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A CONTRIBUTION TO THE GEOLOGIC HISTORY
OF THE FLORIDIAN PLATEAU.

BY THOMAS WAYLAND VAUGHAN,
Geologist in Charge of Coastal Plain Investigation, U. S. Geological Survey,
Custodian of Madreporaria, U. S. National Museum.

15 plates, 6 text figures.

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A CONTRIBUTION TO THE GEOLOGIC HISTORY OF THE FLORIDIAN PLATEAU.

BY THOMAS WAYLAND VAUGHAN.

INTRODUCTION.

This paper is the outgrowth of my association with two organizations, the United States Geological Survey and the Carnegie Institution of Washington. As Geologist in charge of Coastal Plain Investigations of the former organization, I have had unusual opportunities to familiarize myself with the geology of Florida, supplementing my previous field work in the State by several additional trips. I supervised and participated in the preparation of a report on the stratigraphic geology and a geologic map of the State, done in coöperation between the United States Geological Survey and the Florida State Survey, by Messrs. George Charlton Matson, Frederick G. Clapp, and Samuel Sanford. I have therefore had at my disposal not only the results of my personal work for the Geological Survey, but also those of Messrs. Matson, Clapp, and Sanford. The information derived from my association with the United States Geological Survey is here utilized with the permission of the Director of that Bureau, and my hearty thanks are extended to him for the privilege.

Through facilities afforded by Dr. Alfred G. Mayer, Director of the Department of Marine Biology of the Carnegie Institution of Washington, I have been able to visit all the principal keys belonging to the main line, to collect and study bottom samples between Miami and Key West, particularly the deposits accumulating behind the keys, to examine several important living coral reefs, and to make detailed investigations of the reefs around the Tortugas. I was also able to visit Cat and Gun keys and the Picquet rocks of the Bahamas.

It was at first contemplated to give an account only of the sedimentation now taking place in the bays and sounds behind the keys. Naturally, the questions arose, whence come these sediments, by what processes are they brought to the sea, how great is their quantity, and how are they distributed over the ocean floor? An extension of these questions led to a general consideration of sedimentation on the Floridian platform and the growth of the platform itself.

The scope of the paper was therefore enlarged, and an attempt is made to trace the geologic history of the Floridian Plateau from Oligocene to Recent time. The work of previous investigators has been extensively drawn upon, and the debt owed them is gratefully acknowledged. The principal of these are Louis Agassiz, Alexander Agassiz, Eugene A. Smith, Angelo Heilprin, William H. Dall, N. S. Shaler, Leon S. Griswold, George C. Matson, Frederick G. Clapp, Samuel Sanford, and E. H.

Sellards. Each of these men has made a distinct contribution to our knowledge of the geology and geologic history of the region.

In the preparation of this paper I have received assistance or advice from several of my scientific colleagues, and express my thanks for their kindness. Professor Charles E. Munroe advised me regarding some of the chemical problems; Mr. J. C. Hoyt supplied information on the surface run-off of streams on the Atlantic slope of the United States; Rear-Admiral Pillsbury, U. S. N., retired, discussed the oceanic currents with me; and Dr. Wm. H. Dall, Mr. George C. Matson, Mr. Samuel Sanford, Dr. L. W. Stephenson, and Dr. Paul Bartsch each read my manuscript. Mr. Matson made physical examinations of the bottom samples collected and has contributed the report published on pp. 120-125 of this paper, and Dr. Dall has furnished a note on the Suwanee Strait region during Miocene time.

Geologic research in Florida, and in Southern Florida particularly, is not now the difficult and hazardous task it was even 10 or 15 years ago. The Florida East Coast Railway has extended its line from the mainland along the keys, and canals have been cut into the Everglades, the excavations for both the railway and the canals revealing excellent exposures hitherto obscured by soil and dense vegetation. Numerous wells, of which we have records, have been put down on both the mainland and the keys, and the shallow-draft naphtha launch renders easy and speedy the examination of banks and keys hitherto accessible only with difficulty. The recently increased facilities for investigation have not been neglected, and results have been obtained sometimes at variance with former opinions, as might have been anticipated.

This is to be regarded as only a sketch of the geologic development of the Floridian Plateau, as many problems need solution and many phases of its history need further investigation. Perhaps its principal value may be in directing attention to some of the unsolved problems. It is necessary to know more accurately the amount of water discharged by the streams and the quantities of solids borne by them to the sea. The chemical processes of precipitation have not been sufficiently studied. Dall's researches on the paleontology of Florida have been epoch-making in their importance, but still our knowledge of the fossils of most of the geologic formations and horizons is far from complete. Additional paleontologic research is needed for every geologic formation known in the State, from the formations of the Vicksburg group to those of the Pleistocene. The paleontologic studies should be an accompaniment of more detailed stratigraphic work. Topographic maps and detailed geologic mapping are essential before the details of the successive deformations to which the area has been subjected can be ascertained. There is also great need for more extensive studies of the marine bottom deposits within the 100-fathom curve.

The deep wells recently put down on Key Vaca, Big Pine Key, and Key West have given valuable data, but deep wells are also needed on Key Biscayne or Virginia Key, the Marquesas, and the Tortugas, in order to discover what underlies the surface formations. It is important to ascertain whether the Miami oolite is older than or contemporaneous

with the Key Largo limestone. A well on Old Rhodes or Elliott Key might give the desired information.

Probably a number of years will elapse before these deficiencies in the information on the geology of Florida will be supplied, as tedious and protracted research is necessary. It is hoped this paper may serve as a convenient summary of the present knowledge of the geologic history of this interesting region, perhaps present an interpretation somewhat different from those preceding, and be a stimulus to further investigation.

TOPOGRAPHY OF THE FLORIDIAN PLATEAU.

That the land surface of Florida represents only about half of the area of the Floridian Plateau has been known for a number of years. A. Agassiz has called attention to it in his "Three Cruises of the Blake"¹; Shaler, in his "Topography of Florida"²; Dall, in his "Neocene" Correlation Paper³; and Sanford in his "Topography and Geology of Southern Florida."⁴

RELATION OF THE 100-FATHOM CURVE TO THE PRESENT LAND SURFACE AND TO GREATER DEPTHS.

The 100-fathom curve, which is considered the delimitation of the continental shelf, lies between 85 and 90 miles offshore, east of Fernandina; south of this locality it curves gently and gradually approaches the shore, until opposite Fort Lauderdale it is less than 5 miles distant. It follows closely the seaward face of the main line of the reefs, curves to the westward, passing between 10 and 15 miles south of Key West, about the same distance south of the Marquesas, and 20 miles south of the Tortugas, beyond which it bends to the north of west. The width of the Plateau along the 25° of latitude, which passes through Florida Bay, is between 240 and 250 miles. Just south of its intersection of the 25° parallel it takes a slightly curving course to the north of west and lies about 45 miles south of Pensacola. (See plate 1.)

The width of the Plateau along different parallels is given in the following table:

Width of the Floridian Plateau along Parallels of Latitude.

Parallel.	Total width.	West of land area.	Land area.	East of land area.
	<i>miles.</i>	<i>miles.</i>	<i>miles.</i>	<i>miles.</i>
Ten miles south of St. Augustine	405	205	135	65
29°	335	180	115	40
28°	310	130	140	40
27°	297	130	145	22
26°	266	160	100	7
25°	242	225	2 ¹	15

¹ Distance across Key Largo.

¹ Vol. 1, p. 152, 1888.

² Mus. Comp. Zool., Bull., vol. 16, p. 139, 1890.

³ U. S. Geol. Surv., Bull. 84, p. 86, 1891.

⁴ Florida Geol. Surv., 2d Ann. Report, p. 180, 1910.

The preceding measurements are made along parallels of latitude and are not precisely transverse to the long axis of the Peninsula, which is from N. 20° W. to S. 20° E., but they clearly indicate the approach southward of the 100-fathom curve to the shore, and the persistent width of the submarine portion of the Plateau on the west. In no instance is the width of the subaerial portion of the Plateau so great as that of the subaqueous portion. They are most nearly equal along parallel 27°.

In the Gulf of Mexico the descent from the 100-fathom curve is abrupt until a depth of 1,500 or 2,000 fathoms is reached. The steepest portion of this declivity is about 60 miles slightly north of west (N. 68° W.) of the Tortugas, where within 22 miles there is a drop from 100 to 1,500 fathoms, and within about 12 miles further an additional descent from 1,500 to 2,000 fathoms. The usual depth to the south in the Florida Straits is over 500 and less than 1,000 fathoms. Off Havana is a tongue of deep water, which the 1,000-fathom curve marks. The Florida Straits are from 500 to 1,500 fathoms shallower than the nearby bottom of the Gulf of Mexico.

The water between the southern portion of the east coast and the Bahamas is still shallower, being less than 300 fathoms in depth. The 500-fathom curve passes around the eastern side of the Bahamas. Off the eastern coast the descent from the 100-fathom curve is not nearly so precipitous or so great in amount as in the Gulf. In the Atlantic the 1,000-fathom curve is slightly sinuous, but follows a southerly course from near Hatteras to the eastern side of the Bahamas and forms the eastern boundary of the "Blake Plateau."¹

THE 10-FATHOM CURVE.

The 10-fathom curve does not in all places lie close to the shore, indicating extensive areas of shoal water. It is about 25 miles offshore east of Fernandina and slightly less opposite Jacksonville, south of which it irregularly approaches the shore, coming very near it opposite Jupiter Inlet and from there to Key Biscayne. It closely follows the outer edge of the growing coral reefs, extends westward beyond the Marquesas and more than halfway from them to the Tortugas. It also incloses the Tortugas, but does not connect them with the Marquesas. North of the latter keys it bends eastward, lying between 40 and 45 miles west of the mouth of White Water Bay. Thence it runs northward to beyond the Thousand Islands, and from there roughly parallels the west coast. It is about 15 miles west of the mouth of Charlotte Harbor, about the same distance west of the mouth of Tampa Bay, 30 miles west of Cedar Keys, 10 miles south of Cape San Blas; westward of the last-mentioned locality it is from 5 to 10 miles offshore. (See plate 1.)

If Florida were elevated only 60 feet, all of the area surrounded by the 10-fathom curve would be added to the land surface. The whole of the key region, excepting the Rebecca Channel, would be above water-level, leaving the bottom of Florida Bay dry, as would also be a strip of land 25 miles wide opposite Fernandina, but narrowing southward on the east coast, and a strip from 10 to 30 miles wide on the west coast east

¹ A. Agassiz, *Three Cruises of the Blake*, p. 96.

TOPOGRAPHIC MAP OF THE FLORIDIAN PLATEAU

Base from the map of Florida prepared by the U.S. Geological Survey, 1909
 Subaerial Contours by G.C. Matson and F.G. Clapp
 Bathymetric Contours from Coast and Geodetic Survey and Hydrographic Office charts

of the mouth of the Apalachicola River. Such a slight elevation would increase the land surface approximately one-third.

THE REEFS.

No attempt will be made to give a detailed account of the reefs, as the classic descriptions of Louis Agassiz¹ and Alexander Agassiz² are so well known. The reefs occur as a disconnected series just landward of the 10-fathom curve, between it and the main line of keys, extend from Fowey Rocks as far westward as the Marquesas, and disappear in the Tortugas. The northernmost living reef known is that at Fowey Rocks. L. Agassiz says³ "in the immediate vicinity of Cape Biscayne there is a mud shoal, laid partly bare at low water, over which grow branching *Millepora*, with small tufts of *Oculina* and *Caryophyllia*⁴ rising between them, and here and there a few *Porites furcata*."

On the surface of the tongue of land east of the northern end of Biscayne Bay and Virginia Key, I collected wave-tossed, dead specimens of the following corals: *Cyphastrea hyades*, *Orbicella annularis*, *Orbicella cavernosa*, *Mussa (Isophyllia) sp.*, *Favia fragum*, *Mæandra areolata*. The original source of these specimens was not determined.

I found living specimens of *Siderastrea radians* and *Porites furcata* off the northeastern end of Key Biscayne in water from 2.5 to 4 feet deep. The living corals do not form a reef, but grow on a sandy flat.

Professor Shaler's report⁵ of the extension of the Florida reef as far north as Hillsboro River is not convincing. An occasional coral does not mean a coral reef; besides "*Manicina*" *areolata* is, according to my experience with Florida corals, not a reef coral, strictly speaking. Its habitat is on protected flats. The species cited, when found alone, rather indicates the absence of a reef.

The water over the reefs is always shoal. The following table, compiled from United States Coast Survey charts, gives the names of the principal reefs from Fowey Rocks southward, and the depths of water over them. It shows that the reefs occur between water-level at low tide and depths of 18 to 20 feet. The reefs, as already stated, are disconnected, with passages a few fathoms—usually 9 to 12 feet, always less than 10 fathoms—between them.

Name.	Depth in feet.	Name.	Depth in feet.
Fowey Rocks.....	1 to 9	Tennessee Reef.....	2 18
Triumph Reef.....	3 15	Coffin's Patches.....	5
Ajax Reef.....	5 12	East Washerwoman.....	3 12
Pacific Reef.....	3 11	Sombrero Key.....	4 5
Carysfort Reef.....	3 19	American Shoal.....	3 16
French Reef.....	1	Pelican Shoal.....	3 4
Molasses Reef.....	1 4	Sambo.....	1
Pickles Reef.....	1 4	Sand Key.....	6 8
Conch and Little Conch reefs..	2 8	Marquesas.....	3 8
Crocker Reef.....	2 5	Tortugas.....Water-level..	15 20
Alligator Reef.....	4 5		

¹ Report on the Florida Reefs, Mus. Comp. Zool., Memoirs, vol. VII, 1880.

² Three Cruises of the Blake, vol. I, Chapter III, 1888.

³ *Op. cit.*, p. 16.

⁴ Probably *Cladocora*.

⁵ Mus. Comp. Zool., Bull., vol. 16, p. 148.

THE HAWK CHANNEL.

Behind the keys is an open-water channel, known as Hawk Channel, having shoals from place to place in it and extending from the upper end of the series of reefs to the Marquesas. Its maximum depth is from 5.5 to 6 fathoms, and its width varies from 3 to 7 miles. The landward boundary is formed by the main line of keys.

THE KEYS.

The Florida Keys are a series of islands rising slightly, a maximum of 10 to 12 feet above tide-level, forming a curve paralleling the reefs, bounded by the landward side of the Hawk Channel as far as the Marque-

FIG. 1.—Tortugas, East Key, west side looking north. Note vegetation on the summit of the key.

FIG. 2.—Middle Key looking north along the axis. This key was washed away during a storm on June 28, 1909, but was restored between August, 1909, and May, 1910.

sas, and extending from the seaward face of Biscayne Bay to the Tortugas. In form these keys may be divided into three groups:

(1) The first group consists of long, narrow islands, stretching along a gentle curve to the southwest from Biscayne Bay to Bahia

Honda Key. Key Largo, the largest, has a maximum width of about 3.5 miles and is about 27 miles in length.

(2) Beginning with Little Pine and No Name keys, the axis of elongation is from northwest to southeast, or practically at right angles to the first group. This group includes the keys between Bahia Honda and Boca Grande, although one key, Key West, has its longer axis east and west, and not north and south. The largest of these keys, Big Pine, has the following dimensions: length 8 miles, width of southern end 2.375 miles, average width about 1.25 miles.

(3) The third group comprises the rather typical atoll of the Marquesas and the less perfect one of the Tortugas.

In composition the keys represent four types:

(1) The most northern group, comprising Virginia Key and Key Biscayne, has its surface composed of sands, largely arenaceous (plate 6, figs. *a* and *b*).

(2) Those from Soldier Key to Bahia Honda inclusive and the southern end of Big Pine are elevated coral reef rocks (plate 15, figs. *b* and *c*).

(3) The group from Little Pine and No Name to Boca Grande are formed of oolite, the Key West oolite (plate 14, fig. *c*; 15, fig. *a*).

(4) The Marquesas and the Tortugas show on their surfaces the more or less comminuted remains of the calcareous skeletons of organisms, mollusks, corals, nullipores, etc. (plate 6, fig. *c*; 7, figs. *a* and *b*, and text figs. 1 and 2).

THE BAYS AND SOUNDS BEHIND THE KEYS.

The landward face of the keys is bounded by a series of bays and sounds, beginning at the north with Key Biscayne, followed, going southward, by Card, Barnes, Blackwater, and Hoodoo sounds, and terminated westward by the Bay of Florida.

Biscayne Bay has a more pointed northern end, bounded on the eastward by a sandy spit of land, Virginia Key, and Key Biscayne, between which are passages. Its southern portion is wider, bounded on the east by Sands, Elliott, and Old Rhodes keys, and has an obtuse termination before communicating with Card Sound, to the south. The length of this bay is 35 miles, maximum width 10 miles, maximum depth 17 feet. Featherbed Bank extends across its median portion and makes two divisions.

Card Sound has its northern end almost opposite the northern end of Key Largo, toward which point is a projection from the mainland; its southern end is formed by a spur projecting from Key Largo toward the mainland. The length of this sound is 6 miles, width 3 to 3.5 miles, maximum depth 12.5 feet.

Barnes Sound has as its northern boundary the spur from Key Largo, forming the lower end of Card Sound; its southern boundary is formed by projections from Key Largo and the mainland. Its length is 6.5 miles, width 5.5 miles, maximum depth 11 feet.

Blackwater Sound is south of Barnes Sound, and has its northern boundary determined by the features forming the southern boundary

of the latter. Its lower boundary is formed by spurs from the mainland and Key Largo. This sound is quadrangular in outline; length 4 miles, width 3.5 miles, maximum depth 9 feet.

Hoodoo Sound is a small body of water lying within the western part of the spur of Key Largo, which forms the southern boundary of Blackwater Sound. It has a length of 1.5 miles, width 0.5 mile, depth 8.5 feet.

Florida Bay is of cornucopia shape, with its narrower end at the western outlets of Blackwater and Hoodoo sounds. The width of the upper end is about 10 miles; it opens toward the west and is 27 miles wide south of Cape Sable. The water also deepens toward the west from 4 to 7 feet, at its upper end, to 10 to 12 feet between Cape Sable and Key Vaca; farther westward it deepens to 12 to 14 feet, and then gradually slopes to the 10-fathom line in the Gulf.

Keys, Mud Flats, and Shoals in the Bays and Sounds.—Here it need only be mentioned that behind the main keys and between them and the mainland are keys mostly overgrown with mangroves, mud flats exposed at low tide, and shoals built almost to water-level. The axes of these keys and banks trend from north to south, at right angles to the main keys, which are elongated from northeast to southwest. Their origin will be especially discussed in succeeding pages.

To summarize the features occurring between the 10-fathom curve and the shore of the mainland, there are:

- (1) The reefs lying just inside the 10-fathom curve.
- (2) The Hawk Channel, separating the reefs from the main line of keys, varying in width from 3 to 7 miles and having a maximum depth of 5 or 6 fathoms.
- (3) The main keys.
- (4) The bays and sounds separating the keys from the mainland.

RELIEF OF THE MAINLAND.

In the following remarks the physiography of the mainland will not be treated in detail, the purpose being to consider the land surface as only a subaerial portion of the more extensive Floridian Plateau. Matson and Clapp have compiled a topographic map of the State, with 50-foot contour intervals. This map, although it does not claim to be without minor inaccuracies, gives the best available information on the relief of the land surfaces. (Plate 1, the subaerial topography.)

Florida is a land of low relief, perhaps two-thirds of it lying below the 50-foot contour. This line extends far up St. Mary's River on the northern boundary of the State, whence, proceeding southward, it passes about 9 miles west of Jacksonville and through Palatka on the west side of St. John's River. On the east side of the latter river, from just below Palatka to the latitude of Lake Monroe, it circumscribes a ridge. It continues down the west side of St. John's River, extending up its tributaries and passes well to the north of Lake Okeechobee, at least 15 or 20 miles. On the western side of the Peninsula it lies above the level of Arcadia on Peace River; it passes around the head of Tampa Bay, thence

northward to Dunnellon at a distance of from 5 to 12 miles from the coast; thence it bends to the northwest and west, keeping from 10 to 25 miles from the shore in the interstream areas, while it digitates up the various rivers and other streams.

If Florida were depressed 50 feet the greater portion of the Peninsula would be submerged—or most of Florida is less than 10 fathoms above sea-level.

The 100-foot contour is not a continuous line around the whole Peninsula, but circumscribes disconnected areas. One of these areas lies west of Kissimmee River, extends from Summit in Marion County southward to near Zolfo Springs in De Soto County, and has its western boundary determined by Hillsboro and Withlacoochee rivers.

There is another ridge, rising above 100 feet, between Dunnellon and Dade City on the west coast. Between Dunnellon and Hawthorne are other but isolated areas above the 100-foot level. From Gainesville northward, lying between the valleys of St. John's and Suwanee rivers, is another area above this level. West of the Suwanee River the 100-foot contour is present on all interstream lobes.

If Florida were depressed 100 feet there would remain of the present land surface of the Peninsula four large and a number of smaller islands.

The 150-foot level is attained in each of the four areas surrounded by the 100-foot contour. Haines City is situated on a ridge extending southward from near the northern boundary to near the southern boundary of Polk County. West of Dade City is another ridge over 150 feet in elevation. Between Dunnellon and Hawthorne are isolated peaks above this level. Between St. John's and Suwanee rivers on the north considerable areas are circumscribed by this contour.

The areas circumscribed by the 200-foot contour are much smaller. Haines City, De Soto County, is located on one of them, and south of that town the map indicates five others on the north and south ridge through Polk County. Four hills over 200 feet in altitude are in northern Pasco County, west of the longitude of Dade City. The only other 200-foot elevation on the Peninsula is the Trail Ridge, along the north and south boundaries of Baker-Duval and Bradford-Clay counties.

The only 250-foot elevation indicated on the Peninsula by the map is south of Haines City in central Polk County.

If the Floridian Plateau were depressed 250 feet (about 42 fathoms) only one small island, about 5 miles long and 2.5 miles wide, situated in central Polk County, would remain of the present land surface of the Peninsula. If the 100-fathom curve is taken as the submarine limit of the Floridian Plateau, it immediately becomes evident that in vertical measure the submarine exceeds the subaerial portion by 58 fathoms; or $\frac{100}{1\frac{1}{2}}$ is below water, while $\frac{42}{1\frac{1}{2}}$ is above water.

In the preceding account, the remarks have been confined to the relief of the Peninsula of Florida, as the westward extension belongs more properly to the continental mass forming the northern boundary of the Gulf of Mexico. In this portion of the State there are higher elevations than on the Peninsula; at Mount Pleasant is a small area over 300 feet in elevation, and considerable areas are above 250 feet. Mossy-

head is 264 feet above tide, and near the Alabama line some localities may be somewhat higher, small areas perhaps exceeding 300 feet.¹

Before leaving the subject of the relief of the subaerial portion of the Plateau, two features should be mentioned. All areas delimited by contours above the 50-foot lie to the west of St. John's and Kissimmee rivers and north of the latitude of Sarasota. Most of the lakes of the State occur in the more elevated region, or along its western or southern periphery. This distribution of more elevated areas, particularly with reference to drainage lines, will be discussed subsequently.

MARINE BOTTOM DEPOSITS FORMING IN THE BAYS AND SOUNDS BEHIND THE KEYS.

During the latter part of April, 1908, I went from Miami to Key West on the yacht *Physalia*; and also made a short excursion from Miami to Cat and Gun keys of the Bahamas. The route followed from Miami to Bahia Honda Key was that known as the "inside passage," but several short side-excursions were made outside the main line of the keys in a smaller launch. One object of making the trip within the main line of the keys was to procure bottom samples, particularly for ascertaining the nature of the deposits now being laid down behind the keys.

The specimens were procured by attaching a cup to the bottom of the sounding lead; they were then put into glass bottles with screw tops and brought to the laboratory for more detailed investigation. The material after arriving in the Geological Survey office was placed in the hands of Mr. G. C. Matson for examination. His report is given on subsequent pages.

For convenience of discussion the material will be described from (1) Biscayne Bay, (2) Card Sound, (3) Barnes Sound, (4) Blackwater Sound, (5) Hoodoo Sound, (6) Florida Bay, (7) Material from Cat and Gun keys, Bahamas.

A few beach specimens will be discussed in connection with the bottom deposits of the neighboring waters, and in a similar connection a few bottom specimens obtained from the outside of the keys will be considered.

¹ G. C. Matson, Preliminary Report on the Geology of Florida, Fla. Geol. Surv., 2d Ann. Report, p. 30.

MAP OF FLORIDA KEYS, ON WHICH ARE SHOWN THE STATION NUMBERS
OF THE BOTTOM SAMPLES

List of Localities from which Bottom Samples were Obtained.

(See plate 2, localities platted on the map.)

Specimen No.	Locality.	Depth.
		<i>Feet.</i>
1	Junction of the two canals off mouth of Miami River.....	
2	Oolite from dredged canal to main ship channel in Biscayne Bay.....	
3	Midway between main ship channel and West Point, Key Biscayne, between buoys 7 and 4.....	12
4	Northern end of Key Biscayne, Bear Cut, Biscayne Bay.....	
5	Opposite West Point, Key Biscayne, Biscayne Bay.....	13
6	Off eastern shore of Cat Key, south of passage between it and Gun Key (Bahamas).....	9
7	Off eastern shore of Gun Key, north of passage between it and Cat Key (Bahamas).....	About 12
8	Calcareous sand from shore, above tide, eastern face of Gun Key (Bahamas).....	
9	Calcareous beach sand, western face of Cat Key (Bahamas).....	
10	Mainland north side of New Cut, Biscayne Bay.....	
11	North side of Norris Cut between Biscayne Bay and ocean.....	
12	Northeastern corner of Key Biscayne.....	2.5
13	South of eastern end of Featherbed Bank.....	About 8
14	Lower Biscayne Bay, deepest portion, southwest of Sands Cut.....	12
15	West of Rubicon Key, off mouth of Caesar Creek, lower end of Biscayne Bay.....	11
16	0.5 mile west of inner end of Caesar Creek, lower end of Biscayne Bay.....	9
17	Off eastern end, western side of Elliott Key, 50 feet offshore.....	2 to 4
18	Hawk Channel, off mouth of Broad Creek, 2 miles offshore.....	18
19	0.5 mile east of mouth of Angelfish Creek.....	12
20	Northern end of Card Sound, inner end of Broad Creek.....	About 9
21	Card Sound, west of Pumpkin Key, about 200 feet offshore.....	12
22	Card Sound, southwestern end, 0.5 mile west of Key Largo, and 0.5 mile north of spur at lower end of the Sound.....	About 10
23	Steamboat Creek, between Card and Barnes sounds.....	12
24	Barnes Sound, near mouth of Steamboat Creek.....	About 12
25	Barnes Sound, center of the Sound.....	11
26	Blackwater Sound, upper end, off mouth of Jewish Creek.....	12
27	Blackwater Sound, 0.5 mile northeast of Bush Point.....	9
28	Lower end of Hoodoo Sound.....	About 6
29	Bay of Florida, entrance from Hoodoo Sound.....	9
30	Bay of Florida, shoal, 2 miles northeast of Pigeon Key.....	1
31	The material composing Pigeon Key.....	
32	Off inner end of Tavernier Creek.....	7
33	Shoal southwest of Tavernier Creek about a mile off Long Island.....	1
34	On Line between McGinty and Torrey keys.....	6
35	1 mile northwest of Shell Key.....	9
36	Southwestern end of cut across the bank south of Bowlegs Key.....	7
37	2.25 miles northwest of upper end of Long Key.....	6
38	1 mile west of north of western end of Long Key.....	6
39	1.25 miles north and east of end of Grassy Key.....	12
40	1 mile N. N. E. of Bamboo Key.....	9
41	0.75 mile north of eastern end of Stirrup Keys.....	9
42	1 mile northeast of the western end of Key Vaca.....	6
43	0.5 mile S. E. of Porpoise Key.....	4
44	0.25 mile W. N. W. of northern end of No Name Key.....	9
45	Middle of channel between No Name and Big Pine keys opposite middle of No Name Key.....	9
46	Eastern shore of No Name Key, opposite middle of island, 100 to 200 feet offshore.....	2.5
47	0.75 mile north of Bahia Honda Key.....	12

BISCAYNE BAY.

