareous. Fossils include miliolids and other fine skeletal grains. Porosity: low; interparticle.	1,500 - 1,520

Table 1.--*Description of lithologic core from test hole NC-4*--Continued

Description	Depth, in feet below land surface
Claystone, grayish-green (5GY6/1), locally quartz silty. Fossils include rare scaphopods and other skeletal fragments. Pyrite common, as well as black organic prints aligned parallel to bedding. Porosity: low; interparticle.	1,520 - 1,555
Sandstone-siltstone with clay-micrite matrix (i.e. silty marls). Fossils include Lepydociclina, miliolids, echinoids, planktonic foraminifera, and molluscan fragments. Lesser claystone. Mudstone, quartz-silty, dolomitic, with planktonic foraminifera. Porosity: low; interparticle.	1,555 - 1,590
Claystone and siltstone, grayish-green (5GY6/1). Fossils include a few molluscan fragments. Dark carbonaceous prints and 'chitinous' material. Porosity: low; microinterparticle.	1,590 - 1,620
Wackestone-packstone, grayish-green (5GY6/1), fine-quartz sandy, clay-rich. Fossils include planktonic foraminifera, large and small benthonic foraminifera and coral. Pyrite very common. Porosity: low; microinterparticle.	1,620 - 1,625
Sandstone, fine-grained/siltstone, with clay-micrite matrix. Lesser claystone. Occasional dark carbonaceous material in thin films and filling molds. Pyrite very common. Porosity: low; microinterparticle.	1,625 - 1,677
Sandstone and siltstone, light olive-gray (5Y8/2), marly and quartz rich, in a micritic and clayey matrix. Fossils include planktonic and benthic foraminifera. Lesser dolomitic mudstone (table 2) and wackestones. Porosity: low; microinterparticle.	1,677 - 1,700
Oligocene Series **Lares Limestone**	
Packstone-grainstone, greenish-gray and greenish-black (5GY6/1 and 6GY2/1), sandy, interbedded with silty marls. Fossils include branching red algae, large benthic foraminifera and coral. Marls often contain bryozoans. Dolomitic near top. Porosity: low-medium moldic; interparticle and intercrystalline.	1,700 - 1,720
Sandstone/siltstone, greenish-gray, (5GY6/1), quartzose and lithic, with a micritic and clayey matrix, bearing miscellaneous skeletal clasts. Dark organic bits locally found.	1,720 - 1,770

Table 1.--*Description of lithologic core from test hole NC-4*--Continued

Description	Depth, in feet below land surface
Mixed, fine siliciclastics and skeletal carbonate grains. The bottom few feet are coral and rhodolite bearing lithic conglomerate with a micritic matrix. The upper 20 ft may be cross-bedded and sediments ranging from quartz and lithic sandy, red algae, planktonic, encrusting and large benthic foraminifera packstone and grainstone to quartz and lithic sandstone-conglomerate, rich in red algae and planktonic foraminifera. From 1,792 to 1,804 ft, quartzose, lithic, silty and fine-grained sandy marls bearing planktonic foraminifera and other skeletal grains. In the top few feet, 1,780 to 1,785 ft, limestone containing head coral and rhodolites. Porosity: low-medium interparticle; moldic.	1,770 - 1,818
Siltstone and fine-grained sandstone, quartzose, and volcanic rock fragments in a micritic matrix with minor skeletal carbonate grains.	1,818 - 1,834
Sandstone, greenish-gray (5GY6/1), medium to very coarse-grained, quartzose, with volcanic rock fragments and abundant skeletal clasts. Near top grades into a skeletal grainstone/rudstone containing head and branching corals, rhodolites and Kuphus? Cross bedding? Porosity: low-medium; interparticle.	1,834 - 1,852
Sandstone-siltstone, greenish-gray (5GY6/1), quartzose with volcanic rock fragments, in a micritic matrix. Coarser skeletal debris are common and include red algae, large benthic foraminifera, echinoid spines, coral, and oysters. Numerous cobble sized intraclasts of coral fragments and of reefal limestone are common. Porosity: low-medium; microinterparticle.	1,852 - 1,874
Lithic arenites, greenish-gray (5GY6/1), quartzose, with a micritic-clayey matrix. Fossils include planktonic foraminifera, pelecypods, red algae, and echinoids. Subequal amounts of quartz and volcanic rock fragments with lesser plagioclase. Much of the volcanic rock fragments are glass and/or have been altered to chlorite or some other secondary mineral. Porosity: low microinterparticle.	1,874 - 1,898

Table 4.--*Description of lithologic core from test hole NC-14*

[(5YR7/2), color code according to the Rock-Color Chart of the Geological Society of America (Goddard and others, 1984)]

