OCCASIONAL PAPERS

OF THE

CALIFORNIA
ACADEMY OF SCIENCES

No. XXIII

A Geological Reconnaissance of Panama

By ROBERT A. TERRY

SAN FRANCISCO
PUBLISHED BY THE ACADEMY · 1956

A Geological Reconnaissance of Panama

BY

ROBERT A. TERRY

SAN FRANCISCO
CALIFORNIA ACADEMY OF SCIENCES
1956

OCCASIONAL PAPERS NO. XXIII
OF THE CALIFORNIA ACADEMY OF SCIENCES
Issued March 2, 1956

CONTENTS

Illustrations

A Geological Reconnaissance of Panama

INTRODUCTION

Sources and Acknowledgments

This paper is based primarily on field work conducted by the author in the Republic of Panama between the years 1920 and 1949. Much of the exploration was carried on as an independent undertaking, pursued as time and opportunity offered. But of the period involved, seven years were spent in the service of the Sinclair Panama Oil Corporation, to whose parent companies, the Sinclair Oil Company and the Cities Service Company, the writer is indebted for the privilege of publishing material from the files, including not only his own work, but that of a previous party which covered a considerable part of the area in 1917 and 1918, as well as material derived from well logs, and results of paleontological examinations of collections from wells and from the field. In this connection, gratitude is especially due to Mr. F. A. Bush, Dr. W. B. Heroy, and the late Mr. A. C. Veatch.

The Gulf Oil Company has given generously of its store of information acquired over years of exploration and drilling in the Garachiné area of Darien Province. The Panama Corporation of Canada, Ltd., through Messrs. Beresford, Benagh, and Retallac, furnished maps and information; and other members of its staff gave advice and assistance in the study of Panama's most famous mine, the Espíritu Santo, of Cana in Darien Province. The officials and staff of the United Fruit Company and its subsidiary, Chiriquí Land Company, have rendered innumerable services of many kinds. Gratitude is especially due to Mr. H. S. Blair, former manager; Mr. Rudolph Jensen, one-time chief engineer; and Mr. F. W. Genuit, once special agent; all of the Chiriquí Land Company at Puerto Armuelles.

Many officials of the Republic of Panama have offered encouragement and assistance, including two presidents of the Republic, Dr. Harmodio Arias Madrid, president from 1932 to 1936, whose letter to local officials greatly facilitated the work during this period; and the late Don Domingo Dias Arosemena, president in 1948 and 1949, to whom the writer is indebted for the opportunity to study in detail the aerial photographs of the Republic.

From various members of the staff of the Panama Canal, particu-

larly the late Mr. R. Z. Kirkpatrick, for many years Chief of Surveys of the Bureau of Maintenance and Operations, there has been received much valuable information and assistance. Dr. D. F. MacDonald, late Geologist of the Panama Canal, and his successor, Mr. T. F. Thompson, placed much information at the writer's disposal, and offered opportunities to visit areas otherwise inaccessible.

Dr. T. W. Vaughan, of the United States Geological Survey, furnished the results of a preliminary examination of fossils submitted to him jointly by Mr. A. A. Olsson and the writer. Dr. G. D. Harris of Cornell University and Dr. H. N. Coryell of Columbia University generously undertook the identification of fossil collections; and other paleontologists, notably Dr. Katherine Van Winkle Palmer, G. D. Tash, and A. D. Brixey, Jr., furnished fossil identifications and offered useful suggestions. Dr. L. G. Hertlein of the California Academy of Sciences and Mr. C. C. Church, research associate of the same institution, and Dr. Hans Thalman of Stanford University checked the nomenclature of the foraminifera identified from well cuttings, and also the mollusks collected in the field. Dr. E. R. Dunn of Haverford College generously took time to collect rock specimens and make geologic observations in the highest part of the Azuero Peninsula, a region from which no other information was available.

However, more than to any other individual, the writer is indebted to A. A. Olsson for advice, encouragement, and active assistance in field and office.

The Lake Nicaragua, Panama, Bogotá, and Barranquilla sheets of the 1:1,000,000 map published by the American Geographical Society of New York, the Lake Nicaragua, Panama Canal, Peninsula of Azuero, and Cape Corrientes sheets of the World Aeronautical Chart, published by the Aeronautical Chart Service of the United States Air Force, have furnished the topographic basis for the maps of the land areas, supplemented by various maps of surveys by the Department of Maintenance and Operation of the Panama Canal, and by maps of the various oil, mining, and fruit companies listed above. In some areas, where no such surveys have been made, the writer has made his own.*

The positions of the isobaths have been taken from the 1:5,000,000 "Map of the Americas" of the American Geographical Society of New York, and from many of the charts issued by the Hydrographic Office

*Discrepancies between elevations as given in the text and as shown on the map are due to recent information arriving too late for inclusion in the map. The elevations cited in the text are taken from the World Aeronautical Charts published by the Aeronautical Chart Service, U. S. Air Force, Washington, D. C., as follows:

769. Panama Canal, Canal Zone-Colombia-Panama. 8th edit. revised, December, 1953.
829. Cape Corrientes, Colombia-Panama. 7th edit., April, 1954.
830. Peninsula of Azuero, Costa Rica. 5th edit., August, 1953.

of the United States Navy, of which charts numbers 2015a, 5011a, 5013a, and 1176 have been particularly useful for areas outside the continental shelf. In addition, the writer secured from the Hydrographic Office, photostats of the "smooth sheets" for most of the Pacific coast and for the Caribbean coast of the Province of Bocas del Toro, and adjacent shores of Costa Rica. Since the "smooth sheets" contain all the soundings instead of the three to five per cent usually shown on the Hydrographic Charts as issued, an enormous amount of detail is made evident which would be unsuspected from a study of the Hydrographic Office charts. Canal Zone geology as shown is adapted from the published maps of MacDonald (1915) and Jones (1950) with some slight modifications.

In 1934, the writer, at the request of Professor Charles Schuchert, submitted to him for publication in his "Historical Geology of the Antillean-Caribbean Region," a geologic map of Panama which had been compiled by the Geology Department of the Sinclair Oil Company some fifteen years earlier. A much-reduced and altered version of the map was included in Schuchert's volume. Since that time two maps, sponsored by the Geological Society of America and the United States Geological Survey, have been published. All these maps are on a scale too small to furnish more than a generalized idea of Isthmian geology. It is hoped that the map presented herewith may be of use to persons interested in the subject, who desire greater detail.

Geologists who have worked in the rainy tropics know the difficulties imposed by heavy vegetation, deep weathering of the rocks, and unfavorable climate. These difficulties are encountered in the most extreme form in Panama. In addition, difficulties in correlation due to lithologic uniformity, and overlapping of fossil species that in other regions are distinctive, make it difficult and in many cases impossible to draw contact lines. Even in the Canal Zone, which has received many times as much attention as any other part of Panama, there are still doubtful contacts and correlations. The writer can only hope that the inevitable errors on the map will not prove too embarrassing.

General Features

The Republic of Panama lies between parallels 7° 9′ and 9° 37′ N., and meridians 77° 9′ and 85° 1′ W., with a maximum east-west extension of about 390 miles and a maximum north-south extension of about 170 miles. Its area is about 29,000 square miles. Of this area probably less than half is permanently inhabited. Approximately one-half the country is above the 1,000-foot contour, but perhaps ninety per cent of the population live below it. All the provincial capitals and also the national capital are below the 100-meter (328-foot) contour. In spite of the fact that Panama has been a highway of international commerce for more than four hundred years, considerable areas are still known only vaguely. The continental divide is crossed by only two highways and one railway, all of them within or adjacent to the Canal Zone, and it is crossed by few trails. Even in the lowlands, large tracts of most fertile soils remain uncultivated.

The topography has been accurately mapped only in the vicinity of the canal, such portions of the coast or other areas as the United States War Department has considered of strategic importance, and in the immediate vicinity of the Pan-American or Inter-American Highway. Other mapping has been done by oil, mining, and fruit companies, and it is of a limited and sketchy character. The country has been photographed from the air for the purpose of constructing an accurate topographic map, but this project will not come to fruition for some years.

About 1,700 square miles in the Intendencia of San Blas, and adjacent areas of the provinces of Darien and Panama are under the control of the Cuna Indians, and are not open to exploration except with their consent, which is almost never given. The topography of this region is known mainly from air observation, although two crossings of the Intendencia of San Blas have been made under military protection, one in 1870 by Selfridge and another in 1947 by Thompson.

GEOMORPHOLOGY

The general form of the country is an irregular sigmoid, elongated in an east-west direction. Its outlines are broken by one large and several small peninsulas; the large one—the Azuero Peninsula—forming the west shore of the Gulf of Panama. This, with two smaller ones, the Burica Peninsula and the Soná Peninsula, are on the Pacific coast; two still smaller ones, the Valiente and San Blas peninsulas, are on the Caribbean coast. If the ocean were withdrawn to the 100-fathom isobath, the area of Panama would be increased by about one-third, most of the addition being on the Pacific side. The elongated sigmoidal form would still be preserved, but the large Azuero Peninsula would no longer be recognizable.

The eastern end of the country is in a more advanced stage of the erosion cycle than the western, and this difference extends across the national boundaries, with the flat basin of the Tuira River of Darien Province merging with the swampy plains of the Atrato in Colombia; while in the west, the rugged continental divide between Bocas del Toro and Chiriquí rises to the lofty volcanic peaks of Costa Rica

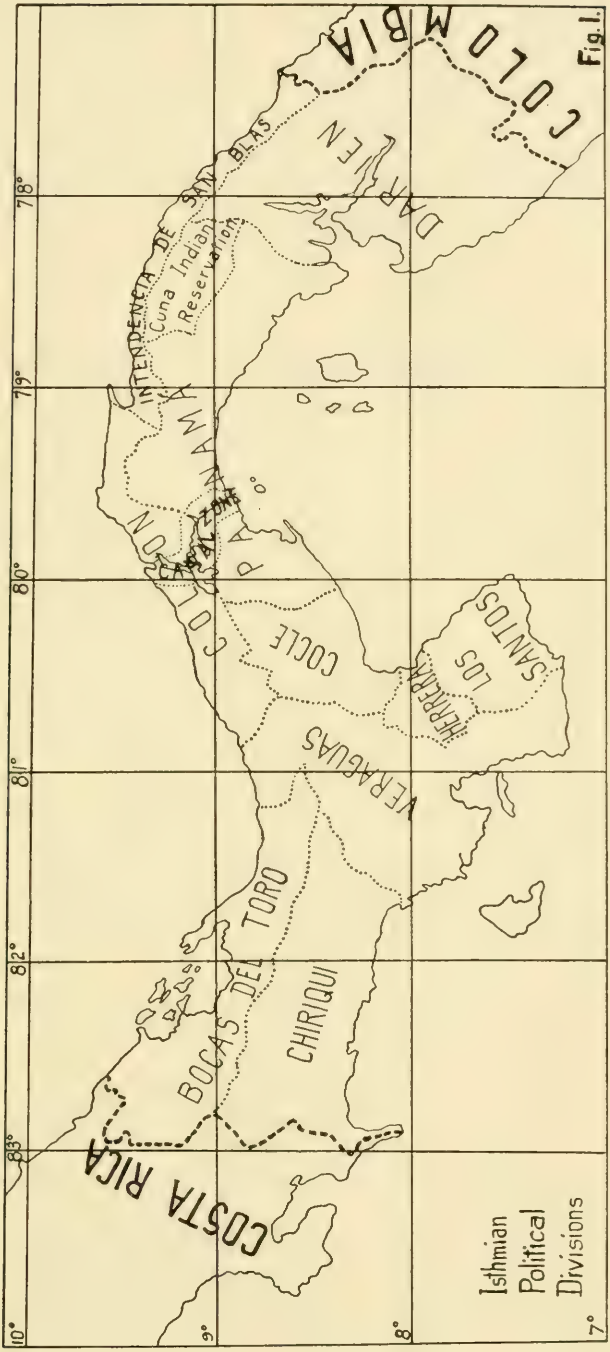


Figure 1. Isthmian political divisions.

(fig. 2). The coastal plain and adjacent lowlands are wider on the Pacific than on the Caribbean side, and this difference extends out to the edge of the continental shelf. If the map were continued to the northwest, the relations between the coastal plain and the continental shelf on the two coasts would be seen to reverse itself, the plain on the Caribbean side becoming wider, that on the Pacific narrower. This physiographic change is evidently the surface expression of a change in the underlying rock structure.

Western Panama

The lowlands of the Pacific side of western Panama can be divided into five distinct physiographic provinces:

1. The *Burica Peninsula,* on the international boundary at the southwestern corner of Panama and the southeastern corner of Costa Rica, is a tightly folded and faulted area, the exposures showing rocks of the basement complex and the entire known sedimentary section of Panama, with the possible exception of the Oligocene, which has not been identified, as yet. Marine Pleistocene occurs at elevations of 100 feet or more. The maximum relief is over 2,500 feet, with the highest point within a mile of the west shore, and the divide between the east-flowing and west-flowing drainages lies close to the west coast from this point to the tip of the peninsula. The short high-gradient streams flowing west are rapidly beheading the long low-gradient streams flowing east. The rocks of the basement complex are mostly in the northwest corner, and the sedimentaries curve round them in arcuate forms, convex to the northeast. Differential resistance to erosion has resulted in a rugged topography, but the surface of the high ridge of basement rocks is so smooth as to suggest peneplanation prior to the last elevation. An extension of this surface tilted to the northeast at about 3 degrees would meet the successive crests of the ridges of sediments, indicating that the entire peninsula was once peneplaned and then tilted to the northeast in late Pliocene or Pleistocene time. In Recent time the peninsula was an island, and it is now a tombolo tied to the mainland by delta deposits. There is almost no continental shelf on the east side, but there is one on the west side, two to three miles wide.

2. The *flat lands at the head of the Burica Peninsula,* composed of Recent alluvium, occupied by the banana farms of the Chiriquí Land Company are a composite delta formed by rivers from the mainland and from the peninsula. Until recently a residual lake remained near the center of the area. This flatland extends from Golfo Dulce on the west to Rio Chiriquí Viejo on the east. Water wells of the

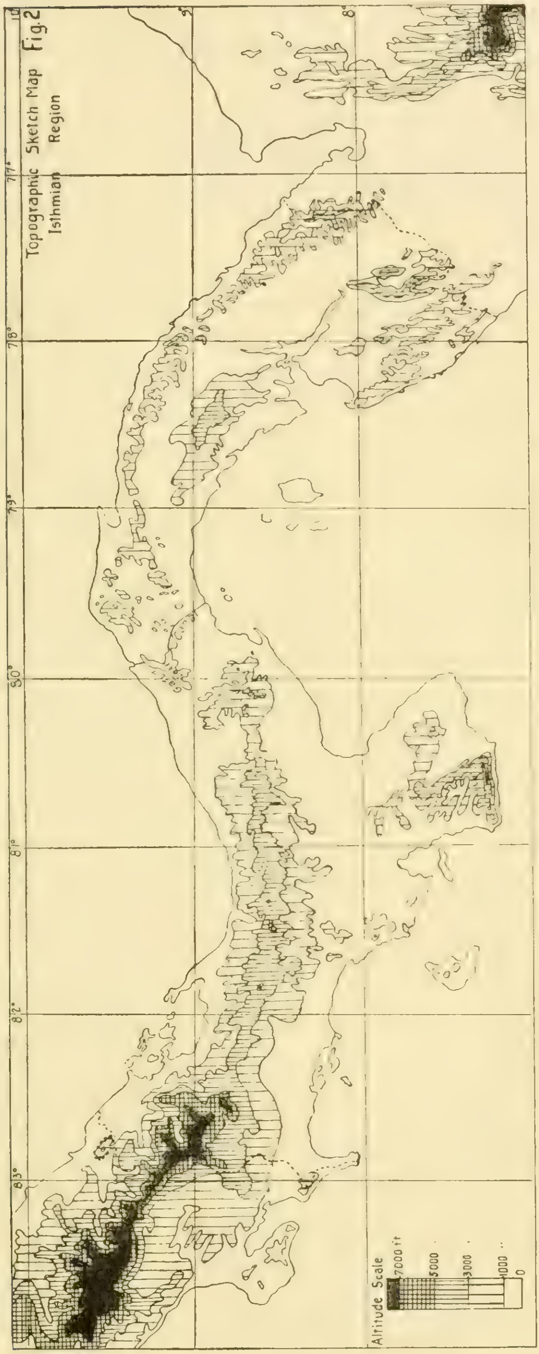


Figure 2. Topographic sketch map—Isthmian region.

Chiriquí Land Company have penetrated more than 200 feet of alluvium. An ancient river system, now submerged, crosses the continental shelf. (Terry, 1941.)

3. A *volcanic outwash plain* extends from the Rio Chiriquí Viejo on the west to the vicinity of David on the east. The maximum relief is 900 feet. Volcanic ejecta cover folded Tertiary sediments. The region is a smooth plain for the most part, but hills of Tertiary sediments appear near its northern edge. Near Concepcion about 14 miles from the coast, a fault-line escarpment separates it from the higher area to the north, in which the streams run in deep box canyons, while below the scarp the channels are shallow, and the streams run out of control in the rainy season. The coastal margin is swampy. The continental shelf widens from 10 miles at the west to 20 miles at the east.

4. *David to Tolé.* This is a maturely dissected belt of tilted and folded Tertiary sediments, with numerous plugs, dikes, sills, and flows of andesite. The igneous outcrops and the numerous faults interfere with the normal development of the erosion pattern. Most of the streams are consequents. The maximum relief is about 1,000 feet, but the average is less than half that. The high points are mostly volcanic plugs, dikes, or lava-capped mesas like the Gran Galera de Chorcha. The coast line is serrated with numerous small islands, and the lower stream courses have been drowned by recent invasion of the sea. The continental shelf widens from 20 miles at the west to 50 miles at the east.

5. *Peninsula of Soná.* This is a rugged igneous area, the rocks being mostly or entirely basement complex. The maximum relief is about 1,500 feet. There is a ria coast and the continental shelf is about 50 miles wide.

On the opposite, or Caribbean coast, some four coastal provinces may be distinguished:

1. *Puerto Limon to Old Harbor* (Costa Rica). This is a flat swampy coastal plain, two to five miles in width, with an extension up the valley of the Estrella River ending in a bolson valley floored with gravel and boulders, with a thin cover of alluvium. Smaller valley flats extend up the Banana and Bananito rivers. The alluvial cover of the coastal plain is thin over folded Tertiary sediments, which are occasionally exposed in stream beds. Drowning of stream valleys is less marked than on the opposite coast of Chiriquí. The continental shelf is seven to eight miles wide from Puerto Limon to Cahuita Point, whence it narrows rapidly to about two miles at Old Harbor. The straight line of the coast suggests fault control, and the rapid

narrowing of the continental shelf east of Cahuita Point, with its steep outer edge carries a similar suggestion.

2. *Old Harbor to Monkey Point* (Costa Rica). This region has no coastal plain. It is composed of sandstone and conglomerate hills of middle and late Miocene age with some Pliocene. These form a belt of hills along the coast, back of which is the flat meander belt of the Sixaola River, about five miles wide. The continental shelf is about two miles wide.

3. *Monkey Point to Chiriquí Lagoon* (Panama). This area consists of a swampy coastal plain, seven to eight miles wide, over which the Sixaola and Changuinola rivers meander. The wide flood plain of the Sixaola extends inland to the bolson Talamanca valley, filled with heavy gravels and boulders with a thin cover of alluvium. The continental shelf is seven to eight miles wide and at the mouth of the Sixaola is deeply notched, apparently because of faulting. (Terry, 1941.)

4. *Almirante to the base of the Valiente Peninsula.* This region consists mainly of the shallow, flat-bottomed Chiriquí Lagoon, which has a maximum depth of about 20 fathoms. In the lagoon are numerous islands of Miocene sandstones and shales, with interbedded and intruded lavas. Along the inner margin of the lagoon from Almirante to Chiriquí Grande, similar hills of sediments and andesite form the coast, but from Chiriquí Grande to the base of the Valiente Peninsula is a swampy, alluvial coastal plain, five to six miles wide. The Valiente Peninsula is a tombolo of Miocene sediments and igneous rocks. The continental shelf varies from about 5 miles wide at Valiente Point to 20 miles at the offshore island, Escudo de Veraguas, from which it narrows rapidly to 10 miles at the base of the peninsula.

Between the two coastal regions just described, the cordillera of the continental divide rises from about 3,000 feet at the head of the Rio Tabasará at the eastern edge of the region to 12,861 feet at Chirripó Grande, southwest of Puerto Limon. The axial portion of the cordillera may be conveniently divided into three parts.

1. *Eastern part,* the *Serrania de Tabasará.* The crest of the cordillera rises from 3,000 feet at the head of the Tabasará, to 9,265 feet at Cerro Santiago, a Pleistocene (?) volcano, from which it descends to about 4,000 feet near the 82nd meridian. There is a fairly even slope on each side to the two coastal plains, with consequent streams running straight down the slope.

2. *Central part from 82° to 82° 30′ W.* The crest line has an average height of 5,000 to 6,000 feet with three peaks—Hornito

(7,200), Cumbre de la Playa (8,235), and Horqueta (7,440 feet). These are apparently all volcanic, probably of late Pliocene or Pleistocene age, but they have not been investigated. The writer crossed the divide on a trail between Hornito and Cumbre de la Playa, and noted the flatness of the divide for a width of a mile, more or less; and he was informed that the Rio Chiriquí rises in a shallow lagoon in a similarly flat area on the crest of the divide. It is not known whether the flattening is erosional or due to flat-lying lava beds, but the last rocks exposed on the south side before reaching the crest, are crystalline, followed by andesite at the crest, but no flow structure was seen.

3. *Western part—the Cordillera de Talamanca.* This portion of the cordillera has eight peaks above 10,000 feet on the divide itself, and four others at short distances from the crest-line. The writer has not crossed this part of the divide, but has climbed one of the peaks on the south side, El Barú, a Pleistocene volcano. Reports of its activity in historic time are of questionable authenticity.

El Barú, which dominates the landscape from almost any point in the province of Chiriquí, is for that reason usually known as the Volcan de Chiriquí. Its peak, 11,410 feet above sea-level, is the highest point in the Republic of Panama, and is about eight miles south of the continental divide. The present cone, which is far from perfect, has an ellipsoidal base about nine miles long on the main axis, which extends on a nearly east-west line, and about seven miles on the shorter axis. This cone is composed mainly of heavy flows of andesite and subordinate amounts of clastic material. Examination of slides made from these Pleistocene flows does not disclose any perceptible difference from slides cut from flows of Miocene age or those of the basement complex.

There are several craters, the largest of which lies west of the high peak and debouches through an opening half a mile or more wide upon the Llanos del Volcan, a gently sloping plain, from which rise a few small andesite hills, which may be volcanic plugs, or remnants of older flows. There are several undrained depressions, two of which are occupied by perennial ponds. The material underlying the surface, so far as can be seen in the erosion channels, is mainly clastic and most of it appears to have been water deposited.

From the Llanos del Volcan a continuous gentle slope extends southward some eighteen miles to Concepcion, where it is intersected by an eroded fault scarp. This sloping plain is drained by radial streams, running in deep box canyons. The interfluvial areas are wide and not much dissected on the upper part of the slope; the lower areas are more cut up, but the entire region has an appearance of extreme topographic youth. The material is mostly clastic and was distributed by explosion and by water. The breach in the old crater wall suggests that a crater lake was released by faulting or by eruption, the succeeding floods spreading loose materials which were carried farther by slope wash. It is possible that other vents contributed, but by far the greater part was apparently derived from El Barú. The area covered by the volcanics has maximum dimensions of about 25 miles east-west and about 30 miles north-south. Near the peak on the east are three small craters of later date with steep andesite walls and flat floors, largely pumice. Narrow notches in their walls cut by the overflow lead to the Cochea River. There are no signs of recent activity in the small craters, but there is a tepid sulphur spring in the large one.

The base of the lava flow cone is overlapped by the clastics, and the platform on which it rests is not visible, but is presumed to consist of sediments of Mid-Miocene age which emerge from beneath the clastics at both the east and west margins of the volcanic area at altitudes of 3,000 to 4,000 feet.

The writer has crossed the continental divide a few miles west of Cerro Santiago at the head of the east fork of Cricamola River, and on the south side of the divide crossed a steep slope of volcanic ash which looked as fresh as the material in the crater of Irazú, an active Costa Rican volcano. The ash was so loose that the accompanying Indians insisted on spreading out to a spacing of 30 feet between men, to avoid starting a slide. It was the writer's impression that Cerro Santiago has been more recently active than El Barú. Most of the high peaks in this part of the Cordillera are probably volcanic and of Pliocene or Pleistocene age, but the divide has not been examined except here and at the crossing between Rio Chiriquí and Rio Guarumo.

The Cordillera de Talamanca continues northwestward in Costa Rica, trending slightly more to the west, and increasing in altitude, to Chirripó Grande at 12,861 feet, from which it descends slowly to the Meseta Central of Costa Rica. According to Lohman (1934), the latter portion is composed of Tertiary sediments dipping north under the cover of Pleistocene and Recent volcanics in the Meseta Central. He shows these sediments as resting on a basement of crystalline deep-seated rocks, which are here and there covered by Pliocene, Pleistocene, or later volcanics; and he considers the crystallines to be older than the basic lavas which cover them. Gabb (1875) considers the granite of Pico Blanco, near the continental divide just west of the international boundary to be a later intrusion which has metamorphosed the Mid-Miocene sediments. The writer thinks Gabb was mistaken, as the Gatun conglomerate contains pebbles and cobbles of granite. In general, the topography of the cordillera is distinctly youthful; but there is an area on the Pacific side of the divide near the international boundary which shows considerable stretches of smooth surface beveling the steeply tilted Oligocene and Miocene strata. These sloping plains at the 3,000- to 4,000-foot level are very clearly seen from the air in the region from Breñon to Canas Gordas. They slope gently to the southwest and the beveling of the surface is believed to be of contemporaneous origin with that of the now-dissected peneplane beveling the ridges of the Burica Peninsula. Both peneplanes dip inward toward the intervening flats of the compound delta which ties Burica Peninsula to the mainland. This delta is still close to sea level. The inward tilting of the peneplaned areas is believed to be due to underthrusting from the Pacific side, and to intrusion from below under the cordillera.

Central Panama

On the south shore of the Azuero Peninsula, an andesite cliff fronts the sea for most of the distance from Punta Naranjos to Punta Búcaru. The narrow width and steep outer edge of the continental shelf suggest close offshore faulting. Near Rio Ocones, west of Morro Puerco, shales and slates apparently underlying the andesite, dip steeply toward the sea. No fossils were found. It is possible that these rocks are of Cretaceous age, but in any case the andesite belongs to the basement.

From Morro Puerco, a narrow coastal plain widens gradually to Punta Búcaru, where it meets the floodplain of Rio Tonosí. This flat extends inland for six or seven miles. From Punta Búcaru eastward to Cape Mala the continental shelf averages about 10 miles in width, but the coastal plain narrows eastward from the mouth of Rio Tonosí to the limestone-andesite contact, about eight miles distance, where the andesite cliffs reappear and form the coast line to Capa Mala, and north along the shore of the Gulf of Panama nearly to Mensabé, where a narrow coastal plain begins and widens slightly northward to the deep reentrant occupied by the delta of Rio Santa Maria. Here the coastal plain merges with the Santiago plain which separates the highlands of the Azuero Peninsula from the foothills of the continental divide. This is a flat erosional surface cut on Oligocene and Miocene sediments, for some forty miles westward to the head of Montijo Bay. These flats extend south along the coast of the bay about 25 miles to the igneous-sedimentary contact north of Rio Toro. The Oligocene and Miocene are intruded and interbedded with basic lavas and tuffs over the entire area, a condition which continues north to within a few miles of the continental divide and east to the vicinity of Anton. Numerous vents through which these volcanics issued can be seen in the form of dikes and volcanic craters, one of which is described by Joukowsky and Clerc (1906): "From the port of Aguadulce to Chitré passing through Sta. Maria, Parri, Parita, and l'Harena describing an arc more or less parallel to the shore with a total length of more than a hundred kilometers I saw nothing but eruptive rocks, lava, or ash. South of Sta. Maria is found a circular plain completely surrounded by a chain of low hills. At its highest point is an outcrop of basic rock with augite microlites. The general arrangement of the rocks suggests a volcanic vent. There are also volcanic rocks, lavas, and cinders which are found from the village of Chitré to the port, forming a plain a little above sea level. On the road from Chitré to Macaracas for a dozen kilometers, one sees nothing but volcanics. At this distance (roughly calculated) is the first sedimentary outcrop, a calcareous marl striking NNE." (Author's translation.)

Other similar and larger volcanic vents can be seen west and northwest of Aguadulce.

The lavas along the coast near Chitré mentioned by Joukowsky apparently overlie the sedimentaries of late Oligocene and early Miocene age, and may be younger than early Miocene. The sediments dip beneath them near Las Tablas and at other points. The peneplane which cuts across them can hardly be older than middle Miocene since it bevels early Miocene strata. The coastal plain continues east beyond Anton to Chame, and from the coast the smooth gentle slope continues 50 miles beneath the sea to the edge of the continental shelf.

