Oligocene assignment fitted the occurrence of these fossils in southeastern United States (Vaughan, 1919*a*, p. 199–203, 207). The *Eulepidina* fauna is found in the Chickasawhay limestone of Alabama, the Suwannee limestone of Florida, and the Flint River formation of Georgia usage, and the Antiguan coral fauna in the Flint River formation. These three formations are now assigned to the upper Oligocene (Cooke, Gardner, and Woodring, 1943, chart; MacNeil, 1944, fig. 1; Cole, 1952 (1953), p. 6). A middle Oligocene age is not unreasonable, if the American deposits that are essentially the equivalent of the European Aquitanian stage are assigned to the upper Oligocene. In the present report, however, they are referred to the lower Miocene. The age range of the *Eulepidina*-Antiguan coral fauna cannot be assumed to be narrowly restricted. It is a reef fauna and may eventually be found to have a considerable time range, like the Lower Cretaceous Urgovian reef fauna. In the Canal Zone and Panamá the *Eulepidina* fauna occurs in the upper part of the Bohio formation and at one locality in the Caimito formation (locality 51), and the closest approach to an Antiguan coral fauna is in the Caimito formation (localities 52 and 57). The time span between the deposition of the upper part of the Bohio in the Pacific coastal area and deposition of the Caimito at localities 51, 52, and 57 in the Gatun Lake area doubtless is not great, but it would be rash to correlate these deposits closely.

CAIMITO FORMATION EXCLUSIVE OF MADDEN BASIN AND PACIFIC COASTAL AREA

The Gatuncillo and Bohio formations are widespread, but are fairly uniform lithologically despite their widespread distribution. The Caimito formation is the youngest widely distributed formation. It is, however, lithologically heterogeneous. Deposits in too many areas have perhaps been included in the Caimito, but within the type region the formation is heterogeneous. In all the areas where the formation is identified it is marine, or at least mainly marine, and contains much volcanic debris.

The name for the Caimito formation was proposed by MacDonald (1913, p. 569). He did not properly define the name then or later, and he specified no type region. In the absence of evidence to the contrary, it may be assumed that the type region was intended to be the region that furnished the name. Caimito, or Caimito Junction, was located on the present alinement of the Panama Railroad near Darien in the Gatun Lake area (MacDonald, 1913, pl. 68). On the basis of accepting the Darien region as the type region, the Caimito formation consists of the strata, mostly tuffaceous, overlying the Bohio formation. MacDonald included in the Caimito formation strata now assigned to the La Boca marine member of the Panamá formation and his representation of the Caimito as overlying the Emperador limestone (now assigned member rank in the Culebra formation) was based on misidentification of both Emperador and Caimito (MacDonald, 1913, pl. 68).

In complete sections the Caimito formation overlies the Bohio formation or volcanic rocks that are thought to include the equivalent of the Bohio. Though the actual contact has not been observed, it evidently represents a discontinuity. In the northeastern part of the Gatun Lake area the Caimito seems to overlap the Bohio and Gatuncillo formations, directly overlying the basement complex, and in the northern part of Madden basin the Caimito overlaps the Bohio and rests on the Gatuncillo. In the southeastern part of the Gatun Lake area the lower part of the Caimito (or perhaps the entire formation), appears to grade into the Las Cascadas agglomerate. Wherever the Caimito formation is dated it is of late Oligocene age, except in Madden basin, where it includes both upper Oligocene and lower Miocene deposits. The Caimito of that area is described under the heading "Oligocene and Miocene series." The Caimito of the Pacific coastal area, which is entirely of Oligocene age, appears to be continuous with the Oligocene part in Madden basin and is discussed under the same heading.

According to estimates, the thickness of the Caimito ranges from 250 to 400 meters.

STRATIGRAPHY AND LITHOLOGY

Gatun Lake area.—Three members of the Caimito formation were recognized by Jones in the Gatun Lake area: lower, middle and upper (Jones, 1950, p. 900–901), which correspond, respectively, to the basal, lower, and upper members of his former usage (Woodring and Thompson, 1949, p. 232–233). According to Jones, the lower member is made up of conglomerate and tuffaceous sandstone. The conglomerate resembles conglomerate of the underlying Bohio formation, but includes pebbles of tuff. The sandstone and the matrix of the conglomerate contain acidic tuff. The lower member is correlated by Jones with the Las Cascadas agglomerate, but perhaps the entire formation is to be correlated with the Las Cascadas. The lower member of the Caimito is recognized only locally. Its absence elsewhere may indicate discontinuity or lateral gradation into deposits grouped with the middle member.

The middle member consists chiefly of tuffaceous sandstone, some of which is calcareous, and lenticular limestone, mostly algal limestone. Tuff, tuffaceous calcareous siltstone, and conglomerate are other constitutents. Agglomerate and poorly sorted, coarse-grained, tuffaceous, nonmarine sandstone in the northeastern part of Barro Colorado Island evidently are the equivalent of marine strata in the middle member. Foraminiferal soft limestone, such as that at locality

54f, doubtless corresponds to the foraminiferal marl of publications issued before the flooding of Gatun Lake. Foraminiferal marl was exposed at localities on Río Chagres, including Peña Blanca, the type of locality of *Lepidocyclina canellei*. The approximate location of Peña Blanca is shown as locality 55 on plate 1. Hill claimed that foraminiferal marl could be seen to rest unconformably on conglomerate (of the Bohio formation) near Bohio (Hill, 1898, p. 178–179), but Howe (1907, p. 113) was unable to recognize the locality Hill described. The rhyolitic tuff on Río Chagres at Barbacoas, where the original line of the Panama Railroad crossed the river about 9 kilometers west of Gamboa, presumably is to be included in the Caimito. The tuff was found to be so similar to tuff in the Panamá formation that Hill (1898, p. 201), Bertrand and Zürcher (1899, p. 91), and Howe (1907, p. 117) did not hesitate to correlate them. Though no data are available on the comparative volcanic constituents of the different formations, the correlation is not accepted (p. 41). Hill casually used the expression "Barbacoas formation" for the tuff and "San Pablo phase of the Barbacoas formation" or "San Pablo formation" for underlying rock he described as conglomerate of volcanic material (Hill, 1898, p. 184–185, 187).

Tuff, agglomeratic tuff, tuffaceous siltstone, and discontinuous sandy tuffaceous limestone are the principal constituents of the upper member, the thickest and most widespread part of the formation (Jones, 1950, p. 901).

The thickness of the Caimito in the Gatun Lake area is estimated to be at least 300 meters and may be considerably more.

Río Mandinga area.—Along a tributary of Río Mandinga, west of the canal and south of Gamboa, the Caimito formation is characterized by a unit of conglomerate and conglomeratic sandstone that has a thickness of between 75 and 100 meters. Conglomerate is not rare in the Caimito of other areas, but it consists of thin scattered beds. The unusual thickness of conglomerate prompted Jones to propose the name "Caraba facies of the Caimito formation" (Jones, 1950, p. 901). The conglomerate is overlain by fossiliferous silty calcareous sandstone (localities 59 and 60) and limestone. Locality 61 represents coralliferous limestone in this area.

The distribution of the conglomerate is unknown. The extensive area farther west along the south border of Gatun Lake, shown on plate 1 as doubtfully underlain by the Caimito formation, has not been examined.

Quebrancha syncline.—The Caimito formation of the Quebrancha syncline consists of two members: in ascending order, the Quebrancha limestone member and the calcareous siltstone member. They have been mapped and described by Thompson (1944, p. 17–21). The economically important Quebrancha limestone member, which is quarried for the manufacture of cement, was named by Thompson (1944, p. 17) as a separate formation. The type region is on the east limb of the syncline and includes the quarry of the Panama Cement Company. The Quebrancha member has a thickness of 110 to 135 meters. Subsurface explorations and outcrops reveal that it is made up, in ascending order, of three parts: calcareous siltstone and calcareous medium-grained sandstone, limestone and thin partings of calcareous siltstone, and somewhat marly foraminiferal limestone consisting for the most part of closely packed specimens of *Lepidocyclina*. The foraminiferal limestone is by far the thickest part.

The calcareous siltstone member, which gradationally overlies the Quebrancha limestone member, includes calcareous siltstone, tuffaceous pumice-bearing siltstone, and calcareous medium-grained sandstone. This member has an estimated thickness of 150 meters and is the youngest unit in the Quebrancha syncline.

Río Chagres area.—The lowland along Río Chagres north-northeast of Gamboa probably is underlain by the Caimito formation, but only a small part of it southwest of Nuevo San Juan was examined. Calcareous coarse-grained pebbly sandstone at locality 93 and limestone and siltstone farther west contain Foraminifera, including orbitoids identified in the field as *Lepidocyclina canellei* and *L. vaughani*. Limestone exposed at and near Las Cruces before the flooding of Gatun Lake yielded a few mollusks (localities 94, 94*a*).

FOSSILS AND AGE

Larger Foraminifera.—Larger Foraminifera are widespread and locally abundant in the Caimito formation of the areas just described, particularly in limestone and calcareous siltstone. No fossils of any kind, however, are known in the lower member in the Gatun Lake area and larger Foraminifera from one locality are the only fossils available for the upper member in that area. Douvillé recorded larger Foraminifera and calcareous algae in collections from localities near Peña Blanca and Bohío Soldado, and expressed the opinion that they are Oligocene (Douvillé, 1891, p. 498, 499). Later he identified the small orbitoid from Peña Blanca as *Lepidocyclina* and reaffirmed the Oligocene age (Douvillé, 1898, p. 598–599). This small species, one of the most common in the Caimito, was still later named *L. canellei* for the collector, an engineer of the first French company (Lemoine and R. Douvillé, 1904, p. 20). *L. vaughani*, another common species, is extraordinarily abundant in the Quebrancha limestone member. The type locality of *L. vaughani* is in the type region of the Caimito formation on the Panama Railroad near Darien: locality 49, which was referred to the Emperador limestone member of the Culebra formation by MacDonald and Vaughan (MacDonald, 1919, p. 539, locality 6021). Seven samples of larger Foraminifera were submitted to W. S. Cole, who identified the species in the following table. Recently Cole (1957, p. 314) also recorded 8 species from the Caimito of Barro Colorado Island, all except one of which occur in the Caimito elsewhere. The exception is *Archaias compressus*, which is still living.

Larger Foraminifera from Caimito formation of Gatun Lake area, Río Mandinga area, and Quebrancha syncline

[Cole, 1952 (1953), p. 7]

	Localities						
	Gatun Lake area					Río Mandinga area	Quebrancha syncline
	Middle member				Upper member	No members recognized	Quebrancha limestone member
	48	51	53	56a	58	59	62a
Operculinoides panamensis (Cushman)				×			
Heterostegina antillea Cushman	×	×					×
israelskyi Gravell and Hanna				×		×	
panamensis Gravell				×			×
Lepidocyclina (Lepidocyclina) asterodisca Nuttall						×	
(Lepidocyclina) canellei Lemoine and R. Douvillé	×		×	×			×
parvula Cushman		×		×			×
waylandvaughani Cole							×
yurnagunensis Cushman		×		×	×		
yurnagunensis morganopsis Vaughan		×	×				×
(Nephrolepidina) dartoni Vaughan							×
tournoueri Lemoine and R. Douvillé		×					
vaughani Cushman	×		×				×
(Eulepidina) undosa Cushman		×					
Miogypsina (Miogypsina) antillea (Cushman)			×				
(Miolepidocyclina) panamensis (Cushman)				×			

All the species in the preceding table occur elsewhere in deposits of late Oligocene age. Though the table does not include the calcareous siltstone member of the Quebrancha syncline, *Lepidocyclina canellei* has been recognized by R. H. Stewart in that member (Woodring and Thompson, 1949, p. 234).

Corals.—MacDonald and Vaughan found corals in the middle member of the Caimito formation of the Gatun Lake area at localities 52 (Geological Survey 6024b) and 57 (Geological Survey 6026). Locality 52 was assigned to the Emperador limestone [member of the Culebra formation] and locality 57 to the Culebra formation (MacDonald, 1919, p. 540, 541). Four of the seven species identified by Vaughan occur in the upper Oligocene Antigua formation of the island of Antigua and one in the lower Miocene Anguilla formation of the island of Anguilla (Vaughan, 1919a, p. 208, 209). Numerous specimens of a coral in limestone of the Caimito at locality 61 in the Río Mandinga area is identified by J. W. Wells as *Goniopora* cf. *G. cascadensis*.

Mollusks.—Mollusks have been found in the areas described in the preceding pages, but they are nowhere abundant. The species covered in chapter A of the present report are as follows:

Mollusks from Caimito formation of Gatun Lake area, Río Mandinga area, and Quebrancha syncline (Calyptraeidae to Turritellidae)

	Localities				
	Gatun Lake area			Río Mandinga area	Quebrancha syncline
	Middle member			No members recognized	Quebrancha limestone member
	56	57	57a	60	62
Trochita cf. *T. trochiformis* (Born)		?	×		
Natica (*Naticarius?*) sp	×				
Sinum sp	×	?			
Globularia (*Globularia*) aff. *G. fischeri* (Dall)	×	×	×		
Pachycrommium? cf. *P.? trinitatensis* (Mansfield)				×	
Turritella meroensis Olsson	×				×
(*Torcula*) *altilira* Conrad, subsp	×				×

Collections of mollusks from Barro Colorado Island and Pato Horqueto Island are not included in the systematic descriptions of chapter A of the present report. (Pato Horqueto Island is one of the Brujas Islands northwest of Barro Colorado Island.) The Barro Colorado collections, which represent a moderate-depth facies, contain unidentified species of *Solariella?* (locality 54l), *Calyptraea?* (locality 54m), *Natica* (*Natica?*) (locality 54k), *Polinices* (locality 54h and probably localities 54j and 54k), and *Neverita?* (locality 54m). Conglomerate on Pato Horqueto Island yielded mollusks of shallow-water facies, including *Calyptraea* sp., *Sinum* sp., *Ampullinopsis spenceri*, and *Turritella* sp. *Ampullinopsis spenceri*, a representative of a genus mainly of Oligocene age not found heretofore in the Canal Zone, is to be described in chapter B.

Echinoids.—Fragmentary remains of *Clypeaster* are fairly common in some areas. C. W. Cooke identified a complete specimen from locality 60 as *C. concavus*.

