GEOLOGY

By Gerald G. Parker, N. D. Hoy, and M. C. Schroeder

RELATIONSHIP OF GEOLOGY TO STUDY OF GROUND-WATER RESOURCES

The occurrence of ground water is governed by the geology, and any attempt toward its evaluation is therefore dependent upon a thorough knowledge of the structure, stratigraphy, and lithology of the area. Studies of outcrops aid in the correlation of the formations and give clues concerning their stratigraphic relations.

In areas where the rocks are hidden, exploratory test-well drilling must be done in order to determine formations present at any given depth and to determine the lithologic, hydrologic, and paleontologic characteristics of the formations. With this information the geologist can then prepare maps and cross sections showing graphically the relationships of the formations, the aquifers, and the aquicludes. Thus, the width, thickness, and general distribution of all formations and water-bearing rocks can be determined, and by constructing water-table maps the movement of water can be traced from the time it enters the rocks until it is finally discharged.

METHODS OF INVESTIGATION

GENERAL STATEMENT

The study of geology in southern Florida is not only difficult to perform, but it is slow and costly. This is because of the combination of low-lying land with little relief; the thick cover of mantling sands, marls, and soft organic soils; the thick growth of vegetative cover; and the large area of swamps and marshes.

These conditions were almost insurmountable to early geologists, whose work was necessarily confined to observation of outcrops around the margins of the peninsula and along the low banks of the few shallow rivers. Only a few water wells had been drilled, and few cuttings had been saved; therefore, adequate studies of the underlying rocks were impossible.

Later, the building of roads, railroads, canals, and cities brought about conditions that made geological research easier. Cuts for roads and railroads in southern Florida are practically nonexistent, but the excavation of borrow pits, ditches, and quarries, and the drilling of thousands of wells have helped. The miles of spoil banks have revealed the surficial distribution of the formations, and the fine state of preservation of the fossils found therein has aided greatly in working out the stratigraphy and paleontology.

The construction of roads, which crisscross hitherto inaccessible portions of the area, has been of inestimable value, and the development of new means of transportation, such as the "glades-buggy," "air-boat," wide-cleated tractor, helicopter, and airplane, has made it possible to explore these trackless wilds. Then, too, the development of efficient drilling machinery has been a relatively recent accomplishment. Light portable drilling equipment can now be utilized in areas where previously only Seminoles or white hunters ventured, and heavy equipment can be hauled over roads to sites where deep exploratory test wells are needed.

The present investigation has been conducted along two main lines of research: 1. study of outcrops and tracing of formations in the field, and 2. study of subsurface conditions by means of samples from exploratory test wells.

GEOLOGIC STUDIES FROM OUTCROP DATA

Natural rock outcrops are very limited in southeastern Florida. Only a few occur in the 4,000 square miles of the Everglades and these are principally lacy solution remnants, which are isolated and widely scattered in the southwestern parts. North and west of the Everglades, except in parts of the Big Cypress Swamp, the rocks are generally covered by sandy marine terrace deposits, and to the east the rocks of the Atlantic Coastal Ridge crop out in a narrow strip bordering the ocean. This strip is likewise largely covered by sand north of Miami, but the sand gradually thins out to the south, and beyond Coral Gables the rocks form the land surface almost everywhere. In the Caloosahatchee River banks west of Ortona the rock exposures (since the dredging of the river and the installation of Ortona Lock) are better than ever before. Recent widening, straightening, and deepening of the river have made fresh cuts through the strata, and the installation of the lock at Ortona has lowered the water level several feet in the stretch of the river west of the locks.

The present areal geologic map (pl. 4) has been worked out largely by tracing formational contacts along canal and borrow excavations during extreme low water of the dry season; it checks fairly closely with that of earlier workers (Cooke and Mossom, 1928). This work has been described in part by Parker (Cross, Love, Parker, and Wallace, 1940; Parker, 1942, p. 47–76; Parker and Hoy, 1943, p. 77–94; Parker and Cooke, 1944) in previous reports.

EXPLORATORY TEST-WELL DRILLING

Various methods of gathering subsurface geologic and hydrologic data were used in this investigation; these methods depended upon the funds available, the data required, and the area in which the data were to be collected. For example, in instances where the area was not directly accessible by road, light portable equipment was transported by special vehicles adapted to that particular area. If a shallow well was installed principally to test the quality of ground water (as were the wells through the heart of the Everglades along Miami Canal), a well $1\frac{1}{4}$ inches in diameter was put down manually. If the purpose was to gather more complete data, portable mechanical drilling equipment was moved in, and wells $2\frac{1}{2}$ to 4 inches in diameter were drilled (a good sampling of the rocks, fossils, and waters can be obtained from wells of this type). If the area was directly accessible by good road, any kind of equipment, from light to very heavy, could be used, and in most instances wells 6 inches in diameter were put down. From an exploratory test well of this size, good to excellent cuttings, fossils, and hydrologic data can be obtained, and it was this kind of well that was principally used in this investigation. Occasionally, where conditions permitted, $2\frac{1}{2}$-inch wells were jetted down; the main advantage of such wells is their relative inexpensiveness. Rock and water samples are satisfactory, but macrofossil data are likely to be poor, and hydrologic data are not so good as from wells of larger diameter.

Most of the test wells were installed by the standard cable-tool method and were drilled in such a manner that the bit was closely followed by the casing, thus shutting off the upper rock and water that had been passed through and assuring the collection of valid samples for any given depth. Samples of the cuttings were collected every few feet, stored in containers, and taken to the laboratory for study. Macrofossils were screened out of the cuttings at the drilling site; later, in the laboratory, microfossils were separated and mounted on faunal slides for identification. Water samples were collected for analysis as often as practicable, although sometimes the formations were essentially without recoverable water and no sample could be obtained.

In drilling by the cable-tool method it is necessary to have enough water in the hole to keep the cuttings continuously immersed. This makes it easier to remove the cuttings, it speeds up drilling, and when the hole is nearly full of water, it helps prevent caving of the soft, unconsolidated materials by maintaining nearly equal hydrostatic pressure inside and outside the well.

Often, however, the deeper formations lacked enough water to supply the well with sufficient drilling water, and it was necessary to add water from the surface. Before collecting a water sample, therefore, it was necessary to bail out all this added water to insure the collection of a sample truly representative of the ground water at that depth. In the relatively impervious materials it required many hours for enough water to seep into the test well for sampling purposes. All samples were collected in 12-ounce bottles and were taken to the laboratory for analysis.

In all, 167 exploratory test wells were drilled in southeastern Florida during the 1940–46 period. Of these, 30 were installed jointly by the U. S. Geological Survey and the Soil Conservation Service. The rest were installed either by the U. S. Geological Survey or, under its supervision, by the Army, Navy, or Defense Plant Corporation. Logs for many of these wells are given in tables 126–134.

THE FLORIDAN PLATEAU

The peninsula of Florida is the emerged part of a much wider projection from the continental mass of North America, called by Vaughan (1910, p. 99–185) the Floridan Plateau (fig. 8).[1] The

[1]Vaughan spelled it "Floridian," but the simpler and etymologically correct spelling is "Floridan," the spelling herein adopted.

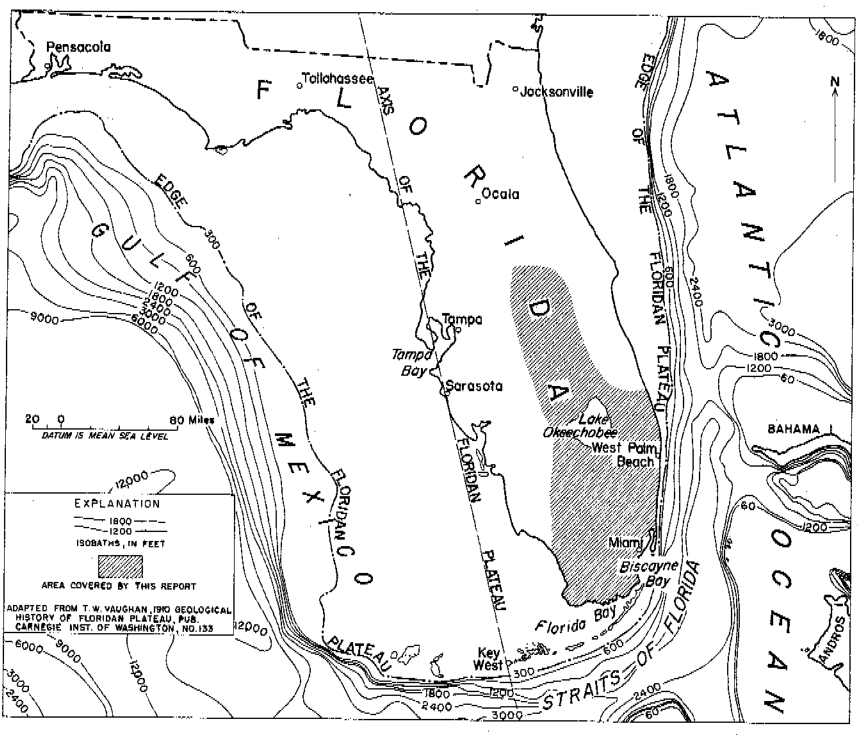

Figure 8. —The Floridan Plateau.

plateau has the appearance of a huge horst, and it separates the deep water of the Atlantic Ocean from the deep parts of the Gulf of Mexico. Its core is composed of metamorphic and igneous rocks similar to those underlying the Piedmont region of the eastern United States, of which, according to Mossom (1926, p. 174–256), it seems to be a southern extension. Campbell (1939c, p. 87–105) has suggested that Paleozoic and Mesozoic rocks may underlie the sedimentary formations and comprise a part of the core of the plateau. The steep submarine slopes that mark its boundaries on the east, south, and west presumably represent fault scarps or monoclinal folds in the original basement rocks, though their outlines may have been modified by solution and erosion and the accumulation of sediments upon them. Pressler (1947) mapped the faults involved in the structure on the east and south, and he suggested that downwarping caused the form of the plateau.

The core or bedrock of the Floridan Plateau is covered with sediments that range in thickness from about 4,000 feet in north-central Florida to more than 15,000 feet in southern Florida. The deepest well drilled in Florida before 1942, located in Monroe County, was started in calcareous sandstone of the Tamiami formation of Miocene age and ended, at a depth of 10,000 feet, in limestone and anhydrite assigned by Campbell (1939b, p. 1713–1714) to the Lower Cretaceous. Cole (1941, p. 16–17) agreed that the rocks are Cretaceous but found no evidence that they are Lower Cretaceous. The rocks penetrated were dominantly limestone and marl. No sand or clay is reported below the Hawthorn formation of Miocene age—an indication that southern Florida was for a long time remote from sources of such sediments.

Since 1942 several deep wells have been drilled in southern Florida in an attempt to discover new oil fields. The deepest of these wells, drilled at Big Pine Key in Monroe County, (about 30 miles east-northeast of Key West) is reported by Campbell (personal communication) to have penetrated more than 15,000 feet and to have ended in undoubted Lower Cretaceous sediments. The materials penetrated were dominantly limestones, dolomites, and anhydrite.

Only the eastern part of the plateau stands above sea level; the western half slopes gently out beneath the waters of the Gulf of Mexico, where it plunges to greater depths. This suggests tilting to the west. Moreover, the trend of the boundaries between successive geological formations is to extend farther out beneath the Gulf. This, however, might indicate merely that the western half of the plateau was eroded more deeply than the eastern half when the sea stood lower with respect to land surface than it does now. More likely, however, it represents tilting that took place largely at the close of the Pliocene epoch and possibly during the early part of the Pleistocene epoch. The sloping surface of the plateau may, in some degree, reflect the contour of the ancient core, or it may be the result of the deposition of a greater thickness of sediments on the eastern side. Since early Pleistocene time no noticeable tilting has taken place—Pleistocene shorelines apparently remain horizontal throughout their distribution in Florida. Cooke (1931, p. 503–515) has traced discontinuous and eroded shorelines from New Jersey into Florida and finds that they are approximately level, thus indicating that this area has been relatively stable for a considerable length of time.

