Geology of Isla Desecheo, Puerto Rico, With Notes on the Great Southern Puerto Rico Fault Zone and Quaternary Stillstands of the Sea

GEOLOGICAL SURVEY PROFESSIONAL PAPER 739

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

GEOLOGY OF ISLA DESECHEO,

PUERTO RICO

Aerial view of Isla Desecheo from the north. Photograph by Pedro Solá Amadeo, Laboratory of Perinatal Physiology, U.S. National Institutes of Health, San Juan, Puerto Rico. Permission to publish the photograph granted by Dr. Ronald E. Myers, Chief, Laboratory of Perinatal Physiology.

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By VICTOR M. SEIDERS, REGINALD P. BRIGGS, *and* LYNN GLOVER III

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The surficial deposits and volcanic bedrock of an island in Mona Passage with comments on regional structure and higher sea levels

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GEOLOGY OF ISLA DESECHEO, PUERTO RICO, WITH NOTES ON THE GREAT SOUTHERN PUERTO RICO FAULT ZONE AND QUATERNARY STILLSTANDS OF THE SEA

By VICTOR M. SEIDERS, REGINALD P. BRIGGS, and LYNN GLOVER III

ABSTRACT

Isla Desecheo is in Mona Passage between Puerto Rico and Hispaniola. The bedrock, 700–1,100 meters of middle Eocene volcaniclastic rocks, consists chiefly of dacitic volcanic sandstone, fine-grained volcanic breccia, and mudstone. Deposition in at least moderately deep water is indicated by the abundance of graded beds and by the fact that interbedded mudstone contains exclusively planktonic faunas. Sparse rounded grains and shallow-water fossil debris in the graded beds indicate that the volcaniclastic debris came from volcanoes in shallow seas. Steep submarine slopes are suggested by submarine-slide deposits and penecontemporaneous deformation structures. The rocks are extensively zeolitized.

The southern two-thirds of the island, south of an east-west vertical fault, has west-trending nearly isoclinal folds which are overturned to the north. North of the fault, the main structural feature is a gentle anticline which plunges south. The contrasting structural features are believed to represent different tectonic levels that are separated by a low-angle thrust fault. The strongly deformed beds may be the remnant of a gravity-glide sheet that was eroded from the northern part of the island.

Isla Desecheo lies along the seaward projection of the great southern Puerto Rico fault zone, which is, perhaps, the major fracture zone of Puerto Rico. Large-scale transcurrent and vertical faults and associated gravity-glide structures seem closely related in age and geometry to similar features in Hispaniola and Cuba.

Surficial deposits include marine terrace deposits, colluvium (in part phosphate cemented), and beach deposits. There is evidence of two stillstands of the sea, one at 12–13 meters and the other at about 2 meters higher than present sea level. The higher level is probably of Pleistocene age and the lower, of Holocene age, perhaps about 3,300 years before the present. Tectonic uplift is believed responsible for the 2-meter level and, therefore, at least in part for the 12–13-meter level.

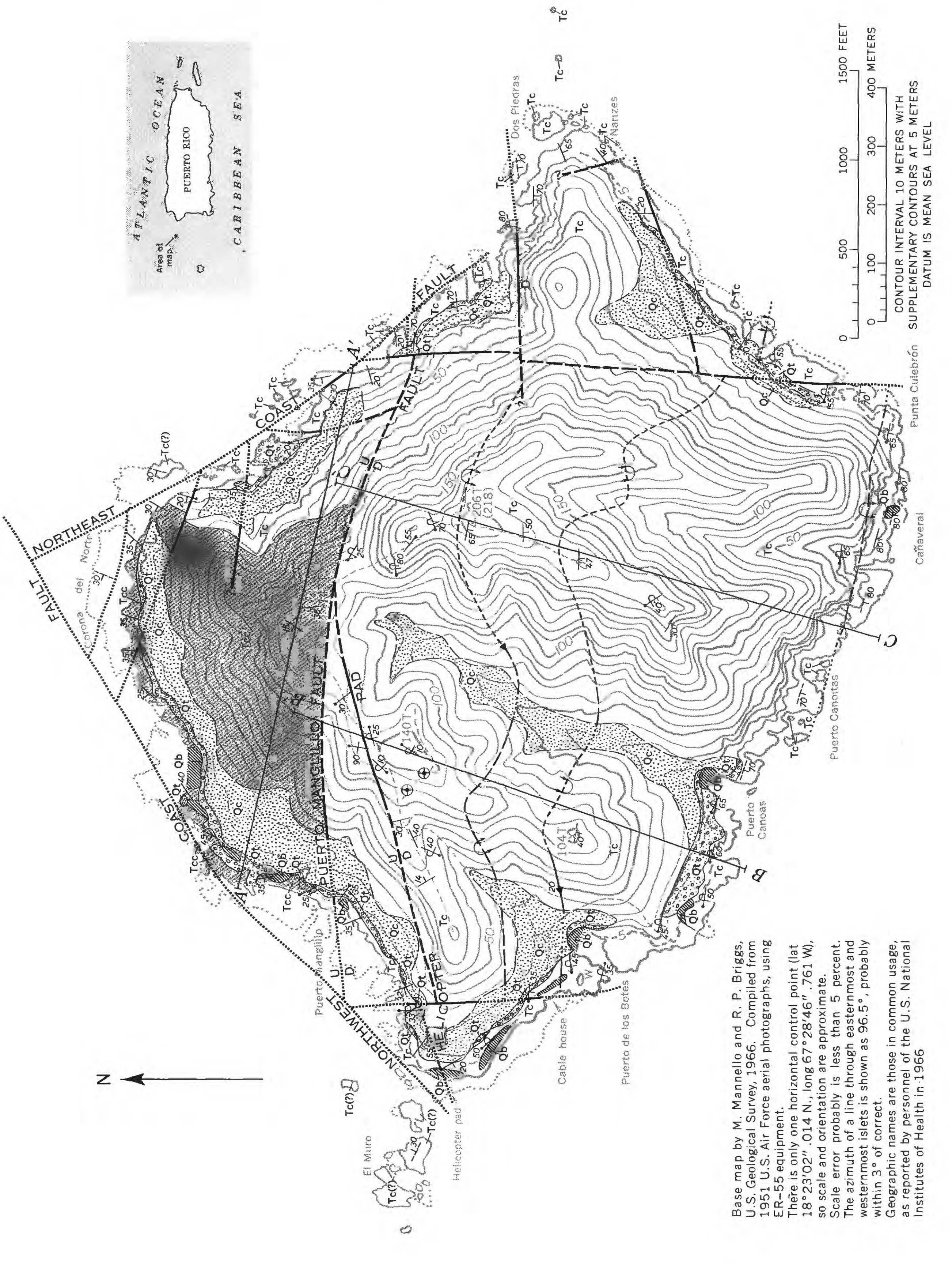
INTRODUCTION

Since 1955, Puerto Rico has been the subject of a detailed geologic investigation by the U.S. Geological Survey in cooperation with the Puerto Rico Economic Development Administration. Although most efforts have been concentrated on geologic mapping of the main island of Puerto Rico, the goal of this program is knowledge not only of the main island, but also of the many smaller adjacent islands.

In this report, Seiders and Glover are chiefly responsible for data and discussion on bedrock geology, and Briggs, for surficial geology. The fieldwork was done during two periods: Seiders, Briggs, and Glover were on Isla Desecheo April 15–19, 1966, and Seiders and Glover returned to the island May 8–10, 1967, accompanied by Eduardo Aguilar-Cortés, geologist with the Puerto Rico Economic Development Administration.

For the first fieldwork period, transportation to Isla Desecheo was by RV *Shimada* of the Puerto Rico Nuclear Center; the return trip was made in a small craft of the National Institutes of Health. For the second period, transportation was by a helicopter of the U.S. Navy Fleet Composite Squadron 8 (VC–8), Commander M. E. Smith commanding. Arrangements for transportation to and from Isla Desecheo were made through the cooperation of the staff of Dr. R. E. Myers, Chief, Laboratory of Perinatal Physiology, San Juan, and J. A. Morrison, Acting Chief, Section on Primate Ecology, Punta Santiago, Puerto Rico, both of the National Institutes of Health. Food and water were supplied to us by National Institutes of Health personnel.

The topographic map used as the base for the investigation (fig. 1) was compiled from 1951 U.S. Air Force photographs and from other data by Marshall Mannello of the U.S. Geological Survey and by Briggs during January 1966.


ATLANTIC OCEAN
PUERTO RICO
CARIBBEAN SEA
Area of map
N
NORTHEAST COAST FAULT
NORTHWEST COAST FAULT
PUERTO MANGLILLO FAULT
HELICOPTER PAD FAULT
Corona del Norte
Puerto Manglillo
El Morro
Helicopter pad
Cable house
Puerto de los Botes
Puerto Canoas
Puerto Canoitas
Cañaveral
Punta Culebrón
Dos Piedras
Narizes
0 500 1000 1500 FEET
0 100 200 300 400 METERS
CONTOUR INTERVAL 10 METERS WITH SUPPLEMENTARY CONTOURS AT 5 METERS
DATUM IS MEAN SEA LEVEL
Base map by M. Mannello and R. P. Briggs, U.S. Geological Survey, 1966. Compiled from 1951 U.S. Air Force aerial photographs, using ER-55 equipment.
There is only one horizontal control point (lat 18°23'02".014 N., long 67°28'46".761 W.), so scale and orientation are approximate.
Scale error probably is less than 5 percent.
The azimuth of a line through easternmost and westernmost islets is shown as 96.5°, probably within 3° of correct.
Geographic names are those in common usage, as reported by personnel of the U.S. National Institutes of Health in 1966

