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OUTLINE OF THE GEOLOGY OF CUBA

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ABSTRACT

Cuba is approximately 700 miles long and 50 miles wide. It is divided into eight physiographic provinces which roughly correspond to geological features. The geological column ranges from Middle Jurassic to Pleistocene. Much of the Middle and Lower Cretaceous is missing or has not been identified. There was extensive Cretaceous volcanism. The Upper Cretaceous and Tertiary have an abundant, well-preserved fauna. The Eocene and Oligocene faunas are Old World in contrast to the Miocene fauna, which is New World in relationships. The Tertiary is well represented from the Paleocene through the Miocene. The Upper Cretaceous and the Paleocene are land-derived sediments of unknown geographical origin. The remaining are largely marls and limestones.

There are both extrusive and intrusive rocks. Basic and acid rocks occur in both types. There are various structures of diverse ages. In the west is a large overthrust followed by two large anticlines to the east. A large overthrust area including the Trinidad Mountains and intrusions occupy the central part of the island. A broad syncline with extensive intrusions forms the eastern end, with a mass of metamorphics lying at the extreme east.

Cuba in its present form dates from late Miocene. Previously the area was occupied by scattered islands or was completely submerged. During late Cretaceous and the Paleocene, portions of what is now Cuba were part of a large land mass that extended as far south as Jamaica.

Since assuming its present form, Cuba was submerged in the Pleistocene or Recent. This accounts for the paucity of land fauna on the island.

INTRODUCTION

The island of Cuba is 1,200 kilometers (720 miles) long with an average width of about 85 kilometers (50 miles). The eastern two-thirds (750 kilometers) lies in a straight line with a bearing of N. 70° W.; the following 200 kilometers lies in an east-west line, and the western 200 kilometers has a bearing of S. 65° W. The 80° meridian and the 27° parallel intersect near the center of the island. Cuba is bounded on the north by the Bahama Channel and the Gulf of Mexico and on the south by the Yucatán Basin and by the east end of the Bartlett Deep.

Recent submergence has left much of Cuba bordered by shallow water and numerous cays. Reference to the map (Fig. 1) shows that with an emergence of 8 fathoms these shoals and cays would become part of the mainland. The resulting outline would give a true picture of Cuba as an island mass surrounded by deep water.

TOPOGRAPHY AND PHYSIOGRAPHY

Cuba may be divided into eight physiographic provinces as follows:

1. The Organos Mountains that lie in the northern half of Pinar del Río Province. This range is 140 kilometers (85 miles) long and from 6 to 14 kilometers (3.5 to 8.5 miles) wide, with elevations to 1,500 feet. It consists essentially of a
Fig. 1.—Map showing principal geological features and general distribution of Cretaceous, Tertiary, and igneous rocks in Cuba. Note re-entrant of 1,000-fathom line between Gulf of Mexico and the Pinar overthrust and a second between the Antillean Sea (Yucatán basin) and the Trinidad overthrust. The arrows indicate the direction of thrust (Vergenz as used by Stille).
OUTLINE OF THE GEOLOGY OF CUBA

sheet of hard Cretaceous limestone overlying younger Cretaceous shales and sandstones of the Cayetano formation in an overthrust position. On the south side of the western end the range is broken up into large isolated blocks known as “mogotes.” These mogotes are the most striking feature of the landscape of Viñales Valley (Fig. 2). Elsewhere, particularly in the eastern end of the range, erosion has left much larger masses of the overthrust sheet that completely cover the Cayetano except where the latter is exposed in the deeper stream beds.

The limestone mogotes support an abundant flora in spite of the scarcity of soil. The shales, on the contrary, have scant vegetation, but this is notable for pines and oaks which are rare elsewhere in Cuba and in striking contrast to the palms which elsewhere characterize Cuban scenery.

This province also includes the relatively high and deeply incised Cayetano shales area bordering the Organos Mountains on the south in a belt 8-12 kilometers wide.

2. The Cayetano Plain lies between the Organos Mountains and the north coast, west of the meridian passing through Pinar del Río City. It is a relatively small area 60 kilometers long by 10 kilometers wide and lies on the Cayetano formation. It is characterized by steep drainage courses near the mountains and by low, flat land nearer the coast. As on the outcrops of the same formation within the mountains, the vegetation is scanty.

3. This is the folded zone occupying the northern half of Habana Province and extending eastward to about the middle of Matanzas Province. It includes the Habana-Matanzas and Madruga anticlines and the Almendares-

San Juan syncline between them. Along both anticlines erosion has removed the Tertiary limestone and exposed the softer Cretaceous shales, producing a topography of low, rolling hills flanked on either side by Tertiary limestone cliffs. The soil derived from the Cretaceous is considered mediocre in Cuba. Cane is its principal crop.

4. South of the Organos Mountains and the folded zone in Habana and Matanzas provinces and extending eastward to about the Cienfuegos meridian in Santa Clara Province is the flat Coastal Plain. In western Matanzas Province an arm of this plain crosses the island to the north coast. This physiographic province is a monotonous plain characterized by red soil, many sinkholes, and underground drainage. A belt of sand and terrestrial debris borders the south coast. The red soil is derived from the underlying Güines limestone and, even where there is only a shallow accumulation, produces the finest cane land in Cuba. Where the rock is at or near the surface, precipitation quickly enters the porous limestone resulting in desert conditions and a xerophytic flora.

5. Santa Clara (or Las Villas) Province forms a single, complicated physiographic province. A zone of overturned folds and overthrusts, called the “Cordillera,” lies along the north coast. This has been reduced to low ridges by erosion. South of the Cordillera is a large area characterized by several types of intruded rocks that stand out as hills up to 600 feet in height. In the southern part of the province are the Trinidad Mountains, with peaks nearly 3,000 feet high.

6. A second coastal plain occupies the

1 The official name of Santa Clara Province has been recently changed to Las Villas. Since the current maps all bear “Santa Clara,” that name has been used here.
Fig. 2.—Looking north across Viñales Valley. The "mogotes" (isolated hills) are remnants of the dissected Viñales limestone sheet thrust from the northwest over the Cayetano shales that form the valley floor. (Photograph by Dr. Roberto Machado.)
southern half of Camagüey Province and extends eastward across the Cauto Valley to the Sierra Maestra in Oriente Province. As in the western Coastal Plain, a broad arm crosses the island to the north.

7. The folded and intruded area in northeastern Camagüey and Oriente provinces.

8. The Sierra Maestra in the southern part of Oriente Province and the moun-

TABLE 1

COLUMN*

<table>
<thead>
<tr>
<th>Series</th>
<th>Formation</th>
<th>Description</th>
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<tr>
<td>Miocene</td>
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<td>La Cruz</td>
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<td>Cayetano</td>
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<td>Aptychus Beds (Viñales)</td>
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<td>Jurassic</td>
<td>Santa Fé Schists</td>
<td>Gerona Marble, Trinidad Schists</td>
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<td>Basal Complex in Oriente (Taber)</td>
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*The principal formations only are given in the column. Unimportant formations, faunal zones, and other small subdivisions are omitted.

coast. This lies between the Cordillera and the meridian passing through Camagüey City. It also resembles the western Coastal Plain in being underlain for the most part by the same Güines limestone capped by the same rich soil. So similar are the two coastal plains that they may be considered a single unit interrupted by the Trinidad Mountains.

tainous zone in the eastern portion of the same province.

These eight physiographic provinces correspond for the most part to geological features that will be described later.

PALEOZOIC?

In the eastern end of Cuba there is an area of badly sheared and contorted
schists which S. Taber\textsuperscript{2} calls the “Basal Complex” and believes to be Paleozoic. The age determination is based entirely on lithology, as no fossils have been found in the series.

**SANTA FÉ SCHISTS, GERONA MARBLE, AND TRINIDAD SCHISTS**

In the Trinidad Mountains of southern Santa Clara Province there is a thick series of hornblende, micaceous, and calcareous schists. On the Isle of Pines there is a similar series of hornblende, micaceous, and quartz schists and phyllites with a thick limestone member that is altered to marble. The schist series on the Isle of Pines, C. W. Hayes, T. W. Vaughan, and A. C. Spencer\textsuperscript{3} named the “Santa Fé schists” and the limestone the “Gerona marble.” Many lithologic similarities have suggested tentative correlation of the two metamorphic areas.\textsuperscript{4} Neither series is fossiliferous, hence their age is not known. The opinion has also been expressed that the marbles and schists of the Isle of Pines are the metamorphic equivalents of the Viñales limestone and the Cayetano shales in the Organos Mountains of Pinar del Río Province,\textsuperscript{5} but no supporting evidence has been offered. Rutten\textsuperscript{6} bases the correlation on lithologic grounds. The Pinar del Río series has not been metamorphosed except locally where shearing has been intense or near intrusions, while on the Isle of Pines the entire mass has been altered to marbles and schists. However, the thinly bedded, 34,500 feet of Cayetano shales with thick lenses of sandstone are suggestive of the thinly bedded micaceous and quartz schists of comparable thickness\textsuperscript{7} of the Isle of Pines. This is particularly true of the siliceous phase of the Cayetano nearest the Isle of Pines toward the southwest end of the Organos Mountains.

**JURASSIC**

**JAGUA FORMATION**

The oldest formation in Cuba whose age determination is based on fossil evidence belongs to the Jurassic. This is a very thinly bedded, shaly limestone of nearly schistose structure that outcrops at the base of some of the northern mogotes in Pinar del Río Province. It has a thickness of about 400 feet. Within the limestone are numerous concretions locally known as “jicoteas” (turtles) or “quesos” (cheese). These concretions contain fish remains that have been identified as Oxfordian and ammonites that range from Bajocian to Portlandian.\textsuperscript{8} Within the chambers of the ammonites there is often liquid or dry asphalt.

In 1935 R. E. Dickerson and W. H. Butt\textsuperscript{9} found ammonite-bearing concretions in the thinly bedded Jagua formation which they mistook for the Cayetano formation which it somewhat resembles. Subsequent work has shown that the Viñales limestone and occasionally portions of the underlying Jurassic Jagua formation have been thrust over the Cayetano, with the result that in


\textsuperscript{3} Informe sobre un reconocimiento geologico de Cuba (Habana: Sec. Agric., Dirección de Montes y Minas, 1938).