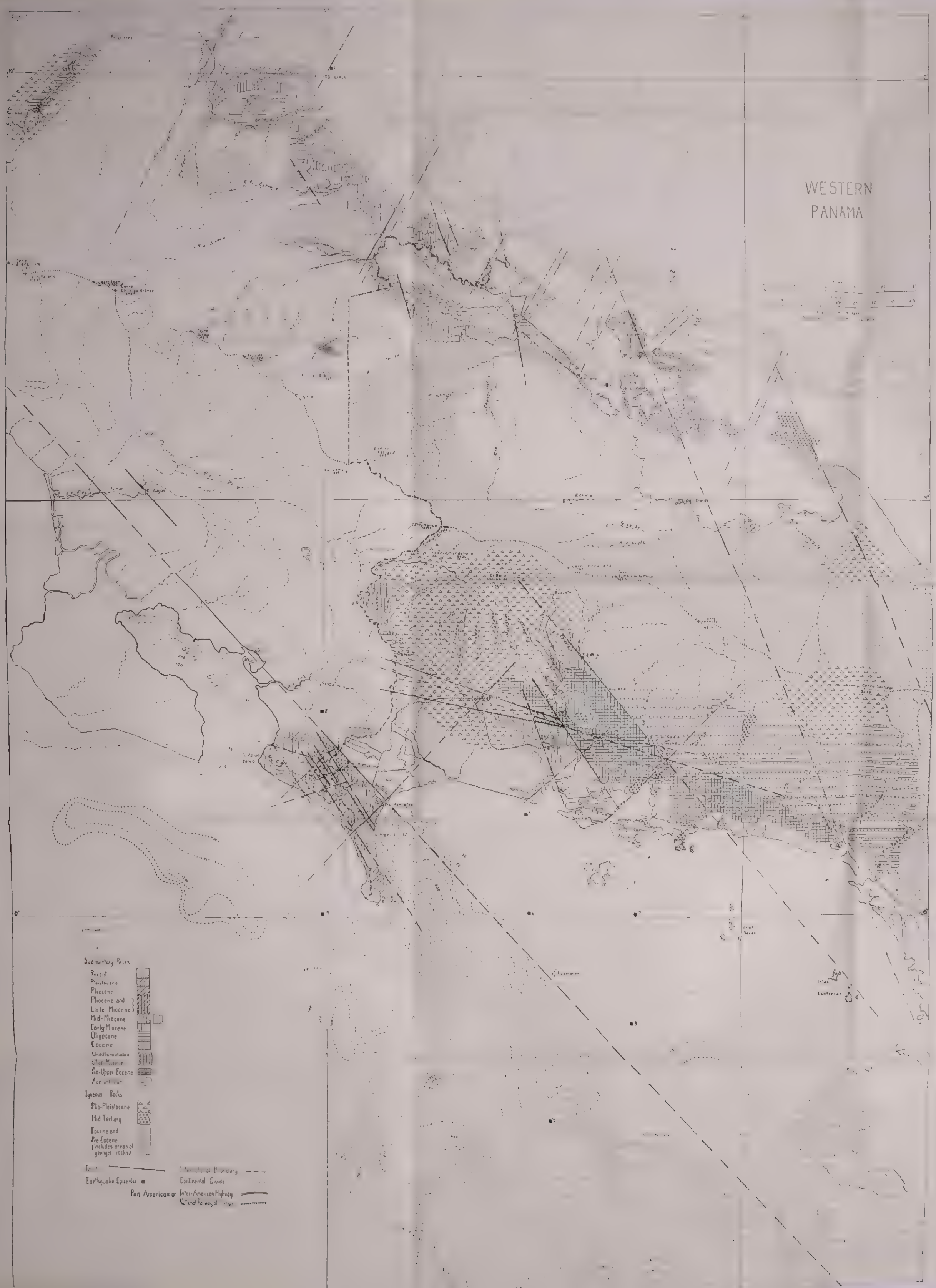
The Azuero Peninsula, aside from the coastal plain, consists of two upland areas, separated in the middle by the Tonosí basin and its narrow connection with the Santiago plain by way of Juanbacho and Macaracas. The highland area west of the Tonosí basin is a deeply dissected plateau, which like the Burica Peninsula, fronts the Pacific with a steep andesite cliff, the highest point of which is less than three miles from the coast, with the drainage running northwest to the Gulf of Montijo. The east side of the plateau is separated from the Tonosí basin by a steep scarp, striking about N. 23° W. The western half of the Azuero Peninsula has thus the appearance of a fault block, elevated on its eastern and southern sides and tilted to the northwest. The plateau area east of the Tonosí basin is somewhat smaller and rises to lesser heights, with no obvious suggestion of tilting. The rocks of higher parts belong mostly to the basement complex, but some of the volcanics are younger. MacDonald (1937) considered Cerro

Quema to be a Pleistocene volcano. The drainage is radial from the central area of the eastern plateau.

On the opposite Caribbean coast, the continental shelf varies from 3 to 12 miles in width, and there is no coastal plain from Rio Pasaula eastward to Belen. Over this distance, the andesite foothills of the cordillera come down to the sea, and are cut up by sharp V-shaped valleys striking N. 45° W. at an acute angle to the coast, instead of running directly down the slope from the continental divide, as might be expected of consequent streams running over unstratified rocks. The parallel stream courses and unexpected orientation suggest control by faulting.

From Belen east to Coclé del Norte the surface as seen from the air, is a series of low parallel ridges striking east-west and rising slowly to the continental divide, which for a distance of twenty miles east of La Pintada averages about 2,000 feet in height. The ridged surface resembles the Santiago plain, and like it seems to be composed of interbedded clastics and volcanics, the latter forming all, or nearly all, the formation on the west, with the clastics increasing to the east. Near Coclé del Norte, specimens seen by the writer were dark gray to black foraminiferal shale resembling the Uscari of early Miocene or late Oligocene age, which had been intruded by an andesite dike and slightly mineralized along the contact. However, on a canoe trip up the river, all exposures seen were igneous. The ridged surface of the flows and clastics, looks like a peneplane which has been slightly elevated, tilted toward the north, and somewhat eroded. This conclusion is supported by the fact that east of Belen the stream courses are in general normal to the coast, as might be expected on a tilted peneplane sloping to the sea. It is the writer's conclusion that this surface is actually of equal age with the south coast peneplane, but has suffered greater elevation and tilting in post-Miocene time. The corrugated surface is the result of erosion of the weaker beds, following the tilting.

This corrugated surface becomes flatter and wider as one approaches the canal, bending south to include Gatun Lake, but east of the lake is cut off sharply by the contact with the basement rocks. This contact strikes about N. 30° E., reaching the sea about halfway between Colon and Portobello. On the Pacific coast, igneous plugs and dikes rise above a surface which appears to be mainly andesite flows west of Anton, and rhyolite flows and tuffs to the east, with some interbedded clastics, partly marine and partly terrestrial. Like the area described above, the surface in general appears to be an elevated, tilted, and slightly eroded peneplane east of the Bay of Chame.


WESTERN
PANAMA
Sedimentary Rocks
Recent
Pleistocene
Pliocene
Pliocene and Late Miocene
Mid-Miocene
Early Miocene
Oligocene
Eocene
Pre-Upper Eocene
Igneous Rocks
Plio-Pleistocene
Mid Tertiary
Eocene and Pre-Eocene (includes areas of younger rocks)
Earthquake Epicenter
Continental Divide
Pan American or Inter-American Highway

Between these two tilted peneplanes is a mountain group, flanked by two volcanic cones, El Valle on the south, San Miguel de la Borda on the north, between which the continental divide traverses an area of rhyolites and granites which culminates at the east in La Campana, 3,300 feet in height. The volcanics of El Valle are rhyolite ash and rhyolite flows. Those of San Miguel de la Borda have not been investigated.

The well-preserved slopes of the El Valle cone with their youthful drainage channels, led the writer to ascribe to it [in Schuchert's (1935) volume] a Pleistocene age. Jones (1950) objects to this and apparently considers it Miocene, saying that the slopes have not been eroded because of the porosity of the tuffs. It is difficult to reconcile this view with the fact that several volcanoes of Miocene age in the area between Santiago, Aguadulce, and Las Tablas have been completely eroded and the surface peneplaned as described by Joukowsky and Clerc (1906). Some of these Miocene volcanoes were of a size comparable to El Valle. It is a fact, however, that the materials ejected by the El Valle volcano are considerably older than the cone itself, and may be of Miocene age. The El Valle volcano is of the caldera type. Its crater was localized by the intersection of four faults, two striking N. 10° W. and two striking N. 60° E. The two latter parallel the continental divide, which is probably itself a fault line scarp. The north and west walls of the El Valle crater are rhyolite, the south wall and at least a part of the east wall rhyolite tuffs and ash, very well stratified. They strongly resemble the Panama tuffs at Diablo Heights in the Canal Zone, and may well be of the same age (early Miocene). The eruptions which formed the cone, however, took place at a much later date, and the Miocene ash was ejected after the manner of the Krakatoa eruption, with a minimum amount of new material. On the floor of the crater, about three miles northwest of the village of El Valle, a well was drilled to secure a domestic water supply for the home of Don Enrique Coronado. This well penetrated 65 feet of tough blue clay, capped by three feet of loose sand, neither of these deposits resembling the stratified ash of the crater walls. The well was unsuccessful. The clay is apparently a lake deposit, made in a water body which filled the crater. The lake was finally drained by the head of Rio Anton cutting along the shattered rhyolite on one of the N. 60° E. faults along which movement has taken place in Recent time.

On the north side of the divide, the San Miguel de la Borda cone has not been investigated by the writer, but as seen from the air, appears to be a volcanic ash cone, somewhat smaller than El Valle.

Central Panama, east of the canal, has a well-developed coastal plain on the Pacific side, which widens from two miles at the eastern limit of Panama City to 15 miles at the Bayano River. The flat surface continues beneath the sea to the edge of the continental shelf, about 75 miles distant at the widest part. On the surface of this plain appear a few monadnocks of igneous and sedimentary rock, those offshore forming the Pearl Islands and other smaller islands of the Gulf of Panama, while the inland monadnocks of the coastal plain are on a smaller scale, but of the same general character. This plain, like the Santiago plain and that of eastern Chiriquí is cut across the edges of tilted marine sediments of Oligocene and Miocene age, which are interbedded with, and intruded by basic volcanics, less numerous than those of Chiriquí. The continental shelf is ended at the south by an arcuate escarpment, convex to the north, with a maximum height of 10,000 feet, and a maximum slope of about 20°. It is almost certainly due to faulting. A conspicuous narrow slot bisects the continental shelf in a north-south direction just west of the Pearl Islands, and during the Pleistocene withdrawal of the sea, was occupied by the channel of the Bayano River. No such submarine channel connects the mouth of the Tuira River of Darien with the edge of the continental shelf, although the Tuira discharges a much greater volume of water than the Bayano. It is therefore believed that the slot west of the Pearl Islands is not due to Pleistocene stream erosion but to faulting. A similar rift about 20 miles long cuts the smooth surface of the continental shelf southeast of the Pearl Islands (plate III). It has a maximum depth of 300 to 350 feet, and a maximum width of two miles. It parallels the coast and is also evidently due to faulting. It is closed at both ends.

An interesting feature of the continental shelf on the two sides of the isthmus is that on the Caribbean side, the shoulder which marks the top of the outer escarpment is around the 42-fathom isobath, while on the Pacific side it is around the 72-fathom isobath, except along the eastern side of the Burica Peninsula and the western half of the Azuero Peninsula. Since this shoulder is no doubt related genetically to the Pleistocene withdrawal of the sea, it would appear that the present difference in elevation indicates differential movement in post-Pleistocene time on a regional scale, with sinking on the Pacific side.

The continental shelf on the north coast of central Panama, east of the Canal Zone, averages about 10 miles in width and its outer edge parallels the coast in a gentle arc, convex to the north. There is no continuous coastal plain, but rather a series of small terraces notched across the igneous rocks of the basement. They are seldom more than a mile or two in width, and are interrupted by fingers of the interior plateau extending to the sea.

The interior plateau is dominated by an arcuate ridge, convex to the north which marks the northern edge of the basin of the Chagres. The crest of the ridge varies from 1,500 to 2,000 feet in height with occasional peaks, the highest of which, Cerro Bruja, reaches 3,200 feet. The ridge is breached by a fault rift which is occupied to the south by the Boqueron River running to the Chagres. This rift is occupied by sedimentary rocks of unknown age, but the ridge itself is, so far as known, entirely igneous, and belongs to the basement complex. The rift mentioned above strikes about N. 20° E. A much larger rift, or graben, forms the basin of Chagres River; the lowest part of the downthrow block is now occupied by Madden Lake. The basin of the Chagres lies between two major faults striking N. 70 E., and is cut by another system striking N. 20° E. to N. 30° E. These two fault systems control the drainage pattern of the Chagres and extend to the Caribbean coast, where the eastern end of the Chagres rift is occupied by the Gulf of San Blas. The part intervening between the Gulf of San Blas and the Madden Basin has been little explored, but is supposed to consist entirely of the igneous rocks of the basement complex. The topography is exceedingly rough, cut by V-shaped stream valleys, and may be classified topographically as a mountain region in early maturity. Looked at from the air, it appears to be topped by the remnants of a peneplane at about 2,500 feet, with a few rounded monadnocks rising to 3,000 feet. The size of the remaining flat remnants of the peneplane is not known, but they cannot be large.

The writer crossed the divide on a traverse from Chepo to the head of the Gulf of San Blas (plate III) and observed the flatness of the crest between the head of the south-flowing Mamoní and that of the north-flowing Samgondí, tributary of the Mandinga. The flat area was narrow, and apparently not due to flat-lying lavas.

Eastern Panama

In eastern Panama, the ridge of basement rocks forming the south escarpment of the Chagres-San Blas graben continues, constituting the continental divide, which extends from the head of the Gulf of San Blas to the Colombian border at Cerro Gandí, and continues to and beyond Cerro Tacarcuna. It lies 5 to 10 miles from the Caribbean coast, and is an arcuate igneous ridge convex to the northeast, for the most part less than 2,000 feet high, with some notches less than

1,000. It is bordered on the south and southwest by a parallel arcuate lowland, a continuation of the Pacific coastal plain of central Panama. Most of this plain is below the 300-foot contour. The northwestern end of this arcuate lowland is occupied by the basin of the Bayano River, the southeastern end by the Tuira-Chucunaque basin. The two basins are separated by a divide so low as to be almost imperceptible from the air. Indians of the upper Chucunaque have told the writer that piraguas (Indian dugouts) are sometimes dragged across the divide from one drainage system to the other. In both basins the level surface of the lowland is cut across tilted sediments of Oligocene and Miocene age. The youngest of these, the Chucunaque formation, is of late Miocene and perhaps Pliocene age. The erosional beveling must have been accomplished mostly in Pleistocene time. At the Bayano-Chucunaque divide the lowland is 10 to 12 miles wide, but from the divide it widens rapidly to the south, and in central Darien Province reaches a width of 30 miles, which with the exception of a few monadnock ridges has been not only peneplaned, but largely base-leveled, so that hundreds of square miles are practically at the level of high tide. This base-leveled swampy region extends from the Chucunaque at the mouth of the Sucubtí to Real on the Tuira, and is bounded on the west by the Rio Sabana and Lower Rio Tuira from the mouth of the Lara to Chepigana on the Tuira and thence south to Tucutí on the Rio Balsa, enclosing an area of about 600 square miles. This area is uninhabited except at its outer edges, and was apparently uninhabited when Balboa made his crossing along its northern end in 1513. Semiaquatic mammals such as the tapir, capybara, and paca can remain there over the rainy season, but other large mammals enter these swampy flats only during the dry season, when it becomes for the Indians, a valuable hunting ground. The larger oxbow lakes hold stagnant water, covered with green scum, throughout the dry season, and outside the meander belts of the larger rivers, water-bearing vines are the only safe source of drinking water for the hunter in February, March, and April.

The largest of the monadnocks in this base-leveled area is the Sanson ridge, the core of an anticline, which rises to a height of 1,800 feet at one point, according to the Air Chart.

The fact that this base-leveled surface still stands at tide level, indicates isostatic stability from its completion to the present, and this is borne out by the seismic records. Few shocks have been recorded from Darien Province.

The eastern side of the arcuate lowland belt continues southward to the head of the Tuira, where only a low ridge separates it from the broad flats of the Atrato, which are obviously its continuation, but cut off from it by faulting of fairly recent date. Hildebrand (1938) has noted that the fresh-water fishes of the Tuira (Pacific drainage) resemble those of the Atrato (Atlantic drainage) more closely than those of the Chagres .resemble those of the opposing Pacific slope.

The Pirri Range of central Darien Province, an asymmetric anticlinal fault block, separates the upper Tuira valley from the valley of the Balsa to the west; the Balsa, in turn, is separated from the Sambú by another fault block of basement rocks, and another fault block of mainly basement rocks separates the Sambú from the Pacific. The Pirri block and the block between the Balsa and the Sambú approach each other closely at the Colombian border, where the summits of each are beveled by a series of small level areas, so flat that water stands in undrained depressions through a large part of the year. The surface of these flats is around 4,000 feet on the Pirri ridge and slightly less on the Altos de Aspavé across the Balsa valley. These flats appear to be peneplane remnants, and if so, the peneplane must have been cut following the mid-Tertiary folding which preceded the deposition of the Gatun (middle Miocene), since it is hardly conceivable that an older peneplaned surface could have remained level following intense asymmetric folding in the Tertiary. The interval between the 4,000-foot mid-Miocene peneplane and the sea-level Pleistocene peneplane of central Darien therefore marks for this area the amount of uplift from mid-Miocene to Recent times. The upper peneplane surface of the Pirri Range slopes gently northward and more rapidly southward from a high point on the Colombian frontier at the head of the Rio Salaquí 7° 44′ N., 77° 44′ W.) The elevation of the high point, which is the summit of a monadnock on the old peneplane, is 5,134 feet on the Aeronautic Chart. Other high points in southeastern Darien are Cerro Pirri on the Pirri ridge at 4,973 feet, and Cerro Sapo on the ridge west of the Sambu at 4,264 feet. The highest point in Darien is at the summit of Cerro Tacarcuna on the continental divide at 6,180 feet.

One of the least-known areas of eastern Panama is the mountain block which divides the upper Bayano valley from the Pacific coast. As the area from the crest of this divide to the Caribbean coast is entirely Indian reservation, from which outsiders are excluded, and since the coastal belt on the Pacific has been unattractive to oil geologists, there has been no mapping of the intervening ridge.

Topographically it is an irregular mountain block rising to a high point of 5,330 feet, elongated in a N. 30° W. direction and apparently a structural continuation of the igneous divide between the Sambú and the Balsa. The mountain ridge sinks to the northwest and west and ends about five miles east of the mouth of the Bayano. Like all the other physiographic provinces of eastern Panama, it is gently arcuate, with convexity to the northeast. Its rocks where-ever examined at its boundary are andesites, probably of the basement complex, but on the upper Rio Congo, the writer saw boulders of mica schist in the stream channel.

Between the ridge and the coast is a coastal plain, varying from 3 to 10 miles in width with an irregular inner boundary. The underlying rocks of the plain, so far as identified, are Oligocene and Miocene shales. Much of this coastal plain is mangrove swamp. The gentle slope of its surface continues southwest beneath the ocean to the Pearl Islands, and on to the edge of the continental shelf, 50 miles away.

San Miguel Bay and its eastward continuations, the estuaries of the Tuira and Sabana rivers, as well as its northward fingers, the estuaries of the Congo and the Cucunatí, are the result of flooding due to the rise of sea level, following the melting of the Pleistocene icecap. The shores of these estuaries mark the limits of the meander belts of the respective rivers during Pleistocene time. In the case of the Tuira, which carries all freight for the Tuira-Chucunaque basin, the meanders of the old channel at the bottom of the estuary are well known to the sailors of the launches running between Panama City and Darien, and their curves are followed closely at low tide. A stranger, watching with amazement the winding course followed by the helmsman of such a craft on the wide estuary, would, if he mapped the course, have a close approximation to the meanders of the Tuira channel in Pleistocene time.

The geomorphology of Panama may be summed up briefly as follows:

Eastern Panama—late stage of the erosion cycle, wide flats, meandering rivers bordered by oxbow lakes in the Chucunaque-Tuira basin, drowned lower valleys. Mountains in mature state, with high peneplane remnants near south border—major physiographic features arcuate, with fault control on N. 30° W. and N. 25° E. lines. Block faulting of mountains following folding. Evidence of recent isostatic stability.

Central Panama—slightly earlier stage of erosion cycle. Streams mostly consequents with fairly straight courses. No drowned valleys on north coast and on Pacific coast small, mostly limited to ends of the Santiago plain. Arcuate form of physiographic features less apparent than in eastern Panama. Block faulting shown in some areas. Volcanic cones, Cerro Quema, El Valle, and San Miguel de la Borda appear young. Coastal plain wide on Pacific side, narrow on Caribbean. Continental shelf the same. Faulting of graben or rift type east of Canal zone, faulting along coast of Azuero Peninsula and continuing to the west.

Western Panama—early stage of erosion cycle. Narrow coastal plain and wide mountain area in youthful stage. Streams mostly consequents, but some meandering on coastal plain. Deformation of Pleistocene peneplane in southwest indicates post-Pleistocene tectonic activity. Pleistocene volcanoes, El Barú, and Santiago, and active volcanoes to the west in Costa Rica, and seismic activity in western part indicate lack of isostatic adjustment. Youthful mountain morphology partly due to Pleistocene and Recent vulcanism.

IGNEOUS ROCKS

About one-half the surface of Panama is made up of igneous rocks, most of which are of basic extrusive types. Crystallines are for the most part confined to the region of the continental divide or to other high mountain areas, where they appear as the result of the erosion of a cover of andesite or basalt flows, a fact noted by Hershey (1901) in central Panama, and by Lohman (1934) in Costa Rica. Gabb (1875) considered the granite of Pico Blanco near the Costa Rica-Panama boundary to be a post-mid-Miocene intrusion, but Lohman (1934) disagrees. Wagner (1862) saw granite on the north side of the divide near the head of the Gulf of San Blas. MacDonald (1919) says the Chagres brings down granite float. The writer saw granite on the head of Rio Indio north of El Valle, and has been informed that it occurs in the Campana district, 20 to 25 miles west of the Canal Zone. Hershey (1901), Taylor (1852), and Wagner (1861) mention granite in the region adjacent to the north coast near the Cocle-Veraguas border. Riddell (1927) says granite occurs on the south slope of the continental divide, about 20 miles north of La Mesa in Veraguas. In the Azuero Peninsula, granite float was seen by Dunn (personal communication) on the head of Rio Quebro, west of the Tonosí basin; and the writer collected a granite specimen from an outcrop about 10 miles southwest of Las Tablas on the trail to Tonosí. The specimen was given to MacDonald (1937), who studied a thin section and reported: "A light-colored, fine-grained, sodic granite, which weathers pinkish. . . . The orthoclase and albite, present in both large and small crystals, have been considerably altered to epidote, calcite, and sericite. Some micrographic intergrowths of quartz and orthoclase were noted. Magnetite appears as a primary mineral, and is also secondary, associated with chlorite from the alteration of hornblende. The alteration of this granite may be due to later igneous intrusions."

MacDonald's conclusion that the granite was older than the adjacent basic rocks is of interest.

Light-colored quartz-bearing rock which may be granite or granodiorite has been seen near the head of the Rio Caldera in Chiriquí Province by the writer. Syenite was reported by Wagner (1861), and Hershey (1901) from the vicinity of Mineral, a few miles from the coast of Veraguas on Rio Concepcion; and Gabb (1875) remarks: "True granite rarely occurs, while Syenites are much more common."

Acidic extrusive rocks in the form of rhyolite or rhyolitic tuffs and ash, cover a large area in central Panama, south of the continental divide, mostly in the provinces of Coclé and Panama between Chame and Anton. In the Canal Zone, Ancon hill was termed rhyolite by MacDonald (1919), and the Panama tuffs are mainly rhyolitic. Riddell (1927) says that Cobriza Peak in central Veraguas is rhyolite and that a rhyolitic cap formerly covered Remance hill.

Serpentine was seen by Dunn on the west side of the Azuero Peninsula on the upper Rio Quebro, and he says that it was also reported to him from Cerro Negrito on the coast of Montijo Bay.

Intrusive basic rocks are probably to be found over much of the isthmus, but have been seldom reported. A specimen collected by the writer in the Azuero Peninsula about 12 miles inland from Las Tablas was sectioned and examined by MacDonald (1937), who reported it a quartz gabbro, somewhat altered by later intrusives.

With the exception of the rhyolites of central Panama, there seems to be little difference in the character of the extrusive igneous rocks which overlie the crystallines. The dominant type is andesite; basalt is next most common. Vulcanism seems to have been more or less continuous from Eocene to Pleistocene time. There are no sediments in which ash or tuff cannot be found; in many it constitutes a large part of the rock. There appears to have been a particularly active volcanic period in mid-Miocene time in connection with the uplift and deformation which preceded and accompanied the deposition of the Gatun formation in western Panama, but this is not true in Darien. Since that time active vulcanism seems to have been limited to the area west of the canal.

In the region between the canal and Soná, tuffs, ash, and lava are included in, and interbedded with marine and terrestrial sediments to an extent that indicates that this area was the principal site of volcanic activity in Oligocene and early Miocene times with the Pearl Islands as another center, while Chiriquí and Bocas del Toro seem to have been the principal center of late Miocene vulcanism. Eastern Costa Rica and Chiriquí were active areas in Pliocene and Pleistocene times; and western Costa Rica and Nicaragua are actively volcanic at present. There seems to have been a steady westward progression of volcanic activity since Eocene time. While late Eocene sediments carry tuff and agglomerate in all parts of the country, the highest ratio of included volcanic materials is in Darien Province, in the eastern end of the country.

The monotonously uniform character of the andesite which forms the larger part of the basement in Panama has discouraged the collection of specimens for microscopic examination. A series of slides made from specimens collected by the writer, mostly from islands in Panama Bay and the Province of Darien, were examined by Dr. A. L. Isotoff, at Stanford University in 1945. Fifty-four slides were classed as andesite, 12 as diabase, and 8 as basalt. As the writer had made some effort to collect from distinctive outcrops, the proportion of andesite is probably too low to represent truly the general character of the igneous in this area. Some typical descriptions are quoted from Isotoff:

> T 3(b). Isla Saboga—Pearl Islands. West side. Andesite. Phenocrysts of labradorite and augite in a groundmass filled with microlites of andesine, grains of pigeonite and magnetite and alteration products, notably carbonate and secondary quartz.
>
> T 12. Isla Saboga—west side—at contact with sediments. Composition similar to the preceding, but with amygdules of calcite and zeolite.
>
> T 15. Isla Saboga—westernmost point. Andesite porphyry. This rock has a coarser-grained groundmass than the preceding, and this suggests it might be an intrusive phase.
>
> T 21. Isla San Pablo. Andesite. A rock of trachytic texture consisting of small laths of acidic andesine and a few larger laths of labradorite. Dark minerals are absent in this section.
>
> T 31. Isla Taboga at north end of village. Andesite (?). The rock is strongly altered—the section shows a mosaic of secondary quartz with sericite and alunite. There are vague suggestions of the original porphyritic texture.
>
> T 36. Isla Taboguilla near Pozo Maluco. Andesite. Trachytic texture. Microlites are acidic andesine. Plagioclase phenocrysts are altered completely to a mosaic of quartz and albite. Dark minerals are represented by "ghosts" of chlorite and magnetite.

T 43. Isla Otoque—N.W. side. Enstatite Andesite. Typically andesitic texture. Microlites of andesine, grains of pigeonite and magnetite with some residual glass from groundmass with phenocrysts of plagioclase, enstatite and augite.

T 52. Chiman. (Shore of Panama Bay about 60 miles east of Canal Zone.) Hornblende andesite. Microfelsitic texture. Andesite with dominant green hornblende, partly fresh, partly changed to ghosts of magnetite and chlorite. Some augite and fairly abundant magnetite and apatite.

T 63. Rio Taimatí. (South shore of San Miguel Bay about 10 miles from coast.) Andesite porphyry. Trachytic texture. Andesine in groundmass and in phenocrysts. Much carbonate and leucoxene.

T 69. Quebrada La Jira. (Tributary of Rio Congo—Darien Province.) Biotite andesite. Microfelsitic groundmass with andesine. Green Biotite is partly chloritized. Epidote, zeolites and secondary quartz indicate an advanced stage of hydrothermal alteration.

T 75. Alhajuela Highway 1 mile S. of Cruces trail crossing. Lamprobolite andesite. Andesite with lamprobolite (basaltic hornblende) as the dominant mineral.

T 88. Setetule Mountain (Darien Province). Andesite agglomerate. Hornblende and lamprobolite andesite.

T 108. Rio Cuasi—tributary of Rio Balsa—Darien Province. Hypersthene andesite. Both ortho- and nonopyroxene are present. The former appears to be optically negative and is therefore hypersthene. Very weak pleochroism indicates low iron content.

T 116. Cerro Mongorodo. Rio Balsa area—Darien. Andesite. Microfelsitic groundmass. Plagioclase phenocrysts with inclusions of groundmass. Dark minerals resorbed and indeterminable. Much apatite and magnetite.

T 133. Volcan—Chiriquí Province. Hornblende andesite.

T 137. Boquete—Chiriquí Province. Lava flow. Lamprobolite andesite.

T 1. Isla Chitré—Pearl Islands. Diabase. A medium-grained rock with subophitic texture. The labradorite is somewhat kaolinized while the augite is altered completely to chlorite and carbonate. There is much secondary quartz.

T 17. Isla del Rey—Pearl Islands. Punta Gorda. Diabase. A coarse-grained rock consisting of labradorite and partly uralitized augite. Chlorite, zeolites and magnetite are abundant in the interstices between fairly fresh plagioclase crystals.