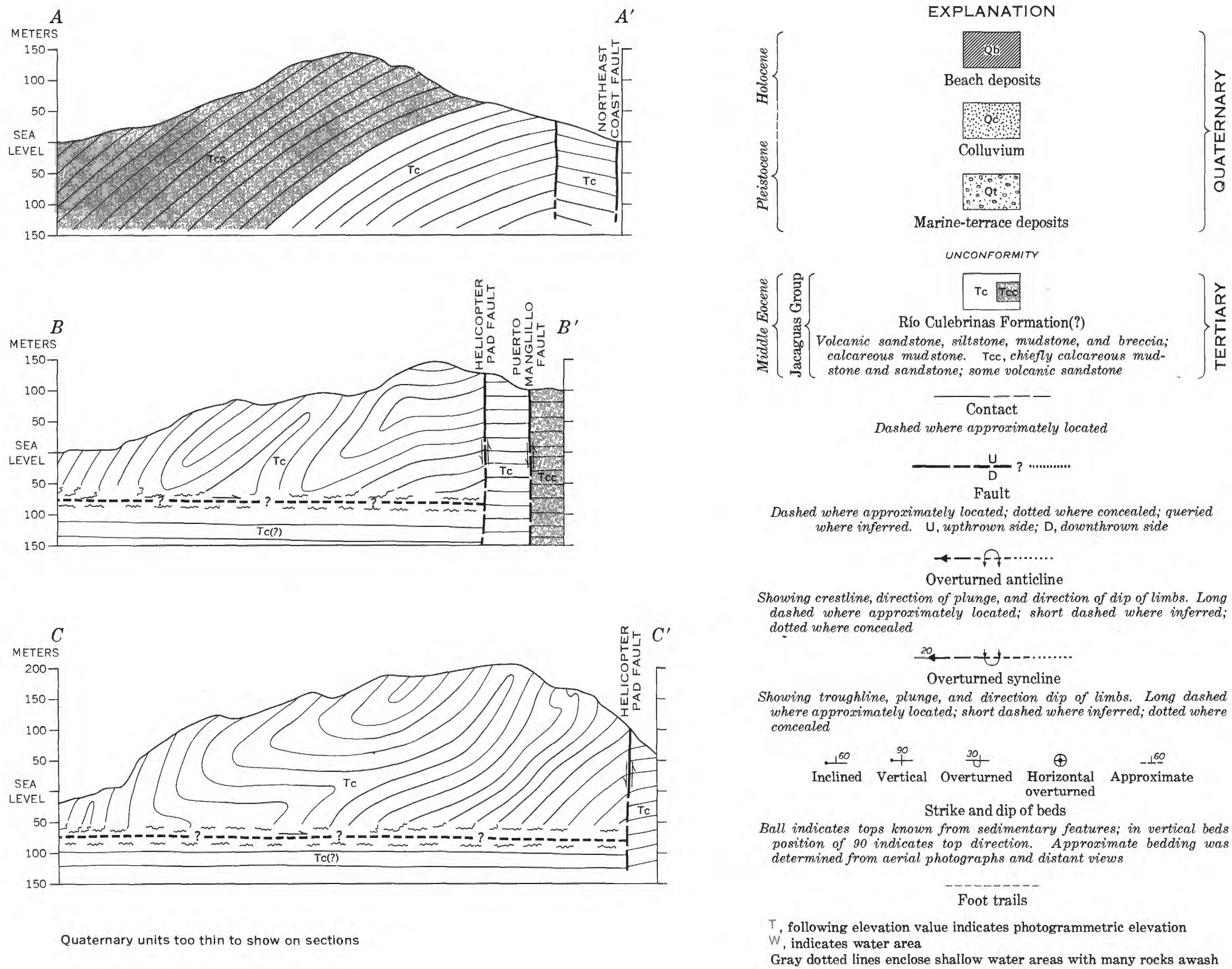


FIGURE 1. — Geologic map and sections of Isla Desecheo.

PREVIOUS WORK

This is the first detailed study of the geology of Isla Desecheo. Brief descriptions and sketch maps of the geology of the island were included in reports of larger areas by Hubbard (1923) and Mitchell (1954). Shoreline features were mentioned by Lobeck (1922).

GEOGRAPHY

Isla Desecheo is in the northeastern part of Mona Passage (fig. 2), the broad shallow strait between the islands of Puerto Rico and Hispaniola that connects the Atlantic Ocean with the Caribbean Sea. The island is about 21 kilometers (km) west of Puerto Rico and about 100 km east of Hispaniola. A low submarine ridge extends between Isla Desecheo and the western tip of Puerto Rico. The head of Mona Canyon, a deep steep-walled submarine depression extending northward to the Puerto Rico Trench, is just north of this ridge. Isla de Mona, the only other island of significant size in Mona Passage, is 51 km southwest of Isla Desecheo, at the southern entrance to the passage and about midway between Puerto Rico and Hispaniola.

In plan, Isla Desecheo is roughly a northwest-trending rectangle having an area of about 1.2 square kilometers. On three sides the island rises abruptly from a narrow wave-cut bench to ridge crests 100–200 meters above sea level (frontispiece). Average slopes range from 20° to 35°. From the southwestern coast, three valleys and the intervening ridges rise northward to a ridge near the northeast coast. Most of the drainage, therefore, is toward the southwest.

Although the island probably has an annual rainfall of about 1,020 millimeters (40 in.), the rapid runoff and high evaporation rate combine to reduce available moisture. As a result, the island has no permanent springs or streams and has a semiarid type of vegetation. Distribution of vegetation is influenced by the prevailing easterly trade winds. On east-facing slopes, where the evaporation rate is highest, is a sparse to dense cover of cactus and thorny shrubs and few small trees. West-facing slopes and sheltered valleys support a moderate growth of small- and medium-sized trees and much less abundant cactus and shrubs.

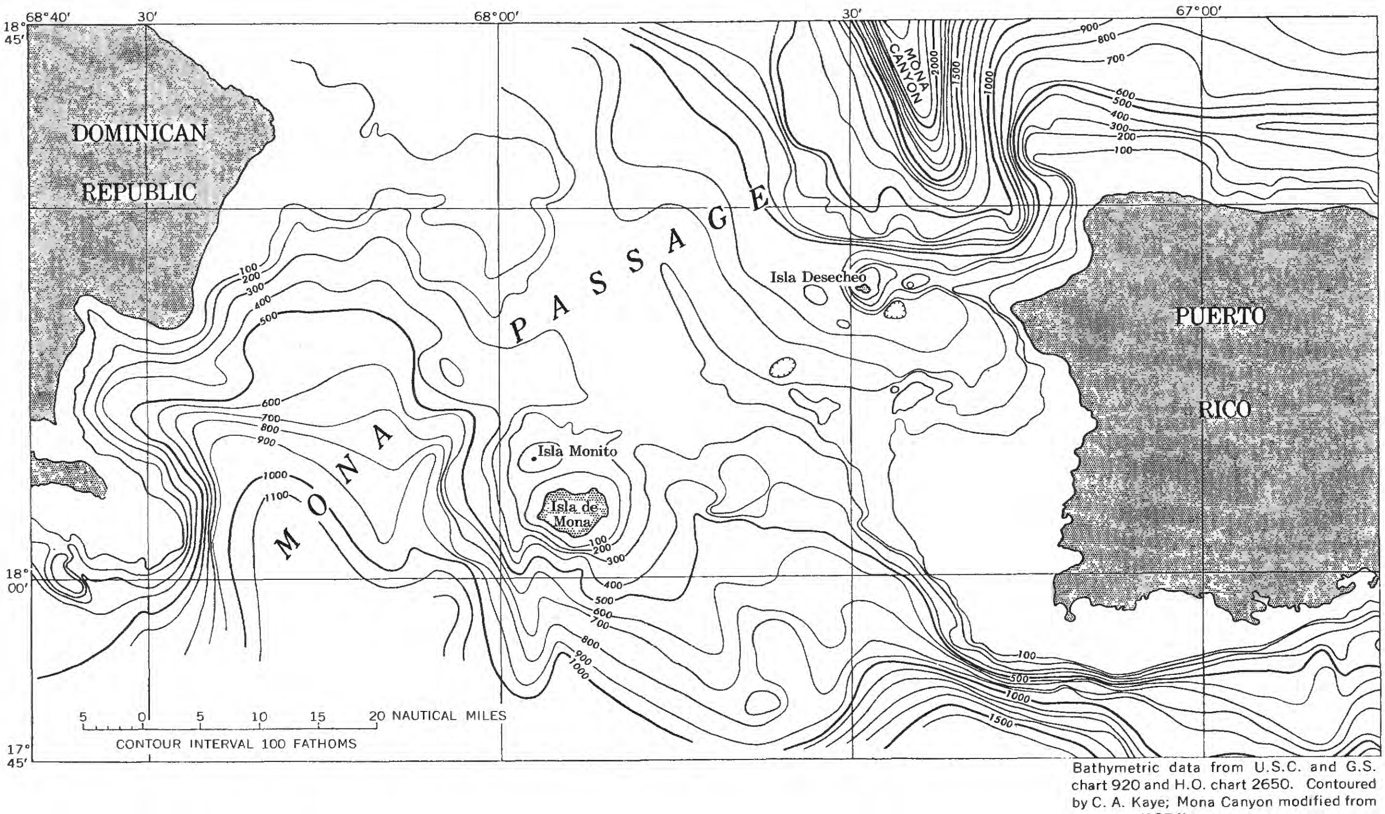


FIGURE 2. — Bathymetric map of Mona Passage (from Kaye, 1959b, fig. 68).

Isla Desecheo can be reached by small boat or by helicopter. At several places narrow inlets indent the rocky shoreline and give access to small beaches where light boats can land in good weather. The best landing place is Puerto de los Botes, followed by Puerto Canoas and Puerto Manglillo. A concrete helicopter pad is on the western tip of the island.

The best rock exposures are along the coast, and most of the coast can be traversed on foot with little difficulty. However, at several places southeast of Puerto Canoas and west of Dos Piedras, passage is blocked by cliffs.

STRATIGRAPHY

TERTIARY SYSTEM

The bulk of Isla Desecheo is underlain by a strongly deformed sequence of dacitic volcaniclastic rocks and less abundant calcareous mudstone. Hubbard (1923) correlated these rocks with his Río Yauco Series of Late Cretaceous age (renamed the Yauco Mudstone by Mattson, 1960). The present study has shown that the rocks on Desecheo are of Eocene rather than Cretaceous age. They are clearly correlative with part of the sequence of lower Tertiary formations in northwestern Puerto Rico described by McIntyre and others (1970). The most probable correlation is with the widespread Río Culebrinas Formation (McIntyre and others, p. D12) but correlation with the Concepción Formation (McIntyre and others, p. D12) is also possible. The Isla Desecheo rocks are herein assigned to the Río Culebrinas Formation of the Jacaguas Group (Glover and Mattson, 1967), a thick sequence of uppermost Cretaceous and lower Tertiary beds characterized by abundant dacitic volcaniclastic rocks.

RIO CULEBRINAS FORMATION(?)

The exposed thickness of the Río Culebrinas Formation(?) on Isla Desecheo is estimated to be 700–1,100 m. The most abundant rock types are dacitic volcaniclastic rocks, chiefly volcanic sandstone and subordinate volcanic mudstone and volcanic breccia.[1] These rocks are interbedded on a scale of a few centimeters to a few meters with generally less abundant calcareous foraminiferal mudstone, calcareous sandstone, and minor calcarenite. In the northern part of the island, part of the section is composed chiefly of calcareous mudstone and calcareous sandstone and is mapped separately.

