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GEOLOGY OF BARRO COLORADO ISLAND, CANAL ZONE

(With Three Plates)

By
W. P. WOODRING
Geologist, United States Geological Survey

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GEOLOGY OF BARRO COLORADO ISLAND, CANAL ZONE[1]

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(With Three Plates)

INTRODUCTION

Barro Colorado Island has been a wildlife reservation since 1923, at first as the Institute for Tropical Research in America under the direction of the National Research Council, and since 1946 as the Canal Zone Biological Area, administered by the Smithsonian Institution. Though hundreds of papers and books have been published on research conducted on the island, only a few sentences on the geology have appeared. One of these sentences deserves special mention, for it was written by a mammalogist: "There are many outcrops of rock, chiefly Bohio conglomerate" (Enders, 1935, p. 387). No geologist could write a more pertinent one-sentence statement concerning the geology of the island. The present account is intended primarily for visitors who may be interested in the geologic background and what it means in terms of geologic history, particularly the geologic history of the Panamá land bridge. For that reason it includes matter that is elementary to geologists. An additional purpose is to show that geological fieldwork is rewarding in a superficially unpromising forested area, provided sufficient time and facilities are available.

During six weeks in January and February (two of the four dry-season months), 1954, Mrs. Woodring and I were granted residence privileges on the island, while I studied its geology and that of nearby areas accessible by launch and cayuca (dugout).

Fieldwork on Barro Colorado was a memorable experience. It was like working in an unfenced combined zoological park and botanical garden. Agouti, coati, howling monkey, and white-faced monkey were seen every day; three-toed anteater, collared peccary, and iguana

[1] Publication authorized by the Director, U. S. Geological Survey. For summary see page 36.

frequently; the elusive little squirrel monkey, three-toed sloth, nine-banded armadillo, white-tailed deer, nutria, and crocodile occasionally. While I was writing notes near the mouth of the first stream south of Fuertes House, 13 collared peccaries, adults and young, slowly filed across the stream not more than 15 meters [2] upwind, unaware of my presence. Spoor of big cats and tapir was the only indication of those animals, the largest on the island. A pair of semidomesticated young tapirs frequently appeared in the clearing during the evening. To our surprise the male one evening chased a tame deer all over the clearing. He probably was resentful because the deer had just been fed. From the vantage point of the laboratory veranda, where so much could be seen, we watched white-faced monkeys making their tremendous leaps in the forest canopy, some of them pausing in a balsa tree to bury their heads deeply in the vaselike flowers, exactly as shown in Chapman's photograph (1938, pl. 5).

Parrot, parakeet, toucan, and antbird were ever present in the forest, and brilliant little honeycreepers were seen every evening in a leafless tree in front of the laboratory veranda. Great tinamou, whose haunting flutelike whistle will always be associated with memories of dawn and dusk, and crested guan (both game birds elsewhere) were common. Black-throated trogon, rufous motmot, and oropéndola were not unusual in the forest. A colony of oropéndolas, which returns to the clearing year after year to build its long pendent nests in a tall sandbox tree near the Chapman Cottage, was engaged in that task.

The big trees—cedro espinosa (*Bombacopsis fendleri*)—plotted on plate 1 are not exceptional but are located along trails, where their towering height and massively buttressed trunks are well displayed. The scarlet-flowered passionflower vine and the purple-flowered jacaranda were in bloom in the forest. It was too early for the guayacán, which in March brightens the forest with clouds of bright yellow blossoms.

Interesting as the animals and plants may be, they have no bearing on the geology, except their effects on a geologist, who may be unable to resist the temptation to spend more time on nongeologic observations than he is accustomed to.

There was only one drawback to fieldwork and that was due to a personal susceptibility. I found no effective way to keep off my body the minute ticks that are prevalent during the dry season, and their

[2] Metric units are used in this paper, not only because Barro Colorado is in the midst of metric-using countries, but also to conform with the system of marking trails on the island.

slightest bite raised a blister. I envied the young people, from schools in the Canal Zone and Panamá, who were attired in shorts for a day-length visit and evidently were not bothered. They, however, were not much exposed to ticks on the well-traveled trails near the laboratory.

For an introduction to the island and its unusual opportunities and beauty, a prospective visitor could do no better than to read Chapman's two delightful books (Chapman, 1929, 1938).

HISTORICAL BACKGROUND

The flooding of Gatun Lake, through the construction of Gatun Dam on Río Chagres, began in 1911 and was completed in 1913-14. Before the damming, the site of Barro Colorado was the high north-eastern part of a ridge between the valley of Río Gigante (part of which now is Gigante Bay) and Laguna de Peña Blanca (now Peña Blanca Bay). The ridge was designated Loma de Palenquilla (fig. 1). The high part of Loma de Palenquilla owed its altitude to a thick cap of basalt, although that was not then known. (The name Palenquilla, displaced westward to the west side of Peña Blanca Bay, survives as the name for a point.) Loma de Palenquilla is labeled on a French map prepared in 1844 and published in 1845 (Garella, 1845). Varro Colorado, presumably named for a bluff of red clay, also appears on the map as the name of a settlement of Río Chagres near the north-east end of Loma de Palenquilla. On a French map dated 1886 Varro Colorado Arriba is on the north side of the Chagres and Varro Colorado Abajo a little downstream on the south side, and the ridge is labeled "Lomas de Palenquillo" (Wyse, 1886). The outline of what was to become Barro Colorado Island is well shown by two 10-meter contours on the last of the French maps, which was published in 1899 and was used in the drafting of figure 1 (Etienne and others, 1899). The outline of the island in figure 1 and slight modifications of minor drainage features are taken from a modern map of the same scale, but the contours on the French map agree remarkably well with the outline. The only serious error on the French map is the drawing of a stream practically along the crest of the present Bohio Peninsula. The French map was prepared under the auspices of a Commission of the second French canal company, a member of which was the French geologist Marcel Bertrand, well known for his early work on over-thrusting in the complexly deformed subsurface coal fields of northern France and on recumbent thrust sheets (nappes) in the Alps. Bertrand collaborated with a resident Swiss engineer, Philippe Zürcher, in preparation of the most satisfactory of the early accounts of

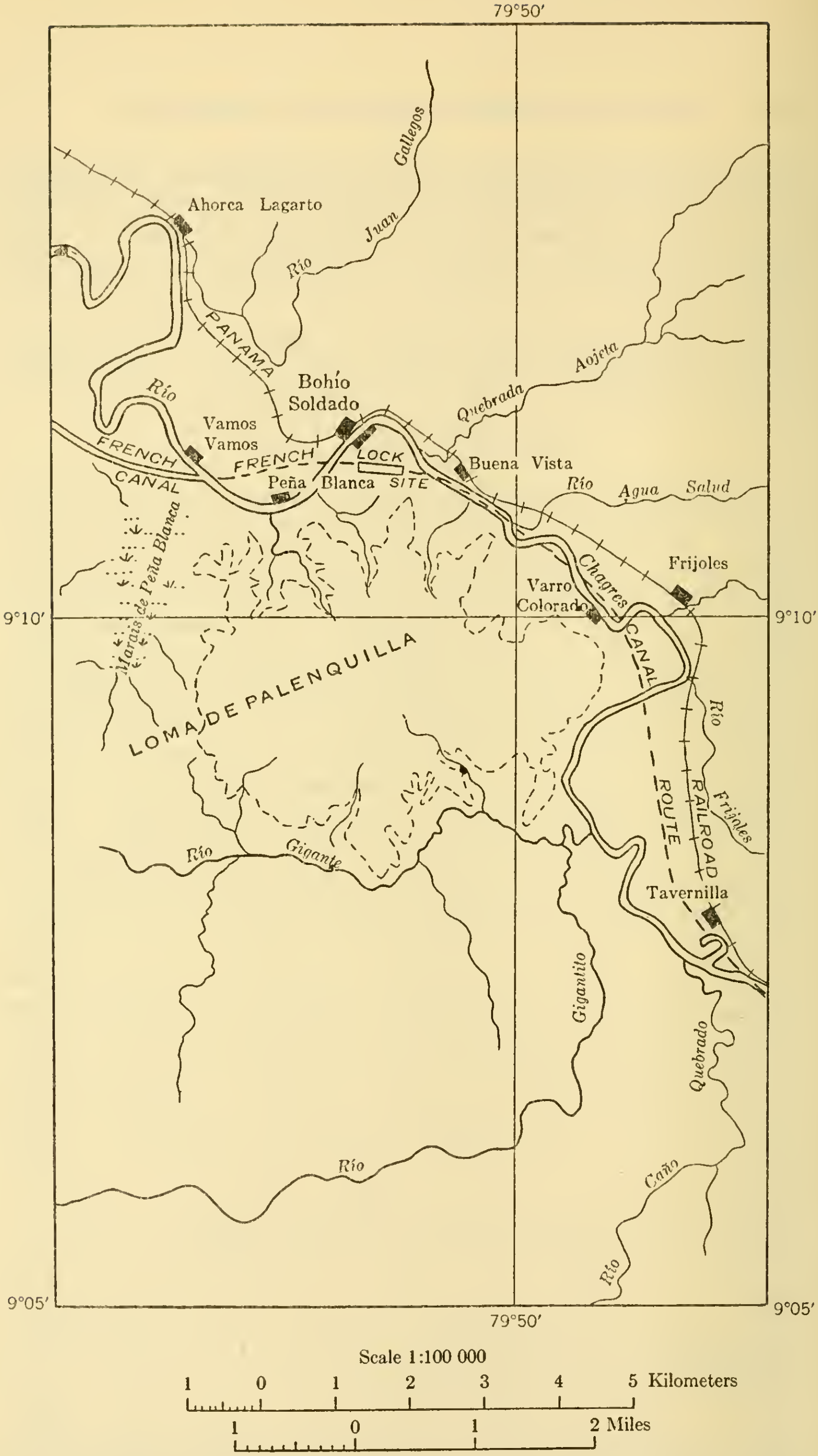

FIG. 1.—Map showing site of Barro Colorado Island before damming of Río Chagres to form Gatun Lake. Outline of island shown by broken line. Modified from map in report of Commission of second French canal company (Etienne and others, 1899).

the geology of the proposed canal route (Bertrand and Zürcher, 1899). Two famous French geologists were involved in the early work: Marcel Bertrand and the paleontologist Henri Douvillé. With few exceptions, Douvillé's (1891, 1898, 1915) age assignments have stood the test of time.

In its lower course Río Chagres was a wide stream, and under the drive of the trade winds during the dry season tidewater extended upstream almost to Loma de Palenquilla (Kirkpatrick, *in* Chapman, 1938, p. 206). In the early 1850's, before completion of the Panama Railroad in 1855, small iron-hulled steamers plied the river up to Gorgona, 12 kilometers in a direct line above Varro Colorado, to supplement the fleet of smaller vessels in accommodating the swarm of California-bound gold-rush travelers. From Gorgona, bongos (large dugouts) ascended the river to Las Cruces, a short distance upstream from the present site of Gamboa, where passengers disembarked for the arduous trip by muleback or on foot to Panamá City.