T 60. Isla Iguana—San Miguel Bay—Darien. Diabase. Subophitic texture. Laths of labradorite, augite, magnetite, chlorite.

T 73. Alhajuela Highway—one-half mile S. of Cruces trail crossing, Canal Zone. Diabase. Dark minerals altered to chlorite. Some jarosite is present.

T 20. Isla del Rey. On coast one-half mile west of San Miguel. Basalt. The texture of the groundmass is intergranulate with microlites of labradorite and grains of augite and magnetite. The phenocrysts are of bytownite and augite, the latter being slightly chloritized.

T 56. South of Chiman village. Basalt. Glomeroporphyritic with subophitic groundmass of labradorite laths and grains of augite. Some chlorite.

T 68. Tucuticito—Rio Balsa, Darien. Amygdaloidal basalt. Labradorite microlites and grains of augite in intergranular groundmass. Amygdules are filled with opal and chalcedony.

T 105. Quebrada Ciega. Head of Rio Balsa near Colombian frontier. Basalt. Fairly coarse rock with labradorite and augite in the groundmass and bytownite and augite in phenocrysts. Intrusive (?).

T 107. Rio del Oeste—Altos de Aspave—Colombian frontier. Basalt. Similar to T 105.

T 117. Rio Aretí—tributary of Rio Balsa—Darien. Basalt. Rather coarse grained with subophitic texture. Possibly intrusive.

In the Canal Zone, MacDonald found Ancon Hill to be a rhyolite plug and called it, and other plugs and sills of basalt, probably Miocene. In Chiriquí Province andesite occurs in the form of flow rocks at the top of the lower Miocene underlying the middle Miocene, considered by Woodring and Olsson (personal communication) to be the equivalent of the Gatun. This condition is well exposed along the Rio David about six miles north of David and about two miles farther north in a hill east of the river, where the stratigraphic position of the andesite flow was confirmed by drilling operations. About 15 miles east of David, the Galera de Chorcha, a flat-topped hill, is capped by andesite overlying lower Miocene shales. In Bocas del Toro Province, along the shore of the Chiriquí lagoon and on several islands of the lagoon, the Gatun lies upon andesite which is probably younger than the lower Miocene, although the complete sequence is not always present, and the Gatun lies directly on the basement andesite on the flanks of the cordillera to the south, by reason of overlap beyond the inner margin of the lower Miocene. It seems fairly certain, however, that vulcanism was widespread at the close of lower Miocene time, taking the form of tuffs and flows in western Panama. Dikes are especially common in the Pearl Islands where they cut the shale series which forms most of the northwestern part of the group. While the fauna of these foraminiferal shales has not been determined, their stratigraphic position and lithologic resemblance to the upper Oligocene of the mainland leaves little doubt as to their age. They may also include some lower Miocene. On Isla Chepillo at the mouth of the Bayano River, no igneous appears at the surface, but the shales are baked to a hard argillite, and the dome structure, together with the baking, indicates the presence of an igneous plug at no great depth. Numerous plugs, dikes, and sills break through the Oligocene and lower Miocene of the coastal plain from David to Penonomé, while on the Canal Zone their number and irregular distribution is mainly responsible for the irregular topography noted by Hill and others. Owing to the lack of later sediments than lower Miocene in much of the coastal plain, this period of igneous activity can not be dated more precisely. Along the Costa Rica border north of Breñon, boulders of andesite occur lying on the surface of the peneplane cut across the outcrop of the Oligocene and lower Miocene shales, and accumulate at the bottoms of the ravines and stream courses. Their source is unknown, but they may have come from a mid-Miocene flow like that observed near David, or they may be of later age.

Pleistocene vulcanism is represented by El Barú (Volcan de Chiriquí), by Cerro Santiago, and presumably by a similar volcanic cone at El Valle, about 40 miles west of the Canal Zone. Although much smaller than El Barú, the El Valle cone is topographically similar, with smooth slope drained by radiating box canyons, which have developed few laterals, and are obviously very young. Like El Barú, it lies on the south side of the continental divide and close to it, and apparently close to the contact of the Tertiary sediments with the basement rocks. A single crater of oval shape, about four miles on the longer diameter, is floored by lake deposits and drained by a tributary of the Rio Anton through a narrow canyon at the southwest end. The wall rocks are rhyolite.

In the Gulf of Panama, off Chame Point, a group of islands of which the largest are Otoque, Boná, and Estivá, enclose a caldera-like circular area resembling that formed in the Sunda straits by the explosion of Krakatoa in 1883. Otoque, the largest of the group, is composed of andesite, apparently a part of the basement rocks, surmounted at the north side by a ridge of bedded white chert and the remnants of Eocene limestones. The andesites continue to the south side of the island, where they front the supposed caldera, on the south side of which, a few miles away, is Boná, a steep hill about 650 feet high composed of steeply dipping, nearly vertical ash and tuffs. Estivá on the west and a few smaller islands occupy intermediate places on the supposed former rim. A small plug of light-colored rock stands at the north foot of Boná, and a specimen from this and from a large bomblike mass at the crest were sectioned for microscopic examination. Isotoff's report on them is as follows:

> T 46 and T 47. Isla Boná. Indeterminable in sections—fine-grained quartz rocks with chlorite, leucoxene, magnetite, and sericite. Possibly altered andesite.

There is no means of determining the date of formation of this caldera, if such it is, but it might reasonably be considered as contemporaneous with the dikes and plugs in the Pearl Islands, some 35 miles away.

At various points along the shores and on the islands in San Miguel Bay in Darien Province, thin-bedded tuffaceous shales, some carrying foraminifera and some of them barren, are encountered in thicknesses running into thousands of feet. Neither the top nor bottom of the section is exposed, but the only other rocks exposed in the adjacent mainland are andesitic flows and agglomerates, supposedly belonging to the basement complex. These tuffs and shales have been considered to belong to the Oligocene from their lithologic resemblance to the known Oligocene near the Canal Zone and in the region of Chepo. A slide made from a specimen taken at the mouth of the Rio Cucunati was reported by Isotoff thus:

> T 62. Ensenada Cucunatí. Tuffaceous shale. Tests of forams, crystal fragments and shards of glass.

Another from Rio Taimití:

> T 63. Tuff. Devitrified tuff with andesitic and crystal fragments.

It would appear from Isotoff's report as well as from field observation, that the only regional difference is the absence of andesite from the basement rocks near the Colombian border in Darien where nothing but basalt was found.

METAMORPHIC ROCKS

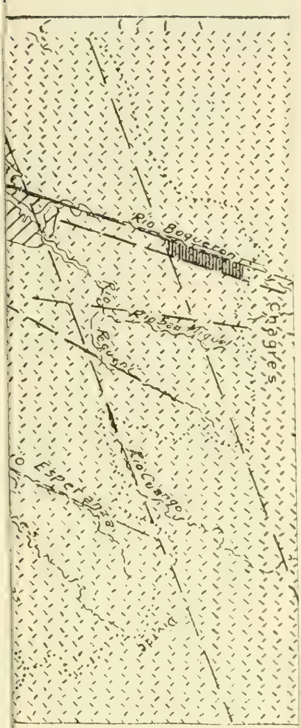
True metamorphic rocks are rare in Panama. Gneiss has never been reported. The writer has seen schist on the Rio Marea, a few miles above the village of that name in Darien and as float in the upper Rio Congo, also in Darien. Slate occurs in central Los Santos Province, and near the south coast of the Azuero Peninsula west of Morro Puercos; and on the Rio Diquis in southern Costa Rica, 35 miles west of the Panama border. All these outcrops are small. Argillite, apparently caused by baking of shale by flows or sills, occurs near Morro Puercos; on the head of Rio Chiriquí north of Caldera; in the Burica Peninsula on the upper Rio Blanco; and near Golfito in southeastern Costa Rica. It occurs commonly as boulders or gravel in the Rio Chiriquí Viejo, and in the Pleistocene conglomerate near Puerto Armuelles. No metamorphic minerals are developed in it; much of it might be called simply baked shale. There are many places where Oligocene and Miocene shales have been baked by intrusive sills and dikes, but in most cases the effect is limited to a few inches, rarely more than a foot from the contact. It is possible that some of the argillite boulders have come from such occurrences; however, the argillite outcrops described above are in the basement complex; they are pre-late Eocene, perhaps Cretaceous. Woodring and Thompson (1949) speak of "indurated fine-grained sediments that were probably originally fine-grained tuffs," which occur in the basement complex of the Canal Zone. These are probably of the same period as the argillites described above.

Near the Rio Ocones on the south coast of Veraguas west of Morro Puercos, there are also black shales which are not indurated, but which do not resemble the Tertiary sediments of the region. These unaltered rocks also appear to belong to the basement complex of Veraguas. There is also a small outcrop of marble farther east.

In general, the basement complex is extrusive volcanics, flows, agglomerates, and tuffs, showing much deformation, but little metamorphism, and predominantly basic. The sedimentaries or altered sedimentaries included with the lavas are probably not older than Cretaceous. Some of them may be early or middle Eocene.

SEDIMENTARY ROCKS

At many places, mostly in Darien from the Sabana River westward; on certain islands in the Gulf of Panama; at Bahia Honda on the south coast of Veraguas; and on the Burica Peninsula, there is found a stratified white, gray, blue, or green chert, which lies on the volcanics of the basement complex where its base is seen, and underlies the Eocene limestone. In the Rio Sabana-Rio Congo area of Darien, it is in some places interbedded with tuffs, but in general it appears to be a separate unit. No fossils have been seen in it, and its age is unknown. Olsson (1942) thinks it may be the equivalent



Rio Boqueron
Chagres

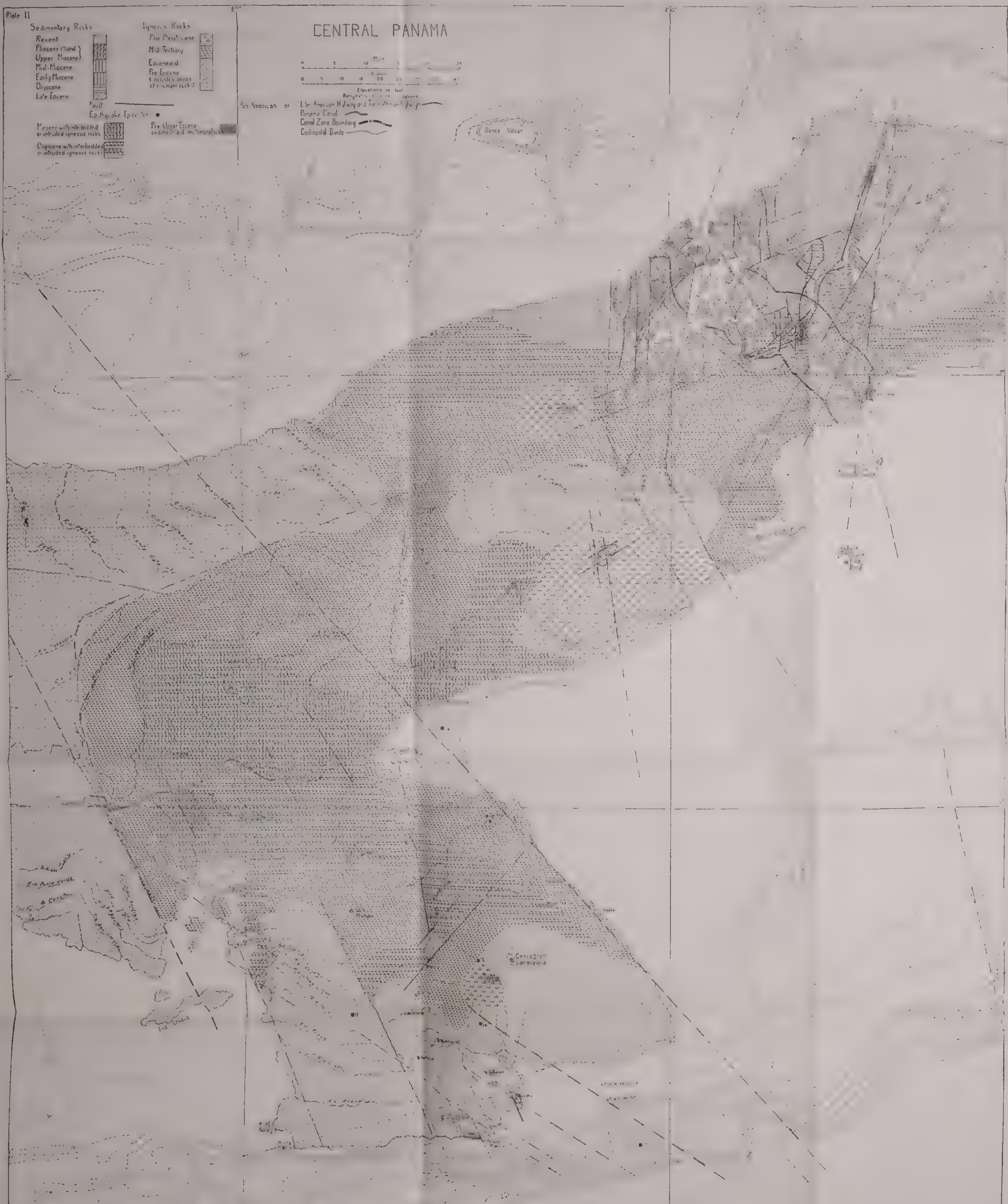


Plate II
CENTRAL PANAMA
Sedimentary Rocks
Recent
Upper Miocene
Mid-Miocene
Early Miocene
Oligocene
Late Eocene
Igneous Rocks
Mid Tertiary
Pre Eocene
Fault
Panama Canal
Canal Zone Boundary
Continental Divide
Banco Volcan

of the Guayaquil chert of Ecuador, which has been assigned various ages from late Cretaceous to middle Eocene. It has been thought to be a chemical deposit, associated with submarine eruptions.

Cretaceous

Although no description has been published, it is known that Cretaceous foraminifera have been found in northwestern Panama. It is also possible that the argillites mentioned under Metamorphic Rocks are of that age.

Eocene

The oldest fossils described from Panama, according to Olsson (1942), are of late Eocene age and belong to the Búcaru formation of Los Santos Province in the Azuero Peninsula. The rocks outcrop near Punta Búcaru near the mouth of the Tonosí River, and underlie the Tonosí valley, a fault basin about 15 miles wide and 35 or more miles long in the south-central part of the peninsula. The exposed thickness approximates 2,000 feet, according to Olsson, and it seems probable that it originally covered a much larger area on both sides of the basin. Small exposures of Eocene occur along the east shore of Montijo Bay on the west side of the peninsula. The Azuero Peninsula Eocene is the only known outcrop of that age between the Canal Zone and David, a distance of some 180 miles, although Eocene may be concealed beneath younger rocks at some intervening points.

The Búcaru formation begins with a volcanic breccia containing worn fossil fragments, and with a limey cement. The large angular volcanic fragments continue upward for some distance in the lower part of the formation, indicating that the beginning of the invasion of the sea was contemporaneous with the last phase of Eocene vulcanism. Following the fossil-bearing conglomerates are blue-green or black shales with thin sandstone beds, with a total thickness of about 1,500 feet, and these are followed by about 500 feet of blue coarse sandstones and sandy yellow limestones. This last section carried a fauna mainly of foraminifera, while in the middle and lower parts of the formation the fauna is mainly molluscan, and Olsson considers it to be the oldest Eocene of Panama, equivalent to the Talaran, the lower late Eocene of Peru. Typical fossils from this part of the section are listed by Olsson as: *Aturia peruviana* Olsson, *Venericardia tonosiensis* Rutsch, *Noetiopsis woodringi* MacNeil, *Raetomya* sp., *Spisula* sp., *Tellina* sp., *Cardium* cf. *samanicum* Olsson, *Conus* cf. *peruvianus*

Olsson, *Lyria* sp., *Clavilithes* sp., *Xancus* cf. *peruvianus* Olsson, and *Harrisonella* cf. *peruviana* Olsson.

From the upper part, *Lepidocyclina panamensis* Cushman was collected by MacDonald, with a still higher horizon containing *Operculina* and echinoids. Olsson believes this horizon to be separated from the *Lepidocyclina* beds by an unconformity. From collections by Olsson and Terry from the upper section, Vaughan (personal communication) identified *Pseudophragmina (Proporocylina)* cf. *P. flintensis* Cushman, *Operculinoides, Carpenteria, Gypsina, Helicostegina* sp., apparently *H. soldadensis* Grimsdale, and *Lepidocyclina (Pliolepidina) panamensis* Cushman, A and B forms.

The Canal Zone Eocene is described by Woodring and Thompson (1949) as beginning with 1 to 3 feet of conglomerate, followed by 25 feet of medium to fine-grained sandstone, the upper part of which is silty. Above this, the formation is made up of mudstone and siltstone, which carries lenses of limestone, mostly thin, but in some places reaching a maximum of 300 feet. The limestone lenses carry orbitoidal foraminifera, including *Lepidocyclina chaperi* and *L.* cf. *pustulosa.* Woodring and Thompson (1949) give the Eocene of the Canal Zone the name Gatuncillo formation and consider it to be the equivalent of the Eocene of the Madden Lake basin described by Reeves and Ross (1930) under the name Bohio. Reeves and Ross were not immediately concerned with Eocene stratigraphy and indicated only that it is divisible into two parts, "a thick series of hard thin-bedded fossiliferous limestone at its top, the rest of the formation consisting largely of soft shale and clay, interbedded with lenses of similar limestone. In addition, there is at the base a conglomerate consisting largely of volcanic boulders." Embich later collected from the shale of Reeves and Ross' lower division a fauna of small foraminifera described by Coryell and Embich (1937), who gave the formation the name, Tranquilla shale. This name is discarded by Woodring and Thompson (1949) because the type area is now covered by the waters of Madden Lake, and no longer accessible. Coryell and Embich describe a fauna of 46 genera and 64 species which they correlate with the McElroy division of the Jackson (upper Eocene) of the United States, "because of the presence of a variety of *Textularia hocklyensis* which is a guide to the McElroy, and the characteristic species, *Dentalina jacksonensis, Eponides jacksonensis, Haplophragmoides dibollensis,* and *Robulus alato-limbatus.*" From the limestones overlying the shale of the Madden Basin Olsson and Terry collected a fauna of orbitoidal foraminifera, which were studied by Vaughan (personal communication). They include: *Camerina striatoreticulata* Rutsch, *Carpenteria, Discocyclina* *georgiana* Cushman, *D. mariannensis* Cushman, *D.* cf. *D. minima* Cushman, *D. (Asterocyclina) asterisca* Guppy, *Eodictyoconus, Amphistegina* cf. *A. cubensis* Palmer, *Gypsina globulus* Reuss, *Heterostegina, Lepidocyclina pustulosa* forma *tobleri* H. Douvillé, *L. duplicata* Cushman A and B forms, *L. macdonaldi* Cushman, *L. (Nephrolepidina)* A form, *L. (Nephrolepidina) panamansis* Cushman, A and B forms, *L. (Nephrolepidina) chaperi* Lemoine & R. Douvillé, and *Operculinoides* cf. *ocalanus* Cushman. The rock contains an abundance of *Lithothamnium.*

On the Rio Gatuncillo, near the village of New San Juan, Olsson and Terry collected specimens identified by Vaughan: *Eodictyoconus, Cibicides, Carpenteria, Camerina, Operculinoides ocalanus* Cushman, *O. soldadensis* Vaughan and Cole, *Heterostegina, Discocyclina (Asterocyclina) georgiana* Cushman, *Discocyclina mariannensis* Cushman, *Gypsina globulus* Reuss, *Amphistegina* cf. *A. cubensis* Palmer, *Lepidocyclina duplicata* Cushman A and B forms, *L. pustulosa* H. Douvillé, and *L. macdonaldi* Cushman.

The Madden dam basin is outlined by faults striking N. 70° E., which enclose an area some 14 miles wide and 25 miles long, including the Canal Zone areas of the Gatuncillo formation. There is reason to believe that the original area of marine Eocene was considerably larger. The N. 70° E. system of faults is intersected by another set striking N. 25° E. to N. 30° E., and at the east end of the basin, there are fault contacts at various places which bring the higher members of the Eocene formation into contact with the basement complex. Owing to the difficulties occasioned by deep weathering and heavy jungle cover, it is not easy to determine the presence, much less the amount of displacement in these faults. However, south from the mouth of Rio Chagres in Madden Lake to the continental divide, the Eocene shales (Tranquilla or Gatuncillo) are apparently missing, whether by faulting or overlap of the limestone section. On the continental divide between the heads of Rio Enrique and Rio Chilibrillo, the orbitoidal limestone lies directly on the andesite of the basement complex. From specimens collected here and submitted to Vaughan, the following were identified: *Eodictyoconus, Camerina, Heterostegina, Gypsina, Lepidocyclina* cf. *L. duplicata* Cushman, *Discocyclina* cf. *D. minima* Cushman, and *Lepidocyclina (Nephrolepidina)* cf. *L. chaperi* Lemoine & Douvillé

Here there seems to be no doubt about the overlap of the limestone beyond the limits of the shale.

In the foothill belt on the south flank of the continental divide, the orbitoidal limestones continue to the east of the Madden Basin, but Eocene has not been identified until the vicinity of Chepo, about 35 miles east of Panama City, is reached. Here on Rio Mamoní, the writer collected the following, identified by Vaughan: *Operculinoides, Gypsina, Lepidocyclina pustulosa* H. Douvillé. On the road east from Chepo to El Llano: *Eodictyoconus, Carpenteria, Gypsina, Operculinoides, Discocyclina minima* Cushman, *D. (Asterocyclina) asterisca* Guppy, *Lepidocyclina macdonaldi* Cushman, *L. pustulosa* H. Douvillé. On Rio Terable: *Operculinoides* 2 spp., *Discocyclina (Asterocyclina)* cf. *D. asterisca* Guppy, *Pseudophragmina (Proporocyclina)* sp., *Lepidocyclina (Pliolepidina)* sp., *Helicostegina* sp. close to *H. soldadensis* Grimsdale. At Peña Tiburon on Rio Bayano above El Llano, were collected *Operculinoides, Lepidocyclina* cf. *pustulosa* H. Douvillé, B. form, and *L. macdonaldi* Cushman. At La Bóbida on Rio Paja, a tributary of Rio Bayano, *Camerina, Operculinoides,* and *Lepidocyclina macdonaldi* Cushman. In the Chepo-El Llano region the limestones are lenticular and on Rio Platanal, Rio Uní, and Rio Terable, small tributaries of the Bayano, clays and marls with occasional coarse sandstones form the bulk of the formation in which a crustacean (*Zanthopsis terryi* Rathbun), and some small mollusks, notably *Ampullina* cf. *depressa* Lamarck, and *Potamides* are common. Volcanic tuff and ash overlie these beds and the transition to Early Oligocene takes place in these tuffs.

The Eocene outcrop continues eastward and has been seen by the writer as far east as Rio Tabardí, about 25 miles east of El Llano; and it is known to exist above the mouth of Rio Ibertí, about 10 miles farther east. Between this point and Rio Chatí in the province of Darien, no exploration has been permitted by the Cuna Indians, but the orbitoidal limestone reappears on the Chatí and continues along the flank of the continental divide to Rio Paya, on the Colombian boundary near the head of Rio Tuira. It also occurs in Darien Province on both sides of the Cerro Pirri, on Rio Sanson, Rio Conglon, Rio Aretí, Rio Cucunatí, and Rio Sabana in central Darien Province, on Rio Congo, and in the valley of Rio Sambú near the Pacific coast. On the coast it has not been discovered.

In central Darien Province, on Rio Pihuila, a tributary of Rio Balsa, the formation is a sandy shale and sandstone, with *Potamides* and *Hemisinus.* On Rio Corcona, a tributary of Rio Chico, in Chucunaque drainage, the base of the Eocene is a dark shale with sandstone layers, carrying *Lepidocyclina* cf. *chaperi.* In general, however, the Eocene of Darien consists of hard, crystalline limestone with, in the larger part, included volcanic matter, which locally runs to hundreds, in some cases thousands of feet in thickness. On Quebrada Los

Nunos, a tributary of Rio Sabana, the thickness of the combined agglomerate, conglomerate, and limestone exceeds 4,850 feet, of which about 1,650 feet is in the coarse volcanic clastics and interbedded limestone lenses of the lower part, and about 600 feet of finer tuffs and limestones, the uppermost 2,600 feet being thin- to medium-bedded limestone with not much noticeable volcanic material. The base of the section rests on well-bedded greenish chert, much deformed and twisted. No fossils were collected, but it appears that the lower and middle sections correspond to the Eocene and that the upper part may be Oligocene.

On the Tupisa and Despreciado of the Chucunaque, the Eocene begins with 850 + feet of dark shale and shaly sandstone carrying orbitoids, followed by 2,540 feet of agglomerates, with a few thin sandstones and conglomerates; and above the agglomerates, 220 feet of clay, 420 feet of sandstone and sandy shale, 430 feet of limestone, 320 feet of sandstone and shale, and 900 feet of limestone and calcareous sandstone—a total of 5,580 feet which includes an unknown amount of Early Oligocene, probably not over 1,000 feet. No such thicknesses of Eocene, and no such amount of interbedded volcanics are known elsewhere in Panama. Evidently Late Eocene vulcanism was much more vigorous in Darien than in central or western Panama.

On Rio Congo a section exceeding 1,000 feet in thickness consists mainly of coarse agglomerate, some boulders reaching 8 to 10 feet in diameter, with a matrix of finer tuffaceous material. In this agglomerate appear occasional lenses of orbitoidal limestone. Here as in Los Santos, the last of the great Eocene volcanic activity coincides with the beginning of marine sedimentation.

In western Panama, recognized Eocene begins three miles north of David, the capital of Chiriquí Province. This is about 100 miles west of the nearest Eocene, on the shore of Montijo Bay. The intervening sedimentary area of Chiriquí and Veraguas is surfaced with Oligocene and Miocene, and the Eocene may underlie them, but is not known to outcrop.

The well-known David Eocene exposure near km. 12 on the Chiriquí National Railway is in a much-faulted area with tepid sulfur springs which have created a swamp surrounding the small outcrop of orbitoidal limestone from which *Lepidocyclina panamensis, L. duplicata,* and *L. macdonaldi* have been identified. Farther west, for a distance of five or six miles, a more complete section is exposed on various tributaries of Rio Platanal; and near the Costa Rica border, on the Rio Blanco de Breñon, a small tributary of the Chiriquí Viejo, an apparently complete section of late Eocene can be seen in the axial part of a large anticline. Three limestone beds, separated by coarse barren sandstones, yielded the following (identifications by Vaughan): Basal bed (lying on andesite)—*Eodictyoconus, Camerina, Heterostegina, Discocyclina* sp. near D. *minima* Cushman, *Lepidocyclina* 2 spp.

Bed 2—*Discocyclina* sp., *Lepidocyclina trinitatis* (?), *Lepidocyclina (Nepthrolepidina)* sp., *Lepidocyclina* sp. Possibly a fourth species of *Lepidocyclina*.

Bed 3—*Lepidocyclina trinitatis* (?) and *L. (Nephrolepidina).*

Above Bed 3 is another barren sandstone and then a conglomerate with lime cement, carrying *Lepidocyclina gigas* and marking the base of the Oligocene.

Twenty miles to the south in the Burica Peninsula limestone forms almost the entire thickness of the Eocene. No fossils have been collected, but the tests of orbitoidal foraminifera constitute a large part of the rock which exceeds 100 feet in thickness and rests directly on the andesite, or, in some places, on a thick chert.

On the north side of the continental divide, in Bocas del Toro Province, the limestone includes much volcanic material, but the chert is missing, the limestone lying directly on the andesite. The collected material in the United States National Museum has not been studied, but the fossils resemble those of the Chiriquí Eocene and the correlation is accepted by geologists who have worked in both areas. The Bocas del Toro Eocene extends westward into Costa Rica as does the Eocene of Chiriquí.

The Eocene of the Isthmian region represents an invasion of the sea over a region predominantly volcanic, or in some limited areas with cherts. The limits of this Eocene sea can not be determined with certainty. In eastern Panama, the Eocene sediments are found bordering all the large areas of basement igneous, and small exposures of infolded or infaulted Eocene can be found within those areas so frequently as to leave little doubt that it once covered the entire province of Darien. West of San Miguel Bay no Eocene is known in Pacific drainage, except the narrow band along the foothills of the continental divide, which ends at the Canal Zone. Eocene is not definitely known in the islands off the Pacific coast, but may be present in small amounts on Isla del Rey.

In central and western Panama, no Eocene occurs in Atlantic drainage between the Canal Zone and the basin of the Changuinola River in Bocas del Toro Province, a distance of more than 200 miles; while on the Pacific side an equal interval is broken only by the outcrop on the Azuero Peninsula. While much of these intervening areas is covered with younger sediments which may conceal Eocene deposits, it seems unlikely in a country so much folded and faulted and with so many exposures of the basement rocks, that the Eocene could remain unknown if it were present. It is the writer's conclusion that the provinces of Coclé and Veraguas were mostly land areas in Eocene time. The deposition of the late Eocene seems to coincide with the dying phases of a vulcanism of which the greatest activity of the period was in Darien Province around the head of San Miguel Bay. Practically all the Eocene is of shallow water deposition.