Volcaniclastic rocks

Volcaniclastic rocks are medium gray to greenish gray; less commonly, grayish red.[2] Beds range from a few millimeters to as much as 10 m in thickness and, generally, grain size increases as bed thickness increases. Many of the thinnest beds are composed of a pale-green aphanitic rock resembling an impure chert, probably an altered very fine grained volcanic ash. Volcanic sandstone beds as much as about 1 m thick are moderately sorted and mostly graded; grain size ranges from silt to coarse sand. Load or flute casts are abundant. Many thin beds and upper parts of thicker beds are crossbedded on a small scale, and the upper parts of some beds are convoluted.

Volcanic sandstone and volcanic breccia beds thicker than about 1 m have a variety of textures. Some beds have an intact framework and are moderately sorted; the grain size ranges from about 2 centimeters down to fine sand and silt. Some beds as much as about 5 m thick are graded, but many very thick beds seem to lack grading. Some otherwise moderately sorted beds contain scattered chips and slabs of mudstone. In some, the mudstone slabs are oriented roughly parallel to bedding (fig. 3), but in others the orientation is random. Other very

[1]The classification of volcaniclastic rocks proposed by Fisher (1961) is used here.

[2]Colors correspond to the "Rock-Color Chart" of the National Research Council (Goddard and others, 1948).

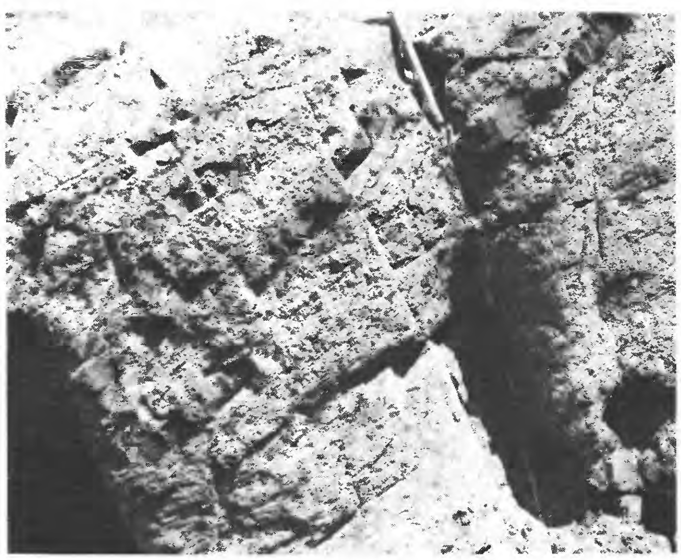


FIGURE 3. — Mudstone slabs oriented parallel to bedding in volcanic sandstone, Río Culebrinas Formation(?), just northwest of Puerto de los Botes.

thick beds are very poorly sorted and have a disrupted framework of angular to rounded pebbles, cobbles, and boulders as large as 2 m mixed with sand and silt. The coarse fragments include dacitic or andesitic lava, volcanic sandstone, and mudstone.

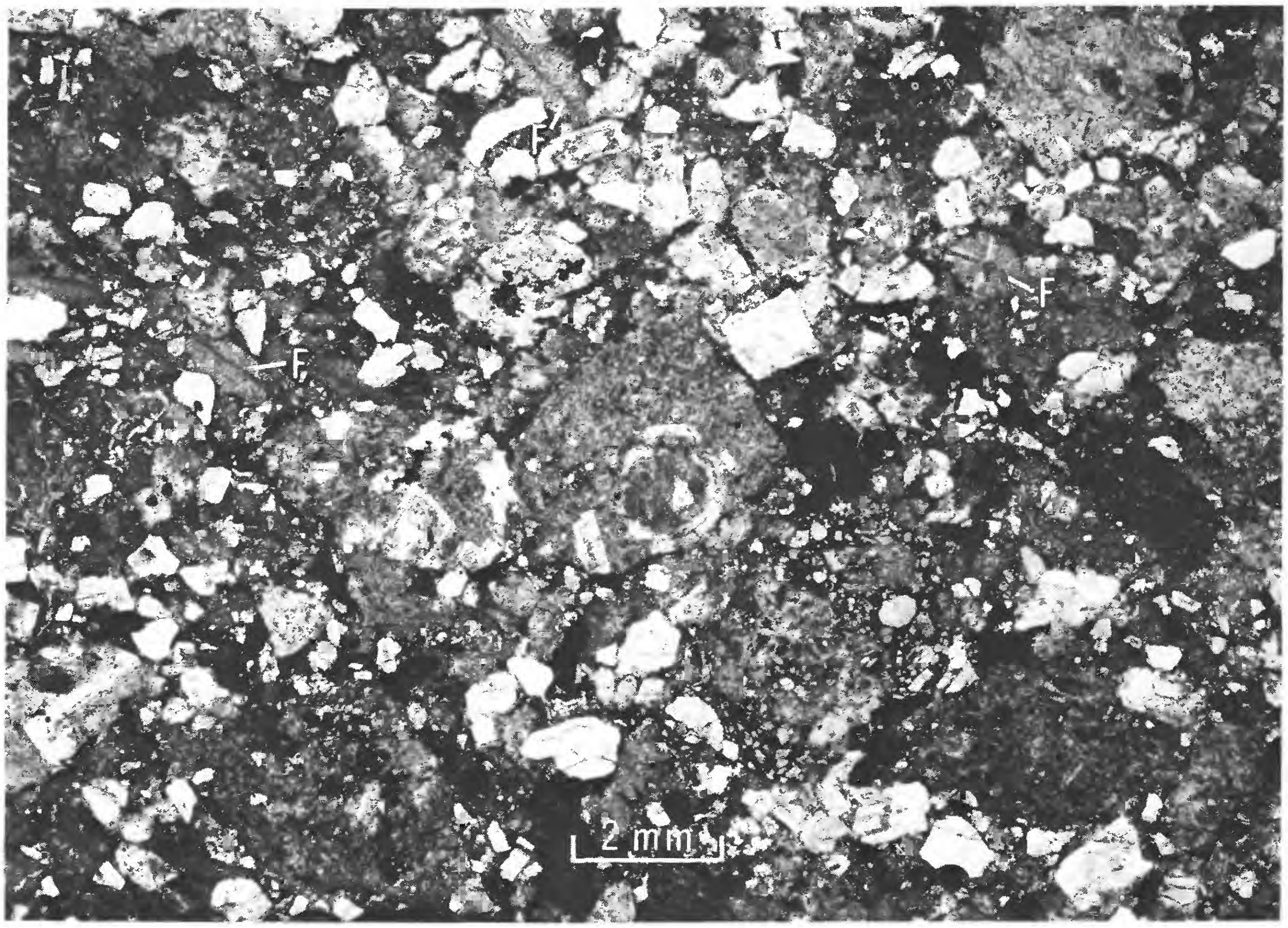


FIGURE 4. — Photomicrograph of volcanic sandstone. Note larger Foraminifera (F). Plane-polarized light.

In thin section, the volcanic sandstone and fine-grained volcanic breccia are composed chiefly of volcanic rock fragments and plagioclase, having lesser amounts of hornblende, clinopyroxene, quartz, opaque minerals, and calcareous fossil debris (figs. 4 and 5). Most grains are angular, but some lava fragments are rounded (fig. 5). The rock has a fairly compact framework, and grains commonly interpenetrate. The matrix consists of recrystallized calcite, zeolites, or very fine grained yellowish-brown material, possibly clay minerals and calcite.

Pumice is absent. The volcanic rock fragments are nonvesicular or, less commonly, sparsely vesicular, and most consist of a very fine grained aggregate of minerals, probably devitrified glass, with or without phenocrysts of plagioclase, clinopyroxene, hornblende, and quartz. Some fragments have a trachytic texture, and a few grains are intergranular or intersertal; a few fragments are oxidized.

Much plagioclase is fresh and zoned from andesine to sodic labradorite (An_{32-60}), but some crystals are clouded and albitized. Hornblende is generally green, rarely brown. Quartz in both euhedral and broken grains is unstrained and is commonly embayed.

Calcareous fossil debris, sparse in most volcanic sandstone, locally makes up as much as 10 percent of the rock. Fragments of calcareous algae and whole and broken larger Foraminifera are the main components of the debris; planktonic Foraminifera are rare.

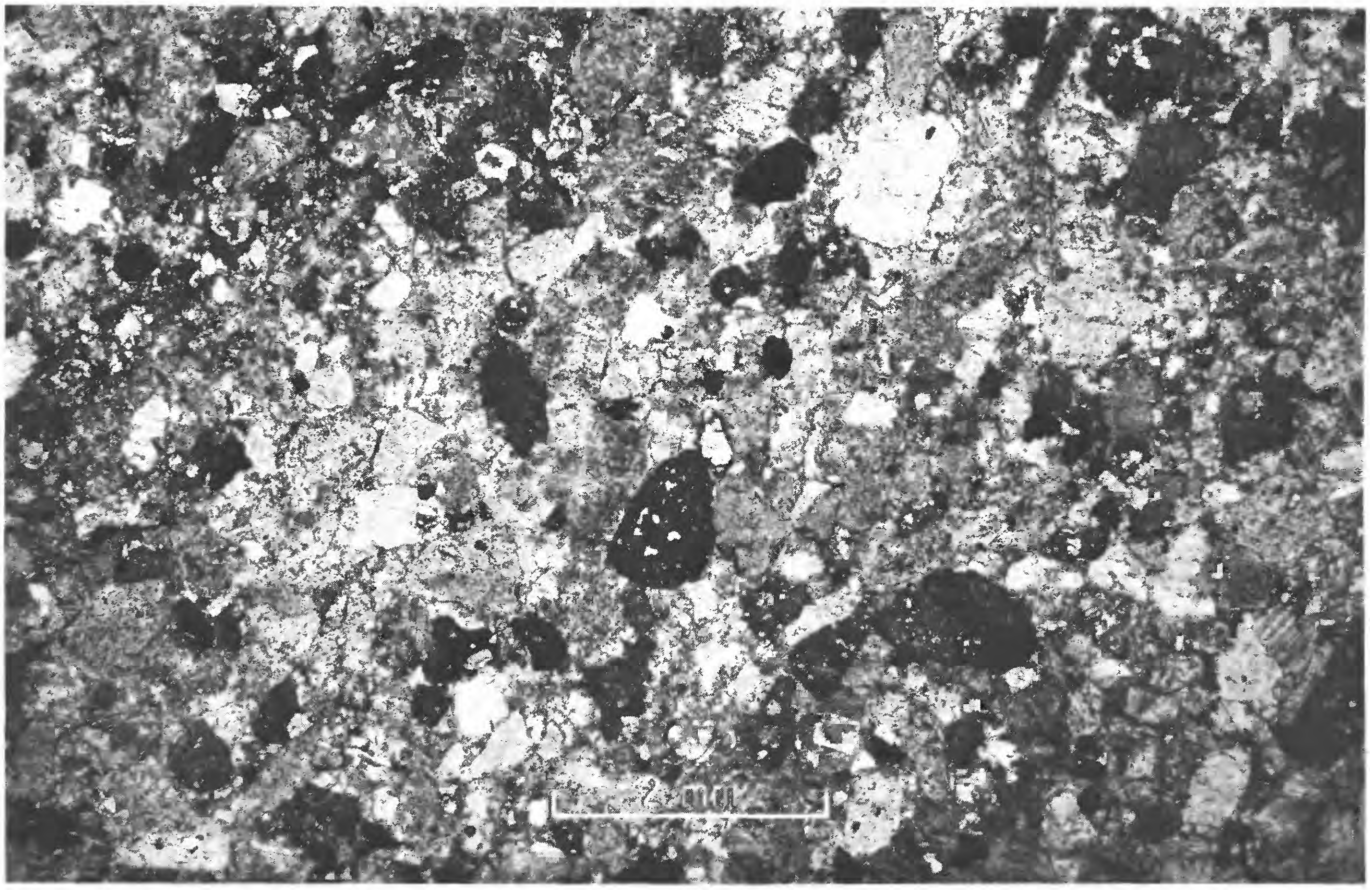


FIGURE 5. — Photomicrograph of volcanic sandstone. Note rounding of some fragments. Plane-polarized light.