From the vicinity and bottom of this bay thirteen samples, including a few beach specimens and one off the northeast corner of Key Biscayne, were obtained. These specimens are Nos. 1 to 5 and 10 to 17 of the list.

Specimen No. 2 and some dredged material obtained in digging the canal from Miami to New Cut, which crosses the southern end of the cape east of Miami, show that the Miami oolite extends beneath the northern end of Biscayne Bay and at least partially forms its floor.

Specimens collected on the north side of New Cut (No. 10) and on the north side of Norris Cut (No. 11) are composed of calcareous and siliceous constituents. There is at both localities a considerable amount of fine quartz sand.

Specimen No. 4, which comes from the northern end of Key Biscayne, Bear Cut, contains an abundance of quartz mixed with shell

fragments and amorphous carbonate of lime. The special point in calling attention to the specimens from the southern end of the cape on the east side of Biscayne Bay and from the two succeeding keys to the south, Virginia Key and Key Biscayne, is to emphasize the presence on them of a large proportion of quartz sand. Cape Florida, which is the southern extremity of Key Biscayne, has its surface covered by siliceous sand with an admixture of comminuted shells.

Soldier Key, the next key to the south of Cape Florida, has on its summit and western side a coating of siliceous sand underlain by elevated coral reef rock. Proceeding southward along the main line of keys the siliceous constituents progressively diminish.

Attempts were made to obtain bottom samples at two places on the east side of Key Biscayne, but in both instances the bottom was hard and no specimens were procured.

Three bottom samples were obtained from the northern end of Biscayne Bay, Nos. 1, 3, and 5. Specimen No. 1, which was collected a short distance off the mouth of the Miami River, showed shell fragments, amorphous carbonate of lime, much quartz sand, sponge spicules, and diatoms. The presence of quartz sand is to be expected, as it forms the surface coating over the Miami oolite of the surrounding country. Specimen No. 3, which was taken between the mouth of the Miami River and the western point of Key Biscayne in about 12 feet of water, was composed mostly of shell fragments and amorphous carbonate of lime, with very little quartz. Specimen No. 5, which was taken in about 13 feet of water off West Point, Key Biscayne, was also composed of shell fragments, amorphous carbonate of lime, and considerable quartz, with some sponge spicules and diatoms.

One specimen, No. 12, collected from the northeast corner of Key Biscayne, depth 2.5 feet, contained shell fragments, calcite, amorphous carbonate of lime, and considerable fine quartz, the quartz passing through the 40 and 80 to the inch mesh sieves, showing some silica on the sea floor east of this key. The bottom off the southwest corner of Key Biscayne consists of calcareous ooze and comminuted shells.

Five specimens, Nos. 13 to 17, were obtained from the southern end of Biscayne Bay, from the latitude of Sands Key southward. An inspection of Mr. Matson's table will show that most of the material is fine; by far the larger portion passed through the 40-mesh sieve but was retained by the 80. Quartz is abundant in No. 13, and there is some in Nos. 14, 15, and 16. In No. 16, however, the siliceous component is comparatively small in amount, while in No. 17 fine quartz, all of which passes through No. 80 sieve, is rare.

These observations on the bottom deposits of Biscayne Bay indicate that considerable quartz is being washed into the northern end of the bay, and that as one proceeds southward the calcareous constituents become predominant, while the siliceous constituents become insignificant. The material, when collected, consisted mostly of oozes and no intimation of the formation of oolite was observed.

BETWEEN OLD RHODES BANK AND CARYSFORT REEF LIGHT.

Two specimens, Nos. 18 and 19, were collected between Old Rhodes Bank and Carysfort Reef Light. Both of these specimens consisted mostly of shell fragments, amorphous carbonate of lime, sponge spicules, diatoms, and a very little quartz. In this region quartz is rare outside the main line of keys.

CARD SOUND.

Three specimens were collected from this sound, Nos. 20, 21, and 22, and one, No. 23, was taken from Steamboat Creek between Card and Barnes sounds. Nos. 20 and 21 both contained considerable quantities of quartz as well as shells, shell fragments, amorphous carbonate of lime, sponge spicules, and diatoms. In No. 22, however, quartz was rare. Specimen No. 23 from Steamboat Creek consisted mostly of organic matter with some amorphous carbonate of lime, sponge spicules, diatoms, and a very little quartz.

BARNES SOUND.

Only two specimens were taken from Barnes Sound, the first, No. 24, near the mouth of Steamboat Creek, at a depth of about 12 feet; the other, No. 25, near the center of the sound, depth about 11 feet. Specimen No. 24 in Mr. Matson's table is queried and perhaps should be omitted from the discussion. No. 25 consists mostly of shells, shell fragments, amorphous carbonate of lime, sponge spicules, and diatoms, with very little quartz, indicating a progressive diminution of quartz toward the southwest.

BLACKWATER SOUND.

Two samples, Nos. 26 and 27, were obtained from this sound. No. 27, it appears, was lost. No. 26, which was taken from the upper end of the sound off the mouth of Jewfish Creek, depth 12 feet, consisted of organic matter, shells, shell fragments, calcite and aragonite, sponge spicules, and a little quartz was retained by sieves Nos. 40 and 80. Material thrown out of a canal dredged between Blackwater and Hoodoo sounds was similar to that forming the bottom of the neighboring sounds, except molluscan remains are so abundant as to constitute a shell marl.

HOODOO SOUND.

This is a small sound between the lower end of Blackwater Sound and Florida Bay. One specimen, No. 28, was obtained from it at a depth of about 6 feet. The material was similar to that from Blackwater Sound with somewhat less quartz.

FLORIDA BAY.

Specimens Nos. 29 to 47 were taken from Florida Bay. Nos. 39 to 42, and No. 47, were procured on the north side of the keys elongated in a northeast-southwest direction. Nos. 43 to 46 were collected along the group of keys lying slightly to the west of Bahia Honda and elongated in a northwest-southeast direction.

North Side of Key Largo.—Nos. 29, 30, and 32 were obtained north of Key Largo in depths ranging from 1 foot to 7 feet; No. 31 is from

the surface of Pigeon Key. The material in general was similar in composition, except the quantity of shells and shell fragments varied. Only one sample, No. 31, which is the surface material of Pigeon Key,¹ contained any quartz. No. 32 was taken off the inner end of Tavernier Creek, which forms the lower limit of Key Largo.

North of Long Island.—One sample, No. 33, was collected on the shoals northwest of Tavernier Creek, about a mile off Long Island. The material consisted of shells, amorphous carbonate of lime, sponge spicules, and diatoms; no quartz was noticed.

North of Upper Matecumbe.—Between McGinty and Torrey keys one specimen, No. 34, was obtained. It consisted of shell fragments, amorphous carbonate of lime, sponge spicules, diatoms, and some calcite, and in the material retained by sieves Nos. 80 and 100 considerable quartz was observed in the 22.9 per cent of the total weight of the sample examined. This sample shows that quartz has worked its way as far to the southwest as a point nearly opposite the lower end of Upper Matecumbe Key. The bottom of the channel southwest of Shell Key is swept clean by the currents passing between Upper and Lower Matecumbe keys.

North of Lower Matecumbe.—Two samples, Nos. 35 and 36, were obtained on the north side of this key: No. 35, a mile northwest of Shell Key; No. 36, the southwestern end of the cut across the banks south of Bowlegs Key. Both specimens consisted mostly of shell fragments, amorphous carbonate of lime, sponge spicules, and diatoms, with very little quartz.

North of Long Key.—A specimen, No. 37, obtained from 2.25 miles northwest of the upper end of Long Key, consisted mostly of calcareous material with sponge spicules and diatoms. There was very little quartz and a few calcareous oval grains. There is some doubt about the identification of the specimens from localities 38 and 39 and they are omitted from the discussion. However, the bottom a mile west of north of the western end of Long Key is hard, being swept almost clean by currents passing between Long and Grassy keys. The bottom material north of Grassy Key is a calcareous ooze with a little quartz (field examination).

North of Key Vaca.—Specimens Nos. 40, 41, and 42 were collected along the north side of this key. The material consisted of shell fragments, amorphous carbonate of lime, sponge spicules, and diatoms. There were a few oval grains in specimen No. 40 and a very little quartz in each of the three. The bottom between Key Vaca and Bahia Honda, midway between Molasses and Duck keys, depth 9 feet, is hard and covered by a thin coating of shells and shell fragments.

North of Bahia Honda.—Specimen No. 47 was obtained 0.75 mile north of this key in a depth of 12 feet. It consisted of shell fragments, amorphous carbonate of lime, sponge spicules, diatoms, and a very little quartz. Bahia Honda is the westernmost of the main line of keys with a northeast-southwest trend.

No Name and Big Pine Keys.—Four specimens, Nos. 43, 44, 45, and 46, obtained in this vicinity, consist mostly of calcareous material with some sponge spicules and diatoms. Oval grains were in three specimens,

¹ This is important in indicating the southward extent of surficial quartz.

Nos. 43, 45, and 46, and these specimens also contained a small proportion of quartz.

The bottom samples show that quartz is disseminated over the entire area of the bottom of Florida Bay; however, in comparison with the calcareous constituents the proportion of quartz in the southwestern corner of the bay is extremely small.

GUN AND CAT KEYS, BAHAMAS.

Four specimens, Nos. 6 to 9, were obtained from the sea-bottom and the beaches of these two keys for purposes of comparison with the material from the Florida keys. Specimens Nos. 6 and 7 were, respectively, from the eastern shore of Cat Key, south of the passage between it and Gun Key, and off the eastern shore of Gun Key, north of the passage between it and Cat Key. The material consisted of shell fragments, amorphous carbonate of lime, sponge spicules, and diatoms, also a little aragonite and calcite. Specimen No. 6 contained a little quartz which did not pass through mesh No. 80. This material is very similar to that from the region of Key Vaca and Bahia Honda, with perhaps a smaller quantity of quartz. Specimen No. 8 was from the eastern shore of Gun Key, above tide, and No. 9 is beach sand from the western face of Cat Key. This material was similar in composition to that taken from the bottom except no quartz whatever was observed. It should be noted that specimens Nos. 6, 8, and 9 all contained oval grains of amorphous carbonate of lime. The nature of these grains will be alluded to in the comparison of the lithologic specimens from the Bahamas with those from the vicinity of the Miami and Key West oolites.

SUMMARY OF DATA ON THE MATERIAL OF THE DEPOSITS.

The material at present being laid down inside of the keys consists mostly of silica and carbonate of lime. Silica is abundant in the form of sand in the northern portion of Biscayne Bay, it becomes rarer toward the southwest, and is present in small quantities as far as Big Pine Key. Toward the southwest, as the siliceous material becomes rarer, calcium carbonate becomes progressively more abundant, occurring as a flocculent sediment or ooze over practically the entire region from the lower portion of Biscayne Bay to the gulf end of Florida Bay.

REPORT ON EXAMINATION OF MATERIAL FROM THE SEA-BOTTOM
BETWEEN MIAMI AND KEY WEST.

BY GEORGE CHARLTON MATSON.

"The accompanying table gives the results of physical and microscopic examination of the sea-bottom materials obtained among the Florida keys. The physical examination was made by passing the material through standard sieves having respectively 20, 40, 80, 100, and 200 meshes to the inch. The percentage of each sample remaining upon the different sieves and the percentage which passed through the 200-mesh sieve were determined by weight. Before sifting, the material was carefully ground in a mortar to separate the grains which were aggregated, care being exercised to avoid crushing the individual grains. In this work considerable difficulty was experienced with the finer-grained specimens because the grains adhered to each other with such tenacity that it was hard to separate without pulverizing them.

"After grinding, a sample was taken for sifting. In order to have the results of the examination of the different specimens comparable, samples of as nearly uniform size as possible were used; the weight of the samples being fixed at 13 grams. In dealing with samples so small, it was necessary to use an accurate balance, because an error of one-tenth of a gram would amount to nearly 1 per cent. For this reason a chemical balance was used, and the weights were determined to thousandths of a gram. The percentage of the material of different sizes was computed from the weights.

"The microscopic study included an examination of each sample after sifting. This examination was made by mounting the material in water and studying it with a petrographic microscope. It was found that the coarse material consisted largely of shells and shell fragments and that amorphous lime carbonate formed a large percentage of most of the samples which passed through the 40-mesh sieve. A few specimens were composed of almost pure quartz sand and this material was found in smaller quantities in specimens from nearly all of the localities.

"Calcite and aragonite in the form of small fragments were present in many specimens and in two cases spherules of chalcedony were observed. Some of the specimens contained oval grains of carbonate of lime which may possibly have an oolitic structure, though such slides as we now have show nothing but aggregated calcite in a finely divided state.

"Sponge spicules and diatoms were noted in many cases and they are probably to be found in all cases where there is amorphous carbonate of lime, but they were seldom detected without first dissolving the lime in acid. After treatment with acid there was a gelatinous residue which blackened on exposure to the air. It is doubtless organic matter of some sort." (For a list of the localities by numbers see p. 115; see map, plate 2, on which the localities are platted.)

Table giving results of physical and microscopic examination of sea-bottom materials obtained among Florida Keys.

Specimen No.	Weight of sample (grams).	Per cent and description of material retained on 20-mesh sieve.	Per cent and description of material retained on 40-mesh sieve.	Per cent and description of material retained on 80-mesh sieve.	Per cent and description of material retained on 100-mesh sieve.	Per cent and description of material retained on 200-mesh sieve.
1	8.208	12 p. ct. Shells, amorphous carbonate of lime.	11.6 p. ct. Amorphous carbonate of lime sand and shell fragments. Quartz sand common.	47.3 p. ct. Amorphous carbonate of lime sand 0.75, quartz sand 0.25.	19.2 p. ct. Chiefly quartz sand, some amorphous carbonate of lime sand.	8.8 p. ct. Chiefly quartz sand, some amorphous carbonate of lime sand, sponge spicules and diatoms.
2		Some large fragments of limestone.				
3	13.000	1.8 p. ct. Shells and shell fragments.	11.6 p. ct. Shell fragments and amorphous carbonate of lime sand. Quartz rare.	13.6 p. ct. Amorphous carbonate of lime sand. Quartz rare.	10.5 p. ct. Amorphous carbonate of lime sand. Quartz rare. Sponge spicules and diatoms.	27.2 p. ct. Like 100.
4	12.558	5.9 p. ct. Shell fragments.	12.6 p. ct. Shell fragments, quartz abundant.	56.1 p. ct. Amorphous carbonate of lime sand. Quartz 0.2 of whole.	See 80. Amorphous carbonate of lime and quartz about equal proportions.	11.9 p. ct. Chiefly quartz sand, some amorphous carbonate of lime.
5	12.820	1.6 p. ct. Shells and shell fragments.	12.8 p. ct. Amorphous carbonate of lime sand. Quartz common.	29.0 p. ct. Same as 40.	20.3 p. ct. Amorphous carbonate of lime sand. Quartz 0.2 of whole.	13.5 p. ct. Chiefly quartz sand, some amorphous carbonate of lime, sponge spicules and diatoms.
6	13.000	6.7 p. ct. Shells and shell fragments.	12.2 p. ct. Like 20.	35.9 p. ct. Amorphous carbonate of lime—smooth oval grains. Quartz rare.	9.9 p. ct. Amorphous carbonate of lime. Some crystalline, diatoms and sponge spicules.	22.0 p. ct. Amorphous carbonate of lime, quartz rare, sponge spicules and diatoms.
7	6.076	3.0 p. ct. Shell fragments and amorphous carbonate of lime.	12.9 p. ct. Like 20 with some oval grains.	21.6 p. ct. Amorphous carbonate of lime sand, sponge spicules and diatoms.	19.4 p. ct. Amorphous carbonate of lime, aragonite, diatoms and sponge spicules.	15.9 p. ct. Amorphous carbonate of lime, sponge spicules and diatoms.
8	13.000	0.4 p. ct. Shell fragments and amorphous carbonate of lime.	7.3 p. ct. Amorphous carbonate of lime, some oval grains.	44.2 p. ct. Some shells, mostly oval grains. Amorphous carbonate of lime.	11.7 p. ct. Like 80.	20.8 p. ct. Like 80. Some aragonite and calcite.
9	13.000	0.5 p. ct. Shell fragments.	36.1 p. ct. Amorphous carbonate of lime, mostly oval.	62.7 p. ct. Like 40.	10.7 p. ct. Like 100.	13.2 p. ct. Like 100 with much calcite.
					0.1 p. ct. Like 40.	

Table giving results of physical and microscopic examination of sea-bottom materials obtained among Florida Keys.—Continued.

Specimen No.	Weight of sample (grams).	Per cent and description of material retained on 20-mesh sieve.	Per cent and description of material retained on 40-mesh sieve.	Per cent and description of material retained on 80-mesh sieve.	Per cent and description of material retained on 100-mesh sieve.	Per cent and description of material retained on 200-mesh sieve.	Per cent and description of material passing 200-mesh sieve.
10	13.000	2.3 p. ct. Shell fragments and amorphous carbonate of lime. Quartz rare.	22.9 p. ct. Amorphous carbonate of lime and quartz 0.2 of whole.	61.5 p. ct. Amorphous carbonate of lime and quartz 0.5 of whole.	5.9 p. ct. Quartz and amorphous carbonate of lime, about equal.	3.2 p. ct. Amorphous carbonate of lime and quartz common.	4.2 p. ct. Like 200. Sponge spicules and diatoms.
11	13.000	1.2 p. ct. Shells, amorphous carbonate of lime and quartz.	15 p. ct. Amorphous carbonate of lime sand. Quartz about 0.1.	76.7 p. ct. Amorphous carbonate of lime and quartz, about equal.	5.5 p. ct. Amorphous carbonate of lime sand. Quartz about 0.25.	0.2 p. ct. Like 100.	
12	13.000	4.6 p. ct. Shell fragments.	11 p. ct. Shell fragments, calcite.	45.7 p. ct. Amorphous carbonate of lime. Quartz about 0.2.	32.5 p. ct. Quartz 0.75, amorphous carbonate of lime 0.25.	6.4 p. ct. Quartz, amorphous carbonate of lime rare.	
13	13.000	0.3 p. ct.	13.9 p. ct.	26.9 p. ct.	18.1 p. ct.	15.9 p. ct.	24.9 p. ct.
14	13.000	0.9 p. ct. Chiefly quartz, some organic matter containing diatoms, &c.	20.9 p. ct. Like 20.	54 p. ct. Like 20. More amorphous carbonate of lime.	9.5 p. ct. Amorphous carbonate of lime. Quartz.	8.3 p. ct. Amorphous carbonate of lime, organic matter, sponge spicules and diatoms. Quartz 0.35.	7.7 p. ct. Amorphous carbonate of lime, organic matter, sponge spicules and diatoms.
15?	13.000	2.4 p. ct. Shell fragments 0.5, quartz 0.5.	24.9 p. ct. Amorphous carbonate of lime 0.1, quartz 0.9.	48.1 p. ct. Chiefly quartz a little amorphous carbonate of lime.	12.5 p. ct. Amorphous carbonate of lime 0.5, quartz 0.5.	7 p. ct. Amorphous carbonate of lime 0.8, quartz 0.2, sponge spicules and diatoms.	5.1 p. ct. Amorphous carbonate of lime, quartz rare, sponge spicules and diatoms.
16	13.000	10.1 p. ct. Shell fragments.	21.5 p. ct. Amorphous carbonate of lime 0.9, quartz 0.1.	40.6 p. ct. Amorphous carbonate of lime and sand, equal proportions.	10.9 p. ct. Amorphous carbonate of lime 0.7, quartz 0.3.	8.7 p. ct. Amorphous carbonate of lime 0.9, quartz 0.1.	8.2 p. ct. Amorphous carbonate of lime, with sponge spicules and diatoms.
17	13.000	14 p. ct. Shell fragments.	18.1 p. ct. Shell and amorphous carbonate of lime sand.	26.7 p. ct. Amorphous carbonate of lime. Quartz rare.	14.7 p. ct. Amorphous carbonate of lime 0.6, quartz 0.4.	10.7 p. ct. Amorphous carbonate of lime 0.75, quartz 0.25.	15.8 p. ct. Amorphous carbonate of lime. Quartz rare, sponge spicules and diatoms.
18	8.840	6.6 p. ct. Shell fragments.	11.2 p. ct. Like 20.	38.1 p. c. Amorphous carbonate of lime sand, some oval grains. Quartz rare.	20.2 p. ct. Like 80.	14.3 p. ct. Amorphous carbonate of lime, mostly oval grains. Diatoms and sponge spicules.	9.6 p. ct. Like 200.
19	3.623	24.4 p. ct. Shells and shell fragments and calcite.	15.9 p. ct. Shell fragments, calcite, quartz rare.	19.6 p. ct. Like 40.	8.5 p. ct. Like 40 but more quartz.	18.4 p. ct. Like 40 quartz rare.	13.2 p. ct. Like 40 but some aragonite, quartz rare.

¹ Specimen contained organic matter.² Like No. 12. (Different sizes not examined separately.)

Table giving results of physical and microscopic examination of sea-bottom materials obtained among Florida Keys. Continued.

Specimen No.	Weight of sample (grams).	Per cent and description of material retained on 20-mesh sieve.	Per cent and description of material retained on 40-mesh sieve.	Per cent and description of material retained on 80-mesh sieve.	Per cent and description of material retained on 100-mesh sieve.	Per cent and description of material retained on 200-mesh sieve.	Per cent and description of material passing 200 mesh sieve.
20	7.225	53.1 p. ct. Shells and shell fragments.	27.2 p. ct. Amorphous carbonate of lime and quartz equal proportions.	15.8 p. ct. Amorphous carbonate of lime 0.75, quartz 0.25.	1.1 p. ct. Amorphous carbonate of lime with considerable quartz. Sponge spicules and diatoms.	1.2 p. ct. Amorphous carbonate of lime, aragonite. Quartz abundant, sponge spicules and diatoms.	1.6 p. ct. Like 200.
21	9.210	13.0 p. ct. Shell fragments, some quartz.	41.0 p. ct. Chiefly amorphous carbonate of lime, some shell fragments.	30.5 p. ct. Quartz 0.75, amorphous carbonate of lime 0.25.	3.8 p. ct. Amorphous carbonate of lime, quartz abundant.	0.6 p. ct. Amorphous carbonate of lime. Quartz common. Sponge spicules and diatoms.	0.6 p. ct. Amorphous carbonate of lime, quartz rare, diatoms and sponge spicules.
22	13.000	10.2 p. ct. Shell fragments.	22.2 p. ct. Shell, amorphous carbonate of lime sand, quartz rare, organic matter.	18.4 p. ct. Chiefly amorphous carbonate of lime.	7.7 p. ct. Chiefly amorphous carbonate of lime. Much organic matter. Sponge spicules and diatoms.	17.1 p. ct. Like 100. More organic matter.	15.4 p. ct. Like 200.
23	4.721	None.	4.1 p. ct. Chiefly organic matter, some amorphous carbonate of lime.	25.7 p. ct. Like 40 but nearly 0.5 amorphous carbonate of lime. Quartz very rare.	17.1 p. ct. Amorphous carbonate of lime and organic matter, sponge spicules and diatoms.	35.6 p. ct. Like 100.	17.5 p. ct. Like 200, sponge spicules and diatoms abundant.
24	13.000	10.7 p. ct. Shells and shell fragments.	15.3 p. ct. Shells and amorphous carbonate of lime.	29.4 p. ct. Amorphous carbonate of lime. Quartz abundant.	27.2 p. ct. Like 80 with less quartz.	10.8 p. ct. Amorphous carbonate of lime. Sponge spicules and diatoms.	6.8 p. ct. Like 100. Some aragonite.
25	13.000	17.3 p. ct. Shells and shell fragments.	17.2 p. ct. Amorphous carbonate of lime. Quartz rare.	39.4 p. ct. Amorphous carbonate of lime. Quartz rare.	8.7 p. ct. Amorphous carbonate of lime. Quartz rare.	11.2 p. ct. Amorphous carbonate of lime.	15.3 p. ct. Amorphous carbonate of lime. Sponge spicules and diatoms.
26	11.373	10.3 p. ct. Shells and shell fragments.	16.2 p. ct. Like 20. Quartz rare.	26 p. ct. Organic matter, sponge spicules and diatoms. Quartz rare.	21.1 p. ct. Like 80.	16.3 p. ct. Like 80 with calcite and aragonite.	10.1 p. ct. Like 200.
27	This specimen was lost.						
28	11.373	58.8 p. ct. Shells and shell fragments.	17.2 p. ct. Shell fragments and amorphous carbonate of lime.	10.9 p. ct. Amorphous carbonate of lime. Quartz rare. Sponge spicules and diatoms.	3.1 p. ct. Like 80 with aragonite.	5.2 p. ct. Like 80 with no quartz.	48 p. ct. Like 200.

Table giving results of physical and microscopic examination of sea-bottom materials obtained among Florida Keys.—Continued.