Southern Florida occupies the southeastern corner of the Floridan Plateau. The edge of the plateau lies only a few miles off the Atlantic coast and sweeps closely around the crescent of the Florida Keys, but it lies many miles to the west off the Gulf coast. The shallow waters of the Florida Bay lie upon the plateau.

THE OCALA ANTICLINE

In his geologic cross section, extending from Alabama through Florida to Cuba, Pressler (1947, p. 1851–1862) shows the Ocala uplift underlain by a dome of schist and granite constituting the principal geologic structure of the State, and high-angle faults bounding the southern tip of the Floridan Plateau. The Straits of Florida is shown as a huge graben. He also says that "on the basis of present data, anticlines are probably the most prevalent structure * * * though faulting is undoubtedly present, and conditions are favorable for the formation of stratigraphic traps * * *."

Overlying the crystalline rocks at the crest of the Ocala uplift are rocks of Late Cretaceous, Tertiary, and Quaternary age. Lower, off the flanks of the uplift, rocks of Early Cretaceous age occur. The Tertiary and Quaternary rocks form a broad elongate dome, or anticline, that trends in a southeastern direction and plunges to the southeast in southern Florida. On its crest, in northwestern peninsular Florida, this huge arch is breached by erosion (see fig. 9), and Ocala limestone of Jackson age (upper Eocene) is exposed at altitudes as much as 150 feet above sea level. In northeastern Monroe County the top of the Ocala limestone lies 1,200 feet below sea level, indicating an average dip southward of about 5 feet per mile. However, because the surface of the Ocala limestone has been modified by faulting, erosion, and solution, this slope probably is not uniform throughout. A slope of 5 feet per mile is less than the slope of many sea bottoms on the continental shelves; nonetheless, it is believed that some deformation is involved.

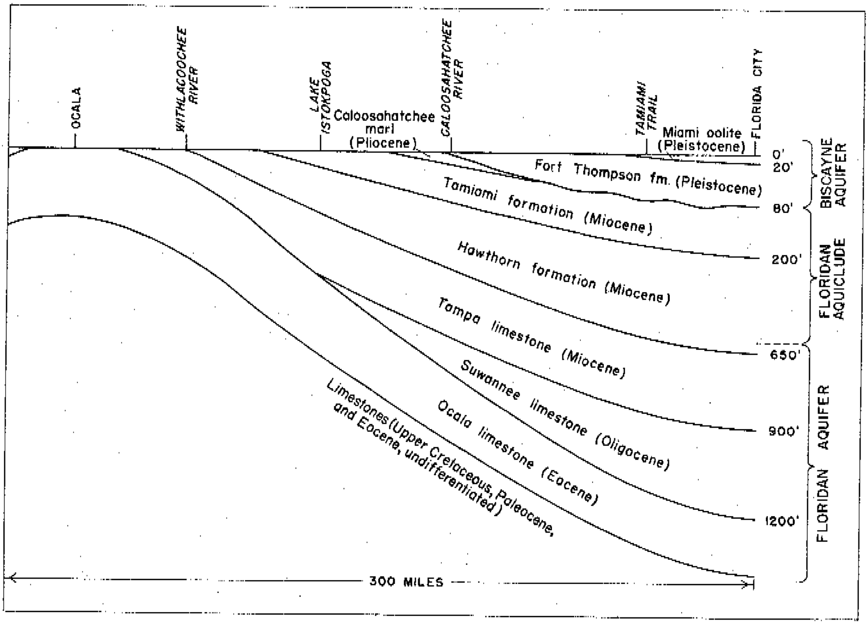

Figure 9. —Generalized NNW-SSE geologic cross section from vicinity of Ocala to Florida City.

Younger geologic formations of Oligocene and Miocene age flank the Ocala anticline and slope away in all directions from the crest of the dome, thickening seaward. Because of their structure and the capacity of some of them for transmitting water, the water-bearing formations constitute notable artesian aquifers. They crop out near the shoreline along Citrus, Levy, and Dixie Counties on the Gulf coast, and at the edge of the continental shelf on the Atlantic coast. Some of their ground-water discharge takes place through submarine springs, such as the one near Saint Augustine, about 2½ miles east of Crescent Beach (Stringfield, 1936, p. 157; Ferguson, Lingham, Love, and Vernon, 1947, p. 9–10), but most of the natural discharge is probably accomplished through unnoticed submarine seepage.

The younger formations of Pliocene, Pleistocene, and Recent age lie more nearly flat. They do not carry artesian water under high pressure as do the older Tertiary formations, but in local instances water is carried under low artesian head, especially in the Pliocene rocks.

STRATIGRAPHY AND WATER-BEARING CHARACTERISTICS OF THE FORMATIONS

GENERAL STATEMENT

The stratigraphic succession of formations in southern Florida was formed, with few exceptions, under a marine environment. The exceptions occur in the lacustrine and swamp deposits of the Lake Okeechobee–Everglades depression and the connecting Kissimmee River valley. These deposits include the fresh-water beds of the Fort Thompson formation, the fresh-water Lake Flirt marl, and organic soils, mostly peats and mucks. In west-central Florida there are deltaic, lacustrine, and alluvial deposits that are believed to be contemporaneous with certain of the Pliocene marine beds (Parker and Cooke, 1944, p. 21, 60, 61).

Most of the geologic materials of southern Florida are limestones, marls,[2] silts, clays, shells, sand, gravel, and various mixtures of these materials; very deep wells penetrate great thicknesses of limestone, anhydrite, and gypsum, with minor amounts of halite. Generally the coarser materials, such as coarse sand and gravel, are scarce, but some occur in the Hawthorn and Tamiami formations (Miocene) and in the Caloosahatchee marl (Pliocene). The clays of southern Florida (except the laterite of the Redlands district—see p. 110) are commonly greenish and calcareous; of marine origin, they usually contain a shallow-water fossil fauna indicative of warm subtropical seas.

This area has long been one of shallow-water conditions with an adjacent low-lying land mass whose usually sluggish streams carried relatively small amounts of suspended or bed-load materials to the sea. Shoreline processes were the major factors in dispersing detrital materials. Conditions such as these have been generally operative at least since the opening of the Tertiary period. Whether they were operative prior to this time, also, remains to be seen from the research now being made by oil-company geologists engaged in deep-well drilling programs.

In the southeastern Florida ground-water investigations no wells were drilled deeper than 812 feet, and very little original

---

[2]Marl is generally considered to be an unconsolidated earthy material consisting of particles of clay size with considerable calcium carbonate included. In Florida almost any unconsolidated material containing variable quantities of calcium carbonate is called a marl, although the term may be qualified by use of an appropriate adjective. Deposits consisting largely of shells plus detrital materials are called "shell marls"; mixtures of peat and calcareous silt or clay are called "peaty marls"; those composed of sand and calcareous silt or clay are called "sandy marl"; and there are many other possible variations, depending upon the character of the dominant constituents.

data have been obtained on formations deeper than the Hawthorn. Therefore, in this report the major emphasis will be placed on the late Cenozoic strata (from the Miocene through the Recent epoch).

PRE-TERTIARY ROCKS

Rocks of pre-Tertiary age are not penetrated for water supplies in southern Florida for two principal reasons: (1) they are deeply buried and thus costly to reach, and (2) they contain only highly mineralized water. Campbell (1939a) gives the following laboratory analysis of water from a depth of 3,000 feet in well S 396 (Cory No. 1).

Constituents	*Ppm*	*Constituents*	*Ppm*
Sodium	7,646	Bicarbonate	439
Calcium	1,552	Total	25,755
Magnesium	268		
Chloride	14,200	Dissolved solids	29,460
Sulfate	1,650		

Comparison data	*Percent*	*Comparison data*	*Percent*
Primary salinity	76.94	Secondary alkalinity	1.66
Secondary salinity	21.40	Chloride salinity	91.91
Primary alkalinity	0.00	Sulfate salinity	8.09

Constituents	*Ratio*	*Constituents*	*Ratio*
$Cl:HCO_3$	54.4	Ca:Mg	3.52
$HCO_3:SO_4$	0.21	Na:Ca & Mg	3.34

Chloride analyses of deeper water from this same well, made by the U. S. Geological Survey, are as follows:

Depth (feet)	*Chloride (ppm)*
9,500	11,200
9,550	24,600
9,772	15,000
9,987	17,100

Cooke (1945, p. 21–32), Applin and Applin (1944, p. 1673–1753), and Pressler (1947, p. 1851–1862) have amply discussed the structure and stratigraphy of these deeper rocks, most of which are limestones, dolomites, anhydrite with minor amounts of gypsum, and some halite; therefore, it is believed unnecessary to give another description in this report.

TERTIARY SYSTEM

GENERAL STATEMENT

In southeastern Florida, water wells do not penetrate rocks deeper than those of Eocene age, and most of the deep wells end in the Ocala limestone of upper Eocene (Jackson) age. Some of the deep wells terminate in middle Eocene rocks, some in Oligocene, and others in lower Miocene. All, however, produce only mineralized artesian water too salty and too corrosive for most uses (see section on Quality of ground and surface waters, p. 824–826).

The following table lists formations encountered in drilling water wells in southeastern Florida.

Table 11.—*Geologic formations of southeastern Florida*

Age	Formation	Characteristics	Thickness (feet)
Recent and Pleistocene	Soils	Peat and muck, all Recent in age; laterite.	0–12
	Lake Flirt marl	White to gray calcareous mud rich with shells of *Helisoma* sp., a fresh-water gastropod. In places case-hardened to a dense limestone. Relatively impermeable.	0–6
Pleistocene	Pamlico sand	Quartz sand, white to black or red, depending upon nature of staining materials, very fine to coarse, averaging medium. Mantles large areas underlain by oolite and the Anastasia formation. Occurs in sand dunes and old beach ridges in elevations up to about 60 feet. Yields water to sand-point wells.	0–60
	High terrace deposits (including Penholoway and Talbot formations)	Principally unconsolidated quartz sand with intercalated clay and silt beds in places, especially the Kissimmee River area. Locally consolidated to scabby ferric sandstone. Generally permeable. Yields water to sand-point wells.	0–100
	Miami oolite	Limestone, soft, white to yellowish, containing streaks or thin layers of calcite, massive to cross-bedded and stratified; generally perforated with vertical solution holes. Fair to very high permeability.	0–40
(Contemporaneous in part)	Anastasia formation	Coquina, sand, calcareous sandstone, sandy limestone, and shell marl. Composed of deposits equivalent in age to the marine members of Fort Thompson formation. Fair to high permeability.	0–100
	Key Largo limestone	Coralline reef rock, ranging from hard and dense to soft and cavernous. Probably contemporaneous with the marine members of the Fort Thompson formation. Outcrops along southeastern coastline of Florida from Soldier Key in Biscayne Bay to Bahia Honda. Highly permeable.	0–60
	Fort Thompson formation	Alternating marine, brackish, and fresh-water marls, limestones, and sandstones. Very low permeability in the upper Everglades-Lake Okeechobee area, but it is the major component of the highly permeable Biscayne aquifer (see p. 160) of coastal Dade, Broward, and Palm Beach Counties, which yields copious supplies of ground water.	0–200