Calcareous mudstone and sandstone

Calcareous mudstone is generally medium to light gray, less commonly grayish red. Beds are thin to medium. The mudstone has an aphanitic calcite-rich groundmass in which are abundant planktonic Foraminifera, less abundant small grains of plagioclase, quartz, volcanic-rock fragments and Radiolaria, and rare microcorals and benthonic Foraminifera (fig. 6). One sample of calcareous mudstone that was broken down with acid was 59 percent calcite; some samples are probably somewhat richer in calcite. The calcareous mudstone grades continuously to noncalcareous aphanitic volcanic mudstone.

The calcareous sandstone differs from the typical volcanic sandstone only in being richer in calcite and poorer in volcanic-rock fragments. Calcareous sandstone is medium gray, medium to thick bedded, and medium grained and is composed of about equal parts of volcanic rock fragments, plagioclase and quartz grains, and recrystallized calcite.

Calcarenite

This rock was found only at two places on Isla Desecheo—on the ridge crest southwest of the 143-m peak as float, and near the western tip of the island in a bed 25 cm thick. The rock is light gray and is composed of well-sorted 0.5- to 3-mm angular to well-rounded grains of calcareous fossil debris, less abundant lava fragments, and plagioclase, hornblende, and volcanic quartz grains. A single grain of multigranular strained quartz was found. The fossils are chiefly larger Foraminifera and coralline algae.

PENECONTEMPORANEOUS DEFORMATIONAL STRUCTURES

The rocks on Isla Desecheo show some features attributable to deformation during or soon after deposition. On a small scale these features are convolute bedding and load and flute casts. On a larger scale some very thick slide and turbidity-current deposits are broadly channeled at the base and contain fragments eroded from the underlying beds.

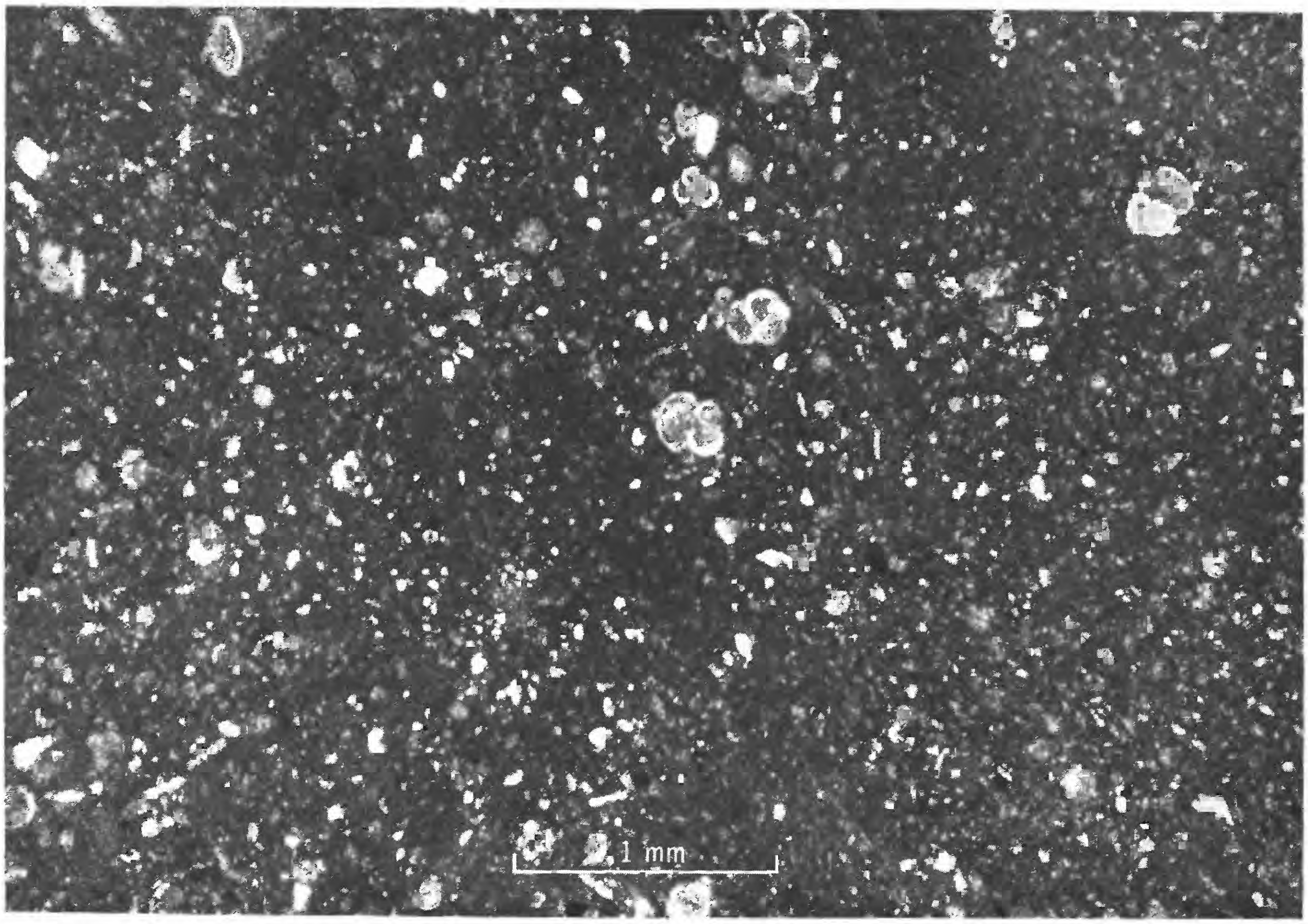


FIGURE 6. — Photomicrograph of calcareous foraminiferal mudstone. Plane-polarized light.

Locally, the eroded edges of the underlying beds are bent upward and into the overlying massive deposit (fig. 7).

Small tight folds a few centimeters to about a meter in wavelength, locally accompanied by small low-angle faults, are seen in a few exposures. The fold axes diverge and bear no relationship to major structures, suggesting that the deformation took place by slumping soon after deposition. At one locality, the deformation preceded deposition of the immediately overlying beds. Figure 8 shows a recumbent fold in thin-bedded mudstone and volcanic sandstone. The fold (at hammer) rests on a low-angle fault that is in contact with moderately deformed beds below. In the upper part of the fold, the beds are broken and pulled apart. The fold is unconformably overlain by a poorly sorted breccia conglomerate about 1 m thick, probably a submarine-slide deposit. The breccia conglomerate contains fragments of mudstone similar to those in the recumbent fold as well as angular to rounded exotic fragments of lava and volcaniclastic rock. The breccia conglomerate is overlain by gently dipping beds (upper right) that were not affected by the deformation that acted on the lower beds. The folding and faulting were probably nearly synchronous with the slide. The deformation may have resulted from slumping which was caused by the same event that triggered the slide, or from passage of the slide itself.

CONDITIONS OF DEPOSITION

That angular volcanic rock fragments of fairly uniform texture and composition are the dominant constituents of the volcaniclastic rocks suggests that these rocks are chiefly of pyroclastic, or slightly reworked pyroclastic, origin. The abundance of graded beds and the exclusively planktonic fauna of the interbedded mudstone indicate that the rocks were deposited in rather deep water below the base of the surge zone. Coarse poorly sorted submarine slide deposits and penecontemporaneous deformation features suggest that at least some of the rocks were deposited on an unstable submarine slope.