\textsuperscript{6} P. 6 of ftn. 4 (1934).

\textsuperscript{7} Ibid., p. 5.

\textsuperscript{8} Brown and O’Connell, ftn. 5 (1922).

been intense or near the Isle of Pines the is altered to marbles ever, the thinly bedded Cayetano shales with limestone are suggestive of siliceous and comparable thickness. This is particularly the case of the Cayetano of Pines toward the the Organos Moun-

ASSIC FORMATION

ation in Cuba whose is based on fossil in the Jurassic. This is a well-developed limestone structure that outcrops of the northern Río Province. It has 4,000 feet. Within the numerous concretions of limestones (turtles) or "scar" that have been identified as Portlandian, 8 years of the ammonites or dry asphalt.

Dickerson and W. H. ammonite-bearing concretion, Jagua formation, it somewhat recent work has shown that the underlying Jurassic have been thrust over the result that in

these places the Jagua appears to be directly above or part of the Cayetano (Fig. 3).

The formation is known only in the Organos Mountains in the western part of the island. The best-known exposure is in the area known as Jagua Vieja, 3 kilometers east of Constancia and 10 kilometers northeast of the village of Vinales. "Jagua" is, therefore, suggested as an appropriate name for this formation.

![Diagram of Northwest-southeast section through the Organos Mountains. The "scar" on the south marks the south edge of the overthrust.]

**Fig. 3.**—Northwest-southeast section through the Organos Mountains. The "scar" on the south marks the south edge of the overthrust.

**CRETAUCEOUS**

**APTYCHUS BEDS—VIÑALES LIMESTONE**

Lying directly above the Quemado formation in Santa Clara and Camaguey provinces are the Aptychus beds, so-called for the abundant aptychi or ammonite opercula they contain. This formation is of long longitudinal distribution, occurring in the northern half of Cuba from Pinar del Río to Camaguey, a distance of 730 kilometers (450 miles). Good exposures occur in the eastern end of the Organos Mountains in western Cuba. In Santa Clara Province one of the best exposures is north of Loma Penton, 10 kilometers west of Sagua la Grande. Here, 1,300 feet is exposed above the Quemado. The long row of hills 5 kilometers west of Camajuaní, Santa Clara Province, is of Aptychus beds, as is also the greater part of Loma Camaján in eastern Camagüey.

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Throughout its extent this formation is strikingly uniform in character. On the surface it is a fine-grained, brownish, thinly bedded limestone. The strata vary from paper thinness to several inches in thickness. In addition to the aptychi, it contains a few ammonite molds and occasional fish skeletons and scales and rare mollusks. Radiolaria abound in many exposures. Locally throughout its distribution there are thin beds of black chert that replace the limestone.

The Aptychus beds weather to a residual red clay with flat, platy boulders. Where not too greatly reduced by erosion, they form rounded hills. The red soil is comparable both in appearance and in fertility to the red soil derived from the Guines limestone. In fact, the red soil derived from both these formations has been mapped as Matanzas Clay by H. H. Bennett and R. V. Allison. At depth the Aptychus beds are bituminous, shaly, soft marlstone. Their bituminous nature, together with the oil seeps occurring in them and in the overlying formations, has led to the conclusion that this formation contains the source beds of oil and asphalt in Cuba.

In many localities throughout its distribution there are thinly bedded, black, shaly cherts lying below the aptychus-bearing member. Below these and at the base of the formation and equally as spotted in occurrence is a coarse, calcareous sandstone or fine conglomerate. The best-known exposure of the three members of the formation is at Santa Fé near Camajuaní, on the road to Santa Clara in Santa Clara Province. At Central Zaza, near Placetas, Santa Clara Province, thin beds of tuff occur in Aptychus beds. M. G. Rutten reports a similar observation.

The typical Aptychus beds do not extend westward beyond San Diego de los Baños in Pinar del Río Province. Here the Viñales limestone appears to occupy the same stratigraphic position. This is a hard, brittle, gray, massive limestone in which fossils have not been found. It forms the mass of the Organos Mountains and weathers in large, steep-sided blocks which are the above-mentioned mogotes (see p. 3) (Fig. 2). A review of the descriptions of the Viñales limestone and the Aptychus beds reveals that the qualities of the two are in distinct contrast. Scarcely a descriptive term of one can be applied to the other, though the two are probably in part equivalent. This as a practical measure warrants the use of two formational names.

The age of the Viñales and Aptychus beds has been a matter of much discussion. Hayes, Vaughan, and Spencer considered the Viñales Paleozoic. E. DeGolyer described the former and ascribed it to the Jurassic on the basis of the ammonites found associated with the mogotes. Later, Brown and O'Connell also considered the Jurassic ammonites as coming from the limestone talus at the base of the Viñales limestone cliffs. J. W. Lewis considered the Viñales to be Jurassic. Dickerson and Butt found an ammonite fauna near

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12 “Geology of the Northern Part of the Province of Santa Clara, Cuba,” Geol. Geol. Mededelingen Phys.-Geol. Reeks No. 17 (1936).
13 P. 21 of Itn. 3 (1938).
15 P. 648 of Itn. 5 (1922).
17 P. 117 of Itn. 9 (1935).

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The Soils of Cuba (Washington: Tropical Plant Research Foundation, 1928).
G. Rutten reports that the Aptychus beds do not extend south of San Diego de los Ríos Province. Here they appear to occupy a middle position. This is a massive limestone in the Pinar del Río Province, in what they believed to be Viñales limestone. Subsequent field work has shown that these fossils come from beds probably equivalent to and herein named "Quemado formation" below the Viñales or Aptychus formation. The fossils are Portlandian in age, according to Implay. F. Trueth, on the basis of the apticy, described the apticy-bearing beds to the Lower Cretaceous Neocomian. Implay uses the term "Viñales" to include both the typical Viñales limestone and the lithologically distinct Aptychus beds and ascribed it to the Jurassic on the assumption that all the ammonites described were from the Viñales formation. But, in fact, the faunas of three formations were described or mentioned in his paper: (1) the Jagua formation, Oxfordian (?), lowest Jurassic which contains ammonite-bearing concretions; (2) the Quemado formation, which furnished the diagnostic fossils of the Portlandian Jurassic; and (3) Aptychus beds which lie immediately above the Quemado formation. The age determination of the Aptychus beds, therefore, remains unchanged and is still open to question.

From the eastern half of the Organos Mountains eastward, the Aptychus beds are generally calcite-veined and much more contorted and sheared than the younger Cretaceous and Tertiary formations, indicating that they were subjected to marked diastrophism prior to the deposition of later sediments. This was the first and the greatest diastrophic event in the history of Cuba of which there is record. In the western 100 kilometers of the island the Viñales underwent the same compression, but it was thrust bodily over younger formations without being sheared except at the base.

**PROVINCIAL LIMESTONES**

The known Cretaceous record from the Aptychus beds to the Habana formation is very incomplete. A number of limestone lenses occur in a thick tuff series in southern Santa Clara and Camagüey provinces. Some of these are referred to the Provincial limestone; others are younger. A. A. Thiedens described the Provincial limestones as follows: "The Provincial limestones are a light yellow, dark gray, grayish blue, fine to medium grained, mostly microconglomeratic rocks, cut by many small and large, white calcite veins. They are thick bedded but mostly they are thin bedded." The formation carries a rather rich though poorly preserved fauna of caprinids, Nerineidae and an occasional Apricardia, which indicate Cenomanian-Turonian age.


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21 P. 1442 ff. of ftm. 10 (1942).
CAYETANO FORMATION

The Cayetano formation has not been recognized outside Pinar del Río Province. It reaches its greatest development north of the Organos Mountains and west of the meridian passing through Pinar del Río City. Here 34,500 feet is exposed. As far as known, this is the thickest formation in Cuba. It extends around the west end of those mountains and eastward along their south flank, occurs under the mogotes within the Organos Mountains, and occupies the greater part of the northern half of the province. It is exposed as windows where the overthrust Viñales limestone is a more or less continuous sheet, as in parts of the eastern end of the range. The Cayetano is a thick series of very dark greenish sandstones and dark micaceous shales that weather to various tints and shades of red and brown and even white. The weathered-surface exposures bear little or no resemblance to the same beds below the oxidized zone. The Cayetano has been referred to in published reports as a series of schists and phyllites. Schuchert speaks of the (San) Cayetano as metamorphosed strata that make up the basement complex. Lewis calls it the "Pinar schist" and describes it as yellowish, friable, mica schists and reddish shale slates. These terms are quite misleading, as they imply metamorphism. Personal observation witnesses no metamorphism except near igneous intrusions or where the rocks were exposed to local stresses incident to the overthrusting. The only alteration shown by the great mass of Cayetano shales and sandstones is due to weathering.

The Cayetano is largely shale, though there are well-defined sandstone lenses, particularly on the north side of the Organos Mountains. Where the latter are of considerable magnitude they form prominent ridges up to several kilometers in length. Near the base of the formation and rarely higher in it there are a few hard, clastic, or massive limestone lenses. Usually the limestone has a bituminous odor, and occasionally oil seeps are seen.

The Cayetano soils are highly siliceous and, except in a few small areas where the limestone is present, are very poor and but little cultivated. As already stated, the formation supports a scant flora, a notable feature of which is pines and oaks. The oaks have not been noted in Pinar del Río except on this formation or its derivatives. Pines occur both on the Cayetano and on the iron-rich residual, lateritic soils of the serpentines. When supplied with sufficient moisture, the Cayetano soil produces the famed tobacco of Vuelto Abajo.

The age of the Cayetano formation is not satisfactorily known. It lies above the Viñales limestone (Aptychus beds) and below the Big Boulder bed of the Habana formation. DeGolyer, who described it, called it "Cretaceous"; Brown and O'Connell consider it pre-Oxfordian; Lewis called it the "Pinar schists" and considered it pre-Middle

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24 The formation was described by DeGolyer (p. 140 of fln. 15 [1918]) and given the name "Cayetano." Dickerson and Butt (pp. 116 ff. of fln. 9 [1935]) referred to it erroneously, using the name "San Cayetano." This error was followed by C. Schuchert and by Inlay (pp. 142 ff. of fln. 10 [1942]). (Historical Geology of the Antillean-Caribbean Region [New York: John Wiley & Sons, 1935], pp. 415, 495, 575, etc.)