Specimen No.	Weight of sample (grams).	Per cent and description of material retained on 20-mesh sieve.	Per cent and description of material retained on 40-mesh sieve.	Per cent and description of material retained on 80-mesh sieve.	Per cent and description of material retained on 100-mesh sieve.	Per cent and description of material retained on 200-mesh sieve.	Per cent and description of material passing 200-mesh sieve.
29	13.000	12.8 p. ct. Shell fragments.	6.1 p. ct. Shell fragments and amorphous carbonate of lime.	13.2 p. ct. Amorphous carbonate of lime, aragonite, sponge spicules, and diatoms.	21.2 p. ct. Like 80.	32.6 p. ct. Like 80, quartz very rare.	14.1 p. ct. Amorphous carbonate of lime, calcite, aragonite, diatoms, sponge spicules.
30?	16.000	24.5 p. ct. Shells and shell fragments.	12.2 p. ct. Amorphous carbonate of lime. Calcite.	16.2 p. ct. Like 40. Sponge spicules and diatoms.	13.6 p. ct. Like 80.	18.2 p. ct. Like 80.	15.3 p. ct. Like 80. Aragonite common.
31	13.000	6.4 p. ct. Amorphous carbonate of lime. Quartz rare.	14.6 p. ct. Like 20.	17.6 p. ct. Amorphous carbonate of lime, calcite, and diatoms.	14.2 p. ct. Like 20. Sponge spicules and diatoms.	28.9 p. ct. Like 100.	18.3 p. ct. Like 200. Aragonite.
32	12.710	5.5 p. ct. Shells and amorphous carbonate of lime.	17.4 p. ct. Like 20. More amorphous carbonate of lime.	22.8 p. ct. Amorphous carbonate of lime, organic matter, diatoms, and sponge spicules.	10.9 p. ct. Like 80.	18.6 p. ct. Like 80.	24.8 p. ct. Like 80. Sponge spicules and diatoms.
33	12.773	3.5 p. ct. Shells and amorphous carbonate of lime.	14.7 p. ct. Amorphous carbonate of lime, largely aggregated.	50 p. ct. Like 40. Less aggregation. Sponge spicules and diatoms.	11.9 p. ct. Like 80.	16.2 p. ct. Like 80.	3.7 p. ct. Like 80.
34	13.000	27.1 p. ct. Shell fragments, amorphous carbonate of lime (aggregated).	40.1 p. ct. Like 20, quartz rare.	19.1 p. ct. Amorphous carbonate of lime 0.25, quartz 0.75, sponge spicules, and diatoms.	3.8 p. ct. Amorphous carbonate of lime. Quartz abundant. Sponge spicules and diatoms.	5.9 p. ct. Amorphous carbonate of lime. Organic matter, sponge spicules, and diatoms.	4 p. ct. Like 200 with calcite.
35	13.000	21.8 p. ct. Shell fragments. Quartz rare.	40.2 p. ct. Amorphous carbonate of lime. Quartz rare.	18.5 p. ct. Amorphous carbonate of lime. Quartz.	6.6 p. ct. Amorphous carbonate of lime. Some oval grains. Quartz very rare. Sponge spicules and diatoms.	8.7 p. ct. Amorphous carbonate of lime, calcite, diatoms and sponge spicules.	4.2 p. ct. Like 200.
36	13.000	14.7 p. ct. Shell fragments. Amorphous carbonate of lime.	46.1 p. ct. Shell sand and amorphous carbonate of lime.	17.3 p. ct. Chiefly calcite. Quartz rare. Diatoms and sponge spicules.	3.1 p. ct. Like 80.	13.4 p. ct. Like 80 but no quartz.	5.4 p. ct. Amorphous carbonate of lime, calcite, aragonite, diatoms and sponge spicules.
37	13.000	14.9 p. ct. Shells and shell fragments. Amorphous carbonate of lime and a few oval grains.	24.9 p. ct. Shell fragments. Amorphous carbonate of lime and a few oval grains.	25.6 p. ct. Like 40. Quartz rare.	12.3 p. ct. Like 80 with sponge spicules and diatoms.	16.6 p. ct. Like 100.	5.7 p. ct. Like 100.

³ Lime aggregated; disaggregates when wet

Table giving results of physical and microscopic examination of sea-bottom materials obtained among Florida Keys.—Continued.

Specimen No.	Weight of sample (grams).	Per cent and description of material retained on 20-mesh sieve.	Per cent and description of material retained on 40-mesh sieve.	Per cent and description of material retained on 80-mesh sieve.	Per cent and description of material retained on 100-mesh sieve.	Per cent and description of material retained on 300-mesh sieve.	Per cent and description of material passing 300-mesh sieve.
38?	7.720	39.2 p. ct. Shells and shell fragments.	23.9 p. ct. Like 20 with amorphous carbonate of lime.	18.4 p. ct. Amorphous carbonate of lime. Some crystalline material.	8.8 p. ct. Like 80.	8.1 p. ct. Like 80. Quartz rare.	1.5 p. ct. Amorphous carbonate of lime.
39?	13.000	13.5 p. ct. Shell fragments.	22.7 p. ct. Amorphous carbonate of lime.	23.4 p. ct. Amorphous carbonate of lime. Chalcidony.	9.3 p. ct. Like 80.	16.9 p. ct. Like 80 but no chalcidony. sponge spicules and diatoms.	14.2 p. ct. Like 200.
40	13.000	32 p. ct. Shell fragments. Amorphous carbonate of lime.	42.4 p. ct. Shell fragments, a few oval grains.	14.8 p. ct. Like 40 with organic matter and calcite.	3.4 p. ct. Quartz rare. Amorphous carbonate of lime, organic matter, calcite. Diatoms and sponge spicules.	4.2 p. ct. Like 100 but no quartz.	3.2 p. ct. Like 200.
41?	13.000	27.6 p. ct. Shell fragments.	20.4 p. ct. Amorphous carbonate of lime, calcite.	14.4 p. ct. Like 40, quartz rare.	7.1 p. ct. Like 80.	6.7 p. ct. Like 80. Sponge spicules and diatoms.	14.8 p. ct. Like 200.
42	13.000	10.6 p. ct. Shells and shell fragments.	30.5 p. ct. Shell fragments and amorphous carbonate of lime.	20.7 p. ct. Like 40, quartz very rare. Sponge spicules and diatoms.	8.4 p. ct. Like 80. Calcite.	11.9 p. ct. Like 100. aragonite.	7.9 p. ct.
43	9.175	11.6 p. ct. Shells and shell fragments.	54.2 p. ct. Shell fragments and amorphous carbonate of lime.	25.6 p. ct. Lime, many oval calcite grains.	1.9 p. ct. Like 80. Quartz rare.	2 p. ct. Like 100.	4.7 p. ct. Like 100. aragonite.
44	13.000	17.8 p. ct. Shell fragments. Amorphous carbonate of lime.	38.3 p. ct. Like 20.	16.4 p. ct. Amorphous carbonate of lime. Sponge spicules and diatoms.	13.8 p. ct. Like 80.	9.2 p. ct. Like 80.	4.5 p. ct. Like 80.
45	13.000	19.6 p. ct. Shells and shell fragments.	33.2 p. ct. Shells and shell fragments.	21.3 p. ct. Amorphous carbonate of lime. Oval grains, quartz rare.	10.2 p. ct. Like 80.	12.6 p. ct. Amorphous carbonate of lime. Some oval grains.	3.1 p. ct. Like 200. Sponge spicules and diatoms.
46	13.000	27.9 p. ct. Shells and shell fragments.	33.4 p. ct. Like 20, some oval grains.	22.4 p. ct. Amorphous carbonate of lime. Oval grains. Quartz rare.	5.9 p. ct. Like 80.	5.6 p. ct. Amorphous carbonate of lime. Some oval grains. Sponge spicules and diatoms.	4.8 p. ct. Like 200.
47	13.000	19.4 p. ct. Shell fragments. amorphous carbonate of lime.	25.1 p. ct. Like 20.	24.8 p. ct. Amorphous carbonate of lime. Quartz very rare.	15.2 p. ct. Amorphous carbonate of lime. Sponge spicules, diatoms.	11.7 p. ct. Like 200. calcite.	3.8 p. ct.

SOURCES OF MATERIAL.

Table of Geologic Formations in Florida.

	Period.	Group.	Formation.	Lithologic description of the formation.	
Quaternary	Recent			Human remains. Vermetus rock. Beach sands. Coquina. Aeolian deposits. Lacustrine deposits. Chemical deposits. Alluvial deposits.	
	Pleistocene		Palm Beach Limestone.....	Yellow sand. "Vermetus rock." Coquina. "Planorbis rock " Gray sand. Fossiliferous marls. Light-colored limestone with sandy beds and loose sand.	
			Miami oolite.....	Light-gray to white oolitic limestone, sandy in places.	
			Key Largo limestone.....	Coral limestone; reef rock.	
			Key West oolite.....	Light-gray to white oolitic limestone.	
			Lostman River limestone....	Dark to light, hard to friable, limestone, sandy or marly in places.	
	Pliocene		Unconformity—Lafayette.....	Largely contemporaneous deposition	Clay and sand with some pebbles, color usually red or yellow. Light-colored gravel and marl, containing phosphatic pebbles. Greenish sandy clay, weathering yellow or red. Light-colored sandy shell marl. Light-colored sandy shell marl.
			Bone Valley gravel.....		
			Alachua clay.....		
		Nashua marl.....			
Miocene		Caloosahatchee marl....	Contemporaneous deposition		
		Unconformity (?) Jacksonville formation (East Coast)			
		Choctawhatchee marl (West Florida and St. John's Valley)			
		Unconformity—Alum Bluff formation.....			
Tertiary	Oligocene	Apalachicola Group	Chattahoochee formation (West Florida)	Largely contemporaneous deposition.	Gray to green sands, clays and fuller's earth. Limestone occurs in some localities but it is usually impure. Light-yellow to gray earthy and siliceous limestones, sometimes cherty. Sand and clay rare.
			Hawthorne formation (Central Florida)		Yellow limestones, often phosphatic. Greenish or reddish sands. Green clays.
			Tampa formation (South Florida)		Yellow limestone and greenish clays. Some chert nodules and layers.
		Vicksburg Group	Unconformity—Ocala limestone.....		Soft, porous, light-gray to white limestone with beds of marl and layers of chert.
			Peninsula limestone (Central Florida)		Soft, porous, light-gray to white limestone containing marl beds and layers of chert.
			Marianna limestone (Western Florida)		Soft, porous, light-gray to white limestones containing some marl and more rarely clay beds. Layers of chert common.

SILICA.

The presence of siliceous sand in the northern portion of Biscayne Bay is accounted for by similar material overlying the Miami oolite in the adjacent regions, and by the streams emptying into the bay mechan-

ically removing to it a portion of the deposit. The sand of southern Florida has attracted the attention of a number of geologists, among them Professor Shaler and Mr. A. Agassiz. The material must have been derived from the continental masses to the north, but the various factors by which it was brought so far south have not been thoroughly understood.

GEOLOGIC DISTRIBUTION OF SILICEOUS SAND IN FLORIDA.

Until recently the amount of sand in the geological formations underlying the surficial Pleistocene deposits was not known. Therefore it may be interesting in this connection to outline the geologic history of arenaceous deposits in Florida. The table of geologic formations on the preceding page is taken, with some verbal changes, from "A Preliminary Report on the Geology of Florida, with special reference to the stratigraphy, by George Charlton Matson and Frederick G. Clapp, including a chapter on the Topography and Geology of Southern Florida by Samuel Sanford."¹

In northern Florida the following geologic formations older than the Pleistocene contain sand beds:

- Pliocene: Lafayette formation, Alachua clay, Nashua marl, Caloosahatchee marl.
- Miocene: Jacksonville formation, Choctawhatchee marl.
- Oligocene: Alum Bluff formation, Hawthorne formation.

In the northern portion of the State formations of every period from the Oligocene to the Recent contain deposits of sand. It should be stated, however, that no predominantly sand beds have been reported from the Vicksburgian Oligocene, although the formations of that group contain some sand and silica of organic origin.

In southern Florida sand of Pleistocene and post-Pleistocene age is generally known to be present, at least as far south as Miami. The three following well records extracted from Mr. Sanford's chapter in the report on the stratigraphic geology of Florida will indicate its distribution in preceding geologic periods:

Partial record of well of C. I. Craigin, Palm Beach.

Description.	Feet.	
Sands with thin layers of semi-vitrified sand at 50 and 60 feet.....	0 to	400
Very fine-grained soft greenish-gray quartz sand, containing occasional foraminifera and water-worn shell fragments.....	400	800
White sand with abundant foraminifera of four or five species.....	850	860
Gray sand, containing shark's teeth, small water-worn shells and bone fragments, sea-urchin spines, and lithified sand fragments.....	904	915
Samples at frequent intervals, Vicksburg limestone containing Orbitoides in abundance throughout, together with occasional indeterminate fragments of molluscan casts, corals, and echinoderms. It is a creamy white, hard, homogeneous limestone throughout.....	1,000	1,212

¹ Prepared in coöperation between the United States Geological Survey and the Florida State Geological Survey, under the direction of Thomas Wayland Vaughan, Florida Geol. Surv., 2d Ann. Report, 1910.

Darton was unable to determine definitely the age of the series overlying the limestones, but the organic remains from 800 to 915 feet suggested Miocene age, while foraminifera between 400 and 800 feet indicated that the beds whence they came are also probably of Miocene age.

This record shows that the top of the Vicksburg group (Lower Oligocene) lies between 915 and 1,000 feet below the surface at Palm Beach. The great thickness of quartz sands is the most noteworthy feature of the record.

Key Vaca.—Two wells were sunk at Marathon, Key Vaca, one reaching a depth of 435 feet, the other 700 feet. The combined records of the two wells gives the following section:

Record of wells of Florida East Coast Railway, Marathon.

Description.	Feet.	
Reef rock.....	0 to 105	
Hard to soft white limestone, with much white marl.....	105	148
Soft white limestone with shell casts.....	148	150
Medium hard white limestone, shell casts and shell fragments.....	150	155
Soft white limestone with quartz grains, proportion of quartz increasing with depth, shell fragments and casts.....	155	176
Medium fine white quartz sand containing numerous irregular nodules, with yellowish marly sand at 210 to 215 feet.....	176	230
Quartz sand in a varying proportion of limy mud, sand grains colorless, mud yellowish to dark green, streaks and beds of friable sandstone containing shell casts, bed of oyster shells at 210 feet.....	210	300
Quartz sands or beds of soft, friable sandstone containing shell casts, streaks of dark green limy clay, 300 to 310 ft.; beds of shells; few determinable fossils, probably Miocene, 375 to 390.....	300	400
Quartz sands as below 230 feet, beds of soft friable sandstone with shell casts, gravel bed with much worn pebbles up to 40 mm. long, tough green limy clay, at 407 to 410 feet.....	400	435
Quartz sands with little sandstone, tough dark clay in occasional streaks.....	435	700

While the many samples of drillings from this well show the lithology of the formations penetrated, they give much less satisfactory evidence as to geologic age. The sands below 176 feet yielded but a small variety of determinable fossils. An occasional claw or carapace of a small crab or a few barnacle plates were the only organic remains noted in going through many feet of sand. The friable sandstones contained many casts, internal and external, of pelecypod shells, the external casts being of sandstone, the internal of more clayey material. These casts, while numerous, were not sharp enough to be of diagnostic value.

The shell beds yielded a small variety of species. T. Wayland Vaughan identified five species, including pectens and an oyster, which were probably Miocene, from collections between 375 and 420 feet.

Thus the Key Vaca section, while it shows limestone, Pleistocene, and sands probably Pliocene, gives no data for separating Pliocene from Miocene. The coarseness of the sands, their barrenness and the character of the few determinable fossils between 176 and 400 feet indicate shoal water and strong currents. No break in deposition is determinable.

Fossils from Marathon Well, Key Vaca, were identified by T. W. Vaughan, as follows:

Depth 375 to 400 feet: *Turritella variabilis* Conrad; *Ostrea*, apparently a new species; *Pecten* sp. fragment, probably *P. madisonius* Say; *Pecten* sp. fragment, very near *P. humphreysi* Conrad; *Pecten* sp. young, apparently *P. eboreus* Conrad.

Geologic Horizon: Although the number of species is small, and positive specific identification can be made in only one instance, the fauna has a distinctly Miocene facies. The series of *Pecten*s represented by *madisonius*, *humphreysi*, and *eboreus* occur in association only in the Miocene.

The matrix of these fossils is light olive-green quartz sand with some calcareous material. A few oolitic granules are present. Similar material continues to 640 feet, becoming coarser at the lower levels. Between 620 and 640 feet there are quartz pebbles 0.375 inch long.

Depth 640 to 660 feet: *Orbitolites complanata* d'Orb.; *Stylophora* sp.; *Porites* sp.

Geologic Horizon: Apalachicola Oligocene. The matrix is a whitish limestone in which are small cavities.

Depth 680 to 700 feet: *Pecten* fragments, probably *P. perplanus* Morton.

Geologic Horizon: Not definitely determinable, but Vicksburgian Oligocene is suggested.

A record of the Buck Key well (of W. H. Knowles) given from memory by the driller, James Sykes, supplemented by samples saved at odd depths, furnishes the following section:

Description.	Feet.
Sand and shells.....	0 to 50
Brown crystalline limestone with cherty streaks and sand grains.....	50 60
White quartz sand, with marl and shell fragments.....	60 63
Brownish sandy limestone with shell fragments.....	63 65
Dark greenish marl.....	65 145
White quartz sand, with shell bed at 150 feet.....	142 275
Medium dark greenish marly sand, with shell beds, and streaks of lighter marl.....	275 490
White to brownish, and soft to hard, limestone, with a few shell casts; hard brownish limestone contains many siliceous grains.....	490 605

The correlation of the geologic formations penetrated in these wells is a difficult matter, but we know sand is abundant below 155 feet in depth on Key Vaca and we may be confident that Pliocene and Miocene sands extend as far southward as that key. The quantity of siliceous material contributed to southern Florida appears to have reached its maximum in the Miocene period and since then to have diminished interruptedly. The Pleistocene limestones of the mainland rest on an arenaceous foundation.

The presence of Miocene sands as far south as Key Vaca possesses a geologic interest in that they indicate that the great Floridian platform existed in Miocene times, and that sand which must have come from the north, as no southern source is known, was being carried to that region during that period.

Silica derived from sponge spicules and diatoms is universally present in the near-shore marine deposits, but not in sufficient quantity to form of itself important deposits.

CALCIUM CARBONATE.

The origin of the material of the calcareous deposits presents a more complicated problem than that of the siliceous. Its source is both inorganic and organic.

CALCIUM CARBONATE OF INORGANIC ORIGIN.

The calcium carbonate is derived through two inorganic agencies: chemical denudation and erosion. In order to understand both the sources and the means by which the material is transported to the ocean, it will be necessary briefly to consider the geologic formations, topography, vegetation, drainage, rainfall, and surface run-off of the land areas.

PLEISTOCENE LIMESTONES OF SOUTHERN FLORIDA.

The whole of the surface of southeastern Florida is either formed or underlain at no great depth by a series of limestones, all of which are of Pleistocene age. The more important of these formations will be described in the succeeding paragraphs.

The Miami oolite, named from the city of Miami, is a soft, white or cream-colored, oolitic limestone breaking with an irregular fracture and containing streaks of thin, irregular layers of calcite (plate 13, fig. *b*). The rock is quarried as a building stone in the vicinity of Miami, and as it hardens on exposure it serves its purpose well. Spheroidal oolite grains are its most important constituent. The diameter of the granules ranges from less than 0.5 mm. to a little over 1 mm. Mr. Sanford, who has studied the granules microscopically, says:

Examination with the microscope shows that the ovules have a well-marked concentric structure; the nucleus of some ovules is a rounded aggregate of minute calcite crystals, of others a rounded aggregate less evidently crystalline; sometimes the nucleus is a shell fragment and frequently it is a grain of quartz. The concentric layers vary in number from 1 to 4 or 5, and in appearance from clear and rather coarsely crystalline to opaque. The layers are darker or lighter from varying amounts of organic matter and amorphous material.

The oolites are embedded in a cement of amorphous or crystalline calcium carbonate, and there is some sand. The latter material is more abundant at the north and decreases southward; there is also a slightly greater proportion of sand along the eastern outcrop than toward the west. This formation has a maximum thickness of perhaps 50 feet. Its areal extent is southward from the vicinity of Del Ray to 10 or 12 miles beyond Homestead, and westward it forms the floor of the eastern portion of the Everglades.

The Lostman River limestone, named by Mr. Sanford from its typical occurrence along Lostman River, is a non-oolitic Pleistocene limestone of varying physical characters; in some places it is hard, largely made up of crystalline calcite; in others, soft and friable. At the head of Henderson Creek it contains considerable sand. Its thickness is said by Mr. Sanford to be 30 feet at Everglade and over 40 feet at the mouth of Shark River. It underlies the shore of the mainland from Jewfish Creek westward and northwestward to near Marco, extends some miles to the north of the last-mentioned place, and to the northeast passes beneath the great swamps of the interior.

The Key Largo limestone is the elevated coral-reef rock forming the main line of keys from Soldiers Key to the southern end of Big Pine Key. Its name was taken from Key Largo because of the excellent exposures recently made there by the excavations along the line of the Florida East Coast Railway extension. The most conspicuous compo-

nent of this formation is coral, usually in the form of large heads of *Mæandra* and *Orbicella* (plate 15, figs. *b* and *c*). The interspaces are filled with various kinds of calcareous débris derived from marine organisms. Over the surface there is frequently a hard crust composed of colored, laminated, amorphous calcareous material. The lime of the coral heads is frequently crystalline.

These three limestones are the principal geologic formations surrounding the bays and sounds of southeastern Florida. Toward the interior of the State, however, both the Miami oolite and the Lostman River limestone are overlain by the great interior swamp deposits, the most extensive and famous of which are the Everglades.

There is in this region another important limestone formation, the Key West oolite, which closely resembles the Miami oolite in appearance (plate 14, figs. *b* and *c*; plate 15, fig. *a*). It is a soft, white or cream-colored limestone, mostly composed of oolitic granules embedded in a loose matrix of amorphous, or occasionally crystalline, calcium carbonate. The structure of the granules of the two is the same, except silica is rarer in the Key West oolite. The thickness of this formation is unknown, but is tentatively placed by Sanford at 50 feet. It is the rock composing all the keys from No Name and Little Pine to Boca Grande, except the purely mangrove keys.

Although the Key West and Miami oolites are so similar and may be geologically contemporaneous, they are not known to be in contact anywhere, as both the Key Largo and Lostman River limestones intervene between their respective outcrops.

TOPOGRAPHY OF SOUTHERN FLORIDA.

The whole of the area under consideration is one of low relief, the greatest elevation known being perhaps 30 feet. The Miami oolite forms a limestone ridge extending southward from the vicinity of Del Ray to beyond Homestead. The elevations along this ridge are about 8 feet at New River, Fort Lauderdale; perhaps 30 feet south of Miami, and about 8 feet on Long Key in the Everglades. In the vicinity of Miami there is a steeper sea-face with a westward slope, the rock passing beneath and forming the floor of the Everglades. The width of this ridge west of Miami is about 3 miles.

The Everglades are a vast interior swamp, the surface of which is mostly an enormous saw-grass marsh with mottes of timber here and there breaking the monotonous expanse. The altitude is almost the same as that generally prevalent over this section of the State. Some determinations along the eastern margin are: "west of Lantana, 18 feet; west of Hillsboro Inlet, 14 feet; west of Fort Lauderdale, 17 feet; at the pool at the head of Miami River, 6.2 feet. South of the Biscayne pineland and Long Key the height of the Everglades is less than 6 feet" (Sanford). The maximum elevation of the keys east of Key West perhaps does not exceed 5 or 6 feet.

VEGETATION OF SOUTHERN FLORIDA.

The vegetation of the area presents three different types. The oolite ridge is mostly covered by pines, the soil is thin and the surface of the ground rocky (plate 8, fig. *a*); in the Everglades (plate 7, figs.

c and *d*) there is a growth of saw-grass and an accumulation of vegetable muck of varying depth—in some places thin, merely a surface veneer; in others 4 or 5 feet, or perhaps even more, in depth. The interior of the keys is usually a jungle, while often, but not invariably, mangroves fringe the water front (plates 9, 10, 11, and 12, fig. a).

DRAINAGE AND RAINFALL OF SOUTHERN FLORIDA.

Southeastern Florida is a very poorly drained country. There are comparatively few streams leading from the interior swamp to the sea. A small river at Miami, known as Miami River, leads from the Everglades to Biscayne Bay. Another, Taylor River, empties into Florida Bay in southern Dade County. However, a large proportion of the waters of the interior works its way to the ocean, as there is a general southward movement of the waters of the Everglades. There is in the vicinity of Miami and also along the keys direct surface run-off from the landmass into the ocean.

The rainfall for this section of Florida, according to Gannett,¹ is between 60 and 70 inches per annum.

No accurate records have been kept of the surface run-off of the streams and from the swamps of southern Florida. Therefore any figure given must be derived by applying the results obtained in other areas and making allowance for peculiar conditions prevailing in this region. Mr. J. C. Hoyt, in his "Comparison between Rainfall and Run-off in the Northeastern United States," makes the statement:

The run-off is very consistent in the various groups, and decreases toward the south, although the rainfall increases. It is about 60 per cent of the precipitation in the northern areas, 55 per cent in the intermediate areas, and 40 per cent in the southern areas. This decrease in run-off is due to the increase in evaporation and the loss by vegetation, and shows that the climate and vegetation are probably the principal regulating factors in the relation between rainfall and run-off.

* * * * * *

The climatic conditions are responsible for this change in the percentage of run-off between northern and southern areas, rather than geologic conditions or topography, as is shown in the "percentage" column for the summer months, where the percentage of run-offs varies between 20 and 32, having a mean of 27 per cent for all principal basins. This column shows no regular variations for the basins. It also shows that the evaporation and loss through evaporation is very nearly the same over the various areas considered, being about 9.5 inches. (American Society of Civil Engineers, Transactions, vol. 49, p. 436.)

As the temperature of southeastern Florida is never lowered to the freezing-point and as there is a luxuriant vegetation, it is probable that the lowest estimate of run-off given by Mr. Hoyt, 27 per cent, is slightly too high. Therefore 25 per cent² is taken as a more probable figure; and the annual run-off for this area is estimated as 25 per cent of 60 inches, or 15 inches.

¹ U. S. Geol. Surv., Water Supply Paper 234.

² Mr. J. O. Wright, Drainage Engineer, U. S. Department of Agriculture, by a somewhat different process, arrived at the same estimate for the percentage of surface run-off in southern Florida. (Report of the Special Joint Committee of the Legislature of Florida on the Drainage of the Everglades of Florida, pp. 25-29, Tallahassee, 1909.)

The area of Dade County, from which the surface run-off is into the bays and sounds behind the keys, is approximately 1,840 square miles. The surface run-off from this territory would be approximately 0.52 cubic mile per annum. This amount, however, ought to be increased as the waters from Lake Okeechobee and the Everglades move southward, and a portion of them apparently must flow to the southeast. As is well known, a considerable portion of the territory to the north of Lake Okeechobee is drained into that basin and the water is discharged through the rivers leading to the west, east, southeast, and south of the Lake or the Everglades. Therefore the discharge into the bays and sounds is probably between 1.0 and 0.5 cubic mile.

CHEMICAL DENUDATION.

Having given in the preceding remarks the physical surroundings of the bays and sounds, and given an estimate of the surface run-off of the waters, the chemical denudation of the region may be discussed. That chemical denudation is active in southeastern Florida is attested by numerous phenomena. The surface of the Miami oolite is extremely irregular; some irregularities are due to rocks torn from the general oolitic mass by uprooted pine trees, while others are produced by the solvent effect of water, as is especially well shown by small sink-holes, pot-holes, and such phenomena as the Arch Creek natural bridge. According to Mr. Sanford:

The holes, which communicate with underground solution channels, are of all sizes, varying from those not over an inch across to those 20 feet or more in diameter. Their depths range from 3 to over 10 feet. Besides the sharply outlined holes, there are throughout the pineland countless shallow hollows 1 to 3 feet deep and 10 to 100 feet across. A few of these hollows may owe their origin to original conditions of deposition, some may be due to the overturning of trees and consequent upheaval of the rocks loosened by roots, while others have been caused by the falling in of the roofs of subterranean water-courses. Few of the holes and hollows are large enough to be termed sinks. The large vertically walled holes running down to permanent water-level form natural wells, the shallow hollows are best denominated pot-holes. The writer has heard of only one rock-rimmed opening in southern Florida that resembles the great sinks in the country to the north.