Table 11.—*Geologic formations of southeastern Florida*—Continued

Age	Formation	Characteristics	Thickness (feet)
Pliocene	Caloosahatchee marl	Sandy marl, clay, silt, sand, and shell beds. Yields some water, in places under low artesian head, but is little used because of low permeability and generally poor quality of water, especially in the Everglades-Lake Okeechobee area. Not nearly so widely spread as was once believed but occurs chiefly as erosion remnants.	0-50
Miocene	Tamiami formation	Creamy-white limestone, and greenish-gray clayey and calcareous marl locally hardened to limestone, silty and shelly sands, and shell marl. Upper part, where permeability is high, is only a few feet thick, and, forms the lower part of Biscayne aquifer. Lower, and major part of the formation, is of low to very low permeability and forms the upper part of the Floridan aquiclude.	0-150
	Hawthorn formation	Sandy, phosphatic marl, interbedded with clay, shell marl, silt, and sand. Greenish colors predominate. Contains beds of flattened, well-worn quartzite and phosphate pebbles up to half an inch in greatest diameter. Water is generally scarce, of poor quality, and in the permeable beds is confined under low pressure head. Comprises the major part of the Floridan aquiclude.	50-500
	Tampa limestone	White to tan, soft to hard, often partially recrystallized limestone. Yields artesian water but not so freely as lower parts of the Floridan aquifer.	150-250
Oligocene	Suwannee limestone	Creamy, soft to hard limestone, similar lithologically to underlying Ocala limestone and often included with it in some earlier reports. With the Ocala, is part of the Floridan aquifer.	0-450
Eocene	Ocala limestone	White to cream, porous and cavernous to dense, in part cherty, in part highly foraminiferal, limestone. An excellent water-bearing formation, although the water is saline in large areas, especially south of Lake Okeechobee and along the Atlantic and Gulf coasts some distance northward. Principal component of the Floridan aquifer.	100-350
	Avon Park limestone	White to cream, foraminiferal limestone, with dark brown to tan crystalline to saccharoidal dolomite. Generally an excellent water-bearing formation and a part of the Floridan aquifer.	150-350
	Lake City limestone	Dark-brown dolomite and chalky limestone. Hydrologic characteristics imperfectly known. Probably a part of the Floridan aquifer.	200-250

EOCENE SERIES

LAKE CITY AND AVON PARK LIMESTONES

In the last few years, older Eocene rocks have been differentiated from the late Eocene Ocala limestones mainly on the basis of the microfossils. In 1937, Stubbs (1937, p. 24–36) tentatively assigned a middle Eocene age to those rocks which underlie typical Ocala limestone but which lack typical Ocala fossils and contain an abundance of the foraminifer *Dictyoconus cookei* (Moberg), mistakenly identified by Stubbs as *Coskinolina* sp. Stubbs gave these rocks the name "Coskinolina Zone." Since then, Cole (1941) has divided the entire middle Eocene into seven zones, the youngest of which he calls the *Dictyoconus cookei* zone; and the Applins (1944, p. 1673–1753) have divided the middle Eocene into two parts, late middle and early middle, and have assigned several geologic formational names to these units.

The Avon Park limestone of the Applins includes the *Dictyoconus cookei* zone of Cole, and their Lake City limestone includes his *Dictyoconus americanus* zone.

On the basis of subsurface data, Cole (1944, p. 25–26) has referred the Avon Park limestone to the Lisbon formation; Erickson (1945, p. 234) has correlated surficial outcrops of a limestone in southern Levy and northern Citrus Counties with the Avon Park and has proposed the new name "Gulf Hammock formation," to replace "Avon Park limestone."

The Eocene rocks older than the Ocala limestone contain a large amount of dolomite and dolomitic limestone with colors ranging from cream through tan to dark brown. Solution activity by circulating ground water in these calcareous rocks has developed caverns and a network of smaller channels, thus giving these formations a high coefficient of transmissibility (see section on Ground water, Quantitative studies, p. 237). Until more deep wells are drilled in southeastern Florida and the data therefrom studied, the thickness of middle and lower Eocene rocks in this area will remain unknown.

OCALA LIMESTONE

The Ocala limestone,[3] of Eocene (Jackson) age, is the oldest and most deeply buried of all formations ordinarily penetrated for water in southern Florida. It was present in the Campbell well, S 396 at 1,220 feet below land surface. (See pl. 19.) According to Mossom (1926, p. 236–237) it was penetrated at about 900 feet below land surface in well S 353 at Belle Glade (about 60 miles north of S 396) and at about 600 feet below land surface in well S 432, at Okeechobee City. The Ocala limestone is exposed at the land surface about 150 miles north of Okeechobee City in Citrus, Sumter, and Marion Counties. From these data it is apparent that the Ocala limestone, within a distance of 250 miles, dips about 1,220 feet. This is at a rate of about 5 feet to the mile. However, it is believed that this rate is not uniform because the upper surface of the Ocala limestone is eroded by weathering and solution processes, and according to R. O. Vernon (personal communication), it is faulted in numerous places; thus, the few control points may be somewhat misleading. The Ocala limestone is not present everywhere in southern Florida. Evidence obtained from study of deep wells in this area by the Applins (1944,

[3]According to Robert O. Vernon, Florida Geological Survey (oral communication), the Ocala limestone can be differentiated into two formations.

p. 1684–1685) indicates that the Ocala limestone is missing in a part of eastern Dade and Broward Counties and in Monroe County at Key West.

The Ocala is essentially a soft, white, foraminiferal limestone, in places a coquina, and, in addition to the Forminifera, it also contains a varied fauna of other marine fossils. In places, beds of chert are present. The formation generally thickens in all directions away from the outcrop area and attains a maximum thickness of 350 feet. In southeastern Florida it averages about 100 feet, but in places, as noted above, it seems to be missing entirely.

The Ocala limestone is an excellent water-bearing formation, widely used, and well known. It is the principal component of the Floridan aquifer (see p. 188–189). Large springs, such as Silver Springs in north-central Florida, and Wakulla Spring in northwestern Florida, issue from the cavernous rocks of the Ocala limestone. Silver Springs alone, as measured by the U. S. Geological Survey (Ferguson, Lingham, Love, and Vernon, 1947, p. 124–125; Stringfield, 1936, p. 155), flows at times more than 31 million gallons per hour, or 756 mgd, and averages 500 mgd; by comparison, a city the size of Miami used about 40 mgd in 1946.

Rainwater enters the Ocala limestone both in the outcrop area and in areas where permeable materials overlie it and permit downward percolation. The part of the water that does not return to the surface as a spring or seep, or is lost by evapotranspiration or by some other means (pumping from wells etc.), flows slowly through the aquifer and becomes highly mineralized. By the time the water has progressed to southern Florida, some of it is so highly mineralized that it is unsatisfactory for most uses. All wells penetrating the Ocala limestone in southern Florida are artesian.

OLIGOCENE SERIES

SUWANNEE LIMESTONE

The southernmost known exposure of the Suwannee limestone is in the northeastern part of Hillsborough County, in the banks of Blackwater Creek. Mansfield (1937, p. 46) describes the rock as "*** a granular to dense, compact, usually cream-colored, rather pure limestone." The Applins (1944, p. 1681–1683) describe the Suwannee: "Throughout most of its underground extent, the Oligocene has a rather uniform lithologic character: white, finely porous limestone composed chiefly of fragmental tests of Bryozoa and miliolid Foraminifera.*** In southern Florida the Oligocene thickens gradually toward the south and southwest from its updip limits, attaining a thickness of about 350 feet in wells near the coast and 450 feet in a well at Key West ***."

The Suwannee unconformably overlies the Ocala limestone and, in turn, is overlain and generally overlapped by younger geologic formations, so that it has a relatively small outcrop area. Its relation with the underlying Ocala limestone in southern Florida is such that artesian water occurs in both formations under essentially the same conditions. Thus, they are components of a single hydrologic underground unit—the Floridan aquifer.

MIOCENE SERIES

GENERAL CONSIDERATIONS

In peninsular Florida, Cooke (1945, p. 109–111) recognizes deposits of early Miocene time (Tampa limestone), middle Miocene time (Hawthorn formation), and late Miocene time (Duplin marl). The Tampa and Hawthorn formations have long been recognized in Florida, but only recently has the name Duplin been extended to Florida. Cooke (1945, p. 181) discontinued the use of the name "Choctawhatchee marl" and regards the four Choctawhatchee zones as parts of two other formations: the *Yoldia* and *Arca* zones (the lower two) are part of the Shoal River formation, and the *Ecphora* and *Cancellaria* zones are part of the extended Duplin marl.

Recently, F. Stearns MacNeil and C. Wythe Cooke (personal communications) have stated that studies of fossils (gathered by themselves, Parker, Schroeder, and others) show that the Tamiami formation, previously regarded as of Pliocene age (Mansfield, 1939), is actually of upper Miocene age.

In southern and southeastern Florida the great bulk of the Miocene formations are buried and can be studied only through the medium of well cuttings and their enclosed fossils. Although numerous wells have penetrated geologic materials (mainly silts, clays, fine sands, or limestones) that are, on the basis of fossil assemblage, Miocene, it has been exceedingly difficult to separate the sediments into the units recognized farther north and west.

In Cooke's correlation chart (1945, p. 110) an erosion interval is indicated between the middle Miocene Hawthorn formation and the late Miocene Duplin marl. This is based on field relationships in northern Florida. There are no significant changes in either lithology or fossil faunas in southern Florida to indicate such an interval. However, without a decided change in lithology such a break would be difficult to detect in well cuttings, and fossils often are of little help; in many instances both microfossil and macrofossil assemblages, collected from carefully controlled test wells, seem to indicate that in this area little reliance can be placed on them for precise age and stratigraphic correlations. It is quite apparent that ecologic conditions are a prime factor in these studies and that the reworking of previous sediments and their enclosed fossils by an encroaching sea and the filling of deep sink holes and solution cavities with younger deposits may be the main reasons for the difficulty in definitely separating the Miocene formations that probably are present in this area, either from one another or from the Pliocene.

There is no doubt that some geologic materials of southeastern Florida, which in the past have been called Miocene (Hawthorn) or Pliocene (Caloosahatchee marl and Tamiami limestone), are in reality of Duplin age and are present beneath the Caloosahatchee marl and younger formations everywhere in southeastern Florida. This belief is based largely upon lithologic correlation of cuttings from numerous wells of this area (in which indeterminate faunas, possibly of Pliocene or Miocene age, occur) with that of test well G 188, 19 miles west of Miami at Krome Road (State Route 27) and Tamiami Trail (U. S. Route 41), where upper Miocene (Duplin) faunas undoubtedly occur. (See pls. 8 and 9, index map, and geologic cross sections for correlation interpretations.)

According to Julia Gardner, who studied the larger fossils from this well, "No age determinations could be made upon the faunas from the four upper levels, -26.2', -32.1', -46.6', and -51.0' (all depths refer to mean sea level). The faunas from -57.3' and -61.8' are referred to the lower Pliocene, and they more closely resemble the mollusca from eastern Florida than they do from the Caloosahatchee region. All the shells from -67.8' are small; they have much less in common with the Pliocene faunas above than with the Miocene below. The finest, the most abundant, and the best characterized assemblages are those from -71.1' and -76.7'. These include several species which characterize the *Cancellaria* zone of the Duplin marl. The collections from -80.2' through -136' are meager and there is nothing new in them. The lower faunas, -140.3', -144.9', and the lowest of all, -155.3', are much better but only in the lowest is there a new element of any significance and that indicates nothing more than a slightly lower horizon in the Duplin [upper Miocene]. The resemblance of the faunas from the Miocene section of the well to those of the Duplin marl of North and South Carolina is marked, and there is no reason to suppose that any fauna older than that of the Duplin is represented. The faunas from top to bottom of the well are conspicuously shallow water faunas with no evidence of marked ecologic changes. This is indicated by the wide distribution of the limpets and barnacles, inter-tidal groups such as *Oliva* and *Olivella*, and reef-making forms such as the oysters, pectens, and anomias. The temperature in the late Miocene was probably not unlike that of the Recent Floridian seas.

The faunal assemblages upon which Dr. Gardner based the above interpretation are given in table 12.