Age.—A late Oligocene age for the fossiliferous parts of the Caimito in the areas described in the preceding pages is indicated by larger Foraminifera, corals, and mollusks. Most of the mollusks just listed would not be out of place in either upper Oligocene or lower Miocene deposits. *Ampullinopsis spenceri* [late Oligocene of Antigua, Puerto Rico(?), western Panamá(?), Ecuador(?), and Perú(?)] and *Turritella meroensis* (late Oligocene of western Panamá, Ecuador, and Perú) however, indicate late Oligocene. The lower member in the Gatun Lake area, the age of which is unknown, is tentatively grouped with the middle and upper members as late Oligocene.

TUFFACEOUS STRATA IN CHORRERA AREA

Tuffaceous strata in the Chorrera area, west of the Canal Zone and south of Gatun Lake, are shown by a separate pattern on the geologic map (pl. 1) in a region of undifferentiated volcanic rocks. Though the unnamed tuffaceous strata consist principally of tuffaceous siltstone, tuffaceous sandstone, and tuff, they include bentonitic clay, conglomerate, and agglomerate. Leaf imprints are the only fossils that have been found. The unnamed strata, which may be the equivalent of part of the Caimito formation of the Gatun Lake area, are doubtfully referred to the late Oligocene.

BAS OBISPO FORMATION AND LAS CASCADAS AGGLOMERATE

The Oligocene formations so far described contain more or less volcanic material, mostly in the form of tuffaceous debris. The Bas Obispo formation and Las Cascadas agglomerate are entirely volcanic. They are interpreted to represent pyroclastic rocks and minor flows that accumulated at the periphery of a volcanic pile. The center of the pile evidently was west of the Canal Zone south of the continental divide, but presumably is concealed by later flows. At all events that region is characterized by thick volcanic rocks. Still farther out from the center of the volcanic pile the Bas Obispo formation and Las Cascadas agglomerate are thought to grade, respectively, into the Bohio and Caimito formations.

The volcanic rocks now included in the Bas Obispo formation and Las Cascadas agglomerate were described as massive igneous rocks by Hill (1898, p. 189–191), and as "roche de Gamboa" by Bertrand and Zürcher (1899, p. 86). They were named the Obispo formation or Obispo breccia by Howe (1907, p. 110–111). The emendation to Bas Obispo formation and the splitting off of the younger part as the Las Cascadas agglomerate were proposed by MacDonald (1913, p. 568). The type region of both formations is in the northern part of Gaillard Cut, where they are the oldest exposed formations. Their thickness is unknown, but the combined thickness is presumably several hundred meters. According to plate 1, near Gamboa the Las Cascadas agglomerate rests on the Bohio formation, the Gatuncillo formation, or the basement complex. Confirmation of this overlap is needed.

STRATIGRAPHY AND LITHOLOGY

The Bas Obispo formation and Las Cascadas agglomerate probably would ordinarily be combined as one formation. They differ, however, in induration and therefore have different properties in excavations. Both crop out in the northern part of Gaillard Cut and in the Gamboa area northwest of the cut. The Las Cascadas agglomerate extends farther west along the canal than the Bas Obispo formation. To the southwest both merge into undifferentiated and unmapped volcanic rocks.

According to Howe and MacDonald (in the publications just cited) and to accounts published by geologists of the Geological Section of the Special Engineering Division, both formations consist principally of agglomerate and tuff. The matrix of agglomerate of the Bas Obispo is hard sandy tuff so firmly indurated that the rock breaks through the larger constituents. Crude bedding is apparent in local thin deposits of the Bas Obispo made up of imperfectly rounded pebbles and cobbles. Such rock is not as well indurated as the agglomerate. The matrix of agglomerate of the Las Cascadas consists of soft fine-grained altered tuff and bentonitic clay. Beds of tuff in the Las Cascadas also are softer than those of the Bas Obispo. Both formations include andesitic and dacitic flow breccias and both are cut by a few andesitic dikes and by numerous basaltic dikes.

AGE

Fossils have not been found in either the Bas Obispo or Las Cascadas. They are doubtfully referred to the Oligocene because of their inferred relations to the Bohio and Caimito formations (p. 25, 28). The Bas Obispo and Las Cascadas presumably represent most of the Oligocene, not only early Oligocene as previously suggested (Woodring and Thompson, 1949, p. 228).

OLIGOCENE AND MIOCENE SERIES

CAIMITO FORMATION OF MADDEN BASIN AND PACIFIC COASTAL AREA

The Caimito formation of Madden basin, unlike that of other areas, includes both upper Oligocene and lower Miocene deposits. As shown on plate 1, in the northern part of the basin the Bohio formation is overlapped by the Caimito. The thickness of the Caimito in the basin appears to be about 450 meters. The deposits now referred to the Caimito formation were designated the Culebra formation, Emperador limestone, Caimito(?) formation, and Gatun(?) formation by Reeves and Ross (1930, p. 14–17).

The strata in the Pacific coastal area assigned to the lower part of the Caimito appear to be a direct extension of that part in Madden basin. These strata in the Pacific coastal area have an estimated thickness of not more than 250 meters.

STRATIGRAPHY AND LITHOLOGY

Madden basin.—Five members are tentatively recognized in the Caimito formation of Madden basin. The only formal member names that are used are those that have already been proposed, for detailed work may show that some arrangement other than that adopted in the present report is preferable. Two members are grouped as the lower part of the formation and the upper three as the upper part. In the following paragraphs the members are described in upward stratigraphic sequence.

The calcareous sandstone-siltstone member overlies the Bohio formation or overlaps it and rests on the Gatuncillo formation. Sandstone of this member, ranging from very fine-grained to very coarse-grained and conglomeratic, is well exposed on Río Chilibrillo upstream and downstream from the bridge on the road from Buenos Aires to Casa Larga. The sandstone is variably tuffaceous, and at least on Río Chilibrillo the member includes massive coarse-grained tuff. The exposures on Río Chilibrillo indicate a thickness of at least 200 meters.

The pyroclastic-clay member includes agglomerate, tuff, bentonitic clay, conglomerate, and limestone. Agglomerate may be seen on the Transisthmian Highway near Río Chilibre on the east side of the basin. The strata on the east side of the basin also include three lenses of limestone, two of which are exposed on the Transisthmian Highway. The thickness of the member on the east side of the basin is about 110 meters. On the west side of the basin, where the member is represented by steeply dipping clay immediately north of Río Chagres and just west of the Transisthmian Highway, the thickness is probably not more than 50 meters.

The Chilibrillo limestone member—the lowest member in the upper part of the formation—consists of lenticular limestone that has a maximum thickness of about 30 meters. Detailed mapping may show that limestone of that thickness lies at more than one horizon. The name Chilibrillo was casually used by Olsson (1942, p. 234). The type region is on the east side of the basin near Río Chilibrillo. Entrances to caves in the limestone are located at locality 81, about 150 meters west of the Transisthmian Highway, and nearby.

The calcareous sandstone member overlies the Chilibrillo limestone member, or in its absence overlies the pyroclastic-clay member and in that event is at the base of the upper part of the formation. The most accessible exposures of the medium-grained calcareous and tuffaceous sandstone are on the east side of the basin along the Transisthmian Highway. Highly calcareous sandstone is exposed at the north abutment of the Transisthmian Highway bridge across Río Chagres. The thickness of this member is about 30 meters.

The Alhajuela sandstone member is confined to a small area in the central part of the basin at and near Madden Dam. Before the construction of the dam the village of Alhajuela was located on Río Chagres opposite locality 85. (For location of Alhajuala see Reeves and Ross, 1930, pl. 5.) The massive fine- to coarse-grained tuffaceous sandstone forms the foundation of Madden Dam and the gorge of Río Chagres below the dam. Plate 7 is a view at the dam site. Fossil shells are more conspicuous in this member than in any other part of the Caimito formation in Madden basin. The thickness of the Alhajuela is 85 meters. The name, in the form "Alajuela sandstones", was proposed by Olsson (1942, p. 234, 243). The restricted usage suggested by his chart (Olsson, 1942, p. 234) is adopted in the present report.

Pacific coastal area.—The lower part of the Caimito formation appears to extend continuously from Madden basin to the Pacific coastal area. Agglomerate, tuffaceous sandstone, tuffaceous conglomeratic sandstone, and conglomerate in the region between the basin and the coastal area are thought to represent the lower part of the Caimito. The geology of this intermediate region, however, is complicated by numerous intrusive stocks, and the succession of sedimentary strata and their relations to those in adjoining areas have not been worked out. Limestone at locality 97, just east of Madden Highway, contains a small *Lepidocyclina* suggesting *L. canellei* on the basis of field identification.

In the Pacific coastal area the lower part of the Caimito is made up mainly of tuffaceous siltstone, tuffaceous sandstone, and conglomerate. Algal limestone, like that at localities 95 and 96, is a minor constituent.

FOSSILS AND AGE

Smaller Foraminifera.—Smaller Foraminifera were found in the calcareous sandstone-siltstone member of Madden basin on Río Chilibrillo: in silty very fine-grained sandstone at locality 68 and in sandy siltstone at locality 70. These collections have not been identified.

Larger Foraminifera.—*Lepidocyclina vaughani* is widespread and abundant in the calcareous sandstone-siltstone member on the west side of Madden basin, ranges throughout that member in the exposures on Río Chilibrillo, and occurs in the lower part of the formation in the Pacific coastal area. Despite an apparently favorable depositional environment, no orbitoids were observed in limestone of the pyroclastic-clay member in Madden basin. In fact, an *Archaias*-like species is the only larger foraminifer noticed in limestone of that member. The species in the table that follows were identified by Cole.

Larger Foraminifera from lower part of Caimito formation of Madden basin and Pacific coastal area

[Cole, 1952 (1953), p. 7]

	Localities			
	Madden basin			Pacific coastal area
	64	67	69	95
Heterostegina antillea Cushman	---	---	---	×
Lepidocyclina (Lepidocyclina) canellei Lemoine and R. Douvillé	×	---	---	---
parvula Cushman	---	---	---	×
yurnagunensis morganopsis Vaughan	---	---	---	×
(Nephrolepidina) vaughani Cushman	×	×	×	×
Miogypsina (Miogypsina) antillea Cushman	---	---	---	×

Mollusks.—Mollusks occur in the Caimito of Madden basin, but none was found in the Pacific coastal area. Limestone in the pyroclastic-clay member (localities 71-73) and submerged calcareous strata of the lower part of the Caimito (localities 65, 66) contain mollusks, but none of the families covered by chapter A of the present report is represented in the collections. The typical form of *Turritella altilira* occurs in the Alhajuela sandstone member at locality 89. Specimens of *T. altilira* from the Alhajuela at localities 88 and 92, and from the underlying calcareous sandstone member at localities 77 (*T.* cf. *T. altilira*) and 80, are not sufficiently well preserved to determine whether they represent the typical form. *Turritella gatunensis?* was found in the calcareous sandstone member (locality 82).

Echinoids.—According to identifications by C. W. Cooke, *Clypeaster lanceolatus* occurs in limestone of the pyroclastic-clay member (locality 71) and in submerged calcareous strata of the lower part of the Caimito (locality 66), and *Clypeaster* cf. *C. pinarensis* in the calcareous sandstone member (locality 84a).

Age.—The lower part of the Caimito formation in Madden basin, consisting of the calcareous sandstone-siltstone member and the pyroclastic-clay member, and the formation in the Pacific coastal area are considered of late Oligocene age, like the entire Caimito of other areas. The two species of larger Foraminifera from the calcareous sandstone-siltstone member in Madden basin and the five species from the Pacific coastal area are typical Caimito species and typical upper Oligocene species. The age of the pyroclastic-clay member of Madden basin is based principally on an early species of *Nodipecten* found also in the middle member of the Caimito in the Gatun Lake area.

The upper part of the Caimito in Madden basin, consisting of the Chilibrillo limestone member, the calcareous sandstone member, and the Alhajuela sandstone member, is assigned to the early Miocene on the basis of mollusks. The lower two members would be referred to the late Oligocene by those who claim that the Aquitanian and its essential American equivalents are of late Oligocene age. The Alhajuela sandstone member, however, is late early Miocene; that is, younger than the disputed Oligocene or Miocene. That it may include early middle Miocene, as suggested in a preliminary account (Woodring and Thompson, 1949, p. 236), appears to be unlikely.

Only the Oligocene part of the Caimito is recognized in the Pacific coastal area. It is overlain and perhaps partly overlapped by the Panamá formation, which is correlated with the lower part of the Miocene strata in the Caimito of Madden basin. No fossiliferous strata as young as the Alhajuela sandstone member have so far been found in the Pacific coastal or Gaillard Cut areas.

MIOCENE SERIES

CULEBRA FORMATION, INCLUDING EMPERADOR LIMESTONE MEMBER

The Culebra formation is recognized along and near the canal in the Gaillard Cut area and immediately to the southeast in the region straddling Pedro Miguel Locks. (For a large-scale map of the Gaillard Cut area see plate 2.) To the southwest presumably it merges into undifferentiated and unmapped volcanic rocks, like other formations in the Gaillard Cut area. The Culebra itself contains volcanic debris, but not nearly so much as the underlying and the overlying formations. The name for the formation, in the form "Culebra clays," was first used by Hill (1898, p. 192–195). The type region is in the central Gaillard Cut area, where the town of Culebra was located on the west side of the canal before and during the construction period. The Culebra formation unconformably overlies the Las Cascadas agglomerate. The maximum thickness of the formation is about 150 meters. The thickness decreases northward, evidently as a result of overlap of successively younger parts of the formation on the Las Cascadas agglomerate.

Coralliferous limestone exposed in a quarry near Empire attracted attention at an early date and was named the Empire limestone by Hill (1898, p. 195–196). MacDonald (1913, p. 569) changed the name to Emperador limestone, presumably because of the possibility of confusion with the Empire formation of Oregon. Empire was the American name for a town near Culebra, whereas the French used the Spanish name Emperador for the same town. The town was located on the pre-construction alinement of the Panama Railroad near Culebra, approximately at locality 117 as plotted on plate 2. The quarry near Empire (locality 118 of plate 2), which is to be regarded as the type locality of the Emperador limestone member, is overgrown and unrecognizable, and so is the similar limestone formerly exposed on a street in Empire. Limestone agreeing with descriptions of the Emperador is still exposed along the canal. These beds of relatively pure coralliferous limestone probably are at different horizons in the upper part of the Culebra formation and probably grade southeastward into calcareous sandstone (Woodring and Thompson, 1949, p. 237). Should it be demonstrated that the name is being used for limestone at different horizons, the name should be abandoned, except for the limestone at the type locality. In that event, however, a formal name would hardly be needed for a single locality, even if the locality were again found. In the meantime no serious errors should result from usage of the name. The coralliferous limestone has a maximum thickness of 15 meters. It therefore is a minor constituent and is given member rank in the Culebra formation.