During the French construction periods (1881-89, 1895-99) or later, Loma de Palenquilla was used for an unexpected purpose. This episode, revealed by countless bottles of assorted design and a French iron dump car set up as a boiler—all near the summit of Barro Colorado—was discussed by Enders (1935, p. 388) and Chapman (1938, pp. 207-209). They concluded that this remote spot was the scene of illicit rum-distilling operations and surmised that the summit area, now sparsely forested, was cultivated to supply sugarcane. As suggested by Chapman, archeological excavations doubtless would throw light on this chapter of the island's history.

GEOGRAPHIC AND GEOMORPHIC SETTING

Barro Colorado, the largest and highest island in Gatun Lake, is 25 kilometers in a direct line south-southeast of Colón and about the same distance north of the continental divide (fig. 2). It is roughly circular and roughly dome-shaped, and reaches an altitude of 164 meters above sea level, or 138 meters above the normal level of Gatun Lake. The greatest diameter is 5½ kilometers and the area 15 square kilometers. Though the island is small, it is so deeply indented that the length of the shoreline is about 50 kilometers. The Panama Canal channel extends north and east of the island. The closest approach is at Salud Point, a view of which is shown on plate 3.

With the exception of the laboratory clearing of 2½ hectares and a few insignificant clearings elsewhere, the entire island is forested, but not all the forest is primary. Plate 2 shows the laboratory clearing and the surrounding forest. A network of well-kept trails extends

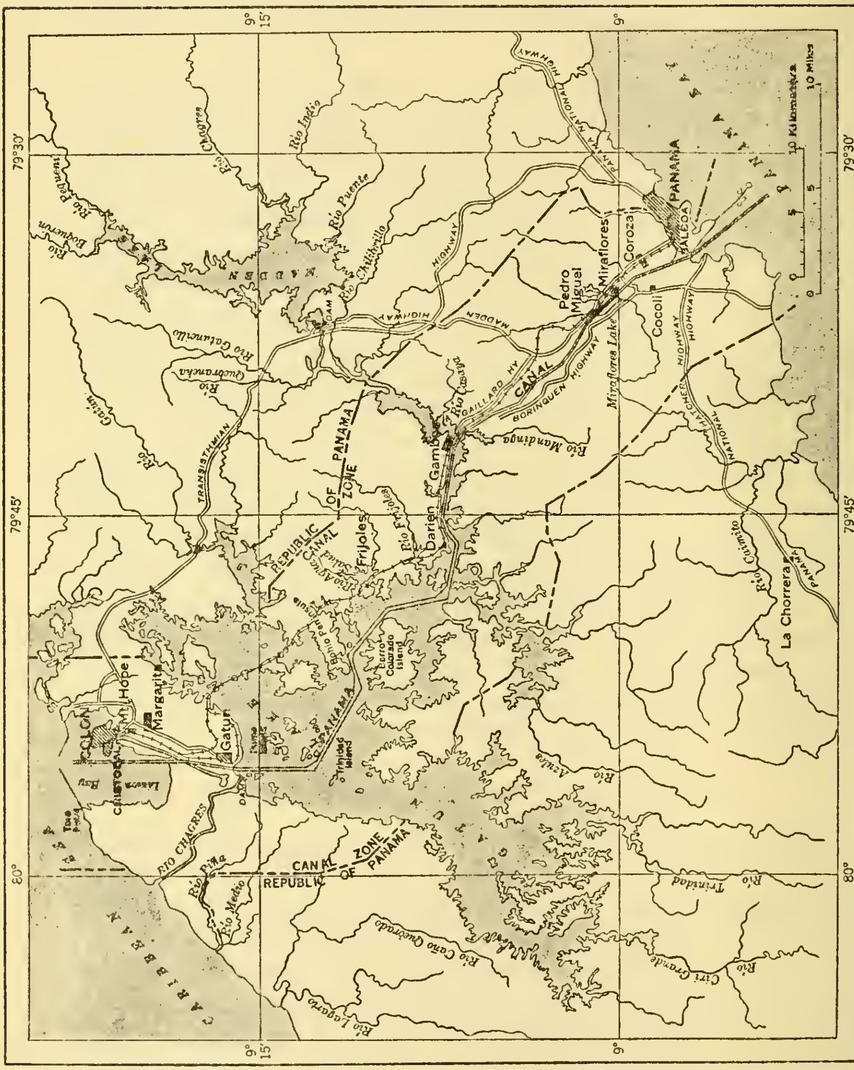

FIG. 2.—Map of Canal Zone and adjoining parts of Panamá showing location of Barro Colorado Island. Adapted from U. S. Geological Surv. Prof. Pap. 244, fig. 2 (Cole, 1952 [1953]).

over the island and a marked launch channel encircles it. Metal markers, bearing the name of the trail and the distance in hectometers from the laboratory or from the end of the trail heading toward the laboratory, are set at 100-meter intervals on the trails. The 1 : 20,000 Army Map Service topographic maps (contour interval 20 feet, converted to an interval of 20 meters on plate 1), now available, and especially the network of trails and their markers, convert the island into an area that has horizontal control perhaps unequaled elsewhere in American tropical forests. The island therefore offers an exceptional opportunity for geologic work.

Streams arranged in a radial pattern drain the island. A few of the streams have been casually named; for example, Lutz Creek and Allee Creek for the minor streams along the east and west sides, respectively, of the laboratory clearing. On a recent map of a small part of the island (Schneirla, 1956, fig. 4, and earlier publications), the stream on which fossil locality *42h* [3] is located is appropriately labeled Fossil Creek and that crossed by the Shannon, Balboa, and American Museum of Natural History (A.M.N.H. of plate 1) Trails is labeled Shannon Creek. Perhaps other investigators have named streams in which they were interested. In describing the geology it would be convenient to have names for the principal streams, but the trails are so closely spaced that a brief phrase is sufficient for locating a stream with reference to the nearest trail. The major streams and some of the minor streams, such as that on the east side of the laboratory clearing, are perennial, but during the dry season their flow is greatly reduced.

The topographic maps used as a base for plate 1 were constructed photogrammetrically. The top of the forest canopy is so uneven, ranging from 15 to 45 meters above the ground, that some minor drainage features inevitably were misinterpreted. Corrections in streams and trend of contours, particularly in the western part of the island, were sketched in the field and transferred to plate 1.

Nearly all the slopes are steep except in an area of considerable extent at the top of the island, which is designated the upland surface. The 20-meter contours of plate 1 show this surface as an area of low relief above an altitude of about 120 meters. The stream courses in

[3] The localities at which fossils were collected are described on pages 34-35, and all except *42i*, which is very close to *42h*, are plotted on plate 1. They have number and letter designations because they are intercalated in a series of report numbers established before the fieldwork on Barro Colorado was undertaken. The same series of report numbers is being used in a report to be published as Professional Paper 306 of the U. S. Geological Survey.

the upland surface are wide swales, dry in the dry season. The upper part of the upland surface is sparsely forested and the swales are covered with a dense growth of pita (wild pineapple), indicating, as suggested by Enders and Chapman, that much of the upland surface formerly was cultivated.

The present remnant is all that is left of a surface formed at a time when the streams were graded to a base level (the ancient Río Chagres) several tens of meters higher, with respect to present sea level, than Río Chagres before flooding of Gatun Lake. The origin of the upland surface is mentioned again on page 33.

Steep-gradient streams flowing in narrow ravines are now destroying the remnant of the upland surface. These streams are cutting farther and farther back into the surface by headward erosion. A neck of the surface, extending northeastward toward the laboratory clearing, is now being cut off from the main body. At the base of the neck, a northward-flowing steep-gradient stream and its tributaries (crossed by bridges on the Wheeler Trail northeast of the summit of the island) captured the headwaters of southward-flowing low-gradient streams. Barring unforeseeable events, the headward erosion of all the streams will continue until the upland surface is completely consumed.

In general the topographic features reflect the geologic background, but the upland surface is an exception. It bevels a thick cap of basalt and also conglomerate, the most durable rocks on the island—an indication that the surface bears witness to a long interval of erosion. The high, rugged nothern part of the island, westward from the laboratory clearing, is underlain by conglomerate of the Bohio formation, which is not readily eroded. The stream courses in that area are narrow ravines or miniature gorges. Rugged slopes are formed by the same kind of rock southwestward from the western part of the Barbour Trail. On the west side of the second main stream west of the Drayton Trail, the slope is very precipitous for a vertical distance of 30 meters.

The softer rocks of the Caimito formation form subdued slopes and more open ravines than the hard rocks of the Bohio formation. Such features are characteristic of both the marine rocks in the western and central parts of the island and the nonmarine volcanic rocks in the eastern part, although the volcanic rocks include thin flows of basalt and small intrusive bodies of basalt.

GENERAL GEOLOGIC FEATURES

Though no account of the geology of Barro Colorado has been published, the island has appeared on several geologic maps. MacDonald's small-scale map (about 1 : 260,000), published in 1915 and again in 1919, shows the Bohio formation cropping out over the entire island (MacDonald, 1915, pl. 4; 1919, pl. 153). MacDonald, who was resident geologist during the last two years (1911-13) of the canal-construction period, was not carrying on geologic mapping—he was engaged in engineering geology. He saw the readily identified Bohio formation at the north end of Loma de Palenquilla during trips on the French Canal and Río Chagres, and later along the north coast of Barro Colorado during trips on Gatun Lake. A geologic map of the Gatun Lake area on a scale of 1 : 62,500 was published in 1950 (Jones, 1950, pl. 2). That map shows the same major rock units on Barro Colorado as plate 1 of the present account. Aside from the greater detail on plate 1 commensurate with its larger scale (1 : 20,000), the chief difference is that on plate 1 the eastern third of the island is shown to be underlain not wholly by basalt, but by a volcanic facies of the Caimito formation that includes basalt. The representation of Barro Colorado on a recently issued 1 : 75,000 geologic map of the Canal Zone and adjoining parts of Panamá (Woodring, 1955) is a generalized version of plate 1. The generalization includes the showing of basalt in the eastern third of the island and the omission of a branch of the Barro Colorado fault.

A visitor to Barro Colorado, who missed the basalt at the stream crossed by the Nemesia Trail 60 meters west of Nemesia 2, could travel every meter of the 36 kilometers of trails without seeing a single outcrop of unweathered rock. He would think, if he thought about it at all, that the island is geologically monotonous: an expanse of red clay with here and there scattered "boulders," or less rounded masses, that have an oxidized ferruginous coat of varying thickness and a heart of hard black rock. The red clay is a product of oxidation and hydration. At least in field features, the red-clay product from different parent material cannot be distinguished. There is one partial exception to that generalization. If the weathering has not gone too far and the clay, as seen in stream banks, shows somewhat rectangular, small, whitish blobs, it may be concluded that the blobs are kaolinized ghosts of feldspar crystals and that the parent material presumably is basalt. It would be uncertain, however, whether it is solid basalt, agglomerate containing fragments of basalt, or conglomerate made up of basalt boulders.