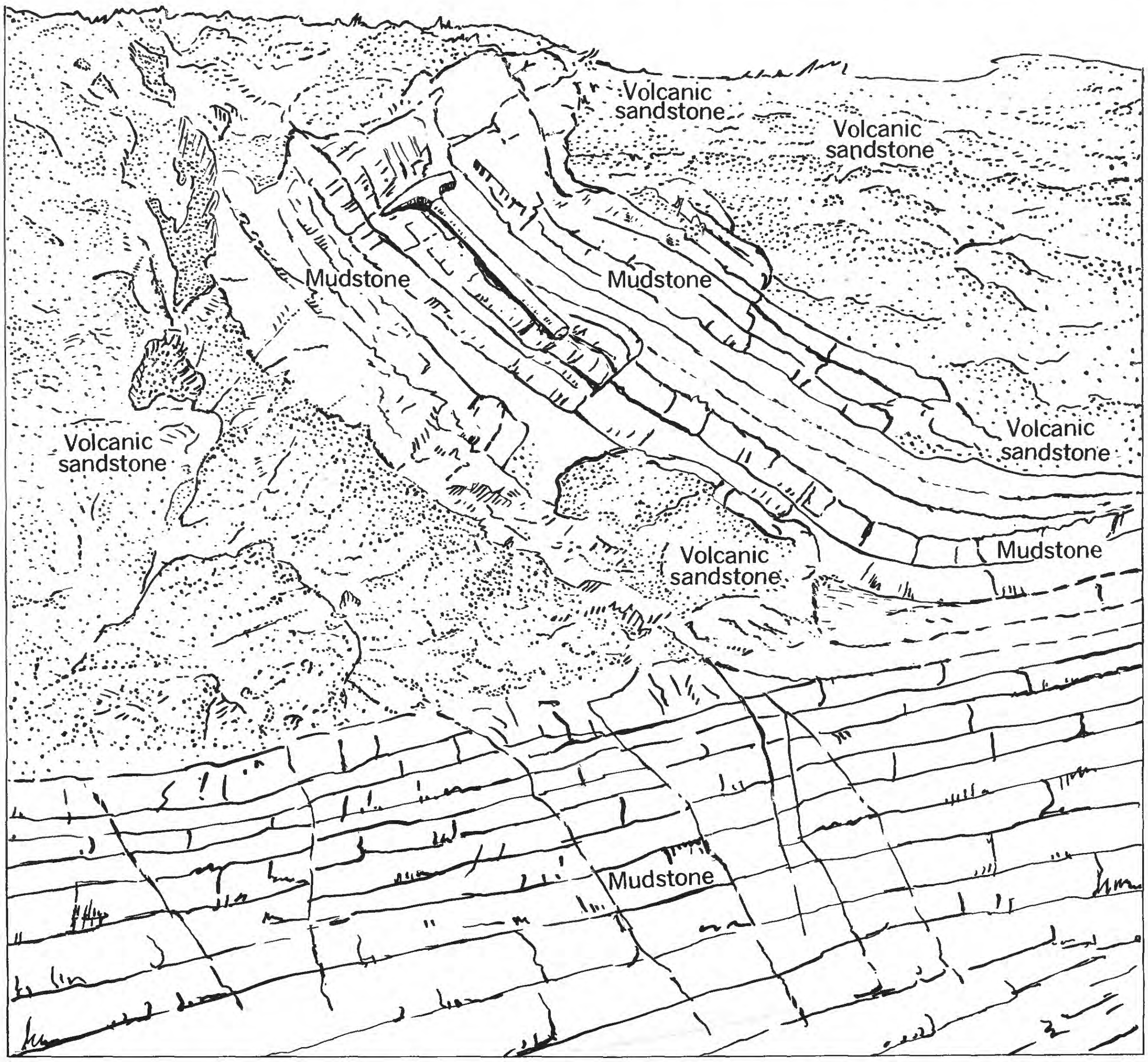


FIGURE 7. — Eroded and upturned mudstone beds in lower part of volcanic sandstone bed which is more than 3 m thick and is locally cut out by Pleistocene terrace deposits. On the northeast coast, 700 m northwest of Dos Piedras.

The source was probably a shallow-sea volcanic area, as is shown by the small amount of rounded volcanic rock fragments and shallow-water fossil debris in the volcaniclastic rocks. Pyroclastic debris, detritus from the active volcanoes, and marine shells were deposited in the shallow water near the volcanoes. Explosive volcanic eruptions and accompanying earthquakes generated submarine pyroclastic ash flows, turbidity currents, and submarine slides. The newly formed pyroclastic debris was mixed with the unconsolidated shallow-water deposits and transported to deep water. Fine ash, transported by winds and surface currents, and the tests of planktonic Foraminifera and Radiolaria settled to the bottom continuously to form the thin beds of volcanic and calcareous mudstone.

FIGURE 8. — Recumbent slump fold and slide breccia on the northeast coast, 575 m northwest of Dos Piedras.

ALTERATION

Secondary minerals are in nearly all the rocks—as vein fillings in the numerous joints, as void fillings or replacements of the matrix in the volcaniclastic rocks, and, less commonly, as replacements of clastic grains. In most rocks the secondary minerals are not abundant, but locally the alteration is intense. Highly altered volcanic sandstone is mottled with light-gray zeolite-rich blebs about 0.25–1 cm in diameter; these give the rock the appearance of being composed of clastic grains of that size (fig. 9). The most abundant secondary mineral is calcite, followed by zeolites, phyllosilicates, and lesser amounts of albite, prehnite, quartz, and epidote.

Except for a single reconnaissance run, X-ray identifications were not used, but in thin section, optical properties suggest that the most abundant zeolite is laumontite. It occurs both in joint fillings and as a pervasive replacement. One vein contains both laumontite and heulandite. Analcime occurs in some veins together with epidote and turbid prehnite. An analcime-calcite vein in calcarenite contains a zeolite with optical properties consistent with those of mordenite.

AGE

Three samples of calcareous mudstone collected north of the Puerto Manglillo fault were examined by E. A. Pessagno, Jr., for planktonic Foraminifera. Pessagno identified *Globigerina* sp., *Globorotalia* s.s. (keeled), and *Tuborotalia densa* (Cushman) in each sample and assigned a middle Eocene age to the samples. A sample of massive volcanic sandstone from north of the Puerto Manglillo fault was examined by K. N. Sachs, Jr., who identified *Discocyclina (Discocyclina) weaveri* and a microspheritic *Asterocyclina;* he also gave a middle Eocene age to this sample.

Sachs examined a specimen of calcarenite from between the Puerto Manglillo and Helicopter Pad faults and reported the following:

This sample has moderately abundant specimens of *Asterocyclina minima*, known typically from the upper Eocene of numerous Caribbean localities. However, there is another, middle Eocene, species of this genus which I consider to be a synonym of *A. minima*. Therefore, my opinion of the age of this sample is probably upper Eocene, but possibly middle Eocene.

Two samples of calcareous mudstone from near Puerto de los Botes on the southwest coast were examined by Pessagno, who found *Globigerina* sp. and *Globorotalia* s.s. (sharply keeled). He assigned an age of late Paleocene to middle Eocene to the samples. From one sample of sandy mudstone collected near the cable house, Pessagno reported *Globotruncana* sp. cf. *G. linneiana* (d'Orbigny) and indeterminate planktonic Foraminifera and Radiolaria. He suggested a possible Late Cretaceous age but pointed out that the Foraminifera may be reworked and are in large part badly recrystallized.

The above determinations show that some rocks are definitely of middle Eocene age and, except for one questioned Late Cretaceous determination, determinations with broader ranges include the middle Eocene. All the Río Culebrinas Formation(?) on Isla Desecheo is probably of middle Eocene age.

FIGURE 9. — Zeolite mottling in zeolitized volcanic sandstone. Note scattered large clasts. Just northwest of Puerto de los Botes.

QUATERNARY SYSTEM

MARINE-TERRACE DEPOSITS

Deposits chiefly between 6- and 12-meter elevation

Discontinuously exposed around the coast of Isla Desecheo and unconformably overlying the volcanic bedrock is an elevated seaward-sloping marine terrace composed of well-indurated calcite-cemented sand and gravel (figs. 10 and 11). At most places, the terrace deposits are about 1 m thick (fig. 10), but, locally, depressions in the preterrace surface, which are channels or zones of plucking, are filled to depths of as much as 3 m (fig. 11). At other places, the deposits abut ramparts of volcanic rock.

The terrace surface dips seaward 5° or less at most points. Landward, the terrace deposits are overlain in many places by colluvium, but it appears likely that no presently exposed terrace surfaces ever were thickly covered. Landward, elevations are about 8–9 m above sea level where terrace surfaces are not extensively covered by colluvium (fig. 10). The highest terrace level on Isla Desecheo is 12 m above sea level at the head of Puerto Canoas and in a small cove 50 m east-northeast of the helicopter pad.

The terrace has been extensively eroded; its widest exposure is about 50 m, but at most places it is less than 10 m wide or is absent. Its upper surface has been pitted and fretted, like the eolianite surfaces in Puerto Rico described by Kaye (1959a, p. 83–88) and like the marine-terrace surfaces seen by Seiders and Briggs on Isla de Mona; this has produced a microkarst having relief ranging from 1 or 2 cm to about 50 cm. Dense cementation, though, has rendered the terrace deposits more resistant to erosion than the underlying weathered volcanic rock. Thus, erosion of the terrace deposits has been largely by undercutting; at many places they now form roofs of sea caves cut in the volcanic rock (fig. 10), and locally they cap arches and pedestals. This ledge-forming characteristic contributes greatly to the assurance that there is only one marine terrace at this general level; despite zones in which the terrace deposits are concealed or have been completely eroded away, the essential continuity can be seen readily (frontispiece).

Distinct layers within the terrace deposits range from 5 cm to about 50 cm thick, and most have gradational lower and upper contacts. At some places, however, the entire thickness of the deposit is formed by one bed only (fig. 12). Locally, snail shells about 6 cm in diameter form layers within the deposits.

FIGURE 10. — Marine-terrace deposits 1 m thick resting on steeply dipping volcanic rocks at Puerto de los Botes. Colluvium, whose apparent great thickness is misleading, rests on upper terrace surface at about 9-m elevation. Sloping volcanic bedrock probably is considerably less than 10 m beneath surface of colluvial deposits in most of the area shown. Note resistant character of terrace relative to volcanic bedrock and colluvium.

FIGURE 11. — Marine-terrace deposits resting on steeply dipping volcanic rocks at Puerto Canoas (lower left).

FIGURE 12. — Marine-terrace deposits in irregular depression in volcanic bedrock just west of Puerto de los Botes. Note boulders and cobbles of volcanic rock, coral heads, subsidiary channel (lower left), and cactus (above outcrop). Hammer 45 cm long.

Sand grains in the terrace deposits are chiefly coarse subround and round fragments of coral, coralline algae, and other marine organisms, but medium and coarse subround and round volcanic-rock fragments are also fairly abundant. The calcareous fragments are very light gray and yellowish gray. Most volcanic rock fragments are moderately weathered and are yellowish brown.

Subangular to subround boulders, cobbles, and pebbles of volcanic rock are the principal large constituents, but there also are large coral heads and coral fragments (fig. 12). At a few places, blocks of volcanic rock are as large as 2 m in diameter. In one such place only a few centimeters separate a block from its preerosion position.

This marine terrace was first recognized by Lobeck (1922, p. 367–368), who believed that its upper surface sloped seaward continuously from 6 m down to and below sea level. Hubbard (1923, p. 97) considered the terrace, which he referred to the "Upper Desecheo Stage," to be in the range of 6–7.5 m. Both early estimates of elevation are appreciably less than the highest elevation, 12 m, of the upper terrace surface measured in this study.

Deposits at about 2-meter elevation

In a few places between the helicopter pad and Puerto Manglillo, beachrock (calcite-cemented beach sand) adheres to bedrock at elevations of about 2 m above sea level. The presence of beachrock, because it forms beneath the surface of beaches from about the low-tide mark to the normal limit of wave uprush, demonstrates that beaches once formed at these places; thus, at one time, sea level stood slightly higher than the present stand. These terrace remnants are too small to show at the scale of the geologic map (fig. 1).

The significance of the Isla Desecheo terrace deposits, evidence for sea stands higher than the present stand, regional relations, and possible ages are discussed in a following section.

COLLUVIUM

Poorly sorted colluvium forms a thin scree over most of the slopes of Isla Desecheo; thicker deposits are at the bases of slopes and in the valleys leading inland from the coast. These deposits are shown on the geologic map (fig. 1) only where they are believed to be 1 m or more thick.