* * * * *

While there is danger of exaggerating the activity of underground and surface water in eating away the soft limestone of the east coast, yet there is plentiful evidence of solution. The pot-holes and the hollow-sounding areas of rock, perhaps 25 feet across, with as many as 6 or 7 holes a foot or so in diameter showing the water beneath, that are found along the edges of the southern Everglades, the springs below tide-level at Cocanut Grove, and other points on the shore of Biscayne Bay, the Punch Bowl, a spring basin, the deep holes in New River, and the shallow gorge of Arch Creek with its low rock bridge, all bear witness to the work being done.

The conditions favorable for vigorous chemical denudation⁷ of limestone are: (1) a supply of water charged with CO₂; (2) the water remaining in contact with limestone a sufficient time to permit solution; (3) having dissolved lime to be able to move onward.

Conditions favorable for such denudation are largely realized in southern Florida: there is limestone; the waters become charged with

carbonic-acid gas from passing over large areas of decaying vegetable matter; and, as the flow toward the sea is gentle, there is opportunity for the dissolving acid to act on the limestone. Over a considerable area in the Everglades, although limestone underlies the surface material, the water is prevented from coming in contact with it. Therefore, most of the solution must be accomplished on the higher region of the Miami oolite and the coastal fringe of the Lostman River limestone. There is also chemical denudation on the Key Largo limestone and Key West oolite of the keys. The following quotation from Dr. Sellards is appropriate in this connection:

Among these agencies of erosion, underground water has acted in Florida under exceptionally favorable conditions. In areas of considerable slope, and with relatively impervious formations, the surface run-off is large. Under these conditions those features of topography determined by the rapid downward cutting of the surface streams and their tributaries predominate. In Florida the surface slope is slight. The open nature of the soil and rock permits the greater part of the water to enter the earth, establishing subterranean rather than surface drainage. The rocks are prevailingly calcareous and soluble. Under these conditions the work of the underground water predominates over surface erosion. In central Florida the topography, soil, and general surface features are determined to a large extent by the work of underground water.

Solution is the most apparent, and geologically the most important result of underground water circulation. Rainwater, while passing through the air, takes into solution a small amount of CO_2 gas. To this is added organic and mineral acids taken up while passing through the soil. Increased pressure, as the water descends into the earth, enables the water to hold in solution greater quantities of gases, acids, and salts, all of which greatly increase the dissolving power of the water.

That underground water is efficient as a solvent is evident from the analyses of well and spring waters. Rainwater entering the earth with almost no solids in solution returns to the surface through springs and wells with a load of mineral solids in solution determined by the length of time it has been in the ground, the distance traveled, and the character of the rocks and minerals with which it comes in contact.

The mineral matter thus taken into solution is carried along with water, and while some of it is redeposited, a large amount is removed annually. An estimate of the total mineral solids thus removed is difficult. A conception of the largeness of the amount removed is obtained from a consideration of some of the individual springs.

The water of Silver Springs contains, as shown by analysis, 274 parts solids per 1,000,000 parts water. Otherwise expressed, each 1,000,000 pounds of water is carrying with it 274 pounds of solids in solution. Silver Spring is estimated to flow a little more than 3,000,000 pounds of water per minute (368,913 gallons). The interior of Florida is thus being carried into the ocean through Silver Springs at the rate of more than 340 pounds per minute or about 600 tons per day.

The total solids removed in solution through 6 other springs of central Florida, expressed in tabular form, gives the following results:

Name of spring.	County.	Total solids parts per 1,000,000. ¹	Estimated flow (gal- lons per minute).	Solids removed (pounds).
Blue.....	Marion.....	112.1	349,166	469,698
Blue.....	Levy.....	196.8	25,000	59,040
Ichatucknee.....	Columbia.....	311.6	180,000	457,056
Newland.....	Suwanee.....	233.5	75,000	210,150
Weekiwachee.....	Hernando.....	227.8	100,000	273,360
White Sulphur.....	Hamilton.....	166.6	32,400	64,744
Suwanee.....	Suwanee.....	332.7	52,000	207,605

¹ Organic matter is deducted from the total solids as given for Suwanee Sulphur and White Sulphur Springs. The organic matter occurring in the other springs is of small amounts and was not separately determined.

As the basis of an estimate of the total solids removed annually from the interior, let it be assumed: (1) that the average total solids in spring water amounts to as much as 219 parts per 1,000,000, this average being obtained from 8 of the typical large springs of central Florida; (2) that the annual escape of the underground water approximates the annual intake, amounting, as previously estimated (p. 16), to 460,536,689 gallons per square mile. Upon these estimates the mineral solids removed amount to a little more than 400 tons annually per square mile.

Of the minerals thus removed, calcium carbonate or limestone greatly predominates, exceeding the combined weight of all other minerals. From the analyses it appears that magnesium carbonate, magnesium and calcium sulphates are present in variable, although usually limited quantities. Chlorides are normally present in small amount, although occasionally, as in the case of Perrian Spring, they are exceptionally high. Silica is present in amounts varying from 5 to 25.5 parts per 1,000,000. Traces of phosphoric acid and of iron and alumina are usually present.

The several undetermined factors which enter into the above estimates of mineral solids removed make it difficult to formulate a concrete statement of the rate of lowering of the general surface level. Nevertheless, such statements are desired and have a comparative value. Assuming for the rock removed, most of which is limestone, an average specific gravity of 2.5, a layer a foot thick over a square mile should weigh about 2,166,666 tons. The calculated rate of removal of this rock is about 400 tons per square mile per year. From these estimates it would appear that the surface level of the central peninsular section of Florida is being lowered by solution at the rate of a foot in 5,000 or 6,000 years. (Preliminary Report on the Underground Water Supply of Central Florida, Florida Geol. Surv., Bull. No. 1.)

When an attempt is made to estimate the amount of calcium carbonate borne into the sea by the waters of southeastern Florida, the difficulty is immediately encountered of no analytical records having been kept of the waters; therefore any estimate must be based upon a comparison with other regions, and the result obtained in those regions is of doubtful applicability to the one under discussion. Sir John Murray¹ averaged the analyses of 19 rivers and obtained the result that 326,710 tons of CaCO_3 per cubic mile of water were discharged into the ocean. The quantity per cubic mile in southeastern Florida may be somewhat greater. Therefore it is suggested that the amount of this material poured annually into the bays and sounds of this region may be between 400,000 and 500,000 tons, or about $\frac{1}{2300}$ of a cubic mile of limestone. This amount of material spread over the floor of the bays and sounds after a considerable proportion has drifted seaward would give only a thin coating for each year.

PRECIPITATION OF CHEMICALLY DISSOLVED CALCIUM CARBONATE.

The problem of the precipitation of the CaCO_3 in solution after it has been carried into the sea presents itself. The only definitely known process by which this may be accomplished is by the expulsion of the CO_2 . This may be brought about by several methods: it may be driven off by the heat of the sun, it may be lost by the agitation of the waters, or extracted by marine plants. As it is not likely that the surface of the sea is heated to a higher temperature than that of the land, mechanical agitation and the action of marine plants are considered the most probable causes of precipitation in Florida waters.

¹ Scottish Geograph. Mag., vol. III, pp. 76, 77, 1887.

In the shallow waters near the shore the opportunity for re-solution as the material settles to the bottom is not afforded and the accumulation on the sea-bottom of large quantities of amorphous calcium carbonate, apparently not of detrital origin, is undeniable. The series of samples collected between Miami and Big Pine Key is evidence of this, and additional evidence was obtained by the examination of the surfaces of numerous banks.

One bank about 2 miles northeast of Pigeon Key and another, the shoal west of the upper end of Long Island, have been built nearly to the surface of the water, and are composed of loose calcareous ooze into which I sank while attempting to walk on them to my knees or slightly deeper. An oar could be pushed an undetermined number of feet into the material. Mr. Sanford informs me that a rod can be forced down 10 feet or more. In fact, the depth of this soft material has not been determined.

WHITE-WATER PERIODS.

The white-water periods in the Floridian region are famous. One of the early descriptions of them was given by Captain Hunt.

The tidal currents set strongly across the reef and through the channels between the keys, the flood running to the north and the ebb to the south side of the key crescent. When storms occur, the agitation of the waves extends to the bottom, over the shallower portions of the grand Bank, and stirs up the sand violently. This causes the water to take up and maintain in mechanical suspension such finely comminuted particles as have too little sinking force rapidly to reach the bottom again. The finer the particles the longer will they remain suspended, and the very coarse grains will hardly be lifted from the bottom. Between the coarsest and finest are grains of all intermediate sizes, and whether they will be suspended or not depends on the violence of the storm, and their interval of suspension varies with their size and the violence of the waves. It results that, in all storms of much violence, the water over the Florida Bank becomes white with the bottom deposits. In long, severe northers or gales, the water becomes almost milk-white across the whole Bank. This "white water" is a familiar appearance, and is one of the sure signs of proximity to the reef. As storms subside, the white sand and mud are gradually thrown down, and the water clears, after a day or two, to its peculiarly delicate transparency. (*Am. Jour. Sci.*, 2d Ser., vol. 35, p. 200, 1863.)

EFFECT OF SEA-SPRAY.

So far the only kind of chemical denudation considered is that resulting from the surface run-off of rainwater, but there is another kind operative around a considerable portion of the south Florida shores. This is corrosion by waves and sea-spray beating on limestone ledges. Very good instances of this kind of corrosion are seen on the western face of Gun Key, Bahamas, and illustrations from photographs are shown on plate 8, figs. *b* and *c*. There are at present no means of estimating the amount of CaCO_3 derived in this way, but it is probably considerable.

CALCIUM CARBONATE DERIVED THROUGH SURFACE EROSION.

A considerable portion of the Miami oolite is soft and more or less pulverulent. The detachment of masses from the surface by uprooting due to falling trees, etc., furnishes an opportunity for running water to wash away considerable quantities of limy matter. A portion of this,

of course, is washed into the sea in suspension, where it is precipitated on the bottom, increasing the quantity of the calcareous sediments.

Another possible source of material is the region north of the west coast of Florida Bay. Various streams, namely Caloosahatchee River, a number of smaller streams emptying into the Gulf in the vicinity of Thousand Islands, and others further south, cross areas underlain by strata containing more or less lime. A portion of these waters may work their way southward into Florida Bay and contribute to the supply of sediment for that region.

CALCIUM CARBONATE OF ORGANIC ORIGIN.

A large proportion of the calcium carbonate of this region is of organic origin. This is shown by the number of tests of various animals found in almost any dredge haul, and those washed ashore, particularly after storms. The principal constituent of this material is furnished by marine mollusks. Foraminifera are important, as along the shores of the keys one of the commonest organisms is *Orbiculina adunca*. Corals have contributed to the calcareous material, but they are not very abundant within the main line of the reefs and behind the keys. The region between the keys and the main Florida shore is decidedly different from that further to the west represented by the Marquesas and the Tortugas. The limestone composing these two groups is very likely almost entirely of organic origin. On the Tortugas, although corals contribute a large proportion of the calcium carbonate, it appears that they are probably secondary in importance to the mollusks. The breccia on Loggerhead Key is largely formed of wave-tossed molluscan shells.

Two additional sources may furnish calcareous sediment to the bays and sounds. The first is one to which attention was first called by Captain Hunt,¹ whose view was advocated by Mr. Agassiz in his "Three Cruises of the Blake" (p. 57).

As the prevailing direction of the winds and waves, both of trade and hurricane origin, upon the Florida reef is from northeast to southeast, they tend to pick up and carry behind the keys the loose sediment previously prepared by the pounding of breakers; and sediment once having lodged behind there is not likely all to be transported back to the sea by the ebbing of the tides, although, as will be shown later, the outward flowing tidal currents in some instances build deltas at the seaward end of passages between keys.

The general character of coral reefs and the effect of the waves in comminuting pieces of coral or the shells of other organisms have been so frequently and fully described that it is superfluous to furnish a description here.

RÉSUMÉ OF SOURCES OF CALCAREOUS SEDIMENTS.

Reviewing the sources of the calcareous sediment poured into the bays and sounds we find:

- (1) That from the mainland and keys surrounding them. This material is derived both by chemical denudation and mechanical erosion.

¹ Am. Jour. of Sci., 2d Series, vol. 35, p. 202, 1863.

- (2) The calcareous remains of organisms living in the waters.
- (3) Detrital material washed behind the keys from the reefs and flats lying outside of them.
- (4) Some material may be brought southward along the west coast of Florida.

At present data are not available for determining the proportion due to each one of these sources.

GEOLOGIC DISTRIBUTION OF LIMESTONE IN FLORIDA.

It may be appropriate here to give a statement of the geologic history of limestone in Florida similar to that made for the siliceous deposits. The following is a list of the calcareous formations of the State, presented in stratigraphic sequence:

Pleistocene: Palm Beach limestone, Miami oolite, Key Largo limestone, Key West oolite, Lostmans River limestone.

Pliocene: Marls are abundant but limestone is not known.

Miocene: Jacksonville formation: Contains some limestone beds.

Oligocene:

Apalachicola group: Alum Bluff formation, some impure limestone; Chattahoochee formation, mostly impure limestone; Hawthorne formation, some limestone; Tampa formation, some limestone.

Vicksburg group: This group is composed mostly of more or less pure limestone. There are some marl and sandy beds and layers of chert.

In reviewing the geologic formation of Florida it is immediately evident that the Vicksburg group comprises the great limestone formations of the State. Although there are calcareous constituents in the Upper Oligocene, Miocene, and Pliocene, very rarely is there pure limestone; more frequently the material is composed of clays or sands with a large proportion of calcareous matter. In other words, Florida is very largely made up of continental waste, but the older geologic formations contain sufficient lime to furnish calcareous material to the streams flowing across their surface.

TERTIARY CORAL REEFS OF THE SOUTHERN UNITED STATES.

The rôle coral reefs have played in building up the Peninsula of Florida can easily be understood by outlining the geologic history of the reefs of that and adjacent regions as we now know them.

Oligocene, Vicksburg Group.—There was no extensive development of coral reefs during Vicksburgian time. In fact, the only reef known which may be referable to it is the one at Salt Mountain, near Jackson, Alabama. It is of comparatively few acres in extent, and regarded as a constructive geologic factor is of almost negligible importance.

Oligocene, Apalachicola Group.—Coral reefs belonging to this group are known at several localities. Probably the most extensive development is in the vicinity of Bainbridge, Georgia, where exposures may be seen along Flint River from a point 3 or 4 miles below that town through a distance of 4 or 5 miles. Reef corals of the same geologic age are also known from the McIntyre plantation, 11 miles south of Thomasville, and at other places in Thomas County, Georgia; and from southern Lowndes County. In Georgia, however, although there were Upper Oligocene coral reefs they were not of great importance as constructional agents.

In Florida, Upper Oligocene reef corals are known from several localities. The most northern is in Wakulla County, near Wakulla Station, between Tallahassee and St. Marks; fossil corals are also found at White Springs, on the Suwanee River; large heads of *Siderastrea* are abundant in the vicinity of Alachua, Alachua County, and the chalcudonic replacements of corals from the vicinity of Tampa are widely known. Compared to the total extent of the Upper Oligocene formations in Georgia and Florida, corals play an insignificant role; they possess more importance as furnishing means of correlating geologic formations than as constructional agents.

Miocene.—No coral reefs of Miocene age are known in the Atlantic and Gulf Coastal Plain. A few fossil species are known and for stratigraphic purposes they are of value.

Pliocene.—No Pliocene coral reefs are known. Professor Heilprin, in his discussion of the exposures along the Caloosahatchee River, called attention to the comparative scarcity of corals and the great abundance of shells in the Caloosahatchee marl. On Shell Creek corals are relatively more abundant, but they are not strictly reef-building species, belonging rather to species that grow on flats, and especially the inner flats behind keys.

Pleistocene.—The second extensive development of coral reefs in Florida took place in Pleistocene time.

Attention may be called to Captain Hunt's estimate of the time necessary for the formation of southern Florida. He bases his estimate on two assumptions: first, the rate of growth of corals as observed by him in the neighborhood of Key West; second, that the whole of southern Florida has been built up by the activity of these organisms, whose calcareous remains after having been pounded into sand by the sea go to form great limestone flats. Captain Hunt's estimate of the rate of growth of corals is open to doubt, and his second assumption is fundamentally wrong.

TRANSPORTING AGENTS OF THE FLORIDA COAST AND THEIR EFFECTS.

In the preceding pages an attempt has been made to give an account of the character of the sediments accumulating along the shores of southern Florida, to determine the sources of their constituents, to indicate the processes by which they were brought to the sea, and to trace in outline the stratigraphic distribution of similar material in the State. It is now proposed to consider the destiny of the sediment delivered to the ocean. This subject will be introduced by an account of the forces operating in the ocean to distribute the sediments or accumulate them in certain areas.

Currents are the agency by which distribution is effected, and are represented by three types, viz: (1) more or less constant oceanic currents; (2) tidal currents; (3) currents due to winds.

FIG. 3.—Current Chart of Florida Water (from Pilot Chart, Hydrographic Office, U. S. N.).

CONSTANT CURRENTS.

The most important constant current is the Gulf Stream, which flows along the 100-fathom curve, passing between the Florida Keys and Cuba on the south, and the eastern coast of Florida and the Bahamas on the east. This current can not directly have much influence on the

sedimentation on the Floridian Plateau, although it is indirectly of great importance. The current of greatest direct importance is the counter-current which follows the eastern coast of the United States from Cape Hatteras southward. In the Floridian region it is called the Florida countercurrent and has long been known to be an important factor in building up the Floridian Plateau, as is attested by the writings of Captain Hunt and Mr. Alexander Agassiz; and Dr. Gulliver has recognized its importance in determining the configuration of the shore-line. This current passes through the Straits of Florida and continues as far west as the Tortugas. The direction of its movement is southward until the southern extremity of the Peninsula is reached, where it turns westward.

According to the Pilot Chart of North Atlantic Ocean, March, 1909:

In the Straits of Florida the countercurrent is very uncertain. Under favorable conditions of weather it extends as much as 11 miles offshore, but it generally makes a westerly course to Sand Key within the line of the reefs, though with certain winds it runs north or south between the keys and northeast around the Tortugas.

TIDAL CURRENTS.

The flow of the tides is transverse to the keys, and rather strong tidal currents pass in and out between the keys. These are strong enough to sweep the bottoms of the passages clean.

WINDS.

The following data on the winds of southern Florida are taken from the Pilot Charts of the North Atlantic Ocean for the year 1907, published by the Hydrographic Office of the Navy Department. No attempt will be made to present the data in detail, and only the prevailing directions of the winds for each month will be given:

Jan. : Northeast, east, northwest, north, southeast. (The component direction is from the northeast.)	June: Southeast, east, south.
Feb.: Southeast, northwest, east, and northeast.	July: Southeast, east, south.
Mar.: Southeast, northwest, northeast.	Aug.: Southeast, east, south.
Apr.: Southeast, east, northeast.	Sept.: Northeast, southeast, east.
May: Southeast, east, northeast.	Oct.: Northeast, east, north.
	Nov.: Northeast, north, northwest.
	Dec.: Southeast, northeast, east, northwest.

The preceding data show the prevailing direction of the winds to be from the southeast from February to August inclusive, varying from northeast to southeast from February to May, and from southeast to south from June to August; from the northeast from September to January, but with considerable variation. The general direction of the winds is either along or transverse to the line of the keys.

The tides and winds, as Captain Hunt suggested, tend to carry material from the reefs and flats to the area behind the keys; while the countercurrent moves material southward and westward. The winds and tides by agitating the sea-bottom bring material within the influence of the countercurrent and thus aid in its work of southward transportation. Without this assistance probably the countercurrent would not produce great effects.

EFFECT OF THE FLORIDA COUNTERCURRENT ON THE SHORE TOPOGRAPHY OF FLORIDA.

When a map of the east coast is examined, its long sweep and gentle curves are immediately observed; there are no prominent salients or deep indentations, no small irregularities, and for miles the shore-line may be almost straight. Several other features are to be correlated with the alongshore current.

(1) *Elongated sounds* called rivers paralleling and lying near the coast: north of St. Augustine are Tolomato or North River and Guano River, both of which empty to the southward, and south of that city is the Matanzas River which empties to the northward, the three finding an exit to the ocean through St. Augustine Inlet (fig. 5). The Matanzas River has a smaller inlet from the sea at its southern end. Following the coast southward, Halifax and Hillsboro rivers are in communication with the ocean through Mosquito Inlet. The latter "river" connects at its southern end with Mosquito Lagoon, which is just north of Cape Canaveral. Back of this cape and of the beach to the south of it is Banana River, which is barely separated from the northern portion of Indian River. In fact, Mosquito Lagoon, Banana River, and Indian River are all more or less in communication through Banana Creek, which forms an irregular, sinuous northern boundary of Merritt Island. Indian River is succeeded to the southward by Hobe and Jupiter sounds and Lake Worth. Between Hillsboro Inlet and the northern end of Biscayne Bay are several small lagoons and salt-water creeks.

(2) *The beaches and islands* along shore have their southern ends elongated, often pointed, while their northern ends are wider and frequently more or less truncated. Amelia Island, on which Fernandina is situated (fig. 4), is an instance of such an island with a truncated northern end. Anastasia Island, on the south side of St. Augustine Inlet, is another instance, but its northern end is not so obtuse as that of Amelia Island (fig. 5).

(3) *Southward Deflection of Stream-mouths*.—Two good instances of this phenomenon are seen in the vicinity of Fernandina (fig. 4). To the north of Anastasia Island is Cumberland Sound, through which St. Mary's River empties into the ocean; to the south is Nassau Sound, through which Nassau River flows. Both of these sounds are directed from the northwest to the southeast. New and Middle rivers, the streams next north of the upper end of Biscayne Bay, have their mouths deflected southward. The phenomenon is general along the Florida east coast.

(4) *Overlaps and Offsets*.¹—Instances of both these phenomena are present and can be seen in the vicinity of St. Augustine (fig. 5). The point of land north of St. Augustine Inlet overlaps the northern end of Anastasia Island; overlap and offset are necessary accompaniments of the kind of stream deflection exhibited along this coast.

(5) *Current Cuspate Forelands*.—Gulliver has cited Cape Canaveral as an almost typical example of this shore form (fig. 6).²

¹ Gulliver, *Shore-line Topography*, Proc. Amer. Acad., vol. xxxiv, 1899, p. 178.

² Proc. Amer. Acad., vol. xxxiv, p. 180, fig. 10.

FIG. 4.—Map of the Florida Coast, from the mouth of St. Mary's River to the mouth of St. John's River. (From U. S. Coast Surv. Chart, No. 158.)

FIG. 5.—Map of Florida Coast in vicinity of St. Augustine. (From U. S. Coast Surv. Chart, No. 159.)

FIG. 6.—Map of Cape Canaveral. (From U. S. Coast Surv. Chart, No. 161.)

MAP SHOWING CAESARS CRI
(From U. S. Coast and Ge

MAP SHOWING CAESARS CREEK AND OLD RHODES BANKS
(From U. S. Coast and Geodetic Survey Chart No. 166)

The west coast of Florida strongly contrasts with the eastern; the absence of prevalent alongshore currents is especially striking. Cape Sable seems current-shaped by alongshore currents. From Cape Sable to Cape Romano the coast line is minutely lacinate; from Cape Romano to Anclote Keys there is evidence of shore currents, keys with sounds behind them paralleling the coast; from Anclote Keys to the mouth of Ocklockonee River, just east of St. George Island, the coast is minutely irregular. From the eastern end of St. George Island the coast is swept by the countercurrent on the north side of the Gulf.

The preceding account of the shore-line topography of Florida from the standpoint of currents has an immediate bearing on contemporaneous sedimentation and the building of such sand-spits as occur on the eastern side of Biscayne Bay, and such keys as Virginia Key and Key Biscayne. Arenaceous material is swept southward by the ocean currents on the outside of this spit and the two mentioned keys; while behind them Snake Creek and Miami River are bringing their burdens of sand from the mainland. The tendency of the process is to fill up Biscayne Bay and not only to connect the spit and arenaceous keys to the mainland, but to join them to the coral reef keys farther south.

BANKS BEHIND KEYS.

Sediment, mostly calcareous, is accumulating in the bays and sounds behind the keys and is gradually filling them, although some is carried to the outside. As has been stated, the tides run across the line of keys, and the tidal currents have usually swept clean the channels between them; but behind them are regions of slack water, and shoals are built. The ridges and shoals behind Key Largo, Long Island, and the Metacumbes are very instructive. No hard material at all was found at any locality examined.

Mangroves are an important factor in this work of construction. When a shoal attains to about a foot of the surface of the water, the floating pods of these plants catch on the soft bottom, take root, grow, and develop root tangles below and tangles of branches above. They catch and retain floating debris and convert the shoal into an island. (See plates 9, 10, 11, and 12, fig. *a*.)

DELTA AT OUTER ENDS OF PASSAGES BETWEEN KEYS.

Attention should also be called to the deltas forming at the seaward end of some of the passages between keys. Professor Shaler was the first to remark on this phenomenon,¹ stating, "The volume of the material can best be judged by the conditions exhibited by the deposits of limy matter at the eastward end of the channel passing from Biscayne Bay to the sea, known as Cæsars Creek." This is not the only locality at which such a delta is forming. The U. S. Coast Survey chart, No. 166, indicates one at the eastern end of Bear Cut, off Cape Florida, and at the mouth of Broad Creek, the last-mentioned bank being known as Old Rhodes Bank (plate 3). There are probably other instances of this phenomenon.

¹ Topography of Florida, Mus. Comp. Zool., Bull., vol. xvi, p. 147, 1890.

AREAL DISTRIBUTION OF THE GEOLOGIC FORMATIONS.

This subject may be introduced by reference to the Table of Geologic Formations given on page 126 of this paper and to plate 4. For stratigraphic descriptions the "Preliminary Report on the Geology of Florida" by Messrs. Matson, Clapp, and Sanford¹ may be consulted.

OLIGOCENE.

VICKSBURG GROUP.

The rocks belonging to this group, the oldest geologic formation known on the Peninsula, form the surface of the area from Sutherland in the northwest corner of Hillsboro County northward to the vicinity of Newberry and Gainesville. The western boundary is almost on the water front at Sutherland and lies only 5 or 6 miles from the shore of the Gulf from that place to Crystal River, beyond which it curves to the northwest, roughly paralleling the shore at a distance of 6 to 12 miles from it, to 6 miles south of the latitude of Cross City. This boundary is slightly concave toward the west and is separated from the shore of the Gulf by a narrow fringe of Quaternary deposits, ranging from 1 to 12 miles in width. The northern boundary of the area is a slightly sinuous line running in an easterly direction from opposite Pine Point through Old Town, Newberry, just south of Gainesville, to Lockloosa. From the last-mentioned town, the boundary bends southward and passes through Sumterville, whence it extends southwestward to Sutherland. The eastern boundary is strongly convex to the east. North of this main area there are outlying small areas almost as far north as the latitude of Lake City. If the boundaries of the main area were extended so as to include the outliers, they would still retain a concavity on the west and a convexity on the east.

APALACHICOLA GROUP.

