Volume 16 Number 6

BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

JUNE 1932

GEOLOGY OF CUBA[1]

J. WHITNEY LEWIS[2]
Havana, Cuba

ABSTRACT

Cuba is regarded as an important though untested oil reserve. A large portion is underlain by a column of conformable unmetamorphosed Jurassic, Cretaceous, and Tertiary sediments. These include limestones with lesser portions of shale, sandstone, and conglomerate. The surface formations apparently reflect the structure of those which lie at greater depths. Adequate source material, reservoir beds, and structure for the formation and accumulation of petroleum are present. In several instances large oil accumulations have been dissipated by surface evaporation through post-Tertiary fissures. It appears that several of the large unfissured and untested anticlines may contain equally important intact and exploitable accumulations.

Though serpentine occurs in large areas, most of it is of late Tertiary intrusion, occurring, almost entirely, as dikes and surface flows and not as masses below folds or a material component of the pre-Jurassic basement. Its only relation to petroleum occurrences is that in certain cases both serpentine and oil have escaped from their respective reservoirs to the surface through the same late Tertiary fissures.

INTRODUCTION

Cuba is one of the few large untested possibly oil-producing areas that are sufficiently near American markets to deserve the consideration of operators who are interested in reserves that can be obtained in large tracts, on reasonable terms, and without drilling obligations.

The geology of the island, though complicated by the lithologic similarity between formations of different ages, can be satisfactorily detailed if a reasonable amount of time is allowed. For such work some knowledge of micropaleontology and tectonic principles is indispensable.

[1]Presented by title before the Association at the Oklahoma City meeting, March 26, 1932. Manuscript received, March 20, 1932.

[2]Consulting geologist, 5823 Monticello Avenue, Dallas, Texas.

A hurried "birds-eye view" of the island is generally a waste of time and money, which leaves the geologist bewildered and inclined to echo the unsound premises and pessimistic conclusions published many years ago before the development of micropaleontology.

Cuba is situated adjacent to the southern portion of the Atlantic seaboard. It has excellent roads, railroads, and shipping facilities. Cities and towns having good hotel facilities are situated at frequent intervals. Fuel and water are available at most points. Excellent skilled and unskilled labor is plentiful. The climate is subtropical. The Cuban Government claims that the island has the lowest death rate in the world. Geologic and geophysical field work and drilling operations there should be no more costly than those conducted in the United States.

Mountainous regions in the eastern, the central, and the western portions of the island occupy approximately one-fifth of its area. The remainder is prairie and plain of comparatively low elevation, which, however, in many places exhibits sharp relief.

There is a line of low hills extending with comparatively few interruptions along most of the northern coast, and another which extends through the east-central portion of Havana Province into western Matanzas Province. Approximately one-third of the island is in cultivation.

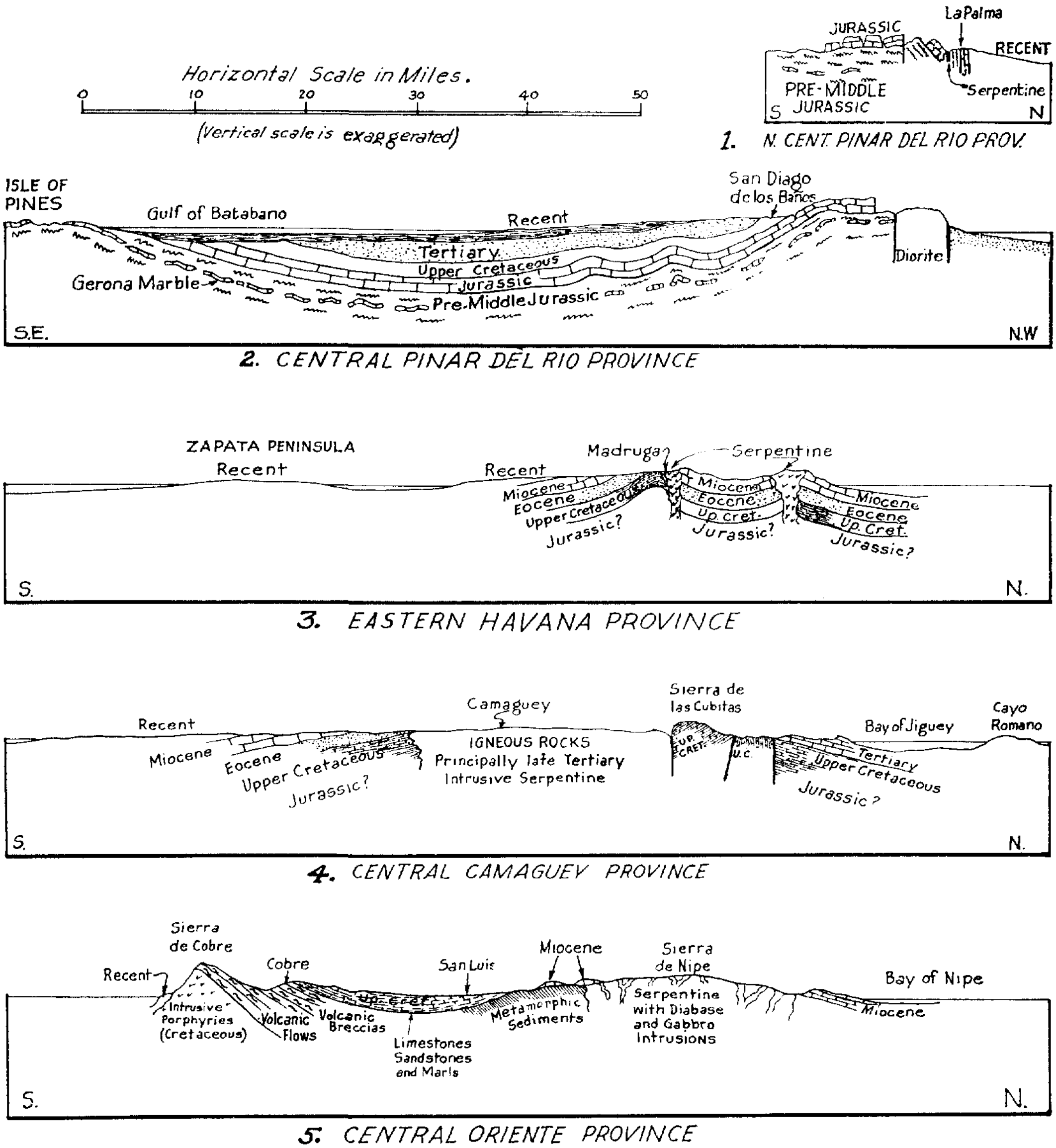
SEDIMENTS

BASEMENT

Schists, slates, granites, gniesses, and lesser portions of serpentine and metamorphosed limestone are the oldest rocks which have been observed on the island and constitute the basement upon which the post-Middle Jurassic sediments were deposited.