346881 O—55——7

Table 12.—*Macrofaunas from U. S. Geological Survey Station 15112 (USGS test well G 188), Krome Road and the Tamiami Trail, 19 miles west of Miami, Dade County*

Collection	Depth (feet)	Macrofauna
15112	-26.2	*Chlamys* sp. ind. *Chione* sp. ind. Indeterminate gastropod Age: Indeterminate.
15112-b	-32.1	Indeterminate bivalve Planorbid? Age: Indeterminate.
15112-c	-46.6	Bryozoa "*Pecten*" sp. ind. *Ostrea* sp. ind. Age: Indeterminate.
15112-d	-51.0	"*Pecten*" sp. ind. Age: Indeterminate.
15112-e	-57.3	Bryozoa Echinoid spine *Nucula proxima* Say *Arca (Fossularca) adamsi* (Shuttleworth) Dall *Anadara improcera* (Conrad) *Eontia* sp. cf. *E. trigintinaria* (Conrad) *Pecten (Plagioctenium)* sp. *Chlamys (Aequipecten) comparilis* (Tuomey and Holmes) *Plicatula marginata* Say *Anomia simplex* D'Orbigny *Ostrea* sp. ind. *Crassinella lunulata* (Conrad) *Cardita (Carditamera) arata* Conrad *Glans (Pleuromeris) tridentata decemcostata* Conrad *Phacoides (Lucinisca) cribarius* (Say) *Phacoides (Parvilucina) multilineatus* (Tuomey and Holmes) *Trachycardium* sp. cf. *T. oedalium harveyense* Mansfield *Metis* sp. cf. *M. magnoliana* Dall *Macoma* sp. *Abra aequalis* Say? *Mactra (Mactrotoma)* sp. cf. *M. (M.) fragilis* Gmelin *Mulinia congesta* Conrad *Mulinia lateralis* Say? *Dosinia (Dosinidia)* sp. cf. *D. (D.) elegans* Conrad *Transenella carolinensis* Dall *Macrocallista (Paradione) reposta* (Conrad) s. l. *Gouldia metastriata* KConrad) *Pitaria (Hyphantosoma)* sp. near *P. (H.) opisthogrammata* Dall *Chione (Chione) cancellata* (Linnaeus) *Chione (Chione)* sp. *Chione (Timoclea) grus* (Holmes) *Venus* sp. ind. *Venus* sp. ind. *Corbula (Varicorbula)* sp. *Corbula (Caryocorbula) nucleata deadenensis* Mansfield *Corbula (Caryocorbula) barrattiana leonensis* Mansfield *Corbula (Caryocorbula) barrattiana leonensis* Mansfield? *Tegula (Omphalius) exoleta* Conrad *Turritella* sp. cf. *T. cookei* Mansfield *Serpulorbis granifera* Say *Cerithium* sp. cf. *C. floridanum* Dall and *C. floridanum leonense* Mansfield *Epitonium* sp. *Calyptraea centralis* (Conrad) *Crucibulum auriculum* (Gmelin) s. l. *Crucibulum multilineatum* (Conrad) *Crepidula fornicata* (Linnaeus) *Crepidula aesop* Dall *Trivia* sp. ind. *Naticoid* fragments *Urosalpinx trossulus* Conrad? *Anachis avara* subsp. near *A. avara caloosaensis* Dall *Anachis camax coenis* Mansfield? *Nassarius bidentatus* Emmons *Nassarius* sp. B. *Nassarius* sp. D. *Nassarius cornellianus* (Olsson) *Nassarius* sp. probably near *N. vibex* (Say) *Olivella mutica* Say including *O. nitidula* Dillwyn *Olivella mutica* Say *Mitra (Tiara)* n. sp. near *M. (Tiara) carolinensis* Conrad and *M. (T.) lineolata* Heilprin.

Table 12.—*Macrofaunas from U. S. Geological Survey Station 15112 (USGS test well G 188), Krome Road and the Tamiami Trail, 19 miles west of Miami, Dade County—Con.*

Collection	Depth (feet)	Macrofauna
15112-e	-57.3	*Marginella* sp. *Crassispira* ? *elegans* EmmonsM *Terebra (Strioterebrum)* sp. *Bulla* n. sp. *Acteocine canaliculata* Say Barnacle plates. Age: Early Pliocene. The faunas from -57.3' and -61.8' include *Chione (Chione) cancellata* (Linnaeus), a species not recognized before the opening of the Pliocene. Four other species, *Phacoides (Lucinisca) cribrarius* Say, *Mulinia congesta* Conrad which seems to be typical, *Tegula (Omphalius) exoleta* Conrad, and *Crucibulum multilineatum* Conrad have not hitherto been reported from pre-Miocene beds. However, because of an apparent break between -61.8' and -67.8', indicated by the introduction of forms as *Astarte (Ashtarotha) bella* Conrad, *Chione (Lirophora)*, and several species of *Turritella* which are common at lower levels, the rather arbitrary line between the Miocene and Pliocene shoild probabli be drawn between those two depths.
15112-f	-61.8	*Anadara improcera* (Conrad) *Chlamys (Aequipecten) eborea darlingtonensis* (Dall) *Anomia simplex* D'Orbigny *Phacoides (Bellucina) tuomeyi* Dall *Trachycardium oedalium harveyense* Mansfield *Mulinia congesta* Conrad *Macrocallista* sp. ind. *Chione (Chione) cancellata* (Linnaeus) *Chione (Timoclea) grus* (Holmes) *Calyptraea centralis* (Conrad) *Crucibulum multilineatum* (Conrad) *Crepidula fornicata* (Linnaeus) *Muricidea*? sp. *Urosalpinx* sp. *Marginella* sp. near *M. floridana* Dall *Marginella bella* (Conrad) Barnacle plates Age: Early Pliocene. The fauna from -61.8' is similar to that from -57.3'
15112-g	-67.8	Bryozoa *Nucula proxima* Say *Glycymeris americana quinquerugata* (Tuomey and Holmes)? *Chlamys* sp. cf. *P. (Aequipecten) comparilis* (Tuomey and Holmes) *Plicatula* sp. *Astarte (Ashtarotha) bella* Conrad *Glans (Pleuromeris) tridentata decemcostata* (Conrad) *Phacoides (Cardiolucina) multistriatus* (Conrad) *Phacoides (Lucinisca) cribrarius* (Say) *Phacoides (Parvilucina) multilineatus* (Tuomey and Holmes) *Phacoides (Bellucina) tuomeyi* Dall Knot typical) *Diplodonta* ? sp. *Aligena* sp. *Mactra (Micromactra) undula* Dall *Mulinia congesta* Conrad *Transenella carolinensis* Dall? *Chione (Lirophora) latilirata athleta* Conrad *Corbula (Varicorbula) caloosae* Dall *Cadulus thallus* (Conrad) *Turritella carolinensis* Conrad *Turritella* sp. near *T. burden* Tuomey and Holmes and *T. cookei* Mansfield *Turritella subannulata* Heilprin, subsp.? *Vermicularia spirata* (Philippi) *Turbonilla* sp. *Calyptraea centralis* KConrad) *Crucibulum multilineatum* (Conrad) *Crepidula aesop* Dall Naticoid fragment *Muricidea*? *Muricidea* sp. cf. *M. floridana libertiensis* Mansfield *Strombina gunteri* Mansfield *Busycon* sp. ind. *Nassarius* sp. B. *Nassarius consensoides* (Olsson) *Nassarius* sp. E. *Oliva* sp. *Olivella mutica* Stay *Marginella* sp. ind. *Marginella* sp. ind. *Marginella aureocincta* Stearns *Eumetadrillia* sp. near *E. lunata porrecta* (Mansfield)

Table 12.—*Macrofaunas from U. S. Geological Survey Station 15112 (USGS test well G 188), Krome Road and the Tamiami Trail, 19 miles west of Miami, Dade County*—*Con.*

Collection	Depth (feet)	Macrofauna
15112-g	-67.8	*Eumetadrillis* sp. near *E. lunata porrecta* (Mansfield) *"Drillia"* n. sp. near *"D". emmonsi* (Olsson) *"Drillia"* sp. near *"D". emmonsi* (Olsson) *Terebra (Strioterebrum) dislocata* (Say) *Terebra (Strioterebrum) concava* (Say) Barnacle Age: Late Miocene. *Chione (Chione) cancellata* (Linnaeus), the characteristic Pliocene species, present in the faunas from -57.3' and -61.8', is absent in the fauna from -67.8', and of probably greater significance is the first appearance of a number of forms including *Astarte (Ashtarotha) bella* Conrad, *Chione (Lirophora) latilirata* Conrad, *Cadulus thallus* (Conrad), *Turritella carolinensis* Conrad, and *Turritella subannulata* Heilprin, subsp.?, which are common at the three next lower levels from which faunas have been taken. To be sure, *C. (C.) cancellata has not been reported from the lower bed of the Caloosahatchee marl in Volusia County, Florida, and is presumably absent, but so are the characteristic Miocene species recorded from -67.8'*
15112-h	-71.1	*Nucula* sp. ind. *Arca (Cunearca)* sp. cf. *A. (C). scalaris* Conrad *Anadara improcera* Conrad *Glycymeris americana quinquerugata* (Tuomey and Holmes) *Mytilus conradinus* D'Orbigny *Pecten (Pecten)* sp. cf. *P. (P.) ochlockoneensis* Mansfield *"Pecten"* sp. *Chlamys (Aequipecten) comparilis* (Tuomey and Holmes) *Anomia simplex* D'Orbigny *Ostrea sculpturata* Conrad *Astarte (Ashtarotha) bella* Conrad *Crassatellites (Crassatellites)* sp. cf. *C. gibbesii* (Tuomey and Holmes) *Cardita (Carditamera) arata* Conrad *"Chama"* sp. *Phacoides (Cardiolucina)* sp. cf. *P. (C). multistriatus* (Conrad) *Phacoides (Lucinisca) cribarius* (Say) *Phacoides (Callucina) radians* Conrad *Phacoides (Parvilucina) multilineatus* (Tuomey and Holmes) *Phacoides (Bellucina) tuomeyi* Dall *Divaricella* sp. cf. *D. quadrisulcata* (D'Orbigny) *Trachycardium oedalium harveyense* Mansfield *"Cardium"* sp. ind. *Mulinia congesta* Conrad *Macrocallista (Paradione) reposta* (Conrad) *Callocardia (Agriopoma)* Conrad s. l. *Antigona* sp. ind. *Chione (Chione) procancellata* Mansfield ? *Chione (Chione)* n. sp.? near *C. (C.) procancellata* Mansfield *Chione (Lirophora) latilirata athleta* Conrad *Venus (Mercenaria) campechiensis rileyi* Conrad *Corbula (Varicorbula) waltonensis rubisiniana* Mansfield *Corbula (Caryocorbula) barrattiana leonensis* Mansfield *Cadulus thallus* Conrad *Calliostoma* n. sp.? group of *C. philanthropum* (Conrad) and *C. willcoxianum* Dall *Astraea* n. sp.? group of *A. precursor* Dall *Turritella carolinensis* Conrad *Turritella etiwanensis* Tuomey and Holmes *Turritella* sp. near *T. burdeni* Tuomey and Holmes and *T. cookei* Mansfield *Turritella subannulata* Heilprin subsp.? *Turritella* sp. near *T. subannulata* Heilprin and the subsp. *jacksonensis* Mansfield in apical sculoture *Serpulorbis granifera* Say *Petaloconchus sculpturatus* H. C. Lea *Cerithium floridanum leonense* Mansfield *Strombiformis* sp. possibly n. sp. *Niso* sp. ind. *Calyptraea centralis* (Conrad) *Crepidula aesop* Dall *Polinices (Neverita) duplicatus* Say *Murex (Chicoreaus) rufus* Lamarck *Muricidea* sp. cf. *M. floridana libertiensis* Mansfield *Urosalpinx trossulus* Conrad? *Anachis camax* Dall subsp.? *Anachis styliola* Dall subsp. *Anachis* sp. *Strombina* sp. *Antillophos sloania* (Gardner and Aldrich) *Busycon* sp. cf. *B. perversum* (Linnaeus) *Busycon* sp. ind.

Table 12.—*Macrofaunas from U. S. Geological Survey Station 15112 (USGS test well G 188), Krome Road and the Tamiami Trail, 19 miles west of Miami, Dade County*—Con.