As is implied in the preceding paragraph rocks of the Apalachicola Group are not present between the western boundary of those of the Vicksburg and the Gulf. The rocks of the main Vicksburg area pass beneath the Apalachicola rocks on all sides except on the west, and all outlying areas of the former are surrounded by rocks of the latter group. The Apalachicola rocks continue northward into Georgia where outcrops of the Vicksburg limit their northern extension. They extend to the westward, separated from the coast by a margin of Pleistocene deposits, to the vicinity of the mouth of St. Marks River, where they reach the coast through a stretch of several miles. Thence they extend westward to the Ocklockonee River near Sopchoppy, from which place the boundary bends northward, passing west of Tallahassee; there it is sharply flexed to the west and crosses the Apalachicola River at Alum Bluff. Westward of a point 9 to 10 miles west of Tallahassee an area of Miocene (the Choctawhatchee formation) intervenes between the Apalachicola and the coastal fringe of Pleistocene deposits.

¹ Florida Geol. Surv., 2d Ann. Report.

data from the map of Florida prepared by the U.S. Geological Survey, 1909
Submarine Contours by G.C. Matson and F.G. Clapp
Submarine Contours from Coast and Geodetic Survey and Hydrographic Office charts

GEOLOGIC MAP OF FLORIDA

കുറിപ്പ്: 2000-01

0 10 20 30 40 50 60 70 80 90 100
kilometers

Geology prepared under the direction of T. Wayland Vaughan by
G.C. Matson, F.G. Clepper, and Samuel Sanford in cooperation
between the U.S. Geological Survey and Florida Geological Survey.
Adapted from Florida Geological Survey, Second Annual Report 1909.

Toward the east the Apalachicola Group is overlain near the eastern boundaries of Baker and Bradford counties by Miocene sediments (Jacksonville formation). The Miocene projects southward, as a tongue, over the Apalachicola as far as Waldo. Northwest from Palatka to the south fork of Black Creek the Apalachicola boundary is formed by the Pleistocene of St. John's River valley. Along the west side of St. John's River valley, from Palatka southward to Enterprise Junction, the boundary is formed by the overlapping of the Pliocene Nashua marl. The boundary curves to the southwest of the latter town, passes through Orlando, Lakeland, and reaches the Gulf at Tampa. Along this stretch from Enterprise Junction to Tampa, the boundary is between the Apalachicola and the Pleistocene. South of Tampa two small outlying areas of Apalachicola sediments are known, one at Ellenton near the mouth of Manatee River; the other at White Beach,¹ between Osprey and Sarasota.

MIOCENE.

Two Miocene areas are known in the State, a western and an eastern. The former extends westward from near Tallahassee, and is bounded on the north by deposits of the Apalachicola Group, and on the south by those of Pleistocene age. The eastern area has its western boundary formed by the Apalachicola Group. Except below the south loop of St. Mary's River, where the Apalachicola outcrops, the northern boundary is formed by Pleistocene deposits to St. John's River, about 6 miles north of Jacksonville. From Jacksonville to St. Augustine on the east the Miocene passes below Pleistocene and also from St. Augustine westward to the South Fork of Black Creek. This area of Miocene is bounded on the west by rocks of the Apalachicola Group; on the north, east, and south by Pleistocene.

PLIOCENE.

There are two principal areas of Marine Pliocene. The more eastern and northern of them (the Nashua marl) flanks the Apalachicola Group from Palatka to Enterprise Junction along the west side of St. John's River, and is overlain on the east by Pleistocene formations. On the northeast the boundary runs southeast from Palatka toward Daytona, thence it turns south to Osteen, then westward to Enterprise Junction.

The other area of Pliocene (the Caloosahatchee marl) is mostly overlain by Pleistocene deposits, and outcrops of it are seen only along streams, the Miakki River, Chilcoccohatchee River, Peace, Prairie, and Alligator creeks, all of which flow into Charlotte Harbor and Caloosahatchee River.

PLEISTOCENE.

Southeast of the surface exposures of the Nashua marl and coastward of the southeastern and southern margin of the Apalachicola Group lying west of those exposures the entire surface to the sea front is formed by Pleistocene formations, except a few outliers of the Apalachicola Group, the marine Pliocene Caloosahatchee marls along some streams, and the non-marine Pliocene Bone Valley gravel near Bartow, from Homeland to Mulberry, and at Bonè Valley.

¹ It seems that this locality was not included by Messrs. Matson and Clapp in their report.

GENERAL RELATIONS OF GEOLOGIC BOUNDARIES IN FLORIDA.

The preceding account of the areal distribution of the geologic formation according to successive ages has been given to show how the rocks of Vicksburgian age form an eccentric nucleus, on whose northern, eastern, and southern slopes younger geologic formations have been laid down. The next younger group extended northward into Georgia, in which State the Vicksburg again comes to the surface; but toward the east, southeast, and south in Florida it is overlain by later sediments. The boundaries between older and younger sediments are roughly concentric to the Vicksburg nucleus on the east and south, tending to widen their areas to the south. This statement may appear doubtful, but when it is recalled that Apalachicola sediments extend from the northern end of Tampa Bay to below Sarasota Bay, a glance at the map will show the greater width along a north-and-south line in this area than along an east-and-west line through Palatka. A curved line would have to be drawn from Daytona to Lake Flirt on the Caloosahatchee to show the widening of the Marine Pliocene toward the south. South of St. Augustine the Miocene has been buried by Pliocene and later sediments.

The present coast line preserves this relation to the Vicksburg nucleus, but with the southward extension there has been a flattening opposite the eastern convexity of the old nucleus.

DRAINAGE LINES.

An examination of the map of Florida with reference to the drainage lines immediately shows that the State may be divided into two areas. In the extension westward from Aucilla River, a region actually a part of the main continental mass lying north of the Gulf of Mexico, the stream courses are normal to the Gulf Coast. The other area is the Peninsula portion of the State. In the latter there is a general conformity of the stream courses in the vicinity of the Vicksburg nucleus to its outline, while away from it they more or less parallel the east and west coasts.

The streams of the Peninsula are those of special importance for this discussion. Santa Fe River runs westward near the northern boundary of the Vicksburg, to its confluence with the Suwanee River, whence the latter stream trends southward across the northwestern corner of the Vicksburg area. Between the headwaters of the Santa Fe River and the Ocklawaha is a comparatively low divide with an elevation of very little over 100 feet. Ocklawaha River follows near the eastern boundary of the Vicksburg-Apalachicola from Lake Griffin northward to the latitude of Nashua; then it bends abruptly eastward and flows into St. John's River. Between the headwaters of the Ocklawaha and those of the Withlacoochee and Hillsboro rivers is a region of low relief, in which, excepting a few hills, no place attains an elevation of 100 feet above the sea. Hillsboro River approximately parallels the southeastern boundary of the Vicksburg-Apalachicola groups. These data show that there is from the confluence of the Santa Fe with the Suwanee

Base from the map of Florida prepared by the U. S. Geological Survey, 1909
Submeral Contours by G. C. Watson and F. G. Clapp
Submeral Contours from Coast and Geodetic Survey and Hydrographic Office charts

TOPOGRAPHIC MAP OF PENINSULAR FLORIDA
WITH PRINCIPAL DRAINAGE LINES EMPHASIZED

Scale 250,000
Submeral contour interval 50 feet

a valley approximately paralleling the northern, eastern, and south-eastern boundary of the Vicksburg and the Apalachicola. (See plate 5.)

The only stream which does not conform to this arrangement is the Withlacoochee. A study of the map leads to the suggestion that it has been formed by a stream working backward from the coast across the Vicksburg area, and capturing a part of the headwaters of both Hillsboro and Ocklawaha rivers, so that the non-conformity of the Withlacoochee to the arrangement of the other streams is a later development.

The striking manner in which the northward flowing St. John's River parallels the coast has frequently been emphasized, but the trends of the southward flowing Kissimmee and Peace rivers are not less striking. South of the elevated region in the vicinity of Haines City, the two main drainage lines not only trend southward, but at their southern extremities are deflected toward the west. The deflection of Peace Creek is through Charlotte Harbor, and the Kissimmee flows through Lake Okeechobee, which is connected with the Gulf by the Caloosahatchee.

The trend of the drainage lines of Florida is therefore at first roughly concentric to the Vicksburg nucleus and proceeding away from this nucleus toward the east and the south the trends conform to the general scheme of arrangement of the geologic formations and to the coast line. The eastern coast of Florida follows a long sweep toward the southeast, then bends south and turns by a curve toward the west.

The analogies of the eastern and southeastern outlines of the Vicksburg nucleus, the arrangement of the main drainage lines, and the outline of the eastern and southern coasts of Florida are so striking that one is forced to the conclusion that some common cause lies beneath all of these phenomena.

GEOLOGIC HISTORY OF THE FLORIDIAN PLATEAU.

EVENTS OF VICKSBURGIAN TIME.

THE VICKSBURGIAN SUBMERGENCE.

During Vicksburgian time remarkable uniformity of marine conditions prevailed throughout an extensive area of what are now the southern United States, from central Louisiana, across Mississippi, Alabama, and Georgia, and similar sedimentation was also taking place on the Floridian Plateau, practically to its southern extremity, should the material from the deep well at Key West, studied by Hovey, be trustworthy. A well record from Palm Beach, given on page 127, shows that Vicksburg rocks were there encountered between 915 to 1,000 feet below the surface. At Key West, according to Hovey,¹ *Orbitoides* first appears in abundance at a depth of 900 feet.

DEPTH AND TEMPERATURE OF THE WATERS.

It is important to determine the approximate depth of the Vicksburgian Sea; as it is the oldest geologic formation known on the Floridian Plateau, light will be thrown on the age of the Plateau. The formation of an opinion on this subject may be made possible by data from two sources: (1) the material composing the sediments; (2) the character of the fauna.

In Florida, the Vicksburg Group has been tentatively divided into three formations, as follows: in west Florida, the Marianna limestone; on the Peninsula, "Peninsular" and Ocala limestones. Recent investigations in Georgia render it probable that only one formation should be recognized, for in that State the Ocala can be definitely identified, and no demarcation of the Marianna or "Peninsular" at present seems possible. In this discussion, which is an account of physical events, the "Peninsular" and Ocala limestones are spoken of collectively by the group-name Vicksburg. The Vicksburg limestones are predominately calcareous, as the terminology suggests, but they are not pure, considerable proportions of both clay and silica being present. Matson makes the following statement:

These beds are uniformly fine-grained and show little variation in chemical composition. There is a predominance of limestone, though sand and clay occur in small quantities, and the percentage of these impurities in the limestone increases in the upper beds of this age. There is also an increased percentage of terrigenous material toward the northern end of the State, where the proximity of older land afforded opportunity for the entrance of considerable sand and mud into the Vicksburg sea. Toward the close of this period of deposition there appears to have been a shoaling of the seas which permitted the entrance of the fresh-water shells and the land-derived sediments noticeable in the Ocala limestone of the Vicksburg Group. The excellent state of preservation of many of these shells shows that the

¹ Mus. Comp. Zool., Bull., vol. xxviii, p. 67, 1896.

water must have been comparatively quiet during the deposition of the limestone. The inclusion of a small percentage of land-derived sediments and in some places of fresh-water shells shows that a portion of the limestones of Vicksburg age were probably deposited at no great distance from land. Locally the calcareous sediments appear to have contained large quantities of silica, probably in the form of tests of microscopic plants (diatoms) and spicules of sponges. (Florida Geol. Surv., 2d Ann. Report, p. 162, 1910.)

The most persistently conspicuous fossils of this group of rocks are foraminifera. Specimens and species of the genus *Orbitoides* are the most abundant. This genus occurs not only from bottom to top, but extends upward from the Jackson¹ below, and into the higher Chattahoochee.²

In the Jackson at Montgomery, Louisiana, *Orbitoides* is associated with shallow-water corals, as *Astrangia*; in the Vicksburg at Rosefield, Louisiana, and in Mississippi and Alabama it is associated with shallow-water mollusks, as *Ostrea*. The Vicksburg corals of Mississippi indicate a depth of water not over 50 fathoms, and it may have been much shallower. As the same species found in Louisiana, Alabama, and Mississippi occur in Georgia, a similar moderate depth is inferred for that region. The fauna of the area extending from Louisiana to the Savannah River distinctly indicates shallow-water conditions, probably a maximum depth of 50 fathoms, as the faunal associations of *Orbitoides* are those of shallow water, or less than 100 fathoms. Doctor Dall has given a list of species from the Ocala limestone in his Tertiary Fauna of Florida.³

The recent collections made by the Bureau of Fisheries steamer *Albatross* in the Philippine Islands throw additional light on this problem. At Station D 5179, off the northeast shore of Tablas Island (depth 37 fathoms, bottom temperature 76.2° F., bottom hard, sandy), hosts of foraminifera were obtained, two of which were identified by Dr. J. A. Cushman as *Operculina complanata* var. *granulosa* and *Amphisitegina lessoni*. The material is remarkably similar to that of which the Vicksburg limestones are composed; and the two are faunally so similar that it seems a sound opinion to consider the conditions of depth and temperature for the two deposits as similar.⁴ *Operculina complanata* var. *granulosa* is a common fossil in the Vicksburgian rocks in southern Georgia.

Mr. A. H. Clark informs me that he found large numbers of an *Orbitolites*-like form in shell sand brought up on the flukes of an anchor on the Grenadine bank near Union Island in a depth of between 4 and 7 fathoms.

The data presented in the foregoing remarks and the conclusion as to the depth of the Vicksburg Sea mean that the Floridian Plateau existed in Vicksburg time, and that its southern extent was about as great as it is at present. The date of the origin of the Plateau is therefore pre-Oligocene.

¹ *Orbitoides dispansa* (Sow.) and *O. papyracea* (Boubée) are found in the Jackson at Montgomery, Louisiana.

² *Orbitoides* occurs in the basal Chattahoochee in the vicinity of Bainbridge, Georgia. *O. dispansa* (Sowerby) is the usual species.

³ Wagner Free Institute, Transactions, vol. III, part VI, 1903.

⁴ I am indebted to Dr. Paul Bartsch for the opportunity of using this note.

SUMMARY OF VICKSBURGIAN EVENTS.

The following statement of the early history of this Plateau seems substantiated:

- (1) The Plateau was in time of pre-Oligocene origin.
- (2) In Vicksburgian time there was an extensive submarine plateau reaching from Central Louisiana to the Atlantic Ocean, with a salient projecting from its southeastern corner as far south as the southern limits of the present land surface of Florida.
- (3) The depth of water on this Plateau probably in no place was so great as 100 fathoms, more likely not over 50 fathoms.
- (4) The temperature of the bottom was tropical or subtropical, between 70° and 80° F.
- (5) Over the Plateau currents from the equatorial regions gently swept, with the general direction of the ocean drift probably from west to east. As no Vicksburgian strata have been found in Texas and as there is a great thickness of Eocene sediments in that State, it seems probable that there were extensive landmasses west of the Vicksburg Sea as well as north of it, and that these landmasses deflected the currents from the south toward the east. However, the data are not at hand for positively determining whether the main drift toward the east passed over the submarine plateau, or whether there was a countercurrent of warm water moving westward.
- (6) Deposits of both terrigenous and organic origin accumulated on this Plateau to a depth ranging from 100 to 200 feet near shore to over 1,000 feet near the southern margin. As the maximum depth at which any of the deposits were formed was probably less than 100 fathoms, the deposition took place on a sinking sea-bottom. The depression, however, kept pace with the deposition of organic and detrital debris, thus permitting a considerable thickness of similar material to accumulate on the sea-floor.
- (7) During the latter part of Vicksburgian time the sea-bottom was gradually elevated and a large area was uplifted into dry land.

THE VICKSBURGIAN-APALACHICOLAN INTERVAL.

A large area of the Vicksburgian sea-bottom was elevated above the sea-level before the initiation of the Apalachicola deposition; and this elevation extended as far south as Tampa, and perhaps further. The Apalachicola Group is divided into four geological formations, three of which, the Hawthorne, Chattahoochee, and Tampa, were in part at least contemporaneous; the fourth, the Alum Bluff, is geologically younger than the three others. The Chattahoochee formation lies in Florida to the northwest and north of the Vicksburg nucleus, and covers an extensive area in southern Georgia; the Hawthorne formation occurs in Central Florida to the north, northeast, and east of the Vicksburg; and the

Tampa lies to the south. The stratigraphic relations of each of these three formations to the Vicksburg have been studied by a number of geologists, and they have been found to rest in the eroded surface of the Vicksburg. Matson and Clapp have described these relations in detail in their Preliminary Report on the Geology of Florida.¹

The uplift of the Plateau produced differential movement, and it is desirable to ascertain the relative amounts of movement in different directions, but at present sufficient data bearing on the problem are not available.

EVENTS OF APALACHICOLAN TIME.

The events of Apalachicolan time need separation into an earlier stage, represented by the deposition of the Chattahoochee, Hawthorne, and Tampa formations; and a later, represented by the Alum Bluff formation.

EARLIER STAGE.

SHORE-LINE.

The elevation which is described in the preceding section was followed by subsidence, and large areas that had been dry land were lowered beneath sea-level. The interior margin of the Apalachicolan Sea lay considerably to the north of the Florida-Georgia line in Georgia, and extended from the southwest corner of Decatur County northeastward to the boundaries of Burke and Screven counties on Savannah River. This sea was a shoreward portion of the Atlantic Ocean, but it seems probable that a small area in Florida, in northeastern Marion County, may not have been entirely submerged, and that in other areas over the Vicksburg nucleus these sediments were very thin. In Apalachicolan time a dome of Vicksburg rocks already existed. This land area in the Apalachicolan Sea, however, could not have been extensive, as rocks of Apalachicolan age occur as patches overlying the Vicksburg in Hernando County, the town of Brooksville being on one of them, and on the highland 6 miles west of Dade City, Pasco County, the Apalachicola forms the ridge from the altitude of 150 feet to the hill summit, 200 feet or somewhat higher. The Apalachicola therefore, it appears, entirely covered the summits of Hernando County and has been removed by erosion. Another outlying area of this group is at Levyville, Levy County. If the outlying patches are connected according to altitude with themselves and the main Apalachicola area, the only area remaining which was probably an island is the one near Orange Lake, on its southwest side, in Marion County.

MATERIAL OF THE SEDIMENTS.

The nature of the deposition in the Apalachicolan Sea varied greatly. Although calcareous constituents were common, argillaceous and arenaceous material frequently predominated. Matson and Clapp state, Florida Geological Survey, Second Annual Report:

¹ Florida Geol. Surv., 2d Ann. Report, pp. 69, 75, 86.

The changes from sediments of one character to those of another were frequently rapid, and during the entire time there was more or less intermingling of different kinds of sediments, giving rise to the marls, impure limestones, shales, and sands of this epoch.

In the east and south central portions of the Peninsula the clay and sand predominated during the earlier part of this epoch, while farther north and west (also east on the Savannah River) similar deposits characterized the later stages. The calcareous materials which are found now in the form of marls and limestones were especially important in the area drained by the Apalachicola River, but they were also deposited in smaller quantities farther south and east. Throughout the period represented by the Apalachicola Group the conditions governing deposition appear to have differed considerably in neighboring localities, but there was no such abrupt variation as may be found along the present coast.

The facts recited in the preceding remarks indicate very shallow-water conditions.

FAUNAL CHARACTERS.

Some of the faunal characters of the older formations of this group are important. Coral reefs and massive corals which probably did not form reefs were present. They have already been alluded to in the section of this paper giving the stratigraphic distribution of reef corals, but may be repeated.

In Georgia fossil reef or massive corals have been reported from the following localities:

Decatur County: Flint River at Cherry Shoot, 3 miles below Bainbridge; Blue or Russell Spring, 4 miles below Bainbridge; Little Horse Shoe Bend, about 0.75 mile below the preceding locality; and Hales Landing, 7 miles below Bainbridge.

Grady County: 4 miles northeast of Forest Falls; 9 miles a little west of north of Whigham.

Thomas County: 3 miles west of Metcalf; 11 miles south of Thomasville; 3 miles west of Boston; 4.5 miles south of Boston.

Brooks County: 1.5 miles east of Quitman.

Lowndes County: Withlacoochee River, about 3 miles below the Valdosta Southern R. R. bridge; 2 miles northeast of Clyatts-ville.

Screven County: Old Jacksonboro near Bascom P. O.

In Florida the following localities are known:

Gadsden County: The vicinity of River Junction.

Wakulla County: The vicinity of Wakulla.

Suwanee County: White Springs on the Suwanee River.

Columbia County: 2 miles south of Lake City.

Alachua County: Numerous localities from 2 miles to 6 miles north of the town of Alachua.

Hillsboro County: Ballast Point.

These corals occur in each of the three local formations forming the lower portion of the Apalachicola group, viz: the Chattahoochee, the Hawthorne, and the Tampa.

SUMMARY OF EVENTS OF EARLIER STAGE.

From the nature of the sedimentation and the faunal characters the physical condition of the Floridian Plateau during this deposition period may be reconstructed with considerable accuracy.

- (1) The Plateau had approximately the same outline as at present, reaching from the northern boundary of the Chattahoochee, which, as previously stated, extends from southwestern Decatur County to the boundary of Burke and Screven counties on the Savannah River, positively south of the latitude of Tampa, and probably to the northern edge of the Florida Strait. In the area now known as Marion County there may have been a small island of Vicksburg rocks.
- (2) The depth of the water was probably at no place north of Tampa so great as 100 feet.
- (3) The temperature was tropical, the lowest for the year at least as high as 70° F.
- (4) As the temperature was tropical, the movement of the waters must have been from the tropics, by a direct or by a return or countercurrent.
- (5) Terrigenous material was deposited over practically the whole submerged plateau surface.

LATER STAGE.

SHORE-LINE.

Conditions in the later stage of the Apalachicola deposition had changed considerably from those of the earlier. The physiography of the region was different, and the approximate distribution of land and sea should be determined at the beginning of this section of the discussion. The sediments belonging to the Apalachicola Group subsequent in age to the Chattahoochee, Hawthorne, and Tampa formations are referred to the Alum Bluff formation. The northern boundary of the Alum Bluff extends from the higher summits in Decatur County northeastward to the Savannah River in southern Screven County. South of this line the sea extended beyond the base of the Florida Peninsula to an island with a north-and-south axis from Gainesville to Tampa, and an east-and-west axis from Ocala to the west coast. This island, here named Orange Island, may have extended farther westward and comprised territory now beneath the waters of the Gulf. A submarine platform extended southward of this island of Vicksburg and early Apalachicola sediments. The evidence of the deposition of later Apalachicola sediments southward of Orange Island rests upon the discovery by Matson and Clapp of fossils of the Alum Bluff horizon in the vicinity of Ellenton, on the Manatee River, south of Tampa¹; and upon Dall's previous record of fossils at White Beach, Little Sarasota Bay, of an Oligocene horizon later than that of the Tampa localities.²

¹ Florida Geol. Surv., 2d Ann. Report, p. 101, 1910.

² Wagner Free Inst. Sci., Trans., vol. III, pt. VI, pp. 1568-1570.

SUWANEE STRAIT AND ORANGE ISLAND.

Orange Island was separated from the mainland to the north by a broad strait, the Suwanee Strait of Dall.¹ That marine conditions prevailed across this area is proven by the occurrence of Alum Bluff species of fossils at White Springs on the Suwanee River, where Matson and Clapp obtained specimens of *Ostrea rugifera* Dall, *Pododesma scopelus* Dall, and *Pecten madisonius* var. *sayanus* Dall.²

For the details of the Alum Bluff formation across northern Florida the report of Matson and Clapp in the Second Annual Report of the Florida Geological Survey may be consulted.

DEFORMATION.

It is evident from the preceding remarks that during Apalachicola time there was differential earth-movement in the Floridian region. As all of the sediments were laid down in shallow water, the sea-bottom must have been subsiding to receive the considerable thickness known to be present in west Florida and through the Suwanee Strait; while the area represented by Orange Island was a region of uplift. These changes in physiography were accompanied by changes in sedimentation, in climate, and in the fauna.

TEMPERATURE.

The basal bed of the Alum Bluff formation on the Apalachicola and the Chipola rivers is a yellow clay marl, the Chipola marl member, replete with excellently preserved fossils, indicating a tropical temperature. The yellow color is noteworthy, as it is predominant in the older stage of the Apalachicola time. The climatic conditions have been the subject of detailed consideration by Dall.³ During the latter part of Apalachicola time the waters gradually cooled, ultimately becoming temperate. These changes are most appropriately described by Dall, whose account is here quoted:

As indicated by the changes in the fauna, the physical changes attending the close of the Oligocene were at first slow, allowing a certain element of transition to appear in the Oak Grove or uppermost Oligocene fauna. At the last they appear to have been sudden, at least the change in the fauna on the Gulf coast was absolute and complete. The change was not only in the species and prevalent genera of the fauna, but a change from a subtropical to a cool temperate association of animals. Previously, since the beginning of the Eocene, on the Gulf coast the assemblage of genera in the successive faunas uniformly indicates a warm or subtropical temperature of water, and the sediments uniformly show, from the Jacksonian upward, a yellowish tinge due to oxidation. In the Oak Grove sands come the first indications of a change towards the gray of the Miocene marls. With the incursion of the colder water the change becomes complete. Not only do northern animals compose the fauna, but the southern ones are driven out, some of them surviving in the Antilles to return later. Some change along the northern coast permitted an inshore cold current to penetrate the Gulf, depositing on the floor of the shoal Suwanee Strait, separating the island of Florida from the continental shore, a thin series of Miocene sediments, which were also carried as far south as Lake Worth on the east coast of Florida and Tampa on the west coast, as shown by artesian borings. (*Op. cit.*, pp. 1549, 1550.)

¹ U. S. Geol. Surv., Bull. 84, p. 111, 1892.

² Florida Geol. Surv., 2d Ann. Report, p. 100.

³ Wagner Free Inst. Sci., Trans., vol. III, pt. II, pp. 1574-1575, 1903.

The series of Apalachicolan events was terminated by a general elevation of the Plateau.

ABSENCE OF APALACHICOLA SEDIMENTS WEST OF THE VICKSBURG NUCLEUS.

Before taking up the discussion of the subsequent stages in the history of the Plateau, the very striking peculiarity of the present surface distribution of the geologic formations will again be noticed. The Apalachicola Group is not now exposed above sea-level on the seaward side of the Vicksburg exposures in Lafayette, Levy, Citrus, and Hernando counties; nor does any later geologic formation except a coastal fringe of Pleistocene occur above sea-level in that area. As it does not seem at all probable that no Apalachicola sediments were laid down in this area, the explanation may be found in erosion during the Apalachicolan-Miocene uplift, or in a subsequent depression which submerged the Vicksburg-Apalachicola boundary. The growth of the Peninsular land-surface toward the east, southeast, and south, while there has been no addition of importance on the west since Oligocene time, will be considered on later pages.

APALACHICOLAN-MIOCENE INTERVAL.

The uplift closing Apalachicolan deposition carried areas of the former sea-bottom above the sea-level, and was followed by the sub-aerial erosion of the Apalachicola sediments. The evidence of the erosion of the Apalachicola previous to the deposition of the Miocene is seen at Alum Bluff on the Apalachicola River and at Jackson Bluff on the Ocklockonee River. At both localities the upper surface of the Alum Bluff formation shows distinct erosion furrows and channels, with the Miocene (Choctawhatchee formation) filling and overlying the irregularities.¹ It is difficult to find a gage of the amount of this elevation, but it is evident that extensive areas of the Apalachicola sediments became dry land and the subsequent Miocene depression did not again carry all of them below the ocean level.