Pinar schist.—The most frequently observed component of the basement is the "Pinar schist." This is composed of yellowish friable mica schists and reddish shale slates with occasional thin beds of blue and brown sandstone and limestone. These rocks are a metamorphosed shale series. All are intensely faulted and folded. A sparse growth of small pine trees is characteristic of exposures of this formation and such areas are locally called pine lands or "Pinares."

These schists, covered by a thin mantle of Tertiary gravel, compose most of the Isle of Pines. They also occupy most of the northwest half of Pinar del Rio Province, where they extend throughout the broad, hilly region between Guane and the northwest coast, and can be traced continuously eastward through the valleys between, and the foothills



Horizontal Scale in Miles.
0
10
20
30
40
50
(Vertical scale is exaggerated)
JURASSIC
La Palma
RECENT
PRE-MIDDLE JURASSIC
Serpentine
S
N
1. N. CENT. PINAR DEL RIO PROV.
ISLE OF PINES
Gulf of Batabano
Recent
San Diago de los Baños
Tertiary
Upper Cretaceous
Jurassic
Gerona Marble
Pre-Middle Jurassic
Diorite
S.E.
N.W.
2. CENTRAL PINAR DEL RIO PROVINCE
ZAPATA PENINSULA
Recent
Recent
Madruga
Serpentine
Miocene
Eocene
Upper Cretaceous
Jurassic?
Miocene
Eocene
Up. cret.
Jurassic?
Miocene
Eocene
Up. Cret.
Jurassic?
S.
N.
3. EASTERN HAVANA PROVINCE
Recent
Camaguey
Sierra de las Cubitas
Bay of Jiguey
Cayo Romano
Miocene
Eocene
Upper Cretaceous
Jurassic?
IGNEOUS ROCKS
Principally late Tertiary
Intrusive Serpentine
UP. CRET.
U.C.
Tertiary
Upper Cretaceous
Jurassic?
S.
N.
4. CENTRAL CAMAGUEY PROVINCE
Sierra de Cobre
Recent
Cobre
San Luis
Miocene
Sierra de Nipe
Bay of Nipe
Intrusive Porphyries (Cretaceous)
Volcanic Flows
Volcanic Breccias
Up. cret.
Limestones Sandstones and Marls
Metamorphic Sediments
Serpentine with Diabase and Gabbro Intrusions
Miocene
S.
N.
5. CENTRAL ORIENTE PROVINCE

FIG. 1

on either flank of the Jurassic limestone mountains, the two ridges which lie between Pinar del Rio and Vinales, and the hills lying between the Organos Mountains and the north coast. They appear in small patches as far east as Martin Mesa in Pinar del Rio Province.

It is estimated that at least 10,000 feet of this formation is exposed in the section between Vinales and the north coast near the town of Cayetano. DeGolyer has called this exposure the "Cayetano formation" (3).[1] Similar pine-land schists are also exposed over a large area in the eastern portion of the Trinidad Mountains in Santa Clara Province.

Gerona marble (1).—Within the Pinar schists are one or more gray and blue marble members which range up to 250 feet in thickness. The most prominent occurrence of this member is near the town of Nueva Gerona in the Isle of Pines. Another extends in a narrow belt in an east-west direction through the schist area north and northwest of the town of Pinar del Rio. This may be seen on the road between Pinar del Rio and Guane and again on the road between Pinar del Rio and Vinales.

A belt of pre-Cretaceous metamorphic rocks skirting the southern flank of the Sierra Nipe in Oriente Province is mentioned by Hayes *et al.* (1), and steep-dipping pre-Jurassic schists in the Guatanomo basin in Oriente Province are reported by Darton (12).

Igneous portions of the basement probably occur in the north-central part of the Pinar del Rio Province. Granitic portions of the basement are exposed in contact with the overlapping Cretaceous and Tertiary sediments in the northern and western foothills of the Trinidad Mountains, and at several points within the serpentine mass in Camaguey Province. Some of the unclassified igneous rocks of the mountainous portions of Oriente Province may also belong to the pre-Middle Jurassic.

Many of the streams which traverse the basement carry clean quartz sands and gravels which indicate that porous clastics are probably present in such portions of the overlying sediments as are situated favorably with respect to old shore lines.

Vinales limestone (3).—Exposed in the mountains of Pinar del Rio is a series of approximately 2,000 feet of massive limestone which rests unconformably upon the base-leveled schists. This limestone is blue in color and saturated with petroleum residues in most places observed. It is not crystalline, but is cut by numerous calcite-filled veinlets. Well preserved ammonites (genus *Idoceras*) occurring in this formation conclusively identify it as Jurassic (2).

[1]Numbers in parentheses refer to list of references at end of paper.

These limestones show very few interruptions of sedimentation; however, organic shales which apparently belong near the top of the series were observed north of Candelaira and again in a small outcrop at a serpentine contact near Martin Mesa. These limestones are very soluble and contain numerous caverns and solution cavities. It is, therefore, probable that the eroded surface of this formation, where buried by younger sediments, is extremely porous. This limestone is believed to underlie the younger rocks in most parts of the island and to be the source of most of the oil and asphalt that occur in the seeps and such pools as may be present.

Barnum Brown and Marjorie O'Connell (9) have described the Jurassic column exposed in Pinar del Rio in considerable detail, identifying a sufficient number of fossils to subdivide it into its European and Mexican, Middle and Upper Jurassic equivalents.

They state that this series was deposited in a sea which encroached from the west. According to them, a thickness of 2,000 feet was deposited in the region north and west of Vinales from which the formations overlap and feather out toward the east until approximately 300 feet of the youngest portion of the series is all that remains in the east portion of the province. They believe that it is not present farther east than Pinar del Rio Province.

Artemisa limestone.—Blue-black shales and limestones containing ammonite aptychi appear in the mountains northwest of Artemisa. The total thickness of these rocks is unknown, but at least 300 feet is exposed. These rocks may be of either Cretaceous or Jurassic age. The writer is inclined to the latter view. He is also inclined to believe that the Jurassic limestone continues much farther eastward than the previously mentioned writers estimate.