The Emperador limestone member of the Culebra formation is known to occur only in the northern part of the outcrop area of the Culebra. MacDonald's representation of the Emperador as widespread and resting unconformably on formations of different age was based on misidentification of limestone in several formations (MacDonald, 1913, pl. 68). According to present interpretations, coralliferous limestone in the La Boca marine member of the Panamá formation on Río Masambí, in the Gaillard Cut area, was recently misidentified as Emperador (Woodring and Thompson, 1949, p 237).

STRATIGRAPHY AND LITHOLOGY

Stratigraphic sections of the Culebra formation in Gaillard Cut have been published by MacDonald (1919, p. 535–539) and he also published structure sections of part of the cut (Natl. Acad. Sci., 1924 figs. 4, 5, op. p. 52). He divided the Culebra into lower and upper parts. The lower part consists chiefly of dark-colored, thin-bedded or laminated, fine-grained rocks: carbonaceous or lignitic shale, carbonaceous silty mudstone, tuffaceous siltstone. It includes, however, minor beds of tuffaceous and calcareous sandstone and conglomerate. The upper part is characterized by calcareous and sandy strata ranging in thickness from 0.3 to 3.5

meters and in composition from tuffaceous and pebbly calcareous sandstone to sandy limestone. The calcareous and sandy strata are separated by dark calcareous or somewhat carbonaceous shale and mudstone. Carbonaceous strata in both parts of the formation contain land plant debris, including identifiable leaves (Berry, 1918).

Generally the Culebra formation is overlain directly by conglomerate at the base of the Cucaracha formation, marking a discontinuity, evidently a minor discontinuity. On both sides of Gaillard Cut, however, just northeast of the site of Culebra, somewhat calcareous silty sandstone and sandy siltstone interbedded with clay like that of the Cucaracha form a transition zone between the two formations. The transition zone is included in the Culebra formation. Sluicing operations carried on in 1947 on the west side of the canal, in the region where the transition zone is represented, exposed the section below. Unit 1 is at the level of the canal.

Section of upper part of Culebra formation, including transition zone between Culebra and Cucaracha formations, on west side of Gaillard Cut at canal station 1759 [2] near site of Culebra

	Meters
Transition zone between Culebra and Cucaracha formations:	
15. Clay, dark-gray, slickensided, and silty carbonaceous clay. Overlain by light-gray medium-grained locally conglomeratic sandstone taken as base of Cucaracha formation	4. 6
14. Siltstone, limonitic-weathering, dark-gray; few gypsiferous shell tips of *Turritella* weathered out	. 9
13. Siltstone, dark-gray, sandy; includes a 15-cm fossiliferous somewhat calcareous layer at base (locality 112) and fossiliferous calcareous concretions at and within 30 cm of top (locality 112a)	1. 0
12. Clay, greenish-brown, slickensided, silty	. 5
11. Sandstone, greenish-gray, silty, medium-grained; and siltstone	1. 6
10. Sandstone, brownish-gray, silty, medium-grained; and siltstone containing petrified wood	1. 1
9. Clay, limonitic-weathering, slickensided, dark-gray	1. 3
8. Clay, grayish-green, somewhat carbonaceous and somewhat fissile	2. 3
Culebra formation proper, upper part:	
7. Sandstone, light-gray, medium-grained, poorly sorted, silty, calcareous; siltstone partings	1. 5
6. Shale, dark-gray, silty, somewhat carbonaceous; includes thin layers of calcareous sandy siltstone	1. 3

[2] The canal stations are located at intervals of 100 feet (30½ meters) along the center alinement and are numbered from the Caribbean terminus to the Pacific terminus. Strictly speaking the rock exposures are opposite the stations, not at them.

Section of upper part of Culebra formation, including transition zone between Culebra and Cucaracha formations, on west side of Gaillard Cut at canal station 1759 near site of Culebra—Continued

	Meters
5. Sandstone, light-gray, medium- to coarse-grained, poorly sorted, calcareous; siltstone partings	3. 2
4. Shale, dark to black, calcareous, somewhat carbonaceous	1. 4
3. Sandstone, light-gray, medium- to coarse-grained, poorly sorted, calcareous, in beds 30 to 90 cm thick and interbedded with poorly exposed somewhat carbonaceous shale. Includes a 15-cm layer of conglomerate	8. 1
2. Sandstone, coarse-grained to conglomeratic, calcareous; contains a moderately large smooth species of oyster	. 5
1. Sandstone, light-gray fine- to medium-grained, poorly sorted, calcareous, in beds 30 cm thick and interbedded with dark to black calcareous and carbonaceous shale and mudstone. Locality 108, 1.5 m above edge of canal	4. 2
Thickness of section	33. 5

Part of the transition zone is exposed on the east side of the canal at canal station 1754. Fossiliferous strata corresponding to the fossiliferous parts of bed 13 of the preceding section are recognizable on the east side, but the best-preserved fossils are weathered out and were put in one collection (locality 110). Silicified wood is common at that locality, including segments of logs riddled with shipworm tubes (*Teredo*).

Limestone of Emperador type in the upper part of the Culebra crops out farther northwest on the west side of the canal on both limbs of a syncline near the site of Las Cascadas. At locality 120 (canal station 1600) the limestone is 6 meters thick and in a nearby core hole is 24.3 meters above the base of the Culebra. At locality 121 (canal station 1619, pl. 8) the thickness is 15.2 meters and the limestone is about 27.5 meters above the base of the Culebra. At both localities the underlying strata consist of dark carbonaceous clay and tuffaceous siltstone. The basal 30 to 60 centimeters of the limestone at locality 120 is silty and contains numerous pectinids. The limestone at locality 121 includes a basal calcareous siltstone bed that has a thickness of 15 to 30 centimeters and a middle calcareous siltstone bed 2.4 meters thick. The limestone at these two localities appears to represent the same zone and probably is the same as limestone near Tower N, a signal tower on the pre-construction line of the Panama Railroad near Las Cascadas. Fossils from "the *Pecten* bed" near Tower N were recorded by Brown and Pilsbry (1913, p. 502–503). The limestone in the Las Cascadas area is presumed to be the equivalent of calcareous sandstone in the measured section at canal station 1759. MacDonald (1919, p. 537) assigned to the Emperador "somewhat sandy limestone" at locality 99g (canal station 1606). The matrix of the numerous fossils MacDonald collected at that locality consists of sandy limestone that does not resemble the Emperador limestone.

FOSSILS AND AGE

Smaller Foraminifera.—A few species of smaller Foraminifera from the Culebra formation were recorded by Cushman (1918). Some of the localities referred to the Culebra in Cushman's publication represent other formations: Geological Survey localities 6009 and 6010 represent the La Boca marine member of the Panamá formation; localities 6024a, 6025, and 6026 the Caimito formation. Though the fauna of the Culebra is not extensive, more species than the few recorded by Cushman are represented in core collections obtained during the operations of the Geological Section of the Special Engineering Division. Meager collections can still be obtained at outcrop localities, such as localities 104 and 108. It has been claimed that *Siphogenerina transversa* is not found in the Culebra formation (Woodring and Thompson, 1949, p. 241). M. N. Bramlette, however, identified a small specimen of that species in core material from a depth of 88 feet (26.7 meters) in core hole SL108 and another small specimen from a depth of 133 feet (40.4 meters) in the same core hole. Core hole SL108 was located 1.1 kilometers west-southwest of locality 101 and evidently the Culebra formation was penetrated at the depths just specified.

Larger Foraminifera.—Cushman's identifications of the species of *Lepidocyclina* in the Culebra formation have not been confirmed (Cushman, 1918a, p. 90). H. G. Schenck identified *Lepidocyclina canellei* in core samples at horizons 30 to 45 meters below the top of the Culebra (Woodring and Thompson, 1949, p. 238). Cole recently described and illustrated *L. miraflorensis* (locality 99g) and *L. waylandvaughani* (locality 99a) from the Culebra formation proper, and *L. miraflorensis* (locality 119a) from the Emperador limestone member (Cole, 1953a). The type localities of *Miogypsina cushmani* (locality 107) and *"Orbitolites" americana* (locality 100) are in the Culebra formation. *Miogypsina intermedia* is recorded from the Culebra at locality 115 near Paraiso (Drooger, 1952, p. 36).

Corals.—Of the four species of corals recorded by Vaughan from the Culebra formation proper, one occurs in the Emperador limestone member, three in the Antigua formation, and all in the Anguilla formation (Vaughan, 1919a, p. 208; Geological Survey locality 6026 represents the Caimito formation). Vaughan listed 24 species of corals from the Emperador limestone member. Four of them occur in the Antigua formation and nine in the Anguilla formation (Vaughan, 1919a, p. 209; Geological Survey locality 6024b represents the Caimito formation and 6256 the La Boca marine member of the Panamá formation).

Mollusks.—MacDonald made numerous collections of mollusks from the Culebra formation during the excavation of Gaillard Cut. Much of the material, however, is poorly preserved. Except in the Paraiso area, the Culebra fauna includes species indicating brackish water, particularly in the transition zone between the Culebra and Cucaracha formations (localities 110 to 112a). The *Neritina*, for example, indicates brackish water and *Littorina angulifera* is a modern species that lives in mangrove swamps. Most of the species indicating brackish water are absent in the Paraiso area (localities 113 to 116). Plate 2 indicates that the fossiliferous strata in the Paraiso area are close to the top of the Culebra. It has been suggested that the uppermost part of the formation in the Paraiso area is the equivalent of the transition zone but represents an environment farther seaward (Woodring and Thompson, 1949, p. 239). According to the evolutionary scheme worked out by Drooger for miogypsinids, however, *Miogypsina intermedia*, which occurs in the Paraiso area, is less advanced than *M. cushmani*, found in the upper part of the Culebra farther northwest (locality 107), where the transition zone is not known to be present (Drooger, 1952, fig. 17, p. 72).

The following mollusks are in the families covered by chapter A of the present report:

Mollusks from Culebra formation, exclusive of Emperador limestone member (Neritidae to Turritellidae)

	98	99a	99b	99c	99d	99f	99g	99h	100	100b	104b	106	107	108b	108c	110	110a	111a	111b	112	112a	114	115a	115b	116
Neritina (*Vitta?*) sp															×										
Littorina aff. *L. angulifera* (Lamarck)																×									
Rissoina (*Zebinella?*) sp			×																						
Xenophora sp							×																		
Hipponix? sp															×										
Crepidula sp			×						×																
Calyptraea cf. *C. centralis* (Conrad)			×	×					×						×		×								
Trochita? cf. *T. trochiformis* (Born)																							×	×	×
Crucibulum sp			×	×								×										×			
Natica (*Naticarius?*) sp																×									
Polinices? sp					×				×			×											×	×	
Neverita? sp		×	×	×	×	×						×								×		×	×		
Sinum sp				×	×						×										×	×			
Globularia (*Globularia*) aff. *G. fischeri* (Dall)							?			×															
Pachycrommium? cf. *P.? trinitatensis* (Mansfield)								×																	
cf. *P. guppyi* (Gabb)																				×			×		
Turritella (*Torcula?*) *amaras* Woodring, n. sp	×		×										×	×	×	×	×	×	×	×	×				×
sp						×	×	×																	
cf. *T. subgrundifera* Dall					×																				
venezuelana Hodson			×										×			×		×		×	×	×			
cf. *T. berjadinensis cocoditana* Hodson																								×	

Collections from the type locality of the Emperador member contain only a few species of mollusks, none of which represents the families described in chapter A of the present report. Limestone in the Las Cascadas area assigned to the Emperador contains *Neverita?* sp. (localities 119a, 120) and *Turritella altilira* in the unrestricted sense (locality 120).

Echinoids.—*Clypeaster lanceolatus* and *Echinolampas semiorbis* were recorded from the Emperador limestone member by Jackson (1917, p. 490, 498).

Mammal.—In 1942 T. F. Thompson found an incomplete mammal bone in the transition zone between the Culebra and Cucaracha formations at locality 110 on the east side of the canal—the first Tertiary mammal to be found in Panamá. The following comments on this fossil and the drawings by O. J. Poe reproduced as figure 2 are available through the kindness of R. A. Stirton, of the University of California.

The bone found by Mr. Thompson is the distal part (length 78 millimeters) of a metapodial of an ungulate of medium size. It was examined by H. E. Wood, 2nd, who thought it represents a rhinoceros similar to *Diceratherium*. G. G. Simpson doubted that it is a South American ungulate, but had no material for close comparison with the leontiniids. The apparent rhinoceros affinities seemed to be conclusive until late Miocene leontiniid foot bones, collected by University of California expeditions in Colombia, were available for comparison. This material indicates that the metapodial from the Canal Zone may represent a South American leontiniid or a North American rhinocerotid.

Despite a search in 1947 and 1949, no additional mammal remains were found at or near locality 110

Age.—Douvillé (1891, p. 499) and Hill (1898, p. 195), relying entirely on lithologic similarity to lignitic strata in the Eocene of the Gulf states, suggested that the Culebra is Eocene. A review of other age assignments—Eocene, Oligocene, Miocene—would hardly be profitable. It may be pointed out, however, that Douvillé (1898, p. 591) and Bertrand and Zürcher (1899, p. 89, 90), evidently following his advice, thought that small orbitoids in strata that presumably represent the Culebra are reworked.