The colluvium is composed largely of angular and subangular volcanic rock fragments that range in size from small pebbles to boulders and are set in a moderately abundant matrix of finer volcanic grains ranging from fine sand down to silt and clay. Locally, the larger fragments are texturally intact and the matrix is sparse. Most colluvium is the result of natural fragmentation and mass movement. However, for many years the island was a practice target for naval and aerial bombardment, evidence of which can be found in the form of metal fragments and, occasionally, unexploded ordnance. Bedrock at some places was extensively fragmented and pulverized by explosions, most notably along the northwest-trending part of the central highland between elevations of 143 and 206 m (fig. 1). The amount of colluvial cover due to target practice is not known.

The colluvium within a few centimeters of the surface commonly is loose or friable, but below this zone it may be moderately to densely cemented. The cement apparently is largely phosphatic; a yellowish-brown specimen of rather fine densely cemented colluvium collected from a 1.5-m-high cut at the south edge of the helicopter pad yielded the analysis shown in table 1. No definitive mineralogical study was done on this sample but, on the basis of a comparison of refractive indices, Virginia S. McIntyre (oral commun., 1968) suggested that some volcanic ash and a zeolite mineral may be present.

TABLE 1.—*Chemical analysis and molecular norm of cemented-colluvium sample from cut at south edge of helicopter pad, Isla Desecheo*

[Percentage: rapid-rock analysis W167676 by P. Elmore, H. Smith, L. Artis, S. Botts, and J. Glenn, U.S. Geological Survey]

Chemical analysis

Oxide;	cation	Percent
SiO_2;	Si^{+4}	47.2; 51.6
Al_2O_3;	Al^{+3}	15.9; 20.5
Fe_2O_3;	Fe^{+3}	4.4; 3.6
FeO;	Fe^{+2}	.36; .33
MgO;	Mg^{+2}	1.7; 2.8
CaO;	Ca^{+2}	5.3; 6.2
Na_2O;	Na^{+}	2.4; 5.0
K_2O;	K^{+}	1.4; 2.0
H_2O^-		5.9
H_2O^+		6.3
TiO_2;	Ti^{+4}	.44; .39
P_2O_5;	P^{+5}	7.6; 7.0
MnO;	Mn^{+2}	.33; .33
CO_2;	C^{+4}	.14; .20
Total		99.4; 99.9

Molecular norm

Mineral	Total phosphate minerals, in percent	
Calcite	0.4	
"Hydroxylapatite"	4.8	
"Brushite"	6.0	15.2
"Variscite"	4.4	
Ilmenite	.7	
Rutile	.1	
Pyrolusite	.3	
Orthoclase	10.0	
Albite	25.0	
Hematite	3.6	
Enstatite	5.6	
Quartz	27.8	
"Boehmite"	11.3	
Total	100.0	

Study of the cation percentages in table 1 reveals that the phosphorus-calcium ratio is too high for the standard normative "apatite." The last section of table 1, therefore, contains a speculative molecular norm based on minerals known to be in rocks from similar geological environments in the Caribbean area (Altschuler, in Kaye, 1959b, p. 157–162; Kaye, 1959b, p. 162–164; Palache and others, 1951, p. 660–661, 684–686, 704–705, 756–760, 878–887). In this norm, brushite [$CaHPO_4 \cdot 2H_2O$] may include monetite [$CaHPO_4$], and hydroxylapatite [$Ca_5(PO_4)_3OH$] may include whitlockite [$Ca_3(PO_4)_2$]. The other unusual normative minerals are variscite [$AlPO_4 \cdot 2H_2O$] and boehmite [$Al_2O_3 \cdot H_2O$], the latter having been reported in surficial deposits in Puerto Rico by Hildebrand (1960).

In calculating this norm, half the calcium remaining after the calcite calculations was assumed to be contained in hydroxylapatite and the other half, in brushite. Phosphorus remaining after the brushite and hydroxylapatite calculations was assumed to be in variscite. The remainder of the norm calculation was essentially standard, varying chiefly in the substitution of boehmite for corundum.

The chief value of this speculative norm is that it shows that the sample analyzed contained on the order of 15 percent phosphate minerals and about 15 percent oxides of aluminum and iron, for the most part probably hydrous, considering the relatively high percentage of combined water. Other combinations of the possible minerals yield similar or higher grouped percentages. The remainder of the norm tends to confirm the dacitic character of the volcanic rock from which the colluvium was derived.

Hubbard (1923, p. 100–111) stated that bird guano was the chief cementing agent in the marine-terrace deposits. In this he was mistaken, for this investigation shows that the terrace cement is largely calcite. We conclude on the basis of the colluvium analysis in table 1 that the sample that led Hubbard to his conclusion came rather from the cemented phosphatic colluvium, the cement in which may have been derived from the bird guano, as he suggested.

At the heads of Puerto Canoas and Puerto de los Botes and at many places along the northwest and northeast coasts, colluvium rests on the higher marine terrace (fig. 10). Small ravines cut in the colluvium reveal crude stratification; beds about 0.5 m thick dip seaward at angles as great as 25° and terminate abruptly against the much less steeply dipping marine terrace. Nowhere was the colluvium seen to interfinger with the terrace deposits, and nowhere were terrace deposits seen resting on colluvium. Most, perhaps all, colluvium is therefore younger than the higher marine terrace. Perhaps preterrace colluvium was largely removed or reworked by the sea at the time of deposition of the terrace deposits, or perhaps a wetter climate prevailed prior to the deposition of the high terrace, promoting much denser vegetation than now occurs and thus inhibiting downslope mass movement.

The thickest colluvium exposed in a vertical cut is about 3 m. However, just northeast of Puerto Manglillo, a large mass of colluvium rests on the upper surface of the higher marine terrace, which is there about 6.5 m in elevation. If the seaward-sloping bedrock surface uphill from the colluvium is projected beneath the colluvium and the surface of the marine terrace is projected landward beneath the colluvium at a positive angle of 5°, the surfaces intersect along a line about 15 m below the present upper surface of the colluvium. The colluvium, therefore, may be as much as 15 m thick in this area, and it may approach this thickness elsewhere as well (fig. 10).

BEACH DEPOSITS

Beach deposits of waterworn sand and gravel are few; the largest are at the heads of coves and reentrants (fig. 10). Elsewhere, waterworn sand and gravel are only in scattered small patches. Only the larger beach deposits are shown on the geologic map (fig. 1).

The larger beach deposits are composed of medium and coarse sand consisting largely of volcanic rock and calcium carbonate fragments. The carbonate fraction is composed principally of first-cycle organic remains, but probably also includes reworked fragments from caved parts of the marine terraces. Pebbles and cobbles are minor constituents. In smaller patches of sand, pebbles and cobbles are abundant, and calcium carbonate grains are fairly rare.

At Puerto Manglillo, exposed beachrock is surrounded by uncemented sand of similar composition. This beachrock is believed related to the present beach and present sea level, unlike the somewhat higher nearby beachrock outcrops referred to earlier. This is the only exposure of recent beachrock seen on Isla Desecheo.

The sparseness of recent beach deposits on Isla Desecheo probably is due chiefly to the presence of deep water that is fairly close to shore all around the island and to the fine particle size of most of the materials available to form beaches. The island is surrounded by waters more than 20 fathoms deep, at no place more than 700 m offshore (as at Corona del Norte) and closer than 200 m offshore southwest of El Muro. The volcanic rocks around the shores are slightly to moderately weathered and tend to disintegrate to particles which, for the most part, are finer than the sand sizes, as is indicated by the appreciable silt and clay fraction of the colluvium. In addition, the deep water just offshore has inhibited establishment of large shallow organic reefs which are known to be excellent suppliers of sand-size material to beaches elsewhere.

STRUCTURAL GEOLOGY

The island is divided by the west-trending Helicopter Pad fault into two areas with sharply contrasting fold types and trends. North of this fault, the folds are gentle. Most beds dip 20°–40° W., though a few beds dip to the southeast in the southeast corner of the area. This area north of the Helicopter Pad fault may be the faulted remnant of a broad southwest-plunging anticline.

Folds south of the Helicopter Pad fault are west trending, nearly isoclinal, and overturned to the north. One fold axis was observed near Puerto de los Botes (fig. 13), but elsewhere axes were located only by reversals in the direction of tops of graded beds. Determinations of the directions of tops, although very sparse in some areas, suggest the presence of two anticlines and an intervening syncline (fig. 1). There is considerable variation in the inclination of axial planes. In the southwestern part of the island (fig. 1, section *B–B'*), near Puerto Canoas, beds dip steeply southward, but to the north the axial planes are more gently inclined; on the 140-m hill the folds are recumbent. No small-scale or drag folds were observed except near faults and in penecontemporaneous deformation structures.

The faults observed on Isla Desecheo are high-angle faults that have slight to moderate amounts of vertical displacement. A low-angle detachment fault or décollement zone, not exposed on land, is inferred beneath the overturned folds of the southern part of the island.

The Helicopter Pad fault is the principal high-angle fault on the island. The fault strikes N. 75° E. from the western tip to the north-central part of the island where it merges with the Puerto Manglillo fault and turns, striking S. 75° E. to the coast. Nearshore topography suggests that it continues eastward under water, probably after slight

FIGURE 13. — Overturned syncline in Jacaguas Group rocks near cable house.

offset along the Northeast Coast fault. The Northwest Coast fault was not observed on land, but its trace can be seen in shallow water on aerial photographs. It seems to cut both the Puerto Manglillo and Northeast Coast faults and, therefore, probably also cuts the Helicopter Pad fault.

The vertical displacement downward on the south side of the Helicopter Pad fault is at least 130 m and could be much more. Considerable displacement probably also took place on the Puerto Manglillo fault. Displacement on other faults, with the possible exception of the Northwest Coast fault, is probably slight.

Nearly all the faults shown on the geologic map were either observed in outcrop at one or more places along the coast or are shown on aerial photographs in the shallow waters just offshore. Most faults dip more steeply than 60°. They commonly have a central gouge zone a few centimeters to 3 m thick with an outer zone of fractured rock locally showing drag. The total width of most fault zones is 2–10 m. The zone of fracturing along the Puerto Manglillo fault at Puerto Manglillo is about 30 m wide. Drag indicates that the south side moved down relative to the north side (fig. 14). At the western tip of the island, where the Helicopter Pad and Northwest Coast faults converge, a zone of fracturing extends along the coast for about 200 m.

Joints are well developed, but cleavage is absent. Most joints are filled with veins of calcite and zeolites. At least two sets of joints are present at most localities (fig. 15). Orientations of 25 joints are markedly diverse. On the south coast the most conspicuous joints strike north-northeast and dip steeply, approximately perpendicular to fold axes.