Oligocene

Oligocene sediments are of two distinct types, marine deposits laid down in waters of moderate depth, and terrestrial deposits, consisting largely of volcanic clastics, with some terrestrial and shallow-water marine sediments. The principal centers of volcanic activity in Oligocene time were the Pearl Islands of Panama Bay (fig. 3), and the shores of San Miguel Bay; and central Panama from the Canal Zone to Montijo Bay. The volcanic clastics occur interbedded with

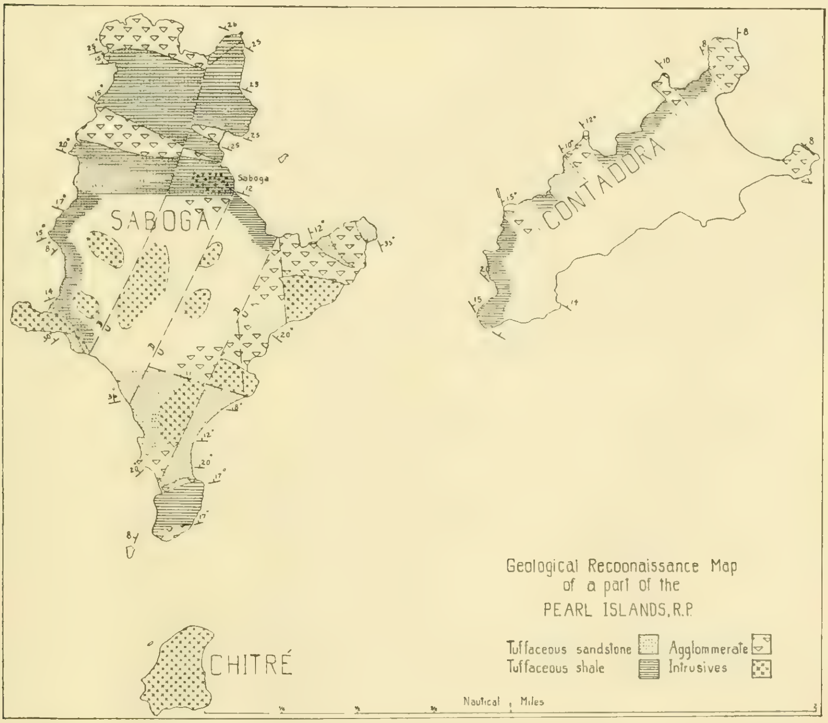


Figure 3. Geological reconnaissance map of a part of the Pearl Islands.

marine shales in the former area, and with lignites and other terrestrial deposits in the latter. No satisfactory separation has been made between the Oligocene and the underlying late Eocene, nor between the Oligocene and the overlying early Miocene. In eastern Panama, the base of the Oligocene probably lies near the top of the limestone section, most of which is undoubtedly Eocene, but no collections from this horizon have been studied.

The bulk of the Oligocene in eastern Panama consists of a massive brownish marl with numerous radiolarian spicules and much fine volcanic ash. In the vicinity of San Miguel Bay, the volcanic material is coarser and constitutes the bulk of the formation, but in the Garachiné-Sambú basin, and the Tuira-Chucunaque valley, the radiolarian ooze is more plentiful. In the Sambú valley geologists of the Gulf Oil Company described the Oligocene as "a marly material which is sometimes hard enough to be classed as limestone. Dark gray to brown in color. Many foraminifera, and also radiolaria which have been replaced by calcite. Much organic matter." Below this the section changes to hard calcareous shale and fine dark crystalline limestone, with the Eocene contact undefined. The equivalent Oligocene section in the Tuira-Chucunaque valley is quite similar and has been called the Aruza formation.

In the lower valley of the Bayano River, near El Llano, the Oligocene appears as a yellowish to brownish gray tuffaceous sandstone and sandy tuffaceous shale with limestone lenses from which collections made by Olsson and Terry yielded: *Heterostegina panamensis* Gravell, *Lepidocyclina canellei* Lemoine and R. Douvillé, and *Miogypsina cushmani* Vaughan. Farther west at Rio Hondo, about three miles west of Chepo, the same assemblage was found, and still farther west at Rio Pacora, a collection by Terry gave *Operculinoides, Lepidocyclina* sp., *Nephrolepidina verbecki* H. &. H. T. Barker, *Eulepidina* sp. aff. *L. undosa* Cushman.

On the old Spanish trail from Panama to Nombre Dios at Monte Oscuro, a few miles outside the Panama City limit, Olsson collected *Gypsina, Heterostegina, Miogypsina,* and *Lepidocyclina* sp. cf. *L. miraflorensis* Vaughan. This locality is close to the Canal Zone limit and the formation is largely volcanic material. It probably belongs in the Bohio formation.

In the Zone, Woodring and Thompson (1949) describe the Bohio as massive or poorly bedded conglomerate, tuffaceous sandstone, and tuffaceous siltstone. The coarse constituents of the conglomerate range up to boulders six feet in diameter and coarse and fine matter is mostly basaltic. Much of it is nonmarine, and silicified tree trunks occur in it. Fossils are rare, but *Lepidocyclina canellei* has been recognized by Stewart from a locality near Darien station on the railroad.

According to Woodring and Thompson in the region of the Gaillard cut the Bohio is replaced by the Bas Obispo and Las Cascadas formations, which are entirely volcanic, consisting of angular and subangular fragments of andesite embedded in tuffs in the Bas Obispo, and waxy and clayey altered tuff in Las Cascadas. The age determination is questionable. West of the Canal Zone, Olsson and Terry, in a traverse from El Valle to Puerto La Tagua, at the southwest corner of Gatun Lake, passed over a ten-mile stretch of volcanics, lava flows, agglomerates, tuffs, and ash. A rude bedding could occasionally be seen, the dip being generally northward at a low angle. Near the Rio Esterial terrestrial sediments appear, including coal. No fossils have been collected from the coal-bearing section, but it is believed to be the equivalent of the lower Caimito, which Woodring and Thompson (1949) consider early Oligocene in the adjacent Canal Zone area. The entire region from the Canal Zone westward seems to have been a volcanic island in Oligocene time. The Canal Zone includes the fringe of these eruptive rocks, where they interfinger with sediments, in some places marine, in other places terrestrial. This band of interbedded sediments and volcanics extends westward to about 80° 45′ on the Caribbean coast. It is hard to draw a contact, for the inner edge of the sediments which are thus interbedded, as the line is undoubtedly extremely irregular and could only be mapped after thorough detailed field work. The writer made a trip up the Rio Coclé del Norte to the mouth of the Rio Toabre and from the canoe could see no outcrops along the river other than the volcanics, but sedimentary beds are present, as samples shown him along the way included foraminiferal shales which had been baked at the contact with andesitic lavas. From the air the region has the parallel-ridged appearance of an area of tilted sediments.

In the Quebrancha syncline, east of the Canal Zone, Woodring and Thompson (1949) divide the Bohio into a gritty sandstone lower member and a volcanic upper member.

The late Oligocene of the Canal Zone is largely missing on the Pacific coast and as far north as the Gaillard cut, but includes the Culebra formation which is limited to the Gaillard cut and the immediate vicinity. The age of the formation is a matter of dispute among paleontologists, depending on personal opinion regarding the diagnostic importance of the lepidocycline species which in California and the Canal Zone occur in the fossil assemblage which would otherwise be regarded as Miocene; while in European and Atlantic coast faunas, their presence is considered proof of Oligocene age. The Culebra is placed by Woodring and Thompson at the top of the Oligocene, but the larger part of the late Oligocene is missing, the Culebra resting on the Las Cascadas agglomerate. The Emperador limestone is in the upper part of the Culebra, including the transition to definite early Miocene. It is a light-colored, occasionally marly limestone, apparently reefs, which are not continuous over more than a few miles, and often much less so. Vaughan (1918) notes the evidently contemporaneous faunas of the Emperador and Culebra with the Antigua Oligocene. The patchy occurrence of the Emperador has led to confusion between it and other limestones.

On the Caribbean side of the Canal Zone, the late Oligocene is included in the Caimito formation. Near the Darien radio station on the railroad, the type section includes a basal conglomerate, which is considered by Woodring and Thompson to be of Las Cascadas age. The conglomerate consists of basaltic cobbles in a sandstone matrix containing acidic tuff. The remainder of the formation in this locality is divided into a lower member chiefly tuffaceous sandstone, with thin limestone lenses, and a thicker upper member composed of tuff, agglomeratic tuff, tuffaceous siltstone, and sandy tuffaceous limestone lenses. The basal conglomerate is not fossiliferous, but in the lower member *Lepidocyclina canellei, L. vaughani,* and other larger foraminifera occur, as also do corals. The upper member is less fossiliferous, but carries *Lepidocyclina canellei.*

In the Quebrancha syncline just west of the Madden Dam basin, Woodring and Thompson (1949) divide the Caimito into two members, the Quebrancha limestone overlying the Bohio without unconformity, and an overlying calcareous siltstone member which includes some sandstone, while in the Madden Dam basin itself, they give the Caimito a five-fold division, of which the three upper members are placed in the early Miocene. The late Oligocene portion consists of a calcareous sandstone member resting on the Bohio and an overlying pyroclastic member containing a thick limestone lens carrying *Lyropecten condylomatus.*

The same authors consider the entire Bohio of Reeves and Ross (1930) as probably belonging to the Gatuncillo (Eocene), but from a collection by Olsson and Terry in 1933, in the area now covered by Madden Lake between the mouth of Rio Pequení and Rio Puente, Vaughan identified *Lepidocyclina (Eulepidina) favosa* Cushman, and placed it in the Oligocene; Embich (personal communication) also collected *Lepidocyclina gigas* from a nearby outcrop. Apparently the upper part of Reeves and Ross's Bohio is actually Oligocene.

In general, the Canal Zone Oligocene is terrestrial and mainly volcanic on the southwest side and increasingly marine in character as one goes northeastward through the Madden Dam basin, suggesting that there may have been an eastward outlet to the sea, which was cut off by the mid-Miocene uplift and deformation. West of the Canal Zone and south of the continental divide, rocks of volcanic origin predominate for some 20 miles or more to the vicinity of Capira; between Capira and the coast an area of coal-bearing sandstone and shale has been reported. The writer has not examined this area, but it seems probable that the coal is of the same age as the Rio Indio coal which occupies a similar stratigraphic position on the other side of the divide. Vaughan (1918) states:

> Dr. MacDonald collected fossil plants at Sta. 6840, about seven miles northeast of Bejuca, near Chame, Panama, in a yellowish argillaceous sandstone that seems to overlap conglomerates and is believed to represent the Caimito formation. Professor Berry records the following species from this locality:
>
> *Guatteria culebrensis* Berry, also Culebra and Gatun formations.
> *Hiraea oligocaenica* Berry.
> *Hieronymia lehmanni* Berry.
> *Schmidelia bejucensis* Berry, also Culebra. As two of the four species also occur in the Culebra formation, it appears that the formation in which they were obtained is in age near the Culebra formation.

It is not known whether these coals are Oligocene or early Miocene, but they appear to be definitely older than the coal of the Gatun formation in Costa Rica, Bocas del Toro, and Chiriquí. The coal-bearing sandstones outcrop at several places in, and on the borders of the Santiago plain, and the rocks in which they occur carry large amounts of volcanic ejecta, flows, tuffs, and ash.

South of the Santiago plain, on the east side of Montijo Bay, on Rio Mariato, Condit collected *Ampullinopsis* cf. *spenceri* Cooke, from a shale overlying sandstones and conglomerates (Olsson, 1942). In the United States National Museum, collection 7962 contains *Turritella* cf. *venezuelana, Nassa, Xancus, Pitaria,* and *Balanus,* and Olsson considers it middle or late Oligocene (personal communication). Collection 8467 from nearby contains *Crassatella* cf. *berryi.* Olsson correlates the shale with the middle Oligocene of northern Peru and with the Oligocene of Antigua, and places the underlying Montijo formation as the equivalent of the Bojio. The coal-bearing sandstones of the Santiago plain thus would fall into late Oligocene classification, although here as elsewhere in Panama, no sharp contact can be drawn between the late Oligocene and the early Miocene. The volcanic land area of Oligocene time apparently continued as far west as the head of Montijo Bay, and probably farther. The Oligocene island of central Panama was fringed by a low swampy coastal region, on the surface of which shallow marine and terrestrial sediments were mingled with the ejecta from the volcanic island.

West of Montijo Bay, the Soná Peninsula is composed of igneous rocks which the writer believes belong to the basement complex, from the presence of stratified chert at Bahia Honda (L. G. Hertlein, personal communication). Stratified chert is known in Panama only below the late Eocene. Near the lower course of Rio Tabasará about 20 miles west of Soná, coarse tuffaceous sediments with interbedded lavas and volcanic clastics of various sizes reappear. The formation has not been studied and its age is uncertain, but at least a part of it, if not all, is accepted as Oligocene by most geologists who have seen it. There are no collections from this area, but United States National Museum collection 6534, from a locality some miles north of San Felix, contains *Glyptostyla* cf. *panamensis,* which suggests late middle or late Oligocene to Olsson (personal communication). The outcrop covers a belt 10 to 15 miles wide across Chiriquí Province to the eastern edge of the Pleistocene volcanics west of the David River, and becomes finer grained westward. At the railroad line from David to Boquete, which is close to the eastern edge of the Pleistocene volcanics, the formation is a hard shale with considerable ash but no coarse tuffs. The hardness is probably due to baking by crypto-vulcanism in mid-Miocene time, as the region for miles around is cut by dikes and plugs; and thick lava flows appear at, or close to, the contact between early Miocene and middle Miocene. The Pleistocene volcanics cover the region westward to Rio Chiriquí Viejo, near the Costa Rica border, where the Tertiary sediments reappear. Here the Oligocene begins with a conglomerate bed lying on late Eocene sandstone. The conglomerate is cemented with lime and carries *Lepidocyclina gigas* and is followed by a shale section, then by two beds of limestone separated by shale. The lower limestone bed carries a large selliform *Nephrolepidina* and the upper one has the same species and also *Eulepidina undosa* (Vaughan, personal communication). In the shale a little above these limestones are what appear to be specimens of *Nummulites,* but identification is not complete as the material collected disappeared in transit. The shales continue with numerous exposures for a distance of 10 miles or more. They are usually gray in color and carry numerous foraminifera, larger fossils being rare. They resemble closely the Uscari shale of Bocas del Toro and Costa Rica and like the Uscari, probably include middle and late Oligocene and early Miocene. In 1925 a well was drilled near David which began in a lava flow of middle Miocene age, passed through some 150 feet of lava, and an equal amount of Gatun sandstone and entered the shale. No faunal record is available, but the writer has been informed that the well passed directly from the Gatun into the Oligocene, no early Miocene being found. There may be involved here the question of diagnostic species, which is often a matter of dispute in the Isthmian region. No Oligocene has been recognized on the Burica Peninsula.

On the Caribbean side the Uscari has been studied by Olsson (1922) from surface outcrops, and a considerable fauna has been determined from well cuttings. As this faunal record has not been published, it is included with the permission of the Sinclair Panama Oil Company. Foraminifera from well on Columbus Island, Bocas del Toro, R.P. (to depth of 7,790 feet):

Amphistegina lessonii d'Orbigny
Anomalina sp.
Bolivina aenariensis (Costa)
Bolivina floridana Cushman
Bulimina bleeckeri Hedberg
Bulimina marginata d'Orbigny
Candorbulina universa Jedlitschka
Cassidulina subglobosa Brady
Chilostomella oolina Schwager
Chilostomella ovicula Nuttall
Cibicides mexicana Nuttall
Cibicides sp.
Clavulina cyclostomata Galloway and Morrey
Clavulina venezuelana Nuttall
Cyclammina cancellata Brady
Cyclammina sp.
Dentalina sp.
Discorbis bertheloti d'Orbigny
Ellipsonodosaria verneuili d'Orbigny
Entosolenia marginata Montagu
Epistomena elegans d'Orbigny
Eponides parantillarum Galloway and Heminway
Gaudryina jacksonensis Cushman
Glandulina laevigata d'Orbigny
Globigerina bulloides d'Orbigny
Globigerina triloba Reuss
Globorotalia sp.
Globobulimina pacifica Cushman
Gyroidina soldanii d'Orbigny
Haplophragmoides sp.
Heterostomella cubensis Palmer and Bermudez
Marginulina basispinosa Cushman and Renz
Marginulina subaculeata (Cushman)
Marginulina wallacei Hedberg
Marginulina sp. "A"
Nodosaria carinata d'Orbigny
Nodosaria longiscata d'Orbigny
Nodosaria raphanistrum (Linne)
Nodosaria vertebralis Batsch
Nonion soldanii (d'Orbigny)
Peneroplis sp.
Plectofrondicularia californica Cushman and Stewart
Planulina sp.
Pseudoclavulina mexicana Cushman
Pullenia bulloides d'Orbigny
Pyrgo murrhyna Schwager
Quinqueloculina lamarckiana d'Orbigny
Robulus calcar Linne
Robulus cultratus Montfort
Robulus formosus Cushman
Robulus oblongus Coryell and Rivero
Robulus sp. "B"
Rzhekina sp.
Sigmoilina sp.
Sigmoilina schlumbergeri A. Silvestri

Siphonina tenuicarinata Cushman
Siphogenerina transversa Cushman
Sphaeroidena variabilis Reuss
Sphaeroidinella dehiscens (Parker and Jones)
Spiroloculina alveata Cushman and Todd
Textularia mexicana Cushman
Textulariella sp.
Trochammina sp.
Uvigerina gardnerae Cushman
Uvigerina pygmaea d'Orbigny
Uvigerina rustica Cushman and Edwards
Verneuilina sp.

In addition, Palmer (1923) determined the following species from Nigua Creek, Panama [erroneously cited as Costa Rica in her account]:

Nodosaria soluta Reuss
Cristellaria cultrata Montfort
Cristellaria reniformis d'Orbigny
Frondicularia sp.
Nummulites costaricensis (Palmer)
Vaginulina legumen Linnaeus

Porter (1942) collected from Amoura River, just above the mouth of Uscari Creek, the following additional species (determinations by P. P. Goudkoff):

Bolivina acerosa Cushman
Bolivina pisciformis Galloway and Morrey
Bolivina rinconensis Cushman and Laiming
Cassidulina crassa d'Orbigny
Cassidulinoides sp.
Cibicides cf. *ungeriana* d'Orbigny
Clavulina communis d'Orbigny
Dentalina cf. *D. communis* d'Orbigny
Dentalina multilineata Bornemann
Dentalina roemeri Neugeboren
Eponides umbonata Reuss
Globigerina conglomerata Schwager
Lagena striato-punctata Parker and Jones
Lamarckina sp.
Liebusella pozonensis var. *crassa* Cushman and Renz
Marginulina subbullata Hantken
Nodosaria ewaldi Reuss
Nodosaria holserica Schwager
Nodosaria koina Schwager
Nodosaria camerina Dervieux
Planulina cushmani Barbat and von Estorff
Robulus barbati Cushman and Hobson
Robulus mayi Cushman and Parker
Robulus cf. *taettowata* Stache
Saracenaria acutauricularis Fichtell and Moll
Textularia mississippiensis Cushman
Uvigerina cf. *gardnerae* Cushman and Applin
Uvigerina hispida Schwager

This collection is from a section believed to be stratigraphically lower than that at the oil seep on Uscari Creek. According to Porter, 15 of the species are to be correlated with the lower Miocene, and 9 with the upper Oligocene. Porter proposes the name Amoura shale for the section represented, leaving the question of member or formation status for future determination.

The Uscari represents the climax of a long period of erosion, beginning in late Eocene time and continuing with only minor and short-lived regressions to mid-Miocene. At the end of the period, the land of the present isthmian region must have been reduced to a group of islands of a total area not exceeding one-half its present size—perhaps much smaller. The total deposits of Oligocene and late Miocene times are 5,000 feet thick or more over great areas and have a total mass which seems to demand as a source a land area of much greater size than the present isthmus. Although volcanic material is present throughout, the bulk of the Oligocene and lower Miocene consists of limy shales with considerable bituminous content. It appears to the writer that the presence of a considerable land area both on the Caribbean and Pacific sides in regions now submerged must be assumed for the greater part of the Oligocene and for much of the lower Miocene.

The Uscari is separated from the overlying middle Miocene by a sharp erosional unconformity over most of the region. However, on Columbus Island, Bocas del Toro Province, the overlying middle Miocene is a shale with limestone lenses, with no basal conglomerate or other lithologic indication of prolonged erosion. A well started in lower Miocene beds was abandoned at 8,640 feet without encountering any significant change of formation. The bottom was in middle Oligocene. According to the paleontologist the faunal record indicates that the well passed through two thrust faults and perhaps three, so that no accurate estimate can be made of the true thickness of the formation. Estimates from measurements of surface outcrops are subject to error arising from lack of continuity of exposures, and especially from the presence of faults, often unrecognized by field geologists.

In the valley of the Reventazon River in Costa Rica, Branson (1928) estimated 5,000 feet of Oligocene and early Miocene without reaching the bottom of the section. This locality is about halfway between Puerto Limon on the Caribbean coast, and the continental divide. Branson's Uscari is mainly sandstones and conglomerates, with two thick limestone members, while the Oligocene, though predominantly shale, also has several thick sandstones, some thin conglomerates and several limestone beds. The whole series has a decidedly shallow-water aspect as compared with the deep-water rocks of the same age in Bocas del Toro.

Miocene

The early Miocene of the Garachiné region of eastern Panama has been described as follows by the geologists of the Gulf Oil Company: "Thinly bedded brown shaly material with lesser amounts of more conspicuous brown limestones. The shale is somewhat argillaceous, compacted ooze, made up largely of radiolarian remains composed of amorphous silica. Series is bituminous; seeps heavy asphaltic oil in several places. Forms small hills and ridges where exposed in tilted structure."

Oil seepages in the low swampy area bordering on the tidal flats of Garachiné Bay undoubtedly come from this shale and limestone section, though there are no exposures at the seeps. Farther inland, these rocks are known as the dry seepage horizon, from their asphalt seams. Wells of the Gulf Oil Company also encountered oil shows in this horizon. Farther east, in the Tuira-Chucunaque basin, the equivalent section is also oil-bearing and similar in lithology to that described above. It grades downward without an erosional break into the brown marl of the late Oligocene. In this area the upper part is called the Aquaqua formation, the lower, the Aruza formation, and the division corresponds approximately to the terms early Miocene and late Oligocene, but no definite contact has been established.

From a well drilled by the Sinclair Panama Oil Company near the Rio Yape, a tributary of Rio Tuira, the following fauna has been determined:

Agathamina sp.
Amphistegina sp.
Astacolus crepidulatus Montfort
Anomalina ammonoides Reuss
Anomalina ariminensis d'Orbigny
Anomalina grosserugosa Gümbel
Bolivina aenariensis Costa
Bolivina argentea Cushman
Bolivina compacta Sidebottom
Bolivina dilatata Reuss
Bolivina floridana Cushman
Bolivina punctata d'Orbigny
Bolivina cf. *pusilla* Schwager
Bolivina cf. *simpsoni* Heron-Allen and Farland
Bolivina schwageriana Brady
Bolivina tortuosa Brady
Bulimina aculeata d'Orbigny
Bulimina cf. affinis d'Orbigny
Bulimina buchiana d'Orbigny
Bulimina elegans d'Orbigny
Bulimina elongata d'Orbigny
Bulimina inflata Seguenza
Bulimina marginata d'Orbigny
Bulimina pupoides d'Orbigny
Bulimina pyrula d'Orbigny
Bulimina cf. *rostrata* Brady
Bulimina sculptilis Cushman
Bulimina subornata Brady
Cassidulina crassa d'Orbigny
Cassidulina laevigata d'Orbigny
Cassidulina cf. *subglobosa* Brady
Cavulina parisensis d'Orbigny
Chilostomella ovoides Reuss
Cibicides culter Parker and Jones
Cibicides pygmaea Hantken
Cibicides ungeriana d'Orbigny
Cibicides (Truncatulina) sp.
Cribrostromoides sp.
Cyclammina sp.
Cyclammina cancellata Brady
Dentalina obliqua Linne
Ellipsoglandulina laevigata A. Silvestri
Fissurina marginata Montagu
Frondicularia alata d'Orbigny
Gaudryina laevigata Franke
Gaudryina paupercula Cushman
Gaudryina rotunda Reuss
Gaudryina subrotundata Schwager

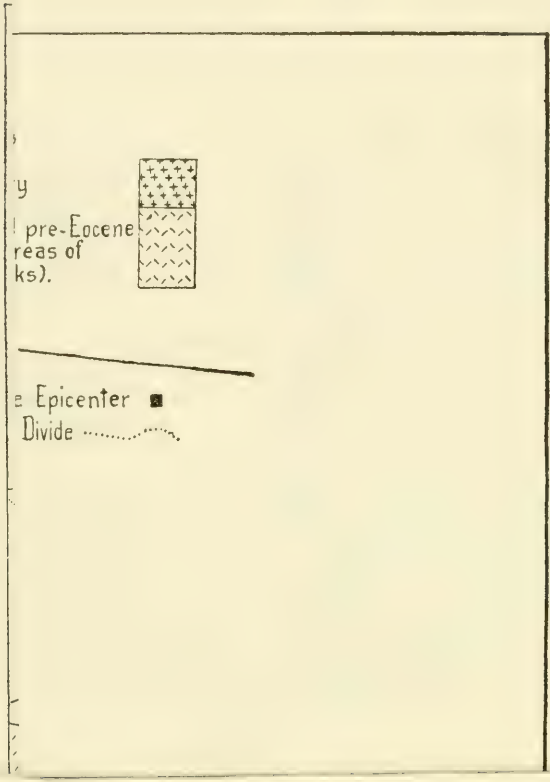
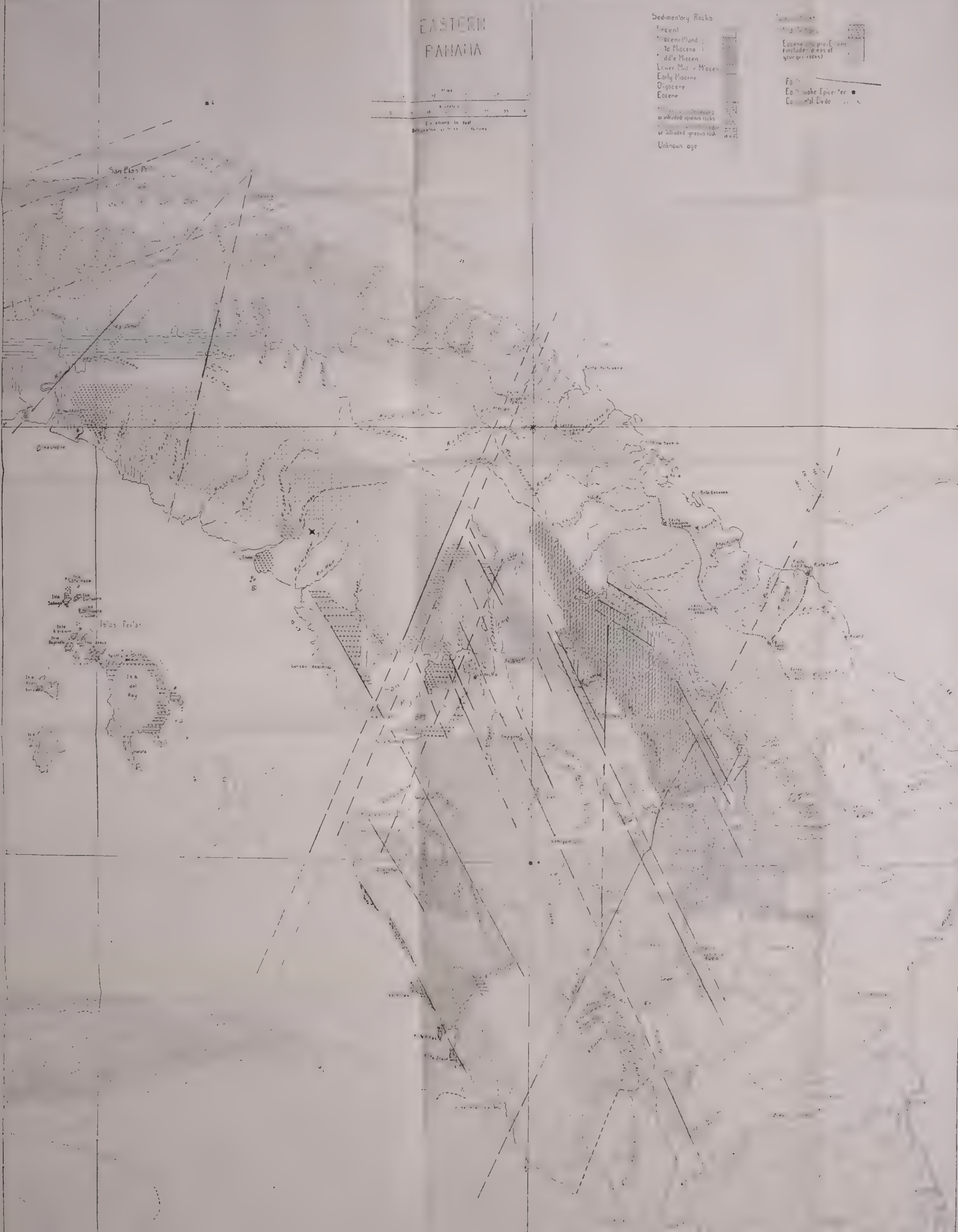

y
pre-Eocene
reas of
ks).
Epicenter
Divide

Plate III


EASTERN
PANAMA
Elevations in feet
Sedimentary Rocks
Lower Middle Miocene
Early Miocene
Oligocene
Eocene
Unknown age
Earthquake Epicenter
San Blas Pt.
Islas Perlas
Isla del Rey
Isla Saboga

Glandulina laevigata d'Orbigny
Glandulina rotundata Reuss
Globigerina bulloides d'Orbigny
Globigerina cretacea d'Orbigny
Globigerina conglobata, Brady
Globigerina dubia Egger
Globigerina cf. *trilobata* Costa
Gyroidina soldanii d'Orbigny
Haplophragmoides sp.
Haplophragmoides canariensis d'Orbigny
Lagena sp.
Massilina sp.
Mucronina (hexacostata) d'Orbigny
Nodosaria costulata Reuss
Nodosaria consobrina d'Orbigny
Nodosaria cf. *farcimen* Reuss
Nodosaria filiformis d'Orbigny
Nodosaria hispida d'Orbigny
Nodosaria obliqua Linne
Nodosaria cf. *pyrula* d'Orbigny
Nodosaria radicula (Linne)
Nodosaria sagrinensis Bagg
Nodosaria soluta Reuss
Nodosaria vertebralis (Batsch)
Nonion boueanus d'Orbigny
Nonion pompilioides Fichtel and Moll
Nonion scapha Fichtel and Moll
Nonion umbilicatula Walker and Jacob
Orbulina universa d'Orbigny
Patrocles calcar (Linne)
Patrocles (Cristellaria) sp.
Patrocles cultrata (Montfort)
Patrocles mammilligera (Karrer)
Patrocles reniformis (d'Orbigny)
Patrocles rotulata (Lamarck)
Patrocles submammilligera (Cushman)
Patrocles vaughani (Cushman)
Planulina ariminensis d'Orbigny
Plectrofrondicularia sp. (bicostate)
Plectrofrondicularia sp. (tricostate)
Plectrofrondicularia sp. (quadrate)
Polymorphina gibba d'Orbigny
Polymorphina burdigalensis d'Orbigny
Pullenia sphaeroides d'Orbigny
Rheofax (?)
Reussella (?)
Rosalina (Discorbina) globularis (d'Orbigny)
Rotalia beccarii Linne
Rotalia globularis (d'Orbigny)
Sigmoilina sp.
Siphogenerina sp.
Siphonina reticulata Czjzek
Sphaeroidina bulloides d'Orbigny
Spiroloculina sp.
Textularia abbreviata d'Orbigny
Textularia agglutinans d'Orbigny
Textularia gramen d'Orbigny
Textularia sagittula Defrance
Themeon (Polystomella) sagra d'Orbigny
Trigonulina obliqua Seguenza
Triloculina sp.
Uvigerina asperula Chapman
Uvigerina canariensis d'Orbigny
Uvigerina pygmaea d'Orbigny
Uvigerina cf. *tenuistriata* Reuss
Virgulina squamosa d'Orbigny
Verneuilina cf. *pygmaea* Egger

The Aquaqua formation is bentonitic in some parts of the section, and in the Yape well, bentonite beds were conspicuous aquifers. It is believed that the forms listed above are entirely from the early Miocene. The Aquaqua formation has been mapped as far north as the Membrillo River, in the central Chucunaque valley, but the outcrop grows smaller from the Tuira northward, apparently partly because of progressive overlap of the middle Miocene, and perhaps to erosion at the mid-Miocene uplift; but seven or eight miles west on the Rio Sabana it is present apparently to a thickness of 2,000 feet or more. On the Pacific coast south of Garachiné Point, a narrow band of it appears standing on edge or dipping steeply in contact with the basement rocks.