The fossils of the Culebra formation, including the Emperador member, have both Oligocene and Miocene affinities. The orbitoids (three lepidocycline species of *Lepidocyclina*) point to Oligocene. In fact, some paleontologists consider lepidocycline species to be decisive for an age not younger than late Oligocene. According to Vaughan's data, the corals favor correlation with the Anguilla formation of Anguilla, which contains no orbitoids. The mollusks also favor correlation with the Anguilla and other formations of the same age,

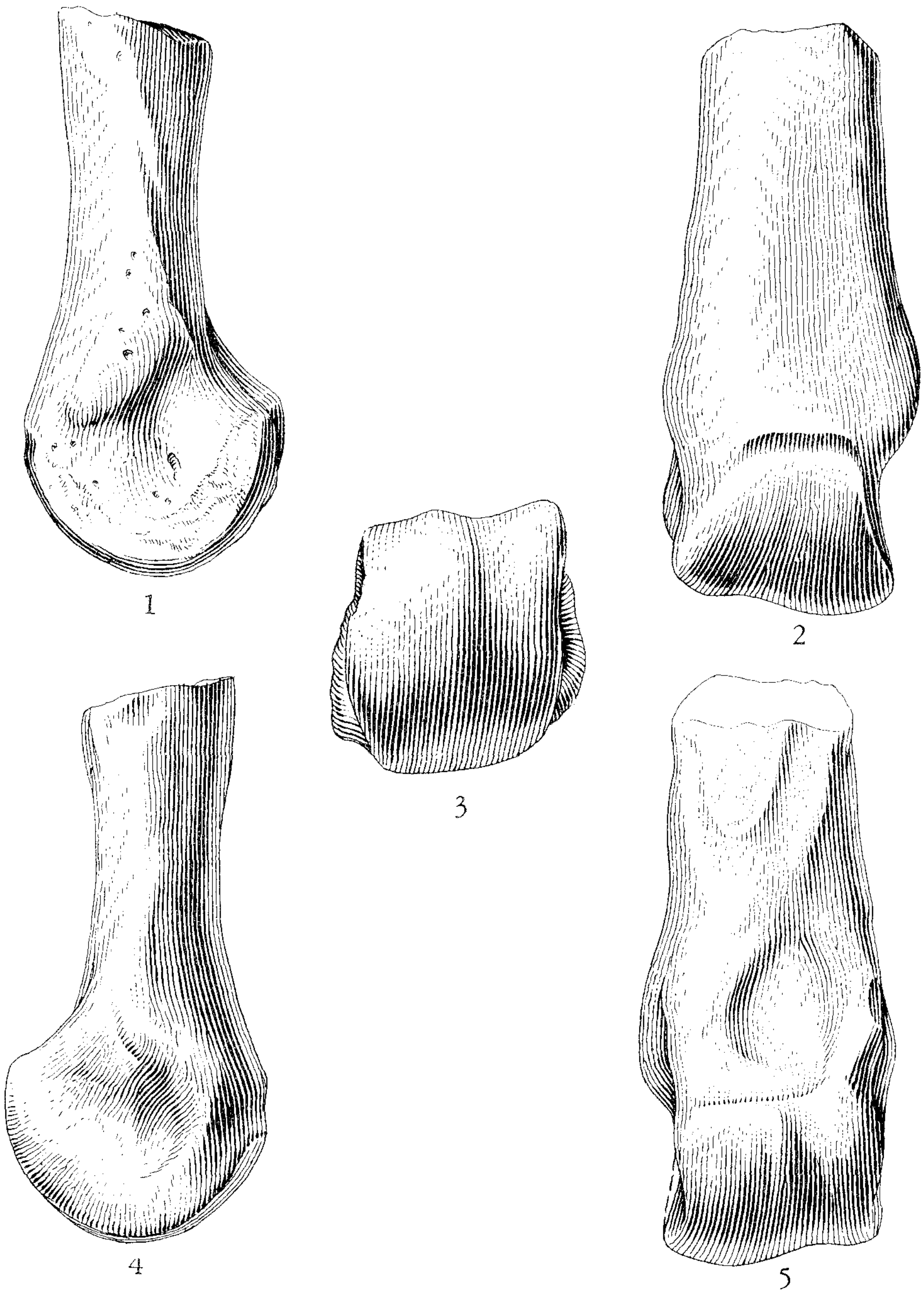

Figure 2.—Ungulate metapodial from transition zone between Culebra and Cucaracha formations. Univ. Calif. Mus. Paleontology 37363, natural size.
1, 4. Lateral views
2. Front view
3. Distal view
5. Posterior view

including the Tampa limestone of Florida, which also contains no orbitoids. None of the mollusks in the preceding list suggest species that are only of greater age than disputed Oligocene or Miocene, whereas *Littorina* aff. *L. angulifera*, *Pachycrommium?* cf. *P. guppyi*, and *Turritella* cf. *T. subgrundifera* suggest species that are only of younger age than disputed Oligocene or Miocene. Whether the Culebra formation is to be assigned to the late Oligocene or early Miocene is part of the larger question of whether the Aquitanian stage of western Europe is late Oligocene or early Miocene, for the Culebra and correlated formations are the essential equivalent of the Aquitanian. It has long been recognized that the marine type Aquitanian of the Aquitaine basin contains an early Miocene fauna. The argument concerning the age of the Aquitanian centers on the Oligocene aspect of the mammalian fauna in nonmarine strata that are thought to be the equivalent of the marine type Aquitanian. An early Miocene age for the Culebra formation agrees with the age assignment adopted by the Geological Survey for the Tampa limestone. That assignment for the Culebra, including the Emperador member, is adopted for the present report, instead of the late Oligocene(?) and early Miocene age assignment recently used (Woodring and Thompson, 1949, p. 239).

CUCARACHA FORMATION

The Cucaracha formation crops out along and near the canal in the Gaillard Cut area and southeastward to Miraflores Lake. Its distribution is much like that of the underlying Culebra formation, but it is recognized at a greater distance from the canal than the Culebra. The name was proposed by MacDonald (1913, p. 569). Up to that time the strata constituting the Cucaracha formation had been included in the Culebra. The type region is in the southern Gaillard Cut area. The site of the village of Cucaracha was on the east side of the canal between the continental divide and Paraiso. The maximum thickness of the formation is about 190 meters. The discontinuity at the base of the Cucaracha generally is sharp and marked by conglomerate, but in central Gaillard Cut a transition zone lies between the two formations. (See p. 35.)

STRATIGRAPHY AND LITHOLOGY

The Cucaracha formation is the most distinctive and the most uniform formation in the Canal Zone. It was involved in the extensive slides in Gaillard Cut during excavation of the cut and during a period of several years after the canal was opened. Its physical properties were exhaustively investigated during the studies of the Third Locks project, carried out by the Special Engineering Division.

The principal constituent of the formation is massive generally grayish yellow green waxy highly slickensided bentonitic clay. Carbonaceous and lignitic clay, clayey siltstone containing yellowish gray calcareous concretions, tuffaceous clayey sandstone, and small-pebble conglomerate that has a tuffaceous matrix are minor constituents (Thompson, 1947a, p. 16–17). A bed of dacitic welded tuff is a useful and exact datum plane. Its thickness ranges from 0.3 to 10 meters. In the type region of the Cucaracha it lies 85 meters above the base of the formation and 60 meters below the top (MacDonald, 1947, p. 9; Thompson, 1947a, p. 17). It is the only hard rock in the formation and looks much like a lava flow. In fact, it was described as a sill by Howe (1908, p. 231), as a flow by MacDonald (1913, p. 569), and was shown as a flow in MacDonald's structure sections (Natl. Acad. Sci., 1924, figs. 4, 5, op. p. 52). Later, however, it was found to be an agglomeratic tuff (MacDonald, 1947, p. 9–10; Thompson, 1947*a*, p. 16). Hand specimens show feldspar crystals, flattened little lentils of dark clay, and greenish angular rock fragments. During the investigations of the Geological Section of the Special Engineering Division this bed of tuff was known as the ash flow. Description of thin sections of the tuff and a chemical analysis are presented on pages 54, 55. Chemical analyses of six samples of clay from the Cucaracha were published in the National Academy of Sciences report on slides (Natl. Acad. Sci., 1924, p. 54) and were reproduced by MacDonald (1947, p. 10). Both reports just cited also include descriptions of microscopic and other features of the clay (Natl. Acad. Sci., 1924, p. 54–66; MacDonald, 1947, p. 12–19, 65–70). No mineralogical study of the clay by modern techniques has been undertaken.

FOSSILS AND AGE

The absence of marine fossils and the presence of plant debris in carbonaceous clay suggest that the bulk of the Cucaracha formation is nonmarine. The only plant remains recorded consist of wood (Berry, 1918). A few marine and brackish-water fossils have been found in the lower part of the formation: *Anadara* and *Crassostrea* in conglomerate and poorly preserved molds and impressions of *Anadara, Lucina?,* and *Tellina?* in carbonaceous clay (locality 122). The collection from locality 122 is the only collection now available.

In November, 1956, R. H. Stewart found the distal end of a femur in the Cucaracha formation, about 10 meters above the top of the welded tuff, at Contractors Hill, in the Gaillard Cut area at the continental divide. It was examined by R. A. Stirton, of the University of California, who reports (in a personal communication) that it may represent a North American rhinocerotid or a South American notoungulate. In other words, the uncertainty is the same as that for the metapodial from the transition zone between the Culebra and Cucaracha formations (p. 37).

The few fossils found thus far furnish no reliable evidence concerning the age of the Cucaracha. It is assigned to the early Miocene because both the underlying Culebra formation and the overlying Panamá formation are considered to be of that age.

PANAMÁ FORMATION, INCLUDING LA BOCA MARINE MEMBER AND PEDRO MIGUEL AGGLOMERATE MEMBER

The Panamá formation is the youngest Tertiary formation in the Gaillard Cut and Pacific coastal areas. It crops out in scattered areas in the central and southern Gaillard Cut area and more extensively farther southeast and east. It consists mostly of volcanic rocks, the youngest volcanic rocks in the Canal Zone. To the west it grades into undifferentiated volcanic rocks and west of the border of plate 1 volcanism continued much later.

The marine strata constituting the La Boca marine member and the agglomerate making up the Pedro Miguel agglomerate member interfinger with each other and with the lower part of the tuff and generally fine-grained agglomerate forming the Panamá formation proper. All three were formerly given formation rank (Thompson, 1947a, p. 18–19, 20; Woodring and Thompson, 1949, p. 241–242). For the time being, however, member rank appears to be preferable for the La Boca and the Pedro Miguel.

The Panamá formation was named by Hill (1898, p. 200–202). That the name was casual is indicated by the expression "so-called Panama formation" on page 206 in his publication. The formation was named for exposures along the water front in the city of Panamá, which is considered the type area. The names La Boca formation and Pedro Miguel agglomerate were proposed by Thompson (1943, p. 16–18). The Miraflores Locks area has been designated the type region of the La Boca marine member (Woodring and Thompson, 1949, p. 241) and the Pedro Miguel area is the type region of the Pedro Miguel agglomerate member. The thickness of the formation is estimated to be at least 300 meters.

STRATIGRAPHY AND LITHOLOGY

The La Boca marine member extends farther inland than any other part of the Panamá formation. It overlies the Cucaracha formation or interfingers with the upper part of that formation. Nevertheless, if the La Boca is correctly identified, it also overlaps the Cucaracha and Culebra formations and rests directly on the Bas Obispo formation. The member consists principally of silty or sandy tuffaceous mudstone, flaggy tuffaceous sandstone, calcareous tuffaceous sandstone, conglomerate, and coralliferous limestone. Agglomerate and tuff, presumed to represent tongues from the Pedro Miguel agglomerate member and the main part of the formation, respectively, are other constituents. The stratigraphic relations of these strata, most of which contain marine fossils, were not understood until the subsurface explorations of the Geological Section of the Special Engineering Division revealed evidence that they overlie the Cucaracha formation. The fine-grained strata formerly were assigned to the Culebra formation, sandstone to the Caimito formation, and limestone to the Emperador limestone member of the Culebra formation. No satisfactory outcrop section showing both a considerable part of the member and its stratigraphic relations is known. For that reason the Miraflores Locks area has been designated the type region. In that area there are outcrops, and relations to the Cucaracha formation are shown by subsurface sections. The town of La Boca, which furnished the name, was located near the entrance to Balboa Harbor, but was abandoned in 1954. Though the La Boca member overlies the Cucaracha formation, the lower part of the La Boca evidently is the southward marine equivalent of the upper part of the Cucaracha formation in the area of maximum thickness of that formation. The maximum thickness of the La Boca member is about 185 meters.

Along and near the canal the La Boca member is represented principally by mudstone in both outcrop and subsurface sections. The mudstone is similar to that in the Culebra formation, but may be distinguished by the lower content of carbonaceous matter and the richer foraminiferal fauna of the La Boca. Locality 124, on the east side of the canal at canal station 1702, is the northernmost locality where such mudstone is now known to crop out along the canal. Core drilling, however, penetrated the La Boca farther north in a syncline on the west side of the canal.

Mudstone of the La Boca exposed in the canal excavation between Paraiso and Pedro Miguel Locks (locality 130), at the north end of Mariflores Locks, and south of those locks (Geological Survey locality 6009) was described by MacDonald as part of the Culebra formation (MacDonald, 1919, p. 533–534).

Fossiliferous calcareous tuffaceous massive sandstone of the La Boca is exposed in an abandoned quarry off old Gaillard Highway near Summit (locality 128). When the cuts along the present alinement of the Panama Railroad were fresh, MacDonald found fossils in similar but less massive sandstone in cuts north and south of Summit (localities 126 to 127b.) At locality 127b the sandstone is overlain by tuff that MacDonald identified as representing the Panamá formation. (See his data in description of locality 127b, p. 124.) Fine-grained fossiliferous tuff and tuffaceous siltstone crop out at locality 132 near Red Tank, a village that has been abandoned since plate 1 was drafted. Flaggy tuffaceous strata, ranging in grain size from sandy siltstone to poorly sorted gritty sandstone, are exposed in a cliff at the mouth of Río Masambí on the east side of the canal. These strata are considered part of the La Boca member. They are unlike any strata in the Culebra formation and, like the La Boca member elsewhere, contain molds of *Acila* cf. *A. isthmica*.

Cream-colored and gray coralliferous limestone of Emperador type at the base of the La Boca member overlies, and partly interfingers with, the Cucaracha formation on Gaillard Highway 400 meters northwest of the junction with Madden Highway (locality 129). Similar limestone on Río Masambí, on the east side of the canal (locality 123), lies directly on the Bas Obispo formation and has a thickness of 35 meters, the greatest known thickness for limestone of Emperador type. A view of this limestone is shown in plate 9. It was recently identified as the Emperador limestone member of the Culebra formation (Woodring and Thompson, 1949, p. 237), but is now thought to represent the La Boca member. It is in an area where the La Boca is known to be present, although no continuity with other La Boca rocks has been established. If the limestone is now correctly identified, the La Boca member overlaps onto the Bas Obispo formation. The strata in Gaillard Cut between canal stations 1720 and 1730, described by MacDonald as "light-colored tuff bed locally overlapping Culebra beds" may possibly represent overlapping La Boca (Natl. Acad. Sci., 1924, p. 52, fig. 4). Limestone of the La Boca near Red Tank (locality 131) was referred by MacDonald to the Emperador member of the Culebra formation, and sandstone and agglomerate overlying the limestone to the Caimito formation (MacDonald, 1919, p. 534, "section at Bald Hill near Miraflores Locks"; for other locality data see p. 124). In fact, MacDonald used the section near Red Tank to define the Caimito formation and its stratigraphic relations to the Emperador limestone member of the Culebra formation (MacDonald, 1913, p. 569).