Most of the contacts between the Jurassic limestone series and the underlying schists are soil covered. However, excellent exposures of this contact may be studied in the section from La Palma southward into the Organos Mountains and on the road between this point and Vinales, where considerable Jurassic limestone float occurs above the Cayetano formation.

Two deep wells were drilled south of the Organos Mountains, one at Taco Taco, and the other near Candelaria. The former was drilled to 3,161 and the latter to 4,015 feet (20). The logs of both these wells indicate that they were drilled through Tertiary and Cretaceous limestones and marls, next encountering more than 1,000 feet of Jurassic limestone, and finally entering typical Pinar schists.

It is important to note that a limestone soil extends, from most of the Jurassic limestone areas, for a considerable distance over the schists and also that schist outliers or patches of soil, which would support the growth of pine trees, are nowhere known to occur above the Jurassic limestone.

Large blocks of blue, petroliferous limestone, which lithologically resembles the Jurassic, are included within serpentine intrusions in the eastern portion of Havana Province and at a number of similar points in Matanzas Province.

In the Menendez well of the Cuban Oil Company, in the northeastern portion of the Matanzas Province, 350 feet of granite arkose containing some bits of serpentine was first encountered, then a limestone from 350 feet to 2,385 feet. This limestone resembled lithologically the Jurassic of Pinar del Rio and was impregnated with asphaltic residues from 1,115 feet downward.

At least 600 feet of dark blue petroliferous limestones cut by veinlets, which are probably Jurassic, occurs on the western flank of the Trinidad Mountains above the basal arkose and igneous masses. Also blue limestones, which may be of Jurassic age, are reported near Trinidad (1). Occurrences of gray limestones containing Jurassic ammonites are reported north of Holguin at a point 3 kilometers east of Central Santa Lucia in Oriente Province (19). Hills of what is probably Jurassic limestone occur within the serpentine area east of Holguin. Also Jurassic limestones are reported to be present in the steep mountains at the extreme east end of the island (19). The writer does not know of any occurrences of Lower Cretaceous sediments in Cuba.

UPPER CRETACEOUS

Basal conglomerate.—The oldest phase is probably the equivalent of the Texas Woodbine. The basal portion of the Upper Cretaceous consists of a conglomerate and sandstone series which rests unconformably on the eroded older rocks and probably overlies most of the Jurassic of the central and western portions of the island. In many places it contains a large percentage of igneous material and much of it is arkose. South of Santa Clara, above the granite and underlying the Cretaceous, and also west of the Trinidad Mountains overlying the Jurassic limestone, several hundred feet of this arkose was observed. The 350 feet of granite arkose found in the Menendez well mentioned previously, is another occurrence. This was probably derived from granite of the ancestral Trinidad mountain land mass. In Pinar del Rio Province it contains

considerable felspathic sand. In this province its exposures are of the same age as that of the El Cano formation.

Havana shales (3).—In Havana and Pinar del Rio provinces the lowest member of the Cretaceous that is exposed is a series of thin-bedded dark green to light gray shales and sandy shales which are composed largely of volcanic ash. This material is not sufficiently plastic to be used satisfactorily for rotary fluid. It crops out in the regional uplift along the north coast of eastern Pinar del Rio, again in the city of Havana, and eastward in the province. It is encountered in most of the deeper wells drilled in Havana Province, in several of which, at least, 2,000 feet was penetrated. It is not known to be present east of Havana Province.

Madruga chalk—Luyano of DeGolyer (3).—Overlying the Havana shale near Madruga and also in the city of Havana and eastward is a series of white chalks and marls with occasional white shales and grits. Near Madruga 800 feet was observed and a thickness of 2,000 feet was encountered in the Sage well, 20 miles west. It also appears above the Havana shales in Havana and also at Mariel, Cabanas, and Bahia Honda in Pinar del Rio Province.

El Cano formation—Lucero of DeGolyer (3).—Above this is a series of thin-bedded clay shales, sandy shales, micaceous sandstones, sandstones, and conglomerates, with occasional thin limestone members. They are yellow to ochre in color and friable.

This formation is composed principally of material that apparently was derived from the Pinar schists. However, there is a large percentage of serpentinic material in some of the occurrences in Havana Province. One of these, encountered in a well, consists of reconsolidated water-lain clastic serpentine which would be considered a serpentine sill were it not for the presence of numerous well preserved foraminifers (21).

At Madruga this series is 200 feet thick. It increases in thickness westward to Pinar del Rio, where 1,000 feet is observed in the northeastern portion of the province. This formation is exposed in a narrow belt rimming the eastern portion of the mountains of Pinar del Rio and extending throughout a large portion of the northeastern part of that province. It reappears at intervals along the crest of the anticline which extends along the northern coast of Havana Province, again near Baldspot dome, and also rimming the chalk at Madruga. No occurrences have been observed east of Havana Province.

CRETACEOUS EAST OF HAVANA PROVINCE

The Cretaceous rocks of Havana Province can not be traced continuously eastward. However, limestones containing Cretaceous fossils crop out intermittently along the major lines of deformation in Matanzas Province and eastward. Such occurrences were observed near the serpentine contact southwest of Cardenas and again near serpentine intrusions in the central part of Matanzas Province. The north coastal hills which extend from the eastern part of Matanzas through Santa Clara and just over the line into Camaguey Province, as well as the mountainous northeastern portion of Santa Clara Province, are composed of Cretaceous limestones. A total thickness of more than 6,000 feet of this section has been measured. These rocks contain so many faults that continuous sections are extremely rare. The lowest portion of this appears to be a 2,000-foot or perhaps much thicker series of white, hard oölitic limestone of undetermined age. Above this a limestone conglomerate of less than 200 feet in thickness is in some places, though not everywhere, encountered. Above this is a 3,000-foot series of blue and gray organic limestone. These rocks are cut by a network of calcite veinlets. A great portion is petroliferous. Ammonite aptychi are present in many places. This series appears to be the equivalent of the Artemisa limestone. Overlying this is an 800-foot series of limestone breccia. This is composed of angular fragments of white limestone and serpentine pebbles in a matrix of hard, white, pure limestone. Portions of this appear to be sufficiently porous to serve as reservoir beds. Above this is 1,000 feet of gray to blue crystalline limestone which contains Cretaceous foraminifers.

Cretaceous limestones overlie a considerable area of granite arkose south of the city of Santa Clara and also cap some of the foothills of the Trinidad Mountains.