The high-gradient streams have cut through this mantle of red clay, ranging in thickness from a few meters to 15 meters, and afford satisfactory exposures of fresh rock. In fact, many of these streams are lined by continuous, or practically continuous, outcrops for considerable distances. Outcrops can be seen also on some of the low-gradient streams, particularly along these underlain by the marine rocks of the Caimito formation, but many of them, especially short streams, are not rewarding.

Exposures of unweathered rock away from streams were found only in the northwestern part of the island, where conglomerate of the Bohio formation crops out along the shore of the bold headlands jutting into Gatun Lake. These headlands are open to a long fetch of the lake, and every afternoon during the dry season white-capped waves are raised by the trade winds. The westernmost peninsula, which is narrow and very precipitous, is the only place where natural outcrops—again conglomerate of the Bohio formation—were observed on the crest of a ridge.

The geology of Barro Colorado is basically simple. As may be seen in figure 3, only two of the six major sedimentary rock units cropping out in the Gatun Lake area are found on Barro Colorado: the Bohio and Caimito formations. The outcropping strata of both are of late Oligocene age. Neither the base of the Bohio nor the top of the Caimito is represented on the island. Both formations include two mapped units of different facies. The bulk of the Bohio is nonmarine, but the formation includes thin tongues of marine strata. In the western and central parts of the island the Caimito consists of marine strata, whereas in the eastern part the marine strata are replaced by nonmarine volcanic rocks.

SEDIMENTARY ROCK FORMATIONS AND FOSSILS

BOHIO FORMATION

The Bohio formation was named for Bohío (originally Bohío Soldado), a village on the Panama Railroad, located on a bluff overlooking Río Chagres (fig. 1). The site of Bohío is close to the north border of plate 1, north of French Lock Point on de Lesseps Island. That island, Orchid Island, and the northwestern part of Barro Colorado, therefore, are in the type region of the formation. During the goldrush travel across the isthmus and later as the center of French operations, Bohío was a town of several thousand inhabitants. In the Canal Zone the name, which is in use for the long peninsula north of Barro Colorado and for the point at the end of the peninsula, is anglicized

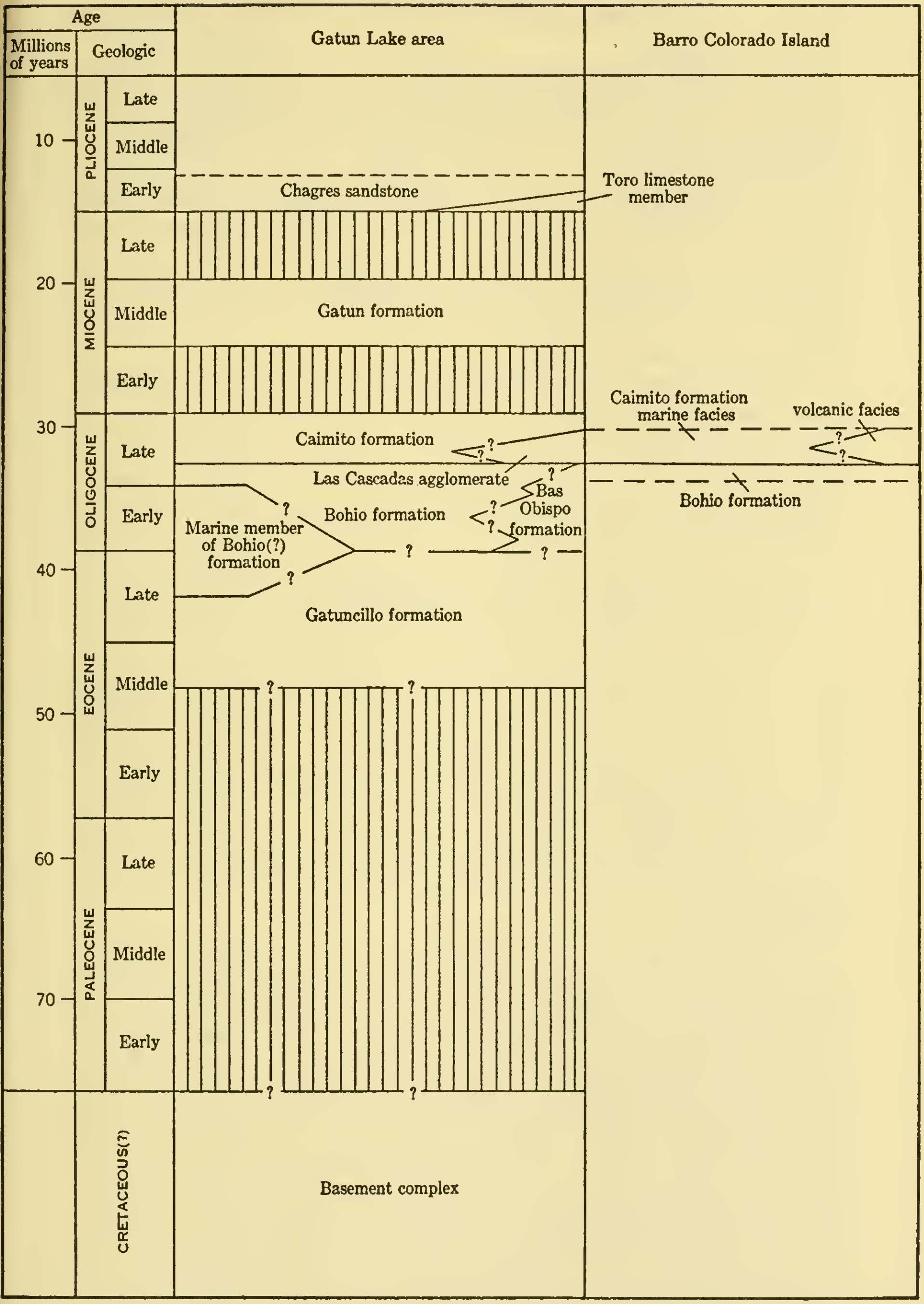

FIG. 3.—Sedimentary rock formations in Gatun Lake area and on Barro Colorado Island. Vertical ruling indicates gap. Broken horizontal line indicates that base or top of formation is not represented. Approximate age in years adapted from Simpson (1947, p. 481).

and the accent is dropped. The formation was named by R. T. Hill, the first American geologist to study the geology of the canal route (Hill, 1898, p. 183). He used the spelling "Bujio," which appears on some early maps.

The maximum thickness of the Bohio formation in the Gatun Lake area is estimated to be 300 meters. On Barro Colorado, however, only about the uppermost 125 meters are exposed. The entire formation, overlying the Gatuncillo formation, of middle and late Eocene age, crops out northwest of Gamboa. On Barro Colorado the Bohio includes both nonmarine and marine strata.

Nonmarine strata.—The Bohio is the most distinctive sedimentary rock formation in the Gatun Lake area. The principal constituent is conglomerate made up almost entirely of boulders, cobbles, and pebbles of basalt. There is no conglomerate like it in older or younger formations. Moreover, the basaltic debris is embedded in a matrix consisting chiefly of coarse-grained, angular grains of basalt. The conglomerate is rudely stratified or unstratified and unsorted, and includes some imperfectly rounded and angular pieces of basalt. Boulders that have a diameter of 2 meters are not unusual, but the maximum diameter generally is a little less. In extensive exposures, such as those on the headlands west of the laboratory clearing, an occasional boulder of other rocks may be seen: altered lava, diorite, and slaty rock. Sharp-edged pieces of white chert are strewn along a shallow ravine near the northwest end of the Standley Trail and also downstream from locality 42*h*, east of the Shannon Trail. Both localities are in the outcrop area of the Bohio formation. Though the chert was not seen in place, it presumably is derived from chert boulders in the conglomerate.

In the laboratory clearing and along the ravines emptying into Gatun Lake east and west of the landing, the conglomerate may be readily observed. That fresh rock is not far below the surface in the clearing is indicated by the hillside excavation for the new laboratory building near the southwest end of the clearing. At a depth of a meter rotten remnants and ghosts of boulders and cobbles can be made out. They consist of igneous rock, evidently basalt, showing kaolinized feldspar crystals. The weathered rock in the excavation disintegrates into coarse-grained sand. A 2-meter boulder in the ravine east of the landing, 10 meters upstream from Gatun Lake, looks like a small outcrop of basalt. It is breaking up along joints into sharp-edged fragments. Good exposures of conglomerate, including a long chute just below the Chichi Cottage, halfway down the slope from the laboratory, are readily accessible along the ravine at the west edge of the

EXPLANATION

SEDIMENTARY ROCKS

pper Oligocene

Tcm | Tcv

Caimito formation

Marine facies
Tuffaceous sandstone, tuffaceous siltstone, limestone.

Volcanic facies
Basaltic agglomerate, graywacke, extrusive and intrusive basalt.

TERTIARY

Th | Thm

GEOLOGIC MAP AND STRUCTURE SECTION OF BARRO COLORADO ISLAND CANAL ZONE

Scale 1: 20 000

1 Kilometer

1 Mile

Contour interval 20 meters

clearing. In fact, conglomerate forms waterfalls, cascades, chutes, or pavements on every stream in the outcrop area of the Bohio, both west of the laboratory and in the narrow strip extending from the Barbour Trail south-southwestward to the south coast west of the Drayton Trail. On the first stream east of the northwest end of the Standley Trail, a pavement of conglomerate extends to the edge of Gatun Lake. The most extensive exposure close to the laboratory is at Salud Point. The view of Salud Point shown on plate 3 suggests a beach boulder rampart. Though the big boulder in the left foreground and others at the water's edge are loose, the others are in rock outcrop.

Interlayered with the conglomerate are beds of massive sandstone like that forming the matrix of the conglomerate. Most of the sandstone contains scattered small cobbles and pebbles. Such sandstone, made up principally of coarse, poorly sorted angular grains of basalt in a claylike binder, and containing some feldspar but little quartz is a particular kind of sandstone called graywacke. Both the conglomerate and the graywacke have features of nonmarine deposits, and silicified wood is found in the Bohio of the Bohio Peninsula (Berry, 1918, p. 32).

Marine strata.—Fossiliferous marine or brackish-water sandstone of another type was found in three areas: West of the Miller Trail (locality 42*d*), south and southeast of Fuertes House (localities 42*e*, 42*f*, 42*g*), and between the Van Tyne and Shannon Trails (localities 42*h*, 42*i*). Upstream from locality 42*f* sandstone containing crumbly molds of unrecognizable pelecypods is underlain by carbonaceous shale, 75 centimeters thick. Some of the sandstone is as poorly sorted and as coarse-grained as the graywacke, but all of it is made up of less basalt, more feldspar and quartz, and less of the claylike binder. This type of sandstone is designated subgraywacke. Carbonized plant debris, apparently mostly bits of wood, is abundant in most of the subgraywacke. At locality 42*d*, however, the subgraywacke has little carbonized debris, and some of the rock, in the form of harder, irregularly shaped lumps, is somewhat calcareous.