The Pedro Miguel agglomerate member is a lens of essentially coarse-grained pyroclastic rocks. In the Pedro Miguel area, the type region, these rocks overlie the Cucaracha formation. The lower part of the pyroclastic rocks, like the lower part of the La Boca marine member, apparently is the equivalent of the upper part of thick Cucaracha sections. Farther south the pyroclastics appear as a tongue in the lower part of the La Boca marine member. The pyroclastic rocks of the Pedro Miguel member, as described by Thompson (1947a, p. 18–19), consist chiefly of fine- to very coarse-grained agglomerate. Bedding and sorting are poor to moderately well developed. Fine-grained tuff is interbedded with the agglomerate. The thickness of the Pedro Miguel member is variable, but the maximum averages about 100 meters. Agglomerate of the Pedro Miguel in the Miraflores area was formerly considered part of the Las Cascadas agglomerate or was doubtfully referred to that formation (MacDonald, 1919, p. 533). Howe, however, realized that agglomerate near the continental divide rests on the Culebra formation (1908, p. 222–223). (The Cucaracha formation had not yet been differentiated.) Like MacDonald, he thought that agglomerate farther south near Corozal is of pre-Culebra age (Howe, 1908, p. 223).

Much agglomerate is known to be present in an unmapped area between Madden Highway and Curundu. It is not known, however, whether all this agglomerate represents the Pedro Miguel member, as shown on plate 1, or what rocks other than agglomerate crop out in the area.

The Panamá formation proper is made up of tuff, tuffaceous siltstone, tuffaceous sandstone, and agglomerate. They evidently represent nonmarine essentially fine-grained tuff and tuffaceous strata that interfinger with and overlie the La Boca marine member and the Pedro Miguel agglomerate member. The geologic map (pl. 1) suggests that in the Pacific coastal area the Panamá formation proper overlaps part of the Caimito formation, but that relation needs confirmation. Tuff characteristic of the Panamá formation is light gray, rhyolitic, and contains much pumice and minute fragments of glass (Hill, 1898, p. 200–201; Howe, 1907, p. 116–117). Such tuff is exposed along the water front in Panamá and in street cuts in Diablo Heights. Similar tuff near Miraflores, now included in the La Boca marine member, was informally designated the Miraflores pumice by Hill (1898, p. 198–199), a name he suppressed on a later page (Hill, 1898, p. 206). Comparison of the volcanic constituents of the Panamá and Caimito formations may afford a basis for confirming or rejecting earlier correlations of tuff in the Panamá formation with rhyolitic tuff along the canal north of the continental divide (Hill, 1898, p. 201; Bertrand and Zürcher, 1899, p. 91; Howe, 1907, p. 117). The apparent overlap of the La Boca marine member of the Panamá formation across the Cucaracha and Culebra formations indicates that their correlation deserves further consideration. In the meantime, however, it is not accepted.

FOSSILS AND AGE

The only available fossils were found in the La Boca marine member.

Smaller Foraminifera.—Smaller Foraminifera are fairly abundant in fine-grained strata. They represent a more open-sea marine environment than the meager fauna of the Culebra formation. M. N. Bramlette, who examined the outcrop sample from locality 124 and some subsurface samples, points out the abundance of *Siphogenerina transversa*. The type locality of that species (Geological Survey locality 6010, 130 of present report) is in strata of the La Boca member penetrated in the canal excavation between Paraiso and Pedro Miguel. *Siphogenerina* also is found in calcareous sandstone at locality 128. Both the type locality of *Siphogenerina transversa* and Geological Survey locality 6009 were assigned to the Culebra formation in Cushman's account of Canal Zone smaller Foraminifera (Cushman, 1918).

Larger Foraminifera.—The type locality of *Lepidocyclina miraflorensis* (locality 132a), a lepidocycline species, represents the La Boca marine member. It has been suggested that that locality is near the railroad tunnel north of Miraflores Locks (Woodring and Thompson, 1949, p. 241), but it probably is submerged by Miraflores Lake. Cole has recently described thin sections of specimens from the type lot (Cole, 1953a). He also identified and described *Lepidocyclina parvula*, also a lepidocycline species, and *Miogypsina panamensis* from locality 131a, MacDonald's locality near Red Tank.

Corals.—MacDonald found two species of corals in limestone at his locality near Red Tank (locality 131). Both were recorded by Vaughan from the Emperador limestone member of the Culebra formation and one from the Anguilla formation (Vaughan, 1919a, p. 209; Geological Survey locality 6256). The following corals, found in limestone at the base of the La Boca member at localities 123 and 129, were identified by J. W. Wells:

Corals from limestone at base of La Boca marine member of Panamá formation

[Identification by J. W. Wells]

	Localities 123	129
Stylophora imperatoris Vaughan	×	--
Stylophora macdonaldi Vaughan	--	×
Acropora saludensis Vaughan	--	×
Porites cf. *P. douvillei* Vaughan	×	×
Montastrea imperatoris Vaughan	--	×
Montastrea costata (Duncan)	×	×

According to Wells, all except one of the above species (or comparable species) occur in the Emperador limestone member of the Culebra formation and that species (*Montastrea costata*) occurs in the Culebra formation proper. Two are found in the Antigua formation and three in the Anguilla formation of the Leeward Islands.

Mollusks.—Though mollusks are widespread in the La Boca member, they are nowhere abundant and most of them are not well preserved. *Crepidula* sp. (locality 125), *Neverita?* sp. (locality 130), and *Turritella* cf. *T. collazica* (locality 123) are the only species in the families covered by chapter A of the present report.

Echinoids.—Limestone at the base of the La Boca member at locality 123 yielded an echinoid identified by C. W. Cooke as *Clypeaster concavus?*. That species occurs in the Caimito formation of the Río Mandinga area and in both the Antigua and Anguilla formations of the Leeward Islands. According to Jackson, *Clypeaster gatuni*, a Gatun species, was found in limestone in a swamp north of Ancon Hill (Jackson, 1917, p. 491). The swamp is now filled, but limestone occuring in that region presumably is in the La Boca marine member.

Age.—The Panamá formation was the first formation in or near the Canal Zone to be given an age assignment. Wagner thought that reddish conglomerate and fragmental rocks at Panamá are Permian (Wagner, 1861, p. 6, 16). Though that opinion, of course, has not been taken seriously, Hill was inclined to consider the formation pre-Tertiary (Hill, 1898, p. 202). Bertrand and Zürcher (1899, p. 90–91), however, pointed out that the tuff on the Pacific slope of the district to be traversed by the canal is younger than strata ("grès ligniteux") now referred to the Culebra formation, and Howe (1907, p. 117) came to the same conclusion.

Though the La Boca fossils and the Culebra fossils for the most part indicate somewhat different facies, they have essentially the same age significance: both have Oligocene and Miocene affinities. The La Boca member—and presumably the entire Panamá formation—is not much younger than the Culebra formation. Like the Culebra formation, it is considered early Miocene. The entire succession above the Las Cascadas agglomerate (Culebra, Cucaracha, and Panamá formations) is thought to represent the early half of early Miocene time; that is, the disputed Oligocene or Miocene. If the Panamá formation east of the Canal Zone does not include the equivalent of the Culebra formation, presumably there is a slight discontinuity between the Caimito and Panamá formations east of the Zone.

GATUN FORMATION

The two remaining Tertiary formations to be described are found in the Gatun Lake and Caribbean coastal districts. The older of the two is the Gatun formation, well-known for its rich fauna. In fact, the fossils of the Gatun formation attracted attention at an early date. When Blake traveled across Panamá in 1853 on his way to California to join one of the transcontinental railroad surveying parties, he collected a few Gatun fossils (Blake, 1857, p. 1). Two years later Newberry crossed Panamá on the same mission and also collected some Gatun fossils, but left no account of his observations. At about the same time another traveler briefly commented on fossils at Monkey Hill (now known as Mount Hope) but saw none at Gatun (Deck, 1855, p. 241). A search of books and magazine articles written by California-bound travelers during and after the gold rush doubtless would reveal other accounts.

The Gatun formation was named by Howe (1907, p. 113–114). In Spanish orthography the name is Gatún. That name, however, was not the earliest for the formation. Hill had already used the names Monkey Hill formation and Mindi Hill beds (1898, p. 176, 180). Howe, indeed, used both Gatun formation and Monkey Hill formation in a structure section in the publication in which he proposed his name (1907, pl. 147), and in a later publication used only Monkey Hill formation (1908, p. 228). MacDonald's usage apparently established preference for Howe's name (MacDonald, 1913, p. 530). The type area is the one described by Howe: from Gatun to Mount Hope (Monkey Hill of Howe's time). As a result of faulty paleontological information, Howe excluded the oldest strata near Gatun from the Gatun formation and grouped them with the Bohio formation (1907, p. 113). It is now known that the oldest outcropping part of the formation is not represented in the type region.

The outcrop area of the Gatun extends from María Chiquita, 20 kilometers northeast of Colón (pl. 1), to Río Miguel, 50 kilometers southwest of Colón (fig. 11), but much of that area has not yet been examined. The relations of the Gatun to the next older formation in the Gatun Lake and Caribbean coastal districts—the Caimito formation—are unknown. In the Canal Zone the contact between the two formations is covered by the waters of Gatun Lake and even before the flooding of the lake perhaps all of the contact was concealed by swamps. East and west of the Canal Zone, however, the Gatun presumably rests on the Caimito formation at outcrop localities, as shown on plate 1. So far as now known, no deposits of early Miocene age are included in the Caimito formation of the Gatun Lake area. The boundary between the two formations therefore is presumed to represent a discontinuity representing early Miocene time. Still farther east the Gatun formation overlaps the Caimito and directly overlies the Cretaceous(?) basement. At the west end of the outcrop area the upper part of the formation is interpreted as overlapping on the Caimito formation, not on the basement complex as previously surmised (Woodring and Thompson, 1949, p. 243).

The dip of the Gatun is low, between 5° and 10°, and flattens out northwestward toward the coast. Nevertheless a water well at Mount Hope penetrated a thickness of 425 meters of Gatun strata without reaching the base of formation (Thompson, 1947a, p. 20). The total thickness is estimated to be at least 500 meters and perhaps a considerable thickness is concealed by overlap.

STRATIGRAPHY AND LITHOLOGY

Massive medium- to very fine-grained sandstone and siltstone are the chief constituents of the Gatun formation. They are somewhat calcareous, or marly, somewhat tuffaceous, and have a clay-like matrix. The sandstone contains numerous grains of black and greenish volcanic rocks and is practically a subgraywacke, as indicated by Boutan's (1880, p. 13) early account, the only description of the microscopic petrology so far published. Conglomerate and hard brittle very fine-grained tuff make up a small part of the formation. Basalt intrudes older formations in the Gatun Lake area, but is not known to penetrate the Gatun.

The Gatun formation has been subdivided in various ways on faunal grounds (Woodring, 1928, p. 76–77; Olsson, 1942, p. 244–247; Thompson and Keen, 1946). The subdivisions adopted for the present report correspond to the three faunal zones proposed by Thompson and Keen. Though the subdivisions are based on faunal grounds, they are simply designated lower, middle, and upper parts, at least until the study of the fossils is completed. Both fossil collections and observations on the lithology, however, are scattered and eventually some other nomenclature may be found to be more satisfactory.

The lower part consists principally of medium- to very fine-grained sandstone. This part of the formation was unknown before the explorations of the Geological Section of the Special Engineering Division. In some exposures along the Transisthmian Highway and the road from the highway to María Chiquita, a basal conglomerate of variable thickness is present. It is most conspicuous along the Transisthmian Highway immediately south of Sabanita and is thin or absent along the road to María Chiquita. At locality 135 molds and impressions of marine mollusks were found in sandstone partings in the conglomerate: in the sandstone itself and in ferrugineous concretions. At some localities along the road to María Chiquita, sandstone is at the base of the formation and at others, where the base itself is not exposed, carbonaceous siltstone or mudstone, containing molds of marine mollusks, is close to the base. Fine-grained sandstone is exposed in cuts on the Transisthmian Highway between Sabanita and Cativa. Much of the sandstone, as at localities 136–138, contains numerous well-preserved fossils.

The middle part includes the best known strata: those at and near Gatun, including the strata excavated for the Gatun Locks and the uncompleted Gatun Third Locks. The three members recognized by MacDonald (1913, p. 570) and the strata he described later (1919, p. 542–543) are in the middle part. Though sandstone is the chief constituent, the middle part includes conglomerate, siltstone, and tuff. When dry the tuff is almost white and forms conspicuous outcrops in excavations. It was designated fullers earth by MacDonald.

The following section, described in a report by the Geological Section of the Special Engineering Division (Thompson, 1943a, p. 10–19, figs. 5–13 to 5–22) and by Jones (1950, p. 916–917, table 3), is exposed in the Gatun Third Locks excavation east of Gatun. The numbering of the units is that used by Thompson and Jones.

Section of strata in middle part of Gatun formation as exposed in Gatun Third Locks excavation

[After Thompson and Jones]

	Meters
12. Sandstone and siltstone	
d. Massive very fine-grained silty sandstone; thin lenses of conglomerate (thickness a few cm) made up of pebbles of volcanic rocks. Contains leached shells and few carbonized plant remains	7. 9
c. Marly siltstone	3. 3
b. Clayey marly siltstone. Contains abundant well-preserved shells and some plant remains. Locality 155c	8. 4
a. Lens of medium- to very fine-grained silty and marly sandstone	0–1. 5
11. Massive medium- to very fine-grained, silty and marly sandstone. Contains abundant shells and fragments of carbonized wood. Shells arranged in layers and concentrated in pockets. Locality 155 represents units 11 and 12	7. 5–9. 1
10. Poorly sorted conglomerate, increasingly calcareous upward. Consists of pebbles of dense volcanic rocks (maximum length 10 cm) in matrix of medium-grained sandstone. Contains shells and bits of carbonized wood. Locality 154	3. 6
9. Coarse-grained tuffaceous sandstone, consisting principally of grains of dark-colored volcanic rocks, quartz, and pumice. Uppermost 60 cm conglomeratic; thin lenses of conglomerate throughout. Contains a few shells, mostly leached	7. 2
8. Sandy and silty tuff. Grain size decreasing downward and pumice more abundant downward. Contains a few leached shells	9. 1
7. Hard, brittle, massive, very fine-grained tuff, consisting chiefly of minute glass shards. Contains rounded pieces of pumice (maximum diameter generally 5 cm)	3. 6–6
6. Coarse-grained sandstone, upper part conglomeratic	1. 2
5. Massive medium- to fine-grained, poorly sorted, somewhat tuffaceous sandstone. Contains scattered basalt pebbles, leached shells, and bits of carbonized wood	11. 5
4. Medium- to very fine-grained tuffaceous sandstone, sandy tuff, and very fine-grained tuff in beds 15 to 90 cm thick. Increasingly fine-grained, tuffaceous, and pumiceous downward	33. 5
3. Massive, medium- to very fine-grained somewhat marly sandstone. Glass shards and pumice fairly common in lowest 3 meters, decreasing upward. Contains scattered shells, echinoid fragments, and fragmentary carbonized and calcified plant remains. Locality 153*a*	21. 3
2. Hard, brittle, massive, very fine-grained tuff	1. 8

Section of strata in middle part of Gatun formation as exposed in Gatun Third Locks excavation—Continued

[After Thompson and Jones]

	Meters
1. Massive medium- to very fine-grained, silty to somewhat marly sandstone. Contains numerous shells, for most part more or less leached. Locality 153	31. 1
Thickness of section	151–156. 5

Units 1 to 4, inclusive, of the preceding section are shown in plate 10. The conglomerate forming unit 10 probably is the same bed as the conglomerate near Gatun described by Howe (1907, pp. 113–114; 1908, pp. 228–229). In his 1908 account Howe was tempted to select the conglomerate as the base of the Gatun formation (his Monkey Hill formation of that account), but his view was influenced by faulty paleontologic information. Unit 10 is stratigraphically not far from the base of the Gatun at Gatun Dam spillway as selected by Olsson (1942, p. 244–245). At all events his unconformity between the Gatun and Caimito formations, as he now realizes (personal communication), is a minor discontinuity in the middle part of the Gatun formation.