The limestones which compose the Cubitas Mountains, which extend parallel to the coast in the northern part of Camaguey Province, seem to belong to this series. Fragments of these limestones ranging up to a kilometer in length are included within the serpentine areas of Camaguey and western Oriente provinces. Cretaceous pyroclastics and limestones are reported on the northern flank of the Sierra Maestra in Oriente Province. Also the lignite series which occurs in the upper Cauto Valley is probably of this age (1).

EARLY TERTIARY

Bejucal formation.—Conformably overlying the Cretaceous in Havana Province is a series of very uniformly bedded limestones and

marls, with some shales in the lower portion. The beds average 3 feet in thickness. The color of this series varies from pale green to white. It weathers to a black soil. It is exposed over a large area in the central part of Havana Province, where approximately 3,000 feet is exposed. There are also exposures of this formation in the northwestern part of Matanzas Province. It is extremely difficult to find fossils in this formation. However, a few Eocene foraminifers have been found in the middle portion.

Most of the plains northwest of the Trinidad Mountains and a narrow belt along the north flank of the eastern portion of the coastal range in Santa Clara Province are covered by white and yellowish marls, limestones, and calcareous sands, many of which are very fossiliferous. Numerous megascopic foraminifers indicate that the age is Eocene. Where this formation overlaps the serpentine west and northeast of Santa Clara, thin-bedded white chalks and marls predominate. Above these, thick beds of fossiliferous yellow limestone appear. In the northwestern portion of Santa Clara Province a maximum thickness of 5,000 feet has been measured. Yellowish Eocene marls and limestones occupy a broad belt along the southern contact of the central serpentine mass of Camaguey Province and also south and southeast of the serpentine mass in northern Oriente Province. They occur along the north foothills of the Sierra Maestra, in the plateau country south of Sierra Nipe, and also around the bays of Santiago de Cuba, Guantanamo, Baracoa and some of the other re-entrants of the coast.

Overlying the Eocene in several localities are limestones which are very similar to the members just described, but which contain foraminifers that are diagnostic of the Oligocene. These can be differentiated only by most painstaking micropaleontology.

MIOCENE

Yumeri limestone (3).—An extremely porous and cavernous thick-bedded limestone series rests unconformably upon the older formations. A maximum thickness of 1,700 feet has been observed. This limestone is very hard and brittle. It is white and gray in color. However, it weathers into a highly ferruginous deep red soil which covers many of the broad valleys and plains. Many of the denuded exposures weather into very sharp points and ridges which are locally known as "*dientes de perro.*" West of the Trinidad Mountains this limestone contains thick conglomerates which are composed of water-worn igneous and limestone pebbles, and elsewhere, many limestone boulders and conglomerates

occur near the base of the series. Portions of this series contain numerous Miocene foraminifers.

This formation is well exposed in the Yumeri Valley near Matanzas. It skirts most of the coast, in places forming a line of low but sharply rising coastal hills. It also caps many of the highlands of older formations at interior points.

Gypsum occurs in the upper part of this formation at several points in the Yumeri Valley. There are also several outlier hills along the northwest coast of Camaguey Province which are composed of gypsum. These may represent a condition of landlocked lagoons.

PLEISTOCENE

Lying unconformably upon the older formations, at many points near the coast, are comparatively thin deposits of coral limestone containing Pleistocene fossils. Many of these deposits occur on the ocean terraces, which may be observed on the hills surrounding Matanzas Bay. Some of these terraces are at least 300 feet above sea-level. Similar Pleistocene terraces of lesser elevations have been noted at many other points along the coast.

QUATERNARY AND RECENT

Generally speaking, there are no broad alluvial valleys, most of the soil being derived from rocks in place. The principal exception is the broad central valley of Oriente Province, which is composed of sand, silt, and gravel from the surrounding mountains. Most of the areas of yellow and black soil in the central part of the island contain enough boulders of Eocene rocks to clearly identify the underlying formations, and the red soil with fragments of Miocene limestone is equally characteristic. The entire coast of the island, including the broad belts of swamp land, the islands and the shallows between them, and the mainland, is composed of recent corals and marls. Mangrove swamps and peat bogs are extensively developed in these areas. Almost all of the beach sands consist of lime fragments and foraminifers. The only silicious sands that were observed occur near the mouths of streams which cross igneous areas or the basement complex. The most noteworthy of these are the micaceous quartz sand beaches of the Isle of Pines.

Recent, though inactive, volcanic cones and large areas covered with volcanic bombs and ash may be observed near Holguin and Sancti Espiritus.

The great areas of surface replacements were developed in this period. These include the iron gossans of Diaqueri and Sierra Nipe in

Oriente Province, the iron and manganese replacements of the plains of Camaguey, Santa Clara, and Matanzas provinces, and the gossan of the northwest foothills of Pinar del Rio Province. Also most of the metalliferous veins occurring in all of the provinces are due to secondary enrichments that took place since the close of the Tertiary.

IGNEOUS ROCKS

Granites and serpentine belonging to the basement complex occur in a belt of frontal hills near the north coast east of Esperanza in Pinar del Rio Province, again south of Santa Clara in the Trinidad mountain region, and possibly within the great igneous mountainous region of eastern Oriente Province.

Granites which may belong to the basement appear at the town of Camaguey and elsewhere within the serpentine mass of Camaguey Province.

Rhyolites overlain by rhyolite flows and pyroclastics which grade upward into limestones of Cretaceous age form the Sierra Maestra in Oriente Province.

Stocks and elongated exposures of serpentine and chlorite appear at intervals along faults throughout the northern portion of Pinar del Rio, Havana, and Matanzas provinces. Very large masses of serpentine occur in the hills southwest of Coliseo, Matanzas Province. Other large areas of serpentine occur northwest and northeast of the Trinidad mountain system, and a great belt of serpentine extends through the center of the southeastern two-thirds of Camaguey Province and eastward into Oriente Province. Another mass extending east and west covers the region near Holguin. The commercially important chromite deposits of Matanzas and Camaguey provinces occur as magmatic segregations in these serpentine masses. This would indicate that these masses are denuded laccoliths.

These intrusions have been cut by secondary intrusions of igneous rocks of every description ranging from pegmatite to obsidian in texture. Many of these serpentine masses include large fragments of Jurassic and Cretaceous rocks. Limestone blocks several hundred meters in length have been observed on edge within the serpentine mass of Holguin and very large blocks of Cretaceous rocks have been noted in the serpentine mass of Camaguey. The smaller intrusions in many places cause very steep tilting of the late Cretaceous and early Tertiary beds at the contact.

At Cumbre and at a number of other points well within the serpentine mass large deposits of asphalt occupy vertical fissures.