Collection	Depth (feet)	Macrofauna
15112-h	-71.1	*Nassarius* sp. near *N. bidentatus* Emmons
		Nassarius consensoides (Olsson)
		Nassarius n. sp.?
		Nassarius sp.
		Oliva sayana Ravenel
		Olivella mutica (Say)
		Mitra (Tiara) sp. ind.
		Maculopeplum trenholmi (Tuomey and Holmes)
		Marginella sp. cf. *M. virginiana* (Conrad) and *M. contracta* (Conrad)
		Marginella gravida Dall
		Cancellaria tabulata Gardner and Aldrich
		Cancellaria sp. cf. *C. reticulata leonensis* Mansfield
		Conus sp. ind.
		Eumetadrillia lunata porrecta (Mansfield)?
		Crassispira antealesidota Mansfield
		"*Drillia*" n. sp. A.
		Terebra (Paraterebra) unilineata Conrad
		Terebra (Strioterebrum) neglecta Emmons
		Terebra (Strioterebrum) sp. near *T. dislocata* Say but axials not bisected
		Terebra (Strioterebrum) dislocata Say
		Acteocina canaliculata (Say)
		Crab remains
		Barnacle plates
		Age: Upper Miocene, Duplin marl, probably the *Cancellaria* zone. The three faunas from the depths -71.1' are the most prolific of those takenffrom the well and obviously are to be included within a single unit. They are characterized by large pectens, *Astarte (Ashtarotha) bella* Conrad, common *Mulinia congesta* and *Chione (Lirophora latilirata athleta* Conrad, and by two of the characteristic species of the *Cancellaria* zone. *Chione (Chione) procancellata* Mansfield. The diversified *Turritella* fauna, first recorded at 67.8', is best developed at this level and at the two immediately succeeding.
15112-i	-75.1	*Nucula proxima* Say
		Arca (Cunearca) scalaris Conrad
		Anadara lienosa (Say)
		Anadara improcera (Conrad)
		Glycymeris americana quinquerugata (Tuomey and Holmes)
		Glycymeris pectinata (Gmelin)
		Glycymeris sp. ind.
		Pecten (Pecten) sp. cf. *P. (P.) ochlockoneenensis* Mansfield
		Chlamys (Aequipecten) eborea darlingtonensis (Dall)?
		Ostrea sculpturata Conrad
		Astarte (Ashtarotha) bella Conrad
		Crassatellites (Crassatellites) gibbesii (Tuomey and Holmes)
		Cardita (Carditamera) arata Conrad
		Glans (Pleuromeris) tridentata decemcostata Conrad
		Venericardia (Cyclocardia) granulata Say
		Phacoides (Cardiolucina) sp. cf. *C. (C.) multistriatus* (Conrad)
		Phacoides (Lucinisca) cribarius (Say)
		Phacoides (Callucina) radians (Conrad)
		Phacoides (Parvilucina) multilineatus (Tuomey and Holmes)
		Phacoides (Bellucina) tuomeyi Dall
		Phacoides (Bellucina) sp. cf. *P. (B.) tuomeyi* Dall and *P. (B) waccamawenis* Dall
		Cerastoderma spl near *C. taprium* Dall
		Cerastoderma? sp. cf. *C. acutilaqueatum* Conrad
		Trachycardium oedalium harveyense Mansfield
		"*Cardium*" sp. ind.
		Tellina (Eurytellina) alternata Say
		Tellina (Moerella) possibly n. sp. near *T. (M.) dupliniana* Dall
		Tellinid
		Metis sp.
		Ensis sp. ind.
		Mulinia congesta Conrad
		Dosinia (Dosinidia) sp. cf. *D. (D.) acetabulum blountana* Mansfield
		Gouldia n. sp.?
		Macrocallista ? sp.
		Callocardia? sp.
		Chione (Chione) procancellata Mansfield
		Chione (Lirophora) latilirata athleta Conrad
		Venus sp.
		Corbula (Varicorbula) sp. cf. *C. (V.) caloosae* Dall
		Corbula (Varicorbula) sp.
		Corbula (Caryocorbula) nucleata Dall?
		Cadulus thallus Conrad
		Calliostoma? sp.

Table 12.—*Macrofaunas from U. S. Geological Survey Station 15112 (USGS test well G 188), Krome Road and the Tamiami Trail, 19 miles west of Miami, Dade County*—Con.

Collection	Depth (feet)	Macrofauna
15112-i	-75.1	*Turritella carolinensis* Conrad *Turritella etiwanensis* Tuomey and Holmes? *Turritella* sp. near *T. burdeni* Tuomey and Holmes and *T. cookei* Mansfield *Turritella subannulata* Heilprin subsp.? *Cerithium floridanum leonense* Mansfield *Crucibulum* sp. *Crepidula plana* Say *Crepidula aesop* Dall *Natica (Tectonatica) pusilla* Say *Natica canrena* (Linnaeus) *Polinices* (Neverita) *duplicatus* (Say) *Trivia pedicula* (Linnaeus) *Cypraea carolinensis* Conrad *Sconsia hodgii* (Conrad)? *Columbella* sp. near *C. rusticoides* Heilprin *Strombina gunteri* Mansfield *Nassarius consensoides* (Olsson) *Nassarius cornellianus* (Olsson) *Fasciolaria* sp. *Fusinus* sp. near *F. carolinensis* (Dall) and *F. dalli* Mansfield *Oliva sayana* Ravenel *Olivella mutica* Say including *O. nitidula* (Dillwyn) *Olivella mutica* Say *Vasum* sp. ind. *Xancus* sp. near *reginia* (Heilprin) *Marginella* sp. *Marginella* sp. cf. *M. precursor* Dall *Marginella virginiana* (Conrad)? *Cypraeolina dacria* (Dall) *Conus adversaeius* Conrad? *Crassispira antealesidota* Mansfield "*Drillia*" sp. cf. "*D.*" *tricatenaria* (Conrad) *Terebra dislocata* Say? Barnacle plates Age: Upper Miocene, Duplin marl, probably the *Cancellaria* zone. The fauna is similar to those from -71.1' and -76.7'
15112-j	-76.7	Boring sponge Coral Bryozoa *Nucula proxima* Say *Nucula taphria* Dall *Sacella trochilia coensis* (Mansfield) *Sacella trochilia hamlinensis* (Mansfield) *Arca (Fossularca) adamsi* (Shuttleworth) Dall *Arca (Cunearca)* sp. near *A. (C.) alcima* Dall *Anadara improcera* (Conrad) *Glycymeris pectinata* (Gmelin) *Pecten (Pecten)* sp. *Chlamys (Aequipecten) eborea* (Conrad)? *Chlamys (Aequipecten) eborea darlingtonensis* (Dall) *Plicatula marginata* Say *Anomia simplex* D'Orbigny *Ostrea sculpturata* Conrad *Pandora (Kennerlia) arenosa* Conrad *Astarte (Aehtarotha) bella* Conrad *Crassatellites (Crassatellites)* sp. *Crassatellites (Crassatellites)* sp. *Cardita (Carditamera)* sp. ind. *Glans (Pteromeris) perplana* Conrad *Anodontia* sp. ind. *Phacoides (Lucinisca) cribrarius* (Say) *Phacoides (Callucina) radians* (Conrad) *Phacoides (Parvilucina) multilineatus* (Tuoney and Holmes) *Phacoides (Bellucina) tuomeyi* Dall *Divaricella quadisulcata* (D'Orbigny)? *Pseudochama straita* (Emmons) *Cerastoderma* sp. ind. *Trachycardium oedalium harveyense* Mansfield *Tellina (Merisca) aequistriata* Say *Tellina (Eurytellina) alternata* (Say) Tellinid *Tellina (Moerella)* possibly n. sp. near *T. (M.) dupliniana* Dall *Semele perlamellosa* Heilprin *Mulinia congesta* Conrad *Ensis directus* Conrad? *Dosinia* sp. *Dosinia (Dosinidia)* sp. *Transenella carolinensis* Dall

Table 12.—*Macrofaunas from U. S. Geological Survey Station 15112 (USGS test well G 188), Krome Road and the Tamiami Trail, 19 miles west of Miami, Dade County*—Con.

Collection	Depth (feet)	Macrofauna
15112-j	-76.7	*Callocardia (Agriopoma)* sp. cf. *C. (A.) sayana* (Conrad) *Gouldia metastriata* (Conrad) *Chione (Chione) procancellata* Mansfield *Chione (Chione)* n. sp. near *C. (C.) procancellata* Mansfield *Chione (Timoclea) grus* (Holmes) *Chione (Lirophora) latilirata athleta* Conrad *Corbula (Varicorbula)* sp. cf. *C. (V.) caloosae* Dall *Corbula (Caryocorbula)* sp. group of *C. (C.) inaequalis* Say *Corbula* sp. ind. *Cadulus thallus* (Conrad) *Diodora carolinensis* (Conrad)? *Tegula (Omphalius) exoleta* (Conrad) *Turbo* sp. group of *T. castaneus* Gmelin Opercula, possibly of *Turbo* sp. *Turritella carolinensis* Conrad? *Turritella* sp. near *T. alumensis* Mansfield *Turritella etiwanensis* Tuomey and Holmes *Turritella etiwanensis* Tuomey and Holmes; very slender and simple shells. *Turitella* sp. near *T. burdeni* Tuomey and Holmes and *T. cookei* Mansfield. *Turitella* sp. near *T. cookei clarkevillensis* Mansfield *Petaloconchus sculpturatus* H. C. Lea *"Vermetus"* s. l. *Cerithium floridanum leonense* Mansfield *Niso* sp. ind. *Turbonilla* sp. *Turbonilla* sp. *Calyptraea centralis* Conrad *Crucibulum multilineatum* Conrad *Crepidula fornicata* (Linnaeus) *Crepidula aesop* Dall *Natica canrena* (Linnaeus) *Trivia* sp. ind. *Favartia cellulosa* (Conrad) *Muricidea floridana libertiensis* Mansfield? *Anachis* sp. near *A. avara* (Say) *Anachis camax* Dall? *Anachis*? sp. *Strombina* sp. near *S. gunteri* Mansfield *Nassarius bidentatus* (Emmons) Nassoids *Dorsanum? plicatilum* (Bose) *Oliva sayana* Ravenel *Olivella mutica* Say including *O. nitidula* (Dillwyn) *Olivella matica* Say *Marginella* sp. *Marginella virginiana* (Conrad) *Marginella gravida* (Dall) *Cypraeolina dacria* (Dall) *Cancellaria tabulata* Gardner and Aldrich *Conus floridanus* Gabb *Brachycythara turrita* Mansfield? *Mangelia* sp. cf. *M. coensis* Mansfield *Eumetadrillia lunata porrecta* (Mansfield) ? *Crassuspira*? sp. group of *C.? elegans* (Emmons) *"Drillia"* n. sp. A *Terebra (Strioterebrum) dislocata* Say *Acteocina canaliculata* Say? *Acteocina myrmecoon* Dall Crab remains Barnacle plates Age: Upper Miocene; Duplin marl, probably the *Cancellaria* zone. The fauna is similar to those from -71.1' and 75.1'.
15112-k	-80.2	*Anomia* sp. ind. *Ostrea* sp. ind. *Ostrea*? sp. ind. *Astarte* sp. *Turritella* sp. cf. *T. etiwanensis* Tuomey and Holmes *Caecum floridanum compactum* Dall *Urosalpinx* sp. cf. *U. trossulus* Conrad *Oliva* sp. *Terebra (Strioterebrum) dislocata* Say? Age: Probably upper Miocene because of the character of the gastropod fauna.
15112-1	-86.0	*Anadara* sp. ind. *Anomia simplex* D'Orbigny? *Ostrea* sp. ind.

Table 12.—*Macrofaunas from U. S. Geological Survey Station 15112 (USGS test well G 188), Krome Road and the Tamiami Trail, 19 miles west of Miami, Dade County*—Con.