Sandy and marly siltstone seem to be the principal constituents of the upper part of the formation, at least in the Mindi (localities 171–173) and Mount Hope (localities 174–178) areas.

Both upper and middle parts are represented west of the canal. Farther south—that is, west of Gatun Lake—the upper part evidently is overlapped by the Chagres sandstone and its Toro limestone member. Collections of fossils west of the canal and west of Gatun Lake were made by A. A. Olsson during explorations for the Sinclair Central American Oil Corporation in 1918, but his map and report are no longer available. Some of the localities at which fossils were collected cannot be plotted on plate 1 and those that are plotted are located only approximately. Olsson's *Anomia* zone west of Gatun Lake is considered part of the Toro limestone member of the Chagres sandstone, not part of the Gatun formation (Olsson, 1942, p. 246–247).

No information is available concerning the Gatun formation between locality 170, west of Gatun Lake near Escobal, and the western end of the outcrop area, where the formation emerges on the coast, as shown in figure 3. Collections of fossils made by geologists of the Sinclair Central American Oil Corporation in 1918 indicate that only the upper part of the Gatun is represented in the far western coastal area. That

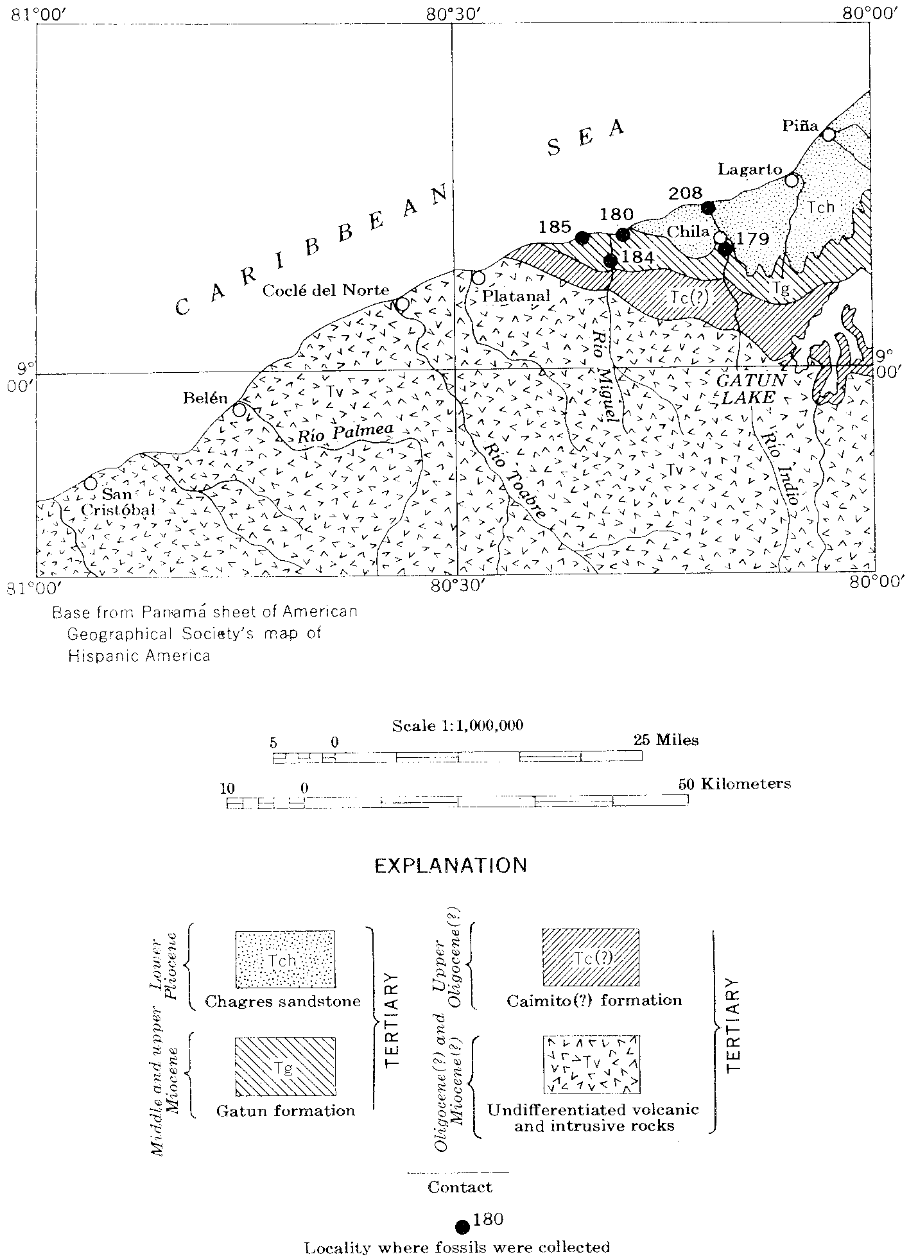

Figure 3.—Reconnaissance geologic map of Caribbean coastal part of Panamá immediately west of Canal Zone. Base from Panamá sheet of American Geographical Society's map of Hispanic America.

interpretation, however, and the areal geology shown on figure 3 need confirmation. The matrix of the fossils consists of silty very fine-grained sandstone and sandy siltstone.

FOSSILS AND AGE

Smaller Foraminifera.—Smaller Foraminifera from the Gatun formation were recorded by Cushman (1918). Marly siltstone in the upper part of the formation in the Canal Zone contains more species than those of Cushman's report.

Mollusks.—Mollusks are by far the most abundant and widespread fossils in the Gatun formation. The collections at the U. S. National Museum represent a collecting span of a century. In 1853 Blake collected three species described two years later by Conrad (1855, p. 18; 1857, p. 328, pl. 6, figs. 53–55). Only one of the fossils found by Blake is known to have survived: the type of "*Gratelupia?*" *mactropsis* [*Lirophora mactropsis*], a double-valve mold to which some inner shell material clings. Blake's form of locality citation is equivocal:

"At Gatun, or Monkey Hill?, where we stopped for a few moments, I obtained several fossil shells from the embankment at the side of the road" (Blake, 1857, p. 1). He evidently meant he was not certain whether the place where the train stopped was Gatun or Monkey Hill, although that uncertainty seems strange. Two of the three species he collected (*Lirophora mactropsis* and *Clementia dariena*) are not known to occur at Monkey Hill [Mount Hope], whereas they do occur at Gatun. The preservation and matrix of the type of *Lirophora mactropsis* strongly suggests unit 1 of the section on page 44. There is no reasonable doubt that Blake picked up his fossils at Gatun. According to the locality data in Conrad's description of Newberry's fossils, Newberry on his trip two years after Blake's also collected at Gatun (Conrad, 1857a, p. 72). Conrad recorded five species, but Gabb added eight others, including the only cephalopod to be found in the Gatun formation (Gabb, 1881). Some of Newberry's fossils have been found recently at the Academy of Natural Sciences of Philadelphia.

Other Gatun fossils of the same vintage were collected at Monkey Hill (Mount Hope of present terminology) in 1857 by J. Rowell. Some of Rowell's specimens have early Smithsonian Institution catalog numbers (6391–6395), which were entered in 1880 under the locality "Monkey Hill, near Gatun." Most of them, however, have National Museum catalog numbers entered in 1893 under the locality "near Gatun." One of the latter series of numbers has the notation "collected in 1857." It is assumed that "near Gatun" should read "Monkey Hill, near Gatun." According to Dall, Rev. J. Rowell was an old collaborator of the Smithsonian Institution and a pioneer of 1849 in California (Guppy and Dall, 1896, p. 307). Rowell also collected fossils in the Dominican Republic. Unfortunately some of his specimens, including the types of *Phos metuloides*, *Terebra bipartita spirifera*, and *Pecten scissuratus*, are alleged to be from the Dominican Republic, but evidently were collected at Mount Hope. On the contrary, a few labeled "near Gatun" apparently were collected in the Dominican Republic.

The bulk of the collections at the National Museum was gathered during the period 1911–13 by MacDonald and Vaughan. Notable later accessions resulted from the field work of Olsson and other geologists of the Sinclair Central American Oil Corporation in 1918. The most recent collections studied for the present report are Thompson's made in 1942–43 and my own resulting from the 1947 field work for the present report.

A total of 90 collections is being studied for the present report: 9 from the lower part of the formation, 58 from the middle part, and 23 from the upper part. On the basis of slight faunal differentiation, the collections from the middle part are divided into those from an eastern area (east of the canal, 43 collections) and those from a western area (west of the canal and west of Gatun Lake, 15 collections). On the basis of both faunal and age differentiation, an eastern area in the Canal Zone (15 collections) and a western area, comprising the western coastal district (8 collections), are recognized in the outcrop area of the upper part. As shown by the data in the description of localities (p. 125–129), many collections, particularly from the middle part of the formation in the eastern area, are duplicates or virtual duplicates. Three collections contain more than 100 species: those from localities 138a and 155 (both about 125 species), and locality 147b (about 110 species). The first two are among Thompson's collections from the lower and middle parts of the formation, respectively. The third, one of MacDonald and Vaughan's from the middle part, is especially rich in minute specimens, including 300 or more of *Teinostoma spermatia* and about 200 microscopic shell tips of *Turritella altilira*.

The scattered publications describing mollusks of the Gatun formation are listed on pages 5–10. The most important are those by Toula (1909, 1911), Brown and Pilsbry (1911, 1913), and Olsson (1922). Almost all the large species that occur in the middle part of the formation have been described, but most of the minute species in that part, and many of both large and minute species in the lower and upper parts are described for the first time in the present report.

The available molluscan fauna is estimated to total about 350 species. In chapter A of the present report 46 species and subspecies are described and 4 others, not represented in the collections at hand, are recorded. The species included in chapter A are tabulated on page 48. In that table "cf." in the locality columns indicates the presence of incomplete or poorly preserved material that may or may not represent the form listed opposite in the species column. Likewise the designation "sp." in the locality columns means an unidentified incomplete or poorly preserved species that may or may not be the same as that in the species column. The designation "?sp." in the locality columns indicates that the genus is questioned. The columns labeled "Other collections" list species or occurrences not represented in the collections at hand.

The table on page 48 includes two of the most characteristic species of the Gatun formation: *Turritella altilira* and *T. gatunensis*. It also includes species that have living relatives in the Pacific Ocean but not in the Caribbean Sea, and species that survived in the Pacific but not in the Caribbean Sea (*Trochita trochiformis*, *Neverita reclusiana*, and *N. helicoides*).

Echinoids.—*Clypeaster gatuni*, *Encope annectens*, *E. platytata*, *E. megatrema*, and *Schizaster panamensis* were described by Jackson (1917).

Ostracodes.—Strata in the lower part of the Gatun formation at Cativa, for which the name Cativa marl was casually used, yielded 18 species and varieties of ostracodes (Coryell and Fields, 1937).

Age.—Age assignment of the Gatun formation was off to a good start when Douvillé (1891, p. 497–498) wrote that strata at Monkey Hill, Mindi, and Gatun are Miocene, and a few years later ventured the opinion that the strata at Monkey Hill are perhaps of Helvetian age, whereas those on the upper Chagres [Alhajuela sandstone member of Caimito formation] seem to be of Burdigalian age (Douvillé, 1898, p. 592). Both age assignments are practically the same as those of the present time. Between publication of Douvillé's two reports, Dall beclouded the issue by maintaining that the strata at Gatun and Mindi are Eocene, and those at Monkey Hill Oligocene (Hill, 1898, p. 176, 180–181, 271–272, 273–274). As already outlined (Woodring and Thompson, 1949, p. 231), Dall was a victim of unfortunate circumstances so far as the Eocene part is concerned. One of Hill's collections was labelled Vamos Vamos, though there is no doubt it was collected from the Gatun formation near Gatun (locality 158), apparently from strata near the base of the middle part; that is, it was labelled as though it represents the late Eocene or early Oligocene marine member of the Bohio(?) formation. (See notations under localities 40 and 158 on p. 115, 127.) Nevertheless Dall certainly would have been suspicious had he arranged the collections according to Hill's field numbers, instead of arranging the real and alleged collections from Vamos Vamos biologically in one lot. The same mistake was made much later when an ill-advised early Miocene age was proposed for Hill's mixed fossils (Woodring, 1928, p. 76). All except a few of the alleged fossils from Vamos Vamos have Hill's field number 17 on the specimens, in the vials, or on the labels written by Dall. Two lots bear the field number 18 (a Vamos Vamos collection, locality 40a), but 17 is written on the labels. One lot of *Turritella altilira praecellens* (USNM 135160) has 18 on the label and nothing but the catalog number in the vial. Regardless of numbering, the fossils from the Gatun formation may readily be sorted out, not only because the rock matrix on microscopic examination is seen to be characteristic, but also because none of the species occurs at Vamos Vamos.