The writer is therefore inclined to believe that an important portion of the serpentine-covered areas is underlain by Jurassic and Cretaceous sediments. It appears probable that most of the serpentine reached its present position by traveling vertically through comparatively narrow dikes, then spreading either as laccoliths and sills at some zone above the Cretaceous formation, or as flows at the surface.

METAMORPHISM

There appears to be no metamorphism of the post-Paleozoic sediments which is due to the depth at which they were buried or the degree to which they were deformed.

There has been regional replacement by chert and hematite over great areas of pre-Jurassic rocks in the northwestern Pinar del Rio Province and over most of the serpentine areas in Havana, Matanzas, Santa Clara, Camaguey, and Oriente provinces. In many places it is extremely difficult to determine the exact nature of the original rocks. This is especially true of the plains of Camaguey, where chert and hematite sinters cover great areas.

The hydrous silicates forming many of the intrusive masses, notably in the northern portion of Havana Province, are varied in color and of characteristic structure due to their hydrothermal genesis. However, these can not be classed as altered sediments.

There is some contact metamorphism of the limestone blocks included within serpentine masses and the sediments immediately adjoining the larger intrusions, but this condition scarcely anywhere extends more than a few feet beyond the contacts.

It seems probable that the fluids, which were contained in such porous beds as were penetrated by the dikes and stocks, were heated sufficiently at the contacts to generate vapors of sufficient pressure to force the fluids away from the contacts until the intrusions cooled. During the cooling and the formation of the secondary fissures, these vapors condensed and the fluids re-occupied the original openings and such cracks and fissures within the intrusive rocks as were connected with the original porous sediments. In places where fissures extended from petroleum accumulations to the surface, oil migrated upward, filling the crevices and fissures and escaping until the openings were sealed by residues. Such petroleum as was lost was dissipated into the air by evaporation or burning.

There is no indication that any of the original petroleum content of the sediments was lost by some underground destructive process.

The occurrence of naphtha at Motembo is especially interesting in that pure colorless naphtha is encountered in wells near the center of the serpentine mass, while light-gravity brown crude oil is found in those on the edge.

STRUCTURE

No attempt will be made to describe the detailed structure of specific areas. However, the principal trends of deformation and their characteristics will be presented.

Superimposed upon the geanticline of the island are a number of long trends of structural weakness that roughly parallel its geographic axis. Along these are a number of long and in many places broad anticlines, many of which occupy topographic highs. Their flanks are generally of uniform dip and apparently composed of unfaulted sedimentary segments. The crests are generally faulted and where incompetent beds crop out along them the dips are generally steep. The strikes of the faults are parallel with the axes of the folds and there is generally little or no throw. In areas of compression where the less competent beds are exposed there are a number of local faults of small horizontal persistence which probably are entirely superficial.

In general, it is believed that the surface rocks reflect the structure of the underlying formations. Indications of the development of important deformation within the post-Jurassic sediments before the end of the Oligocene are conspicuously absent, for in the areas of steep dip the Eocene rocks are generally tilted almost as steeply and in the same direction as the Cretaceous. There are even many exposures of the Miocene which dip at very steep angles, which indicates that an important portion of the deformation of the entire post-Jurassic column took place at the close of the Tertiary.

In this connection, a conformable sequence of Cretaceous, Eocene, and Miocene sediments may be observed along the central highway west of the town of Madruga in Havana Province, and another on the east side of Mariel Bay.

Many of the contacts are soil-covered and there are numerous instances where steeply dipping older beds are faulted into contact with more gently dipping younger beds. However, in all of the instances observed by the writer, the younger beds did not contain material derived from the older beds or the clastics which one would expect in an overlap.

Serpentine intrusions occur in many places along the folds, but are by no means general. There are several folds from 5 to 20 miles in length, along which no igneous rocks are exposed.

The most noteworthy structural trend is the chain of écheloned faulted anticlines which extends close to and parallel with the north coast for almost its entire length. Through the center of the island is another which appears in the mountains of Pinar del Rio, also in the center of Havana and Matanzas provinces, and continues eastward through the central serpentine areas of Santa Clara, Camaguey, and Oriente provinces. The structure of the eastern half of Santa Clara Province is complicated by regional dips away from the Trinidad mountain uplift. South of this trend the Cauto Valley of Oriente Province forms a broad westward-dipping syncline, south of which is the northward-dipping monocline of the Sierra Maestra which ends in the profound fault of the south coast.

GEOLOGIC HISTORY

The pre-Jurassic basement, where exposed in Cuba, the Isle of Pines, Haiti, and Puerto Rico, is composed of metamorphic sediments with smaller amounts of igneous rock, all of which are highly folded and faulted. It appears to be the base-leveled remnant of a land mass that once stood high above sea-level, for many exposures of granites and pegmatites are found which could form only at great depths.

During the Jurassic the portion of the basement lying east and south of Cuba probably remained close to sea-level, while that of the region now including Cuba and the Isle of Pines subsided with comparative uniformity and a slight northwestward inclination. Except for basal conglomerates, few if any clastics interrupted the lime deposition, and it is presumed that there were few, if any, elevated land bodies near by. Apparently the seas were sheltered and generally very shallow and vegetation was plentiful, for almost the entire series contains organic material. The total subsidence appears to have been at least 2,000 feet in the western portion.

This was followed by a gradual and uniform emergence of a great area which included Cuba and the shallow waters near by. The Trinidad mountain region seems to have been elevated at least 2,000 feet more than other areas, for south of Santa Clara the Jurassic limestone is absent. The land was completely base-leveled and a gradual submergence commenced at the end of the early Cretaceous. This was characterized by a tilting of the ocean floor away from the Trinidad Mountains both on the west and on the north and northeast. The marked

thickening toward the west, in Havana Province, of the Upper Cretaceous members is evidence on this point and is also indicative of the fact that lines of weakness and consequent tendencies toward deformation during this period were parallel with the old shore line and not with the present axis of the island. The first actual submergence, in this period, of the area which is now Cuba was the development of a broad embayment in Havana and northeastern Pinar del Rio provinces, and the deposition of the Havana shales. It appears that the remainder of the island and a great area south and east were at that time above water.

It seems probable that at the beginning of this period, volcanoes appeared immediately south of the Sierra Maestra region and extruded the rhyolite that composes most of the range. The only other evidence of vulcanism at the beginning of this period is the volcanic ash of the Havana shales, which evidently was derived from near-by submarine or terrestrial vulcanism. Subsidence continued without important interruption until the entire ancestral land mass was submerged, with the accompanying deposition of the Madruga chalk and the limestones of the areas east of Havana Province.