Fossils and age.—Locality 42*g* is the only place where fossils were found in conglomerate: a cluster of oyster shells in the hard matrix around a cobble. A considerable number of marine fossils occur in the subgraywacke, especially at locality 42*d*, which yielded 80 species representing 6 phyla. Though no marine fossils were heretofore known in the present outcrop areas of the Bohio formation in the Gatun Lake area, Wyse (1886, p. 17) mentioned fossil shells near Bohío Soldado, and Howe (1908, pp. 220-221) found them in carbonaceous sandstone penetrated in coring operations at the French

Lock site. His description fits the carbonaceous subgraywacke of Barro Colorado. The lock-site excavation now is the launch channel between Orchid and de Lesseps Islands. Anyone who has passed through the channel will remember the concrete French canal markers, shaped like bottle-necked sentry boxes, lined up on the islands.

The fossils collected are listed in the table on pages 15-17.

Except for *Elphidium* aff. *E. craticulatum* and *Quinqueloculina akneriana,* the smaller Foraminifera, all from locality 42*d,* are poorly preserved. *Heterostegina antillea, Archaias compressus, Miogypsina antillea,* and *M. gunteri* from Barro Colorado localities have recently been described and illustrated by Cole (1957). The remaining larger Foraminifera, as represented at other localities in the Canal Zone, were treated in his 1952(1953) publication.

The two species of corals include an incomplete specimen of *Galaxea.* In a personal communication, J. W. Wells reports that, except for an undescribed species in the lower Miocene Tampa limestone of Florida and the Barro Colorado form, *Galaxea* is a tropical western Pacific genus ranging from Pliocene to Recent.

The list of mollusks is preliminary and shows hardly more than the generic makeup, aside from some among the first 13 species—the only ones studied so far. The new species among these and eventually the other identifiable species are to be described in a report, "Geology and Paleontology of Canal Zone and Adjoining Parts of Panamá," to be published as U. S. Geological Survey Professional Paper 306. The mollusks found at locality 42*d* are notable, not only on account of their diversity and the large number of specimens, but also because they include the only nautiloid in some 260 collections of Tertiary mollusks from the Canal Zone and adjoining parts of Panamá now being studied. The nautiloid is a species of the genus *Aturia,* widely distributed in both hemispheres in deposits of Eocene to Miocene age.

The fossils from localities 42*d,* 42*g,* 42*h,* and 42*i* indicate a shallow-water marine environment. *Anomalocardia* (locality 42*i*), however, now is a brackish-water genus and probably always has been adapted to that environment. *Neritina* (locality 42*g*), *Crassostrea* (the type of which is the eastern oyster, *C. virginica*), the only fossil from locality 42*e* and occurring also at 42*d* and probably (in the form of a young shell) at 42*g,* and *Tagelus* (locality 42*i*) tolerate a fairly wide range of salinity. Locality 42*f* yielded a mixture of fresh-water (*Hemisinus*), brackish-water (*Polymesoda, Anomalocardia*), brackish-water or marine (*Crassostrea, Tagelus*), and marine genera. At locality 42*f* the fossils were collected from slide material choking the stream

Fossils from upper part of Bohio formation

[R, rare; F, few; C, common; A, abundant]

	Localities					
	42d	*42c*	*42f*	*42g*	*42h*	*42i*
Smaller Foraminifera (identifications by Ruth Todd):						
Amphistegina? sp.	R					
Elphidium aff. *E. craticulatum* (Fichtel and Moll)	C					
Eponides? sp.	R					
Massilina sp.	R					
Peneroplis? sp.	R					
Quinqueloculina akneriana d'Orbigny	R					
Quinqueloculina sp.	R					
Triloculina sp.	R					
Larger Foraminifera (identifications by W. S. Cole):						
Heterostegina antillea Cushman					A	
Archaias compressus (d'Orbigny)	A					
Lepidocyclina (*Lepidocyclina*) *canellei* Lemoine and R. Douvillé	R				R	
Lepidocyclina (*Lepidocyclina*) *giraudi* R. Douvillé	R					
Lepidocyclina (*Lepidocyclina*) *waylandvaughani* Cole	R					
Lepidocyclina (*Nephrolepidina*) *vaughani* Cushman	R					
Miogypsina (*Miogypsina*) *antillea* (Cushman)	R				C	
Miogypsina (*Miogypsina*) *gunteri* Cole					R	
Unidentified sponge spicule	R					
Corals (identifications by J. W. Wells):						
Asterosmilia exarata (Duncan)	R					
Galaxea sp.	R					
Mollusks (identifications by W. P. Woodring):						
Gastropods:						
Solariella n. sp. cf. *S. depressa* Dall	R					
Neritina sp.				R		
Hemisinus (*Longiverena*) n. sp., cf. *H. atriformis* Cooke			A			
Crepidula? sp.				R		
Natica (*Naticarius*) sp.	F			?R		
Polinices sp.	F			?R		
Sinum sp.	F					
Globularia (*Globularia*) aff. *G. fischeri* (Dall)	A			F		
Pachycrommium aff. *P. guppyi* (Gabb)	R					
Turritella cf. *T. altilira* Conrad	R					
Turritella n. sp. aff. *T. venezuelana* Hodson	A			?F		
Cerithium (*Thericium*) n. sp.	A			?R		
Orthaulax cf. *O. pugnax* (Heilprin)	R					
Cymatid, genus?	R					
Ficid, n. genus	R			R		
Muricid?, genus?	R					
Mitrella sp.	R					

Fossils from upper part of Bohio formation—continued

	Localities					
Mollusks—continued						
Gastropods—continued	*42d*	*42e*	*42f*	*42g*	*42h*	*42i*
Buccinid, genus?	R					
Nassarius sp.	R					
Mitra (*Thiara*) sp.	R					
Plochelaea cf. *P. crassilabrum* Gabb	R					
Agaronia? sp.	R			R		
Cancellaria sp.	R					
Conus sp.	C					
Strioterebrum sp.	R					
Borsonine? turrid, genus?	R					
Clavine turrid, genus?	R					
Acteon sp.	R					
Acteocina sp.	R					
Atys sp.	A					
Scaphander sp.	A			C		
Pyramidella sp.	R			R		
Scaphopods:						
Dentalium sp.	R					
Siphonodentalium? sp.	R					
Pelecypods:						
Nucula? sp.	R					
Adrana cf. *A. crenifera* (Sowerby)	C			R		
Orthoyoldia? sp.						R
Anadara cf. *A. notabilis* (Röding)	R					
Anadara (*Cunearca*) sp.	R			?R		
Pecten (*Flabellipecten*) aff. *P. gatunensis* Toula	R					
Anomia aff. *A. berryi* Spieker	R					
Crassostrea sp.	R	R	R	?R		
Venericaria? sp.						R
Polymesoda sp.			R			
Lucinoma sp.			R			
Myrtaea sp.	R					
Miltha cf. M. woodi (Olsson)	R					
Divaricella sp.				R		
Diplodonta sp. (large)	R		A	R		
Diplodonta sp. (small)	F					
Trachycardium cf. *T. dominicense* (Gabb)	A			R		
Trachycardium cf. *T. dominicanum* (Dall)						R
Dosinia aff. *D. delicatissima* Brown and Pilsbry	C					
Macrocallista cf. *M. maculata* (Lìnné)	R			?R		
Chione cf. *C. spenceri* Cooke	A			F		R
Anomalocardia sp.			A			C
Pleiorytis cf. *P. caroniana* (Maury)	R					
Tellina sp.			R	R		R
Tellinid, n. genus	R					

Fossils from upper part of Bohio formation—continued

	Localities					
Mollusks—continued						
Pelecypods—continued	*42d*	*42e*	*42f*	*42g*	*42h*	*42i*
Semele sp.	R					
Semele? sp.	R					
Tagelus sp.			F			R
Solecurtus sp.	R					
Mactrid?, genus?			F			
Labiosa aff. *L. undulata* (Gould)						R
Mesodesma? sp.	C			F		
Corbula sp. (large)			R			
Corbula sp. (small)	F			R		
Thracia sp.	R					
Cephalopod:						
Aturia cf. *A. curvilineata* Miller and Thompson	R					
Ostracodes (identifications by I. G. Sohn):						
Cytheridea (s.l.) sp.	C					
Cytherura? sp.	R					
Cytherine? cytherid, genus?	R					
Genus?	R					
Genus?, aff. *Macrocypris*	R					
Decapod crustaceans (identifications by H. B. Roberts):						
Callianassa aff. *C. vaughani* Rathbun	R					
Callianassa floridana Rathbun	F					
Undeterminable callianassid limb fragments	C					
Unidentified fish tooth	R					

to the east and leaving a scar on the ridge slope, where the locality is plotted.

The larger Foraminifera and mollusks show that the upper part of the Bohio formation is late Oligocene, agreeing with the age previously determined for the upper part of the formation at the continental divide along the Transisthmian Highway east of the Canal Zone (Woodring and Thompson, 1949, pp. 231-232; Cole, 1952 [1953], p. 6). All the larger Foraminifera except two (*Archaias compressus* and *Miogypsina gunteri*) are found in late Oligocene rocks elsewhere in the Canal Zone and all occur in late Oligocene deposits of other regions. *Lepidocyclina* and *Miogypsina* became extinct in Miocene time. *Lepidocyclina* first appeared in the early Eocene and *Miogypsina* in the late Oligocene.

Like late Oligocene molluscan fanuas elsewhere, that from the Bohio of Barro Colorado has as a minor element an Eocene survivor (*Globularia*), a genus that has a time span of late Oligocene to early Miocene (*Orthaulax*), and a strong representation of genera and subgenera that first appeared in late Oligocene time and reached their fullest development in late Tertiary and modern seas (*Naticarius, Dosinia, Chione, Anomalocardia*). *Globularia,* however, survived until late early Miocene time. In the Canal Zone *Globularia* aff. *G. fischeri* is found in formations of both late Oligocene and the early half of early Miocene age, and *G. fischeri* itself occurs in the late early Miocene of Florida. The Barro Colorado species of *Anomalocardia* is the earliest species of that genus.

CAIMITO FORMATION

The Caimito formation takes its name from a construction-period junction on the Panama Railroad near the present Darien station, 8 kilometers west of Gamboa. The formation was named by MacDonald (1913, p. 569). Though no type locality was specified, he evidently intended Caimito and its vicinity to be the type region. It is not a good type region, but the characteristic lithology is shown there and, according to the regional relations near Darien, it is evident that the Caimito overlies the Bohio formation.