25 I am indebted to E. N. Pennypacker for this calculation. It was taken from a section from the central part of the Organos Mountains northwest to the coast.

26 P. 495 of fln. 24 (1935).

27 P. 534 of fln. 17 (1932).
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Jurassic. Metcalf, in a discussion of
Lewis' paper, said he believed it to be
above the Viñales. Dickerson and Butt ascribed it to the Jurassic, believing that
the Jurassic ammonite-bearing con-
cretions were indigenous to it. H. M. E.
Schürmann places the phyllite (Cayetano) stratigraphically below the Jurassic.
Vermut placed the Viñales and
Cayetano together in one formation—
the San Andres. This formation also includes the Quemado. Referring to the
San Andres, he states: “We take the
phyllitic, quartzitic rocks and the lime-
stones to belong to a continual sedimen-
tation cycle in Jurassic to lower Creta-
ceous time.” Imlay quotes Dickerson
to the effect that the high fixed-carbon
ratio of the bitumen often found in the
chambers of ammonites from the con-
cretions presumed to have been taken
from the Cayetano formation are an
indication of age. This is misleading, as the
ammonites in fact come from the Jurass-
ic, and, furthermore, bitumen is merely
dried petroleum which in the tightly
sealed chambers is often found as a
liquid; where evaporation has been pos-
sible the volatiles have left, giving a higher
percentage of fixed carbon in the resi-
due.

The only fossil remains in the typical
Cayetano are small clams resembling the
genus Sphaerium, which have been
found in a few localities, and a few
vegetal remains. In the limestone lenses,
however, near the base of the formation
there are a few Foraminifera. As these
have not been studied in detail, nothing
31 Ibid., p. 553.
32 P. 17 of fn. 9 (1933).
33 “Massengesteine aus Cuba,” Neues Jahrh.
34 P. 7 of fn. 11 (1937).
35 Ibid., p. 11.
36 P. 1422 of fn. 10 (1942).
can be stated except that the genera ap-
pear to be the same as those occurring in
the Lime gravel member of the Upper
Cretaceous Habana formation. It is these
limestone lenses in the Cayetano that
Vermont calls the “Mountain facies” of
the Habana formation.

TUFF SERIES

A thick series of tuffs, agglomerates,
and flows makes up a large portion of the
Cretaceous column. These range from a
few thin beds in the Aptian to the top of
the Cretaceous (see Table 1) and in
Oriente Province to the Middle Eocene.
The series has its greatest development
in southern Santa Clara Province in
central Cuba. Here it forms a belt 120
kilometers (75 miles) long by 25 kilo-
meters (15 miles) wide and, according to
Thiadens' estimate, has a thickness of
8,000 meters, though it now is believed
to be much thicker. In Matanzas Pro-
vince more than 2,000 feet is known; in
Habana 5,000-6,000 feet; and north of
the Organos Mountains in western Cuba,
1,300 feet is exposed. In Camagüey
Province the thickness is comparable to
that of Santa Clara. The tuffs have been
encountered in oil wells in Habana and
Matanzas provinces.

Except in central Cuba, the tuffs are
not everywhere continuous. In Habana,
for example, there is a tuff lens entirely
surrounded by normal marine sediments,
indicating that it is the product of a
single volcano.

The ejected material consists of tuffs,
agglomerates, and flows. These have
been excellently described by Thiadens,
who named the formation. The lithology
of the series is of the intermediary type,
and attention may be called to the fact
that none of the known examples is suf-
37 P. 12 of fn. 23 (1937).
38 Ibid., p. 12.
iciently basic to be the parent-rock of serpentine. This suggests that the extensive serpentines of Cuba are genetically unrelated to Cretaceous igneous activity.

The widespread occurrence of Radiolaria and Foraminifera in the tuffs and agglomerates indicates that a large portion of them was deposited in the sea. Many lenses of marine limestone, varying from a few feet to several hundred, are indicative of the same origin. Several of these lenses are referred to the Provincial limestone described above.

HABANA FORMATION 39

This widely distributed formation occurs in all the provinces of Cuba. It carries an abundant and well-preserved fauna of foraminifers, corals, mollusks, and echinoids that is Maestrichtian, Upper Cretaceous, in age. The Habana formation is well exposed along the axes of both the Habana-Matanzas and the Madruga anticlines. In central Cuba several hundred square miles of Upper Cretaceous deposits are exposed on the Rodas anticline (see p. 25).

There are three members in this formation in the northern half of the three western provinces. The oldest is termed the “Lime gravels,” composed of loosely consolidated limestone pebbles which vary in size from coarse sand to half an inch in diameter. The gravels contain orbitoids, rudist fragments, and, rarely, echinoids. Within the pebbles themselves there are often alveolinellid Foraminifera which are also considered Upper Cretaceous in age.

The second member is the “Cone sandstone,” so called from the cone-shaped concretions that form under subaerial weathering. These cones develop in an inverted position with the base parallel to the bedding plane. This member is a light-gray, uniformly fine-grained, calcareous sandstone with scattered chlorite grains and lime cement. Both the Lime gravel and Cone sandstone are well exposed at San Francisco on the Central Highway, 12 kilometers southeast of Habana. Locally the Cone sandstone varies laterally to white marls. Its hardness makes it a valued stone for building and road purposes. Topographically it forms hills.

The third and youngest member of the Habana formation is the “Big Boulder bed,” named from the habit of weathering to a residue of large boulders that makes its identification in the field possible even at a distance. The boulders are in part from conglomerates in the formation and in part from the disintegration of the limestone beds. The excellent Upper Cretaceous molluscan, coral, foraminiferal, and echinoid fauna with few exceptions is confined to this member. Very rarely large fragments of silicified wood in the form of rounded boulders are encountered. Though this member is well represented in both the large anticlines of western Cuba, the fauna is very largely confined to the southern one. On the other hand, tuffs are by far the more abundant in the northern structure, where fossils are few.

The three members occur together at Cantarana, 9 kilometers east of Madruga, Habana Province. They were, however, not recognized in oil wells located at a considerable distance south of their surface exposures in Habana and Matanzas provinces, but instead there was a dark-gray shale that is their equivalent. On the other hand, Big Boulder bed foraminifers and Cone sandstone

39 The Upper Cretaceous and Tertiary of Habana and Matanzas provinces have been studied and ably described by Ing. Jorge Brodemann, “Determinación geológica de la cuenca de Vento,” Tercer Congreso Nacional de Ingeniería (1940), pp. 8–28.
form under subaerial cones develop in an with the base parallel to. This member is a oly fine-grained, cal-with scattered chlorite ment. Both the Lime sandstone are well exi-sciso on the Central meters southeast of the Cone sandstone white marls. Its hard used stone for building s. Topographically it was the "Big Boulder form the habit of weather- of large boulders that in the field pos- tition. The boulders nalineates in the for- t from the disintegrat- ed beds. The excellent fossil, coral, fo- thinioid fauna with fe- ened to this member. fragments of silicified of rounded boulders the member is the both the large anti- caba, the fauna is very the southern one. On es are by far the more northern structure, w. bers occur together at oters east of Madru- nce. They were, bow- in oil wells located a distance south of sures in Habana and es, but instead there ale that is their equi- er hand, Big Boulder and Cone sandstone were encountered in a well near the north coast a short distance east of Habana. The data seem to indicate that the three members of the formation were not de- posed as much except in the general area mentioned.

The two lower members of the Upper Cretaceous are confined to the three western provinces. The Big Boulder bed is the sole representative of the Upper Cretaceous occurring in all the provinces. The three members are shallow-water deposits with the exception of the white marls, which are believed to be the later facies of the Cone sandstone. In southern Santa Clara and Camagüey provinces, both the Middle and the Upper Cretaceous are tuffs with clastic limy lenses.

TWO PHASES OF UPPER CRETACEOUS

There are two phases of the Upper Cretaceous (see Fig. 1), as pointed out by M. G. Rutten. The marls, sandstones, limestones, conglomerates, and igneous debris already mentioned as occurring in Pinar del Río, Habana, Matanzas, and the southern half of Santa Clara and Camagüey provinces constitute the southern phase as described by Rutten. The name "Habana formation" usually refers to this phase. The northern phase is limited to the northern half of Santa Clara, Camagüey, and Oriente provinces. This latter phase is almost a pure lime- stone.

JARONÚ LIMESTONE

The best-defined exposure of the northern phase is on the lands of the Jaronú sugar mill in Camagüey Province, where a section of 27,000 feet was measured. According to the name "Jaronú limestone" has been applied to this phase. The presence of Barretia, caprinids, and Nerinea low in this section indicates that some of the northern phase is older than Upper Cretaceous.

LIMESTONE BRECCIA

Near the top of the northern phase in the vicinity of Camajuaní is a thick limestone conglomerate carrying large, sharply angular fragments of Aptychus limestone and chert. What appears to be the same conglomerate appears near the top of the Jaronú section. The angular boulders suggested the name "Lime- stone breccia" for this member of the Jaronú limestone. This member carries Foraminifera of the species occurring in the southern phase of the Upper Cretaceous.

Small chloritized fragments of tuff also occur in the Limestone breccia. These are the only evidence of Upper Creta-

Although at least in part the same age, the northern and southern phases were deposited under entirely different conditions of sedimentation and evidently in widely separated areas. There is some 27,000 feet of limestone lying above the Aptychus beds on the north and a comparable amount of tuffs occupying the same stratigraphic position to the south, and yet the two are separated by a distance of only 5–10 kilometers (see Fig.5). It appears that the southern representative was pushed northward during the extensive overthrusting that will be dis-
Fig. 4.—Viñales Valley looking southwest. The cliff is the south side of Sierra de Viñales. The portion below the white line resembling talus is the remnant of an earlier overthrust sheet of Viñales limestone; that above is a later overthrust sheet. See section, Fig. 3. (Photograph by T. E. White)
Fig. 5.—Northeast-southwest section (A-A') through eastern Santa Clara Province. Stratigraphically the Limestone breccia of the north phase and the tuffs of the south phase both directly overlie the Aptychus beds. Overthrusting has reversed this position along the north fault and has brought the tuffs of the south phase to within 5 kilometers of the north limestone phase. Late in 1943 a light oil was encountered at shallow depth along the serpentine-Aptychus beds contact in the Sierra de Matahambre.
ceous. There are granites, granodiorites, andesites, rhyolites, basalts, and boulders of sedimentary origin, such as slates, quartzites, schists, and gneisses, whose sources are so hidden that they are but themes for speculation. The boulders in the Cretaceous exposures in the southern or Madruga anticline average somewhat larger than similar boulders in the northern anticline. This has suggested that the mass supplying them lay to the south.\textsuperscript{43} Evidence in line with this suggestion is found in the similarity of the Upper Cretaceous shore fauna of Jamaica and Cuba. This in many cases amounts to identity of species. Such similarity in a distinctly shallow-water fauna is difficult to explain if it be assumed that during Cretaceous times Jamaica was separated from Cuba by an expanse of deep water as it is today.