There is little, if any, direct evidence of vulcanism during the deposition of the Madruga chalk. However, at the end of this period several areas must have been elevated above sea-level and a number of volcanoes developed, for certain members of the El Cano formation are dominated locally by volcanic material which is intimately mixed with unaltered foraminifers. The El Cano formation, especially its western portion, is clearly derived from the Pinar schists, and land bodies in the area lying south of the present position of the island were probably present. The Trinidad mountain region probably also emerged, for the El Cano formation does not appear in that vicinity. The continued westward tilting of the ocean floor in Havana Province is evident from the westward thickening of the El Cano formation.

It appears that the deposition of the Cretaceous rocks kept close pace with the subsidence and that the seas were always relatively shallow.

A slight emergence followed this deposition. That this elevation and subsequent erosion were unimportant is indicated by the fact that the succeeding formations consist principally of marls and limestones rather than of clastics.

This emergence was followed by the gentle and continuous regional submergence of the Tertiary.

The great thickness of Eocene and Oligocene limestones in both Havana and Santa Clara provinces indicates a general subsidence, with

a continued tilting both northward and westward from the Trinidad mountain region, which probably remained slightly above sea-level. It also appears that the western portion of the Pinar del Rio Province and the Isle of Pines were above water during the first part of the Tertiary and that these areas subsided with a northeastward tilting.

Through the Cretaceous and the early Tertiary there seem to have been no noteworthy interruptions of the subsidence other than occasional oscillations of the shallow seas, for very few, if any, important angular unconformities are observed. All of the evidence now available indicates that up to this time there were no shore lines with consequent zones of weakness and lines of folding parallel with the present axis of the island.

The first important deformations of the post-Paleozoic sediments and the first important intrusions of serpentine appear to have occurred at the close of the Oligocene.

At this time an entirely new set of tectonic stresses began to develop, the building of the present mountain systems commenced, and for the first time Cuba and the Isle of Pines began to emerge from the seas in their present forms.

The nature of the platform on which the Cretaceous rocks were deposited was the dominant factor influencing the type of structure and vulcanism that developed in western Cuba. This platform consisted of a thickness in excess of 10,000 feet of incompetent mica schists, slates, and occasional limestones and sandstones, which were highly contorted and shattered before the Jurassic deposition. Over these was a continuous bed of hard Jurassic limestone, averaging 2,000 feet in thickness, and of almost continuous depositional sequence containing very few shale partings or other planes of weakness for the internal adjustment of stresses.

The manner in which this platform reacted to the late Tertiary and post-Tertiary stresses can be studied in considerable detail in the mountains of Pinar del Rio, where the Jurassic limestone has adjusted stresses by breaking into very large blocks, almost all of which are considerably greater in both length and breadth than its thickness. In most cases these are more than a kilometer wide and several kilometers long in an east-west direction. As this is the point of maximum elevation of the Jurassic, it is logical to infer that structural conditions there observed are similar to, though much more intense than, those of the portions which underlie the island toward the east.

The compressional stresses acting in a north-south direction were relieved by long east-west-trending faults in the competent Jurassic platform. These probably extended to great depths, many of them to the molten rocks, and also caused the type of deformation observable in the comparatively incompetent overlying formations.

It seems probable that the conglomeratic basal members of the Cretaceous were subjected to no contortion whatever during these deformations, and that the overlying Cretaceous and Tertiary rocks were but little disturbed other than being tilted with the fault blocks of the Jurassic, and sharply upturned locally at contacts with intrusions. Near the crests of such anticlines as developed above these faults, considerable purely superficial local faulting and steep inclination naturally took place.

It seems probable that the network of veinlets, which characterizes much of the Jurassic limestone, was formed at this time, and that these openings were sufficiently continuous to permit the migration of petroleum from the limestone to such overlying reservoir beds as were present. This probably took place before the veinlets were filled with calcite by the lime-saturated water which followed the oil in its upward movement.

It would appear that most of the serpentine which reached the surface consisted of comparatively narrow dikes and stocks along the fissures in the Jurassic limestone which became irregularly greater in width as they approached the surface, occasionally intruded as sills in the less competent members of the Cretaceous and Tertiary, and some of which spread as broad flows at the surface. In some of the larger intrusions the cooling of the serpentine seems to have caused a shrinkage of the masses which resulted in a tilting toward the contacts of the sediments immediately adjacent, even though the regional dips are away from the intrusions. In both Santa Clara and Camaguey provinces the Cretaceous rocks adjoining the serpentine masses on the north have steep dips toward the contacts, though the dips near the coast are generally northward. This is thought to be due to the subsidence of the areas immediately adjoining the intrusions into the deep-seated reservoirs of molten rock from which the serpentine was extruded. In other words, a phenomenon appeared similar to that which forms the rim synclines of salt domes.

The post-Oligocene emergence and erosion was sufficient to remove a great thickness of Eocene sediments from the regions of uplift along the north coast and also much of the Cretaceous from the mountainous parts of the island. Portions of the ancestral Organos Mountains

and the ancestral Trinidad Mountains may have been denuded to the Jurassic limestone and other portions to the Pinar schist.

During the Miocene the entire island, with the exception of the Organos Mountains, the Trinidad Mountains, the Sierra Nipe, the Sierra Maestra, and a few isolated peaks along the axis of the island, was submerged and reef limestone, marls, and limestone conglomerate, reaching, in some places, a thickness of 1,700 feet, were deposited, overlapping the slightly folded and eroded older formations. The gypsum deposits of the north coast were formed in land-locked lagoons during this period.

At the end of this period further deformation, of the same character as that which followed the Oligocene, took place. Many of the fissure systems and incipient folds developed into more steeply folded anticlines with faulted crests, and additional intrusions of serpentine and other igneous rocks occurred. From the relatively slight discrepancy of dip between the Miocene and older rocks in many of the folds, it appears that in many instances most of the deformation and intrusion of the post-Paleozoic sediments occurred at the end of the Miocene. The fact that many oil seepages occur in Miocene rocks is further evidence that a large part of the deformation took place at the close of the Tertiary. At this time the island emerged to approximately its present position.