On the east coast, in the vicinity of Jacksonville and St. Augustine, it appears from well-borings that sediments of Apalachicolan age are either very thin or even absent,² the Miocene apparently resting on the eroded surface of the Vicksburg. It is probable that the rocks of the Apalachicola Group were entirely or almost entirely eroded away over this area during the erosion interval immediately previous to the Miocene depression.

EVENTS OF MIOCENE TIME.

DISTRIBUTION OF MIOCENE SEDIMENTS.

The Miocene was another period of subsidence and the sea was again admitted over a considerable area of the Apalachicola sediments which had been subjected to subaerial denudation, but not all of the previous land area of those sediments returned to marine conditions. The present

¹ Vaughan, in Matson and Clapp's report, Florida Geol. Surv., 2d Ann. Report, pp. 114, 115.

² Matson and Clapp, Florida Geol. Surv., 2d Ann. Report, p. 108, 1910.

surface distribution of Miocene deposits is from a locality about 9 miles southwest of Tallahassee westward along the western extension of the State. This is a narrow strip, 6 to 12 miles wide, bounded on the north by the Apalachicola Group, on the south by Pleistocene deposits, except at the eastern end of the area where the Miocene has been eroded and the Apalachicola is exposed southwest of Wakulla River. No Miocene outcrops are known on the base of the Peninsula between Tallahassee and Trail Ridge, which forms the divide between the headwaters of Santa Fe River and the St. John's River drainage. Miocene sediments compose Trail Ridge whence they extend eastward to Jacksonville and St. Augustine. The Miocene Sea extended northward, Miocene fossiliferous deposits being known at Brunswick, Doctortown, on the Altamaha River, and at Porter's landing in Effingham County, on the Savannah River, in Georgia. South of the latitude of St. Augustine the Miocene is usually overlain by more recent deposits, and few exposures have been reported. The reported localities are given in the following notes:

Dall¹ reports *Pecten jeffersonius* and *Carditamera arata* from Preston sink, 3 miles north of Waldo, Alachua County, a locality at the southern end of Trail Ridge; and *Venus rileyi*, *V. permagna*, and *Arca limula* at a depth of 208 feet in a well at St. Augustine. The presence of *Pecten madisonius* in a collection of Pliocene fossils from the banks of St. John's River, a quarter of a mile below Nashua, Putnam County, indicates Miocene at that locality.² *Pecten* of the type of *madisonius*, and a *Chione* of the type of *cancellata* were obtained from a well at De Land, the former suggesting Miocene as the age of the bed.²

E. A. Smith obtained from Rock Springs near Zellwood, Orange County, *Pecten madisonius*, *Venus alveata*, *Venericardia granulata*, *Carditamera arata*, and *Mytiloconcha incurva* identified by Heilprin.³ Heilprin reports from Rocky Bluff on the Manatee River, 5 or 6 miles above Braidentown, *Arca incongrua*, *Perna maxillata*, *Pecten jeffersonius*, *P. madisonius*, and *Venus alveata*.⁴ Dall states that "it is probably from more westerly submarine strata belonging to this series of beds that was derived the *Ecphora* collected by Doctor Stearns in 1868-69 on the beach of Long Key."⁵ Miocene fossils, *Pecten jeffersonius* and *Pecten madisonius*, were also obtained by Professor Heilprin on Phillips Creek, which flows into Little Sarasota Bay.⁶

No Miocene outcrops occur between the Vicksburg and Apalachicola areas of the Peninsula and the west coast.

Well-borings show that Miocene is present beneath later formations even as far south as the keys. The records of the Palm Beach well given on page 127 of this paper show Miocene between 800 and 915 feet and perhaps at 400 feet beneath the surface. The deep well at Marathon on Key Vaca (see page 128) revealed probably Miocene fossils between 375

¹ U. S. Geol. Surv., Bull. 84, pp. 124, 125, 1892.

² Matson and Clapp, Florida Geol. Surv., 2d Ann. Report, p. 122, 1910.

³ Am. Jour. Sci., 3d ser., vol. XXI, p. 302, 1881.

⁴ Wagner Free Inst. Science, Trans., vol. I, p. 13, 1887.

⁵ U. S. Geol. Surv., Bull. 84, p. 125, 1892.

⁶ Dall, *op. cit.*, p. 126.

and 420 feet below the surface. The arenaceous composition of the Miocene near the southern edge of the Plateau has already been stated, but may be repeated.

LITHOLOGY.

Lithologically the Miocene of the western area (the Choctawhatchee formation) and that of the eastern (the Jacksonville formation) are decidedly different. The former is predominantly arenaceous, the sands are of a greenish color, weathering yellow or reddish, with an abundance of well-preserved fossil shells, overlain at Alum Bluff by a bed of plastic clay; the latter contains light-colored, impure, arenaceous limestone beds, particularly near the top, with a large amount of argillaceous material, varying in color from light gray to pale yellow.¹ There are sands and clays below the limestone beds of the Jacksonville formation. The thickness of the Choctawhatchee formation varies from 25 to 50 feet, while that of the Jacksonville may be from 400 to 500 feet.

MIOCENE CORALS.

Attention has not been called to the changes in the coral fauna of the Miocene from that of the preceding Apalachicola Group. The change in it is more striking, if not more important, than that in the mollusks. Reef corals abounded in the older beds of the Apalachicola Group. Corals of that type become rarer in the younger deposits of that group, and are entirely absent in the Miocene formations. The change is dramatic in its intensity.

SHORE-LINE.

In reconstructing the marine conditions of Miocene time the approximate shore-line must be determined, and the focal point of interest is the Suwanee Strait. As has been stated, no Miocene deposits are definitely known between Tallahassee and Trail Ridge. The altitude of the exposures near Tallahassee is about 100 feet; near Trail Ridge they attain a height, according to the map, of 200 feet. Intervening altitudes are above 150 feet, as at Lake City and Houston. Dall says:

West of Jacksonville, at Live Oak, Suwanee County, and Lake City, Columbia County, specimens of fossils were obtained which may prove to belong rather to this (Jacksonville formation) than to the Chattahoochee group of beds. (U. S. Geol. Surv., Bull. 84, p. 125, 1892.)

This is a surmise and not an opinion, and later work has not verified the surmise, but it seems probable that Miocene deposits may have extended across this intermediate area. Matson and Clapp say:

At the close of the Oligocene the State of Florida appears to have had the same general form that it now has, though its area was doubtless less than it is at the present time. With the inauguration of the Miocene there came a submergence which appears to have reduced the land area to a narrow strip along the northern end of the State, and a peninsula which was shorter and narrower than it is at present. During part of this period the central portion of the peninsula may have been separated from the mainland by a shallow strait. The exact extent of the encroachment of the sea during Miocene times is difficult to determine because

¹ Matson and Clapp, *op. cit.*, p. 108.

the deposits have been partially removed by subsequent erosion and their present extent is often obscured by considerable thickness of younger beds. (Florida Geol. Surv., 2d Ann. Report, pp. 165, 166, 1910.)

The question as to whether or no the Miocene sea extended through the Suwanee Strait must for the present remain without a definite answer. The available evidence now permits only the statement that the Strait may have again had ocean currents flowing through it. Except in the Suwanee Strait region, the Miocene shore may be outlined with considerable definiteness. In west Florida it reached from a short distance north of the present Apalachicola-Miocene boundary, probably not extending to the southern limits of Georgia, into Alabama in the vicinity of Mobile. The problematic condition of the Suwanee Strait has been fully discussed; it is not positively known whether the Strait was open, or whether there was a short peninsula bounded on the east by a shore-line just west of Trail Ridge and projecting as far south as Tampa. Doctor Dall has at my request contributed the following remarks to this discussion:

In the absence of evidence which would conclusively prove the post-Oligocene existence of the Suwanee Strait, one consideration had much weight with me in assuming it as highly probable. This is connected with the presence of the phosphate beds in the central peninsular region of Florida. There is practically no doubt as to the origin of these beds from the presence in Miocene and perhaps later times of immense rookeries of birds, and perhaps other animals, whose guano was absorbed by the porous limestone underlying their chosen habitat. Now experience shows that such rookeries are invariably separated from possible incursions of carnivorous continental enemies by impassable bodies of water. Otherwise the birds could not maintain themselves, and the occupation of their rookeries for a period, such as was necessary for the formation of the phosphatic deposits, would have been impossible. The erosion of shallow beds of Miocene age under conditions which have existed in Florida, over part of the area of the supposed strait, is not an exceptional or remarkable phenomenon; and it is quite possible that more exhaustive exploration than has yet been possible may reveal traces of the missing Miocene sediments.

In Georgia the shore of the Miocene sea lay somewhat west of a line passing through Doctortown, on the Altamaha River, and Porter's Landing, on the Savannah River, but it did not entirely overlap the Apalachicola sediments. All of Florida excepting the land areas indicated was submerged.

DEPTH OF WATER.

The depth of the sea is shown by both the kind of sediments and the fauna. The sediments are near-shore, shallow-water deposits, and are predominantly terrigenous, although there is some lime in the Jacksonville formation, probably chemically precipitated, and lime of organic origin, the calcareous remains of fossils. The fossils, comprising such genera as *Ostrea*, etc., indicate shallow-water conditions. The Floridian Plateau extended to the southern margin of the keys, as shown by the deep well at Marathon, Key Vaca. Probably at no place over the platform did the depth exceed a few fathoms, 25 or 30 seems a safe maximum. The maximum thickness of the Choctawhatchee formation, 50 feet, demands no continuous depression of the sea-bottom along the

western extension; but the thickness of the Jacksonville formation, 400 to 500 feet, indicates progressive subsidence during a portion of Miocene time.

TEMPERATURE.

Dall has given an excellent statement of the temperature of the Miocene waters of the region (see quotation on page 156). He also says:

As I have on various occasions insisted, the faunal gap between the uppermost Oligocene (Oak Grove)¹ and the Chesapeake or Miocene is the most sudden, emphatic, and distinct in the whole post-Cretaceous history of our southeastern Tertiary, and indicates physical changes in the surrounding region, if not in Florida itself, sufficient to alter the course of ocean currents and wholly change the temperature of the waters of our southern coast. (Wagner Free Inst. Sci., Trans., vol. III, pt. VI, p. 1594, 1903.)

Temperature conditions had within a relatively short time passed from tropical to those of the latitude of Chesapeake Bay, or even the southern coast of Cape Cod and Long Island.

In an attempt to deduce the temperature of the Miocene waters of Florida, the data presented in Sir John Murray's "On the Temperature of the Floor of the Ocean and of the Surface Waters of the Ocean"² have been used. As the Miocene fauna was one of shallow water, the bottom temperature was probably not greatly different from that of the surface. It may also be said that the minimum temperature of the winter months is much more influential in determining the distribution of organisms than the maximum temperature of the summer months. For instance, according to Map 3 of the paper cited, a summer temperature of 80° to 90° F. extends from the Caribbean Sea and Gulf of Mexico northward to New York Harbor, or during the summer a tropical temperature extends far northward.

In the winter conditions are very different. The minimum temperature for the west coast of Florida is between 60° and 70° F.; for south Florida and the east coast, between 70° and 80° F.; on the south side of Cape Hatteras, 40° to 50° F.; north of Hatteras to Delaware Bay, 30° to 40° F.; north of the last-named locality the temperature may be below 30° F. Therefore during the Miocene the minimum winter temperature of the waters was at least as low as between 40° and 50° F. and it may have been as low as between 30° and 40° F.; or between 20° and 30° F. cooler than the present winter temperature of the west coast, and between 30° and 40° or even 50° cooler than the present winter temperature of the east coast.

CURRENTS.

There was indisputably, as Dall has so often emphasized, a cold current admitted along the shores of the land of embryonic Florida, assuredly as far west as Pensacola Bay. This current could not have been from the Equator, but must have been a southward flowing return or countercurrent from the north; and in my opinion this countercurrent

¹ The Shoal River marl, member of the Alum Bluff formation, has been subsequently differentiated. (Vaughan, in Matson and Clapp, Preliminary Report on the Geology of Florida, Florida Geol. Surv., 2d Ann. Report, pp. 104-106, 1910.)

² The Geograph. Jour., July, 1899.

initiated that series of countercurrents so important in the subsequent accumulation of sediments on the Floridian Plateau, and the formation of much of the present land surface of Florida. It brought sand and other terrigenous material from the north to be dropped on the Plateau, causing its surface gradually to approach sea-level. The transportation of sediment from the north by a current flowing down the western side of the Peninsula or island of Vicksburg and Apalachicola formations partly explains why the land surface has grown on the east and south and why there has been so little growth on the west. It partly explains the arrangement of the surface outcrop of the later geologic formations with reference to the older eccentric nucleus, and the arrangement of the main drainage lines, described on preceding pages. It also partly explains why there are 400 to 500 feet of Miocene sediments on the east coast and only 25 to 50 feet on the westward extension. The burden of sediment brought to the ocean by streams in Georgia and the Carolinas was by the agency of this current moved southward to the Florida bank. Henceforth, the development of Florida was largely dominated by the southward moving shore currents.

UPLIFT AT THE CLOSE OF THE MIOCENE.

Toward the close of Miocene time the Plateau was again subjected to an upward earth-movement, whereby the Suwanee Strait, which, should it have been open during a portion of the period, was definitely closed, and it is probable the Trail Ridge was uplifted. There was more upward movement on the east and south than on the west, for no Miocene was brought above the sea-level along the shore from Levy to Pasco counties, while submerged Miocene is apparently present off the mouth of Tampa Bay.

EVENTS OF PLIOCENE TIME.

STRATIGRAPHIC RELATIONS OF PLIOCENE TO MIOCENE SEDIMENTS.

There is a lack of definiteness of information regarding the stratigraphic relations of the Pliocene to the Miocene sediments. It is not positive whether there was a subsidence at the beginning of the Pliocene or whether Pliocene sedimentation took place on areas of the Miocene that remained submerged. Matson and Clapp say concerning the stratigraphic position of the Pliocene Nashua marl of St. John's River valley:

The Nashua marl is thought to rest unconformably upon the Miocene at De Land, but this opinion lacks confirmation, as the collections from that locality have not been studied in sufficient detail to determine the exact age of the beds. (Florida Geol. Surv., 2d Ann. Report, p. 128, 1910.)

The same authors say concerning the Caloosahatchee marl:

The contact of the Caloosahatchee marl with the underlying Miocene has not been observed, but there is considerable change in fauna between it and the Miocene, which is probably due to physiographic changes which may have permitted the erosion of the Miocene beds before the beginning of the Pliocene deposition.

AREAL DISTRIBUTION OF MARINE PLIOCENE IN FLORIDA.

There are two important areas of marine Pliocene in Florida. The more northerly, the Nashua marl, occurs along the St. John's River valley from the vicinity of the town of Nashua southward to Enterprise

Junction, and extends eastward until overlain by Pleistocene deposits. There are certain peculiarities of this formation that should be noticed. The following five species, collected at Nashua, *Eupleura miocenica* var. *intermedia* Dall, *Ilyanassa porcina* Say, *I. isogramma* Dall, *I. granifera* Conrad, and *Nassa scalaspira* Dall, occur in the Waccamaw Pliocene of the Carolinas, but not in the Caloosahatchee marl of Florida. The presence of *Pecten madisonius* suggests Miocene in the same bluff, and that both Miocene and Pliocene are represented, but the beds have not been differentiated.

Exposures of Pliocene marl occur at the following additional localities southward along the St. John's River: 0.5 mile above the Atlantic Coast Line bridge over St. John's River, Putnam County; 0.5 mile south of De Leon Springs Station, Volusia County, 5 miles below Sanford railroad bridge, east side of St. John's River, and perhaps 7 miles below Sanford railroad bridge.

Proceeding southward the species belonging to the Waccamaw fauna disappear; they are found only at Nashua; and the southern exposures seem geologically younger. In the exposure 7 miles below the Sanford railroad bridge, every species might be Pleistocene, and the exposure was tentatively referred to the Pleistocene because of its similarity to the one 5 miles below the bridge.

In the northern drainage ditch 6.5 miles west of Fort Lauderdale, Mr. Matson obtained 17 species of fossils that were specifically identified; 16 of these are also Recent, and one, *Strombus leidyi*, was not previously known from beds younger than the Caloosahatchee. This exposure was tentatively referred to the Pleistocene because of its relation to other exposures definitely Pleistocene. These facts lead to the inference that southward from Nashua younger Pliocene beds are encountered, and that the Pliocene fauna is very gradually supplanted by that of the Pleistocene.¹

A considerable collection of Pliocene fossils was obtained from a well on the property of Mary Boss, on an island in Lake Tohopekaliga, about 3 miles from Kissimmee, at a depth of 150 feet. The Pliocene is here overlain by at least 100 feet of Pleistocene beds.

The eastern Pliocene area overlaps the Miocene, and flanks the eastern side of the Apalachicola Group, extending southward along St. John's River valley from Nashua to Sanford; it is overlain on the east and south by Pleistocene deposits, but is shown by well-borings to be present at a depth of 150 feet in Lake Tohopekaliga. No surface exposures of marine Pliocene are known between Sanford and Zolfo Springs on Peace Creek.

The Caloosahatchee marl constitutes the second, the more southerly, of the marine Pliocene formations. The type locality is along the Caloosahatchee River from Fort Thompson, near Labelle, to Olga. This river stretch has been studied and described by Heilprin,² Dall,³ Matson and

¹ A collection made by me on North Creek, near Osprey, Manatee County, furnishes additional evidence in favor of this opinion. Besides usual Pleistocene species I also obtained at this locality specimens of *Pyrazisinus scalatus* Heilprin, a species previously known only from Pliocene beds.

² Wagner Free Inst. Sci., Trans., vol. 1, pp. 22-33, 1887.

³ U. S. Geol. Surv., Bull. 84, pp. 142-146, 1892, and Wagner Free Inst. Sci., vol. III, pt. VI, pp. 1603-1614, 1903.

Clapp,¹ and I went over it with the two last-named geologists. Thanks to the splendid researches of Dall, no Tertiary horizon is paleontologically better known.

Besides the exposures along Caloosahatchee River, others are known along streams or the tributaries of streams flowing into Charlotte Harbor, viz: Miakki River, Chilcoccohatchee River, Peace Creek, as far north as Zolfo Springs, Prairie Creek, Alligator Creek, and the famous Shell Creek; and along streams that do not flow into Charlotte Harbor, "Rocky Creek, which flows into Lemon Bay, near Stump Pass."² Considerably east of Peace Creek beds of marl containing "large clams" have been reported to Mr. Willcox as occurring on the banks of Arbuckle Creek.²

The last-mentioned exposure deserves careful investigation, as it is directly in line between the Caloosahatchee exposures and the buried Pliocene of Lake Tohopekaliga.

It has not so far been possible to differentiate Pliocene from Pleistocene and Miocene in the well-borings south of the latitude of the southern end of the Lake Okeechobee, but it is not to be doubted that Pliocene is represented in the wells. The borings, however, do not indicate any great changes of deposition conditions.

LITHOLOGY AND THICKNESS.

Both the Nashua and Caloosahatchee marls bear close lithologic resemblance, both consisting of shell marls interstratified with beds of sand. The maximum thickness of the former is about 32 feet at De Land³; that of the latter probably about 25 feet.⁴

SHORE-LINE.

The Pliocene submergence was not so extensive as that of the Miocene. The shore-line lay west of St. John's River from Palatka southward to opposite Sanford, whence it continued southward keeping on the west side of Lake Tohopekaliga; it probably passed around the southern end of the ridge on which Haines City is situated, and then turned southwest to the vicinity of Sarasota Bay. Probably the territory east of St. John's River extending from Palatka northward to beyond Jacksonville, was also submerged. There is no evidence of any submergence of the west coast north of Tampa.

DEPTH AND TEMPERATURE OF THE PLIOCENE SEA.

Dall has attempted to reconstruct the conditions of depth and temperature prevalent during the deposition of the Caloosahatchee marl. He says:

The assemblage of species on the whole, in the principal stratum, is such as one might expect to find in water from 20 to 25 feet in depth, judging by what we know of living mollusks. Mixed with these are a certain number of shallow-water forms which may be supposed to have flourished as the water became shoal by

¹ Florida Geol. Surv., 2d Ann. Report, pp 123-128, 1910.

² Dall, U. S. Geol. Surv., Bull. 84, p. 148.

³ Matson and Clapp, Florida Geol. Surv., 2d Ann. Rept., p. 129.

⁴ Matson and Clapp, *op. cit.*, p. 124.

elevation of the sea-bottom. There were lagoons of fresh water and probably streams emptying into the sea and in time of flood sweeping their fresh-water population out onto the shoals, where it perished. Part of the bottom became elevated nearly to the surface, oyster banks were formed on it, and the compacter parts became water-worn. The absence of shells like *Litorina* and *Nerita* seems to indicate that the dry beaches were muddy or sandy rather than rocky. In the course of time elevation so shoaled the water that only species like *Venus cancellata* and others able to live between tide marks could remain. This portion of the formation constitutes the so-called *Venus cancellata* bed, though neither of its component species is peculiar to it. Finally the area became cut off almost entirely from the sea and occupied more or less by fresh-water ponds in which the pond snails multiplied in myriads. (U. S. Geol. Surv., Bull. 84, pp. 145, 146.)

Concerning *Venus (Chione) cancellata*, Dall says in a preceding paragraph:

In this connection it may be stated that *Chione cancellata* is known from the Chipola Old Miocene [Apalachicola Group] marls, in no respect differing from recent specimens, and that it has continued as a conspicuous member of the Florida fauna (except during the epoch when the Ecphora beds [Miocene] were being deposited) up to the present day. It is a warm-water shell and extended in abundance farther north during Chipola times and the newer Pliocene than during the period when the beds of the Chesapeake Group were being deposited or at present. The last-mentioned periods were and are entirely relatively cooler, and the two former relatively warmer, judging by the fauna. The species has never been entirely absent and at the present day reaches as far north as Hatteras, in the warm-water area. It is also a shallow-water shell, living chiefly between tides when the climate is mild enough.

Corals are found fossil in the Caloosahatchee marl, although no reefs are known. The genera comprise *Dichocænia*, *Meandrina* ("*Pectinia*"), *Cyphastrea*, *Mæandra* (*M. areolata* is abundant), *Siderastrea*, etc. These genera indicate shallow water, a maximum of not over 25 or 30 feet, more probably not more than 10 or 15 feet, and a tropical temperature, 70° F. as a minimum. The assemblage is that of an extensive flat. The corals and mollusks both indicate the same physical conditions prevalent over the areas in which the Caloosahatchee marl was deposited.

In the area of the Nashua marl conditions nearly the same, but with a slightly lower temperature, must have prevailed, for *Chione cancellata* was included in the collections of fossils from every locality except one, and that was a small collection from the east side of St. John's River, 7 miles below Sanford. The opinion may therefore be confidently expressed that seaward, east and south of the Pliocene shore, the Floridian Plateau continued as a shallow submarine bank, having practically the same outline as the present Plateau. The cold water of Miocene time had been diverted offshore, or had at least been replaced by warm waters from the tropical regions, and on this bank arenaceous sediments brought from the north entombed the calcareous remains of organisms that lived on it.

CONFORMITY OF THE PLIOCENE TO OTHER GEOLOGIC BOUNDARIES.

The conformity of the western boundary of the Miocene sediments to the outline established by the Oligocene, Vicksburg and Apalachicola, formations, and to the present outline of the east and south coasts of the State, is observed by the Pliocene deposits, leading to the inference

that the material was largely brought from the north by alongshore currents, moving toward the south and southwest. This was not a cold but a warm return or countercurrent similar to the one now moving southward along the Florida east coast.

EVENTS ABOVE SEA-LEVEL.

Important events were taking place on the land on which fluvial and lacustrine deposits were accumulating, while the marine history outlined in the foregoing remarks was being enacted. As this paper is especially devoted to the marine history of the State, the episodes confined to the land surface will not be recounted. They may be found in Dall's chapter on Florida in the Correlation Paper, "Neocene,"¹ by him and Harris, and Matson and Clapp's Preliminary Report on the Geology of Florida.²

UPLIFT AT THE CLOSE OF THE PLIOCENE.

Toward the close of the Pliocene deposition the Plateau mass again began an upward movement, as was evidenced by the shoaling in the Caloosahatchee area and the formation of fresh-water ponds. This upward movement continued until extensive areas of the Pliocene sea-bottom were lifted above sea-level.

PLIOCENE-PLEISTOCENE INTERVAL.

The history of this interval unfortunately is not so clear as is desirable. The shoaling of the Pliocene sea and the rise of former sea-bottom was made evident in the preceding paragraph. Data are deficient for a definite estimate of the amount of the emergence.

Professor Shaler, because the Vicksburg limestone has lost its salt water to a depth of a thousand feet, postulated an elevation of at least that amount.³ Matson in criticism of this conclusion says:

The deep wells all penetrate the limestones of Vicksburg age, and hence it is the beds of that age which have been drained of salt water. As a portion of these beds have been above sea-level since Oligocene time, the salt water may have been removed before the Pleistocene. The magnitude of the emergence is not necessarily so great as 1,000 feet, because, given the necessary chance for escape, the salt water would probably be displaced by fresh water, provided the surface was high enough to afford a small hydrostatic pressure. The absence of impervious beds of clay above the submarine portion of the Oligocene limestones would permit the escape of the water, and hence considerable thicknesses of the older rocks may have been filled with fresh water without being raised much above their present altitude. (Florida Geol. Surv., 2d Ann. Report, p. 169, 1910.)

Two other probable criteria are left. The first is the existence of underground channels from which submarine fresh-water springs issue near the coast. The best known of these springs is one near St. Augustine. Matson and Clapp furnish the following account of it:

According to Captain E. C. Allen of that city [St. Augustine], the orifice of the spring is about 60 feet across and the depth is about 200 feet. The depth of the sea at the point of emergence is said to be about 50 feet and the water emerges

¹ U. S. Geol. Surv., Bull. 84, pp. 127-131, 1892.

² Florida Geol. Surv., 2d Ann. Report, pp. 133-145, 167, 1910.

³ Bost. Soc. Nat. Hist., Proc., vol. xxiv, p. 584, 1890.

with force enough to cause a distinct convexity of the surface during calm weather. According to some authorities, it is difficult to row a small boat across the surface above the spring on account of the outward movement of the water from above the orifice.

These springs can scarcely be older than the age here assigned them, otherwise they would have been filled by sediments. During this uplift, it appears the main drainage lines north of Lake Okeechobee were determined. It is known that the St. John's River channel has a depth of 65 feet below mean tide opposite Jacksonville.¹

The precise date of the cutting of the submerged channel at the mouth of St. John's River has not been determined and is here only tentatively referred to the interval between the deposition of the Pliocene and Pleistocene.

That there was uplift in this interval is indisputable. The available evidence does not suggest that it was over 200 feet.