Collection	Depth (feet)	Macrofauna
15112-1	-86.0	*Mulinia congesta* Conrad *Turritella cookei clarksvillensis* Mansfield *Calyptraea centralis* (Cokrad) *"Drillia" aphanitoma oxia* Dall? Barnacle plates Age: Probably upper Miocene but there is not sufficient evidence to place it more accurately.
15112-m	-91	*"Pecten"* sp. ind. *Plicatula*? sp. *Anomia simplex* D'Orbigny *Ostrea* sp. ind. *Mulinia congesta* Conrad *Chione (Lirophora)* sp. *Turritella* sp. cf. *T. etiwanensis* Tuomey and Holmes *"Vermetus"* s. l. Age: Probably upper Miocene but the evidence is slight.
15112-n	-98	*"Pecten"* sp. *Ostrea* sp. ind. *Chione (Chione)* sp. Age: Indeterminate.
15112-o	-194.7	*"Pecten"* sp. *Chlamys* sp. cf. *C. (Aequipecten) comparilis* (Tuomey and Holmes) *Ostrea* sp. ind. Lucinoids *Corbula* sp. *"Vermetus"* s. l. Barnacle plates Age: Indeterminate.
15112-p	-110.9	Echinoid spine *Nucula proxima* Say *Chlamys (Aequipecten) comparilis* (Tuomey and Holmes) *Ostrea* sp. ind. *Glans* (Pleuromeris) *tridentata decemcostata* Conrad *Phacoides* (Parvilucina) *multilineatus* (Tuomey and Holmes) *Mulinia congesta* Conrad *Transenella carolinensis* Dall *Turritella subannulata* Heilprin subsp. *Serpulorbis*? sp. *Nassarius bidentatus* (Emmons)? *Brachycythara* sp. cf. B. turrita Mansfield *"Drillia"* n. sp. A. Age: Upper Miocene, probably the Duplin marl.
115112-q	-115.2	*Pecten (Plagioctenium)* sp. *Ostrea* sp. ind. *Anodontia* sp. cf. *A. chrysostoma* (Meuschen) *Dosinia (Dosinidia)* sp. *Chione (Chione?)* sp. *Turritella* sp. cf. *T. cookei clarkevillensis* Mansfield *Anachis*? sp. cf. 15112-j *Marginella* sp. Barnacle plate Age: Probably the Duplin marl.
15112-r	-120.3	Bryozoa *Glycymeris pectinata* (Gmelin) *"Pecten"* sp. *Ostrea* sp. ind. *Cardita (Carditamera)* sp. ind. *Cerastoderma* sp. ind. *Mulinia congesta* Conrad? *Turritella etiwanensis* Tuomey and Holmes? *Calyptrea* sp. Crab claw Barnacle plate Age: Probably upper Miocene.
15112-s	-125	*Chlamys* sp. ind. *Anomia* sp. ind. *Phacoides (Bellucina) tuomeyi* Dall *Macrocallista (Paradione) reposta* (Conrad) n. subsp.? *Corbula* sp. *Natica canrena* (Linnaeus) *Olivella mutica* Say Barnacle plates Age: Probably upper Miocene.

Table 12.—*Macrofaunas from U. S. Geological Survey Station 15112 (USGS test well G 188), Krome Road and the Tamiami Trail, 19 miles west of Miami, Dade County*—Con.

Collection	Depth (feet)	Macrofauna
15112-t	-130.1	Echinoid Bryozoa *Anadara improcera* (Conrad) *"Pecten" improcera* (Conrad) *Pecten (Plagioctenium)* sp. *Ostrea* sp. ind. *Anomia* sp. Lucinoid *"Cardium"* sp. *Mulinia congesta* Conrad *Choine (Chione)* sp.? *Corbula* sp. *Turritella subannulata* Heilprin subsp. *Calyptraea centralis* (Conrad) *Oliva* sp. ind. Barnacle plate Age: Probably upper Miocene.
15112-u	-136	Echinoid spines *Plicatula* sp. *Anomia* sp. *Ostrea* sp. ind. *Pandora (Kennerlia)* Conrad *Crassatellites* sp. *Mulinia congesta* Conrad *Turritella* sp. ind. Barnacle plates Age: Probably upper Miocene. The faunas from -80.2' through -136' are all meager, but most of them include fragmentary mactroids which seem to be typical *Mulinia congesta*, a characteristic upper Miocene species not recorded from the Alum Bluff group nor from the St. Marys formation. The Turritellas, though fragmentary, seem seem also to be referable to the groups common in the Duplin marl.
15112-v	-149.3	*Anadara improcera* (Conrad) *Glycymeris americana quinquerugata* (Tuomey and Holmes) *Pecten (Plagioctenium) gibbus* (Linnaeus) subsp.? *Ostrea* sp. ind. *Anomia* sp. *Astarte (Ashtarotha) bella* Conrad *Crassatellites* sp. ind. *Cardita (Carditamera)* sp. ind. *Phacoides (Parvilucina) multilineatus* (Tuomey and Holmes) *Phacoides (Bellucina) tuomeyi* Dall *Diplodonta acclinis* (Conrad) *Trachycardium* sp. cf. *T. malacum* Dall *Mulinia congesta* Conrad *Gouldia metastriata* (Conrad)? *Chione (Chione) procancellata* Mansfield? *Chione (Lirophora)* sp. *Corbula (Caryocorbula) nucleata* Dall? possibly a subsp. *Turritella* molds *Turritella cookei* Mansfield? *Crepidula plana* Say? *Muricidea* sp. near *M. floridana* Dall *Olivella mutica* Say *Marginella bella* (Conrad)? Barnacle plate Age: Upper Miocene, Duplin marl. The fauna is larger than any of those recovered from depths intermediate between -76.7' and -140.3', but there is no indication of a change in formation. Not only are species species common between -71.1' and -76.7', such as *Anadara improcera* (Conrad), *Glycymeris americana quinquerugata* (Tuomey and Holmes), *Astarte (Ashtarotha)* bella Conrad, *Phacoides (Bellucina) tyomeyi* Dall, *Mulinia congesta* Conrad, *Chione (Lirophora) latilirata athleta* Conrad still persisting, but there is no indication of the introduction of a new fauna.
15112-w	-144.9	*Anadara improcera* (Conrad) *Glycymeris subovata* (Say) *Glycymeris americana quinquerugata* (Tuomey and Holmes) *Pecten (Plagioctenium)* sp. cf. *P. (P.) choctawhatcheensis* Mansfield *Plicatula* sp. *Anomia simplex* D'Orbigny *Ostrea* sp. ind. *Astarte (Ashtarotha) bella* Conrad *Cardita (Carditamera)* sp. *Venericardia (Cyclocardia) granulata* Say? *Phacoides (Parvilucina) multilineatus* (Tuomey and Holmes) *Phacoides (Bellucina) tuomeyi* Dall *Diplodonta*? sp.

Table 12.—*Macrofaunas from U. S. Geological Survey Station 15112 (USGS test well G 188), Krome Road and the Tamiami Trail, 19 miles west of Miami, Dade County*—*Con.*

Collection	Depth (feet)	Macrofauna
15112-w	-144.9	*Tellina (Moerella) sayi deadenensis* Mansfield? *Mulinia congesta* Conrad *Chione (Chione)* sp. *Chione (Lirophora) latilirata athleta* Conrad *Venus* sp. ind. *Panope* sp. ind. *Tegula (Omphalius) exoleta* (Conrad) *Turritella etiwanensis* Tuomey and Holmes *Turritella subannulata* Heilprin subsp. *Serpulorbis*? sp. *Calyptraea centralis* (Conrad) *Crepidula plana* Say *Oliva* sp. *Olivella mutica* Say including *O. nitidula* (Dillwyn) *Olivella mutica* Say *Marginella virginiana* (Conrad) *Marginella bella* (Conrad)? *Conus* sp. ind. Barnacle plates Age: Upper Miocene, Duplin marl. The fauna is similar to that from -149.3' but carries more Turritellas. These Turritellas are identical with or closely resemble species common in the Duplin marl of northern Florida and North and South Carolina.
15112-x	-150.3	*Pecten (Plagioctenium) choctawhatcheensis* Mansfield? *Pecten (Plagioctenium)* sp. cf. *C. (P.) choctawhatcheensis* Mansfield *Plicatula*? sp. ind. *Anomia simplex* D'Orbigny? *Ostrea* sp. ind. *Crassatellites* sp. ind. Barnacle plates Age: Upper Miocene, probably the Duplin marl.
15112-y	-155.3	Echinoid fragments *Anadara improcera* (Conrad) *Anadara improcera* (Conrad)? *Glycymeris americana* (deFrance) *Glycymeris pectinata* (Gmelin) *Crassinella lunulata* Conrad *Cardita (Carditamera)* sp. ind. *Glans (Pleuromeris) tridentata decemcostata* Conrad *Phacoides (Parvilucina) multilineatus* (Tuomey and Holmes) *Phacoides (Bellucina) tuomeyi* Dall *Mulinia congesta* Conrad *Transenella carolinensis* Dall *Gouldia* sp. cf. *G. metastriata* (Conrad) *Chione (Chione)* n. sp. near *C. (C.) procancellata* Mansfield *Chione (Chione)* sp. *Chione (Lirophora)* sp. *Corbula (Caryocorbula)* sp. cf. *C. (C.) cuneata* Say *Auctores* *Tegula (Omphalius)* sp. *Serpulorbis*? sp. *Calyptraea centralis* Conrad *Crucibulum multilineatum* Conrad *Crepidula fornicata* (Linnaeus) *Turritella* sp. cf. *T. alumensis gardnerae* Mansfield *Turritella* sp. cf. *T. cookei clarksvillensis* Mansfield *Turritella* sp. *Natica canrena* (Linnaeus) *Urosalpinx*? sp. *Coralliophila*? sp. *Anachis camax* Dall subsp.? *Busycon* sp. ind. *Oliva* sp. *Marginella gravida* Dall *Crassispira*? *elegans* Emmons? Crab remains Barnacle plates Age: Upper Miocene, Duplin marl. The fauna is similar to those from -140.3', -144.9', and -150.3' but, in addition to many species common to the higher levels and to the *Cancellaria* zone of the Duplin marl, it includes a *Turritella* of *T. variabilis* group, a species closely related to *T. alumensis gardnerae* Mansfield described from the *Ecphora* zone. Probably, however, the zonal separations made in north Florida can not be carried far to the south. Indeed, Robert O. Vernon, of the Florida Geological Survey, was unable to trace them into Holmes and Washington Counties.

Microfossils from this well (G 188) were studied by Lloyd G. Henbest and Joseph A. Cushman. Henbest, reporting in 1942 upon a sample from -51 to -57.3 ft (relative to mean sea level), says:

> Among the Foraminifera in this sample I find the following species:
>
> *Peneroplis* aff. *P. protens* D'Orbigny. Lower Miocene. Chipola (western Florida) is the only record so far as I know for this particular form.
>
> *Elphidium poeyanum* D'Orbigny. Miocene to Recent.
>
> *Quinqueloculina costata?* D'Orbigny. Miocene and Pliocene.
>
> *Q. lamarckiana* D'Orbigny. Oligocene to Pliocene.
>
> *Rotalia beccarii* var. *tepida* Cushman. Pliocene to Pleistocene.
>
> *Amphisorus* sp., fragments. Very closely resembles the form called *"Sorites"* by Cushman from the Chipola. Range above the lower Miocene is unknown to me.
>
> *R. beccarii* var. *parkinsoniana* Cushman. Miocene to Pliocene.
>
> *Discorbis orbicularis?* Miocene to Recent.
>
> *Cibicides americanus* (Cushman). Oligocene to Miocene. The specimen at hand resembles the variety reported by Cushman in 1918 (U. S. Geol. Surv. Bull. 676) from the Duplin marl at Mayesville, South Carolina.
>
> *Amphistegina chipolensis* Cushman. Lower Miocene.
>
> As the stratigraphic notes after each species indicate, the sample includes Miocene and Pliocene forms and appears to contain mixed faunas *** If the method of determining the age by the oldest fauna, which is used where drill cuttings are contaminated or mixed, is followed here, the age is lower Miocene. Inasmuch as the evidence is not extensive, the determination as lower Miocene must be qualified with corresponding reservations.

Thus, in the same well and at the same depth, Henbest finds a fauna of Foraminifera that, from limited data, appears to be lower Miocene where Gardner finds a macrofauna of probably lower Pliocene age. This rather anomalous situation is not at all unusual in southern Florida. Cushman found the foraminiferal faunas so baffling that in many instances, including well G 188, he could not, with any degree of certainty, separate the Pleistocene and Pliocene from the Miocene.