In central Panama the early Miocene has been carefully studied only in the Canal Zone, where it is recognized by Woodring and Thompson (1949) only in the region south of Gamboa, and in the Madden Lake basin. In the Gaillard cut it is represented by the Cucaracha formation which is mostly nonmarine, consisting of carbonaceous and lignitic shale, and massive greenish gray bentonitic and tuffaceous clayey sandstone. There is usually a conglomerate at the base. The bulk of the formation is the bentonitic clay.

The La Boca formation, known mostly from borings, according to Woodring and Thompson, extends from the Gaillard cut to the Pacific entrance of the Canal, and is chiefly silty or sandy mudstone. Conglomerate and sandstone are found in some bore holes in the lower part. Near the base cream-colored coralliferous limestone of the type of the Emperador interfinger with the clays of the Cucaracha formation. In the Pedro Miguel area the Pedro Miguel agglomerate overlies the Cucaracha, but the lower part of it is apparently equivalent to the upper part of the thicker Cucaracha section.

The Panama tuff is apparently a facies of the Cucaracha, a well-stratified water-laid rhyolitic tuff with fragments of pumice. A few foraminifera of Oligocene age have been found in the type region near Diablo Heights, but these are probably inherited.

In the Madden Lake basin, the youngest rocks exposed are massive, fossiliferous tuffaceous sandstones, which form the foundation of Madden dam. Olsson (1942) named the formation the Alhajuela sandstone. These sandstones are increasingly calcareous downward and have been divided by Woodring and Thompson (1949) into the upper Alhajuela sandstone member and the calcareous sandstone member. The latter contains so much lime that it might in some places equally well be called a sandy limestone. The caves caused by solution in this member were a serious engineering obstacle in the construction of the Madden Dam, as some of them were of dimensions ranging up to 100 feet. This member, according to Woodring and Thompson, carries *Turritella gatunensis*, and is assigned to the early Miocene. The Chilibrillo limestone which underlies it may be the equivalent of the Emperador of the Canal Zone. It is considered to be early Miocene by Woodring and Thompson. In the region between Gamboa and the limits of the Canal Zone west of Gatun Lake, early Miocene rocks are missing, according to Woodring and Thompson (1949), but Jones (1950) disagrees.

West of the Canal Zone in central Panama, the early Miocene is probably represented only by volcanic ejecta, but lack of fossiliferous sediments makes any dating questionable. Basic lavas and agglomerates form the surface from the Canal westward to Capira, beyond which acidic rocks are found. The quartz sand beaches below these acid rocks have been a much sought source of sand for concrete work around Panama City. In the south wall of El Valle crater, well-bedded rhyolitic tuffs, much resembling the Panama tuffs at Diablo Heights, dip southward, and similar material with crossbedded tuffaceous clays, sands, and gravels occurs in the vicinity of Penonomé. Some of the sediments are diatomaceous, but no marine fossils were seen. They are believed to be fresh-water deposits. Similar material occurs along the road to La Pintada, a town about two miles south of the continental divide and seven miles north of Penonomé. About a mile north of La Pintada basic lavas appear, which are believed to belong to the basement complex, as between these andesites and La Pintada is a chert outcrop, a rock which is known elsewhere in Panama only from below the late Eocene at the top of the basement complex. To the south and east of La Pintada on the trail to El Valle are outcrops of rhyolite resembling the north wall of the El Valle crater. The rhyolite flows also occur along the road from Penonomé to Natá, where they can be traced westward to the Rio Grande where andesite flows begin. The andesite flows strike northeast and dip northwest, but the rhyolite flows and ash strike east-west and dip south, apparently overlapping the andesite. The andesite flows form the foothills of the continental divide toward which they dip. They can be traced westward to the vicinity of Cañazas where they are overlain by shale of probable early Miocene age, and on north to the continental divide.

The structure is well shown in Hershey's (1901) structure section. (H-H). The writer has made many plane flights along this mountain front and has checked the northward dip of the lavas and interbedded sediments. It would appear that the andesite flows can not be younger than early Miocene nor older than late Oligocene, and that they were eroded and overlain by the rhyolite in the Natá-Penonomé-La Pintada area. Shales of the Santiago formation of Hershey are considered to be of early Miocene age by Woodring and late Oligocene by Olsson (1942) The lava beds to the north overlie them and are without much doubt early Miocene.

Collections made by Sinclair geologists in the vicinity of Santiago are deposited in the United States National Museum, but have not been studied. The collector's notes are of some interest:

On the road from Santa Maria to Santiago—2nd hill of main divide 5 miles northeast of Santiago—close-textured shaly ls.—*Melanopsis*, *Cyrcanacea* (?) like *Inoceramus*, fresh-water fauna. (U.S.N.M. Coll. 8465.)

Three-quarter mile southwest of Santiago on road to Montijo—calcareous agglomeratic ss. Large *Amusium*, *Ostrea*—small, falcate, narrow sharp plication of entire periphery, *Phacoides*, *Chione*, *Arca (Cunearca)*, *Harpa*, large *spatangoid echinoid*. (U.S.N.M. Coll. 8466.)

Road crossing of Rio Martin Grande, one-quarter mile west of Santiago—agglomeratic ss. *Turritella* cf. *venezuelana*, *Oliva*, *Terebra*, with large axial costae on anterior half of whorl, 2 spiral bands on posterior half, *Conus*, *Triton*, *Natica* small, *Nassa*, *Glycymeris*, *Phacoides* cf. *anodonta*, *Venericardia*, *Pitaria*, fragments of *Crassatella* cf. *berryi*. (U.S.N.M. Coll. 8467.)

These last beds appear to Olsson (personal communication) to be borderline late Oligocene or early Miocene.

In Bocas del Toro Province, early Miocene shales form the upper part of the Uscari formation and have been described by Olsson (1922), who lists a molluscan fauna. Many of the foraminifera previously listed under the late Oligocene of Bocas del Toro also occur in the early Miocene, but only three—*Eponides parantillarum*, *Discorbis berthelotti*, and *Spiroloculina alveata* are apparently limited to the Miocene in the recovery from the Bocas well.

South of the divide in Chiriquí Province, the early Miocene consists of tuffaceous shales and shaly sandstones. From collections in the United States National Museum, Olsson has identified the following (personal communication):

Arca macdonaldi Dall
Arca veatchi Olsson
Architectonica sexlinearia Nelson
Chione propinqua Spieker
Clementia dariena Conrad
Conus multiliratus Böse
Crassatella berryi Spieker
Dosinia cf. *delicatissima* Brown and Pilsbry
Mactra cf. *plicatella* Lamarck
Phos inornatus Gabb
Turritella altilira Conrad
Turritella cf. *venezuelana* Hodson

A well drilled a few miles north of David is stated to have passed directly from middle Miocene to Oligocene with no early Miocene present. It is possible that this may be because of erosion preceding the Gatun deposition, or the statement may be merely the paleontologist's opinion regarding the disputed position of the Oligocene-Miocene contact.

On the Burica Peninsula, lower Miocene is possibly present. From a collection on the upper San Bartolo River, *Nonion grateloupi*, *N. mesonense*, *Quinqueloculina lamarckina*, and *Virgulina pontoni* have been identified by Clift.

In general the early Miocene of eastern Panama is an offshore deposit of fine texture with some fine volcanic matter; in central Panama, it is shallow water or terrestrial with large amounts of volcanic ejecta of all sorts, agglomerates, flows, tuffs, and ash; in western Panama, it is a fine-textured shale of offshore type in Bocas del Toro, somewhat sandier in Chiriquí and Costa Rica, and becomes conglomeratic in central Costa Rica west of Puerto Limon. The difficulty in distinguishing the early Miocene from late Oligocene appears to be about the same everywhere, indicating continuity of deposition in all areas without regard to the character of the deposit.

Middle Miocene

The long period of continuous deposition from late Eocene through early Miocene was broken in mid-Miocene time by uplift and erosion in all parts of the Isthmian region. The uplift was accompanied by vulcanism in western and central Panama, but apparently not in eastern Panama. Folding and faulting were a part of the movement, but much of the evidence is concealed beneath the deposits of middle Miocene and later time. The angular unconformity between middle Miocene and older sediments is sharply marked in the Burica Peninsula, where on the upper Rio La Vaca, Eocene limestone striking N. 55° W. and dipping 65° NE. is overlain by Miocene conglomerate and sandstone striking N. 75° W. and dipping 43° NE., and not far away the Miocene with about the same dip and strike lies on the edges of vertical Eocene limestone beds striking N. 72° W. Angular unconformity between early and middle Miocene is generally much less sharp, although often perceptible. As there has been much post-Miocene folding, followed by erosion, the middle Miocene is now found mostly in synclines, grabens, and basin areas, and is generally lacking on anticlinals, horsts, or other areas of uplift.

The best-known middle Miocene is in the sedimentary basin centered round Gatun at the northern end of the Panama Canal. This region because of its accessibility and economic and strategic importance has long been the object of study, and as it has not been much affected by post-Miocene tectonic movements, the sequence, thickness, and character of the beds has been well established. The basin is gently arcuate, opening to the northwest and the strike of the basal contact varies from nearly due north-south on the east side of the basin to about N. 70° W. at the west side. On the east side, the Gatun rests on the basement rocks, but on the southeast, south, and southwest sides it lies on the late Oligocene (lower Caimito), or early Miocene, according to Jones (1950).

Jones describes the Gatun as "mudstones, siltstones, conglomerates and tuffs, all thickly and massively bedded. The siltstones, sandstones, and conglomerates are variably marly and tuffaceous, highly fossiliferous and massively jointed. . . . The tuffs are uniformly grained siltstones and claystones except for local streaks, sparsely scattered with pumice pebbles and cobbles. The formation has a thickness known to exceed 1,400 feet and probably much more."

Olsson (1942) divides the Gatun into three parts, a lower and upper member of marine, highly fossiliferous sandstones, shales, and argillaceous limestones; the middle member tuffaceous sandstones, or beds of fuller's earth with plant remains, only rarely containing marine fossils. He cites the principal fossils of the base as *Pecten gatunensis* Toula, *Arca dariensis* Brown and Pilsbry, *Clementia dariena* Conrad, *Antigona caribbeana* Anderson, *Conus molus* Brown and Pilsbry, *Turritella gatunensis* Conrad. At the Gatun spillway, he finds underneath this a brown, gray, or black tuffaceous sandstone, with lignitic material and plant remains, and carrying a few marine fossils, such as *Bittium, Cerithium, Conus, Arca, Tellina,* and *Nucula.* This series he assigns to the Caimito. Keen and Thompson (1946) and Woodring and Thompson (1949), however, include it and other still lower beds in the Gatun.

Keen and Thompson (1946) list from the lowest exposed Gatun, "a subgenus, *Bornia (Temblornia),* known elsewhere only in the Round Mountain silt (Temblor) of California. *Cancellaria (Aphera) islacolonis* Maury, the zone fossil of the Cercado formation of Hispaniola, occurs somewhat higher, in the middle part of the lower Gatun. Therefore, the lower part of the Gatun may be in part older than middle Miocene."

In eastern Panama, two outcrops of middle Miocene have been mapped, a small area in the Sambú basin south and east of Garachiné, and a much larger area in the Tuira-Chucunaque basin in eastern Darien. In the Tuira basin the middle Miocene is in general divisible into three parts, a lower member of conglomerate and sandstone with small limestone lenses, a middle member of shale and shaly sandstone, and an upper member of limey sandstone with limestone in thin beds or lenses. The upper member is the most fossiliferous and carries a fauna closely related to that of the Mount Hope section of the Canal Zone Gatun. The sandstone and limestone of this member stand up strongly against erosion, form ridges or cliffs along rivers so that its outcrop is easily followed. Its distinctive appearance has led to its being given member status under the name Pucro, the other two members being grouped as lower Gatun. The fossils collected by the Sinclair party of 1923–24 have not been carefully studied, but among the commoner forms in the Pucro are:

Arca chiriquiensis Gabb
Cancellaria dariena Toula
Cancellaria solida Sowerby
Fasciolaria gorgosiana Brown and Pilsbry
Malea camura Guppy
Melongena consors Sowerby
Murex messorius Sowerby
Panopea reflexa Say
Pitaria gatunensis Dall
Turritella robusta Grzybowski

The conglomerate at the base of the lower Gatun has a thickness of about 300 feet near the Colombia border, but increases northward reaching a maximum of about 1,900 feet on the Rio Chico, the southernmost tributary of the Chucunaque. There the conglomerate is extremely heavy at the base, containing boulders up to six feet in diameter and thins out rapidly in all directions. It apparently is a delta deposit and probably indicates the position of the mouth of a large and vigorous river of middle Miocene times. The lower Gatun sandstone, while richly fossiliferous is perhaps less so than the Pucro. Heavy-shelled mollusks are plentiful in the lower member, with foraminifera and thin-shelled mollusks in the shale above. Leaves and bits of wood or charcoal are common in the shale, which in many places has a greenish cast. In spite of the presence of much vegetable matter, the Darien Gatun is not lignitic like that of Chiriquí and Bocas del Toro. Attempts to measure the thickness of the middle Miocene of the Chucunaque-Tuira basin have encountered the usual difficulties, massive bedding in the sandstones, discontinuous outcrops in the shales, and numerous faults, which are difficult to evaluate and often are passed unseen by geologists who confine their observations to the rivers. A probable maximum thickness for the lower Gatun is 3,300 to 3,500 feet, and for the Pucro 1,500 to 2,000 feet, but the average amounts for each member would be somewhat less.

The middle Miocene represents transgressive overlap in the two lower members and off lap in the Pucro, continued in the overlying Chucunaque formation of late Miocene and perhaps Pliocene age. In the Sambú basin, the middle Miocene is less well known. Its thickness is estimated at 2,700 feet with a sandy conglomeratic limestone at the top, composed largely of oyster and pecten shells, probably corresponding to the Pucro and shales and sandstones below. There is no evidence that the two areas, Sambú and Tuira, were ever in communication with each other. There was no vulcanism in these areas in mid-Miocene time.

In western Panama, the deposition of the middle Miocene was preceded and accompanied by widespread vulcanism, which has left a record in the form of dikes, flows, and plugs, as well as much tuffaceous matter included in the sediments. In addition to the marine beds, terrestrial deposits including a considerable amount of low-grade coal and lignite occur in Bocas del Toro and the Caribbean side of Costa Rica, and to a lesser extent in the foothills of the cordillera in Chiriquí and on Isla Muertos off the Pacific coast. In Bocas del Toro the coal beds are found in several of the islands off the coast, in the Valiente Peninsula, and in the headwaters of the Changuinola River, and continue in the hills on the inner side of the coastal plain in Costa Rica. They apparently lie in the upper part of the formation and may not be represented by contemporaneous marine deposits except offshore.

The middle Miocene in western Panama has not been studied as closely as in central and eastern Panama, and is less well known. The formation in general carries a fauna closely related to that of Gatun. The mollusks have been described by Olsson (1922). Coarse conglomerates occur, not only at the base, but throughout the formation, even at the top, where they are transitional with the Pliocene conglomerate; shales are present but not so plentifully as in other parts of the country. Sandy lenticular limestones are common, and in the coastal belt coral reef limestones, usually of small dimensions, occur. The larger part of the formation is coarse gray tuffaceous sandstone derived mainly from the volcanics of the basement complex and the andesite flows which form the base of the Gatun in many places. Black sand beaches, composed largely of magnetite, occur in some places where the Gatun is furnishing most of the sediment brought down by the rivers. On Isla Colon (Columbus Island) and Isla Bastimentos (Provision Island) the base of the Gatun is a shale (Bastimentos shale) which interfingers with a coralline limestone (Minitimi limestone). No conglomerate is present, but there is probably an erosion interval at the base of Minitimi-Bastimentos formation. The underlying Conch Point shale (lower Miocene) resembles the Bastimentos shale so closely that field geologists have had great difficulty in separating them. Both are massive, poorly bedded, soft, gray clay shales, which weather so rapidly that fresh exposures are rare. On some of the other islands and on the Valiente Peninsula at the eastern end of Chiriquí Lagoon, the base of the Gatun is basaltic or andesitic flows.

The middle Miocene of Chiriquí is mostly concealed by younger rocks, principally by the volcanic ejecta of El Barú. An area west of David shows about 500 feet of section mostly sandstone, but because of low dips, and massive bedding, and a great deal of faulting, the actual thickness present is only approximately known. Cross-bedded, poorly consolidated sandstones, and soft sandy shales carrying a considerable amount of vegetable remains, make up the visible part of the section. Fossils collected from the area have not been carefully studied, but field workers have agreed that they are closely related to those of the Canal Zone Gatun. On the Burica Peninsula, the Miocene is transitional with the Pliocene, and over a range of some 3,500 feet of section, foraminifera, which in the United States are considered diagnostic for each of the two periods, are intermingled. This condition apparently includes both late and middle Miocene, and the resulting confusion will probably not be disentangled for many years to come. A fauna collected from various stations in Rio San Bartolo, near Puerto Armuelles, and determined by W. O. Clift, is appended:

Bolivina sp.
Bolivina cf. *acerosa* Cushman
Bolivina cf. *alazanensis* Cushman
Bolivina interjuncta var. *bicostata*
Bolivina malkinae Coryell and Embich
Bolivina marginata Cushman
Bulimina inflata Seguenza
Bulimina pupoides d'Orbigny
Buliminella elegantissima (d'Orbigny)
Candorbulina universa Jedlitschka
Cassidulina californica Cushman and Hughes
Cassidulina cf. *crassa* d'Orbigny
Cibicides isidroensis Cushman and Renz
Cibicides refulgens Denys de Montfort
Cibicides sinistralis Coryell and Rivero
Cibicides sp.
Eponides coryelli Palmer
Gaudryina soldanensis Cushman and Renz
Globigerina bulloides d'Orbigny
Globigerina concinna Reuss
Globigerina triloba Reuss
Globigerina sp.
Globorotalia menardii (d'Orbigny)
Gyroidina soldanii d'Orbigny
Marginulina pediformis Bornemann
Nonion grateloupi (d'Orbigny)
Nonion mesonense Cole
Nonionella auris (d'Orbigny)
Nonionella miocenica Cushman
Nonionella miocenica var. *stella* Cushman
Planulina ariminensis d'Orbigny
Pyrgo sp.
Quinqueloculina lamarckiana d'Orbigny
Quinqueloculina seminula Reuss
Rotalia caloosahatcheensis Cole
Robulus oblongus Coryell and Rivero
Saracenaria acutauricularis Fichtell and Moll
Textularia sp.
Trochammina sp.
Uvigerina beccarii Fornasini
Uvigerina pygmaea d'Orbigny
Valvulina oviedoiana d'Orbigny
Virgulina pontoni Cushman
Virgulina sp.

The stream crosses outcrops of various formations from Eocene to Pliocene, as can be seen from the map.

Upper Miocene and Pliocene

As noted in the preceding paragraphs, the late Miocene and Pliocene of western Panama can not at present be distinguished by the fossils, owing to the overlap of diagnostic species. A fauna collected by the writer was determined by Coryell and Mossman (1942) as Pliocene. Other paleontologists, however, regard it as late Miocene, and a similar condition exists with regard to the Toro and Chagres formations of the Canal Zone and the Chucunaque formation of Darien. In all three cases, the formations in question overlie middle Miocene beds conformably, and with no evidence of a persistent erosion interval, although there may be small local breaks. The Chagres formation has been described by Jones (1950) and by Woodring and Thompson (1949). It is a shallow-water marine sandstone of which a limy phase is given member rank under the name Toro. It is limited to a zone 7 to 10 miles in width along the coast west of the Caribbean entrance to the Canal Zone. It narrows westward and apparently disappears at some point within the next 15 miles. According to the mapping by Jones, it overlaps the Gatun increasingly westward.

In the Tuira-Chucunaque basin in eastern Panama, the youngest consolidated sediments are a series of sandstones and shales carrying a marine fauna, mainly foraminiferal. It has been correlated with the Charco Azul of Coryell and Mossman (1942) and is thus involved in the same age controversy. It overlies the Pucro sandstone of upper middle Miocene age apparently conformably, beginning with a massive cross-bedded sandstone followed by gray foraminiferal shales, and at the top is again sandy. It occupies the trough of the long narrow synclinorium stretching from Chepo to and beyond the Colombian border, and in central Darien occupies a low swampy area, much of which has been peneplaned or baseleveled. Where outcrops occur, the formation is seen to have been deformed by folding and faulting, apparently prior to the peneplanation. No material of fresh volcanic origin has been noted. An interesting feature is a narrow band of flat chert pebbles near the base. Since chert is known to occur only below the Eocene at the base of the sedimentary column, it would seem that this occurrence represents erosion of a chert horizon at some point within the "forbidden land" of the Cuna Indian reservation, as chert is not known south of Membrillo. The Chucunaque is a normal marine off-lap deposit, and represents the final withdrawal of the sea from this part of the Isthmian region. It should be noted that the formation is not known in Darien outside the Chucunaque basin, but that its greatest width is at the south end of the basin, suggesting that it, like the conformably underlying Pucro, once extended to and beyond the Colombian border. However, the paleontological correlation with the Charco Azul suggests that the final connection of this arm of the sea may have been with the Pacific rather than the Caribbean. If this arm of the sea were simply cut off and left to dry up, salt and gypsum deposits would be expected, but have not been reported, nor is the fauna depauperate, so far as known.

In Bocas del Toro and adjacent Costa Rica, upper Miocene has not been differentiated, but it may well be present. On the Pacific side of western Panama, the Charco Azul formation, considered to be Pliocene by Olsson (1942) and by Coryell and Mossman (1942) apparently includes as much or more Miocene than Pliocene. A. D. Brixey, Jr., in a report on foraminifera from a well drilled near Puerto Armuelles makes the following comment:

From the surface down to 1900 feet the foraminifera show closer affinities with Pliocene age (Charco Azul) than to Pleistocene species of the Armuelles formation. The marked absence of *Miliolidae* and *Textularidae* from 10 to 100 feet especially would tend to support a Pliocene (Charco Azul) age for the upper part of the Corotú well. The presence of rather abundant *Valvulineria inflata*, *Bolivina costata* var. *bicostata*, *Buliminella constans* cf. var. *basispinata*, and *Bulimina denudata* also substantiate this belief.

Due to the overlapping range of certain foraminifera species, the contact between the Miocene and Pliocene can not be sharply defined, either by changes in lithology or by the distribution of foraminifera. In addition to the species mentioned above which are Charco Azul types, other species were found which point to Pliocene strata down to at least 1900 feet. At 1900 feet, a well-preserved large *Robulus americanus* var. *grandis* showed strong resemblance to *R. americanus* cf. var. *grandis* which occurs in the Bowden formation of Jamaica. This occurrence is especially interesting because *R. americanus* cf. *grandis* was the only species more typical of the Atlantic-Caribbean middle Tertiary faunal zone, the other species being more characteristic of the Pacific coast middle Tertiary. One from the upper Monterey shale of California *(Nonionella* cf. *miocenica)*, was found at 1484 and 1720–1750 feet. Since only two specimens of *N. miocenica* were found, there are two explanations for the occurrence: (a) either the form was in a section of reworked sediments, or (b) the range of this species is greater than originally believed. It is significant, however, that *N. miocenica* was the only typical Miocene species occurring between 1485 and 1750 feet. One of the shortcomings in using foraminifera for correlation studies is that quite often they appear as reworked specimens, having been moved by currents and/or waves from different ecological zones or from different horizons.

A Mio-Pliocene age is given the section between 1900 and 5400 feet, due to the presence of foraminifera which were characteristic of both Pliocene and Miocene age sediments. Three species believed by Kew to be characteristic of the lower Pico formation, lower Pliocene, of California were found in the section between 5290 and 5300 feet. These species were *Gyroidina soldani* var. *rotundimargo*, *Bulimina pagoda* var. *hebespinata* and *Virgulina* cf. *no-*

dosa. In the same section the following Miocene forms were identified: *Nodogenerina advena* and *Baggina* cf. *cancriformis*, *Nodogenerina advena*, first recognized in the lower Mohnian, Luisian, Relizian, and Saucesian of California, would indicate an upper middle to lower middle Miocene age. *Baggina cancriformis* is typical of the lower Monterey (lower Relizian and lower Modelo shale of Las Sauces Creek) of California.

Definite Miocene species begin at about 5400 feet and continue to 7790 feet where the last microfossils were encountered. These species include the following: *Bolivina aenariensis* (which first appeared in the Mio-Pliocene at 4540 feet), *Cassidulina margareta*, two additional occurrences of *Nodogenerina advena*, *Uvigerinella* cf. *californica*, *U. obesa* and *Virgulina floridana*. The last foraminifera identified in Corotú No. 1 were a broken *Bathysiphon* sp. and a poorly preserved *Bolivina* sp. which were both found at 7770 feet. (Private report by A. D. Brixey, Jr., to Sinclair Panama Oil Co., 1949.)