The prevalence of rhyolitic tuff, generally greatly diluted by detrital material, is a distinctive feature of the Caimito formation as far as the Gatun Lake area is concerned. The tuff (partly vitric and partly devitrified) forming a 15-meter cliff at the north abutment of the bridge at Barbacoas (10 kilometers west of the present site of Gamboa), where the original line of the Panama Railroad crossed Río Chagres, is presumed to be an example of undiluted tuff of the Caimito. The tuff at Barbacoas was described by practically every geologist and engineer who examined the rocks along the railroad. Boutan's (1880, pp. 19-20) early account is a good example and so is R. T. Hill's (1898, pp. 184-186), whose publication includes petrologic descriptions of the tuff by Wolff and Turner. There is a possibility that the tuff represents overlapping younger deposits of the lower Miocene Panamá formation, but that possibility seems to be remote. This matter can no longer be resolved, for the entire area is under Gatun Lake.

The Caimito is the most widely distributed formation in the Gatun Lake area. It consists chiefly of tuffaceous sandstone and tuffaceous siltstone. Hard algal-foraminiferal limestone, soft marly foraminiferal limestone, conglomerate, tuff, and agglomerate (coarse, angular, waterlain volcanic debris in a tuff matrix) are minor but significant constituents in the marine facies of the formation. The conglomerate lacks the great basalt boulders of conglomerate in the Bohio formation and, except for local basal deposits, is made up of cobbles and pebbles representing a greater variety of rock types. The matrix of the conglomerate (even of the local basal basaltic conglomerate), unlike conglomerate of the Bohio, contains tuff (Jones, 1950, p. 900). The total thickness of the Caimito is estimated to be at least 300 meters, but on Barro Colorado only about the lowest 100 meters of the marine facies crops out. The thickness of the volcanic facies on the island is estimated to be about the same.

Jones (1950, pp. 900-901) recognized three members in the Caimito formation of the Gatun Lake area. The lower member, consisting of basaltic conglomerate, was found only locally. The middle member is made up of tuffaceous sandstone and lenticular limestone, and the upper member (the thickest and most widely distributed part) of tuffaceous sandstone and siltstone, tuff, agglomerate, and sandy limestone. Whether the lower member represents a distinct time interval and is overlapped by the middle member or grades northwestward (seaward) into strata like those in the middle member—and is therefore indistinguishable from the middle member—is uncertain and may be indeterminable, as much of the critical area is under water. At all events, the marine facies of the Caimito of Barro Colorado, resting directly on the Bohio formation, consists of rocks like those in the middle member. Jones found that to the east-southeast, near and southeast of Gamboa, the Caimito grades into volcanic rocks of the Las Cascadas agglomerate of the Gaillard Cut area (the part of the canal excavation southeastward from Gamboa across the continental divide). He reached the conclusion that only the lower member grades into the Las Cascadas, but it seems to be more probable that more of the Caimito, if not the entire formation, is involved in the gradation.

The actual contact between the Caimito and Bohio formations was not observed on Barro Colorado Island, although on several streams in the northwestern part of the island the contact lies within narrow stratigraphic and horizontal limits. The contact evidently represents a sharply marked change in rock types and doubtless indicates a discontinuity. If so, it is a minor discontinuity, for the strata below and above the contact are of late Oligocene age.

A marine facies of the Caimito crops out in the western and middle parts of Barro Colorado and a nonmarine volcanic facies in the eastern part.

Marine facies.—Well sorted or moderately well sorted, tuffaceous, fossiliferous sandstone, ranging from gritty and coarse-grained to very fine-grained and silty, is the chief constituent of the marine facies. Soft sandstone of medium grain is the most widespread type. Some of the sandstone, however, is slightly or moderately calcareous and therefore moderately hard. Medium-grained, somewhat carbonaceous sandstone, containing slightly calcareous lumps, forms a pavement upstream from the mouth of the first stream east of the end of the Armour Trail (locality 54*m*). Gritty, calcareous somewhat carbonaceous sandstone and somewhat calcareous flaggy sandstone are exposed on the second stream west of the end of the Armour Trail (locality 54*l*). Silty, very fine-grained, richly fossiliferous sandstone was found at locality 54*n*, on the same stream as that for 54*m*, just mentioned. Conglomerate made up of small pebbles was observed about 100 meters downstream from locality 54*j* on the stream crossed by the Conrad Trail at Conrad 2.

Lenticular beds of limestone, not more than a few feet thick, are widespread on the north slope of the island. Though the limestone is a minor constituent, it is conspicuous. Hard algal-foraminiferal limestone is the common type. Soft, marly, foraminiferal limestone crops out in an area straddling the northwestern part of the Standley Trail. Such limestone is accessible at locality 54*f*, 30 meters downstream from the Standley Trail on the stream crossing the trail 60 meters northwest of Standley 11. Limestone of a different type strikes across the lower fork of the first long stream east of the Armour Trail. It is hard and contains scattered pebbles and fragments of calcareous algae, mollusks, and echinoid.

Nonmarine volcanic facies.—East of the Barro Colorado fault the marine facies is absent. In its place are nonmarine volcanic rocks and detrital rocks derived from a volcanic source: basaltic agglomerate; gritty, coarse-grained, poorly sorted, tuffaceous graywacke; and moderately coarse-grained, somewhat better sorted, tuffaceous graywacke. Agglomerate is exposed on the little stream heading at Barbour 12 (the third stream east of the laboratory clearing) and forms a small gorge downstream from locality 42*h* east of the Shannon Trail. Outcrops of basalt in this area of volcanic rocks evidently represent thin flows and small intrusive bodies.

It cannot be directly demonstrated that the volcanic and associated tuffaceous detrital rocks are the equivalent of some part of the marine facies of the Caimito formation. Nevertheless that interpretation is supported by the relations between the Caimito formation and the Las Cascadas agglomerate. There is no indication of interfingering of thin volcanic strata with marine rocks on the second stream east of the laboratory clearing. Likewise there is no indication of interfingering of thin marine strata with volcanic rocks on the next stream to the east. To be sure, interfingering may take place on the intervening ridge, but that is unlikely in view of the short distance between the streams: 350 meters. Therefore it is concluded that the two facies are separated by a fault, the Barro Colorado fault. The further conclusion is reached that the volcanic and associated detrital rocks are intermediate in the transition between the marine deposits of the Caimito formation and the wholly volcanic rocks of the Las Cascadas agglomerate and that the intermediate rocks, instead of being in their normal geographic position south-southwest of Barro Colorado, have been displaced northward along the fault.

Fossils and age.—Fossils are widespread and locally abundant in the marine facies. Very fine-grained silty sandstone at locality 54*n* yielded planktonic discoasters and other coccolithophores and a rich fauna of smaller Foraminifera, including a large number of planktonic species. A preliminary list of the coccolithophores is as follows.

Discoasters and other coccolithophores from Caimito formation at locality 54n

[Identifications by M. N. Bramlette. R, rare; F, few; C, common; A, abundant]

Discoaster deflandrei Bramlette and Riedel	C
Discoaster aff. *D. deflandrei* Bramlette and Riedel (some characters intermediate between those of *D. deflandrei* and *D. woodringi*)	C
Discoaster woodringi Bramlette and Riedel	C
Discoaster aff. *D. challengeri* Bramlette and Riedel	F
Discoaster perplexus Bramlette and Riedel	F
Thoracosphaera imperforata Kamptner	F
Sphenolithus abies Deflandre	F
Sphenolithus? sp.	C
Coccolithus cf. *C. pelagicus* (Wallich)	C
Coccolithus cf. *C. leptoporus* (Murray and Blackman)	R
Coccolithus sp.	C
Discolithus sp.	F
Helicosphaera aff. *H. carteri* Kamptner	C
Rhabdosphaera cf. *R. claviger* (Murray and Blackman)	R
Unidentified coccoliths, including many having diameter of 2 to 3 microns	A

The coccolithophores, as outlined by Bramlette and Riedel (1954, p. 386), are minute biflagellate protists found in vast numbers in the near-surface waters of the oceans. They have a calcareous skeleton. The discoasters are not known to be living and therefore their relations to typical coccolithophores are uncertain. Some of the species in the preceding list were described in the paper just cited.

The following is a preliminary list of smaller Foraminifera collected at locality 54*n*.

Smaller Foraminifera from Caimito formation at locality 54n

[Identifications by H. M. Bolli. R, rare; F, few; C, common; A, abundant]

Amphistegina sp.	R
Angulogerina byramensis (Cushman)	R
Angulogerina cooperensis Cushman	F
Anomalinoides trinitatensis (Nuttall)	F
Arenobulimina? sp.	R
Bermudezina cubensis (Palmer and Bermúdez)	R
Bolivina byramensis Cushman	F
Bolivina caudriae Cushman and Renz?	R
Bolivina cf. *B. cochei* Cushman and Adams	F
Bolivina sp.	F
Bulimina cf. *B. alazanensis* Cushman	R
Bulimina inflata alligata Cushman and Laiming	R
Bulimina (*Globobulimina*) *perversa* Cushman	R
Bulimina pupoides d'Orbigny?	R
Cassidulina bradyi (Norman)	R
Cassidulina laevigata d'Orbigny	F
Cassidulina subglobosa Brady	F
Cassigerinella chipolensis (Cushman and Ponton)	F
Catapsydrax cf. *C. dissimilis* (Cushman and Bermúdez)	R
Catapsydrax cf. *C. stainforthi* Bolli, Loeblich, and Tappan	R
Ceratobulimina alazanensis Cushman and Harris	R
Chilostomella sp.	R
Cibicides americanus Cushman	F
Cibicides aff. *C. compressus* Cushman and Renz	F
Cibicides sp.	F
Clavulina carinata Cushman and Renz	F
Ehrenbergina caribbea Galloway and Heminway	F
Elphidium sp.	F
Gaudryina flintii Cushman?	F
Globigerina bradyi Wiesner	F
Globigerina ciperoensis angustiumbilicata Bolli	A
Globigerina cf. *G. ciperoensis ciperoensis* Bolli	F
Globigerina cf. *G. trilocularis* d'Orbigny	C
Globigerina venezuelana Hedberg	F
Globigerinoides triloba immatura LeRoy	F
Globorotalia kugleri Bolli	F
Globorotalia mayeri Cushman and Ellison	C
Globorotalia obesa Bolli	F
Globorotalia opima nana Bolli	F
Globorotaloides suteri Bolli	F
Gümbelina cubensis Palmer	R
Gümbelina goodwini Cushman and Jarvis	R
Gümbelina paralleli Beckman	R
Gümbelina sp.	R
Gümbelina sp., group of *G. trinitatensis* Cushman and Renz	R
Guttulina jarvisi Cushman and Ozawa?	R
Guttulina sp.	R
Gyroidina cf. *G. parva* Cushman and Renz	F