The Upper Cretaceous fauna is southern European in its affinities and distinctly not North American. It is a part of the Caribbean fauna which in turn belongs to the Tethyan or Mediterranean realm of the Old World.

TERTIARY

CAPDEVILA FORMATION, PALEOCENE

The Capdevilà formation is a thick series of shales, sandstones, and a few conglomerates which is rather widely distributed in western Habana and eastern Pinar del Río provinces. It weathers to an ochreous brown soil that is rather poor for agriculture.

The Capdevila is folded with the Upper Cretaceous, and in some localities its lithology recalls the Big Boulder bed. Its scanty fauna is confined to Foraminifera and Radiolaria. Some of the Foraminifera are Midway Eocene in age. As

pointed out by Brodermann,\textsuperscript{42} this is probably a transitional formation. It is well exposed at Capdevila, 10 kilometers south of Habana.\textsuperscript{44}

EOCENE

P. J. Bermúdez\textsuperscript{46} described the white marls on the University of Habana campus as Lower Eocene and named them the "Universidad de la Habana formation." In its typical exposures in Habana this formation is a white- or cream-colored marl less than 100 feet in thickness.

Deposits ascribed to the Middle Eocene occur in all the provinces of Cuba, the greatest development being in Habana Province in a part of the Madruga anticline known as the Bejucal uplift. Marls, sandstones, and fine-grained conglomerates are the principal elements. These deposits yield excellent foraminiferal faunas representing the Cook Mountain and Mount Selman series of the Claiborne group of the Gulf Coastal Plain. In Oriente Province the thick basaltic flows between Palma Soriano and Santiago de Cuba are Middle Eocene in age. It is possible that some deposits previously referred to the Middle Eocene may be a shallow-water phase of the Upper Eocene.

The Principe formation\textsuperscript{47} is the principal formation in the Upper Eocene. It is a white- or cream-colored marl that closely resembles the Universidad. It has a large and well-preserved foraminiferal fauna with a few echinoids, echinoid spines, corals, crinoid stems,

\textsuperscript{42} P. 23 of fn. 39 (1940).
\textsuperscript{43} Palmer, p. 132 of fn. 41 (1934).
\textsuperscript{46} Palmer, p. 132 of fn. 41 (1934).
odermann, this is a fossil formation. It is levada, 10 kilometers and barnacles. At the type locality in Habana City the marls are about 70 feet thick but thicken to the south. Both the Universidad and the Principe were deposited in water 100 or more fathoms deep, and both retain much fossil salt. The Principe formation weathers to a loose pink or brownish soil that, with sufficient moisture, is rather productive.

OLIGOCENE AND MIocene

Tinguaro Marl

The oldest known Oligocene in Cuba is found in the Colon anticline in Matanzas Province. It is a thick series of bluish-gray marls that weathers to a buff or tawny soil which is very compact and impermeable to water. It is poor agricultural land. Good exposures of these marls occur on the lands of the Tinguaro sugar mill and suggested the name for the formation. The marls yield an excellent foraminiferal fauna, part of which was described by D. K. Palmer and P. J. Bermúdez. The Tinguaro marls are believed to be in part the deep-water equivalent of the zone of the large Lepidocyclina that occurs directly above the Eocene in many widely separated localities in Cuba. Lepidocyclina undosa and L. favosa are two characteristic species of the shallow-water facies. Though these species are referred to the Middle Oligocene or even Miocene in the Gulf States, they occur near the base of the Oligocene in Cuba.

The echinoid fauna of the Upper Eocene and Lower Oligocene, like that of the Upper Cretaceous, has striking Old World affinities. So great are the similarities that many species from Cuba and Egypt are indistinguishable.

The remaining divisions of the Oligocene and Miocene are marls and limestones. For the most part they weather to a residual brown or red clay that ranks high as cane land.

GUINE Limestone

One of the well-recognized formations of Cuba is the Oligo-Miocene Guine limestone. This is the most widely distributed formation in the island. It is nearly coextensive with the fourth and sixth physiographic provinces. At the surface the formation is a hard, brittle, white or pinkish limestone, in places packed with molluscan and coral molds; a few feet below the surface it is soft, fragmental, and loosely consolidated. Where elevated a few hundred feet, it forms jagged hills such as flank the Habana-Matanzas anticline on the south. The Guine limestone is very porous and easily channeled, with the result that the drainage of this terrain is almost entirely underground. Collapse of cave roofs has formed sinkholes, and in elevated areas a slump or karst topography has resulted. Good examples of this topography are at Jamaica, 25 kilometers southeast of Habana, and in the irregular hills between Limonar and Coliseo in Matanzas Province.

These hills of Guine limestone, though nearly barren of soil, support a dense growth of bushes, vines, and trees. In the underground streams and caves there lives a diversified blind fauna of fishes, spiders, crickets, and shrimps.

The residual soil from the Guine limestone is a red laterite highly prized for agricultural purposes. As stated above, it makes the best cane land in Cuba. The formation of laterite is a tropical or subtropical process or weathering. In the temperate zones the products of weathering are carbonates, silicates, oxides, and hydrous silicates in

41 (1934).


41 (1934).

the tropics the process takes another course or continues to a more complete oxidation, and decomposition of the silicates and the end products are iron and aluminium hydroxides. These insoluble products accumulate as residual soil known as laterite. Laterite in Cuba is derived from both limestone and serpentine. Over large areas in Camagüey and Oriente provinces laterite derived from serpentine has an iron content sufficiently high to make it a valuable iron ore. On the surface of the laterite numerous small pellets of hematite called “perdigones” (shot) have formed. So abundant are these in places that they give a distinctly purplish color to the soil. Under conditions not well understood these perdigones become imbedded in a matrix of limonite, the whole forming a barren soil known as mocarrero.

PLIOCENE AND PLEISTOCENE

Deposits of either of these epochs have not been definitely recognized. Bordering the coast in many places is a narrow collar of hard limestone into which the sea has cut terraces. The city of Habana is located on these marine terraces. Above one of the cliffs is Morro Castle, a well-known landmark of Habana. This limestone contains a few molluscan species and many unidentifiable molluscan and coral molds, but whether the deposits are Pliocene or more recent is not known.

IGNEOUS ROCKS

INTRUSIVES—BASIC

Both intrusive and extrusive igneous rocks occur in Cuba. They in turn are both acid and basic. The basic rocks are

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47 Schurmann (pp. 339-42 of ftn. 32 [1935]) divides the igneous rocks of Cuba into three classes: (a) The intrusions related to the intensive orogeny (Hochorogene), one of which he places in the Upper Cretaceous. These are the serpentines (syntectonic) and the granodiorite (post-tectonic). (b) Older pre-Cretaceous intrusives and extrusives of the Tuff series. These are porphyries and diabases. In contrast to the orogenic intrusions he refers these to geosynclinal types. (c) Post-orogenic serpentines, porphyrites, and intrusions of more acid rocks into serpentines and, in southern Oriente, flows of basalt and andesite. These may be Middle Eocene.

48 P. 13 of ftn. 13 [1936].
OUTLINE OF THE GEOLOGY OF CUBA

later date for that intrusion. In Santa Clara Province a dike is known to cut the Eocene. In Matanzas Province there are serpentine outcrops in an Upper Oligocene limestone terrain. The limestone immediately around the serpentine is marmorized in a zone a few feet wide, while beyond this it is entirely normal. Around the intrusion the Upper Tertiary limestone has dips up to 30°, whereas ordinarily these limestones are flat or, where they border low, post-Oligocene structures, they have dips of 5° or, at most, 8°. In these localities the intrusions appear to be late Tertiary in age. Obviously, there have been several different times of intrusion.

The serpentine-derived soils support a very scant vegetation and are probably the poorest agricultural soils in Cuba. Palma cana (Sabal parviflora Bec.), Yuraguana (Coccolothryx miragyno Bec.), and Jata de Guanabacoa (Cayennia macroglossa C. Wendl.), while not entirely confined to the serpentine, are characteristic of it. However, the lateritic soils derived from iron-rich serpentine support valuable pine forests. Analysis of the soils from the iron-rich and the iron-poor serpentines show a notable percentage of potash in the former and but traces in the latter. The presence of this essential ingredient in the iron-rich serpentine may in part account for its heavy pine growths.

The solid stand of pines is a notable exception in tropical forests. In general, a tropical forest is an indiscriminate mixture of numerous species. Except in high altitudes where temperate conditions prevail, solid stands, like an oak or maple or beech forest of the north, do not occur. It seems strange that these low hills should supply the proper conditions for the pines. The rule seems to be that in the tropics abundant species with few individuals comprise the forests; in the north the reverse prevails. Curiously, the same rule applies to marine molluscan faunas.

The serpentines of Cuba are, however, of economic importance for their local mineral content. The iron-ore deposits that accumulate in the residual laterite from serpentine have already been mentioned. The iron deposits of Mayari and Moa districts in Oriente, in San Felipe in Camagüey, and on Loma Cajalbana in Pinar del Río are examples. The Mayari deposits contain about 1 per cent nickel, which is at present (1944) being exploited. Valuable deposits of chrome also occur in serpentine. They were originally magmatic segregations in the dunite or peridotite, the parent-rocks of the serpentine. There are a number of these deposits scattered over Cuba, the most important being in Camagüey and northern Oriente provinces.