After detailed and painstaking study of microfaunal slides from various test wells in southern Florida, Cushman stated in 1942: "The material from well G 188 is apparently the most nearly complete and therefore has been taken as the basis for the shallower part of the section in all the wells. As the faunas change with increasing depth of the well, ten zones may be recognized *** The tops or first occurrences of the (key) species downward in the well are taken as the indication that the particular zone has been reached. The various species may have long or short vertical ranges, but the first occurrence is an important factor in the correlation. Gaps in the occurrence of many of the species as plotted are probably due to loss of specimens or failure to find them by the person picking out the material *** The relative abundance of certain species is often a very excellent indicator of certain zones but it is evident that, except in well G 188, this can be little used here (in southeastern Florida) *** It is also evident from a study of the samples that changes in ecologic conditions are definite factors to be reckoned with in such work. The great abundance of *Rotalia beccarii* (possible var. *tepida*) might indicate very shallow, almost brackish water, especially where accompanied as it is by other species known also to have similar preferred habits. Even a short distance away the constituents of this fauna might be decidedly changed. This must be allowed for in all such work with samples of shallow origin."

Despite all the study given these samples from well G 188, Cushman did not feel justified in marking the boundaries between Miocene, Pliocene, and Pleistocene but, instead, marked off the 10 faunal zones. As later studies showed, these zones could not be used successfully because they seldom could be recognized in other wells.

The list of specimens, prepared by Cushman from samples of the formation that Gardner identified as being of Duplin age, contains species that have either, or both, Miocene and Pliocene ranges. This evidence, along with that of Henbest (p. 114-115), and the overwhelming evidence of the macrofossils as listed by Gardner (table 12), leads the writers to the conclusion that Duplin deposits of upper Miocene age, herein assigned to the Tamiami formation, are present at a relatively shallow depth in G 188, probably at 51 feet below mean sea level or, at the most, at 62 feet (pls. 8 and 9).

Similar data, though sometimes with the foraminiferal evidence stronger than the macrofaunal evidence, have been found in other wells of southeastern Florida. All this, together with the great similarity in the lithologic character of the materials in question, is evidence pointing to a Duplin age for some of the materials heretofore called Caloosahatchee marl and for a part of the sediments called Hawthorn (silty and sandy phase) in southeastern Florida. The deeper Miocene clays and marls that lie between the Tamiami formation and the Tampa limestone belong to the Hawthorn formation, but it is practically impossible to separate them. For the study of the occurrence of ground water this is not necessary, because in southeastern Florida all these deeper Miocene materials are of low to very low permeability; they act as a thick, relatively impervious layer (the Floridan aquiclude, p. 188—189), which separates the deep, saline artesian water in the Floridan aquifer from the permeable Pliocene and Pleistocene rocks that comprise the Biscayne aquifer in southeastern Florida (p. 160 et seq.).

TAMPA LIMESTONE

The oldest Miocene formation in southeastern Florida is the Tampa limestone. Surficial deposits of that formation occur in west-central Florida, 40 to 50 miles west of the upper Kissimmee River valley, in Hillsborough, Pinellas, and Pasco Counties. In its outcrop area, the Tampa formation is a yellow to cream limestone, hard to soft, and in some places (as at Ballast Point in Tampa Bay) siliceous. In the outcrop area and along the Gulf coast it is permeable and a component of the Floridan aquifer (p. 188–189).

In southeastern Florida the Tampa limestone is present in most areas, underlying the Hawthorn formation and overlying the Suwannee limestone. Parker and Hoy, and others (Parker and Hoy, in press; Stringfield, 1933a; Mossom, 1926) have found the Tampa limestone as far north as the Lake Okeechobee area but have not found it in the Kissimmee valley. In table 2 of their publication Parker and Hoy show correlation studies made on the basis of paleontologic and lithologic data from well cuttings. Cooke (1945, fig. 14, p. 112) shows the probable position of the shoreline of the Tampa (early Miocene) sea and indicates the area of known Tampa deposits. All southeastern Florida except the Kissimmee River valley, is thus shown to contain Tampa deposits at depth.

Much remains to be learned of the water-bearing characteristics of the Tampa limestone. It is believed that in southeastern Florida, as in upstate areas, the Tampa is a part of the Floridan aquifer, but the yield and artesian pressure are both somewhat lower than in the underlying Ocala limestone; the quality of the water, however, is essentially the same—hard, saline, and corrosive.

HAWTHORN FORMATION

Parker and Cooke (1944, p. 96–112) referred to the Hawthorn formation as greenish marine clay marls, and silty, shelly sands underlying the highly permeable limestones of the Biscayne aquifer (p. 160 et seq.). The bulk of the limestones of the Biscayne aquifer are now considered to be of Pleistocene age and are assigned to the Fort Thompson formation. They were formerly correlated with the Tamiami limestone, which Mansfield (1939) referred to the Pliocene. Materials of upper Miocene age had never been recognized in southern Florida, and because of the lithologic similarity between the Hawthorn formation in outcrop areas and the sediments underlying the Biscayne aquifer, and the Miocene appearance of the faunas, the correlation with the Hawthorn formation was made. These materials are here referred to the upper Miocene and to the Tamiami formation.

Separation of the greenish clays, silts, and marls of the Tamiami formation (upper Miocene) and those of the Hawthorn formation (lower and middle Miocene) is impossible unless an adequate macrofossil collection can be gathered from each well penetrating the boundary. Because faunal collections are inadequate, no attempt has been made to place the separating boundary. However, the fauna from several wells was studied by Julia Gardner and later examined by F. Stearns MacNeil, who states (in a personal communication): "I agree essentially with Miss Gardner's determinations. The wells[4] in which the middle Miocene appears to be penetrated are:

G 190 Probably middle Miocene at 190 feet
G 220 Possibly middle Miocene at 189 feet
G 101 Probably middle Miocene at 206–220 feet

Wells with good samples that did not penetrate the middle Miocene are:

G 219 Still in upper Miocene at 180 feet (lower sample)
G 188 Still in upper Miocene at 155 feet (lowest sample)."

In general, the Hawthorn formation contains more clay than does the Tamiami formation. Both are characterized by greenish marine sediments: clay, silt, sand, (all more or less marly and phosphatic, and having a large and varied fauna); the permeability is generally low to very low and is controlled by the finer rather than by the coarser detritals.

Quartzite and phosphate pebbles, some as much as half an inch in greatest diameter, are not uncommon in the Hawthorn formation and were distributed throughout a vertical range of 52 feet in G 223 (from 214 to 266 ft below mean sea level). In well HE 4, near Clewiston, the top of the zone bearing these pebbles was 76 feet below mean sea level, and the bottom was 127 feet; thus, this zone had a total thickness of 51 feet. The thickness is almost identical in these two wells, which are 63 miles apart. Based on this zone, the dip in the Hawthorn formation between Lake Okeechobee and the Tamiami Trail is 2.2 feet per mile.

In southeastern Florida, the Hawthorn formation is generally relatively impermeable. Except in shell beds, occasional "shoestring deposits of coarser sand, and some of the limestone layers, water either is not available, or it is obtainable only in very limited quantities. Most of the available water occurs under low artesian pressure. In southwestern Florida, in coastal Collier County, some of the artesian wells of the Hawthorn formation have piezometric heads similar to those found in the Ocala limestone, which are as much as 25 feet above mean sea level and yield as much as 150 gpm. Although the water is hard and somewhat saline, it is usable and far superior to that of the Floridan aquifer (see section on Quality of ground and surface waters, p. 823, table of analysis of water for Collier County).

TAMIAMI FORMATION

The name Tamiami limestone was proposed by Mansfield (1939, p. 8) for "a limestone penetrated in digging shallow ditches to

[4] All depths referred to mean sea level.

form the road of the Tamiami Trail over a distance of about 34 miles in Collier and Monroe Counties, Florida." Mansfield considered that the faunas, which include 6 genera of gastropods, 15 genera of pelecypods and 2 genera of echinoids collected mainly from spoil banks, were possibly of Pliocene age (older than that of the Caloosahatchee marl). Parker and Cooke (1944, p. 62) traced the surficial outcrops of the non-oolitic, permeable, sandy limestone eastward from the type locality into western Dade County, where the formation gently dips eastward beneath younger materials (pl. 9, sec. f-f'). From this area, near the Everglades–Big Cypress Swamp border, they correlated the Tamiami limestone by subsurface data obtained from test wells, drilled by cabletool or jet rigs (percussion-type drills), with the highly permeable rocks that unconformably underlie the Miami oolite (of Pleistocene age) in the Miami area (see p. 94). Core borings, unavailable until 1947 and later, have since revealed thin (a few inches to several feet), fresh-water, Pleistocene, limestone beds intercalated with marine limestone to depths of 55 feet below sea level. Such limestones are unrecognizable in the comminuted cuttings from percussion-type drilling. Most of this section of permeable rocks in the Miami area is tentatively assigned to the Pleistocene Fort Thompson formation, and the remainder, the Tamiami limestone of Mansfield, was restricted by Parker (1951), and by Hoy and Schroeder (1952), to the basal part of the highly permeable rocks below the lowest fresh-water bed. The total thickness of the restricted Tamiami limestone is probably less than 15 feet.

Beds of hard, cream to tan, sandy limestones and calcareous sandstone (1 to 3 feet in thickness, which in many instances contain abundant *Chione cancellata*) overlie and fill depressions in the Tamiami formation in the areas along, and adjacent to, the Tamiami Trail (U. S. Route 94). One such bed, as described by Mansfield (1931, p. 2), overlies a sand containing shells of upper Miocene age. A similar cream, calcareous sandstone overlies the Tamiami formation unconformably in a pit 1½ miles south of Sunniland, Collier County. Obviously, these sandstones and limestones are not a part of the Tamiami formation and are here assigned to the Anastasia formation of Pleistocene age.

The Tamiami formation, as seen at the type locality along the Tamiami Trail, unfortunately is not typical of the formation as a whole. As here defined, the formation is composed of the thin Tamiami limestone of Mansfield and of a thick section underlying the Biscayne aquifer (consisting chiefly of greenish clay marl, silty, and generally very shelly sand, and calcareous marl locally indurated to impure limestone). The formation includes all the upper Miocene materials in southern Florida and has a maximum thickness of about 150 feet. The detritals are characterized by greenish colors.

F. Stearns MacNeil reports (personal communication) the accumulated macrofossil collection from two Tamiami formation localities as follows:

Locality 1. Borrow pit at junction of U. S. Route 41 and Florida Route 29 (Carnestown), about 4 miles north of Everglades, Collier County.

Mollusca:

Ostrea tamiamiensis Mansfield
Ostrea lochlini Gardner
Pecten (Nodipecten) pittieri collierensis Mansfield
Pecten (Plagioctengium) evergladensis Mansfield
Modiolus sp. (large)
Eucrassatella sp.
Cardita (Carditamera) cf. *C. tamiamiensis* Mansfield
Chione ulocyma Dall
Chione aff. *C. cortimaria* Rogers

Echinodermata:

Encope macrophora tamiamiensis Mansfield
Cassidulua evergladensis Mansfield

Locality 2. Two borrow pits west of Florida Route 29, respectively 1½ miles south and ½ mile north of Sunniland, Collier County.