Dall's assignment of part of the Gatun formation to the Oligocene was the result of his conviction, first published in 1896 (Guppy and Dall, 1896, p. 303–304), that the Miocene of the Caribbean region (and all except the very latest of the Miocene in southeastern United States) really is upper Oligocene. Toula justly protested against an early Tertiary age for the Gatun formation, but went too far in the opposite direction in claiming that the Gatun (that is, the middle part of the formation) is of late Miocene or even Pliocene age (Toula, 1909, p. 737). For many years the Gatun formation has been considered middle Miocene. A discussion of the age would be premature until the numerous mollusks are identified. Preliminary examination suggests that in the Canal Zone the formation represents the entire span of middle Miocene time—essentially the equivalent of the Cercado and Gurabo formations of the Dominican Republic—and that the upper part in the western area, west of the Canal Zone, is late Miocene.

PLIOCENE SERIES

CHAGRES SANDSTONE, INCLUDING TORO LIMESTONE MEMBER

The youngest Tertiary marine formation, the Chagres sandstone, overlies and partly overlaps the Gatun formation. The outcrop area lies entirely west of the canal, extending from the Canal Zone southwestward along the Caribbean coast to a locality between Río Indio and Río Miguel, about 45 kilometers southwest of Colón (fig. 3). Much of the outcrop area, except in the Canal Zone and along the coast, still remains to be examined. Calcareous strata at the base of the formation throughout most of the outcrop area in the Canal Zone constitute the Toro limestone member.

The name Chagres sandstone was proposed by MacDonald for the sandstone forming the hills that overlook the coast from Toro Point to the mouth of Río Chagres (MacDonald, 1919, p. 532). The sandstone is so massive that estimates of thickness are uncertain. MacDonald's estimate of 1,000 feet (300 meters) or more may be excessive.

The Toro limestone member also was named by MacDonald, who designated it a separate formation (MacDonald, 1915, p. 26). Toro Point was specified as the type locality. Earlier MacDonald (1913, p. 570) used the informal name Caribbean limestone for this unit. The average thickness of the Toro is about 40 meters (Thompson, 1947a, p. 21).

STRATIGRAPHY AND LITHOLOGY

The Toro limestone member is a local basal calcareous deposit of variable thickness. It consists princi-

Mollusks from Gatun formation

[For explanation of symbols see p. 46]

	Localities																																
	Lower part									Middle part																							
										Eastern area																							
	135	136	136*a*	137	137*a*	138	138*a*	139	Other collections	140	141	142	144	144*a*	144*b*	146	147	147*a*	147*b*	147*c*	147*d*	147*e*	147*f*	147*g*	147*h*	147*i*	147*j*	150	150*a*	151	152	153	153*a*
"*Margarites*" sp.																																	
Calliostoma (Leiotrochus) eremum Woodring, n. sp.																						?sp											
Turbo (Marmarostoma) aff. *T. castaneus* Gmelin																																	
Tricolia? syntoma Woodring, n. sp.																																	
Neritina (Vitta?) cf. *N. virginea* (Linné)																																	
Teinostoma (Idioraphe) spermatia Woodring, n. sp.																×			×				×	×	×	?							×
angulatum trochalum Woodring, n. subsp.			×	×			×																										
(Aepystoma) andrium Woodring, n. sp.				×																						×							
(Pseudorotella) pycnum (Woodring)						×													×														
stemonium Woodring, n. sp.							×																										
(Diacrecallus) sychnum Woodring, n. sp.																			×														
Anticlimax (Anticlimax) gatunensis Pilsbry and Olsson						×	×																										
(Subclimax) teleospira teleospira Pilsbry and Olsson									×																								
hystata Woodring, n. subsp.																																	
Cyclostremiscus (Ponocyclus) pentagonus (Gabb)						×	×									×			×				×	×	×								×
Solariorbis (Solariorbis) strongylus Woodring, n. sp.						×	×																										
(Hapalorbis) hyptius hyptius Woodring, n. sp. and n. subsp.							×									×			×				×										
anebus Woodring, n. subsp.																																	
Episcynia megalia Woodring, n. sp.						×																											
"*Alvania*" aff. "*A.*" *epulaa* (Pilsbry and Johnson)			×																														
Rissoina (Phosinella) oncera Woodring, n. sp.																																	
Xenophora delecta (Guppy)																																	
Crepidula cf. *C. maculosa* Conrad				×		×													×														
plana Say					×	×	×																										
Calyptraea centralis (Conrad)				×		×	×																				cf.						
Trochita trochiformis (Born)		×	×																														
Crucibulum (Crucibulum) chipolanum Dall																																	
(Dispotaea) springvaleense Rutsch				×	×	×	×	×								×			×			×	?	×	×					×	×		
Cheilea princetonia Brown and Pilsbry																																	
Natica (Natica?) bolus Brown and Pilsbry						×						×	?						×					×									
(Naticarius) canrena (Linné)																																	
stenopa Woodring, n. sp.		×		×	×	×	×									×			×					×	?					×			
Stigmaulax guppiana (Toula)				×	×	×	×					×				×	?		×				×	×	×				×	×		×	×
Tectonatica agna Woodring, n. sp.																×			×				×	×	×					×			×
Polinices canalizonalis (Brown and Pilsbry)			×																														
brunneus subclausus (Sowerby)																																	
stanislas-meunieri Maury		×	×	×		×	×			×						?			?					?	?								
Neverita (Glossaulax) reclusiana xena Woodring n. subsp.			×	×	×										?sp.																		
(Hypterita) helicoides (Gray)			×																														
Sinum gatunense (Toula)																																	
euryhedra Woodring, n. sp.					×																												
gabbi (Brown and Pilsbry)																			×														
Turritella (Torcula) altilira Conrad, s. l.								×												cf.		×									×		
altilira altilira Conrad					×		×				×	×				×			×				×	×	×				×	×		×	×
altilira praecellens Pilsbry and Brown			×	×		×	×						cf.																				
abrupta Spieker														×																			
matarucana Hodson	?	×	×	×	×		×							?																			
gatunensis gatunensis Conrad			×	×	×	×	×	sp.		×	×		×	?				×			×	×				×			×			×	
rhytodes Woodring, n. subsp.																																	
mimeles Brown and Pilsbry											?																	×					
bifastigata Nelson				×	×																												

(Trochidae to Turritellidae)

[For explanation of symbols see p. 46]

Localities																																													
Middle part																										Upper part																			
Eastern area													Western area													Eastern area															Western area				
154	155	155a	155b	155c	156	157	158	159	159a	159b	160	Other collections	161	161a	161b	161c	161d	162	162a	165	166	168	169	170	170a	163	171	172	173	173a	174	175	176	176a	177	177a	177b	177c	177d	178	182	182a	183	184	185
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												×																																	
	×			×		×							×	×		×	×	?sp.						×	×							×		×			×	×					×		×
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pally of lime-cemented coquina made up of small fragments of barnacles, shells, echinoid spines, and corals (pls. 11, 12). Barnacle fragments predominate at many localities and cross-bedding is common. Lenses of medium- to coarse-grained sandstone occur in the coquina. Descriptions of outcrops of the Toro have been published by MacDonald (1919, p. 544–545) and Olsson (1942, p. 246).

The Chagres sandstone proper is made up of massive generally fine-grained sandstone and some siltstone (pl. 13). Unlike the Gatun formation, the Chagres is not known to include conglomerate or tuff, and the sandstone itself contains less volcanic material than sandstone of the Gatun.

FOSSILS AND AGE

Mollusks.—A few molds of mollusks from Olsson's *Anomia* zone are included in the families covered by chapter A of the present report: *Calliostoma?* sp. and *Turritella gatunensis?* from locality 194; *Turritella altilira* s. l. from locality 195; *Turbo* aff. *T. castaneus*, *Turritella gatunensis?*, and *Turritella mimetes?* from locality 195. Olsson's *Anomia* zone (Olsson, 1942, p. 246–247) appears to be part of the shallow-water calcareous deposits forming the overlapping Toro limestone member of the Chagres sandstone rather than part of the Gatun formation.

A new species of *Calliostoma*, *C. metalium* (localities 206, 206a), an unidentified mold of *Crucibulum* (locality 201), and *Stigmaulax guppiana* (locality 208) occur in the Chagres sandstone proper. The mollusks of the Chagres sandstone proper, unlike those of the Toro limestone member, indicate deposition in water of moderate depth.

Echinoid.—A large species of *Clypeaster*, found in the Toro limestone member at locality 196 (Olsson's *Anomia* zone), is identified by C. W. Cooke as *C.* aff. *C. bowersi*. *C. bowersi* occurs in the Imperial formation of the Colorado Desert, of disputed Miocene or Pliocene age (probably late Miocene).

Age.—The Chagres sandstone is close to the border between Miocene and Pliocene; it has been assigned to both series. Preliminary examination of the mollusks suggests early Pliocene, despite the presence of a few Gatun species, such as *Stigmaulax guppiana*, and of other species that have Gatun affinities.

PLEISTOCENE SERIES

STRATIGRAPHY AND LITHOLOGY

Pleistocene marine deposits occur at altitudes of a few feet above sea level and in the seaward part of buried valleys are interbedded with swamp and stream deposits. Swamp and stream deposits filling buried valleys extend as far inland as Gamboa on the Caribbean side of the Canal Zone and as far as Miraflores Locks on the Pacific side (Thompson, 1947a, p. 22). Black organic muck is the most widely distributed type of deposit. In fact, the geologists of the Geological Section of the Special Engineering Division used the informal designations Atlantic muck and Pacific muck for the Pleistocene deposits (Thompson, 1947a, p. 22). According to Thompson's description, much of the black muck represents swamp deposits and is a mixture of silt, very fine-grained organic debris, and partly carbonized wood, stems, and leaves. Layers of marine fossils are found in black organic silt and calcareous mud containing plant matter. They were encountered at the north end of the excavation for the Gatun Locks and in ditches in swamps north and east of Mount Hope (Brown and Pilsbry, 1913, p. 493–494; MacDonald, 1919, p. 544). Brown and Pilsbry casually used the name Mount Hope formation, which they attributed to W. B. Scott, for Pleistocene strata near Mount Hope (Brown and Pilsbry, 1913a, p. 493).

FOSSILS AND AGE

Corals.—Corals in collections from localities near Mt. Hope have been listed by Brown and Pilsbry (1913a, p. 497) and Vaughan (1919b, p. 563). They evidently represent reef-flat species.

Mollusks.—A few new species of mollusks were described by Dall (1912, p. 1–6) and Brown and Pilsbry (1913a). Brown and Pilsbry listed the species in the two collections they studied. The few species in their collection from the north end of the Gatun Locks excavation indicate brackish water and the deposits themselves point to deposition in a swamp. The depositional environment of the large number of marine species in their collection from a locality near Mount Hope, and in MacDonald's collections from the same region, is uncertain on the basis of published data.

Contrary to Dall's statement (1912, p. 1), MacDonald's collections from the Caribbean side do not contain any species now living along the Pacific side.

The Pleistocene mollusks are not described in the systematic part of the present report.

Age.—With the exception of the new species of mollusks, the identified fossils from the Pleistocene marine deposits on the Caribbean side of the Canal Zone are known to be living in the Caribbean Sea. Dall, and Brown and Pilsbry realized that their new species may be found to be living when the fauna along the Caribbean coast of Panamá is better known. The Pleistocene deposits—at least the marine deposits—probably are of late Pleistocene age, but may be too old for radiocarbon dating.

CORRELATION OF TERTIARY FORMATIONS IN DIFFERENT AREAS

Correlation of the Tertiary formations in different areas and age assignments, as adopted in the present

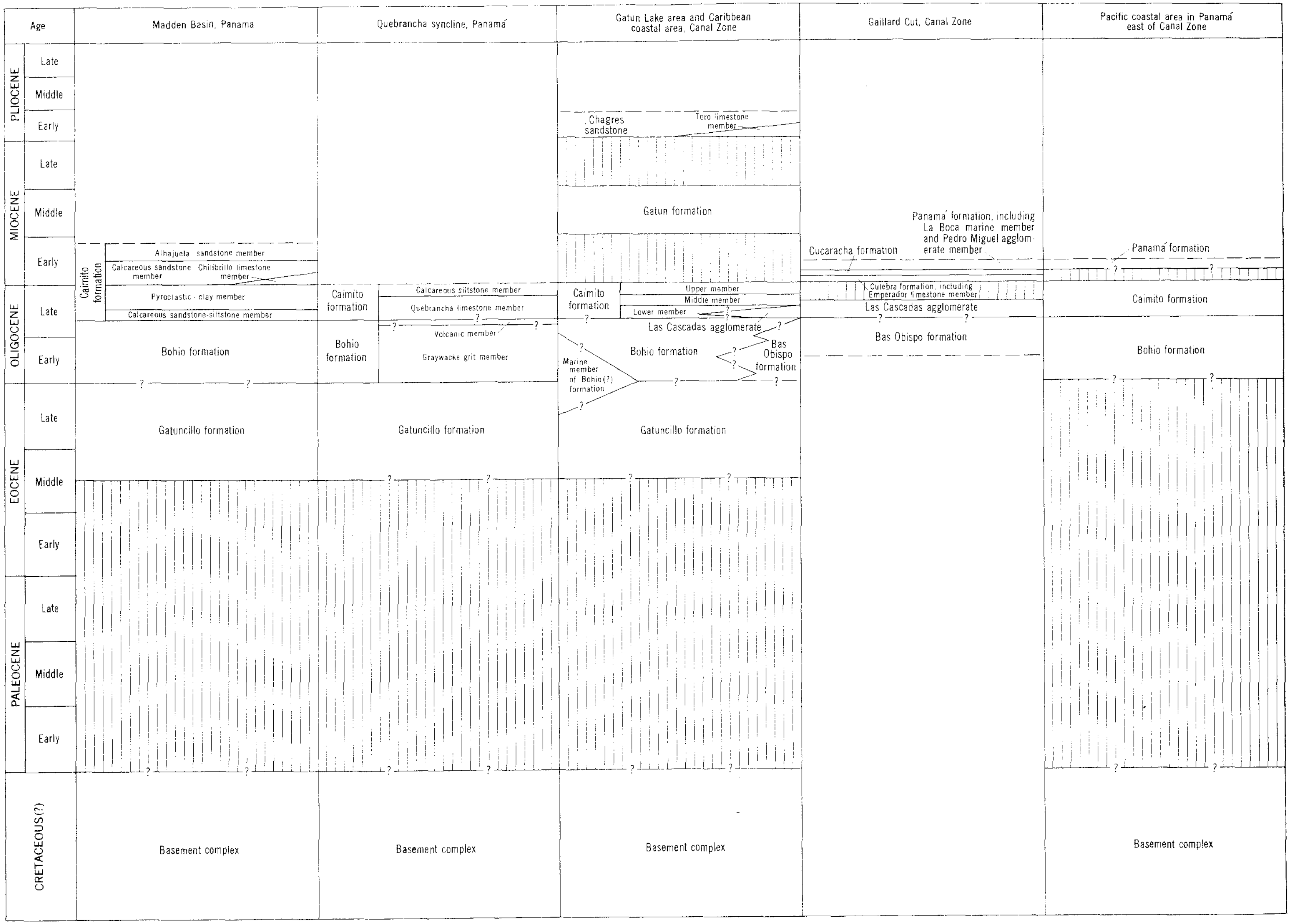

FIGURE 4.—Correlation of Tertiary formations in different areas.