In addition to the serpentine masses, there are many smaller intrusions of diorite, gabbro, and a few of granite and granodiorite in the northern half of the island. In the eastern part of Oriente altered intrusions associated with serpentines form the core of the mountains. Around this core and dipping away from it is a collar of sediments. The intrusions are pre-Tertiary, and the attitude of the Tertiary sediments is due to the late Tertiary folding.

INTRUSIVES—ACID

The southern half of the island has fewer intrusions. On the north side of the Trinidad Mountains in southern Santa Clara Province there are two large granite and granodiorite intrusions whose

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36 For the data and comments on the geology of eastern Oriente I am indebted to Dr. Thomas Thayer.
weathered debris produces a loose, highly siliceous soil similar to that of the Cayetano and, like that soil produces high-grade tobacco. Acid intrusions border the large serpentine mass on the south in southeastern Camagüey Province.

In western Oriente there is a large intrusion of granodiorite and granite occupying an area of 400 square kilometers. In central Camagüey granodiorite and granite are exposed in patches over an area of 250 square kilometers near Florida. In the latter area an attempt was made to remove a supposed boulder, but the project was abandoned when 6 or 8 feet of excavating revealed that the boulder became larger at depth. Instead of being a boulder, it was in reality a knob from a large mass of granodiorite lying buried under the surrounding sediments. The excavation was made in the Habana formation chalk and marl, and these showed no trace of metamorphism along the contact with the granodiorite, indicating the latter to be pre–Upper Cretaceous. A similar granodiorite occurs at Ciego de Avila in western Camagüey, and there are like patches in eastern Camagüey.

Field evidence indicates that the granodiorite intrusions in central and eastern Cuba are approximately the same age. The data in the preceding paragraph clearly show that the Camagüey granodiorite precedes the Habana formation. What precedes the granodiorite, however, is not so clear. Thiadens states: "The contact phenomena in the Tuff Series near the contact with the diorite prove that the Tuff Formation is older than the diorite."39 L. Rutten31 states that the granodiorites are post-

39 P. 12 of fn. 23 (1937).

Tuffs and probably pre-Emscher (Lower Senonian). Both calculations are based on the assumption that the tuffs are Cenomanian–Turonian–Emscher, which, as has been pointed out, is true only of parts of the Tuff series. From the data at hand the only statement that can be definitely made as to the age of the granodiorites is that they are later than some of the tuffs and are older than the Habana formation.

It will be noted that the intrusive rocks in the southern half of the island do not extend west of about the central meridian and that they are acidic types. In contrast, the intrusions in the northern half occur throughout the length of the island and are basic.

**EXTRUSIVES**

Extrusive rocks occupy a very small portion of the Cuban terrain. Only two late Pleistocene or Recent unburied flows of any importance are known. One is a comparatively recent flow that covers an area of approximately 25 square kilometers in central Santa Clara Province. The other is an andesitic flow of some 200 square kilometers in Oriente and adjacent parts of Camagüey. In western Camagüey there are two small basaltic cones.

The Cretaceous igneous activity has already been mentioned, and the character of the erupted material and its general distribution discussed. The Cretaceous tuffs, though occupying but a small percentage of the area of Cuba, do in the aggregate amount to many thousand hectares. The tuff-derived soils are for the most part poor and are avoided by agriculture.

There was minor Eocene volcanic activity in the provinces of Matanzas and Oriente, but it was of little importance except for the thick basaltic series that
forms the greater part of the Sierra Maestra in southern Oriente. Taber\textsuperscript{29} estimates the Cobre formation, which is largely made up of these flows, to be over 4,500 meters, and "may be as much as 6,000 meters," in thickness.

No Oligocene or Miocene volcanic rocks are known in Cuba.

**STRUCTURE**

No statement can be formulated to cover the general structure of Cuba. Past attempts to generalize have given impressions that are erroneous. The position of Cuba on the margin of the great Tethyan belt has subjected it to tectonic forces operating both on the American continent and in the Tethyan zone. This, together with its size (1,200 kilometers long), precludes any possibility of a unit structure throughout the entire island. It has, on the contrary, been broken into blocks somewhat smaller than those on the continent which constitute major structural units. An acquaintance with these major units is sufficient to form an idea of the general anatomy of the island. An account of the minor structures would confuse rather than clarify the general picture. The account will therefore be confined to the major structures as far as known, starting at the western end of the island. These structures are located on the map (Fig. 1).

Occupying nearly the entire length of Pinar del Río Province in a strip 4–10 miles wide is the Pinar overthrust. Here the Jurassic and the Viñales limestone that are normally below the Cayetano are thrust southeastward over this formation (Figs. 2 and 3). The dissected, overthrust sheet of Viñales limestone forms the greater part of the Organos Mountains. The overthrusting was more intense in the eastern end of the range, where it was of the order of 10 miles, diminishing toward the southwest and, at the end of the range, dying out.

The hard Viñales and Jurassic limestones advancing over the soft Cayetano plowed deeply and crushed and contorted the shales before them. After the movement ceased, the front of the limestone sheet retreated as a result of erosion, leaving a valley between the limestone mass on the north and the wall or scar in the Cayetano on the south gouged by the overthrust front. North of Pinar del Río City on the Viñales road the Cayetano wall or overthrust scar is 150 feet high, and the shale beds in the base are crushed and contorted (Fig. 3).

The overthrust was not the simple case of a limestone sheet thrust upward to the surface along a straight line and then southward over the Cayetano. Instead, the overthrust mass broke into segments that came to the surface en echelon along a general line. Examples are the Pan de Guajaibón, about 2 miles north of the general line, and the Sierra Quemado, which is 5 miles south of it. Nor is there everywhere only a single overthrust in a given segment. There are cases of two and even three imbrications. A notable example is the segment containing the two parallel ridges, Sierra del Ancon on the north and Sierra de Viñales on the south. The overthrust apparently started along the southern ridge. This was followed by a second slice on the north which passed over the first. Erosion has reduced the two, leaving the front of the second mass as a steep cliff above the first, whose gentler incline has the appearance of a talus slope (Figs. 3 and 4).

The overthrust structure has been complicated by contemporaneous and possibly minor subsequent folding. This has left the Organos Mountain area
folded in a broad anticlinal structure along the central part of which lies the Pinar overthrust (Fig. 3). The entire column from the Jurassic to the Miocene participated in this folding. The name "Pinar anticline" is proposed for this extensive structure.

The Cayetano, very probably, and possibly the Habana formation capped the Viñales limestone during the overthrusting, but they have since been eroded from the overthrust sheet, leaving no trace of their former presence. Erosion has dissected the limestone sheet and cut it into blocks with nearly perpendicular sides varying in size from small hills to masses of several square kilometers often 500 feet high. These isolated blocks are the "mogotes," the most striking feature of the Viñales landscape, as already stated (Fig. 2).

The pressure causing the overthrusting was from the northwest (see Fig. 1). The configuration of Cuba suggests a possible correlation between several features. Pinar del Río Province has a bearing of N. 70° E., and the adjacent part of the island an east-west bearing, a difference of 20° (see Fig. 1). The 1,000-fathom line of the Gulf of Mexico makes a deep re-entrant off the north coast of Pinar del Río. Southeast of the province is the Isle of Pines, and between it and the mainland are shoals. This combination of features suggests that pressure from the northwest, using western Habana Province as a pivot, moved the western end of the island to the southeast through an arc of 20°. In the northern half of the Isle of Pines the structural lines lie in a north-south direction. This does not oppose the above suggestion.

In the southwest quarter of the island the Sierra la Cañada and Cerros del Monte have a strike of N. 55° W. and in the southeast quarter strike east-west with a dip of 10° to 15° north. This is the general attitude of the schists and phyllites of the area. Late movement from the southwest would explain this marked change in the latter structural lines.53

A second major structural unit lies in the provinces of Habana and Matanzas. Here two large anticlines or anticlinoria, with an intervening syncline, are the principal features. These lie in an east-west direction. The northern structure, called the Habana-Matanzas anticline, extends from Matanzas City westward to Habana, a distance of 90 kilometers (55 miles). At Habana the structure passes under the Lower Eocene Capdevilla formation and continues into Pinar del Río Province. Along the axis of the structure erosion has removed the Tertiary capping and exposed the underlying Cretaceous in a belt 10 kilometers (6 miles) wide except about midway between Habana and Matanzas, where a narrow saddle of Oligocene remains. On this high saddle the Hershey sugar mill is located. The Cretaceous is composed of soft shales, sandstones, and tuffs that are easily eroded. The Oligo-Miocene, on the other hand, is a hard limestone that resists erosion. The resulting topography is a broad valley with a Cretaceous floor flanked on either side by steep Upper Tertiary cliffs. Prominent portions of this wall of cliffs have specific names, as Escaleras de Jaruco, Sierra Camerones, El Palenque, and Pan de Matanzas. As

53 This suggestion is in keeping with B. Willis' "Isthmian Links," Bull. Geol. Soc. Amer., Vol. XLIII [1932], p. 927 theory of sinking basins (in this case the Gulf of Mexico) and rising and expanding borders. Schuchert (pp. 37, 358, 400, 406 of ln. 24 [1933]) mentions specific application of this theory to the area in question. On the other hand, this theory would recognize the overthrusts toward the north in central Cuba as overthrusts from the Yucatán Basin (Antillean Sea of Suess and Schuchert) of the Caribbean Sea.
already stated, many serpentine intrusions occur along the valley. The east end of the valley is drained by Yumuri River and is known as the valley of the Yumuri. The river has cut through the eastern end of the anticline near Matanzas City, forming the picturesque and well-known Yumuri Gorge.

Paralleling the Habana-Matanzas anticline and lying 20 kilometers to the south is the Madruga anticline named for the town located near the middle of the structure. This structure extends from central Matanzas westward through Habana Province and into Pinar del Rio Province nearly to the Organos Mountains, a distance of 150 kilometers (90 miles), where it flattens out and disappears. The folding was less intense in the Madruga anticline than in the structure to the north, with the result that the Cretaceous is exposed in a few places only. Elsewhere the Eocene forms the surface along the axis, and in Pinar del Rio, where the structure dies out, only the Oligocene is exposed.

Between the two major anticlines is the Almendares-San Juan syncline, named from the two rivers that drain each end of the structure. Near the eastern end the synclinal axis turns to the northeast around the eastern end of the Habana-Matanzas anticline and passes under the water. This submerged portion forms Matanzas Bay.