The fauna as determined by Brixey is as follows:

	Depth in Feet		
	Plio.	*Mio-Plio.*	*Mio.*
Angulogerina angulosa Williamson	180– 190		
Angulogerina carinata Cushman	110– 150		
Angulogerina occidentalis Cushman			6050–6060
Anomalina grosserugosa Gumbel	180–1120		
Anomalina sp.			
Baggina cancriformis Kleinpell			5410–5420
Bolivina advena Cushman			5410–5420
Bolivina aenarieniss (Costa)		4540–4550	5420–5440
Bolivina alata (Seguenza)	1435–1860	2400–2410	
Bolivina costata var. *bicostata* d'Orbigny	0–1750	3220–5300	
Bolivina dattiana Coryell and Mossman	110– 190		
Bolivina foraminata Stewart		2000–5300	
Bolivina floridana Cushman			5410–5475
Bolivina interjuncta Cushman	0–1900	4780	5440
Bolivina marginata Cushman			5410–5440
Bolivina cf. *pomposa* Coryell and Mossman	0– 120		
Bolivina cf. *punctata* d'Orbigny			6340–6400
Bolivina cf. *simplex* Phleger and Parker			6730–6790
Bolivina sinuata var. "B" Galloway and Wissler		4790–5300	
Bolivina subadvena var. *spissa* Cushman	1435–1750		
Bolivina sp.			6850–7770
Bulimina affinis d'Orbigny	0– 10		
Bulimina cf. *denudata* Cushman and Parker	1235–1900	4010–5300	
Bulimina elongata d'Orbigny			5430–5440

	Depth in Feet		
	Plio.	Mio-Plio.	Mio.
Bulimina inflata Seguenza			6250–6260
Bulimina marginata d'Orbigny	110– 190		
Bulimina cf. *pupoides* d'Orbigny	1235–1750	4540–4560	
Bulimina pagoda Cushman	0–1660	3000–5000	
Bulimina pagoda cf. var. *hebespinata* R. E. and K. C. Stewart		5290–5300	
Buliminella curta Cushman	190		5420
Buliminella curta var. *basispinata* Stewart	140– 190		
Cancris cf. *panamensis* Natland	1406–1416		
Cassidulina californica Cushman and Hughes	0	5000	
Cassidulina cf. *cushmani* R. E. and K. C. Stewart	120		
Cassidulina margareta Karrer			5700–6390
Cassidulina cf. *pulchella* d'Orbigny	140	5300	
Chilostomella czjzeki Reuss	0– 190		
Chilostomella cf. *ovoidea* Reuss	1720–1750		
Cibicides americanus (Cushman)	1236	5300	
Cibicides cf. *hodgei* Cushman and Schenck			5410–5420
Cyclammina cancellata Brady		4190–4200	
Dentalina cf. *soluta* Reuss	1090–1100		
Ellipsolagena sp.			5410–5420
Epistomina bradyi Galloway and Wissler	0		5300
Globigerina bulloides d'Orbigny	0		7780
Globigerina conglomerata Schwager			6000–6350
Globigerinoides cf. *sacculiferus* Brady	110– 120		
Globigerinoides triloba Reuss	1110	5300	
Globorotalia menardii d'Orbigny	0		5400
Guttulina sp.			6050–6060
Gyroidena soldanii d'Orbigny	0		5420
Gyroidena soldanii var. *rotundimargo*		5290–5300	5290
Haplophragmoides sp.			5430–5440
Lagena cf. *sulcata* Walker and Jacob	1306– 201	2010	
Lagena sp. "A"	0– 10		
Lagena sp. "B"		4990–5000	
Nodogenerina advena Cushman and Laiming		5290	6350
Nodogenerina sp.			5410–5420
Nodosaria sp.		4190	5460
Nonion costifera Cushman	1500		
Nonion incisum Cushman	180	5300	
Nonion scapha Fichtel and Moll	1236	3230	
Nonionella cf. *miocenica* Cushman	1485–1750		
Orbulina universa d'Orbigny	0		5430
Planulina ariminensis d'Orbigny		3000–4200	

	Depth in Feet		
	Plio.	*Mio-Plio.*	*Mio.*
Plectofrondicularia californica Cushman and Stewart		4540	7730
Pleurostomella sp.			6850–6860
Polystomella crispa Linne	0– 10		
Pyrgo cf. *depressa* d'Orbigny	0– 190		
Quinqueloculina akneriana d'Orbigny	0–1416		
Quinqueloculina oblonga Montagu	1650–1660		
Quinqueloculina seminuda Reuss	1720		
Quinqueloculina sp.	110	5300	
Robulus americanus var. *grandis* Cushman		1900–1910	
Robulus cf. *calcar* Linne			6340–6350
Robolus cushmani Galloway and Wissler	0	3000–3010	
Robulus cf. *simplex* d'Orbigny			6050–6060
Robulus sp.		5290	5420
Rotalia subtenera Galloway and Wissler	110– 120		
Sigmoilina tenuis Czjzek		4010–4020	
Textularia abbreviata d'Orbigny		2000–3010	
Textularia sp.			5410–5420
Uvigerina brunnensis Karrer	10– 120		
Uvigerina cf. *hispida-costata*		3000–3010	
Uvigerina cf. *mexicana* Nuttall			5410–5420
Uvigerina peregrina Cushman	0– 10		
Uvigerina striata Schwager	110	5300	
Uvigerina striata cf. *attenuata* Coryell and Mossman	0	5000	
Uvigerina cf. *tenuistriata* Reuss		5420–5430	
Uvigerinella cf. *californica* Cushman			6340–6350
Uvigerinella obesa Cushman			6000–6060
Valvulineria inflata d'Orbigny	0–1416		
Valvulineria sp. (large)	180– 190		
Valvulineria sp. (small)			7090–7100
Virgulina bramlettei Galloway and Morrey			6050–6060
Virgulina cf. *californiensis* Cushman			7720–7730
Virgulina floridana Cushman			6850–6860
Virgulina cf. *nodosa* R. E. and K. C. Stewart		5290–5300	
Virgulina sp.			6340–6350

The Charco Azul is predominantly shale and siltstone, carrying plant remains and lignitic seams as well as an abundant marine fauna of mollusks and foraminifera. The mollusks have been described by Olsson (1942) and the foraminifera by Coryell and Mossman (1942). Occasional beds are sandy or limy, but there is little true sandstone or limestone. The base is conglomeratic, and at the eastern side of the Burica Peninsula (near Puerto Armuelles) in Rio Corotú the basal conglomerate runs to 600 feet in thickness, the boulders of the conglomerate being almost entirely of basic igneous rocks. The conglomerate thins westward and is thinnest where it lies on the basal complex near the west side of the peninsula.

The Charco Azul is a strongly transgressive formation, its base lying on successively older formations from northeast to southwest, and represents an advance of the sea toward the southwest on a land body of unknown size, which was certainly a large island and may have been of subcontinental dimensions, since the western limit of continental structure in the eastern Pacific is a line running from a point west of Easter Island to southern Mexico (Gutenberg and Richter (1949), p. 27). The Charco Azul has never been identified on the mainland of Chiriquí Province, but may exist in a narrow belt along the coast under alluvial cover or on the islands. It would appear that the invasion of the sea took place northeast to southwest, suggesting that the sea advanced over a fault block which was sinking more rapidly on the northeast side. This agrees with present structure of the Burica Peninsula, which consists of a series of fault blocks tilted toward the northeast, and it indicates that such structures may exist far to the southwest beneath the sea (fig. 6).

The Corotú well encountered no conglomerates other than the basal conglomerate; but other conglomerates are found in the interior of the peninsula, especially to the northwest along the strike. Since the section is repeated by faulting, it is probable that some of these occurrences are merely repetitions. Nevertheless the section appears thicker to the northwest and the portion between the Eocene limestone and the first conglomerate above the basal one has been differentiated on the map (pl. I, and fig. 6) as middle Miocene and giving the tentative name of the La Vaca formation. It is believed to be the equivalent of the part of the Charco Azul below 5,400 feet in Brixey's division, where the middle Miocene would have only member status.

In the Corotú well, 7,785 feet of sediments was encountered. The field work indicated that about 1,100 feet of the formation had been removed by erosion at the well site, making a total of 8,885 feet, a figure reduced by the fact that the dipmeter readings indicated dips of 8° to 20° at various points in the hole. Allowing for this reduction, the total thickness of the formation would be between 8,000 and 8,500 feet, probably nearer the latter. Of this thickness about 2,700 feet would be undisputed Pliocene, 3,500 feet Mio-Pliocene, and 2,300 feet undisputed Miocene. All paleontologists who have worked on the Charco Azul fauna have noted the moderately deep to deep-water character of the fossils. This is also borne out by the lack of coarse sediments, except at the base.

On the Caribbean side, the Pliocene is represented by a group of coarse sandstones and soft shales near Puerto Limon, Costa Rica, from which Gabb (1881) described a molluscan fauna; and by the boulder conglomerates of the Talamanca valley and adjacent regions in Bocas del Toro and Costa Rica. Olsson (1922) has noted the presence of interbedded thin blue clays among these conglomerates, carrying a small fresh-water fauna. On the northwest coast of Columbus Island, Bocas del Toro, Pliocene coral-reef limestones with interbedded bands of marly shale have been found in small outcrops [Olsson (1922)].

Pleistocene

The Pleistocene of central Panama, identified only in the Canal Zone, consists of muds along the coast east of Colon and in Limon Bay; it is also found in borings in the northern part of the Canal Zone. They are littoral and swamp deposits. They have been described by MacDonald (1919), Woodring and Thompson (1949), and Jones (1950).

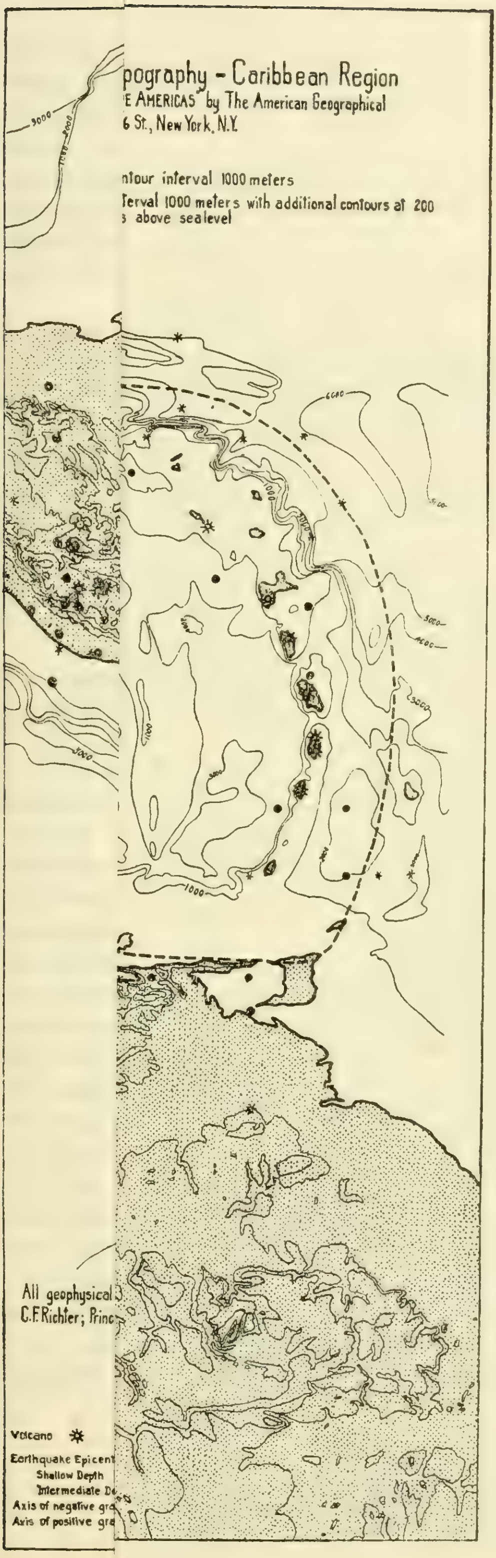
Pleistocene has not been recognized in eastern Panama, although no doubt present over large areas. In western Panama a group of soft clays with layers of sand, outcrops in Rio Rabo de Puerco and Monte Verde ravine near Puerto Armuelles. In Rabo de Puerco a conglomerate forms the base of the formation. The total thickness is unknown, but apparently exceeds 600 feet. The upper part of the formation lies offshore or beneath the alluvium to the east. The base of the formation is found inland up to elevations of 100 feet or more above sea level. From these beds Olsson (1942) has identified 113 species.

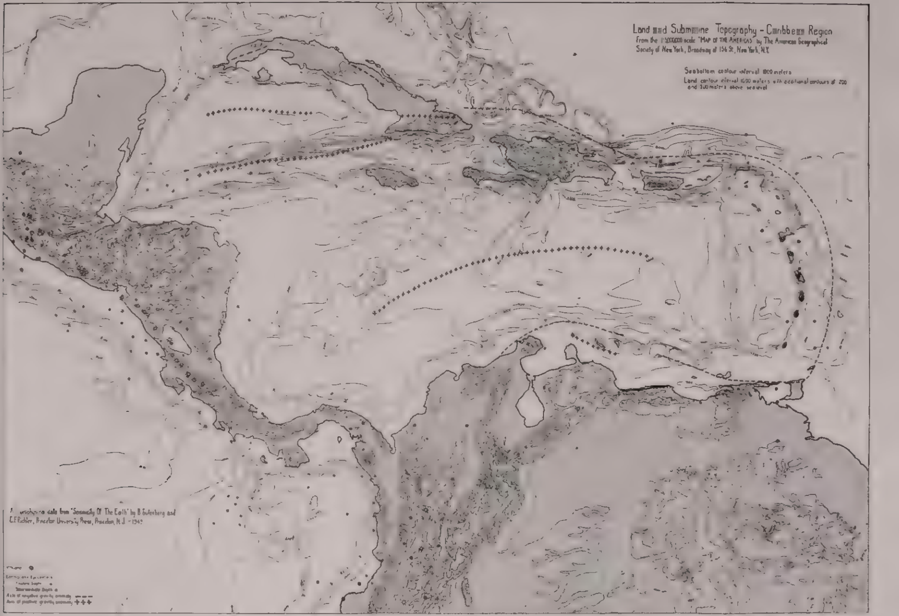
Recent

Recent deposits consist of stream deposits or outwash from volcanic clastics or other unconsolidated rocks. For the most part they occur on the flood plains of streams or along the coast or in swampy areas or pocket valleys such as the Talamanca Valley, close to steep mountain slopes. In such localities they often form boulder and gravel fans, but in general they are sands, silts, or muds, and are flat or with gentle slopes.

STRUCTURE

Central America from Salvador to northern Costa Rica, including eastern Honduras, Nicaragua, and northern Costa Rica, is here con-


pography - Caribbean Region
E AMERICAS" by The American Geographical
6 St., New York, N.Y.
ntour interval 1000 meters
terval 1000 meters with additional contours at 200
s above sealevel
All geophysical
C.F. Richter; Princ
Volcano
Earthquake Epicent
Shallow Depth
Intermediate De
Axis of negative gra
Axis of positive gra


Land and Submarine Topography - Caribbean Region
Society of New York, Broadway at 156 St, New York, N.Y.

sidered to form the western end of the Caribbean arc, of which the other visible features are the Greater Antilles and Lesser Antilles, which are separated from northern South America by the Caribbean basin, an arcuate submarine depression with a maximum depth of something over 5,000 fathoms. The Caribbean arc is considered by many geologists and geophysicists to be a typical representative of the Pacific island arcs, the features of which have been set forth by Gutenberg and Richter (1949), as follows:

Beginning on the convex side of the arc

A—An oceanic trench.

B—A narrow belt of shallow earthquakes and negative gravity anomalies, on the concave side of the trench. This belt frequently rises in a ridge, which may emerge into small nonvolcanic islands.

C—A belt of maximum positive gravity anomalies, with earthquakes, frequently large, at depths near 60 km.

D—The principal structural arc of late Cretaceous or Tertiary age with active or recently extinct volcanoes. Shocks at depths of the order of 100 km. Gravity anomalies decreasing.

E—A second structural arc. Vulcanism older and usually in a late stage. Shocks at depths of 200–300 km.

F—A belt of shocks at depths of 300–700 km.

Details vary widely from region to region; often one or more features are poorly represented or unknown.

When these features are combined in a diagrammatic section, they suggest that a typical island arc is underlain by a sloping fault plane or zone of fault planes which emerges at the oceanic trench and dips toward the concave side of the arc. The mechanism has been described by Benioff (1949), the activating agent being the dense oceanic block underthrusting the lighter continental block. The Caribbean arc at its northern front presents the trench, the belt of negative anomalies, the shallow shocks, and a belt of maximum positive anomalies, but no active volcanoes. At its eastern end, the Lesser Antilles, it presents a trench (not deep), a belt of negative anomalies, and a belt of active volcanoes. At its western end, Central America, is a trench (depth, 4,000 fathoms), a belt of shallow shocks, a belt of active volcanoes, and a belt of intermediate shocks. The typical gravity anomalies may exist, but are unknown. These conditions extend from Salvador to northern Costa Rica, but in southern Costa Rica and Panama there are new and confusing factors.

There are no active volcanoes in Panama, although there was volcanic activity from the Eocene to the Pleistocene. Gravity anomalies have not been recorded. The convexity of the structural and topographic forms is mainly toward the Caribbean arc, rather than away from it, as at other points in its perimeter; but there is evidence of local convexity to the southwest. The ends of the northeastwardly convex arcs appear to extend to the southwest as submarine swells across the floor of the Pacific into a region described by Gutenberg and Richter (1949) as of continental structure, although at present submerged. The northeastwardly convex arcs are cut by a series of radial arcuate faults convex to the west. When these faults are projected north and northeast across the Caribbean basin they appear to border topographic swells and troughs. With these facts in mind, we may take up the consideration of local structure.

Eastern Panama

Central and eastern Panama show a series of concentric structural arcs, convex to the north, cut by a series of trans-isthmian faults which intersect the concentric structures radially (fig. 4). The northernmost of these structural arcs forms the continental divide from the Colombian boundary to a point a few miles east of the Canal Zone. The core of the divide is the basement complex. Over much of its length, its outer (northeast) flank lies in the territory of the Cuna Indians, whose attitude toward strangers prevents geologic field work in their territory except under military protection. In 1870, the Selfridge expedition crossed from Caledonia Bay to the Chucunaque River, under such protection, and the mineralogist of the expedition, Carson (1874), reported sandstone on the outer (northeastern) flank of the ridge. In 1947, geologists in the service of the War Department crossed on the same route, and while no report has been published of their work, the writer has been informed that Carson's observation was verified. The writer has flown over this stretch of coast several times, he has walked across the Isthmus from Chepo to the Gulf of San Blas, and he has studied the air photographs. Over considerable stretches, the continental divide is paralleled on the outer (northeast) side by a series of low ridges, such as would be formed by tilted sedimentary strata. On the southwestern side of the divide the sedimentary rocks dip away from the divide at fairly low angles. The impression gained by the writer is that the continental divide is an asymmetric anticline with the steep side toward the Caribbean. About halfway between Nombre Dios and Punta San Blas, on the Caribbean coast, coarse sandstones of unknown age stand on edge striking E–W. —Schuchert (1935).

From the head of the Gulf of San Blas westward, the rocks on the north side of the divide belong to the basement complex, until the Madden basin is reached, where the divide is seen to be the escarpment forming the south limit of the Madden graben. The fact that

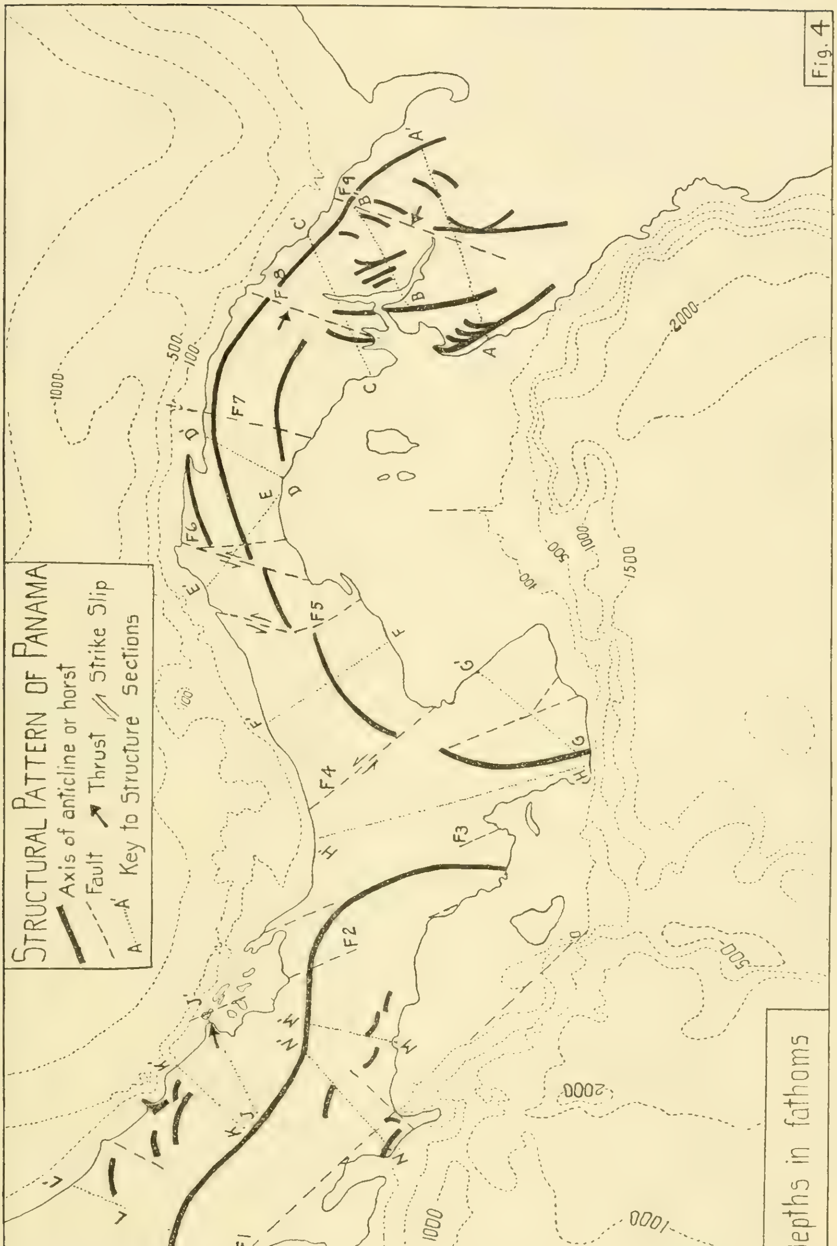


Figure 4. Structural pattern of Panama, with a key to structure sections shown in figures 5 and 6.

the divide is here paralleled by a fault on the north side suggests that it may be so paralleled for much more of its length.

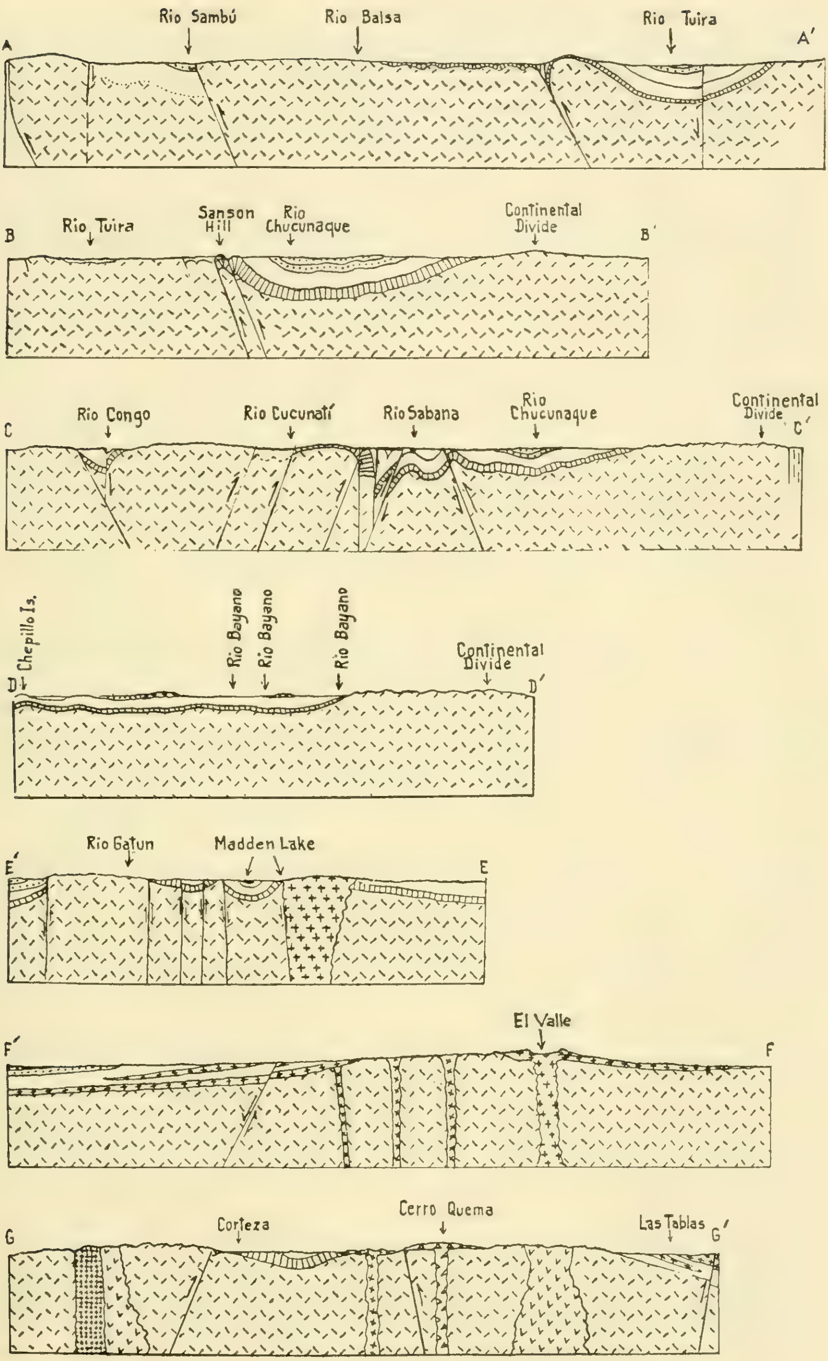
The continental divide east of Chepo is paralleled to the south by another igneous ridge which forms the divide between the Bayano River basin and the Pacific. The rocks on the south side of the latter ridge are Oligocene shales dipping southwest at low angles toward the Pacific, where seen by the writer on Rio Pásiga and Rio Chiman. The rocks of the northeast side are also sediments, but their attitude is unknown. The ridge appears to be anticlinal.

In central Darien Province, the structural situation is quite different. In the area west of the structural trough occupied by the Tuira and Chucunaque rivers, is a group of tightly folded asymmetric anticlines, with their steep sides facing west and in several cases bordered by thrust faults dipping east. Of this group, the largest is the Pirri anticline, which separates the basin of the upper Tuira from the basin of the Balsa. The core of the anticline is the basement complex, from which the sediments dip to the southeast at low angles on the east side; they stand on edge on the west side, which is cut off by a thrust fault, striking about N. 25° E. (F. 9, fig. 4). The angle of dip of the thrust fault is apparently high (structure section A–A).

North of this and west of the Chucunaque River lies a conspicuous ridge, which is also the core of an asymmetric fold, the Sanson anticline, which consists of vertical Oligocene and Eocene strata on the west flank and the same formations plus the Miocene on the east flank, dipping east at angles of 5° to 45°. The fold is cut off at its western foot by a thrust fault striking N. 25° W., and a drag fold on its eastern flank is cut off by a parallel fault (structure section B–B). From the Sanson anticline to the estuary of the Rio Sabana only some very sketchy reconnaissance notes are available. The rocks are apparently Oligocene and Eocene, tightly folded and faulted and standing at steep angles mostly from 60° to 90°. The outcrops are separated by swampy areas, as the entire region has been deeply eroded, much of it based leveled. It appears that the outcrops represent portions of tight asymmetric folds, striking N. 25° W., pushed toward the west. The air view and air photographs support this impression.

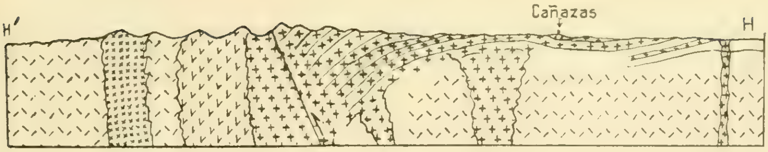
Crossing the Rio Sabana and ascending its tributary from the west, Quebrada Los Nunos, the Aquaqua black shale (early Miocene) appears standing on edge or dipping steeply to the west near the Sabana, followed by vertical Oligocene and Eocene strata with a variety

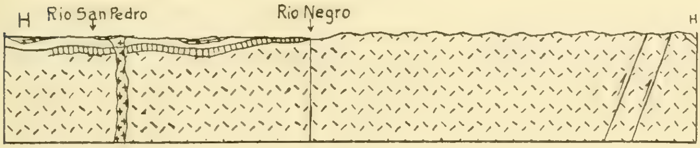
Figure 5. Structure sections. See figure 4 for the location of these sections. See plates I, II, and III for an explanation of the symbols used to represent the formations shown here.