Accompanying this oscillation, either with the uplift or the subsequent depression, there was deformation. Pliocene fossils occur at a depth of 150 feet in Lake Tohopekaliga and it is overlain by at least 100 feet of Pleistocene deposits—perhaps 150 feet. As the elevation of the land surface at Kissimmee at the northern end of this lake is 60 feet, the Pliocene is 90 feet below sea-level. The Pliocene at De Leon Springs on the north is between 20 and 40 feet above sea-level; along the Caloosahatchee River 6 to 12 feet. The Pleistocene in the vicinity of Kissimmee fills a depression in the surface of the Pliocene to a depth of at least 100 feet, while it is thin along the Caloosahatchee and also at De Leon Springs. The thickening of the deposits near Kissimmee seems to indicate that a Pliocene syncline existed at the time of this deposition, and that there was a very gentle anticlinal ridge, or swell, parallel to the east coast, and a second similar gentle swell extending north from the Caloosahatchee west of Kissimmee River, between it and Peace Creek. Haines City occupied the northern end of this ridge. Between these two gentle anticlines is the shallow syncline occupied by the Kissimmee Valley. The eastern anticline was one of the agencies determining the location of St. John's River. It seems probable that there was a third gentle fold between Peace River and the west coast.

These structural features have their axes parallel to the axis of the Peninsula. Heilprin, Dall, and Matson and Clapp have all described the folding of the Pliocene strata along the Caloosahatchee. Dall says concerning these folds:

As the river [Caloosahatchee] is ascended, a close scrutiny shows that it cuts through a succession of gentle waves, gradually increasing in height, inland, whose crests would show a general parallelism with the direction of the Peninsula of Florida, or transverse to the average course of the river. Near the headwaters of the river these waves of elevation rise above the level of the river at low water to a height of perhaps 12 feet at most, and their individual length from one trough to another may average about a quarter of a mile. Though insignificant as flexures, they are interesting as showing that a lateral as well as a vertical thrust has attended the movements of the rocks in this part of the State, a fact which has been questioned. (U. S. Geol. Surv., Bull. 84, p. 143, 1892.)

¹ Matson and Clapp, *op. cit.*, p. 172.

In February, 1908, I went over the exposures along the Caloosahatchee described by Dall in the preceding quotation, and observed the phenomena. The Pleistocene deposits did not seem to participate in all of the deformation of the Pliocene, pointing to the conclusion that deformation intervened between the two deposition periods. This period of elevation was succeeded by one of depression.

EVENTS OF PLEISTOCENE TIME.

The elevation described in the preceding section is supposed to initiate the Pleistocene, but it is given an individual caption, following the plan of separating intervals of uplift from those of depression. In a region such as the Floridian, which lies outside the area of glaciation, it is not possible sharply to differentiate between the end of the Pleistocene, marked by the final retreat of the glaciers, and Recent, which succeeded their disappearance.

PLEISTOCENE SUBMERGENCE.

The Pleistocene submergence was extensive. Along the western extension and the west coast as far south as Tampa, a narrow border was below sea-level. Proceeding eastward from Tampa Bay, marine Pleistocene fossils are found at the following localities: Six Mile Creek, at Orient Station, Hillsboro County; in a ditch alongside the railroad, 0.125 of a mile south of Manatee Station, Manatee County; North Creek near Osprey; Caloosahatchee River; Kissimmee, in wells at depths of 90 to 100 feet; West Palm Beach, depth 74 feet; 2 miles southeast of Eau Gallie; 4 miles west of Eau Gallie; 0.25 mile and 1 mile north of Mims; Ormond, depth 50 to 56 feet; St. Augustine, at least 30 feet thick, and on St. Mary's River near its mouth.

The localities mentioned indicate that the Pleistocene shore-line lay slightly north of the head of Hillsboro Bay, whence it probably passed south of the southern end of the divide west of Peace Creek, keeping between the 50- and 100-foot contours of the present land area; thence it extended around the southern end of the divide between Peace Creek and Kissimmee River, it followed the west side of the valley of the latter stream, by Orlando, a few miles west of Sanford, and very likely the area east of St. John's River was submerged; certainly the valley of this stream and a coastal fringe from Daytona northward into Georgia were under water. Over half of the present land surface of Florida was below sea-level.

The Pleistocene formations extend down the east coast and thence across the southern end of the Peninsula, exhibiting relations to the old Oligocene nucleus and the present coast line similar to those exhibited by the Miocene and Pliocene, except there is a coastal fringe of Pleistocene on the west coast north of Tampa Bay.

DIFFERENCES IN PLEISTOCENE SEDIMENTS.

The material of the marine Pleistocene varies greatly in different areas. There are shell marls, coquina beds, the Palm Beach limestone, the Miami oolite, the Key Largo and Lostman River limestones, and

the Key West oolite, besides deposits of non-fossiliferous sands. There are estuarine deposits along the lower courses of some streams and stream terraces. The respective areas of the various marine deposits will be briefly outlined in order to determine the physical conditions prevailing over those areas during the deposition of each kind of material.

COQUINA.

Coquina is composed of more or less water-worn molluscan shells embedded in a matrix of calcium carbonate and sand. The degree of cementation varies from that sufficient for use as building stone, as in the neighborhood of St. Augustine, to very loose aggregation. The loose aggregations of coarse grade into shell marls. Coquina occurs along the Florida east coast southward from St. Augustine to beyond Palm Beach, as far as Boca Ratone, forming in its more southern exposures a portion of Sanford's Palm Beach limestone; in fact the Palm Beach limestone extends northward and some of the east coast Pleistocene coquina may be referable to it. Localities at which this kind of rock has been observed are St. Augustine, Ormond, Mims, and Canaveral,¹ north of Palm Beach; and south of the last-mentioned place at Linton,¹ Hillsboro Inlet, and Boca Ratone. Griswold says, concerning the southern localities examined by him:

About 30 miles north of New River, at Linton, another examination was made. A cross-bedded fragmented rock was abundant, but contained considerable quartz. Coquina was also abundant, and the two rocks were found interbedded.

At Palm Beach and vicinity the Coquina and fine fragmental rock also occur closely associated; the Coquina perhaps predominates. This is about 20 miles north of Linton. * * *

A trip to Cape Canaveral disclosed there a rock which may well represent the fine fragmental rock of Palm Beach and Linton. The quantity of quartz is greater, the quartz grains are larger, and the rock less coherent than to the south.

The following record of a well drilled at Delray by Edwin T. King, for O. Eleasen, shows that the coquina is interbedded with sand.

Record of well at Delray.	Depth.	Thickness.
	<i>Feet.</i>	<i>Feet.</i>
Surface sand.....	0 to 40	40
Coquina.....	40 43	3
Quicksand.....	43 108	65
Coquina.....	108 119	11

A list of a collection of fossils obtained here by Mr. King from a depth of 118 feet is given below.

<i>Oculina</i> sp.	<i>Terebra concava</i> Conrad, var., may be new. x
<i>Siderastrea radians</i> (Pallas).	<i>Conus floridanus</i> Gabb.
<i>Porites divaricata</i> Le Sueur.	<i>Drillia digitalis</i> Reeve.
<i>Cidaris tribuloides</i> Lamk.	<i>Oliva reticularis</i> Lam. var.
<i>Tornatina bullata</i> Kiener.	<i>Olivella mutica</i> Say.
<i>Terebra dislocata</i> Say.	<i>Marginella opalina</i> Stearns.
dislocata var. indenta Conrad.	<i>Latirus brevicaudata</i> Lam. ? x
protecta Conrad.	

¹ Griswold, Mus. Comp. Zool., Bull., vol., xxviii, p. 59, 1896.

<i>Murex rufus</i> Lam.	<i>Erato maugeriæ</i> Gray.
<i>Sistrum</i> sp., recent on Florida east coast.	<i>Trivia quadripunctata</i> Gray.
<i>Engina turbinella</i> Kiener ? x	<i>Omphalius fasciatus</i> Born.
<i>Columbella pulchella</i> Kiener.	<i>Fissurella alternata</i> Say.
<i>mercatoria</i> Lam.	<i>Arca gradata</i> Broderip.
<i>Colubraria lanceolata</i> Menke.	<i>Lucina radiata</i> Conrad.
<i>Strombus</i> , young, probably <i>pugilis</i> Linn.	<i>Chione cancellata</i> Linn.

All of the identifiable forms perhaps excepting three (those indicated by an "x") are recent. On a percentage basis 90 per cent are surely recent. The horizon is therefore probably old Pleistocene, probably somewhat older than the Miami oolite.

This list will be referred to subsequently.

The prevalence of coquina on the east coast indicates shallow-water beach conditions, with alternations of accumulations of sands and wave-ground shells.

Dall says concerning the west coast:

There is general opinion among the inhabitants, which was frequently expressed to me in conversation, to the effect that between Tampa and the keys Coquina-rock is only to be found at one place, the mouth of Little Sarasota Bay. But this idea is certainly erroneous, as at every projecting point of the keys along the Gulf shore which we visited, I found traces of this rock, though often not visible above water, and frequently composed more of sand grains than of shell, so that it looks much like wet loaf sugar. (*Amer. Jour. Sci.*, 3d ser., vol. XXXIV, pp. 162, 163, 1887.)

SHELL MARL.

This material is composed mostly of the tests of mollusks, embedded in a matrix of quartz sand with a varying proportion of amorphous and fragmental calcium carbonate. It occupies a very large area extending south and southwest from Daytona from the northern margin of the Pleistocene sea at least as far as the northern margin of Lake Okeechobee, on both its east and west sides. It probably extends as far as the southern end of the Lake on its east side; and certainly does on the west, where there are excellent exposures on Caloosahatchee River.

The fossils listed from the well at Delray represent a shell marl, and give evidence of the southward extension of this class of material along the east coast.

West of Fort Lauderdale, along the southern drainage ditch, there is evidence of intergradation of shell marls and the Miami oolite. First Shaler ¹ and later Griswold ² have called attention to the contemporaneity of coquina and the oolite. The same may be said of the shell marls.

The collections of fossils from the shell marls, made by Dall and Willcox, later by Matson, Clapp, and myself, have given a fair knowledge of the paleontology of these Pleistocene deposits. Dall has published a list of the species obtained from North Creek, near Osprey, Manatee County,³ and Matson and Clapp have published lists, based on my identifications, of the species from a number of localities. They, however, omitted two important lists, and I insert them in this paper:

¹ *Mus. Comp. Zool., Bull.*, vol. xvi, p. 143, 1890.

² *Mus. Comp. Zool., Bull.*, vol. xxviii, pp. 55, 56, 1896.

³ *Wagner Free Inst. Sci., Trans.*, vol. iii, pt. vi, pp. 1616, 1617, 1903.

*List of Fossils from Oscar Michael's Marl Pit, One Mile Southwest of Daytona
(George C. Matson, collector).*

<i>Tornatina canaliculata</i> Say.	<i>Ostrea virginica</i> Gmel.
<i>Drillia</i> sp.	<i>Plicatula spondyloidea</i> Meusch.
<i>Olivella mutica</i> Say.	<i>Venericardia radians</i> Conrad.
<i>Marginella</i> sp.	<i>Cardium isocardia</i> Linn.
<i>Nassa acuta</i> Say.	<i>Venus campechiensis</i> Gmel.
<i>Anachis</i> sp.	<i>mercenaria</i> Linn.
<i>Turbonilla</i> sp.	<i>Chione cancellata</i> Linn.
<i>Cerithium</i> sp.	<i>Timoclea grus</i> Tuomey and Holmes.
<i>Bittium</i> sp.	<i>Anomalocardia caloosana</i> Dall.
<i>varians</i> Pfr.	<i>Gemma magna</i> Dall.
<i>Crepidula fornicata</i> Say.	<i>Parastarte trigona</i> Dall.
<i>plana</i> Say.	<i>triquetra</i> Conrad.
<i>Nucula proxima</i> Say.	<i>Tellina</i> (<i>Angulus</i>) <i>tampaensis</i> Conrad.
<i>Arca pexata</i> Say.	<i>Tagelus divivus</i> Spgl.
<i>transversa</i> Say.	<i>Semele</i> sp.
<i>ponderosa</i> Say.	<i>Donax variabilis</i> Say.
<i>Anomia simplex</i> d'Orb.	<i>Mulinia lateralis</i> Say.

*List of Pleistocene Fossils from Labelle, Caloosahatchee River
(T. Wayland Vaughan, collector).*

<i>Ameria scalaris</i> Jay.	<i>Natica canrena</i> Linn.
<i>Bulla striata</i> Brug.	<i>Barbatia adamsi</i> Smith.
<i>Actæon</i> sp.	<i>Arca transversa</i> Say.
<i>Tornatina canaliculata</i> Say.	<i>Plicatula spondyloidea</i> Meusch.
<i>Terebra protexta</i> Conrad.	<i>Crassinella lunulata</i> Conrad.
<i>dislocata</i> Say.	<i>Carditamera arata</i> Conrad.
<i>Conus floridanus</i> Gabb.	<i>Venericardia tridentata</i> Say.
<i>proteus</i> Hwass.	<i>Codakia speciosa</i> Rogers.
<i>Drillia</i> aff. <i>ulocyma</i> Dall.	<i>Phacoides</i> sp. indet.
<i>Olivella mutica</i> Say.	<i>nassulus</i> Conrad.
<i>Marginella avena</i> Val.	<i>pennsylvanicus</i> Linn.
<i>apicina</i> Menke.	<i>multilineatus</i> T. & H.
<i>Fasciolaria distans</i> Lam.	<i>radians</i> Conrad.
<i>Fulgur perversum</i> Linn.	aff. <i>waccamensis</i> Dall.
<i>pyrum</i> Dillwyn.	<i>anodonta</i> Say.
<i>Melongena corona</i> Linn.	<i>Montacuta floridana</i> Dall.
<i>Urosalpinx floridanus</i> Conrad.	<i>Cardium robustum</i> Sol.
<i>Nassa vibex</i> Say.	<i>isocardia</i> Linn.
<i>Columbella rusticoides</i> Heilprin.	<i>Lævicardium mortoni</i> Conrad.
<i>Astyris lunata</i> Say.	<i>Dosinia elegans</i> Conrad.
<i>Eupleura caudata</i> Say.	<i>Callocardia sayana</i> Conrad.
<i>Strombus pugilis</i> Linn.	<i>Macrocallista nimboza</i> Sol.
<i>Eulima subcarinata</i> Orb.	<i>Transennella caloosana</i> Dall.
<i>Turbonilla</i> sp.	<i>Chione cancellata</i> Linn.
<i>Pyramidella</i> sp.	<i>Anomalocardia caloosana</i> Dall.
<i>Cerithium muscarum</i> Say.	<i>Venus campechiensis</i> Gmel.
<i>floridanum</i> Morch.	<i>Parastarte triquetra</i> Conrad.
2 sp. indet.	<i>Tellina</i> sp. indet.
<i>Bittium</i> sp.	<i>sayi</i> Desh.
<i>Modulus floridanus</i> Conrad.	<i>Tellidora cristata</i> Recluz.
<i>Turritella perattenuata</i> Heilprin (prob-	<i>Macoma</i> sp.
ably not in place).	<i>Semele purpurascens</i> Gmel.
<i>Calyptrea trochiformis</i> Lam.	<i>Mulinia lateralis</i> Say.
<i>Crepidula aculeata</i> Lam.	<i>sapotilla</i> Dall.
<i>convexa</i> Say.	<i>Corbula cuneata</i> Say.
<i>Cryptonatica pusilla</i> Say.	aff. <i>caloosæ</i> Dall.
<i>Neverita duplicata</i> Say.	

As there is intergradation between the fossiliferous marls and the Miami oolite in the vicinity of Fort Lauderdale, as exposed in the drainage ditches to the west of the village, lists of the fossils from there are inserted here.

List of Fossils from near Fort Lauderdale (George C. Matson, collector).

Locality: South drainage ditch, 8 miles from Fort Lauderdale.	
Pecten irradians Lam.	Chione cancellata Linn.
Lævicardium serratum Linn.	
Locality: 7 miles from Fort Lauderdale, south ditch.	
Cerithium thomasiæ Sowerby.	Transennella caloosana Dall.
Phacoides pennsylvanicus Linn.	Anomalocardia caloosana Dall.
trisculatus Conrad.	Chione cancellata Linn.
Divaricella densata Wood.	Mærella sp.
Locality: 6.5 miles from Fort Lauderdale, Florida, northern drainage ditch.	
Bulla striata Brug.	Avicula atlantica Lam.
Conus proteus Hwass.	Cardium isocardia Linn.
Marginella apicina Menke.	Lævicardium serratum Linn.
Melongena corona Linn.	Phacoides pennsylvanicus Linn.
Cerithidea turrita Stearns.	Semele sp.
Pyramidella dolabrata Lamarck.	Phacoides trisculatus Say.
Strombus leidyi Heilprin. (Hitherto	amiantus Dall.
known only from the Pliocene.)	Divaricella densata Wood.
Cerithium muscarum Say.	Chione cancellata Linn.
thomasiæ Sowerby.	Dosinia elegans Conrad.
Cerithium prob. littoratum Born, junior.	Anomalocardia caloosana Dall.
Modulus floridanus Conrad.	Macoma brevifrons Say.
Arca auriculata Lam.	Ervilia (4 lots).
Pecten irradians Lam.	Mærella sp.

Two warm-water non-reef-building corals, *Siderastrea radians* and *Porites divaricata*, were obtained from the well at Delray, depth 118 feet. This place is slightly north of Hillsboro Inlet, but slightly south of the latitude of the Caloosahatchee exposures and considerably south of those around Charlotte Harbor. It appears that in Recent time the waters may have been cooled somewhat more.

SOUTHWARD EXTENSION OF BURIED SANDS.

The intergradation between both the coquina and the Miami oolite with arenaceous shell marls has already been described, also the interbedding of siliceous sands with the predominantly calcareous material has been mentioned. On the east coast south of Delray, the surface, except a surficial coating of sand, is formed by the Miami oolite and the Key Largo limestone; on the west coast by the Lostman River limestone; and that of the keys west of Bahia Honda by the Key West oolite. Beneath these limestones, however, are sands probably in part Pleistocene and in part Pliocene in age.

The following well records will show the southward extension of these buried sands:

	Depth.	Thickness.
Well at Fort Lauderdale; P. N. Bryan, owner; record furnished by Edwin T. King:		
Sand.....	0 to 2	2
Oolitic limestone (Miami oolite).....	2 14	12
Sand.....	14 30	19
Limestone.....	30 30.5	0.5
Sand and gravel.....	30.5 68.5	38
Hard white limestone.....	68.5 69.5	1
Sand and gravel.....	69.5 100.5	31
Limestone, in alternating harder and softer layers.....	100.5 108.5	8
Well at Dania; property of town; record furnished by Edwin T. King:		
Surface sands.....	0 to 6	6
Oolitic limestone (Miami oolite).....	6 40	40
Blue mud with some gravel.....	46 80	34
Hard limestone.....	80 88	8

At Miami, "samples from the wells of the water company show that the oolite loses its typical appearance a few feet below sea-level and rests on an irregularly cemented aggregate of shell fragments and quartz sand."¹

The record of the well at Marathon, Key Vaca, revealed quartz sand below 155 feet (see page 128). Some of these sands may be Pleistocene.

Sands underlie the Lostman River limestone at a depth of 30 feet at Everglade postoffice.²

Sanford reports a thickness of probably less than 50 feet for the Key West oolite³ and mentions over 200 feet of quartz sand beneath it⁴ on Big Pine Key.

These records show sand beds underlying the Pleistocene limestones as far south as Big Pine Key; some of the sands, the more northerly, are surely Pleistocene, the more southerly may be partly Pleistocene and partly Pliocene.

THE FLORIDA OOLITES.

The presence of two oolitic formations in Florida, the Miami and Key West oolites, has been stated on preceding pages (pp. 130, 131) and certain of their characters have already been given, viz.: their geologic age, their general appearance, the structure of the granules, and their areal distribution. As the object of the following remarks is to throw such light as is possible on the origin of these deposits, a brief statement will be made of the views of the principal previous students.

Louis Agassiz⁵ in his report for 1851 to Professor A. D. Bache, Superintendent of the Coast Survey, says:

The main islands of this group (west of Bahia Honda) are very flat, and consist of thin layers of a regularly stratified and somewhat oolitical limestone, evidently formed by deposits of limestone mud.

E. B. Hunt⁶ seemed to be of the opinion that the Key West oolite might be partly due to the direct transformation of calcareous mud, or to the transformation of calcareous sand lying above sea-level.

Shaler considered the oolite a coral-reef rock and named that in the vicinity of Miami the Miami Reef.⁷ The oolite is distinctly not a coral-reef rock, and Shaler's opinion is to be attributed to the fashion at that time of considering practically all limestone in that area as having been formed through the agency of corals. The differentiation⁸ of varieties of limestone had not then progressed so far as at present.

The next important contribution to the subject came from Mr. Alexander Agassiz in his "The Elevated Reef of Florida," with notes on

¹ Florida Geol. Surv., 2d Ann. Report, p. 212, 1910.

² Sanford, *op. cit.*, p. 223.

³ *Op. cit.*, p. 220.

⁴ *Op. cit.*, p. 206.

⁵ Mus. Comp. Zool., Mem., vol. vii, p. 19, 1880.

⁶ Amer. Jour. Sci., 2d Ser., vol. xxxv, p. 203, 1863.

⁷ Topography of Florida, Mus. Comp. Zool., Bull., vol. xvi, p. 143, 1890.

⁸ Compare Mr. Agassiz's remarks in his "A Reconnaissance of the Bahamas and of the Elevated Reefs of Cuba in the Steam Yacht *Wild Duck*, January to April, 1893." (Mus. Comp. Zool., Bull., vol. xxvi, p. 179, 1894.)

⁹ Mus. Comp. Zool., Bull., vol. xxvii, pp. 29-62, 26 plates, 1896.

the Geology of Southern Florida by Leon S. Griswold." Mr. Agassiz has presented the salient features of his conclusions as follows:

I was quite surprised on examining a bluff about 10 feet in height, extending eastward from Cocanut Point toward the mouth of the Miami River, to find that it consisted of *æolian rocks* which have covered the elevated reef in many places. On the low shores these *æolian rocks* are honeycombed and pitted and might be readily mistaken for decomposed reef rocks; but they contain *no* corals. This looks as if the lower southern extremity of Florida, the Everglade tracts, was a huge shallow sink, or a series of more or less connected sinks, into which sand had been blown, forming low dunes which have little by little been eroded, and which former observers had mistaken in some localities for reef rock. The material for these dunes coming from the now elevated reef or the beach rock at a time when it was either a fringing or a barrier reef along the former coast line of Florida, all of which, back of the reef, has little by little been eroded by the mechanical and solvent action of the sea, leaving on the mainland only an occasional outcrop of the elevated reef as observed by Professor L. Agassiz and Shaler. The outer line of reef has also been elevated.

There are in this view several points that need to be emphasized: (1) The Miami oolite is *not* a coral reef rock. (2) It is of *æolian* origin. (3) In southern Florida a huge sink existed, into which the material of the oolite was blown. (4) The source of wind-blown sand was either the now elevated reef or the beach rock at a time when it was either a fringing or a barrier reef along the former coast-line of Florida. (5) The bays and sounds are due to the mechanical and solvent action of the sea. What is of particular concern here is the supposed *æolian* origin of the oolite and the source of the material. The discussion of the "huge shallow sink" and the formation of the bays and sounds may be laid aside for the present.

A careful reading of the text of Mr. Agassiz's remarks does not reveal the criteria by which he determined the oolite to be *æolian*; he has merely given his opinion. In his foot-notes to Mr. Griswold's "Notes on the Geology of Southern Florida," although dissent from Griswold is expressed, still no criteria are given for distinguishing between water-laid and *æolian* cross-bedded calcareous deposits. At the bottom of page 52 is the statement: "This bluff is a most distinctly marked *æolian* rock exposure, with characteristic knife-edge stratification." A comparison of plate xv of Mr. Agassiz's report on the Bahamas with plate xix of Griswold's "Notes" will show considerable similarity in structure of the Bahaman and Floridian materials.

Griswold in his "Notes on the Geology of Southern Florida," already cited, says concerning the origin of the oolite:

The low undulations of the land surface in the pine belt can scarcely be accepted as evidence of former dunes. They would well accord, however, with the inequalities of a sea floor like the present one between the keys and the mainland. The cross-bedding and oolitic structure favor neither water nor wind as the primary agent in the construction of the rock. Therefore, since the land appears to be very young, being almost without soil and surface drainage ways, the topography favors an origin for the limestone in water.

Sellards has published the opinion that the Miami oolite is a marine formation.¹

¹ Florida Geol. Surv., 1st Ann. Report, p. 22, 1908.

Vaughan published the next opinion on the origin of the oolite.¹ According to him it was formed as a water-laid deposit, probably behind a seaward barrier. He states:

The reasons for this opinion are that numerous marine fossils are found in the oolitic material, the two valves of bivalve mollusks are frequently in place, showing no damage by attrition, and fossil corals which exhibit no indication of having been rolled or waterworn were found. The marine fossils found in the oolite had evidently lived in the water during the formation of the oolite. On the surface of Big Pine Key original mud cracks formed by desiccation were observed and photographed.

The last published opinion is that of Sanford, who says:

The characteristics of the calcareous sands and marls accumulating about the keys and in the Bay of Florida, and the distribution, topographic relief, bedding, contained fossils, and structure of the Key West and Miami oolites indicate that the latter were limy muds, with a varying proportion of lime sand and a little quartz sand, which accumulated on the bottom of shallow bays or lagoons, where in places the water was relatively still, in places agitated by waves and currents strong enough to build up and level off banks and bars. (Florida Geol. Surv., 2d Ann. Report, p. 222, 1910.)

Two theories have been proposed for the origin of the Florida oolites, viz: (1) that of Alexander Agassiz, who considered that the deposits were of æolian origin and were made in a "huge shallow sink"; and (2) that of Louis Agassiz, which considered them of aqueous origin.

In the following account an attempt will be made to assemble the data bearing on these two theories.

The macroscopic and microscopic structure of the oolite granules shows them to be composed of concentric shells of calcareous substance accumulated around a nucleus in some instances calcareous, in others siliceous. This structure is characteristic of concretions, but the problem of the origins of concretions is raised, and a definite answer is not obtained as to whether the material is of subaqueous or subaerial origin. However, it may be mentioned that the specimens I collected on Cat and Gun keys, Bahamas, distinctly showed their detrital nature, while the typical Miami and Key West oolites are distinctly not detrital. But as I did not visit a great number of the Bahaman Islands and have seen none of the Bermudas, I have not the necessary information for a general comparison.

The topography of the surface of the Floridian oolites is not of criterional value, as gentle undulations may be produced under the water or the air, or by slight folding. Here again, however, the flat upper surface of the Key West oolite is more suggestive of water-laid than wind-blown deposits.

The strong cross-bedding of the Miami oolite has been mentioned in the quotation from Griswold. This has been interpreted by Mr. Agassiz as evidence of æolian action, and it is stated by Griswold that as evidence it is not decisive.

In order to illustrate bedding presumably due to wave and æolian action, separate or combined, a series of photographic illustrations are introduced. Plate 13, fig. *a*, illustrates an exposure on Gun Key, Ba-

¹ Carnegie Institution of Washington, Year Book No. 7, p. 133, 1909.

hamas, eastern side, below the lighthouse. This is probably an æolian sandstone, and exhibits cross-bedding very well. Plate 7, fig. *b*, represents the western beach of Loggerhead Key, Tortugas, looking northeast. It shows indurated calcareous sandstone along the water's edge and loose calcareous sands higher on the beach slope. Note the continuity of the slope of the lower indurated with that of the higher unconsolidated material.

The material represented in all of the illustrations mentioned is of detrital origin, and illustrates bedding by shore waves and the wind. Plate 14, fig. *a*, illustrates cross-bedding in a water-laid deposit.