Description	Depth, in feet below land surface
Quaternary Series	
Claystone, dark yellowish-orange.	0 - 20
Sandstone, dark yellowish-orange, clayey, quartzose.	21 - 40
Miocene Series	
Aymamón Limestone	
Wackestone, creamy white, pale yellow, fragmental; silty and clayey matrix (post depositional?) fossils include red algae, encrusting foraminifera, molluscs, and sparse bryozoans.	40 - 152
Packstone, creamy white, clayey; fossils include red algae, encrusting foraminifera, and molluscs.	152 - 266
Packstone-grainstone, creamy white, pale yellow, minor wackestone, fossils include red algae, echinoids, Amphistegina, and coral.	266 - 442
Wackestone-packstone, pale yellow, dolomitic, chalky, skeletal.	442 - 518
Wackestone-packstone, creamy white, pale yellow and dark gray mottled; fossils include echinoids, corals, and Halimeda.	518 - 628
Wackestone, creamy white and pale yellow; fossils include molluscs, encrusting foraminifera, and minor echinoids.	628 - 675
Los Puertos Limestone	
Wackestone medium gray, skeletal, well cemented; fossils include red algae, molluscs, soritids, and sparse echinoids.	675 - 766
Wackestone-packstone, medium gray, pale yellow, dolomitic, slightly quartz sand; fossils include red algae, reef, and molluscs.	766 - 843
Packstone/packstone-grainstone, creamy white, dolomitic in part; fossils include molluscs and corals.	843 - 904
Wackestone-packstone/wackestone, creamy white and pale yellow mottled; fossils include red algae (crustose and branching), molluscs, soritids, and miliolids.	904 - 1,000

Table 4.--*Description of lithologic core from test hole NC-14*--Continued

Description	Depth, in feet below land surface
Cibao Formation **upper member (typical Cibao lithology)**	
Claystone-marl; molluscs (oysters and others) and ostracods.	1,000 - 1,010
Wackestone-packstone, similar to 904-1,000 ft.	1,010 - 1,020
Marl, greenish-gray; fossils include molluscs, ostracods?, and other skeletal grains.	1,020 - 1,032
Claystone, greenish-gray, slightly quartz sand; fossils include thin-shelled bivalves and small gastropods.	1,032 - 1,040
Claystone-marl, olive-gray, minor quartz sand; large calcitic molluscs.	1,040 - 1,043
Wackestone, olive-gray, chalky, clayey, skeletal.	1,043 - 1,056
Marl, olive-gray, clayey; fossils include oysters, thin-shelled pelecypods, and coalified plant material.	1,056 - 1,065
Sandstone, greenish-gray, marly, skeletal.	1,065 - 1,070
Claystone-siltstone, light grayish-olive, quartz sandy, skeletal.	1,070 - 1,077
Wackestone, very pale orange, slightly quartz sandy; fossils include molluscs and soritids.	1,077 - 1,100
Claystone-marl, dark grey to greenish-gray, locally silty; poorly fossiliferous.	1,100 - 1,180
Siltstone, grayish-yellow-green (5GY7/2), yellowish-brown stained; sparsely fossiliferous.	1,180 - 1,184
Wackestone, chalky, clayey, skeletal.	1,184 - 1,189
Wackestone-packstone, light gray, slightly clayey; fossils include soritids, miliolids, molluscs, and ostracods.	1,189 - 1,195
Marl, light olive-gray, clayey; fossils include thin-shelled pelecypods, foraminifera, and other unidentified skeletal grains.	1,195 - 1,200
Wackestone, grayish-yellow-green (5GY7/2), chalky, slightly clayey, quartz sandy; fossils include soritids, penneropolids, bryozoans, miliolids, and molluscs.	1,200 - 1,205

Table 4.--*Description of lithologic core from test hole NC-14*--Continued

Description	Depth, in feet below land surface
Same as in 1,195-1,200 ft.	1,205 - 1,241
Marl-packstone, light gray; fossils include molluscs, soritids, oysters, miscellaneous foraminifera, and other skeletal grains.	1,241 - 1,260
Wackestone, pale orange, clayey, chalky, slightly quartz sand; fossils include soritids, peneropolids, miliolids, and red algae?	1,260 - 1,276
Same as 1,260 to 1,276 ft, with other unidentified skeletal grains.	1,276 - 1,280
Claystone, light olive-brown and moderate olive-brown silty and sandy, light olive-brown and moderate olive-brown (5Y5/6 and 5Y4/4), calcareous, with numerous dark organic? tubes and fragments.	1,280 - 1,286
Marl, very pale blue (5B8/2), mottled, miscellaneous skeletal grains; dark, organic? remains.	1,286 - 1,292
Wackestone, olive-gray mottled, chalky, clayey, quartz sand; fossils include foraminifera, molluscs?; sample has mottled look with greenish clay and white carbonate.	1,292 - 1,295
Wackestone, pale blue, pale blue-green, clayey, skeletal.	1,295 - 1,334
Sandstone, quartzose, medium coarse-grained, angular, poorly sorted, calcareous, poorly indurated; yellow, and red-brown stains (oil residue?, iron oxides?).	1,334 - 1,336
Wackestone, as above; chalky and quartz silty.	1,336 - 1,353
Wackestone, as above; quartz sand; burrowed.	1,353 - 1,355
Wackestone-packstone, yellowish-gray, quartz sand; fossils include foraminifera, molluscs, and other unidentified skeletal clasts.	1,355 - 1,380
Wackestone, light greenish-gray, very quartz sandy; fossils include soritids and other skeletal clasts.	1,380 - 1,400
Wackestone-packstone, same as 1,380 to 1,400 ft, clayey.	1,400 - 1,415
Wackestone, marly, skeletal; rest as from 1,400 to 1,415 ft.	1,415 - 1,428
Claystone, grayish-olive (10Y4/2); fossils include pectens, echinoids, and foraminifera (Heterostegina).	1,428 - 1,430