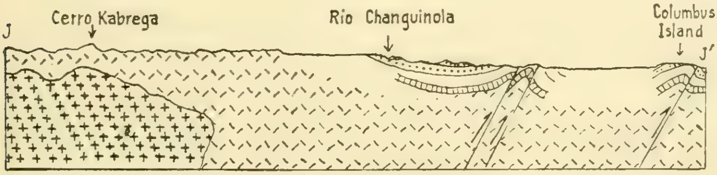

A
Rio Sambú
Rio Balsa
Rio Tuira
A′
B
Rio Tuira
Sanson Hill
Rio Chucunaque
Continental Divide
B′
C
Rio Congo
Rio Cucunatí
Rio Sabana
Rio Chucunaque
Continental Divide
C′
D
Chepillo Is.
Rio Bayano
Rio Bayano
Rio Bayano
Continental Divide
D′
E′
Rio Gatun
Madden Lake
E
F′
El Valle
F
G
Corteza
Cerro Quema
Las Tablas
G′

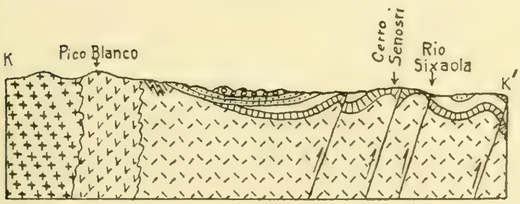
of strikes of which N. 25° W. to N. 30° W. are the most common. Something over 4,800 feet of Oligocene and Eocene limestones and shales with interbedded volcanics is exposed before reaching the crest of the divide between Rio Sabana and Rio Cucunatí drainage. Here the strata flatten out and on the west side dip at low angles toward the Cucunatí. On the west side of the Cucunatí valley this low-dipping westward inclined Eocene is cut off by a cliff of basement andesite. The contact is apparently a thrust fault (F. 8), or series of thrust faults dipping west at a high angle (structure section C-C), (F. 8, fig. 4). The section between the Sanson and the Cucunatí is one of the mostly tightly compressed and intricately faulted areas between Lake Nicaragua and the Atrato River, fronted on each side by an advancing overthrust and broken into a mass of squeeze blocks which would be almost impossible to map in detail. The soft Oligo-Miocene shales are so incompetent that a section 3,000 to 4,000 feet thick may be squeezed down to 1,000 to 2,000 feet and the fault breccia of the competent limestones, cherts, and tuffs crowded into this from each side. Much of the area has been baseleveled by erosion, and is now a swamp barely above the level of high tide. In these portions, the structure is, of course, unknown. However, the Cucunatí fault zone can be traced across the Isthmus. The writer has visited it as far north as the head of the Rio Sabana where the soft brown Gatun sandstones stand on edge striking N. 25° E. The fault zone crosses the Chucunaque in the "forbidden land" of the Cuna Indians, but from the air a conspicuous bulge of the mountains of the continental divide can be seen crowding southwest and narrowing the sedimentary valley of the Chucunaque by several miles. In spite of this narrowing and crowding, no conspicuous ridge marks the divide between the heads of the Artigartí (Chucunaque drainage) and the Cañasas (Bayano drainage). The writer has flown repeatedly over this area in a small airplane at an altitude of 800–900 feet, and neither he nor the pilot of the plane could detect the divide between Bayano and Chucunaque drainages. The region has been peneplaned and both streams are meandering in such an intricately interlaced pattern that in many places it was hard to tell whether the drainage was to the north or south. This peneplanation must have taken place after the fault movement had ceased, indicating that the stresses which caused the faulting had ceased before the end of Pleistocene time, and probably considerably earlier.

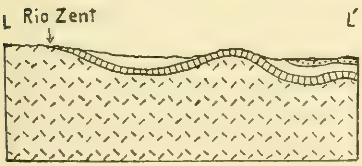
Figure 6. Structure sections (continued). See figure 4 for the location of these sections. Structure sections H[1]–H and H–H should be joined to form the complete cross section; Cañazas is on the Caribbean half; Rio Negro is on the Pacific half. See plates I, II, and III for an explanation of the symbols used to represent the formations shown here.

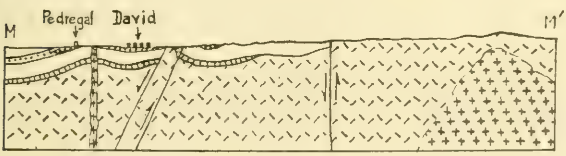

H′
Cañazas
H

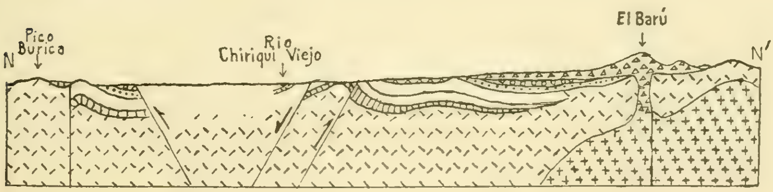

H
Rio San Pedro
Rio Negro
H


J
Cerro Kabrega
Río Changuinola
Columbus Island
J′


K
Pico Blanco
Cerro Senosri
Rio Sixaola
K′


L
Rio Zent
L′


M
Pedregal
David
M′


N
Pico Burica
Rio Chiriqui Viejo
El Barú
N′

The southern part of the Cucunatí fault zone appears to pass through San Miguel Bay and across the continental shelf, and from the edge of the continental shelf to turn south into the head of the 2,000-fathom trench which parallels the coast of northwestern Colombia and Ecuador. The curve of Garachiné Point from northwest to northeast suggests that there has been a strike slip along the fault, the east side moving south, and the west side to the north. This strike slip, however, is only part of the movement. The overthrust from the northwest, or underthrust from the southeast, was evidently the first and major movement, and the present arrangement of the outcrops is the net result of repeated movements, not all in the same direction.

The parallel Pirri fault (F. 9, fig. 4), 45 miles to the east, also shows some indication of a strike slip, the east side moving south as in the Cucunatí fault. It is possible that this apparent strike slip may be actually a secondary effect of the thrust. The Pirri fault is traceable into the Gatun outcrop at the point where it crosses Rio Tuira about a mile east of Real, but is less evident in the Pucro and still less in the Chucunaque, indicating that its main movement took place in Gatum time.

West of the Pirri anticline the valley of the Rio Balsa is filled in its lower half by alluvium over folded Tertiary sediments, mostly Eocene. The upper half of the valley is occupied by igneous rocks of the basement complex. West of the Balsa valley, an area of basement rocks separates it from the Sambú valley. These basement rocks contain small infaulted areas of Eocene limestone. At the west edge of this block, the basement rocks are terminated by a fault striking N. 30° W., forming the east side of the Sambú valley, which is filled with Tertiary sediments dipping east at low angles, and between this sedimentary area and the sea is another area of basement complex, terminated at the coast by another fault. At intervals along the coast Oligocene-Miocene shales appear, standing on edge (structure section A-A).

The structure of Darien south of San Miguel Bay and west of the Tuira, thus appears as a series of three fault blocks tilted toward the east and cut off on their western edges by faults. One of these blocks, the Pirri block, is known to be an asymmetric anticline with its western flank vertical or overturned. It is believed that the two blocks west of it are of the same type more deeply eroded, and that the faults which cut them off at their western edges are steep angle thrusts dipping east. It is believed, also that these faults are splinter faults from the Cucunatí fault zone.

The continental divide is believed to be an asymmetric anticline with the steep side toward the east. The fact that it is apparently offset where intersected by the transisthmian faults indicates that there has been movement on these faults since the anticline was formed. However, late Miocene sediments are not much affected by these faults.

An interesting structural feature of eastern Darien is a series of small anticlinal noses in echelon along the east side of the Chucunaque-Tuira basin. They extend in a NE.-SW. direction and are slightly arcuate, convex toward the southeast. On the opposite side of the basin, a similar anticlinal nose branches from the Sanson anticline on a NE.-SW. strike. Farther south, a drag fold rising on the eastern flank of the Pirri anticline near the village of Aruza, strikes first north and then northwest, crossing the Tuira River about a mile east of the village of Pinogana and continuing across the basin on a N. 65° E. strike.

Darien displays little seismic activity. Gutenberg and Richter (1949) list only four epicenters, one of which (9° N.–78° W.) lies near the Cucunatí fault near the Caribbean coast. This shock is described by Kirkpatrick (1939) as the "most pronounced shock of instrument record at Balboa. It was felt generally throughout the Republic." Gutenberg and Richter list it as of intermediate depth and of magnitude 7.2. Another heavy shock, of which there is apparently no instrument record, took place on September 7, 1882, in which the Cathedral in Panama City, and several other buildings suffered some injury. Part of the old municipal building fell and the Panama railroad suffered some damage. This shock is believed to have originated off the San Blas coast, as Mr. Fred McKim (1947) was told in 1936 by one of the oldest Indians that in his boyhood a great wave swept over the island on which he lived, destroying all the houses and causing some loss of life. This is the only record of a tsunami east of the Canal Zone, and is believed to indicate a movement of the sea bottom in or near the Gulf of San Blas.

Central Panama

The next important transisthmian fault zone is in and adjacent to the Canal Zone; it is probably the fundamental reason the canal is where it is. There are apparently several of these transisthmian faults in a belt crossing the isthmus and emerging between Nombre Dios and Rio Indio on the Caribbean side and between Old Panama and San Carlos on the Pacific side. They are in some cases arcuate, convex to the west, and vary in strike from N. 20° E. to N. 30° W., crossing the continental divide in most cases on a nearly N.–S. strike. The divide itself in this region is almost entirely in extrusive igneous rock in which structure is difficult to detect. The rocks are believed to be mostly Oligocene and Miocene; and are bordered on the north by late Oligocene and Miocene sediments dipping north in the region west of the Canal. On the Pacific side clastic volcanics of probable Miocene age dip toward the sea, where dip can be seen. Gravity determinations by Wuenschel, reported by Jones (1950) showed the highest positive anomalies on the basement complex east of the Zone, and increasingly negative anomalies westward as far as Chorrera, which Jones interprets to mean that these areas are underlain by lighter Tertiary rocks, and that "the Tertiary cover over the Pre-Tertiary basement is thicker toward Chorrera. The isogals strike E.-W." Jones also indicates the Chorrera basalt is of uppermost lower Miocene age, implying that the thickening of the Tertiary section must be in the lower Miocene, Oligocene, or Eocene. The continental divide is about seven miles north of Chorrera and runs N. 70° E., so that the E.-W. isogals are nearly parallel to it. This would indicate that the divide is anticlinal, with the sediments thickening seaward on the Pacific side, as well as on the Atlantic.

The Caribbean ends of several of the transisthmian faults are indicated on Jones' map (1950), the principal one passing through Limon Bay, along the west shore of Gatun Lake for about eight miles, crossing the lake and entering Trinidad River south of the lake. It apparently controls the course of the Trinidad to the continental divide following an arcuate course, convex to the west. Immediately east of it, the continental divide parallels it in a general N.-S. direction for some fifteen miles, almost at right angles to its normal N. 70° E. course. It seems unlikely that this 15-mile right-angle shift of the continental divide resulted from strike slip along the fault, but, the faulting undoubtedly controls its location. South of the divide the fault enters the granite of the Campana area, which is cut by three deep parallel valleys (beautifully shown on the air photographs), one of which leads directly up to the notch at the head of Rio Trinidad, and is undoubtedly due to the continuation of the fault on a S. 30° E. strike, which carries it out to sea just west of Chame. A continuation of the strike across the continental shelf leads directly to the notch in the edge of the shelf south and west of the Pearl Islands, and to the head of the trench paralleling the coast of northwestern Colombia.

An interesting fault valley (F. 6) parallel to that just described is occupied by the Boqueron River north of Madden Lake. It is in fact a narrow graben striking N. 20° E. across the basement complex, and is of particular interest because it contains the only manganese deposit in Panama which has been worked at a profit. This deposit has been described by Sears (1919), who says it occurs in a sedimentary complex of shales, sandstones, and limestones, which he does not identify as to age, but says they are older than the sediments outcropping downstream, which are late Eocene. They occur in the valley of the Rio Diablo, the tributary of the Boqueron nearest its head. The sediments show such a confusion of dips and strikes that Sears was unable to determine their sequence. The faults bordering this graben can be seen in the Eocene limestone and basement complex at the head of Madden Lake.

Other NE.-SW. faults can be seen in the Madden Lake basin and a very prominent set of parallel faults striking N. 70° E.–S. 70° W. intersect them, outlining opposite sides of the depressed fault block occupied by Madden Lake. This last set of faults is very persistent. They apparently extend eastward to the Caribbean, where they outline the Gulf of San Blas, and Jones (1950) shows some of them extending west to the edge of his map, south of the middle of Gatun Lake. Some of them extend across the Rio Indio coal fields as shown in the figure, where they intersect a group of N.-S. faults. The regional dip is of the order of 10° or less, but where the coal is intersected by the faults, the dips are from 40° to 60°. A dike on one of the N.-S. faults is intersected by two of the N. 70° E. faults, and the ends of the dike twisted east at the south end and west at the north end. Strike slip is shown by these ends of the dike and by the corresponding shifts of the coal bed. The indicated movement is left lateral. In the Boqueron manganese deposit the only dip recorded by Sears (1919) is one in which the limestone is standing on edge striking N. 70° E., obviously on one of the series of N. 70° E. faults.

Still farther west, the N. 70° E. series of faults reappear along the north flank of the continental divide, where they are shown in the structure section by Hershey (1901) (reproduced with slight modifications in structure section H–H). At the heads of Rio San Pablo, Rio Cobre, and Rio Tabasará, a series of parallel arcuate valleys convex to the northwest apparently mark the position of a series of splinter faults along the northwestern edge of the central Panama arcuate structural system.

The group of arcuate faults along the upper Tabasará, Cobre, and San Pablo rivers and their branches has attracted some attention as the locus of copper prospecting in Panama. The copper occurs as low-grade sulphide ores carrying gold (Riddell (1927)).

The continental divide in central Panama west of the head of Rio Indio follows close to the north rim of El Valle volcano, and its south flank for some miles is concealed by the ejecta from that crater. About 20 miles to the west, near the village of La Pintada, andesite flows dipping to the northwest are overlain to the south by rhyolite flows and tuffs dipping south at a low angle. The northwest dip of the andesites can be seen along the edge of the hills bordering the west edge of the plain which extends from Penonomé southward to the coast. The Pan-American Highway from Penonomé to Natá follows a course approximately parallel to and a little southeast of an arcuate anticlinal axis, on the northwest side of which the andesite flows dip to the northwest, while on the southeast side the rhyolite flows dip to the southeast. This axis appears to be the continuation of the anticlinal axis which forms the continental divide east of La Pintada. It can no longer be followed after entering the coastal plain a few miles north of Aguadulce, but on crossing the plain in a southwesterly direction it can be picked up again. At Pesé, Oligocene calcareous shales dip northeast, while about seven miles to the west near Ocú they lie nearly flat apparently on the anticlinal axis, and farther west near the head of Montijo Bay they dip northwest. South of Pesé in the vicinity of Macaracas, the dip of the Oligocene and Miocene changes from northeast to east and to southeast as one goes south (Joukowsky and Clerc (1906)). It appears that an anticlinal axis run-

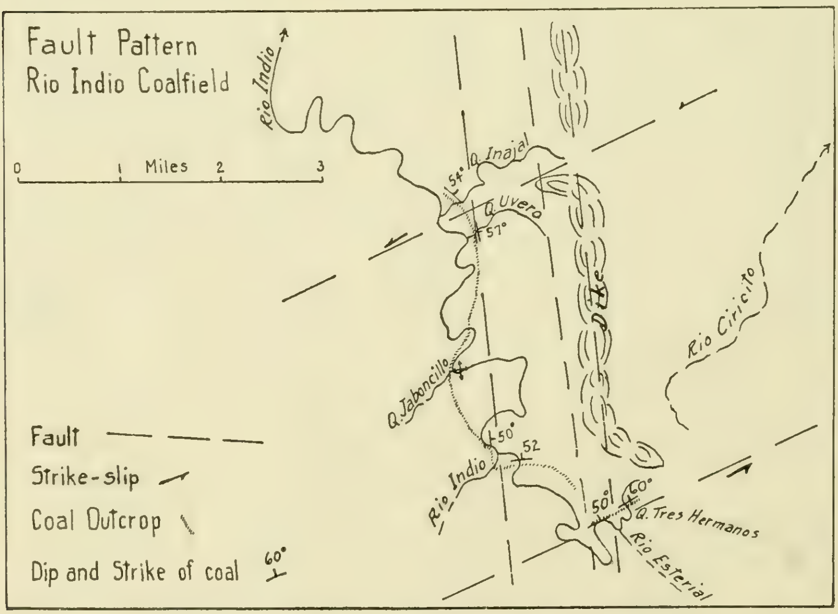


Figure 7. Fault pattern—Rio Indio coalfield.

ning NE.-SW. through Ocú continues southwest to the coast at some point east of Punta Mariato and west of Morro Puercos. The greater part of this region is basement complex bordered on the west by a narrow band of Eocene and Oligocene sediments along the east shore of Montijo Bay, and on the east by the Eocene and Oligocene of the Tonosí valley. The Tertiary sediments curve round the nose of the igneous northeast of Ocú, and near Las Tablas can be seen to dip underneath another band of andesite flows which border the east coast of the Azuero Peninsula. These andesites are believed to be a part of the same group of flows as those which appear west of the road from Penonomé to Natá.

Whether the anticlinal axis described above was originally continuous with the one extending southwest from La Pintada is not known. At any rate they are separated by a transisthmian fault (F. 4, fig. 4) striking N. 42° W., which can be clearly seen from the air or on the air photographs, although difficult to trace on the ground as it traverses a low flat region of swamps and coastal plain from Aguadulce south. To the north it cuts across the isthmus in a region entirely igneous. Its course to the south can be located by a succession of dikes, shifted stream courses, and small linear depressions, on the eastern coast of the Azuero Peninsula; and where its extension crosses the edge of the continental shelf, it is marked by a deep reentrant as far as the 1,000-fathom isobath, but can not be traced farther. Whether this fault belongs to the same system as the arcuate transisthmian faults farther east is not apparent.

The anticlinal, described above, which occupies the west side of the Azuero Peninsula is cut by a great number of faults, only a few of which are shown on the map. The commonest strikes are from N. 25° W. to N. 55° W., but there also are numerous others on various strikes. The writer is indebted to Dr. E. R. Dunn of Haverford College for the following notes on a region on which there is practically no other information. His letter reads:

I have had my rocks determined at the Bryn Mawr Geological laboratory, and this is about what I have to report.

We went pretty nearly straight south along Ocú, Las Minas, and thence south along the divide. At first this was pretty straight and we didn't have to cross much water, but later it began to swing very widely.

1. At Ocú sedimentary rocks were exposed, lying almost horizontally. The terrain is pretty flat and it is savanna country. Altitude 300.

2. We got into hills before we reached the Parita River. At the river sedimentaries were exposed, lying nearly vertically with an E.-W. strike. Altitude about 300.

3. Around Las Minas we saw quite a bit of manganese ore and of course

there was a gold mine there once, with pretty old workings but I imagine there is plenty of dope on that.

4. Rock was exposed in the bed of the Quebrada Piedra, some 20 miles south of Las Minas. This stream was said by Davies to enter the La Villa (the river which forms the border between Herrera and Los Santos). This was andesite at an altitude of about 1,500.

5. North face of Mangillo partial section. Altitude about 2,500 to 3,000. Bottom (Davies saw this, I didn't), sedimentaries dip 50° W., strike N.-S., then andesite (I saw this and have a piece), on top of the andesite sedimentaries, limestones and shale, dip 30° S., strike E.-W. (I have some of this). This was exposed in the bed of a small stream running north to Queb. Piedra. There is no doubt of the sedimentaries on top of the andesite. Exposed on the top of Mangillo was some andesite, thus andesite both above (since the top was south of the stream exposure) and below the sedimentaries I saw, and if Davies is right, and I see no reason why not, you have from bottom up, andesite, sedimentary strike N.-S., andesite, sedimentary strike E.-W., andesite.

6. Going south from Mangillo, on side of a long ridge, at head of a small stream, rhyolite was exposed at about 2,000. Stream tributary to Rio Quebro.

7. At Dos Bocas, 375 feet where the Quebro really starts as a combination of a big stream coming from the west and another coming from the east (the one from the west rises on Cerro Negrito and is mapped as running west) there were many granite boulders in both branches, obviously coming from somewhere upstream. Alluvial gold was present.

8. The exposed rock at this place, forming the walls of the canyon, was a smooth green serpentine.

From Las Minas south, we crossed east-west ridges in the following order: Penalosa, Buenavista, Jacinto, Piedra de Tigre, Macaracito, Mangillo. We had to cross the head of a small west-flowing stream (tributary to Negro-Mariato) to reach Macaracito, which ridge was said to run down to Macaracas. We had to go down pretty far and cross a larger east-flowing stream (tributary to Lavilla) to get to Mangillo. Beyond Mangillo we had to go down to 375 feet and hit the canyon of the west-flowing Quebro.

From the situation at the Parita, and on the north slope of Mangillo, it looks to me that these ridges are structural and based on titled (folded ?) sedimentaries, interspersed with volcanics and based on intrusives.

Davies says that the serpentine at Dos Bocas (which he called dunite) is exposed in Cerro Negritos near the west coast.

At any rate, there are tilted sedimentaries in the very middle of the peninsula at 2,500 feet.

The rock exposed on top of Cacaranao, 3,300, looked like the rock on top of Mangillo (andesite).

Dunn's notes on serpentine and dunite are of particular interest, in view of Hess's theory of the relation between serpentinized basic rocks and the course of old island arcs.

The eastern half of the Azuero Peninsula is also occupied by an anticlinal axis, arcuate and convex to the northwest. In the axial region, granite is exposed, with heavy basic igneous rocks to the east. It is bordered on the west by the Tonosí valley Eocene which is connected with the Tertiaries to the north by a narrow corridor of Oligocene and Miocene in the region of Macaracas. This sedimentary band is overlapped in the southeast by volcanics partly from Cerro Quema, which MacDonald (1937) considers a Pleistocene volcano.

The continental divide west of La Pintada is not anticlinal, but apparently consists of a series of fault slices striking NW.-SE. cutting the andesite flows and dikes at the top of the Oligocene-Miocene sequence which farther southwest is interbedded with sediments of that age. The orientation of stream courses is interesting. The rocks on both sides of the divide are igneous, those on the north being granite, syenite, and andesite in the region of Mineral and to the west, and on the south side the andesite flows mentioned above. Seen from the air, the north side is a series of precipitous ridges, separated by deep narrow canyons, which instead of running straight to the sea as might be expected in a region of igneous rocks of great relief close to the sea, form a parallel series at an acute angle to the sea on a strike of about N. 45° W. They appear to be caused by parallel faulting. South of the divide the streams run in courses S. 70° W. parallel to the divide and gradually curve more to the south in their lower part. Some sharp changes in the course of the divide are probably due to faulting. However, the region has not been studied, and although there has been a good deal of mining going on ever since the Spanish conquest, there are few references in the literature to regional structur, aside from Hershey (1901) and Wagner (1862). Taylor (1852), however, indicates that the rocks show stratification, and refers to "porphyroid, pyritous, ferruginous, granitoid trap," and on his map shows the contact of porphyry and trap running about N. 85° E. near the mouth of Rio Escribanos near Belen, and shows the strike of the gold-bearing quartz veins as parallel to it, suggesting that there may be a fault system causing the structure. In view of the fact that granite and syenite, mentioned by Wagner (1862) and Hershey (1901) in the coastal region near Mineral, are considered by all the geologists with the exception of Gabb (1875), to belong to a pre-upper Eocene complex, the map (pl. II) represents this area as basement complex.

The Azuero Peninsula is second only to southwestern Chiriquí as a locus of seismic activity. The greatest and most destructive activity took place in 1913, and was investigated by MacDonald (1913), whose account was published in the Canal Record of December 10, of that year. The epicenters shown on the map are based on MacDonald's work. The fault along the east coast of the Azuero Peninsula is apparently the cause of many small shocks recorded on the Balboa seismograph.

The arcuate form of the major structural features of central and eastern Panama resembles that of a typical island arc of the Pacific type, and the occurrence of serpentine and dunite on its outer flank in Veraguas conforms to Hess's theory of the association of such rocks with belts of negative gravity anomalies in the island arcs of the East and West Indies. However, nothing is known as to the distribution of gravity anomalies in Veraguas.

Western Panama

In western Panama, as in eastern Panama, there are a series of arcuate anticlinal and synclinal folds. They are convex to the northeast, for the most part, but volcanic ejecta of Pliocene and Pleistocene age in enormous amount have concealed the structure of the Tertiary sediments over much of the area. Volcanics of contemporary origin are also interbedded in the Oligocene and Miocene sediments, but perhaps to a lesser degree than in central Panama. The two arcuate structural systems of eastern and western Panama are separated by a fault (F. 3, fig. 4), running N. 24° W. from Montijo Bay to the Valiente Peninsula, and other faults on the same strike occur to the west of it. The writer crossed this area from the head of navigation on Rio Cricamola to San Felix. No sedimentaries were observed north of the divide, but they may be concealed under the alluvium of the coastal plain which is three or four miles wide. The observed rock in place south of the coastal plain along the Cricamola was andesite, but no structure could be detected until the continental divide was reached where flat-lying lava beds were observed. On the south side of the divide, slopes of very fresh volcanic ash were crossed, the Indians who accompanied the writer spreading out along the path to avoid starting a slide. The first sediments were observed about seven miles south of the divide where foraminiferal shales of Oligocene age dipped south at a low angle. They appeared to be interbedded with volcanics, but all rocks seen were so deeply weathered that it was difficult to distinguish the tuffaceous shales from the tuffs. The age of the beds was inferred from a *Glyptostyla* cf. *panamensis* collected by Olsson some miles north of San Felix. The contact of the sediments with the igneous is known to be a few miles east of Tolé, and to reach the sea near the mouth of Rio Tabasará, but the region has not been mapped in detail. The contact apparently follows an arc convex to the northeast, suggesting that it is following the curve of an anticlinal axis to the east. The axis connects the Soná Peninsula (believed to be basement rocks from the presence of the bedded cherts at Bahia Honda), with the continental divide near Cerro Santiago, and is thus, structurally and petrographically, the continuation of the continental divide of Chiriquí and Bocas del Toro, although it is no longer the continental divide. The southwestward trend of the isobath contours off the coast indicates that the structure continues out to sea in that direction. The continental divide from Cerro Santiago east is apparently a series of fault ridges without anticlinal folding.

Folding on lines approximately parallel to the continental divide takes place on both sides of the isthmus in western Panama, two general zones of folding being present on each side; and there are many faults. Most of the folds on the Caribbean side are asymmetric with the steep side toward the sea, and in several cases are faulted on the steep side, with a strong suggestion of thrust faulting. In one case this suggestion was confirmed by drilling. On Columbus Island, at the northwestern end of Chiriquí Lagoon, the surface structure was interpreted by geologists as a gently rounded dome on which the early Miocene Conch Point shale outcropped at the crest, over an area perhaps a mile in diameter, surrounded by the Bastimentos shale of middle Miocene age. A seismograph survey indicates that the structure is cut by a fault striking N. 24° E. (F. 2, fig. 4).

The result of drilling is indicated in the following excerpt from a report of the paleontologist, A. D. Brixey, Jr., who examined the well cuttings:

> Excellent proof of thrust faulting within the Bocas del Toro dome section occurs between 1,630 and 2,520 feet and between 4,350 and 4,570 feet, respectively. At 1,630 feet a zone of fossilized, large (2–4 mm.) flat seeds (Seeds A) is followed by a zone of *Virgulina* sp. *a*, and a zone of *Siphonodosaria* sp. *a* at 2020 ft. At 2,120 Seeds A recur, followed by *Virgulina* sp. *a* at 2,370, and another zone of *Siphonodosaria* sp. *a* at 2,520. This would indicate thrusting of a section of 390 to 400 feet.
>
> The second phase of major thrusting between 4,350 and 4,360, a sandy facies, poor microfauna with the exception of a rather small *Globigerina bulloides* followed by a zone of *Amphistegina lessonii* and an abundance of *Miliolidae.* Again between 4,530 and 4,540 a sandy facies was noted, a poor microfauna followed by small *Globigerina bulloides* and a zone of *Amphistegina lessonii* and *Miliolidae.* Another zone of possible thrusting occurs between 6,360 and 6,380 feet and 6,750 to 6,780 feet where the microfauna again show a significant repititious similarity.

In addition an unprecedented thickness of the Conch Point shale was encountered. The measured thickness of the Uscari (the inshore equivalent of the Conch Point) rarely exceeds 5,000 feet, and was nowhere estimated at over 6,000, but the well penetrated 8,621 feet and was abandoned because of drilling difficulties in heaving shale, without reaching the base of the formation. A dipmeter reading at about 4,500 feet gave a dip of about 25° to the southwest, and cores showed even higher dips. It seems obvious that the structure of Columbus Island includes a series of thrust faults. If a fold is present it is asymmetric with the steeper side toward the Caribbean.

The largest inshore anticline mapped is Senosri Hill near Guabito on the Sixaola River. This structure is a faulted anticline with vertical or overturned beds on the seaward (northeast) side and dips of 40° to 45° on the southwest side. Further inland a smaller structure, the Yorkin anticline shows similar dips. The axis of the fold turns westward up the Talamanca valley. Near Old Harbor in Costa Rica, vertical and steep-angle dips occur in the Gatun formation on the coast, and steeply dipping Oligocene shales are to be seen along the line of the railway between Almirante and the Changuinola River in Panama. Between the Chiriquí Lagoon and the Sixaola River the coastal plain is five or six miles wide with no exposures of consolidated rocks, but a couple of miles beyond the Sixaola in Costa Rica a band of Oligocene, Miocene, and Pliocene rocks appears fronting the sea. The strike gradually changes from N. 50° W. to N. 70° W. to W., and finally the Miocene rocks disappear under the Pliocene boulder conglomerate in which little or no bedding can be detected. E.-W. strike is also seen in the early Miocene shales which outcrop in a narrow band along the north side of the Talamanca valley, and which also disappear under the boulder conglomerates. There are numerous drag folds, some of which develop locally into small anticlinal and synclinal structures, but the regional structure is arcuate with the steeper side facing northeastward. This convexity is reflected in the course of the continental divide but is obscured by the cover of Pliocene and Pleistocene volcanics; and similar suggestions of arcuate structure on a large scale with minor drag folds can be seen on the Estrella, Banana, and Blanco rivers.

These arcuate folds are cut by transverse faults, some of which may belong to the transisthmian system of central and eastern Panama described above. Others appear to be merely stretch faults incidental to deformation. A study of some of the "smooth sheets" on which the charts of the Hydrographic Office are based was made by the writer (1941). The "smooth sheets" show all the soundings instead of the three to five per cent usually shown on Hydrographic Office charts, and the detailed contouring of the continental shelf reveals some obvious continuations of faults observed on land, and suggests the presence of others so far unmapped. Some of these faults have been indicated on plates I, II, and III. Those off the mouth of the Sixaola River, Bocas del Toro, and Valiente Point are of particular interest. The shape of the edge of the continental shelf off Cahuita Point as shown on the hydrographic charts is also indicative of faulting on a grand scale, with strike slip shown along the course of the Sixaola River at the end of Senosri ridge. Andesite dikes appear along the course of this fault north of the Rio Sixaola.