Santa Clara Province forms a third geological unit. It is characterized by overturned folds, overthrusts, and intrusions. There are three principal structural features in this province: the Cordillera along the north coast, the Santa Clara intrusion in the central part, and the Trinidad Mountains in the southern part.

There are many minor structures in Santa Clara that are more or less subsidiary to the major features. A description of these, however, belongs to detailed accounts and is not within the scope of this paper.

The Cordillera is a series of overturned folds and overthrusts. The force causing these structures was directed toward the north and northeast. The Middle Eocene is the youngest formation observed to have participated in the folding of the Cordillera. A small overthrust of Lower Cretaceous over Middle Eocene occurs 5 kilometers west of Sagua la Grande. The folding is, therefore, late Middle or early Upper Eocene in age. There are several intrusions along the Cordillera, the largest being in the east end.

The Santa Clara intruded zone, in the central part of the province, is a complicated series of rocks ranging from serpentines to granites. The details of this zone and the relationships of the various intrusions have not been worked out.

The Trinidad Mountains (see Figs. 1 and 6) in the southern part of Santa Clara Province is a thick block of schists overthrust from the south and lying on granite and granodiorite. The mass is 80 kilometers (50 miles) wide by 30 kilometers (20 miles) long in a north-south direction. The granodiorites are exposed along the north side of the mountains and are separated from the schists by a highly sheared fault plane (Fig. 5). The main mass of the schists has a uniform south dip. On both the east and the west ends of the mountains the tuffs, Upper Cretaceous limestone, and Tertiary strike north-south and dip away from the schists (Fig. 6). Between the sediments and the schists are wide shear zones. Farther to the north these formations resume the east-west direction in accordance with the general grain of the country.
Thiadens, in a brief discussion of the Trinidad Mountains, considers the possibility of their being an overthrust mass but believes that "the schist-formation is an autochthonous complex."

to the similarity of the Mediterranean and Caribbean regions.

Reference to the map (Fig. 1) suggests a possible correlation between the overthrust features and the topography of

Fig. 6.—Plan of Trinidad overthrust. The Trinidad Mountains are a mass 80 kilometers wide bounded on the east and west by north-south-striking Cretaceous and Tertiary. The mass was pushed northward during late Upper Eocene. North of the mountains earlier movement in late Middle Eocene caused folding in the tuffs, and still farther north in the Cordillera it caused overturning and overthrusting. See Fig. 5.

The overthrust features of central Cuba are suggestive of the Alpine structure of southern Europe with the Trinidad overthrust analogous to the alpine nappes. The Caribbean structures, however, were less intensive and on a much smaller scale. L. Rutten calls attention

§ P. 48 of fn. 23 (1937).


the adjoining sea bottoms to the north and south. The 1,000-fathom line on the south side of Cuba makes a detour of 60 kilometers (35 miles) to the north as it passes Santa Clara Province. North of this detour on the mainland are the Trinidad’ Mountains, followed by a second overthrust zone (Fig. 5). Off the north coast is Cayo Sal Bank. This combination may be viewed as a segment of
of the Mediterranean
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ion between the over-
and the topography of
the surface that was pushed northward, bringing the deep water near the south coast and causing telescoping of the land, a part of which was taken up by the over-thrusting on the mainland and a part by the elevations forming the shoals of Cayo Sal Bank. The slight curve in the north coast of Santa Clara and the direction of the over-thrusting on the mainland fit into the picture without alteration. According to this suggestion, the Trinidad Mountains were pushed from their former position east of the Isle of Pines northward to their present location, a distance of 50 kilometers (30 miles). Over-thrusting on the north side of the province thrust the Aptianus beds over the Upper Cretaceous Limestone breccia and brought the south sandstone-shale-conglomerate-tuff Upper Cretaceous phase in close proximity to the northern limestone phase (see section, Fig. 5). It will be noted that the pressure here was directed to the north and northeast (the Vergeus of Stille) in contrast to western Cuba, where it was toward the southeast. In the former case it came from the Caribbean Sea and in the latter from the Gulf of Mexico (see p. 22).

In this connection José Isaac Corral\[56\] presents a noteworthy theory that is an application of the theory of Continental Drift. His thesis is that the Greater Antilles were formerly adjacent to and a part of Colombia and Venezuela and that during the Upper Miocene they were detached and drifted northward to their present position. This theory may find some support in the over-thrusts and overturned folds directed toward the north in Santa Clara Province.

In the southwest corner of Santa Clara Province there is an area outside the over-thrust zone. A low, broad, east-west fold known as the Rodas anticline exposes the Cretaceous for a distance of 60 kilometers. Here and in southern Camagüey are the rare places in Cuba where the Upper Cretaceous may be seen lying flat or nearly so.

In Camagüey Province no major structure can be delimited in its entirety. The western half of the province is a plain covered by flat-lying Upper Tertiary limestone. In the north-central part there is an immense structure in which 27,000 feet of Middle to Upper Cretaceous limestone (Jaronú) with a southwest dip has been measured. This structure passes under the Tertiary both to the northwest and to the southeast, and the north flank is under the Bahama Channel. Whether the north side is the limb of an anticline or is faulted off is not known.

In the northern part of western Camagüey there are several structures that bear strong evidence of being salt domes. In general, they have the form of domes; in two places there are large deposits of gypsum of the salt-dome type from which the Tertiary deposits dip. Salt springs occur associated with the gypsum. At present the general area is being investigated by two of the large oil companies.

In eastern Camagüey the most important structure is the large basic intrusion on which Camagüey City is located. This is bordered on the north and on the southeast by rhyolites and diorites and on the south and west by tuffs.

In Oriente Province the major structures are known only in part. The dominant structure in the south is the large and highly complicated monoclinal fold that forms the Sierra Maestra. The basalt and associated tuffs in this fold dip northward from the long system of

faults that bounds the Bartlett Deep on the north. North of this is the broad syncline of the Cauto Valley. This may be conveniently referred to as the Cauto syncline. This structure extends northward to the intruded zone at Holguin. Along the northeast coast is a folded zone that has been extensively intruded by serpentine. Both the Upper Cretaceous and the Middle Eocene are involved in the folding. Mention was made in the discussion of igneous rocks of the extensive intrusions in the northeast part of Oriente that form large structures surrounded by Tertiary marls and limestones. The prevailing structure of the metamorphics reported in the east end of Oriente is unknown.

HISTORY

The geological history of Cuba does not begin with any definite event or events. The oldest rocks of definitely known age are the Jurassic deposits of Pinar del Río Province. These are marine, and there is no evidence that any land existed at that time anywhere in the area now occupied by Cuba. Except for islands of varying size, there was nothing to suggest the present island until the Middle Miocene. To begin the geological history with events prior to this period is akin to ascribing to its political history events that occurred prior to 1492. The following is rather a history of that part of the Caribbean now occupied by the island of Cuba.

The known geological history of the area starts with the Jurassic. The accounts of events described as occurring in the pre-Cambrian, Paleozoic, and early Mesozoic may be dismissed as fantasies. They have been aptly, though conservatively, described as "contemplative geology . . . . giving a history es-

sentially hypothetical." It is true that the crystalline limestones and schists on the Isle of Pines and in the Trinidad Mountains appear to be old. There is, however, an entire lack of palontological evidence from which their position in the column can be determined. They may with equal reason be ascribed to the Paleozoic or to the Tertiary.

There were several periods of folding. As far as known, only one, the first, was general throughout the island. The remaining orogenic events were more or less local in character, as is evident from the subsequent account.

JURASSIC

The distribution of the Oxfordian Jurassic indicates marine conditions in western Cuba. It is unknown elsewhere in the island. The thin, limy beds with a bituminous content were deposited in quiet waters at no great distance from land, but whether the land lay to the north or south can only be guessed.

In central Cuba and eastward in Camagüey Province the appearance of Upper Jurassic (Quemado formation) may be due to a general inundation of a large land mass or local embayments in such a mass. The localized occurrences near the north coast in central Cuba suggests the latter alternative. The clastic, calcareous sandstone of the Quemado was apparently deposited along the shore of a transgressive sea. Judging from later events, this land mass probably lay to the south.

In central Cuba the Upper Jurassic Quemado formation passes into the Lower Cretaceous Aptychus beds without a break. No evidence of orogeny between them has been noted.

The account of the late Jurassic orog-
It is true that estones and schists on and in the Trinidad to be old. There is, lack of paleontological in their position in the determined. They may be ascribed to the Tertiary.

Several periods of folding, only one, the first, was on the island. The re- events were more or later, as is evident from count.

Jurassic

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The Upper Jurassic passes into the Lower Apt Chus beds without a trace of orogeny between them.

The late Jurassic orog... and Spencer, p. 30 of ftm. 3

eny described by Schuchert was based on a failure to recognize the Pinar over- thrust. The supposed unconformity between the Viñales (Aptychus beds) and the underlying younger Cayetano is the overthrust zone between the two.

CRETACEOUS

The local inundations during the Upper Jurassic were followed by complete submergence of at least the northern half of Cuba in the Lower Cretaceous (Aptychus beds). The coarse basal sand followed by the uniformly thinly bedded Aptychus-bearing beds reflect a transgressive sea that covered the five central provinces and probably also Oriente. The presence of Radiolaria and vegetal fragments and the uniformly fine-grained, thin-bedded marls indicate quiet waters at some distance from the shore but not beyond currents bearing debris from land.

A period of intense orogeny followed the deposition and consolidation of the Aptychus beds. This orogeny is unique in two respects: (1) it was the first definitely dated and (2) it was the most intense in the entire geological record of the island. From eastern Pinar del Río to eastern Camagüey, badly sheared, contorted, and calcite-veined Aptychus beds are evidence of its intense, far-reaching effects. As far as is known, the activity in Cuba was confined to the northern half of the island. Here structural lines were laid out that were followed by all subsequent orogenies.

This folding event occurred within the North American realm and is of importance. In spite of its intensity and its locality, search for orogenic events on the North American continent comparable in time is vain. South America provides the only possible analogue in the New World. H. Stille states: "The South American Andes afford us on the whole, the most striking example of subherzian (intra–Upper Cretaceous) folding known to the present time." While this pre-Laramide folding of the Aptychus beds cannot be dated except as between their deposition (Neocomian?) and the pre-Maestrichtian, this limit places it within the range of the Andean folding and suggests orogenic relationship between the Greater Antilles and South America. His statement that "weak subherzian (intra–Upper Cretaceous) movements may likewise exist in Cuba" may well have been prophetic of the discovery of this first great orogenic event in Cuba.