The most striking structural feature of Isla Desecheo is the sharp contrast in fold type and trend on either side of the Helicopter Pad fault. This contrast, the variable inclination of axial planes, and the inverted structure on the 140-m hill strongly suggest that deformation in the southern part of the island was by gravity-gliding tectonics (de Sitter, 1956, p. 289–290). We believe the most probable interpretation of the observed structures

FIGURE 14. — Puerto Manglillo fault, looking east at Puerto Manglillo. Central gouge zone is to left of man. Note drag of beds behind man.

is that the rocks north and south of the Helicopter Pad fault represent different tectonic levels that are separated by a low-angle detachment fault or décollement zone. The isoclinally folded beds south of the Helicopter Pad fault are probably a remnant of a gravity-glide sheet that moved northward and folded above essentially undeformed strata. Subsequent movement on the Helicopter Pad fault raised and gently folded the northern part of the island; the strongly deformed upper sheet was removed by erosion in the north but was preserved in the south.

The age of the major deformation on Isla Desecheo is middle Eocene or younger, as indicated by the middle Eocene age of the rocks on the island. Elsewhere in Puerto Rico, gravity-glide structures in middle Eocene and older rocks are unconformably overlain by essentially undeformed early Oligocene and younger beds (Glover, 1971). By extrapolation, the age of the deformation on Isla Desecheo probably is middle Eocene to early Oligocene.

THE GREAT SOUTHERN PUERTO RICO FAULT ZONE

In south-central Puerto Rico, gravity-glide structures have been described by Glover and Mattson (1960) and Glover (1971). These structures are restricted to rocks of the Jacaquas Group, which are largely restricted to the proximity of a major fault zone named the "great southern Puerto Rico fault zone" by Glover (1971). Mapping (Briggs and Akers, 1965; Mattson, 1960, 1967a, b; McIntyre and others, 1970; Glover, 1971) indicates that the fault zone (fig. 16) trends about N. 70° W. from the central part of the south coast to the northern part of the west coast of Puerto Rico. Its continuation at least as far west as Isla Desecheo is suggested by submarine topography (fig. 2).

The great southern Puerto Rico fault zone divides areas of strongly contrasting structure and stratigraphy. In southwestern Puerto Rico (Mattson, 1960), a sedimentary-volcanic sequence largely no older than

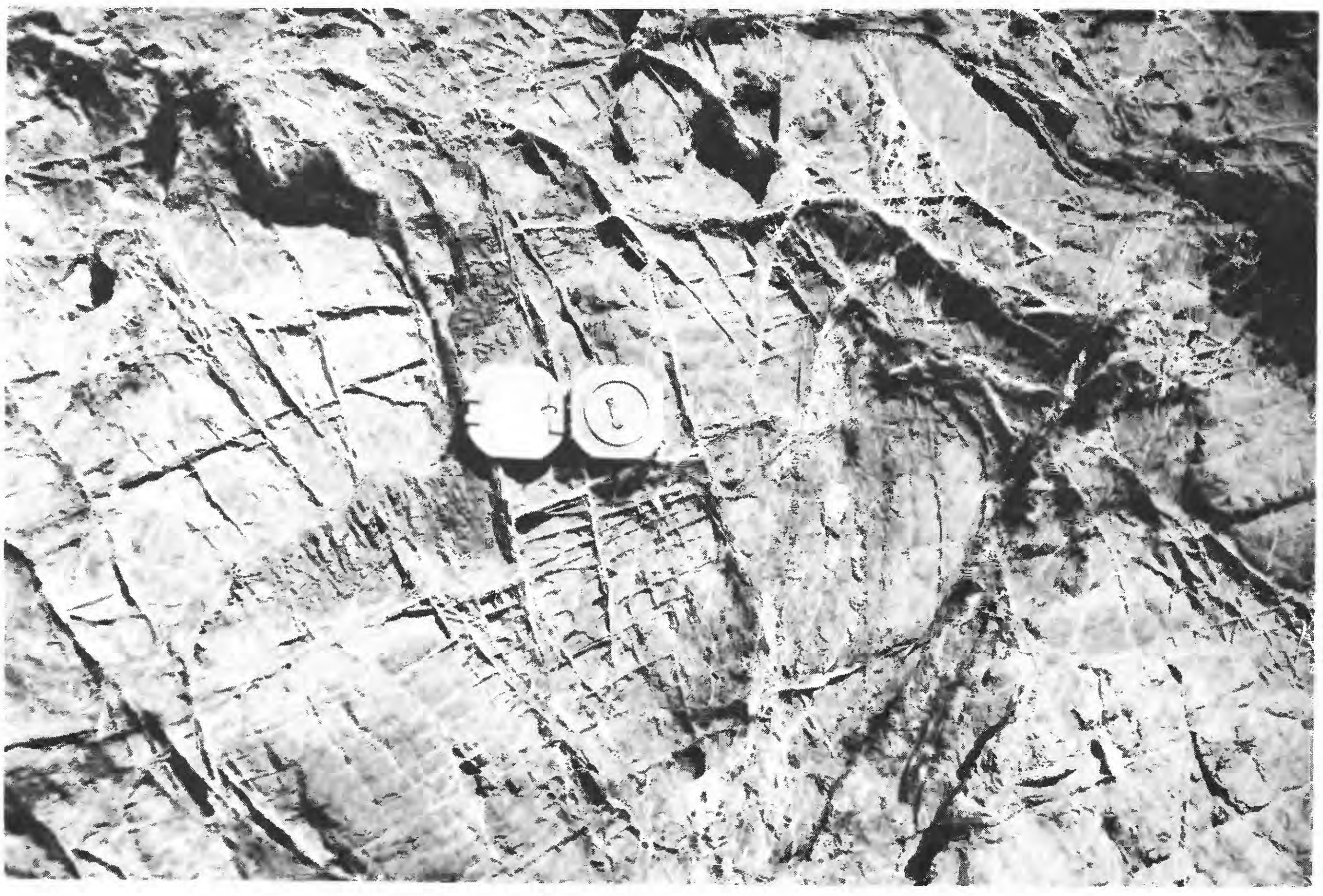


FIGURE 15. — Joints filled with calcite and zeolites, just northwest of Puerto de los Botes.

Campanian (Late Cretaceous) in age rests on a basement composed chiefly of serpentinite. North of the fault zone, a much thicker sedimentary-volcanic sequence ranges down to at least the Albian (Early Cretaceous) (Douglas, 1961), and no basement is exposed. The upper part of the Cretaceous section is correlative with rocks in southwestern Puerto Rico, but the lithofacies are quite different (Glover, 1971). The structure of southwestern Puerto Rico is dominated by west- and northwest-trending folds, asymmetric or overturned toward the south-southwest. North of the fault zone, folding is quite gentle, and fold axes trend east, locally northeast (Briggs and Akers, 1965).

Details of the great southern Puertò Rico fault zone in south-central Puerto Rico have been described by Glover and Mattson (1960) and by Glover (1971). The fault zone is a west-northwest-trending belt of horsts and graben. Within the fault zone, rocks of the Jacaguas Group are highly deformed by folding and faulting. In addition to the high-angle faults, the Jacaguas Group is cut by low-angle imbricate thrust faults. Beds in some of the thrust plates show tight, locally almost isoclinal, folds. A giant slide breccia within the fault zone, the Guayabal megabreccia, contains blocks from the Jacaguas Group as well as blocks from nearly all older formations. The complex structures in the Jacaguas Group were formed by submarine sliding of recently deposited sediments. The sliding was probably initiated by both vertical and left-lateral movements along the great southern Puerto Rico fault zone. Various lines of evidence show that the sliding was directed to the north-northeast. The great southern Puerto Rico fault zone may have been intermittently active since as far back as the Early Cretaceous, with a major episode of movement and most of the gravity gliding concentrated in the interval between the middle Eocene and early Oligocene.

Just west of the area described by Glover (1971), rocks of the Jacaguas Group are generally more massive and, although they are in part strongly folded, no gravity-glide structures have been described (Mattson, 1967a, b). In northwestern Puerto Rico, the Río Culebrinas Formation is in part strongly folded (McIntyre and others, 1970, fig. 3), and J. M. Aaron (written commun., 1969) indicated that gravity-glide structures are present in three places and are of the same type and scale as those on Isla Desecheo.

Elsewhere in the northern Caribbean region, de-

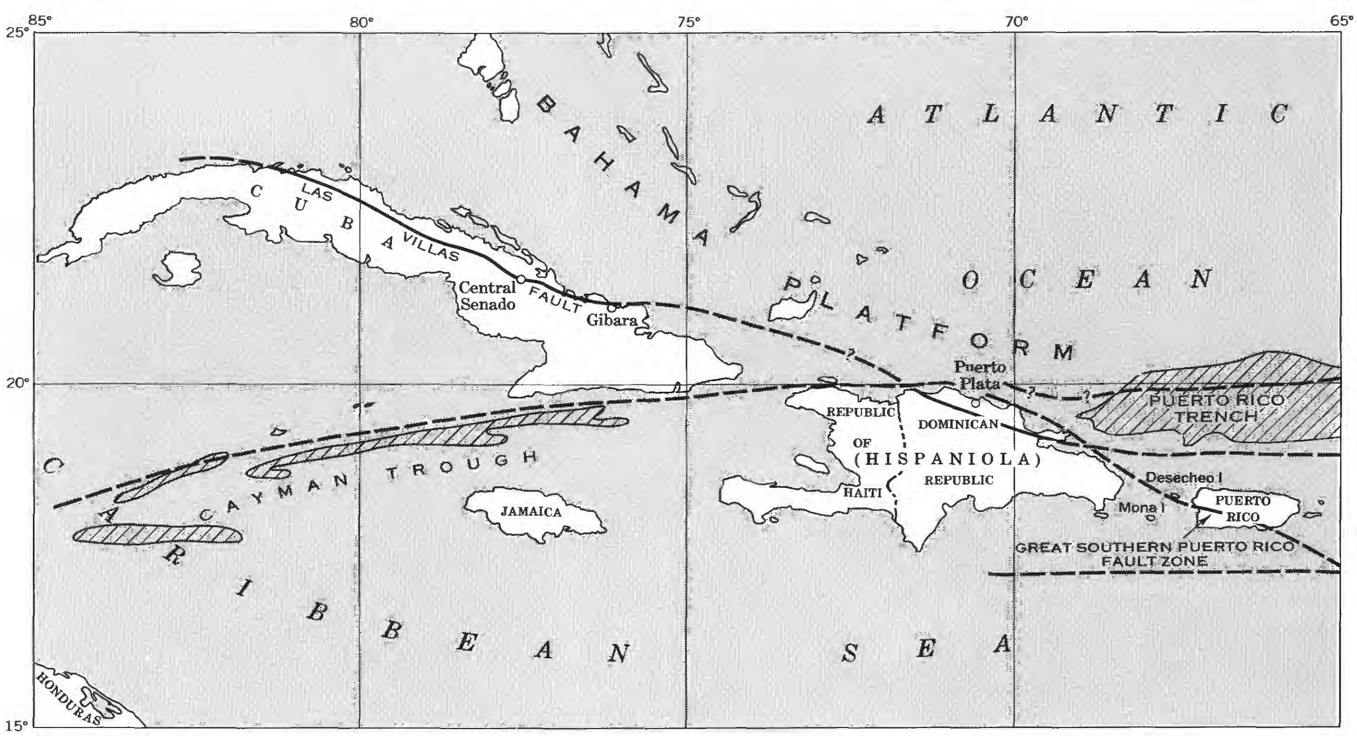


FIGURE 16.— Major fractures of the Greater Antilles. Patterned areas show approximate limits of the Cayman Trough and Puerto Rico Trench.

scriptions of several areas suggest a relationship between submarine sliding and fault zones. Nagle (1966, 1968) described a giant breccia or olistostrome near Puerto Plata, on the north coast of the Dominican Republic (fig. 16). The breccia has an outcrop area of about 90 sq km and was emplaced during the middle Eocene as a great submarine slide. The geology of the surrounding region is not yet known in detail. South of the slide deposit large faults trend N. 70° W. (Nagle, 1966, p. 139–140), and, to the north, a major submarine fault may separate the volcanic and plutonic rocks of Hispaniola from the Bahama Platform.