Gyroidina sp. ....F
Gyroidinoides byramensis campester (Palmer and Bermúdez)........F
Höglundina elegans (d'Orbigny)?...F
Lagena sp. ....R
Lagena cf. *L. sulcata* (Walker and Jacob)..........................F
Lenticulina sp. ....R
Nodosaria longiscata d'Orbigny..F
Nodosaria obliqua (Linné)? ....R
Nodosaria spinicosta adelinensis Palmer and Bermúdez..............R
Nodosaria vertebralis (Batsch) ....R
Nonion incisum kernensis Kleinpell.....................................R
Nonion pompilioides (Fichtel and Moll)...............................F
Planularia sp. ....R
Planularia venezuelana Herberg?..R
Planulina sp. ....R
Plectofrondicularia floridana Cushman ....R
Plectofrondicularia morreyae Cushman.................................R
Pseudoglandulina comatula (Cushman) ....F
Pseudoglandulina laevigata (d'Orbigny) ....R
Pullenia bulloides (d'Orbigny)...R
Ramulina polita Bermúdez?..R
Reophax acosta Bermúdez...R
Robulus sp., group of *R. americanus* (Cushman).....................C
Robulus sp. ....R
Robulus sp., group of *R. subaculeatus glabratus* (Cushman)..........F
Saracenaria senni Hedberg...R
Schenckiella pallida (Cushman)...R
Sigmoilina tenuis (Czjzek)..F
Siphogenerina aff. *S. multicostata* Cushman and Jarvis..............R
Siphogenerina transversa Cushman...C
Siphonina sp. C
Siphonodosaria verneuili (d'Orbigny).....................................F
Siphonodosaria nuttalli gracillima (Cushman and Jarvis)?..........F
Sphaeroidina variabilis Reuss ....F
Spiroloculina jarvisi Cushman and Todd?...............................R
Textularia cf. *T. excavata* Cushman ....F
Textularia cf. *T. vasicaensis* Bermúdez...............................F
Uvigerina auberiana attenuata Cushman and Renz.....................F
Uvigerina capayana Hedberg ....F
Uvigerina isidroensis Cushman and Renz ....R
Uvigerinella sparsicostata Cushman and Laiming......................R
Vaginulina aff. *V. alazanensis* Nuttall...................................F
Valvulineria inaequalis (d'Orbigny?)......................................F
Virgulina sp. ....R
Vulvulina pachyheilus Hadley ....R

Smaller Foraminifera are fairly common in the Caimito formation of Madden basin, east of the Canal Zone, and in the Pacific coastal district east of Panamá City, but the fauna at locality 54*n* is by far the largest found anywhere. It is especially rich in planktonic species: the species of *Cassigerinella, Catapsydrax, Globigerina, Globigerinodes, Globorotalia,* and *Globorotaloides.* A collection from locality 53, including *Siphogenerina,* has not been identified.

Larger Foraminifera from the Caimito are listed below.

Larger Foraminifera from Caimito formation

[Identifications by W. S. Cole. R, rare; C, common; A, abundant]

	Localities				
	53	54*f*	54*h*	54*k*	54*l*
Operculinoides panamensis (Cushman)					A
Heterostegina antillea Cushman		R			
Heterostegina israelskyi Gravell and Hanna		A			R
Archaias compressus (d'Orbigny)			R		
Lepidocyclina (*Lepidocyclina*) *canellei* Lemoine and R. Douvillé	A	R	C	A	C
Lepidocyclina (*Lepidocyclina*) *giraudi* R. Douvillé					R
Lepidocyclina (*Lepidocyclina*) *yurnagunensis morganopsis* Vaughan	R				
Lepidocyclina (*Nephrolepidina*) *vaughani* Cushman	R				
Miogypsina (*Miogypsina*) *antillea* (Cushman)	C	A			C
Miogypsina (*Miolepidocyclina*) *panamensis* (Cushman)		R			

Larger Foraminifera are the most widespread fossils in sandstone, siltstone, and limestone of the Caimito formation. In fact, with a little search the small orbitoid *Lepidocyclina canellei* can be found in most outcrops of those rock types. In weathered sandstone, however, the fossils are leached and rotten. Collections were made at 12 localities, but only 5 were selected for identification. Hand specimens of the soft marly limestone at localities 54*e* and 54*f* contain hundreds of *Heterostegina,* closely matted and lying flat parallel to the bedding. In the preceding list the occurrences for locality 53—on the north coast of the islet (Slothia Island) off the laboratory landing, where the fossils are found in sandy calcareous siltstone—are taken from Cole's 1952(1953) publication (p. 7), which includes illustrations of *Lepidocyclina canellei* from that locality. In his recent publication (1957) the species of *Heterostegina* and *Miogypsina* are described and illustrated.

The type material of *Lepidocyclina canellei* was collected by an engineer of the first French canal company on Río Chagres at Peña Blanca. As shown in figure 1, Peña Blanca was located 1.2 kilometers northwest of what now is Peña Blanca Point at the northwest end of Barro Colorado. It got its name from an outcrop of soft whitish rock, probably calcareous siltstone. Lemoine and R. Douvillé (1904, p. 20) named *Lepidocyclina canellei* for the original collector. It is one of the most widely distributed fossils of late Oligocene age in the entire Caribbean region.

The following mollusks were found in the Caimito formation.

Mollusks from Caimito formation

[Identifications by W. P. Woodring. R, rare; F, few; C, common; A, abundant]

	Localities						
	54*g*	54*h*	54*j*	54*k*	54*l*	54*m*	54*n*
Gastropods:							
Solariella? sp. (immature)					R		
Calyptraea? sp.						R	
Natica (*Natica?*) sp. (operculum)				R			
Polinices sp.		R	?R	?R			
Neverita? sp.						R	
Architectonica (*Architectonica*) sp.		R		R			
Semicassis (*Echinophoria*) sp.		R	R		R		
Ficus cf. *F. pilsbryi* (B. Smith)		R			R		
Ficid, n. genus	R						
Tritiaria? sp.	R	R	F				
Metula? sp.						R	
Vexillum sp.	R						
Ancilla sp.			R				
Cancellarid?, genus?				R			
Conus sp.		R					
Strioterebrum sp.		R		R			
Turricula (*Orthosurcula?*) sp.			R				
Turriculine turrid, genus?							R
Cochlespira sp.	R						
Bathytoma sp.			R				
Borsonia? (*Paraborsonia?*) sp.				R			
Scobinella sp.	?R	F		R		R	
Crassispira sp.	R						
Leptadrillia? sp.				R			
Clavine turrid, genus?							R
Atys sp.							R
Pyramidella sp.				R			R
Vaginella cf. *V. chipolana* Dall			F		R		
Cavolina sp.	R		R				
Scaphopods:							
Dentalium cf. *D. uscarianum* Olsson	R	C	F	A	R	F	R
Dentalium sp.		A		F			
Pelecypods:							
Nucula sp.		R					R
Acila cf. *A. isthmica* Brown and Pilsbry				F	F	R	R
Nuculana? sp.						R	
Saccella sp.		R		C	R	R	

Mollusks from Caimito formation—continued

	Localities						
Pelecypods—continued	54*g*	54*h*	54*j*	54*k*	54*l*	54*m*	54*n*
Orthoyoldia? sp.		R					
Dimya? sp.					R		
Ostreid, genus? (immature)							R
Venericardia? sp.		R					
Callucina? sp.	R	A	R	C	R	R	
Parvilucina sp.				R			
Lucinoma sp.		C		?F		R	
Microcardium sp.			?R	F			
Lirophora? sp. (immature)							R
Gemmine venerid, genus? (immature)					R		
Tellina sp. (of medium size)				R		R	
Tellina sp. (small)		R		R		R	
Tellina (*Phyllodina*) sp.		R					
Labiosa sp.					R		
Cuspidaria sp.						R	

The identifications in the preceding list are preliminary, except those for the first eight species. As may be seen from the list, all except a few of the species are rare, a notable exception being the large species of *Dentalium, D.* cf. *D. uscarianum.*

Locality 54*n* yielded the following ostracodes, most of which are poorly preserved.

Ostracodes from Caimito formation at locality 54n

[Identifications by I. G. Sohn. R, rare; F, few]

Cytherella 2 spp.	F
Bairdoppilata? sp.	R
Paracypris? sp.	R
Xestoleberis? sp.	R
Krithe sp.	F
Cytheridea sp.	R
Kangarina sp.	R
Cytherura or *Cytheropteron* 2 spp.	F
Brachycythere sp.	R
Hemicythere sp.	R
Trachyleberis 3 spp.	F
Loxoconcha? sp.	R
Genus?, aff. *Orthonotacythere*	R

The fossils from the Caimito formation indicate both shallow-water and moderate-depth environments. The algal-foraminiferal limestone on the north slope of the island and the pebbly limestone on the south slope containing fragments of calcareous algae, mollusks, and echinoid (fragments of *Aequipecten, Amusium,* and *Clypeaster*) point to shallow water. The other fossiliferous strata contain a faunal assemblage indicating depths of 100 to 200 meters. Though the occurrence of great numbers of planktonic coccolithophores and planktonic foraminifera in itself does not demonstrate deposition in moderately deep water, the absence of adult typically shallow-water fossils at locality 54*n* and elsewhere support the inference that much of the formation actually represents a moderately deep-water environment. The mollusks include a relatively large percentage of moderately deep-water turrid gastropods (*Turricula* and the eight genera following that genus) and pteropods (*Vaginella, Cavolina*), a planktonic group of gastropods. Heretofore only a shallow-water facies was known in the Caimito, at localities eastward and southward from Barro Colorado—that is, at localities farther landward in the Caimito sea.

The Caimito formation, like the exposed part of the Bohio formation on Barro Colorado, is of late Oligocene age. In a personal communication, M. N. Bramlette reports that the assemblage of coccolithophores suggests that found in the *Globigerinatella insueta* zone of Trinidad and other Caribbean localities. He adds that it does not suggest assemblages of later age, but may be the equivalent of that in the *Globigerina dissimilis* zone, which underlies the *Globigerinatella insueta* zone. (Though both zones formerly were considered of Oligocene age, they are now designated as Miocene.)

H. M. Bolli assigns the foraminiferal fauna at locality 54*n* to the recently defined *Globorotalia kugleri* zone of Trinidad (Bolli, 1957, p. 118). According to the recent downward shifting of the Oligocene-Miocene boundary adopted by the micropaleontological laboratory of the Trinidad Oil Co., Ltd. (so as to include in the lower Miocene the presumed Caribbean equivalents of the European Aquitanian stage), the *Globorotalia kugleri* zone is at the top of the Oligocene. The downward shifting of the Oligocene-Miocene boundary was suggested by H. G. Kugler (1954). It has the effect of bringing into agreement age assignments of Caribbean foraminiferal zones and molluscan zones. The age advocated for the molluscan zones agrees with age assignments adopted by the U. S. Geological Survey for southeastern United States.

The assemblage of larger Foraminifera is typical for upper Oligocene throughout the Caribbean region.