Plate 13, fig. *b*, represents exposures of the Miami oolite. The sharp cross-bedding is brought out, but the rock occurs in distinct ledges. This massive bedding with the cross-bedding of the smaller divisions is suggestive, and it should be emphasized that the oolite granules are not similar to the detrital sands composing the Bahaman and Tortugas exposures.

The data so far presented indicate an individuality of the Floridian oolite areas different from that of the other areas discussed, although as yet definite criteria for determining the conditions under which the oolite was formed have not been advanced. Cross-bedding may be due to current, wave, or wind action, and the three processes may be more or less coöperative.

Illustrations of the surfaces of two oolitic keys bear on the solution of the problem, viz: Plate 14, fig. *c*, which represents Summerland Key; and plate 15, fig. *a*, a view of Boca Grande Key, show remarkably flat surfaces, not in the least suggestive of dunes. On Big Pine Key the surface of the oolite shows mud cracks from drying (plate 14, fig. *b*). Fortunately the oolites are rather rich in fossils.

Fossils from the Miami Oolite.¹

Locality: Golf Ground, Miami.

Cyphastrea hyades (Dana).

Conus floridanus Gabb.

Columbella mercatoria Lam.

Cerithium muscarum Say.

littoratum Born.

Arca gradata Broderip.

Glycymeris pectinata Gmelin.

Avicula atlantica Lam.

Lævicardium serratum Linn.

Codakia orbicularis Lam.

Phacoides pennsylvanicus Linn.

Chione cancellata Linn.

Locality: Kronkheit-Offet Quarry, Miami.¹

Siderastrea radians (Pallas).

Livona pica Linn.

Strombus gigas Linn.

Correlation.—The species are all Recent, and the age of the oolite is therefore Pleistocene.

Locality: Buena Vista.¹

Mellita sexforis Lamarck.

Fossils from the Key West Oolite.

Locality: Big Pine Key (collected by Samuel Sanford).

Mussa (Isophyllia) sp.

Encope michelini Agassiz.

Terebra dislocata Say.

Strombus pugilis Linn.

Cardium isocardia Linn.

Lævicardium serratum Linn.

Phacoides pennsylvanicus Linn.

Divaricella densata Wood.

¹The fossils from these localities were presented by Dr. J. N. McGonigle, of Miami.

Dolium galea Linn.
Natica canrena Lam.
Neverita duplicata Say.
Pecten irradians Lam.

Tellina radiata Linn.
Metis intastriata Say.
Macrocallista maculata Linn.
Chione cancellata Linn.

Locality: Torch Key, eastern side, along railroad embankment (A. G. Mayer and T. Wayland Vaughan, collectors).

Siderastrea radians (Pallas).
Fulgur perversum Linn.
Dolium galea Linn.
Cerithium thomasiæ Sowerby.
Cerithium littoratum Born.
Modulus modulus Linn.
Pecten gibbus Linn.

Cardium isocardia Linn.
Phacoides pennsylvanicus Linn.¹
Divaricella quadrisculata Orb.
Dosinia elegans Conrad.¹
Chione cancellata Linn.
Tagelus divisus Spengler.
Semele cancellata Orb.

¹The two valves are still adherent.

All of the species are Recent, and the geologic age is Pleistocene.

The fossils show no attrition, and the two valves of some of the pelecypods are still in their natural position. These fossils must have remained embedded in the material in which they were more or less embedded when alive. In other words, the surrounding oolite must have originated as a water-laid deposit.

Mr. Agassiz, in his theory of sands blowing into sounds behind the keys and still preserving the character of wind-blown deposits, could scarcely have had it in mind that the sounds or hollows were filled with water, as it could not be expected that sand blown into water, and deposited through it, would preserve the same structure as if subaërially deposited.

To summarize the conclusions pointed by the data presented in the foregoing remarks:

1. The fossils show that the oolite is a water-laid deposit formed in shallow water, a few fathoms, or more probably only a few feet, in depth.
2. The cross-bedding shows it was formed in areas of moderate and variable currents.
3. The topography shows it was formed on flats.
4. The Miami oolite has been elevated above the water-level a sufficient time for it to have suffered considerable denudation; while the Key West oolite preserves its original flat surface with intact mud cracks.

One object in view in collecting bottom samples within the keys was to obtain light on the problem of the origin of the oolites, and the effort had a negative result. A study of the oolites themselves seems to have answered the question. While on Boca Grande Key, on the beach of which oolite occurs, I obtained a suggestion that was perhaps of value. It seems to me that the shells of an oolite grain accumulate around some nucleus by the gentle rolling of that nucleus on a bottom on which calcium carbonate is being precipitated. There is no evidence that oolite is being formed behind the keys east of Bahia Honda, but I think it very likely that it is forming around some of the more westerly keys.

Two geological formations of marine origin remain to be discussed: the Lostmans River and Key Largo limestones. The former was described on page 130; the latter on pp. 130, 131.

LOSTMANS RIVER LIMESTONE.

Sanford says concerning the origin of the Lostman River limestone:

Origin:—Willis has suggested that the rock at Lostmans River was perhaps formed by the deposition of crystallizing calcium carbonate from the presumably limy waters of the Everglades. While there can be no doubt that deposits of marl are now accumulating along the coast, the present hardening of marl to crystalline limestone or the direct deposition of such limestone is not established. As the writer has stated, the bed rock of the western coast, wherever soundings have been made, whether in the Everglades, on swamp islands, along the coast, or in the numerous creek channels, seems to have a gentle slope toward the Gulf. The rock is no farther below water-level in the swamp than in adjacent channels; moreover, the rock surface in channels where the current runs strongly is full of crevices, is extremely rough, and is evidently being eroded. Loose fragments that have been detached by solution are found, not only near the mouths of rivers, but at their heads, on the bare rock, under marl, and under vegetable muck. Another fact that impairs the deposition and crystallization theory is the character of the Everglades water. Most of the marl in the Ten Thousand Islands has come from the ever-dirty shallows of the Gulf. The dark limestones below water in the creeks are the same as those that outcrop above water a short distance away, and a recent crystallization from solution of those is hard to understand.

The limestone on Lostmans River, though containing calcite crystals an inch long, is not greatly different from other limestones of southern Florida; removal, deposition, and crystallization of carbonate of lime are characteristic of the region.¹

The limestone, from its petrographic and paleontologic characteristics, is a shoal-water deposit of marl and limy sand, containing shells of living species of mollusks, that has been solidly cemented and subjected to conditions favoring crystalline growth. This growth may be in progress. (Florida Geol. Surv., 2d Ann. Report, pp. 224, 225.)

KEY LARGO LIMESTONE.

The Key Largo limestone is so closely similar to that being formed by the present reefs, that it is safe to postulate the same physical conditions for the fossil as for the living reefs. They were formed in water having a maximum depth of 18 to 20 feet, a minimum temperature of 70° F., and lay just landward of the current of the Florida Straits. They were separated from the inner bank by a deeper channel, comparable to the present Hawk Channel, and now represented by the bays and sounds between the keys and the mainland.

SURFACE SANDS OVERLYING THE MARINE PLEISTOCENE.

The surface of the Pleistocene fossiliferous deposits is usually overlain by a coating of surface gray or white sand, of variable thickness, from a few inches to several feet. Most probably this sand was originally a marine deposit, laid down as the sea shoaled. Wind has been active in distributing some of it over the land surface, as is attested by the dunes of the east coast as far south as Pine Island in the Everglades, back of Fort Lauderdale,² and on the west coast as far south as Caximbas Pass.

UPLAND GRAY SANDS.

The suggestion may be ventured that a portion of the upland gray sand, which covers all pre-Pleistocene formations and has puzzled so many geologists, may be sand of beaches formed as the successive seas

¹For references to calcite crystals in other Pleistocene limestones of Florida, see pp. 130, 131.

²Florida Geol. Surv., 2d Ann. Report, pp. 224, 225.

shoaled and then blown inland by winds. According to this theory the surface sands would belong to no one geological period, but would represent all the periods since the Vicksburg. Some of these surface sands are undoubtedly residual deposits.

RIVER TERRACES AND OTHER PLEISTOCENE FORMATIONS.

River terraces are present in Florida, as in the valley of St. John's River, where a well defined one rises 20 to 30 feet above tide,¹ and there is evidence of their occurrence along other streams, but in the absence of detailed topographic maps they can not be satisfactorily discriminated.

Other Pleistocene formations are aggregates of the shells of the fresh-water mollusk *Planorbis*² and masses of the tubes of the marine mollusk *Vermetus negricans*.³

SUMMARY OF PLEISTOCENE HISTORY.

In the preceding discussion of the marine Pleistocene formations of the Peninsula of Florida, their salient characteristics, their distribution, and the conditions under which they were formed have been given. These data permit a general statement of the conditions prevalent over the submarine portion of the Plateau, with some deficiency in precision due to a lack of accurate knowledge of succession and synchrony between all of the deposits. There are undoubtedly several horizons in the Pleistocene. The material from west of Fort Lauderdale seems, from the fossils, to be older than the Miami and Key West oolites. The material in the Delray well, depth 118 feet, may be older than that west of Fort Lauderdale. Additional detailed stratigraphic and paleontologic work on the Pleistocene deposits is needed.

The Pleistocene shore-line has already been outlined. Seaward of this margin the entire Peninsula was submerged, but to no great depth; very likely, unless in channels or entrants, in no place did the depth of the water exceed 50 feet. During a portion of the period of submergence the sea-bottom was gradually lowered and deposition kept pace with the sinking.

Shell marls were deposited over practically the entire surface of the submerged platform north of the present southern margin of Lake Okeechobee. The fauna indicates for this region a warm temperature; however, it was a few degrees cooler than that of the present east coast south of Key Biscayne. Arenaceous sand was brought from the north and carried practically to the southern margin of the Plateau, but in the later Pleistocene in much diminished quantities south of Miami. This sand came partly from the mainland to the north and partly by southward-moving shore currents, which must have been warm return-currents, as the fauna was characteristic of warm water. Shell-banks formed by wave-wash accumulated on the east coast from St. Augustine to at least 20 miles below Palm Beach, and are now coquina. These deposits may have been formed along the margin of the bank as it was elevated. Similar coquina beds appear to have been formed on the west coast.

¹ Matson and Clapp, Florida Geol. Surv., 2d Ann. Report, p. 39, 1910.

² Matson and Clapp, *op. cit.*, p. 153.

³ Matson and Clapp, *op. cit.*, p. 154.

South of the latitude of the present southern end of Lake Okeechobee, limestones were the prevalent geologic formations, and in this region the four limestone formations of south Florida were formed, all in shallow water. On the southwest it was the Lostman River limestone; along the southeastern and southern margin coral reefs grew and formed the Key Largo limestone. Behind the line of reefs was a channel comparable to the Hawk Channel of present time. East of the Lostman River limestone, in shoal water, agitated by strong currents, the Miami oolite accumulated. Whether this oolite was formed previous to the formation of the Key Largo limestone, or whether the two are contemporaneous, is an unsolved problem. Westward of the Key Largo limestone, oolite was forming on a shallow bank, later to form the group of keys from the Pine Keys to Boca Grande.

The temperature of this portion of the ocean and the direction of the currents were practically as to-day.

Pleistocene time was closed by an uplift of the Plateau—the uplift evidently being accompanied by deformation, as the elevations of the surface of the marine Pleistocene are by no means the same. Those in the central portion of the Peninsula are greater than toward the south, and the east coast is higher than the west. There is evidence of a slight ridge on each side of Lake Okeechobee, the eastern ridge being the higher.

J. O. Wright, Supervising Drainage Engineer of the Department of Agriculture, in a report embodied in the Report of the Special Joint Committee of the Legislature of Florida on the Everglades of Florida,¹ gives the mean water-level in the Okeechobee Lake as 20.5 feet above tide, level at low stage about 19 feet; the greatest depth at low water is 22 feet, or the bottom is 3 feet below sea-level; the average depth is 12 feet, or the bottom is 7 feet above sea-level. Heilprin says concerning the depth of the Lake:

We took numerous soundings all along our course, probably fifty or more, which gave an average depth ranging from about 7 to 10 feet. The deepest sounding made on the diagonal connecting Taylor Creek and the mouth of the canal, about 4 miles southwest of Eagle Bay, gave 15 feet, but this is the only instance when we obtained this depth. (Wagner Free Inst. of Sci., Trans., vol. 1, p. 41, 1887.)

Accurate geologic information on the bottom of the Lake is scanty, but as it is surrounded by marine Pleistocene, the surface deposit on the bottom may be safely inferred to be Pleistocene. As Pleistocene occurs at higher elevations on both the east and west sides, the conclusion is pointed that the Lake lies between gentle anticlines, one toward the east, the other westward, and there may have been somewhat greater elevation between its southern end and the southern shore than in the area of the Lake itself, producing a shallow synclinal hollow.

In the vicinity of Kissimmee the amount of elevation was 60 to 70, or perhaps 100 feet; of Miami, 40 to 50 feet; along the coral reef keys, 10 to 15 feet; along the Caloosahatchee, near Fort Thompson, perhaps 30 to 40 feet; near Osprey, less than 30 to 40 feet; along the keys west

¹ Tallahassee, Florida, 1909.

of Bahia Honda, perhaps 10 to 20 feet. Along the west coast in places there may have been very slight elevation.

The details of these differential earth-movements have not been worked out, and until accurate topographic maps are available and more thorough studies of the stratigraphy and structure have been made, it will not be possible to decipher them.

This uplift may have been intermittent, or there may have been oscillation. The presence of terraces along some stream indicates one or the other. The amount of the elevation closing the main Pleistocene deposition was probably greater than that now shown by the land surface, it being followed by a slight depression, as is evidenced by the drowned valleys of recent times; that of St. John's River is an instance.¹

RECENT.

The events closing Pleistocene time gave the Plateau its present configuration, and although no attempt will be made to recount in detail Recent phenomena, the development of both the present coral reefs and the interior swamps of the Everglades may be mentioned. The reefs developed next the pure ocean waters just inside the 10-fathom curve, and the Everglades were formed on the flat, imperfectly drained area south of Lake Okeechobee.

The geologic history of the Marquesas and Tortugas is reserved for future consideration. The present surface above sea-level of these two groups of islets seems to be geologically Recent. They are mostly or entirely composed of organic detritus and calcareous material drifted westward along the southern margin of the Floridian bank, as both Hunt and A. Agassiz have contended. However, important geologic details remain to be worked out for each group.

RÉSUMÉ OF THE GEOLOGIC HISTORY OF THE FLORIDIAN PLATEAU.

The agencies which originally shaped, and subsequently dominated, the development of the Plateau, were of two kinds: (1) those that cause warpings of the earth crust; (2) those resulting in the deposition of material on the sea-floor, viz: corrosion and erosion of the land surface above sea-level, transportation to the sea, transportation and deposition of land-derived material in the sea, and organisms which added their skeletal remains to the material of inorganic origin.

The Plateau existed in Vicksburgian, Lower Oligocene, time, projecting as a submarine platform from the southeastern corner of the continental shelf and extending at least to its present southern limit. The forces by which this older Oligocene platform was formed at present can only be the subject of speculation. It was due to some fold of the ocean-bottom, perhaps in some way connected with the angle of the Piedmont area in central Georgia.

The water over this Plateau was shallow, probably in no place 100 fathoms deep; the bottom temperature was between 70° and 80° F.; tropical currents passed over its surface; deposits of both terrigenous

¹ Matson and Clapp, *op. cit.*, p. 172.

and organic origin accumulated on it ranging in thickness from 100 to 200 feet near shore to the north to over 1,000 feet near its southern margin. As the water was shallow, the sea-bottom must have been gradually depressed while the material accumulating on its surface was being deposited.

At the close of Vicksburgian time the Plateau was elevated and areas of its surface were subjected to subaerial denudation, as is attested by the erosion unconformity along the contact of the basal Apalachicola with the underlying Vicksburg sediments.

Apalachicolan time needs separation into two stages, an earlier, represented by the Chattahoochee, Hawthorne, and Tampa formations, and a later, represented by the Alum Bluff formation. The areal extent of the deposits of the earlier stage was not so great as that of the Vicksburg deposits, indicating the later was not so extensive as the previous submergence. The northern shore-line was seaward of that of the Vicksburg Group; it seems probable that a small island existed in the sea in what is now the northeastern corner of Marion County, and in other areas the sedimentation over the Vicksburg deposits was thin. Along the western coast of Florida the Vicksburg formations were being gently folded, and a dome-like structure was developing southward.

The Plateau, in early Apalachicolan time, had practically the same outline as at present; the depth of water north of Tampa was probably in no place over 100 feet. Coral reefs were present in southern Georgia, across the base of the present Peninsula, and around Tampa; the temperature was tropical, the minimum for the year being at least as high as 70° F.; the main movement of the ocean water was from the tropics; the sediments consisted to a lesser degree of organic débris, and were predominantly of terrigenous constituents.

In the later stage of Apalachicolan sedimentation, the island of Oligocene lying west of the present longitudinal axis of the Peninsula, here named Orange Island, had by further uplift increased in size and was separated from the mainland to the north by the Suwanee Strait. There was differential earth-movement, the sea-bottom being depressed around Orange Island and between it and the shore of the mainland to the north, permitting additions to the thickness of Apalachicola sediments. During this later stage of the Apalachicola the oceanic waters of the region gradually cooled and coral reefs disappeared. The sediments were mostly of terrigenous origin and were laid down in shallow water.

This period of deposition was succeeded by one of uplift and subaërial erosion, the Apalachicolan-Miocene Interval, after which was another, the Miocene, subsidence. This subsidence was not so extensive as that of the preceding deposition period, and although it seems probable it is not positively proven that the Suwanee Strait was again open water, the Miocene deposits did not extend so far inland as the margin of the Apalachicolan Sea, and there were extensive land areas west of the present longitudinal axis of the Peninsula. The Plateau had approximately its present outline, and thick deposits of arenaceous sands were formed practically to its southern limit, certainly as far south as the locality of Key Vaca; the sea was shallow, perhaps 25 fathoms is a safe

maximum; there was depression coincident with deposition on the east coast; the waters were cold, a cold inshore countercurrent lowered the temperature to that of the region between Cape Hatteras and Long Island. This southward-moving countercurrent, aided by winds and waves, is largely responsible for the greater thickness of sediments on the east than on the west coast, and it is the forerunner of the series of countercurrents so important in the later history of the region. Toward the close of the Miocene period uplift was again initiated, and the Suwannee Strait, should it not have been previously closed, was then assuredly above sea-level, and the north and south Trail Ridge was formed. The uplift seems to have been greater on the east than on the west, for no Miocene is above sea-level from Levy to Pasco counties on the west coast, while submerged Miocene is apparently present off the mouth of Tampa Bay.

The Pliocene submergence was extensive, over half of the present land surface of the Peninsula lying below sea-level. The submergence of the present land surface along the east coast extended down the west side of St. John's River valley, and entirely across the median portion of the Peninsula northwest of Lake Istokpoga. No known marine Pliocene occurs on the west coast north of the Charlotte Harbor localities. The general outline of the Plateau remained as it was in Miocene time; the water was shallow, usually between 20 and 30 feet in depth; the temperature was tropical in the southern, the Caloosahatchee area; and warm, but slightly cooler in the northeastern area, in the vicinity of Nashua. The oceanic current over the Pliocene bank must have been a warm countercurrent—a countercurrent because it brought sands from the north and deposited them on the Pliocene submarine bank.

While the Pliocene marine deposition was taking place important lacustrine and fluvial deposits were accumulating on the land surface above the sea.

Pliocene deposition was closed by another uplift of the Plateau. Data for a precise estimate of the height of the land during this emergence are not available, but the evidence obtainable indicates that it was not over 200 or 250 feet as a maximum, and as the previous movements of the Plateau were differential it is most probable that only portions were subjected to oscillations so great. Accompanying this oscillation a shallow syncline was developed along the axis now occupied by the Kissimmee River, with low anticlines on each side. Probably a third anticline was developed west of Peace Creek. The axes of these folds are parallel to the longitudinal axis of the Peninsula, and have been important in influencing the drainage courses of middle Florida.

The Pleistocene submergence was as extensive as that of the Pliocene, all Pliocene areas, perhaps, but not probably, excepting one between St. John's River and the east coast, being resubmerged, and there is a border of Pleistocene on the west coast and the western extension where Pliocene is not now known. The Plateau throughout Pleistocene time preserved its general outline. Shallow-water conditions prevailed over its entire submerged portion. In no place were the known deposits laid down in water much deeper than 50 feet, and usually from

barely below sea-level to 25 or 30 feet. The temperature north of the latitude of the southern end of Lake Okeechobee was slightly cooler than in Pliocene time, but it was still warm. In this shallow, warm sea sediments of diverse kinds were deposited. Sands and shell marls are probably the most extensive, forming widespread deposits over almost the entire submarine bank. The sands extend beneath the limestone formations as far south as Miami, and perhaps to the southern keys. Along the more northerly portions of the bank coquina accumulated. Along a curve, first southward and then bending westward, from Biscayne Bay, a coral reef flourished, separated by a channel of deeper water from the main bank, on which the Miami oolite was forming or had formed in shoal water strongly agitated by currents. Along the southwestern portion of this bank, also in shoal water, the Lostmans River limestone accumulated. West of the coral reef, on an extensive flat in the shoal water over them, the Key West oolite was formed. Toward the close of the Pleistocene the previously formed sands, marls, and limestones southward beyond Miami received a thin coating of siliceous sand. Contemporaneous with this purely marine work, the terracing of rivers to the north was taking place.

Pleistocene time was closed by an uplift, which may have been intermittent or may have been accompanied by oscillations. There is some evidence of slight depression since the principal uplift. After this uplift the living coral reefs developed, the Everglades were formed, and the Florida of to-day was the result.

This summary will be closed by an account of the rôles played by deformation and ocean currents in the history of the Plateau.

DEFORMATION.

The Floridian Plateau owes its origin to a fold of the sea-floor in pre-Oligocene, probably Eocene time, producing a platform on which sediments during the later geologic periods were laid down. The whole earthmass, since the origin of the platform, has been subjected to a succession of deformations due to compression between forces acting from the east and west, resulting in the axes of the gentle folds being coincident in direction with the longitudinal axis of the Plateau, and to downward and upward tilting around a landward fulcrum. The initial uplift with deformation took place, as nearly as can be determined, toward the close of the Vicksburgian deposition period. The Vicksburg nucleus lay nearer the eastern than the western margin of the Plateau surface, and was roughly dome-like in form, but with a longer north-and-south than east-and-west axis. The subsequent growth of the Peninsula was by filling the channel between the island of older Oligocene (Vicksburg) rocks and the mainland, and by growth eastward and southward from it. There was little or no westward growth. There was additional deformation in later Oligocene (Apalachicola) time, between the Apalachicola and Miocene deposition periods, between the Miocene and Pliocene, between Pliocene and Pleistocene, and succeeding the Pleistocene deposition. The result of each of the series of deformations was to add, beginning with the Miocene-Pliocene member

of the series, one or more anticlinal swells with intermediate synclinal depressions to those that preceded, the additions above sea-level always taking place toward the east, and at each elevation the uplifting was propagated southward. The continued effect of all the uplifts was to elevate the eastern portion of the Plateau above the western, or there has been elevation on the eastern side of the Plateau coincident with stability or even slight depression on the western side.

CURRENTS.

The importance of currents in shaping the land area of Florida has been emphasized in several sections of the preceding discussion. Before the history of the currents of the region can be thoroughly understood it is necessary to know the history of the Hatteras axis of North Carolina. The present Florida countercurrent seems due partly to the impingement of the Gulf Stream against the Hatteras projection, resulting in a portion of the waters being deflected southward along the coast instead of continuing their northward journey. The Hatteras axis has existed as a dividing line between depositional areas apparently since middle Cretaceous time, and it has been either a region of shoal water, or occasionally a land area, since later Eocene time. The Vicksburgian and Apalachicolan seas were both warm, tropical or subtropical in temperature. It is not definitely determinable at present whether the warmth of these waters was due to currents directly from the Tropics or to warm return currents produced by the northward flowing Gulf Stream having a portion of its waters diverted southward by impinging against a salient from the more northerly land area.

In Miocene time it is definitely known that a cold inshore current found its way southward to Florida and westward to Pensacola. This current may be due to the Miocene submergence of the Hatteras area sufficiently lowering the sea-bottom off Hatteras to permit the Gulf Stream to continue its course unobstructedly northward. Should this hypothesis be correct a re-examination of the faunas of the Miocene deposits of northern North Carolina and Virginia, and those of southern North Carolina (the Duplin marl), South Carolina, Georgia, and Florida, with reference to synchrony may be necessitated. The Miocene southward current transported quantities of terrigenous material and deposited it on the eastern border of the Floridian Plateau.

Since Miocene time there have been constantly return currents of warm water (however, not so warm as the Gulf Stream), and they, aided by winds and tides, have deposited terrigenous material on the eastward side of the existing land areas, sweeping a portion of it to the southern end of the Plateau. These currents were active during Pliocene and Pleistocene times, and are still active to-day.

The shape of the upper surface of the Floridian Plateau, the land area of its eastern side, the arrangement of the geologic formations of successive ages, the directions of the stream courses, and the contour of the present coast line, owe their peculiarities and characteristics to the concomitant operation of the forces producing deformation and to oceanic currents.

A.

B.

C.

A, Cape Florida, showing surface of siliceous sand and cocoanut palms.
 B, Cape Florida, showing surface of siliceous sand and sea-grape.
 C, The Marquesas, south side, beach ridge of calcareous sand in the foreground, mangroves in the distance.

A

B.

C.

D.

- A, Loggerhead Key, showing bay cedars and loose calcareous sand.
 B, Loggerhead Key, western beach, northeast of lighthouse, showing passage of beach curve from indurated material along water's edge into that of loose material above it.
 C, Edge of the Everglades, near Miami, showing saw-grass.
 D, Edge of the Everglades, near Miami, showing a lily pad.

A.

B.

C.

A, Miami oolite, pine lands, outskirts of Miami.

B, Erosion by sea-spray, Picquet Rocks, Bahamas, western shore, distance 15 feet.

C, Erosion by sea-spray, Gun Key, Bahamas, western shore.

Young mangroves, showing stages of development from the pod. The four small figures represent pods plucked from the tree.

A.

B.

C.

D.

Young mangroves. A and B, shoal about 2 miles north of Pigeon Key, water about a foot deep. C and D, shoal upper end of Long Island, water about a foot deep.

A.

B.

Mangroves, Miami River.

A.

B.

A. Mangrove roots, Pigeon Key.

B. "Black Mangroves," Pigeon Key.

A.

B.

- A. Cross-bedded calcareous sandstone, probably aeolian, western side of Gun Key, Bahamas.
- B. Miami oolite exposure, Miami, showing cross-bedding.

A.

B.

C.

- A. Cross-bedding by water in an Eocene exposure,
Central of Georgia Railway, two miles northeast
of Andersonville, Georgia.
- B. Mud cracks, surface of Key West oolite, Big Pine Key.
- C. Surface of Key West oolite, Summerland Key.

A.

B.

C.

- A. Surface of Key West oolite, Boca Grande Key.
- B. Key Largo limestone, southern end of Old Rhodes Key.
- C. Coral head in Key Largo limestone, Key Vaca.

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