On the south side of the continental divide, middle Miocene (Gatun) shallow water and terrestrial sandstones with thin beds of lignite appear both east and west of El Barú, the Volcan de Chiriquí. The ejecta of the volcano conceal the structure over an area of 600 or 700 square miles, but at the edges of the volcanics folds appear which presumably continue beneath the cover of tuffs, agglomerates, and flows. The visible folds of the Tertiary sediments roughly parallel the course of the divide and bring the base of the sedimentary series to the surface near David and near Breñon. Whether a continuous fold connects the two is not known but they lie on approximately the same strike. A complex fault network complicates the structure near David. Only the principal faults are shown on plate I. The outcrop of Eocene limestone on the David River about three miles northeast of the town is the first appearance of this formation west of Montijo Bay. It occurs at the intersection of two faults, one striking N. 35° W., the other N. 78° 30′ W. The latter brings the basement rocks in contact with the middle Miocene and is apparently the older of the two. The other crosses the Majagua River east of the railroad bridge and for a distance of about three miles is marked by a large andesite dike, which furnishes road metal for the David-Boquete Highway. To the south the fault can be traced to the coast. Its intersection with Rio Chiriquí is marked by a sharp hairpin bend of the river about a mile in length. At the limestone outcrop on David River, dark shales, apparently of early Miocene age, are standing on edge striking N. 35° W. on the left bank of the river, while on the right bank, the limestone dips 80° N. and strikes N. 75° W. The indicated stratigraphic displacement is over 3,000 feet, while on the older N. 78° W. fault, the entire Tertiary section below the mid-Miocene is missing, showing a displacement of not less than 5,500 to 6,000 feet. This fault's course westward is marked by a low escarpment in the Pleistocene volcanics and judging by the topography, continues west across Costa Rica to the coast, intersecting Golfo Dulce en route. It is not apparent that this fault is due to the stresses of the arcuate folding. There seems to have been movement on it recently, forming a scarp in Recent gravels west of the Chiriquí Viejo. Another fault on a strike N. 71° E. converges on the other two near their intersection, and this one is marked by a much sharper escarpment near Concepcion, and by a line of small igneous hills, apparently dikes. The two faults diverge westward and cross the Chiriquí Viejo River about five miles apart. The interval between them includes the crest of a rather tightly folded anticline, with the complete Eocene section showing at the crest and on the north flank, the complete Tertiary sedimentary section up to and including at least a part of the middle Miocene. On the south side of the fold a small section of Oligocene shale is exposed, which is followed to the south by the alluvial flats occupied by the banana farms of the United Fruit Company. The alluvial area is about 12 miles wide and beyond it to the south are the gently arcuate folds of the Burica Peninsula, including marine Pleistocene as well as Tertiary.

The contact of these folded sediments with the alluvium is a fault (F. 1, fig. 4, Structural pattern) which is traceable on land and under the sea for a distance of more than 350 miles. It probably extends much farther. From Puerto Armuelles to and beyond Jicarilla Island, it coincides with a submarine cliff, which off Jicarilla drops 5,400 feet in three miles. On land its course can be plainly traced on air photographs and can be seen at Golfito. At El Cajon, a box canyon on Rio Diquis about four miles above Palmar, Costa Rica, on a fault paralleling it, the basement rocks are thrust to the southwest over the Eocene limestone. This fault plane dips 60° to the northeast, suggesting that there is a zone of thrust faulting, of which both faults are a part. Three recently active volcanoes of Costa Rica lie on the fault first mentioned (F. 1, fig. 4) and a fourth is close to it. An oceanic trench, slightly arcuate with convexity to the southwest parallels the coast of Nicaragua and Costa Rica, and numerous earthquakes of shallow depth (less than 60 km.) have epicenters between the trench and the shore. On land a belt of active volcanoes and shocks of intermediate depth (70 to 300 km.) parallel the trench. No gravity anomalies have been measured, but the other features are characteristic of an island arc of the Pacific type, which implies the presence of a thrust fault or zone of thrusting which dips toward the northeast. It is believed that the long fault described above is a part of this zone of thrust faulting, or at least is due to the same stresses. A series of faults striking about N. 45° E. are found in Chiriquí Province, the most important passing through Puerto Armuelles, crossing the Burica Peninsula and making a perceptible re-entrant in the continental shelf where it enters the Pacific. These faults intersecting those of NW.-SE. strike, break up the area into a number of fault blocks, which are at present unstable.

For the past 30 years, this general area of southwestern Panama and southeastern Costa Rica has shown the greatest seismic activity in the isthmian region. The climactic year was 1934, and the most destructive shock took place on July 21 of that year at 5:00 a.m. The epicenter is shown on the map as number 5. (Epicenters are located by Gutenberg and Richter (1949) to one fourth of a degree, leaving a margin of error of one eighth of a degree, about 8½ miles. There is reason to believe that the location given above is incorrect, or one of a simultaneous flock.)

The Chiriquí Land Company, a subsidiary of the United Fruit Company, suffered losses of close to a million dollars, including the destruction of a pier and banana-loading machinery, housing and other structures, and fruit which rotted before new loading devices could be installed. Unfinished houses thrown down were thrown to the southwest. The rails of the railroad which crosses the NE.-SW. fault at right angles were thrown into sigmoidal kinks, but were unbroken, indicating a shortening of the surface from northwest to southeast. Cracks opened on the beach in a NE.-SW. direction and remained open several hours. No tsunami was observed at Puerto Armuelles, but a small one was observed at Punta Burica. Landslips occurred along the line of the N. 45° E. fault for a few miles to the southwest but beyond that the region is unsurveyed virgin forest and destruction was not recorded. The fault controls the course of the Rio Guanabanon at several points and a confusion of steep dips is observed in the Pliocene and late Miocene sediments at these places. The fault zone is about 100 feet wide where it crosses the Rio Corotú, with the beds standing at 60 to 90 degrees. In 1949 a well was drilled about 1,300 feet northwest of the fault. This well entered the fault at 7,785 feet indicating a hade of 10° to the northwest.

On the Caribbean coast two intersecting systems of faults, one striking NW.-SE. and one NE.-SW., are apparently the product of the same stresses as those of the Pacific side. The edge of the continental shelf is notched at points where it is apparently intersected by some of these faults. Seismic activity, however, is apparently less than on the Pacific side and damage has been comparatively small.

A summary of the structural conditions in the isthmus indicates that in both eastern and western Panama, asymmetric anticlines facing toward the sea are found on both sides of the country. These structures are believed to be, in most cases, cut off by offshore thrust faults dipping toward the land. Most of the structures facing the Caribbean are arcuate and convex to the north. Those facing the Pacific are straighter but may be parts of larger arcuate folds. In central and eastern Panama, a series of transisthmian faults intersect the folds, and at some of the intersections there is indicated strike slip, the general movement being left lateral. The transisthmian faults strike NE.-SW. in eastern Panama, N.-S. in the region of the Canal Zone, and NW.-SE. in Veraguas and Coclé. Similar transisthmian

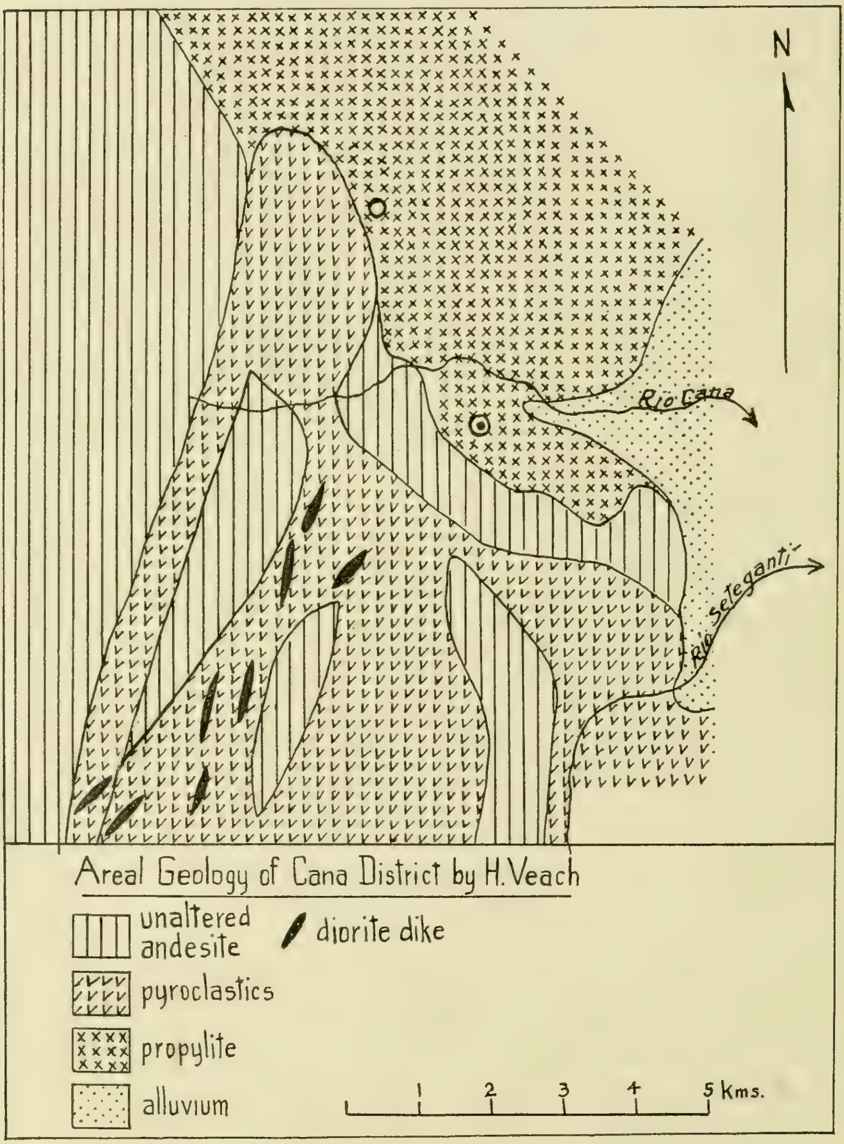


Figure 8. Areal geology of Cana District, by Dr. H. Veach.

faults probably occur in western Panama, but are obscured by Pleistocene and Recent volcanics.

If the offshore thrust faults are projected downward they intersect, giving the isthmus the appearance of a wedge uplifted by pressure from both sides. These stresses have apparently arrived at an isostatic balance in eastern Panama, are slightly active in central Panama, and are vigorously active in western Panama. The sinuous form of the country may be due to local variations in the pressures from the two sides. The squeezing appears to have begun at the east and moved westward. The elevation of the isthmian region which began at the end of early Miocene time apparently had brought all or nearly all the region above sea level by the middle Pliocene. Woodring (1949) has stated the case as follows:

According to vertebrate paleontologists familiar with the Tertiary land mammals of North and South America, the Panama bridge was completed and open to traffic immediately after the end of middle Pliocene time, about 5 million years ago. The first North American migrants, however, reached South America in the late Miocene or early Pliocene, and the earliest South American invaders reached North America in the middle Pliocene. These first arrivals in both continents were small animals and presumably reached their destination by using still separated spans and completed piers as stepping stones.

Economic Geology

Gold mining in Panama goes back to pre-Colombian days and was vigorously continued by the colonists. The metal is to be found in streams heading in the cordillera of the continental divide from one end of the country to the other, as well as in the Azuero Peninsula. Some of the old Spanish mines have been reopened in modern times, but the results in general have been disappointing. Mineralization was shallow, and the Spaniards, despite their lack of modern machinery and technical knowledge, were able to work everything but ores of grades so low as to be unprofitable even now.

Panama's most famous mine was the "Espíritu Santo," near the now-abandoned town of Cana in Darien Province. This mine, one of the Spanish crown's richest revenue producers, was worked from the early part of the seventeenth century to 1727, about one hundred years, when on account of the raids by buccaneers it was declared by the viceroy to be a menace to Spanish rule in the isthmian region and abandoned. It was rediscovered in the latter part of the nineteenth century.

Woakes (1899) has given an account of the mineralization, from which the following excerpt is taken:

The country rock is essentially andesite in an extremely decomposed state.

There are two predominant series of cleavage planes apparent, the first, generally the most marked, running N. 55° W. with a westerly dip, and the second running N. 65° E. with a southerly dip. Roughly speaking, the ore-body appears to have been formed in an irregular quadrilateral, the N. 55° W. cleavages forming the east and west walls while the N. 65° E. form the north and south walls. In adopting this theory, liberal allowance must be made for the variations of bearing, such as would naturally occur in fissures running through such brittle and jointy rock. The sides of the quadrilateral figure are by no means equal or parallel in their entire length. The longer side or base of the figure may be taken as that forming the north wall of the deposit, the shortest is then the opposite or south wall. This gives to the figure the shape of an irregular truncated cone. So far as can be seen, the extreme length of the deposit from east to west is 120 feet while from north to south it is about 90 feet. . . .

By far the greater part of the ore-body is composed of boulders and rock fragments of the adjoining country rock, varying in size from pieces as small as a walnut to masses of many tons weight. They are generally completely angular, but at times are as round as a pebble. In the writer's opinion this roundness is due not to the action of water but rather to a process of decomposition. The rock fragments are completely surrounded by concentric shells of brilliant, crystalline sulphurets and calcite. The order of deposition of these minerals around the matrix is generally iron pyrites, then blende, and then galena, with an outer covering of calcite, in which occur acicular quartz crystals. . . . The gold occurs for the most part in a crystalline form, but often as wires or strings. It is found adhering to the sulphurets, and no doubt the very fine gold is disseminated through them. It is a rule that the greater the percentage of zinc and lead sulphides, in the ore, the richer it is in gold. Three distinct classes of ore have been observed in the lode mass. In the vicinity of the walls, especially the north and south walls of the deposit, the cementing materials of the breccia are chiefly calcite and quartz, while the matrix is softer from more advanced decomposition. Here, therefore, we find low grade ore. Immediately inside this mass, which varies from 15- to 40-feet wide at the different levels, and reckoning from north to south, we find the interstices of the breccia not entirely filled up with the cementing material, an infinity of vugs being left. Here calcite, quartz, and iron pyrites, all more or less crystalline, form the cement. This class of ore assays from one to one and a half ounces of gold per ton, according to the amount of matrix present. To the center and southwest of the lode mass we find the ore very rich in the sulphides of zinc, lead, and iron, all more compact, the vugs being absent. This may be said to be the best class of ore in the mine. Occasional pockets and veins of a soft and friable mixture of all the lode-forming constituents are met, containing free gold in quantity.

Following a bad cave-in in 1911, the mine was abandoned, as production had fallen to an unprofitable level. Production figures for the years 1899 to 1907 are given as follows by Oller (1933):

Produccion por años en libras esterlinas (*production by years in pounds sterling*):

1899–1900 (Feb.)	91,671
1901	43,833
1902	41,031
1903	66,970
1904	154,418
1905	52,164
1906	50,070
1907	20,000

Other old Spanish mines have been reopened at Remanse and Mineral in the province of Veraguas, where some production was attained, and near Capira, in the province of Panama, but there are now no active operations.

Mineralization in basic rock practically always is accompanied by propylitization of the andesite. A few slides from specimens taken by the writer near the old adit to the Cana mine were determined as follows by Isotoff:

T 77 —Cana (country rock) Basalt. Intersertal texture-laths of labradorite, grains of augite, etc. Interstitial glass is heavily charged with red iron oxide dust. Phenocrysts of bytownite and augite. Chlorite, opal, and carbonate are conspicuous.

T 78–T 79—Cana. Propylitized basalt. These sections exhibit various degrees of propylitization of the basalt described under T 77.

T 96 —Pio Nono mine—Darien. Country rock. Augite andesite.

T 97b—Pio Nono near vein. Propylitized augite andesite.

T 100–T 104—Sta. Lucia mine—Coclé. Propylitized augite andesite.

Manganese oxides occur in small quantity in many parts of the country, but mining operations have been profitable only when war preparations caused unusually high prices. The only such operation on a commercial scale was in the upper valley of Rio Boqueron, between Madden Lake and Nombre Dios. The deposit was reported on by Sears (1919), who regarded it as a blanket deposit formed by the alteration of primary ore of unknown character, with subsequent erosion and redeposition in sedimentary rocks which he was unable to date. The region has been intensely faulted and the ore occurs largely as breccia, some of the boulders being 8 to 10 feet in diameter. The work was carried on under the stimulus of the high prices occasioned by World War I and was abandoned after the war.

A manganese deposit of the blanket type occurs near Bahia Honda on the southwest coast of the Soná Peninsula in Veraguas, in a region of pre-upper Eocene igneous rocks. No reports on it are known. Manganese ore also occurs in some quantity near Las Minas in the Azuero Peninsula and in other places.

Copper has never been mined in Panama, but occurs as low-grade sulphide deposits in the province of Veraguas south of the continental divide on the Vigui, Cobre, and Tabasará rivers, and near the head of Rio San Felix. Gold occurs with these copper sulphides and the occurrence of a gold-copper natural alloy has been reported from the region of Remanse, but no reference to it has been found in the literature.

Riddell (1927) reported the existence of a hematite deposit near La Mesa, and unsuccessful attempts have been made at commercial exploitation of magnetite sands on the Caribbean coast near Old Harbor, Costa Rica.

Coal and lignite beds occur at many places in Panama and Costa Rica. They appear in beds of middle Miocene age in the islands and shores of the Chiriquí Lagoon in Bocas del Toro Province and on the upper Changuinola River in the same province, and continue northward in Costa Rica as far as the Reventazon River where their presence is noted by Branson (1928). In central Panama, coal occurs in beds of late Oligocene or early Miocene age in the vicinity of La Mesa, Santiago, Parita, and Macaracas in the provinces of Veraguas, Herrera, and Los Santos; in Panama Province south of Capira, and on the Rio Indio in Colon Province just west of the Canal Zone. Not one of these occurrences has been successfully exploited, although some of them have been prospected.

Oil seepages from the early Miocene occur near Garachiné in Darien Province, Panama, and on Uscari Creek and at Uruchico in the Talamanca valley of Costa Rica. At numerous other places oil can be extracted from these shales with chloroform or other solvents. The presence of these seepages long ago became known to Europeans and several European and American companies have made geological investigations, and four companies (Sinclair, Cities Service, Gulf, and Texas) have engaged in drilling operations, with a total of ten wells in Panama, and three in Costa Rica. No production has resulted, although five wells have had shows of oil or gas in the early Miocene, and one found asphaltic residues in beds of middle or late Miocene age. The lack of accumulation in commercial quantity is accounted for by the lack of porous beds in the shale.

BIBLIOGRAPHY

BENIOFF, H.

1949. Seismic evidence for the fault origin of oceanic deeps. *Bulletin of the Geological Society of America*, vol. 60, pt. 2, pp. 1837–1856.

BRANSON, E. B.

1928. Some observations on the geography and geology of middle-eastern Costa Rica. *University of Missouri Studies*, vol. 3, no. 1, pp. 29–72.

BROWN, A. P., and H. A. PILSBRY

1911–1913. Fauna of the Gatun formation, Isthmus of Panama. *Proceedings of the Academy of Natural Sciences of Philadelphia*, vol. 63, pp. 336–420, and vol. 64, pp. 500–519.

CARSON, J. P.

1874. Geological report on the Darien route and Nercalagua River, Bay of San Blas. *In* T. O. Selfridge—Reports of explorations and surveys to ascertain the practicability of a ship canal between the Atlantic and Pacific oceans by way of the Isthmus of Panama. Washington.

CORYELL, H. N., and J. R. EMBICH

1937. The Tranquilla shale (upper Eocene) and its foraminiferal fauna. *Journal of Paleontology*, vol. 7, no. 4, pp. 285–309.

CORYELL, H. N., and R. W. MOSSMAN

1942. Foraminifera from the Charco Azul formation. *Journal of Paleontology*, vol. 16, no. 2, pp. 233–246.

CROSBY, I. B.

1942. Geology of the Virilla canyon, Meseta Central Occidental, Costa Rica. *Proceedings of the Eighth American Scientific Congress*, Washington, 1940, vol. 4, pp. 483–494.

DALL, W. H.

1912. New species of fossil shells from Panama and Costa Rica. *Smithsonian Miscellaneous Collections*, vol. 59, no. 2, pp. 1–10.

DOUVILLÉ, H.

1915. Les couches à orbitoïdes de l'isthme de Panama. *Comptes Rendus Sommaires de la Societe Geologique de France*, No. 16, pp. 129–131.

GABB, W. M.

1875. Note on the geology of Costa Rica. *American Journal of Science*, third series, vol. 9, no. 51, 198–204, and p. 320.

1881. Descriptions of new species of fossils from the Pliocene clay beds between Limon and Moen, Costa Rica, together with notes on previously known species from there and elsewhere in the Caribbean area. *Journal of the Academy of Natural Sciences of Philadelphia*, series 2, vol. 8, pp. 349–380.

Gabb, W. M.—(Cont.)

1895. Informe sobre la exploración de Talamanca verificada durante los años 1873–1874. *Anales del Instituto Fisico-geografico Nacional de Costa Rica*, vol. 5, pp. 67–90.

Goudkoff, P. P., and W. W. Porter, II

1942. Amoura shale, Costa Rica. *Bulletin of the American Association of Petroleum Geologists*, vol. 26, pp. 1652–1655.

Gutenberg, B., and C. F. Richter

1949. Seismicity of the earth and associated phenomena. Princeton University Press.

Hershey, O. H.

1901. The geology of the central portion of the Isthmus of Panama. *Bulletin of the Department of Geology, University of California*, vol. 2, no. 8, pp. 231–267.

Hildebrand, S. F.

1938. A new catalogue of the fresh-water fishes of Panama. *Zoological series, Field Museum of Natural History*, vol. 22, no. 4, publication 425.

Hill, R. T.

1898. The geological history of the Isthmus of Panama and portions of Costa Rica. *Bulletin of the Museum of Comparative Zoology*, vol. 28, pp. 154–281.

Howe, E.

1907. Geology and the Panama Canal. *Economic Geology*, vol. 2, no. 7, pp. 639–658.

Jones, S. M.

1950. Geology of Gatun Lake and vicinity. *Bulletin of the Geological Society of America*, vol. 61, no. 9, pp. 893–920.

Joukowsky, E., and M. Clerc

1906. Sur quelques affleurements nouveaux de roches tertiaires dans l'isthme de Panama. *Memoire de la Societe de Physique et de Histoire Naturale de Genève*, vol. 35, pt. 2, pp. 155–178.

Kirkpatrick, R. Z.

1939. Trigger forces—Canal Zone earthquakes. *Bulletin of the Seismological Society of America*, vol. 28, pp. 15–22.

Keen, A. M., and T. F. Thompson

1946. Notes on the Gatun formation (Miocene), Panama. *Bulletin of the Geological Society of America*, vol. 57, pt. 2, no. 12, p. 1260.

Lemoine, P., and R. Douvillé

1904. Sur le genre *Lepidocyclina* Gümbel. *Memoire de la Societe Geologique de France, Paleontologie*, no. 32.

LOHMAN, W.

1934. Stratigraphie des hochlandes von Costa Rica. *Geologische Rundschau*, bd. 25, hft. 1, pp. 10–26.

MAACK, G. A.

1874. Report on the geology and natural history of the Isthmus of Choco, of Darien, and of Panama. *In* T. O. Selfridge—Reports of explorations and surveys to ascertain the practicability of a ship canal between the Atlantic and Pacific oceans by way of the Isthmus of Darien. Washington.

MACDONALD, D. F.

1913. Isthmian earthquakes. *Canal Record*, Dec. 10, 1913, pp. 144–149.

1915. Some engineering problems of the Panama Canal. . . . *Bulletin of the United States Bureau of Mines*, no. 86, pp. 88.

1919. Sedimentary formations of the Panama Canal Zone with specific reference to the stratigraphic relations of the fossiliferous beds. *Bulletin of the United States National Museum*, no. 103.

1937. Contributions to Panama geology. *Journal of Geology*, vol. 45, no. 6, pp. 655–662.

MANROSS, N. M.

1860. In relation to contract made by the Secretary of the Navy for coal and other privileges on the Isthmus of Chiriquí. In *H. R. 1*, Committee on Naval Affairs, House of Representatives, Washington, D. C.

MCKIM, F.

1947. San Blas, an account of the Cuna Indians of Panama; and the forbidden land, a reconnaissance of the upper Bayano River, R. P., in 1936. *Etnologiska Studier, Etnografiska Museet*, no. 15, pp. 185, Goteborg.

OLLER, JOSÉ

1933. La industria minera en Panama—*Segunda Epoca, no. 19, Biblioteca Cultura Nacional, Panama.*

OLSSON, A. A.

1922. The Miocene of northern Costa Rica with notes on its general stratigraphic relations. *Bulletins of American Paleontology*, vol. 9, no. 39.

1942. Tertiary deposits of northwestern South America and Panama. *Proceedings of the Eighth American Scientific Congress, Geological Sciences*, Washington, 1940, vol. 4, pp. 231–287.

1942. Tertiary and quaternary fossils from the Burica peninsula of Panama. *Bulletins of American Paleontology*, vol. 16, no. 106.

1942. Some tectonic interpretations of the geology of northwestern South America. *Proceedings of the Eighth American Scientific Congress, Geological Sciences*, Washington, 1940, vol. 4, pp. 401–416.

Palmer, K. V. W.

1923. Foraminifera and a small molluscan fauna from Costa Rica. *Bulletins of American Paleontology*, vol. 10, no. 40.

Reeves, F., and C. P. Ross

1930. A geologic study of the Madden dam project, Alhajuela, Canal Zone. *Bulletin of the United States Geological Survey*, no. 821B, pp. 11–49.

Reid, H. F.

1917. Notes on the Almirante earthquake. *Bulletin of the Seismological Society of America*, vol. 7, pp. 27–30.

Riddell, G. C.

1927. Is mining to thrive again in Panama? *Engineering and Mining Journal*, vol. 124, no. 16, pp. 605–810, and no. 17, pp. 649–653.

Romanes, J.

1912. Geology of a part of Costa Rica. *Quarterly Journal of the Geological Society of London*, vol. 68, pp. 103–159.

Sapper, K.

1905. Ueber gebirgsbau und boden des südlichen mittelamerika. *Petermann's Geographische Mittheilungen*, erg. 32, hft. 151.

Sapper, K., and W. Staub

1937. Mittelamerika, handbuch der regionalen geologie. Carl Winter, Heidelberg.

Schuchert, C.

1935. Historical geology of the Antillean–Caribbean region, or the lands bordering the Gulf of Mexico and the Caribbean Sea. pp. 811. John Wiley and Sons, New York.

Sears, J. D.

1919. Deposits of manganese ore near the Boqueron River, Panama. *Bulletin of the United States Geological Survey*, no. 710C, pp. 85–91.

Taylor, R. C.

1852. Substance of notes made during a geological reconnaissance in the auriferous porphyry region next to the Caribbean Sea, in the province of Veraguas and Isthmus of Panama. *Journal of the Academy of Natural Sciences of Philadelphia*, series 2, vol. 2, pp. 81–88.

Terry, R. A.

1941. Notes on submarine valleys off the Panama coast. *Geographical Review*, vol. 31, no. 5, pp. 377–384.

Toula, F.

1909–1911. Eine jungtertiäre fauna von Gatun am Panama-Kanal. *Kaiserlich-königlichen Geologischen Reichsanstalt, Jahrbuch*, vol. 58, pp. 673–760, and vol. 59, pp. 487–530.

VAUGHAN, T. W.

1918. Geologic history of the West Indies and Central America during Cenozoic time. *Bulletin of the Geological Society of America*, vol. 29, pp. 615–630.

1919. The stratigraphic horizon of the beds containing *Lepidocyclina chaperi* on Haut Chagres, Panama. *Proceedings of the National Academy of Sciences*, vol. 12, pp. 519–522.

1919. Contributions to the geology and paleontology of the Canal Zone, Panama, and geologically related areas in Central America and the West Indies. *Bulletin of the United States National Museum*, no. 103, pp. 547–612.

WAGNER, M.

1861. Beiträge zu einer physisch-geographischen skizze des isthmus von Panama. *Petermann's Geographische Mittheilungen, Ergänzungsheft*, pp. 1–25.

1862. Eine reise in das innere der landenge von San Blas und der cordillere von Chepo in der Provinz Panama, . . . *Petermann's Geographische Mittheilungen*, pp. 128–141.

WOAKES, E. R.

1899. Modern gold mining in the Darien. *Transactions of the American Institute of Mining Engineers*, vol. 29, pp. 249–280.

1923. Darien gold mines. *Mining Magazine*, London, Nov. 1923.

WOODRING, W. P.

1949. The Panama landbridge. *Science*, vol. 109, p. 437.

1954. Caribbean land and sea through the ages. *Bulletin of the Geological Society of America*, vol. 65, no. 8, pp. 719–732.

1955. Geologic map of Canal Zone and adjoining parts of Panama. United States Geological Survey, Miscellaneous Geologic Investigations, Map 1–1. [This map was issued after the present paper was submitted for publication.]

WOODRING, W. P., and T. F. THOMPSON

1949. Tertiary formations of the Panama Canal Zone and adjoining parts of Panama. *Bulletin of the American Association of Petroleum Geologists*, vol. 33, pt. 1, pp. 223–247.