The molluscan fauna cannot be compared with other Caribbean faunas, not even with the fauna of the Caimito itself at other localities. So far only a few species have been recorded from formations in the Caribbean region that are of late Oligocene to early Miocene age and are of comparable depth facies: such as the Uscari shale of southeastern Costa Rica and the Las Perdices shale of Colombia. The mollusks of the Caimito, however, are intermediate between those of Eocene and Miocene age. When they are studied, they may be found to include species closely related to those in the Oligocene Vicksburg group of southeastern United States, which contains faunas of comparable depth facies. In southeastern United States *Scobinella* is an Eocene and Oligocene genus, but in the Caribbean region it survived until early Pliocene time. If the fossil from the Caimito listed as *Borsonia?* (*Paraborsonia?*) sp. is a species of *Paraborsonia,* it is the earliest species of what is otherwise a Miocene subgenus.

IGNEOUS ROCKS

BASALT

Basalt is hard black rock, generally showing in hand specimens crystals of feldspar and ferromagnesian minerals in a dense groundmass. It occurs as lava flows and intrusive bodies. In the form of somewhat angular or rounded boulderlike masses, covered with an oxidized rind, it is the rock most frequently seen along the trails on Barro Colorado, especially on and immediately below steep slopes leading to the upland surface. Not only are the angular and boulderlike masses strewn along the trails, but the heads of streams draining the upland surface, notably those in the swalelike valleys in the surface itself, are choked with them. Though the "boulders" are indistinguishable from real boulders, that term is reserved for the large, rounded, or imperfectly rounded, product of stream and wave erosion. With few exceptions, the "boulders" seen along the trails are the product of spheroidal weathering. They are formed by the breaking off of angular blocks along joints and the smoothing of the edges by spalling of the oxidized rind. They may be seen in place in the low cliff of weathered basalt at Colorado Point, at the end of the Barbour Trail. At a few places in the northwestern part of the island basalt boulders, weathered out of conglomerate of the Bohio formation, were found on trails as follows: On steep slopes on the Fairchild Trail, on the Gross Trail between Gross 8 and 9, on the Miller Trail at Miller 18 and farther northwest, and on the Pearson Trail between Pearson 10 and 11. These boulders, however, generally are smaller than the "boulders" resulting from spheroidal weathering. Areas of basalt cannot be exactly outlined by the occurrence of the boulderlike masses, for they creep far down slopes and are carried by floods far downstream.

The areal relations of the thick cap of basalt almost coinciding with the upland surface indicate that it is a flow with a maximum exposed thickness of about 85 meters. The outer edge of the flow in general is marked by a steep slope and concentrations of "boulders" resulting from spheroidal weathering. The foot of the steep slope at an altitude of 75 meters on the Snyder-Molino Trail 100 meters southwest of the old laboratory, for example, was mapped as the edge of the basalt. An outcrop of fairly fresh rock was seen in the thick cap along the stream on which locality 42*e* is located, but nowhere else.

Basalt also occurs on the island as dikes and sill-like intrusive bodies. (Sills are parallel to the layering of intruded layered rock and dikes cut across the layering.) Two sill-like bodies were mapped on the north slope of the island. An outcrop of fresh basalt in the larger body may be seen at the crossing of the stream on the Nemesia Trail 60 meters west of Nemesia 2. Other outcrops are accessible on a stream 15 meters north of Barbour-Lathrop 7 and farther north on the same stream.

Dikes a few feet wide—too narrow and of too limited known extent to plot on plate 1—were observed in outcrop areas of the Bohio formation on both the north and south slopes of the island.

For the most part the basalt in the volcanic facies of the Caimito formation is greatly weathered and not identified with any assurance. Much of the weathered rock probably is basaltic agglomerate. Nevertheless both extrusive and intrusive basalt seem to be present. The fairly fresh basalt on the stream immediately below the crossing of the Chapman Trail at Chapman 9 and upstream on the east fork of the same stream is thought to represent thin flows. Jones (1950, p. 901) mentioned columnar basalt, presumably intrusive, on the south coast of the island.

The extrusive and intrusive basalt are indistinguishable in field examination. No microscopic study of these igneous rocks was undertaken. The following notes on similar rocks of the same age elsewhere in the Canal Zone are extracted from a manuscript by D. F. MacDonald that was found in the papers of W. H. Dall at the U. S. National Museum. The larger crystals and most of the groundmass of a basalt flow in the Gaillard Cut area consist of feldspar, mostly labradorite, and augite. The groundmass is distinctly crystalline, though very fine-grained. Magnetite, apatite, and ilmenite are accessory minerals. Epidote fills cracks in broken feldspar crystals and occurs in cloudy masses in the interior of feldspar crystals. Labradorite, andesine, and augite are the principal constitutents among the larger crystals in basalt forming dikes in the Gaillard Cut area. Some of these dike rocks also contain enstatite and a little biotite. The groundmass is made up of laths of plagioclase and grains of augite, but generally includes a little glassy material. Magnetite and ilmenite are the chief accessory minerals and a little chlorite and serpentine are present.

In the Gatun Lake area basalt is not known to be younger than the Caimito formation. In that area, however, no deposits of early Miocene age crop out. In the Gaillard Cut area basalt intrudes formations of Oligocene(?) and early Miocene age, and basalt flows are interbedded with the Oligocene(?) rocks and the dated Oligocene formations in the southeastern part of the Gatun Lake area. The basalt on Barro Colorado represents this Oligocene and early Miocene episode of volcanic and intrusive activity.

STRUCTURE

Structurally Barro Colorado west of the Barro Colorado fault is a shallow, irregularly warped syncline trending in an east-northeastward direction and plunging westward. East of the fault the structure is unknown, except in the northwestern segment where the strata dip southeastward. In the northwestern part of the island the Bohio formation evidently is arched in a gentle asymmetric anticline, the north limb being steeper than the south limb. The crest of the anticline was not satisfactorily located. Indeed, there is a remote possibility that the strata dipping in opposite directions are separated by an undetected fault. The 20° dips on the north coast of the island and on de Lesseps Island are taken from Jones's (1950, pl. 2) map. Except for that area, the strata generally dip more gently. Two other exceptions may be noted: the 35° northwestward dip on the stream on which locality *42e* is located and the 20° northward dip adjoining the minor western branch of the Barro Colorado fault. The 35° dip was measured in strata including readily deformed carbonaceous shale and is not of regional significance. The 20° dip is attributed to deformation resulting from movement along the fault.

The Barro Colorado fault and its minor branch are the only faults that were recognized. The fault is shown on Jones's (1950) map, but on that map and also on a more recent map (Woodring, 1955) the main fault north of the split into two branches was not shown. The fault is thought to extend northeastward and southwestward beyond the island, as indicated on the maps just cited. The relative vertical displacement is downward to the east a few tens of meters on the minor branch, and on Bohio Peninsula, north of Barro Colorado, the relative displacement on the main fault also is downward to the east. As outlined in the discussion of the volcanic facies of the Caimito formation (p. 21), there is fairly convincing evidence that the principal displacement on the main fault is horizontal, the east side being displaced northward relative to the west side. In M. L. Hill's (1947, pp. 1670-1671) useful classification, the Barro Colorado fault is a left lateral fault. (A left lateral fault is a wrench—Blatt of German geologists—or transcurrent fault, along which the side opposite an observer looking across the fault is relatively displaced to the left.) The displacement may be as much as 10 to 15 kilometers.

When I first briefly visited Barro Colorado in 1947, under the guidance of S. M. Jones, he pointed out two outcrops at locality 54, on the stream along the east side of the laboratory clearing. Conglomerate of the Bohio formation striking east-northeastward was exposed in the stream bed and fossiliferous calcareous sandstone of the Caimito formation on the east bank, striking more to the north. In view of the regional relations of the two formations in this area, it was concluded that the two outcrops were separated by a concealed fault, now designated the minor branch of the Barro Colorado fault. In 1954 no trace of either outcrop could be found. They evidently were covered by debris during floods in one or more of the intervening wet seasons. Downpours of 104 millimeters of rain in 1 hour and 266 in 24 hours have been measured on the island (Zetek, 1956, p. 132).

The Bohio and Caimito formations probably were deformed in early Miocene time before deposition of the middle Miocene Gatun formation. This matter is discussed in the forthcoming U. S. Geological Survey publication.

BARRO COLORADO'S CONTRIBUTION TO GEOLOGIC HISTORY OF PANAMÁ LAND BRIDGE

Though Barro Colorado is only a small segment of the Panamá land bridge and its rocks represent only a very small fraction of the geologic history of the bridge since the known history began in Cretaceous(?) time, it offers contributions to that history. Its chief contributions are in late Oligocene paleogeography and paleontology. Its sedimentary rocks and fossils amply confirm what had been known or inferred previously: that the Bohio sea and the Caimito sea advanced southeastward from the ancestral Caribbean Sea. The shallow-water marine fossils from the Bohio formation and the moderately deep-water fossils, including the planktonic species, from the Caimito formation are new additions to documents covering the geologic history of the bridge.

During the early part of late Oligocene time when the upper part of the Bohio formation was deposited, high-gradient streams flowing northward from a volcanic center west of the present Canal Zone deposited a great quantity of coarse basaltic debris on an alluvial plain, the seaward edge of which shifted northward and southward. Locality 42*f*, south of Fuertes House, was close to the mouth of one of the streams. The fossils found there include snails that lived in the stream, other mollusks that lived in the brackish tidal inlet at the mouth, and still others that lived in the sea outside the inlet. Localities 42*d* and 42*h* were farther out in the sea but close to the shore. At that time there was no land bridge, for marine deposits are found in the upper part of the Bohio formation at the continental divide east of the Canal Zone.

Deposition of the coarse basaltic material ceased as a result of a change in the regimen of the streams, following mild deformation. When deposition was resumed at the beginning of Caimito time, the sea had advanced farther inland south of Barro Colorado and inundated an extensive area to the east and southeast. Volcanoes, located in the same general region as the earlier basaltic center, contributed rhyolitic ash to the sediments, which were of much finer grain than the earlier basaltic sediments. Though Barro Colorado then was the site of moderately deep-water deposition, shallow-water deposits accumulated here and there on mounds that reached upward to at least about 100 meters below the surface of the water, where calcareous algae could grow.

It may be worth while to attempt to date the island's upland surface in terms of what is known about the late Tertiary and Pleistocene history of the bridge, although the island itself has nothing to contribute to dating, other than the preservation of a remnant of a surface that evidently is not very old. During, or after, emergence and tilting of the early Pliocene Chagres sandstone, the land stood at least some 60 meters (perhaps as much as 90 meters) higher, with respect to sea level, than at present. This high stand took place during late Pliocene and Pleistocene time (early Pleistocene, according to subsequent history), for then the land bridge was completed and the great interchange of North American and South American land mammals was under way (Simpson, 1950, pp. 379-383). During the high stand an extensive area now covered by shallow water in the Bay of Panamá presumably was dry land and the bridge was at least twice as wide as it now is. The ancient Río Chagres and its tributaries cut deep, wide valleys, which were partly outlined by drilling operations during construction of the canal and later. These valleys then were filled with sediments, evidently in middle or late Pleistocene time, during a lower stand of the land with reference to sea level. At Gatun Dam, at an altitude of 6 meters above sea level, the sediments have a thickness of some 60 meters. According to Thompson's (1947, p. 22) description of these Pleistocene deposits, they consist of silty clay, plastic clay, and black organic muck. The black muck is the most characteristic, and at some localities the thickest, constituent. It includes lenses of matted, partly decomposed wood, leaves, and other plant remains. The muck is a swamp deposit, probably laid down in mangrove swamps. It should yield a rich harvest to anyone interested in pollen and spores.