Several oscillations of the island and important movements along the old lines of weakness have continued from the Miocene to the present. Horizontal Pleistocene terraces, some of which are several hundred feet above sea-level, indicate that the island was submerged and elevated several times without material tilting. These oscillations are probably related to the withdrawal of water from the ocean during the periods of continental glaciation. The mountains of Oriente Province and the great Bartlett Deep south of the island appear to have developed simultaneously in the latter part of the Pleistocene or possibly even Recent time. These mountains appear to be among the youngest and best defined fault-block mountains in the world. In fact, many of the fault scarps in this region are of such recent origin that no appreciable talus has formed (16). Recent severe earthquakes in this region are further evidence of movement along these faults. These faults seem to be due to the vertical movements of large blocks of the earth's crust and not to compressional forces.

Recent corals occurring far inland indicate that just before the last emergence of the island, a branch of the sea extended through the Cauto

Valley to the Bay of Nipe, separating the area on the southeast from the rest of the island. The recent, though extinct, volcanoes in the central and eastern part of the island and the live-oil seepages which occur in every province also indicate comparatively recent movements.

Post-Tertiary erosion has removed much of the Tertiary sediment, especially from areas of uplift, in many places exposing the Cretaceous rocks on the structural highs.

SURFACE OCCURRENCES OF PETROLEUM AND DEVELOPMENT

Numerous petroleum occurrences, including clear naphtha, oils resembling Mid-Continent crude, heavy asphaltic oils, and hard gilsonite are found in every province of the island. In most instances these are clearly related to fissures which extend to petroleum accumulations in sedimentary rocks. Generally the petroleum appears to have migrated upward from reservoirs close to the Jurassic limestone or possibly from source and reservoir beds in the younger sediments. The fissures developed in serpentine intrusions, due to shrinkage after cooling, have in some places acted as avenues of migration between oil accumulations in the sediments penetrated and the surface, and also as reservoirs of minor importance. Such serpentine or other igneous rocks as appear near seepages are generally incidental to the fissure systems and in no way related to the seepages. Most of the seepages appear to be of Quaternary origin, for asphalt deposits observed in mines are laminated horizontally, with little, if any, indication of vertical flow structure, which indicates that they have not been subjected to appreciable lateral compression since they were formed.

An excellent description of the better known surface occurrences of oil and asphalt on the island is already available (3). Space does not permit either its repetition or a detailed description of the exploitation of and prospecting for petroleum which has taken place. There are at least thirty asphalt mines that have been operated in the past. Two are being exploited at the present time. In one of these, the Mariel mine in Pinar del Rio Province, more than 1,000,000 metric tons of gilsonite has been proved by mining and core drilling.

Light oil is being obtained from many shallow wells in a serpentine mass at Bacuranao, 15 miles east of Havana, and colorless naphtha is being produced from a similar area at Motembo, in the northeastern part of Matanzas Province. The daily production from each area is less than 50 barrels. Approximately 20 wildcat wells have been drilled in the western half of the island, principally in Havana Province, but prac-

tically none of these was located favorably, from a geologic standpoint, nor drilled to a depth that would adequately test the formations. In most cases where geologists were employed, the wells were shifted to locations other than those recommended, because of the ownership of concessions, and in practically no instances were they drilled to the recommended horizons.

These surface occurrences of oil and asphalt are evidence that, at the close of the Tertiary, there existed widespread sedimentary and structural conditions which caused the formation and accumulation of large petroleum deposits, some of which were partially or totally dissipated through fissures.

The logical inference is that some of the unfissured anticlines still contain important deposits.

ACKNOWLEDGMENT

The writer wishes to thank those geologists and mining engineers whose willingness to exchange information and comment has been of real value in the preparation of this paper. He is especially grateful to R. H. Palmer and Mrs. Palmer, H. Larios, W. T. Boulton, J. Hoskinson, R. N. Kolm, and D. McArthur. He would name several others had he their permission.

REFERENCES

1. C. W. Hayes, T. W. Vaughan, A. C. Spencer, "Report on a Geological Reconnaissance of Cuba. Made for the Military Governor" (Government Printing Office, Washington, D. C., 1901).
2. Carlos de la Torre, "Excursion Cientifica a Vinales" (Academia de Ciencias Medicas, Fisicas y Naturales, Habana, Cuba, 1909).
3. E. DeGolyer, "The Geology of Cuban Petroleum Deposits," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 2 (1918), pp. 133 *et seq.*
4. T. W. Vaughan, "Geologic History of Central America and the West Indies during Cenozoic Time," *Bull. Geol. Soc. Amer.*, Vol. 29 (1918), pp. 615-30.
5. ———, "Correlations of the Tertiary Geologic Formations of the Southeastern United States, Central America, and the West Indies," *Jour. Washington Acad. Sci.*, Vol. 8 (1918), pp. 268-76.
6. ———, "Contributions to the Geology and Paleontology of the West Indies" (Carnegie Institution of Washington, 1919).
7. J. A. Cushman, "Fossil Foraminifera from the West Indies." *Carnegie Institution of Washington, No. 291* (1919).
8. Marjorie O'Connell, "New Species of Ammonite Opercula from the Mesozoic Rocks of Cuba," *American Museum Novitates No. 28* (1921).
9. Barnum Brown and Marjorie O'Connell, "Correlation of the Jurassic Formations of Western Cuba," *Bull. Geol. Soc. Amer.*, Vol. 33 (1922), pp. 639-64.
10. Albert Wright, Jr., and P. W. K. Sweet, "The Jurassic as a Source of Oil in Western Cuba," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 4 (July-August, 1924), pp. 516-19.
11. T. W. Vaughan, "Criteria and Status of Correlation and Classification of Tertiary Deposits," *Geol. Soc. Amer.*, Vol. 35 (December 30, 1924), pp. 677-742.
12. N. H. Darton, "Geology of the Guatanamo Basin, Cuba," *Jour. Washington Acad. Sci.*, Vol. 16 (1926), pp. 324-26.

13. Dorothy O. Carsey, "Foraminifera of the Cretaceous of Central Texas," *Univ. Texas Bull. 2612* (March 22, 1926).
14. R. H. Palmer, "Geology of Eastern Hidalgo and Adjacent Parts of Vera Cruz, Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 11 (November, 1927), pp. 1173-1220.
15. Charles Schuchert, "Geologic History of the Antillean Region," *Bull. Geol. Soc. Amer.*, Vol. 40 (1929), pp. 337-60.
16. Stephen Taber, "The Structure of the Sierra Maestra near Santiago de Cuba," *Jour. Geol.*, September, 1931.
17. *Boletin de Minas Nos. 13 and 14* (Dirección Montes y Minas, Republica de Cuba).
18. Von Walther Straub (Bern), "Zur Entstehungsgeschichte des Golfes von Mexiko Ecoglae Geologicae Helvetiae," Vol. 24 (1931), No. 1 (Buchdarucherie Emil Birkhauser & Cia., Basel).
19. H. Larious, Havana, Cuba. Statement to author.
20. A. E. Fath, personal communication.
21. "Orbitoides Palmeri Gravell." *Jour. Paleont.*, Vol. 4, No. 3, p. 269.
22. J. Whitney Lewis, "Occurrence of Oil in Igneous Rocks of Cuba," (Amer. Assoc. Petrol. Geol., 1932). Manuscript for August Bulletin.