TUFFS

During the deposition of the latest Aptychus beds there was initiated a long period of volcanic activity which continued during the rest of the Cretaceous and to the Middle Eocene. The center of this activity was in central Cuba, where 25,000 feet or more of tuffs, agglomerates, and flows accumulated. The activity extended to all the other provinces but with a lesser degree of intensity and was intermittent, both in space and in time. There are long and wide belts of deposits, long and narrow ones, and small isolated areas, and in many places they are entirely missing. Much or nearly all of Cuba was beneath the sea during this long period of volcanism, as the numerous intercalated limestone lenses and Radiolaria and Foraminifera within the tuffs bear witness. Cuba, then, was in


97 "...schwache subherzynische Bewegungen mögen gleichfalls in Cuba vorliegen."

98 P. 17 of ftm. 59.
effect a row of volcanic islands not unlike the inner row of volcanic islands in the Lesser Antilles. In time the activity was long ranged. In western Cuba it was Upper Cretaceous, in south-central Cuba from the Aptychus beds through the Upper Cretaceous, and in eastern Cuba it was Middle Eocene. In the latter case it was contemporaneous with similar activity in Haiti.

**UPPER CRETACEOUS**

The deposition of 34,500 feet of Cayetano consumed a long period of time. No explanation is offered for this formation's being limited to the province of Pinar del Río. Whether the remaining part of Cuba was above water and hence received no sediments or whether it was submerged and received sediments that were subsequently eroded cannot be answered. The high colors of the formation when weathered and the scarcity of fossils suggest estuarine or even fresh-water deposition. Either of these postulates a much larger land mass in this part of the Caribbean than now exists. The limestone lenses with marine fauna may be due to local incursions of the sea. A noteworthy query is the origin of 34,500 feet of Cayetano sediments or the 30,000 cubic kilometers of this formation that has been eroded from Pinar del Río. Cuba could provide no bulk of this order. The sands predominate in the exposures on the north side of the Organos Mountains and shales on the south side, suggesting that transportation was from the north, an area now occupied by the Gulf of Mexico. This is in accord with the interpretation of the Lime gravels, but quite the opposite conclusion was reached in the case of the Big Boulder beds already described and also a part of the Habana formation.

The events occurring during the deposition of the Upper Cretaceous were outlined in part in the description of the Habana formation. The main series of events was, in general, as follows. It has been suggested that possibly most of Cuba was above water while the Cayetano was being laid down. At any rate, except for a few volcanic islands, Cuba was entirely submerged during the deposition of the Habana formation. This is shown by the presence of these marine beds both inland and near the coast in all the provinces of the island. In Pinar del Río, Habana, and Matanzas provinces the succession of Lime gravel, Cone sandstone, and Big Boulder beds indicates a near-by rising land which furnished coarse material. The presence of alveolinellid Foraminifera in Lime gravel pebbles is evidence of Cretaceous exposures in that terrain. The Cone sandstone, with its finer grain, may be interpreted as resulting from a lowering of the topography, possibly due to erosion. The location of the land mass is problematical. The finer-grained Lime gravels in the south anticline, as compared to the north, point to its location on the north. The advent of the Big Boulder bed with an almost complete change in lithology witnesses an equally marked change in the topography and perhaps in the location of the catering land mass. For the reason pointed out, namely, the larger boulders in the south anticline, this land appears to have lain to the south, in the opposite direction from the previous land that furnished the Lime gravels. The north limestone deeper-water phase (Jaronú formation) and the south conglomeratic phase of the Big Boulder bed (see Fig. 1) lend support to this suggestion.

The scattered volcanic activity during the deposition of the Big Boulder bed has already been noted. The tuffs with
Cretaceous were outlined in the description of the island. The main series of volcanics, as follows. It has not yet possibly most of water while the Cayetano formation. At any rate, volcanic islands, Cuba emerged during the Habana formation. This presence of these marine and near the coast in of the island. In Pinar del Rio and Matanzas provinces, Lime gravel, Cone Big Boulder beds in rising land which flourished. The presence of nunataks in Lime gravel and Cretaceous exuviae. The Cone sand grain may be inferred from a lowering of the island due to erosion. The land mass is problematic, as compared to the location on the north. Big Boulder bed with its characteristic lime gravel in the center, as compared to the location of the south, in the north from the previous bed, the Lime gravel, the deeper-water phase of the south cone of the Big Boulder bed support to this suggestion. Volcanic activity during the Big Boulder bed noted. The tuffs with marine fauna imply rather small volcanic islands.

It is a curious commentary that, in spite of the orogenic disturbances presumably necessary to produce the marked changes within the Maestrichtian sediments and of the volcanism in that period, no evidence of any general movement during the Maestrichtian has been observed in Cuba itself.

Attention has been called to the Old World affinities of the Cuban Upper Cretaceous and Middle Tertiary faunas. The shallow-water, shore type of fauna makes the similarity the more striking. The explanation seems to lie either in a migratory route in shallow water along the shores of a Gondwana Land or Isthmian Link, as discussed by Willis and between North Africa and the Caribbean or in resorting to the Wegenerian theory of continental drift.

The granodiorite masses in Camagüey and western Oriente provinces, partly buried under unaltered Upper Cretaceous sediments, have been mentioned (p. 20). The evidence there leads to the conclusion that a large island mass was elevated sufficiently above the sea to allow erosion to expose the erstwhile deeply buried plutonic rocks and to reduce the island nearly to base level. The whole island was then lowered to receive the Habana formation sediments. The even larger mass of granodiorite in western Oriente Province appears genetically the same as that in central Cuba. The suggestion comes to mind that the various granodiorite masses are parts of a single mass more than 200 kilometers long extending through Camagüey and into Oriente Province. The existence of this Upper Cretaceous granodiorite island or islands has not heretofore been noted.

**ORIGIN OF SEDIMENTS**

The south phase of the Habana formation and its equivalent are the only formations whose lithologic content evidences a foreign source. The shales, marls, chalks, and limestones in the various other formations are of material derived from near-by land or from the sea itself.

The source of a large portion of the sands and boulders in the few known Tertiary conglomerates can with considerable confidence be referred to antecedent formations, easily available through natural agencies of transportation. The siliceous content of the Cretaceous Cayetano formation is the logical parent of the sands and shales of the Paleocene Capdevila. The thinly bedded radiolarian limestone and black chert boulders in the Limestone breccia, and the Habana formation in the northern phase, with but little doubt were derived from the contiguous Aptychus beds. Search is in vain, however, for a parent of the highly diversified boulders of the Habana formation above listed (p. 13), nor could any older formation in Cuba have provided the bulk for the 34,500 feet of Cayetano. A source outside of Cuba must be sought. For reasons pointed out, the catering land mass must have lain to the south. The size of this Upper Cretaceous land was considerable. It bordered the entire south coast of Cuba except perhaps the eastern end. It extended an unknown distance to the south but at least as far as Jamaica, judging from the identity of the Upper Cretaceous shore fauna in Cuba and Jamaica. In Curaçao the rudist genera *Vaccinites* and *Durania*, which are common shore genera in Cuba, suggest land connections with northern South America. The presence of *Chiapasella pauciplicata* and other shore species in Cuba and Chiapas...
indicate a connection with southern Mexico.

No rudist or molluscan fauna thus far reported from northern Mexico shows any relationship with the Upper Cretaceous fauna of Cuba. The same comment applies to Hispaniola and Puerto Rico. From the present data this land mass was therefore bounded in part on the north by Cuba and on the east by a line passing between Jamaica and Hispaniola and as far south at least as Jamaica and possibly to the north coast of South America. The lack of data on Upper Cretaceous history of Central America prevents any attempt to locate this line on the west except that it included Chiapas in southern Mexico.

**PALEOCENE**

At the close of the Cretaceous or the beginning of the Paleocene there was mild orogeny on the site of the future Organos Mountains in western Cuba. This is the first known folding in the western end of Cuba. It took the form of a low elevation on which the Cayetano formation was raised above sea-level and exposed to erosion. The very siliceous content of the Cayetano furnished the sands and shales of the Paleocene Capdevila that are exposed on both flanks and east of the mountains. At a distance from the mountains this formation lies upon the Habana formation with no indication of unconformity between them. Evidently the elevation was not sufficient to expose the Aptychus beds or their western equivalent, the Viñales formation, as no trace of limestone fragments has ever been reported from the Capdevila near the Organos Mountains. In passing, it should be emphasized that this is strong evidence supporting the contention that the Aptychus beds lie below the Cayetano. It was not yet exposed to erosion while the Capdevila was being deposited.

The Capdevila shales, sandstones, and rare conglomerates indicate near-shore conditions with no accentuated topography in the adjoining land mass. Near Capdevila, the type locality, ripple marks show actual strand conditions. A part of Cuba was at that time above water.

**EOCENE**

In Habana Province the shallow shore-deposited Capdevila is followed successively by brown and then white marls of the Universidad formation. The latter carry an abundant fauna of pelagic Foraminifera and Radiolaria bearing witness of a rapid submergence of considerable magnitude.

The later part of the Middle Eocene witnessed the second great period of orogeny. In Pinar del Río the presence of large boulders of both Upper and Lower Cretaceous rocks in early, rather steeply dipping, Upper Eocene, shows that the Organos Mountains had been elevated above the sea and were being subjected to rapid erosion. It is probable that the pivotal movement of western Cuba from an east-west to a southwest direction accompanied by the beginning of the Pinar overthrust occurred at this time.

This orogeny is the first of any great magnitude that western Cuba experienced. There is no evidence of the late Jurassic orogeny that produced the "ancestral Organos Mountains" mentioned by Schuchert.63

West of central Cuba the Habana-Matanzas and the Madruga anticlines were blocked out. At this time occurred the extensive overthrusting in northern Santa Clara when the Lower Cretaceous

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63 P. 496 of fn. 24 (1932).
was thrust over the Upper Cretaceous and the Middle Eocene, the south phase of the Upper Cretaceous pushed northward in close proximity to the northern phase, and the Cordillera, in general, further elevated (Fig. 5). In Camagüey Province the 27,000 feet of Upper Cretaceous Jaroni limestone was folded. It seems probable that this orogenic activity extended to Oriente Province and continued eastward into Haiti and the Dominican Republic. In eastern Cuba there was extensive igneous activity, the record of which is preserved in the basalts of Sierra Maestra. The pillow structure of these basalts and the interbedded limestones are evidence that they were deposited under water.