In the valley of Río Chagres the muck extends inland to Gamboa and on the Pacific side, where the Pleistocene deposits are not known to have a thickness of more than 15 meters, to the upper end of Miraflores Locks. Marine fossils have been found as far inland as the lower end of Gatun Locks and the upper end of Miraflores Locks. In other words, during this episode of Pleistocene submergence the width of the isthmus was two-thirds of the present width and a wide tidal inlet extended 35 kilometers inland from the sea at the site of Gatun Locks.

The surface of low relief, represented by the upland surface on Barro Colorado, evidently was formed during the later part of this episode of submergence, at a time when the ancient Río Chagres was flowing in an alluviated valley some tens of meters above the present valley. R. T. Hill's (1898, p. 183) Baila Monos Plain, now submerged, may be part of the ancient valley.

If the channel cutting and channel filling took place at the same time in the Caribbean and Pacific parts of the bridge, the relations between land and sea are not solely the result of eustatic changes of sea level resulting from glaciation and deglaciation in high latitudes, for the channels on the Caribbean side are four times as deep as those on the Pacific side. The latest relative movement, an emergence of a few meters, affects both coasts and may be due entirely to a eustatic lowering of sea level.

The wood and other plant material in the Pleistocene muck is not suitable for radiocarbon dating, even if it were young enough. A very high moisture content is a characteristic feature of the muck (Thompson, 1947, p. 22).

FOSSIL LOCALITIES

Report No.	Permanent USGS No.	Field No.	Description
			Bohio formation
42d	18837	207	Northern part of island, stream heading west of Miller Trail near Miller 17, about 100 meters above mouth. Somewhat calcareous, medium-grained subgraywacke. W. P. Woodring, 1954.
42e	18835	205	Northern part of island, stream southeast of Fuertes House, about 275 meters above mouth. Conglomerate. W. P. Woodring, 1954.
42f	18836	206	Same stream as that for locality *42e,* but about 60 meters upstream and from slide on west side of stream. Poorly sorted subgraywacke. W. P. Woodring, 1954.
42g	18832	203	Northern part of island, stream crossing Pearson Trail at Pearson 6, about 365 meters above mouth. Poorly sorted subgraywacke. W. P. Woodring, 1954.
42h		215	Eastern part of island, stream east of Shannon Trail, about 365 meters above mouth. Somewhat calcareous, coarse-grained gritty subgraywacke. W. P. Woodring, 1954.
42i	18845	215*a*	Same stream as that for locality *42h*, but 30 meters downstream. Soft muddy subgraywacke. W. P. Woodring, 1954. Not plotted on plate 1.
			Caimito formation
53		53	North coast of low islet (Slothia Island) 400 meters northeast of laboratory landing. Soft sandy calcareous siltstone. S. M. Jones and W. P. Woodring, 1947.
54		46	Stream on east side of laboratory clearing, 150 meters above mouth at landing. Calcareous tuffaceous sandstone. W. P. Woodring, 1947.
54*a*			Northeastern part of island, second stream east of laboratory clearing, 150 meters above mouth. Soft sandstone. W. P. Woodring, 1954.
54*d*		202	Northwestern part of island, stream heading north of Zetek Trail at Zetek 9, about 550 meters north-northwest of Zetek 9. Calcareous tuffaceous sandstone. W. P. Woodring, 1954.

FOSSIL LOCALITIES—continued

Report No.	Permanent USGS No.	Field No.	Description
			Caimito Formation
54*e*		202*a*	Same stream as that for locality 54*d*, but about 200 meters downstream. Soft marly limestone. W. P. Woodring, 1954.
54*f*		201	Northwestern part of island, stream crossing Standley Trail 60 meters northwest of Standley 11, about 30 meters downstream from trail. Soft marly limestone. W. P. Woodring, 1954.
54*g*	18840	210	Western part of island, first stream north of Zetek House, about 300 meters above mouth. Soft medium-grained sandstone. W. P. Woodring, 1954.
54*h*	18841	210*a*	Same stream as that for locality 54*g*, but at mouth. Soft sandstone containing calcareous lumps. W. P. Woodring, 1954.
54*i*		211	Western part of island, mouth of small stream 450 meters south-southeast of Zetek House. Soft sandstone. W. P. Woodring, 1954.
54*j*	18833	204	Southwestern part of island, stream crossing Conrad Trail at Conrad 2, about 365 meters upstream from mouth. Soft sandstone. W. P. Woodring, 1954.
54*k*	18834	204*a*	Same stream as that for locality 54*j*, but about 60 meters upstream from mouth. Soft sandstone. W. P. Woodring, 1954.
54*l*	18842	212	Southwestern part of island, second stream northwest of end of Armour Trail, 60 meters above mouth. Gritty sandstone and somewhat calcareous sandstone. W. P. Woodring, 1954.
54*m*	18843	213	Southwestern part of island, small stream 400 meters northeast of end of Armour Trail, 15 meters above mouth. Medium-grained sandstone containing somewhat calcareous lumps. W. P. Woodring, 1954.
54*n*	18844	213*a*	Same stream as that for locality 54*m*, but 100 meters above mouth. Very fine-grained silty sandstone. W. P. Woodring, 1954.

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SUMMARY

Barro Colorado, the largest and highest island in Gatun Lake, has a maximum diameter of 5½ kilometers, an area of 15 square kilometers, and reaches an altitude of 164 meters above sea level, or 138 meters above the normal level of Gatun Lake. With the exception of the laboratory clearing of 2½ hectares and insignificant clearings elsewhere, the entire island is forested.

The high central part of the island is a remnant of a surface of low relief—the upland surface—formed in middle or late Pleistocene time when the streams were graded to a base level several tens of meters higher, with respect to present sea level, than Río Chagres before flooding of Gatun Lake.

Two fossiliferous sedimentary rock formations, the Bohio and the Caimito, crop out on Barro Colorado and the outcropping strata of both are of late Oligocene age. Neither the base of the older formation (Bohio) nor the top of the younger crops out. The outcropping thickness of the Bohio is estimated to be 125 meters, that of the Caimito 100 meters. Two mapped units of different facies in both formations are recognized: a prevailing nonmarine facies and a minor marine facies in the Bohio, an extensive marine facies and a more restricted nonmarine volcanic facies in the Caimito.

Small dikes and sill-like bodies of basalt intrude the Bohio formation and the volcanic facies of the Caimito formation, and in nearby areas rocks of the marine facies of the Caimito also are intruded by basalt—the last intrusive episode in the Gatun Lake area. The thick cap of basalt on the upland surface evidently is a flow. Thinner basalt flows and basaltic pyroclastic rocks are found in the volcanic facies of the Caimito formation.

Structurally the island west of the Barro Colorado fault is a shallow, irregularly warped syncline trending in an east-northeastward direction and plunging westward. The Barro Colorado fault and a minor branch of that fault trend northeastward. The facies distribution of the Caimito formation indicates that the principal displacement on the main fault is horizontal, the east side being displaced northward relative to the west side; that is, the evidence is fairly conclusive that the main fault is a left lateral fault. The displacement may be as much as 10 to 15 kilometers.

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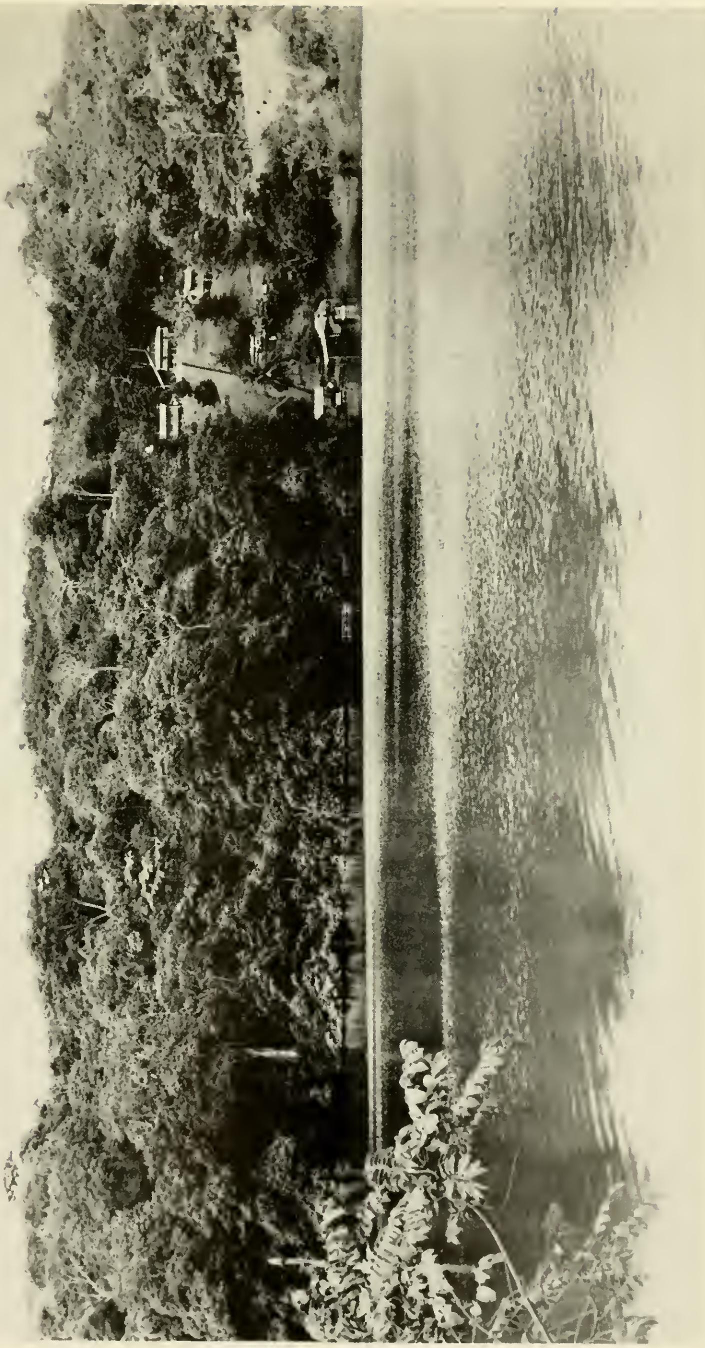

Laboratory clearing and surrounding forest, Barro Colorado Island.

Boulder conglomerate of Bohio formation at Salud Point, Barro Colorado Island. Photograph by Geological Section, Special Engineering Division, Panama Canal Company.