DISCUSSION

R. J. METCALF, Fort Worth, Texas (written discussion, March 23, 1932): We believe that Mr. Lewis is in error in describing the schistose shale series in Pinar del Rio Province as a part of the pre-Middle Jurassic basement rocks. This series which has been cal'ed the Cayetano formation by Mr. De Golyer[1] is believed by us to be above the Vinales limestone. The Cayetano beds and the Vinales limestone are exposed in a major structural fold through Pinar del Rio Province and are intensely broken by a system of block faults, causing a complication of conditions which perhaps make the question of their position debatable. However, the areal distribution of the two formations in the western part of the province, where the Vinales limestone occurs near the axis of the fold with the Cayetano beds both north and south of it and having a similar angle of dip, makes it appear quite definite that the Vinales limestone underlies the Cayetano. Definite contact of the two formations as seen in the mountains about 6 kilometers north and slightly east of San Diego de los Banos, where the Cayetano definitely overlies the Vinales, shows little evidence of unconformity between the two formations.

The Vinales and Cayetano formations represent a depositional unit, the massive limestones of Vinales grading into calcareous shales of the lower Cayetano and later into ferruginous shales higher in that formation. Before the deposition of the Cretaceous, this series was tilted westward at a low angle and peneplaned, allowing the Cretaceous to be deposited on Vinales limestone in eastern Pinar del Rio Province, while on the west it rests on progressively younger strata of the Cayetano formation.

We have no definite proof of the existence of Vinales limestone through Havana, Matanzas, Santa Clara, and Camaguey provinces, although a number of folds and uplifts occur which should bring it to the surface if it exists in this area. Isolated exposures which Mr. Lewis mentions as being probably Jurassic are believed to be for the most part Cretaceous limestones metamorphosed by igneous intrusives.

[1]Geology Cuban Petroleum Deposits, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 2 (1918), p. 133.

The position of the Vinales limestone below a series of shales which have undergone such metamorphism as to become schistose in structure makes it appear extremely doubtful whether that limestone can be considered the source bed for petroleum or the asphalt deposits of Cuba. Most of the asphalt deposits are found in Cretaceous beds or in close proximity to beds of Cretaceous age and these are the most probable source of the material.

There is evidence that important deformation along the present system of folding began in late Cretaceous or early Eocene time. The Bejucal formation of Mr. Lewis, wherever observed, is much less intensely folded and faulted than the Cretaceous beneath it and it is fully as thin-bedded and incompetent to resist stresses as the Cretaceous. Exposures of the contact between the Cretaceous and Eocene are rare, but examples of it may be seen about 1 mile west of Madruga in Havana Province and 6 miles northwest of Matanzas in northwestern Matanzas Province. At both of these localities there is evidence of angular unconformity.

J. WHITNEY LEWIS (written reply, April 5, 1932): Just prior to Mr. Metcalf's departure from Cuba in the fall of 1931, he explained his interpretations of the geology of the island to the writer. Following this the writer made a two-weeks' horseback trip through portions of Pinar del Rio Province, visiting the area north of San Diego de los Banos and other contacts along both the southern and northern sides of the central mountain system. The writer is satisfied that his interpretations and reasons therefor, as summarized in his paper under the heading of "Vinales Limestone" and "Artemisa Limestone," are essentially correct.

Especial attention is invited to the well records furnished by Mr. A. Fath and also to the section south of La Palma (Section No. 1) where the geology is simple and beautifully exposed.

Barnum Brown and Marjorie O'Connell (9) have published excellent detailed descriptions and clear photographs of several sections which show the Jurassic limestone resting unconformably on the Cayetano formation. They furnish a photograph of the Cayetano formation where exposed near the town of that name, and state: "The pronounced folding of the underlying schists on which the Oxfordian limestones rest unconformably is well shown on the road to Esperanza north of the limestone mountains." They describe well preserved ammonites, pelecypods, gastropods, fishes, and marine reptiles that occur within the unmetamorphosed Jurassic limestones and shales.

In contrast to these the Cayetano schists are so highly metamorphosed that very few fossils have been preserved. The only definitely known occurrences are poorly preserved casts of fern fronds and spores (resembling Paleozoic types) which were found near the town of Cayetano. At this exposure the schists are on edge, striking parallel with the coast and exhibiting an apparent thickness ranging from 10,000 to 20,000 feet.

The writer does not think it possible that such a great thickness of shale series could be deposited above the Jurassic sediments, then further buried by an overburden sufficiently great to produce schistosity, and finally contorted, without similarly affecting the Jurassic sediments. Moreover, it is difficult to explain how the island could have been elevated sufficiently in early Cre-

taceous time to permit the removal of this great thickness of sediments from the Jurassic now exposed. The absence of schist remnants and soil on the great fault-block mountains of but slightly tilted Jurassic limestone is also significant.

The extent of the Jurassic sediments east of Pinar del Rio Province must of necessity be a matter of speculation until the results of detailed paleontological studies are made public. The writer has already cited one reported occurrence of Jurassic ammonites in Oriente Province.

Regarding what Mr. Metcalf considers as evidence of important deformations along the present system of folding in the late Cretaceous or early Eocene, the writer can only state that numerous personal observations point to the opposite conclusion. The writer has found *Rudista* and other Cretaceous fossils in the area between Madruga and a point 2 miles west, and places the Cretaceous-Eocene conformable contact 1 mile farther west than the point described by Mr. Metcalf. The writer has not studied the area 6 miles northwest of Matanzas. DeGolyer (3) states that this is where the Yumeri limestone (Miocene) attains its greatest development. There would be considerable uncertainty attached to the identification of Eocene formations in this area unless diagnostic fossils were encountered. In fact, stratigraphic relationships in Cuba can be conclusively determined only from unfaulted contacts where diagnostic fossils are present.

The writer assumes no claim to finality. The generalizations which he draws are based upon such information as is now in his possession. He fully recognizes that this is far from complete and welcomes both additional information and other interpretations.