In Cuba, Furrazola-Bermúdez and others (1964) and Khudoley (1967a) have described a major lineament, the Las Villas fault, known to extend about 800 km along the north coast of Cuba. The Las Villas fault marks an abrupt facies change. To the south are large ultramafic masses and Cretaceous eugeosynclinal deposits, whereas to the north are carbonate deposits of equivalent age. Both thrust faults and high-angle faults have been described along the Las Villas lineament, but there is little agreement among workers as to which type of fault predominates (Hatten, 1967; Khudoley, 1967a, b). Thayer and Guild (1947) have described two areas in eastern Cuba, near Central Senado and Gibara (fig. 16), where large low-angle thrust faults are associated with giant submarine breccias. In central Cuba, Georges Pardo (unpub. data, 1965) has proposed large-scale northward gravity gliding followed by left-lateral wrench faulting. The Las Villas fault may have been active intermittently since the Early Cretaceous (Furrazola-Bermúdez and others, 1964, p. 197), and major movements and thrusting occurred during the middle Eocene (Thayer and Guild, 1947, p. 929; Hatten, 1967, p. 785).

The submarine-slide deposits and gravity-glide structures of Puerto Rico, Hispaniola, and Cuba are remarkably similar in age and in their position along boundaries between contrasting geologic provinces. Although they define a roughly straight lineament nearly 2,000 km long extending N. 70° W. through the Greater Antilles (fig. 16), the apparent linearity may well be fortuitous. South of Puerto Rico, the great southern Puerto Rico fault zone abuts a major east-west fault and may be a second-order shear subordinate to first-order east-west shears (Glover, 1971). North of Hispaniola, the Las Villas–great southern Puerto Rico fault lineament crosses the lineament defined by the north walls of the Cayman Trough and the Puerto Rico Trench at a sharp angle. The nature of the junction of these two major lineaments still remains to be investigated by marine geophysicists.

QUATERNARY STILLSTANDS OF THE SEA

On Isla Desecheo there is widespread evidence for two stillstands of the sea higher than present sea level. Hubbard's terms (1923, p. 97), the "Upper Desecheo Stage" and the "Lower Desecheo Stage," no longer can be used completely because the term "Stage" is now restricted (American Commission on Stratigraphic Nomenclature, 1961, art. 31[a]). In this report no formal names are applied.

UPPER DESECHEO STILLSTAND

The marine terrace deposits which constitute the chief evidence for this stillstand are described in a preceding section. These deposits rest unconformably upon what was apparently a solid rock apron having only moderate relief and completely surrounding the island. Quite plainly this apron was formed by wave attack as sea level rose gradually relative to the land, for the apron rises landward at slopes commonly approaching 5°. The highest measured level of this terrace basement is about 11 m higher than present sea level, where the upper surface of the terrace deposit is at 12 m. To have eroded materials at the 11-m level, the sea must have stood somewhat higher, probably in the range of 12–13 m. This estimate is considerably higher than the range of 6–7.5 m suggested by Hubbard (1923, p. 97).

Sea level probably remained at 12–13 m for some time, for the associated terrace deposits contain appreciable quantities of calcium carbonate detritus that must have been derived from nearby organic reefs. Time must have been sufficient for the formation and erosion of reefs on the rather shallow wave-cut apron in order to supply the sand in the marine terraces. Later erosion has removed all vestiges of these organic reefs.

The retreat of the sea from this 12–13-m stillstand was probably rather rapid, because the terrace deposits remain. Had the retreat been slow, most of these deposits probably would have been removed by wave-reworking and surface runoff. Rapid accumulation of colluvium may have rendered the marine-terrace deposits closest to the island more resistant to subaerial erosion.

LOWER DESECHEO STILLSTAND

The chief evidence for a stillstand of the sea at about 2 m is the broad irregular wave-cut platform that surrounds much of Isla Desecheo (frontispiece). At Corona del Norte and on the northwest coast, this platform extends seaward as far as 100 m (fig. 17). On the geologic map (fig. 1) the seaward edge of the platform is shown by a dotted line partly surrounding the island. The shoreline shown represents the approximate limit of the highest tides. Local relief on the platform is about 2 m, so many rocks are above sea level most of the time, and unusually low tides probably bare much of the area between shoreline and dotted line. Tides in this area commonly range from about 0.3 to 0.8 m, so the elevation of this wave-cut platform may be considered as approximately zero, or present sea level.

FIGURE 17. — View of northwest coast from near helicopter pad. Lower Desecheo stillstand platform extends seaward as far as 100 m to zone of breaking waves on left. Note local relief on platform. Resistant marine-terrace deposits crop out in right center (at Puerto Manglillo) and in right foreground. The suggestion of two terrace levels at Puerto Manglillo is due to the seaward dip of marine-terrace deposits. On the horizon in right center, land to right of break in slope is underlain by volcanic bedrock; land to left underlain by colluvium.

Unlike the sloping apron of the 12- to 13-m stillstand, this lower platform is nearly horizontal. The lack of significant seaward slope indicates that the platform was shaped during an extensive stillstand, not during a period of gradually rising sea level.

At present the sea is eroding the edge of the platform, and water of only moderate energy flows over the shallows to the shore. Plainly then, the platform cannot have been formed during the present regime. For the platform to have been cut, sea level must have been from 1 to 2 m higher than present sea level, enabling energetic surf to travel the whole width of the platform.

This estimate of sea-level difference from the present stand coincides with elevations of floors of some sea caves and the 2-m beachrock and is of the same order as the range estimated by Hubbard (1923, p. 97), 0.6–1.5 m.

REGIONAL RELATIONS AND AGE

Kaye (1959a, p. 131), Williams (1965, p. 162–182), and Monroe (1968) cited evidence for raised marine terraces in Puerto Rico. Evidence for a stillstand at 1.6–2 m is found at many places around the Puerto Rican coast, and at least five higher stillstands are suggested, including one in the range from 12 to 15 m.

On Isla Desecheo, no evidence gives strong support to stillstands of the sea higher than 12–13 m. There is no firm evidence for stillstands between the upper and lower stillstands, and bathymetry in the area is too sparse to allow meaningful comment on possible submarine terraces.

Hubbard (1923, p. 103) considered the upper Desecheo stillstand as "post-Pleistocene" in age. Kaye's (1959a, p. 135) analysis, however, related the Puerto Rican equivalent of the upper Desecheo stillstand to either upper Yarmouth or lower Sangamon Interglaciations of the Pleistocene. Williams (1965, p. 176) recognized no equivalent to the upper Desecheo stillstand, but he (p. 163) considered all stillstands higher than the 2-m level as Pleistocene in age.

No new evidence on the age of the upper Desecheo stillstand was found during the investigations reported herein. We can say only that the work of Kaye and Williams strongly suggests that the upper Desecheo stillstand took place during the Pleistocene Epoch, rather than during the Holocene Epoch as was suggested by Hubbard.

The lower Desecheo stillstand was believed Holocene in age, and perhaps historic, by Hubbard (1923, p. 103); Williams (1965, p. 163) also concluded that the 2-m stillstand took place in Holocene time. Kaye, on the other hand, reasoned that this stand of the sea took place in the Pleistocene Epoch, in a Wisconsin interstade or perhaps in the latter part of the Sangamon Interglaciation.

Probably the strongest evidence for the age of this 2-m stand is the carbon-14 age determination made on a sample of carbonized wood collected by Briggs from a swamp deposit in north-central Puerto Rico (71,090 m N.; 142,242 m E.; Puerto Rico coordinate system). The relations of this deposit to the present shoreline and sea level indicate that the swamp originated as a coastal lagoon during a sea-level stand about 2 m higher than the present. The age reported was 3,300 ± 300 years before the present (USGS lab. No. W–1036), thus Holocene.

Kaye (1959a, p. 131–135) and, for the most part, Williams (1965, p. 162–163) ascribed the terraces to the advance and retreat of the sea due to glaciation. However, Williams (p. 171–175) considered the 2-m stand to have been caused by tectonic elevation of the land which was accompanied by tilting, the uplift being greater to the west than to the east. We concur with Williams that the 2-m terrace results from tectonic uplift, for the reason given in the following paragraph, but the concept of west-to-east tilting we consider unproven. Briggs has seen raised beachrock, fossiliferous terrace deposits, and other features at elevations commensurate with a stand at about 2 m in the Fajardo area of extreme eastern Puerto Rico, along the central and western north coast of Puerto Rico, and on Isla Desecheo. Therefore, it appears that any regional tilting from west to east after the 2-m stillstand cannot have exceeded 1 m in the 200-km distance that separates Isla Desecheo from extreme eastern Puerto Rico.

The evidence for the 3,300-year age of the 2-m stand of the sea appears to conflict with the consensus of most investigators of late Quaternary sea levels that about 3,300 years ago, sea level stood about 2 m lower, not higher, than it does at present (Curray and others, 1970, p. 1878, fig. 6). Thus, if the age assigned to the 2-m stand in Puerto Rico is correct, about 4 m of tectonic uplift in the past 3,300 years is indicated for northern Puerto Rico and Isla Descheo. This conclusion appears reasonable in the light of the present seismicity of the region (Sykes and Ewing, 1965).

Holocene tectonic activity also would have had an effect upon the present levels of other terraces. If the elevation of the terrace of the lower Desecheo stillstand is controlled tectonically, then it follows that the upper Desecheo stillstand level, and other earlier terrace levels in this area, no longer can be considered as having been controlled solely by glacioeustatic rises and falls of sea level.

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