In addition to the Organos Mountains, land of considerable elevation undoubtedly appeared throughout the areas of the structural features mentioned. The resulting group of elongated islands with east-west axes assumed a form roughly outlining Cuba as now known. This great period of orogeny corresponds in part to the Laramide revolution on the North American continent.

The widespread distribution of the deep-water Upper Eocene indicates a general subsidence during which probably the greater part of Cuba was again flooded. In Habana City the Upper Eocene is a pure-white marl which is for the most part massive, carries much fossil salt, and is characterized by a distinctly deep, open-water foraminiferal fauna. Land debris is entirely absent. The foraminiferal assemblage of the marls, according to D. K. Palmer,64 indicates a depth of water of at least 600 feet. This is about at the edge of or somewhat beyond the continental shelf. In

extensive that Cuba has experienced. In the west, islands probably persisted on the site of the present Organos Mountains. All of Habana and Matanzas provinces were open ocean. A few islands marked the Cordillera in Santa Clara, and shallow water covered most of the remaining parts of the province. The sea crossed western Camagüey and covered the southern part of the province, extending eastward into the Cauto Valley of Oriente Province. The deposits laid down during this widespread marine incursion are the Güines limestone. This is the most extensive and most unconformable formation in Cuba. Normally it rests on the Cojimar formation (Upper Oligocene), but it is transgressive on various stages of the Oligocene, on the Eocene, and even on the Upper Cretaceous. During this period there was nothing that suggested the Cuba of the present.

Late in the Lower Miocene there occurred another mild orogeny. Quantitatively the movements were small, but, as shallow water covered the deposits involved, the effects were striking. Cuba emerged and for the first time assumed approximately its present outline. The old structures were rejuvenated, and further folding occurred along the Habana-Matanzas and Madruga anticlines. The latter presented an aspect very different from the present. Instead of the broad valleys that now mark these features the Güines limestone covered them in the form of a low swell. Post-Miocene erosion has removed the Güines from the higher elevations and has exposed the softer Eocene and Cretaceous marls, shales, and sandstones, leaving the line of cliffs retreating down the flanks of the two anticlines as stated in the discussion of the third physiographic unit and the second structural unit. In Santa Clara Province the Cordillera was further folded. In Camagüey and Oriente provinces the history is not known in detail, but post-Miocene elevation and minor folding have been recognized.

Deposits subsequent to the Lower Miocene are rare and confined to the coast or inlets of the coast. Examples are the Middle Miocene La Cruz marls in Santiago de Cuba and Manzanillo in Oriente Province. In Matanzas Province the Middle Miocene is exposed on the Canímar River, in a narrow belt extending westward from Matanzas City, and in the gorge of Yumurí River. In the last two localities the inclination of the Middle Miocene beds is greater than can be attributed to initial dip. As they are on the flank of the Habana-Matanzas anticline, it is evident that post-Middle Miocene folding has taken place in this structure.

During the Pleistocene and Recent, vertical movements of considerable magnitude are recorded in the terraces and in sand-choked river channels. Hayes, Vaughan, and Spencer record terraces in widely separated parts of the island. In each locality there are from three to five. The highest are, in Habana, 200 feet; in Matanzas, 300 feet; in Gibara on the north coast of Oriente Province, 150-80 feet; in Manzanillo, 200 feet; and in Santiago de Cuba, 280 feet; while Point Maisí at the extreme eastern end of Cuba is estimated to be 600 feet in height. These wave-cut terraces indicate wide marine incursions.

The drowned valleys that form the harbors of Cuba and the sand-choked river channels are evidence of former elevations of the land or lowering of the sea. In the channel to Habana Harbor that cuts through hard limestone there is 100 feet of sand; in the Almendares...
River channel on the west edge of Habana there is 69 feet, and in the valley of San Juan River in Santiago de Cuba, Hayes, Vaughan, and Spencer noted rounded boulders 70 feet below sea-level. Whether there was actual elevation or a lowering of the sea, possibly as the result of the withdrawal of water required in the accumulation of the Pleistocene ice caps, cannot be answered.

Wave-cut terraces above 35 feet elevation have not been observed in Santa Clara or Camagüey provinces. However, there is striking evidence of folding accompanied by elevation in the Cordillera in eastern Santa Clara. The Jatibonico del Norte River crosses a wide limestone ridge in the Cordillera through a natural tunnel. Above the tunnel and passing over the ridge 200 feet above the entrance to the tunnel is the former clearcut channel with boulders brought from the igneous terrain in the upper reaches of the basin. Salvador and Sarah Massip have also observed this feature. Along the north coast of Camagüey Province a syncline is forming between the mainland and the outer row of islands. Such phenomena as drowned drainage courses, a warped, oxidized surface that is submerged, and drowned vegetation furnish evidence both of the structure and of its recent advent.

Taber considers the faulting of the Bartlett Deep and the rising of the Sierra Maestra as Pleistocene events. The clear evidence of recent movements from the eastern tip of Cuba westward to Habana prompts the suggestion that the Pinar overthrust in the western end may have been active at least during the Pleistocene or Recent. It is recognized that earlier orogeny had left local high hills or mountains during the Lower and Upper Eocene. The boulder content of conglomerates of that age bear witness of this. Similar features continued with or without interruption into the Oligocene and probably into the Miocene. The thrusting, however, at least in its final stages, occurred at a later time. The deep and very steep drainage courses in the soft Cayetano shales are the result of recent elevation. These shales border the overthrust sheet on the north and participated in the movement of the overthrust. On the north side of the overthrust sulphide ores occur on the surface of the Cayetano shales, indicating erosion of such rapidity that oxidized products could not accumulate. In the tropics this implies very recent elevation. The limestone mogotes, though subject to acid solutions from the dense growth of vegetation, retain a young topography (Fig. 2). A striking example of recently formed topography is the scar, earlier described (Fig. 3 and p. 21), that marks the south front of the overthrust. Though the terrain is the soft Cayetano shales, the face of the scar is still steep and scarcely gullied, and the top or crest has no more than started to retreat. The relative recency of the uplift of these mountains is well shown in the north coastal plain. The portion of the plain lying north of the mountains has a youthful topography with sharp ridges and active streams. On the other hand, the adjacent portion to the east and beyond the end of the mountains has a mature topography with low, rounded hills and sluggish water courses.

**Biological Effects of Geology**

The vicarious events in the geological history of Cuba have had a vital effect on the biological content of the island.
It is only through such favorable events as the appearance of land that terrestrial or marine shore life was even possible. To a satisfactory understanding of the living fauna and flora as well as the fossil, the general geological background is of material assistance.

Attention has been called to the fact that, with the possible exception of portions of the Cayetano formation, the sediments of Cuba are entirely marine. The absence of terrestrial deposits effectually answers the often-repeated question of why no land-vertebrate fauna is ever found in the Cretaceous or Tertiary of Cuba. The only vertebrate remains are a few Pleistocene forms found in cave deposits near Ciego Montero and Mayajigua in Santa Clara Province.

The striking feature of the Cuban mammalian fauna is its scantiness. A list of the living and fossil mammals of Cuba has been compiled by Dr. G. Aguayo of the University of Habana. This comprises 59 species, and his analysis shows that 3 insectivores, 2 carnivores, 5 edentates, and 9 rodents, or 32 per cent, make up the entire list of strictly land mammals. The remaining 40 species, or 68 per cent, are bats, cetaceans, and a sirenian. To the first group, a passage across water is a fortuitous event and accomplished but rarely. Sufficient time has not elapsed for this group to land more than a few species. The flying and swimming mammals, however, quickly populated the island and adjacent waters, and the species soon reached a maximum.

Three factors contributed to the paucity of the strictly land-mammal fauna. First, the shortness of the time available for its development. As pointed out earlier, Cuba as a large island such as it is today did not exist until after the Middle or Upper Miocene. The small islands that marked its location did not afford either space or variety of habitats for an abundant and diversified mammalian fauna.

The second factor is one of both space and time. The source of the Cuban mammalian fauna appears to be South America. Two migration routes have been suggested. One, over former land connections through Central America and by way of Honduras, Jamaica, and Hispaniola to Cuba. The other, via the Lesser Antilles, Puerto Rico, and Hispaniola, and finally, Cuba. In either case, only the tapering ends of the migrations reached Cuba in the limited time available. This was a factor in the low census of Cuban mammals.

The third factor, equally important and possibly the most important, is the Pleistocene or recent submergence of Cuba. The terraces along the north coast, and also those on the south coast of Oriente Province, evidence a Pleistocene or later repetition of the Miocene marine inundation. They indicate that the submergence was of the order of 300 feet or more. This submergence, coupled with the fact that many areas were at that time at a relatively much lower elevation than at present (see pp. 32–33), killed off the greater part of the terrestrial life. Except for the descendants of those few types that found refuge on the scattered Pleistocene islands and possessed the hardihood to meet the fierce competition in those crowded quarters, the present fauna as well as the flora of Cuba are post-Pleistocene arrivals.
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OUTLINE OF THE GEOLOGY OF CUBA .................. R. H. PALMER 1

SOME REVISIONS OF THE LATE CENOZOIC STRATIGRAPHY OF THE SOUTHERN OREGON COAST .................. EWART M. BALDWIN 35

EXAMPLES OF THE INTERPRETATION OF FOLDING ......... E. SHERBON HILLS 47

AN OCCURRENCE OF "CAVE PEARLS" IN A MINE IN IDAHO
J. HOOVER MACKIN AND HOWARD A. COOMBS 58

A GEOMAGNETIC SURVEY OF SOME BLADEX COUNTY, NORTH CAROLINA, "CAROLINA BAYS" .................. JOHN C. McCAMPBELL 66

REVIEWS
The Mineral Resources of Africa, A. Williams Pottel (E. S. Bastin) .............. 68

PUBLICATIONS RECEIVED .................. 69

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