Broken horizontal line indicates top or base of formation is not represented. Vertical ruling indicates hiatus.

report, are shown in figure 4. Some features cannot be shown properly in figure 4: the age assignment for the Bas Obispo formation and Las Cascadas agglomerate is Oligocene(?), despite the seemingly definite position on the chart; the age assignment for the marine member of the Bohio(?) formation of the Gatun Lake area is late Eocene or early Oligocene, not late Eocene and early Oligocene as the chart suggests.

The correlations differ only in some minor details from those of Woodring and Thompson in 1949 (fig. 2). The following changes have been made in age assignments: Gatuncillo formation, middle and late Eocene instead of late Eocene; Bohio formation of all five areas, early and late Oligocene instead of only early Oligocene (except in Pacific coastal area, which was not shown in the 1949 chart); Culebra formation, including Emperador limestone member, early Miocene instead of late Oligocene(?) and early Miocene; upper part of Gatun formation in western area (not shown in figure 4), late Miocene, instead of middle or late Miocene; Chagres sandstone, early Pliocene instead of late Miocene or early Pliocene. Though the Bas Obispo and Las Cascadas formations are still considered Oligocene(?), they are given a greater probable time range in the Oligocene.

Some of the proposed correlations are unsatisfactory. There is no satisfactory faunal or lithologic correlation between Madden basin and the Gaillard Cut area. On the contrary, at least parts of the Caimito formation of the Quebrancha syncline, the Gatun Lake area and the Pacific coastal area can be correlated with the lower part of the Caimito of Madden basin on fairly satisfactory faunal grounds. Plate 1 shows at a glance that Gaillard Cut and the Pacific part of the canal are close to the eastern border of a pile of volcanic rocks. Madden basin, the Quebrancha syncline, and the Gatun Lake area are farther seaward in the marine basin. The coarse pyroclastic rocks and flows of the Bas Obispo formation and Las Cascadas agglomerate, and the coarse pyroclastic rocks in the Panamá formation represent seaward extensions of volcanic rocks from the volcanic pile. In Madden basin and the Quebrancha syncline such rocks are much thinner and are found only in the volcanic member of the Bohio formation and the pyroclastic-clay member of the Caimito formation. Pyroclastic deposits in the Gatun Lake area are of much finer grain than in Gaillard Cut. Tuffaceous debris is present in the Tertiary formations of all the area, but is more dominant in the Gaillard Cut area and the Pacific part of the canal than in Madden basin, the Quebrancha syncline, or the Gatun Lake area. The Cucaracha formation, for example, consists almost entirely of altered volcanic ash.

The lack of studies of the pyroclastic rocks and the tuffaceous constituents of other rocks is the most serious deficiency in present knowledge of the geology of the Canal Zone and adjoining parts of Panamá. Such studies are likely to yield clues to correlations of the formations that may be more convincing than the faunal correlations.

IGNEOUS ROCKS

The following brief account of the igneous rocks is based principally on MacDonald's manuscript on the geology of Panamá mentioned on page 4. Much of the original manuscript, including some pages of the part dealing with the igneous rocks, is not preserved and his rock specimens and thin sections are no longer available. MacDonald's 1915 publication (p. 27–30) contains more data on the igneous rocks than his other publications.

The igneous rocks may be divided into two age groups: Cretaceous(?) and Tertiary. That classification embodies the chief addition to MacDonald's treatment.

CRETACEOUS(?) VOLCANIC AND INTRUSIVE ROCKS

Altered basaltic and andesitic lavas are the most common rocks in the basement complex, at least along the Transisthmian Highway and the pipe-line road in the eastern part of the Canal Zone. Two samples from the eastern part of the Canal Zone were examined by W. S. Burbank, who reports that the rocks are similar in texture and composition to the basalt-andesite rocks of the Southern Peninsula of Haiti (Woodring, Brown, and Burbank, 1924, p. 320–330). Chlorite, calcite, and a little epidote are the principal alteration products in the two samples.

Basalt containing unaltered olivine is exposed on Quebrada López (between Sabanita and Río Agua Clara) at the Transisthmian Highway bridge. According to R. H. Stewart, similar olivine-rich basalt crops out in an extensive area northeast of the highway.

Andesite at Porto Bello—the colonial settlement 35 kilometers northeast of Colón—is presumed to be part of the basement complex. As described by MacDonald, the rock is dark. Under the microscope it is markedly porphyritic and the phenocrysts are andesine, labradorite, bronzite, and some augite. The groundmass is largely glassy, but contains some minute crystals of plagioclase. This rock was used for concrete in the construction of Gatun Locks and great slabs were quarried for armoring the Limon Bay breakwaters.

The Cretaceous(?) lavas are intruded by dioritic rocks and dacitic porphyry. Though no debris from these intrusive rocks was noticed at the few localities where conglomerate of the Gatuncillo formation was observed, they probably antedate the Gatuncillo formation and probably are of late Cretaceous, Paleocene, or early Eocene age. Cobbles of granodiorite, found by MacDonald in the gravels of Río Chagres and in conglomerate of the Bohio formation, presumably represent a group related to the Cretaceous(?) dioritic rocks.

TERTIARY VOLCANIC AND INTRUSIVE ROCKS

Though Tertiary lavas are found east of the canal and are widespread west of the canal, most of the Tertiary igneous rocks described by MacDonald and selected by him for chemical analysis were obtained from intrusive bodies.

GRANULAR INTRUSIVE ROCKS

Quartz diorite.—Cocovi Island, a small island in Panamá Bay west of the entrance to the canal, was found by MacDonald to be made up of quartz diorite porphyry. The rock is light gray but weathers almost white. It is markedly porphyritic, the phenocrysts, up to 6 millimeters in diameter, consisting of andesine, andesine-labradorite, some quartz, and a little orthoclase. Some of the feldspars are partly saussuritized. The ferromagnesian minerals are highly altered and for the most part unidentifiable; a few outlines of hornblende crystals were recognized. Though the finely crystalline groundmass is somewhat cloudy and altered, it seems to consist of plagioclase and shreds of ferromagnesian minerals. Magnetite, apatite, and chlorite are found in the rock. A chemical analysis of the porphyry is included in the table on page 55 (analysis 1).

Augite quartz diorite forms Point Farfan, on the west side of the Pacific approach to the canal at the ferry terminus opposite La Boca. At Point Farfan, like on Cocovi Island, MacDonald obtained, by blasting, rock that proved to be considerably altered, although of fresh appearance. The quartz diorite at Point Farfan is gray and weathers light gray. In hand specimens it is slightly porphyritic and the groundmass is granular and almost medium grained. In thin sections andesine and somewhat altered augite are conspicuous. Quartz is present in small irregular masses, some of which appear to be secondary. Many small shreds of highly altered indeterminable ferromagnesian minerals were observed. Magnetite and apatite are accessory minerals and chlorite is the chief secondary mineral. The rock was analyzed and the results of the analysis are presented in the table on page 55 (analysis 2).

Dacite.—The rock forming the Ancon Hill stock (between Ancon and Balboa), as well as Naos Island and Culebra Island in Panamá Bay, was described as rhyolite by Howe (1908, p. 230–231) and MacDonald (1915, p. 28–29). In his manuscript MacDonald points out that although the rock has the appearance of rhyolite and some thin sections show as much quartz as shown by many rhyolites, the chemical analysis and additional microscopic examination show that it is dacite.

The dacite at Ancon Hill is light gray and weathers to a light creamy color. As described by MacDonald, it has a fine-grained texture and some lathlike phenocrysts of plagioclase, the largest of which have faces measuring about 1 by 5 millimeters. In thin section the rock shows flow structure, particularly around the phenocrysts, which consist principally of andesine and some albite. Quartz in irregular grains, some augite, and a few small greatly altered needles of hornblende are present. The phenocrysts are widely scattered and grade in size into the coarser particles of the groundmass. Though the groundmass is somewhat cloudy and altered, it consists principally of perthitic aggregates of orthoclase and plagioclase and some quartz and feldspar intergrowths. Accessory minerals, in order of decreasing abundance, are magnetite, ilmenite, and apatite. A considerable amount of chlorite is present and scattered patches of an unidentified light yellowish secondary mineral show in the groundmass. (See analysis 3, p. 55.) W. S. Burbank suggests that MacDonald's description and the chemical analysis indicate that the rock is considerably altered, principally by processes allied to albitization. During the construction of the canal a quarry on the west face of Ancon Hill, at a locality now known as Quarry Heights, furnished great quantities of this dacite for use in concrete in the construction of Miraflores and Pedro Miguel Locks.

The stocks of porphyry between the canal and Madden basin, northeast of Gaillard Cut, include dacite porphyry, according to geologists of the Geological Section of the Special Engineering Division. The porphyry intruding the Gatuncillo formation in the Río Casaya area (locality 38), for example, is dacite porphyry. The borders of this stock and the intruded rocks are slightly mineralized and some mining operations were carried on many years ago, as described on p. 59. MacDonald thought some of the rock in this area probably is granodiorite, but he found nothing suitable for microscopic examination.

Diorite.—A minor facies of the quartz diorite at Point Farfan is described by MacDonald as quartz-bearing gabbro. W. S. Burbank, however, points out that MacDonald's description of the mineralogical composition and the chemical analysis indicate a classification near diorite. The rock is dark gray, medium-grained, and equigranular. The principal minerals, arranged in approximate order of relative abundance, are andesine, augite, and oligoclase. Quartz in small irregular patches is a minor constituent, which W. S. Burbank suggests may be secondary. Accessory magnetite, apatite, and ilmenite are present. Chlorite is found in the rock and some of the feldspars show slight saussuritization. W. S. Burbank points out that the soda content of the analysis of this rock on page 55 (analysis 4) is slightly high for normal diorite and suggests that the alteration recorded by MacDonald may indicate weak albitization.

Andesite.—Andesite porphyry forms some of the stocks in the area between the canal and Madden basin. A small stock of hornblende andesite, characterized by conspicuous needles of hornblende, is being quarried along the road between Miraflores Lake and the Trans-isthmian Highway.

DIKE ROCKS

Andesite.—Andesitic dike rocks that cut the Las Cascadas agglomerate are mentioned by MacDonald.

Basalt.—Dikes and small irregular intrusive bodies of almost black rocks, all grouped as basalt, are widely distributed southwestward from the southeastern part of the Gatun Lake area and the southern part of Madden basin. The irregular intrusive bodies form hills; in fact, most of the high hills in the southeastern part of the Canal Zone are formed by intrusive or extrusive basalt.

Basalt obtained from dikes at 10 localities, for the most part in Gaillard Cut, was examined by MacDonald. These rocks are very dark and fine-grained. Labradorite, andesine, and augite are the principal constituents among the larger crystals. Some of the 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. Some chlorite and a few patches of serpentine—possibly an alteration product of olivine—are present.

Basalt from a dike on the Panama Railroad 3 kilometers northwest of Monte Lirio was selected for chemical analysis. (See table, p. 55, analysis 5.) As described by MacDonald, the rock is of coarser texture than the usual basalt in the Canal Zone and its feldspars are more calcic. Hand specimens show crystal faces of pyroxene that shine with a resinous luster and have a maximum diameter of 4 millimeters. Under the microscope the largest phenocrysts are seen to be augite. The feldspar crystals, slightly in excess of the ferromagnesian minerals, are for the most part labradorite and some of them are zoned. A little andesine is present. Augite occurs in granular aggregates as well as in phenocrysts. Magnetite, apatite, some ilmenite, and a few small grains of zircon are present. Secondary minerals consist of numerous patches of iron oxide(?), some serpentine that may be an alteration product of olivine, and a few small patches of chlorite. Some of the feldspar crystals are partly saussuritized and in zoned crystals the alteration is zonally selective. This rock was quarried for use in facing the water-level part of Gatun Dam.

VOLCANIC ROCKS AND TUFF

Dacite.—Dacitic glassy lava from the Las Cascadas agglomerate is included in the rocks selected for chemical analysis (see analysis 6, p. 55). According to MacDonald's description, the glassy lava forms the matrix of thin flow breccia. The brecciated fragments enclosed in the glassy matrix consist chiefly of pyroclastic rocks of the Las Cascadas. Some of the glassy lava contains elongated gas cavities drawn out in the direction of flow.

The hard dacitic tuff in the Cucaracha formation, mentioned in the description of that formation, was also analyzed (analysis 7, p. 55). Thin sections of the tuff were examined by W. S. Burbank and R. L. Smith, who found it to be a welded tuff. The glassy base consists of compressed glass shards, for the most part partly or entirely altered to clay. Some of the plagioclase (andesine-labradorite) crystals are euhedral; others are fragmental. Decomposition products of a few unidentifiable ferromagnesian minerals are recognizable and the rock has a few veinlets of calcite. Fragments of finely crystalline lavas of varying composition are scattered through the tuff. The dark little lentils, conspicuous in hand specimens, consist of saponite (a clay mineral of the montmorillonite group), evidently an alteration product of compressed pumice lapillae.

Andesite.—MacDonald mentioned andesitic flow breccias and dark coarse-grained andesitic flows in the Las Cascadas agglomerate.

Basalt.—Some of the basalt in the southern part of the Canal Zone consists of remnants of flows and the undifferentiated volcanic rocks in the southwestern part of the map area include much basaltic lava.

A flow remnant capping Gold Hill, which forms the continental divide on the east side of Gaillard Cut, is described by MacDonald as dark fine-grained basalt. The larger crystals consist of feldspar, mostly labradorite, and augite. Augite also occurs as grains and irregular aggregates. The groundmass is distinctly crystalline, though very fine-grained. It has about the same composition as the larger crystals. Small grains and irregular aggregates of magnetite, some apatite, and a little ilmenite are scattered through the rock. Epidote in light and dark yellow irregular patches fills cracks in broken feldspars and occurs as cloudy masses in the interior of some feldspar crystals. The thin sections show no olivine, but a light yellow secondary mineral may represent altered remnants of olivine. A chemical analysis (No. 8) of this rock is included in the table on page 55.