Table 4.--*Description of lithologic core from test hole NC-14*--Continued

Description	Depth, in feet below land surface
Claystone, dark gray, locally silty and sandy; organic; sandy.	1,430 - 1,440
Cibao Formation **Undifferentiated Quebrada Arenas and Río Indio Limestone Members**	
Packstone, yellowish-gray, bluish-white (5Y8/1, 5B9/1), clayey; fossils include red algae, foraminifera, and echinoid spines.	1,440 - 1,460
Packstone, light gray (N7), very-coarse grained, quartz sand; volcanic rock fragments; fossils include molluscs (oysters), red algae, foraminifera, echinoids, bryozoans, and large benthic foraminifera.	1,460 - 1,467
Sandstone, medium grained; calcareous clayey matrix; quartzose with minor volcanic rock fragments; fossils include echinoid spines and several foraminifera types.	1,467 - 1,472
Sandstone, fine-grained, moderate-to well-sorted, quartzose; calcareous clayey matrix; minor skeletal fragments; a few large micritic intraclasts.	1,472 - 1,500
Sandstone, fine-grained; siltstone; marly, quartzose; minor volcanic rock fragments; fossils include oyster fragments and foraminifera; numerous pyrite-filled molds; irregularly interbedded with wackestone and packstone, clayey, quartz-sandy.	1,500 - 1,540
Cibao Formation **unnamed mudstone unit**	
Packstone, marly, quartzose, volcanic rock fragments; fossils include Amphistegina, red algae? bryozoans, echinoid spines, ostracods, and Heterostegina.	1,540 - 1,588
Siltstone, pale yellowish-brown (10YR6/2); sparse pyritized carbonaceous traces; fossils include miscellaneous foraminifera and echinoid spines.	1,588 - 1,595
Sandstone, medium-grained, quartzose, clayey; volcanic rock fragments; plagioclase?; fossils include bryozoans, large benthic foraminifera, and echinoids.	1,595 - 1,640
Siltstone, clayey; sandstone, fine-grained, quartzose; plagioclase; fossils include Amphistegina, echinoid spines, red algae, and molluscs.	1,640 - 1,660

Table 4.--*Description of lithologic core from test hole NC-14*--Continued

Description	Depth, in feet below land surface
Marl, grayish-olive (10Y4/2), sandy; fossils include large benthic foraminifera, Amphistegina, miliolids, molluscs, coral?, and echinoid fragments.	1,660 - 1,680
Marl, sandy; fossils include large benthic foraminifera, oysters, and other skeletal grains; sandstone, quartzose, with volcanic rock fragments and plagioclase.	1,680 - 1,700
Siltstone, clayey; sandstone, fine-grained, calcareous; fossils include skeletal grains, Kuphus?, echinoid spines, planktonic foraminifera, and bryozoans; pyritized organic material.	1,700 - 1,720
Claystone, pale blue-green, slightly silty, slightly calcareous, sparely fossiliferous; minor pyrite.	1,720 - 1,740
Siltstone, clayey, calcareous, bearing abundant skeletal clasts; molluscs, bryozoans?, and red algae?	1,740 - 1,750
Siltstone, clayey; sandstone, fine-grained, quartzose; volcanic rock fragments; plagioclase?; unidentified skeletal carbonate grains; several pyrite and carbonaceous-material filled molds.	1,750 - 1,763
Sandstone, medium-coarse grained; siltstone, clayey, quartzose; volcanic rock fragments; plagioclase?; and skeletal carbonate grains; miscellaneous foraminifera; irregularly interbedded with claystone.	1,763 - 1,768
Siltstone, grayish-green, pale green (5G5/2, 10G6/2), clayey, burrowed?, slightly calcareous; fossils include foraminifera and ostracods; pyrite and organic films present.	1,768 - 1,776
Siltstone, clayey; sandstone, very fine-grained, moderate olive brown, slightly calcareous, quartz, skeletal; volcanic rock fragments; plagioclase; films of dark organic material and associated pyrite are common.	1,776 - 1,800
Siltstone, light bluish-gray (5B7/1), clayey, with minor sand-sized grains; quartz, volcanic rock fragments and plagioclase?; fossils include large benthic foraminifera and other skeletal fragments.	1,800 - 1,820
Claystone; siltstone, clayey, light bluish-gray (5B7/1); fossils include pelecypods and miscellaneous foraminifera.	1,820 - 1,837

*U.S. Government Printing Office: 1992 — 631-117/60005