Mollusca:

Turritella pontoni Mansfield
Turritella aff. *T. perattenuata* Heilprin
Cerithium n. sp. aff. *C. floridanum* Morch
Calyptraea sp.
Strombus sp.
Cypraea sp.
Busycon maximum Conrad var.?
Dorsanum? aff. *D. plicatilum* (Bose)
Fasciolaria sp.
Conus adversarius Conrad
Glycymeris sp. aff. *G. subovata* Say
Glycymeris cf. *G. quinquirugata* Conrad
Glycymeris sp. aff. *G. Pectinatus* (Gmelin)
Arca (Arca) sp.
Anadara cf. *A. improcera* Conrad
Anadara sp. aff. *A. lienosa* Say
Anadara (Cunearca) sp.
Calloarca sp.
Modiolus sp. (large)
Plicatula aff. *P. marginata* Say
Amusium mortoni (Ravenel)
Pecten (Pecten) ochlochomeensis violae Tucker
Pecten (Plagioctenium) evergladensis Mansfield
Pecten (Plagioctenium) eboreus Conrad
Pecten (Nodipecten) pittieri collierensis Mansfield
Chlamys (Chlamys) exasperatus (Sowerby)
Anomia simplex d'Orbigny
Ostrea lochlini Gardner
Ostrea disparilis Conrad
Ostrea tamiamiensis Mansfield
Placunanomia plicata Tuomey and Holmes (*P. aclinica* Tucker and Wilson)
Cardita (Carditamera) arata Conrad
Miltha sp. (large)
Cardium (Trachycardium) sp. aff. *C. dalli* Heilprin
Cardium (Trachycardium) sp. aff. *C. isocardia* Linne
Dosinia sp.

Chione sp. aff. *C. cancellata* Linne
Chione athleta Conrad
Chione ulocyma Dall
Semele sp. aff. *S. leana* Dall
Large tellened or semilid with *Quidnipagus*-like sculpture
Cyatholdonta sp.

Echinodermata:

Encope macrophora tamiamiensis Mansfield
Cassidulus evergladensis Mansfield

Cirripedia:

Balanus concavus Bronn

MacNeil states that:" * * * the faunas contained in the beds at these two localities are of upper Miocene age" and that "*Ostrea disparilis, Chione ulocyma,* and *Turritella pontoni* are not only characteristic upper Miocene species, but they represent groups that have no known post-Miocene relatives, at least in this part of the world. The two echinoids are not known outside of the Tamiami formation."

The Caloosahatchee marl, the Buckingham marl, and the Tamiami formation when they were all referred to the Pliocene were considered by Parker and Cooke (1944, p. 56–65) to be equivalent and to grade one into another. There is a striking similarity of the macrofauna of the Buckingham formation in Lee and Hendry Counties as described by Mansfield (1939, p. 11–12) to that of the Tamiami formation in Collier County. Lithologically, the white, silty marl locally hardened to a soft limestone near Sunniland, Collier County, and the cream, clayey marl at Buckingham, Lee County, are nearly identical. It is concluded that the Buckingham marl is merely a facies of the Tamiami formation.

Exposures observed during traverses along the Caloosahatchee River suggested a transition of Buckingham marl to Caloosahatchee marl. The typical shell beds of the Caloosahatchee marl with their characteristic Pliocene fauna were not noted at any place in contact with clay marls containing a characteristic Buckingham fauna; therefore, the exact relationship could not be established.

The recent discovery by Parker of a key gastropod, and further detailed checking of the stratigraphic section in southern and southwestern Florida, indicates that beds formerly called the Buckingham marl do not grade into the Caloosahatchee marl but probably underlie it with a masked unconformity. The gastropod, *Ecphora quadricostata umbilicata* (Wagner), is from beds formerly known as the Buckingham marl, 2 feet above low tide at station 24 of Parker and Cooke (1944, p. 84). F. Stearns MacNeil states (personal communication) concerning this fossil:

"Upper Miocene: The genus *Ecphora* is not known in beds younger than Miocene. The species *Ecphora quadricostata* is known from the St. Marys formation to the Duplin formation in Virginia, North Carolina, and South Carolina, and from the *Ecphora* zone of the

Choctawhatchee formation of western Florida. As far as is known, the variety *umbilicata* has no stratigraphic significance, but merely includes those individuals with low non-overhanging spiral ribs.

"I suggested [to Mr. N. D. Hoy] recently that even though the Buckingham limestone is older than the Caloosahatchee, it still might be younger than the Duplin formation of North Carolina and possibly, therefore, of "lower Pliocene" age. In view of the fossil herein reported on, I am inclined to concur in Mansfield's earlier determination of an uppermost Miocene age for the Buckingham— and for the equivalent Tamiami limestone."

The permeability of the thick detrital section of the Tamiami formation is generally very low, but the thin, upper, solution-riddled limestone (the Tamiami limestone of Mansfield) part of the formation is extremely permeable. The lower and major part of the formation is generally very silty and clayey and comprises the upper part of the Floridan aquiclude (see p. 189).

PLIOCENE SERIES

CALOOSAHATCHEE MARL

The Caloosahatchee marl discontinuously underlies much of the Everglades and the Big Cypress Swamp and extends northward beneath the Pleistocene terraces of the Kissimmee River area (see pl. 4). Its distribution at the north end of the Kissimmee valley, in the Orlando area, caused Unklesbay (1944, p. 11–12) some concern. He was attempting to work out the stratigraphy of the Miocene to Recent formations in the Orlando area, but he concluded that because of the lack of data it was not possible to do so. He says: "A few of the wells in the County (Orange) penetrate 30 to 40 feet of shell marl immediately under the surficial sand. This marl contains mollusks and foraminifera which appear to be contemporaneous with Choctawhatchee forms, but proof of this age relationship will require detailed examination of many well cuttings. The shell marl may represent highly fossiliferous portions of the Hawthorn, or it may actually be a deposit of Choctawhatchee time. As the shell marl has been reported in only a few wells, its areal extent is not known."

Unklesbay tentatively assigned this marl to the Hawthorn formation.

From the outcrop area in the Caloosahatchee River and Lake Okeechobee region the Caloosahatchee marl gently dips to the south and southeast under the Everglades and Atlantic Coastal Ridge. It probably never was a thick deposit, possibly not more than a maximum of 50 feet, and now it is considerably thinner because of erosion and solution. In fact, in many places in southeastern Florida the Caloosahatchee marl is absent, and in others it appears only as isolated reefs, or as lenticular bodies preserved in depressions in the underlying Tamiami formation (upper Miocene).

The Caloosahatchee marl is dominantly a grayish-green or greenish-gray silty, sandy, shell marl with interbedded layers and lenses of sand, silt, clay, and marl. In some areas of the Everglades it includes carbonaceous zones containing remnants of roots, stems, and other organic debris that suggest former mangrove swamps. In some places the Caloosahatchee marl is composed of cemented shells or sandy shell marl that has been changed to a sandy, shelly limestone which, by solution of percolating ground water, has been made highly permeable.

Generally, however, the Caloosahatchee marl is of low to very low permeability, and often it is difficult to develop small wells finished with a sand point. However, wells that end in the sandy limestone may have a high yield when the loose sand is cleared from the aquifer in the area surrounding the intake portion of the wells.

In some parts of the northern Everglades, south of Lake Okeechobee, there are shallowly buried Pliocene reefs and "shoe-string" deposits of permeable sand. These ancient reefs are composed of calcareous sandstone or sandy shelly limestone and were carved out of the Caloosahatchee marl by erosion during early Pleistocene time. Although now overlain and hidden by younger and denser materials, these reefs and "shoe-string" sands are permeable and yield water freely to wells.

Where the Caloosahatchee marl is more permeable, and near the coast, it contains hard, but potable, water; inland, around Lake Okeechobee and in the upper part of the Everglades, the water is hard, in places highly colored, and often it is so highly mineralized that it is unfit for use. These variously mineralized bodies of ground water near the lake are probably the result of Pleistocene (Ice Age) invasions of the Everglades area by the sea during the several interglacial ages. Partial flushings or dilution by fresh percolating ground water occurred during subsequent glacial ages, and various chemical reactions, especially the cation-exchange variety (Love, 1945, p. 951–955), took place with the surrounding rock materials—this action is still taking place.

QUATERNARY SYSTEM

PLEISTOCENE SERIES

GENERAL STATEMENT

The Pleistocene rocks of southern Florida are of particular interest because they record several oscilliations of sea level, due in part to continental glaciation and deglaciation during the Pleistocene or "Great Ice Age." This record appears to be most nearly complete in the Fort Thompson formation along the upper Caloosahatchee River, but rocks of this epoch are widespread in southern Florida. They include marine, brackish, and fresh-water marls, limestones, sandstones, coquinas, and sands, as well as a fringing coral reef (bioherm) that grew along the southern edge of the Floridan Plateau from Miami at least as far south as Big Pine Key, and possibly farther. These formations have been most difficult to correlate, but during the ground-water geology investigation a working hypothesis was reached and published by Parker and Cooke (1944).

FORT THOMPSON FORMATION

The Fort Thompson formation takes its name from the type locality at Fort Thompson, the site of an army outpost of the Seminole Indian Wars, about $1\frac{3}{4}$ miles east of La Belle on the Caloosahatchee River. The formation there is about 6 feet thick and is composed of alternating fresh-water, marine, and brackish-water marls, limestones, shell beds, and sand (see fig. 11). The beds differ in thickness from place to place as the formation is traced out into the Lake Okeechobee–Everglades depression or westward toward the Gulf of Mexico, and in some places individual beds may be missing entirely or preserved only in solution holes or cavities in lower beds. In the Lake Okeechobee area its thickness averages less than 10 feet, whereas in the Miami area it averages about 80 feet, and the maximum thickness there may be about 200 feet (pl. 8, sect. G-G').

The Fort Thompson formation forms the floor of the Lake Okeechobee–Everglades depression as far east as the Atlantic Coastal Ridge, where its marine beds merge with, and appear to be extensions of, the main mass of the Anastasia formation. This relationship has been well demonstrated by subsurface studies in the vicinity of Fort Lauderdale (see fig. 10).

The Fort Thompson formation appears to have suffered little deformation although many small undulations in the beds are present. Many of these probably represent almost equal deposition over the uneven floor on which the formation lies; some, however, appear to be due to sagging where solution by percolating ground water has removed the soft calcareous marl from beneath the hard limestone layers (see fig. 11).

The Fort Thompson formation can be separated into two parts on the basis of its hydrologic characteristics. The northern part of the formation underlies the upper Everglades area, which includes northwestern Broward County; its rocks are generally of low permeability, and it averages less than 10 feet in thickness. The southern part of the formation is extremely permeable and forms the major part of the Biscayne aquifer (p. 160).

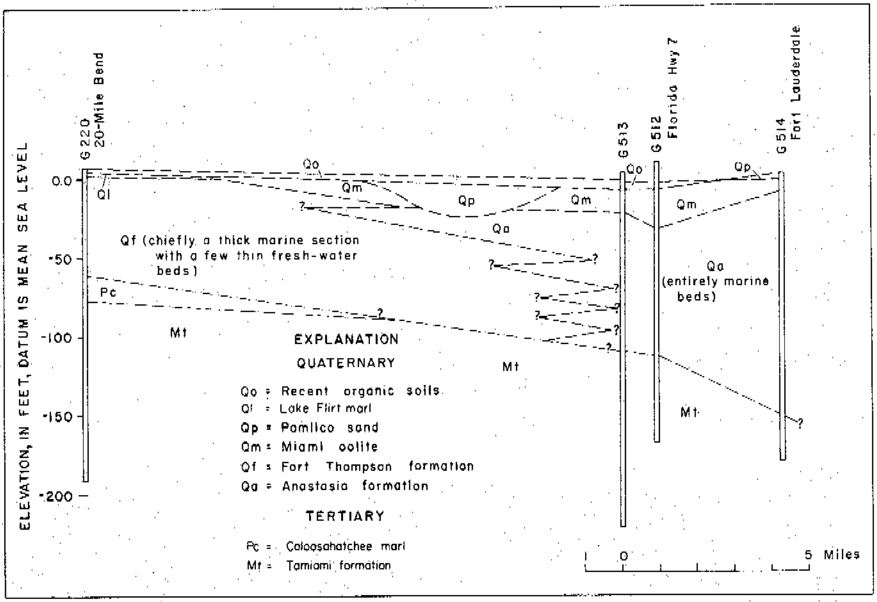

Figure 10. —East-west cross section along North New River Canal from 20-Mile Bend to Fort Lauderdale.

The southern part of the Fort Thompson formation is composed principally of white to cream sandy limestone, calcareous sandstone, beds and pockets of quartz sand and thin beds of dense, hard, fresh-water limestone, perforated by numerous solution holes, many of which are filled with younger materials. Where

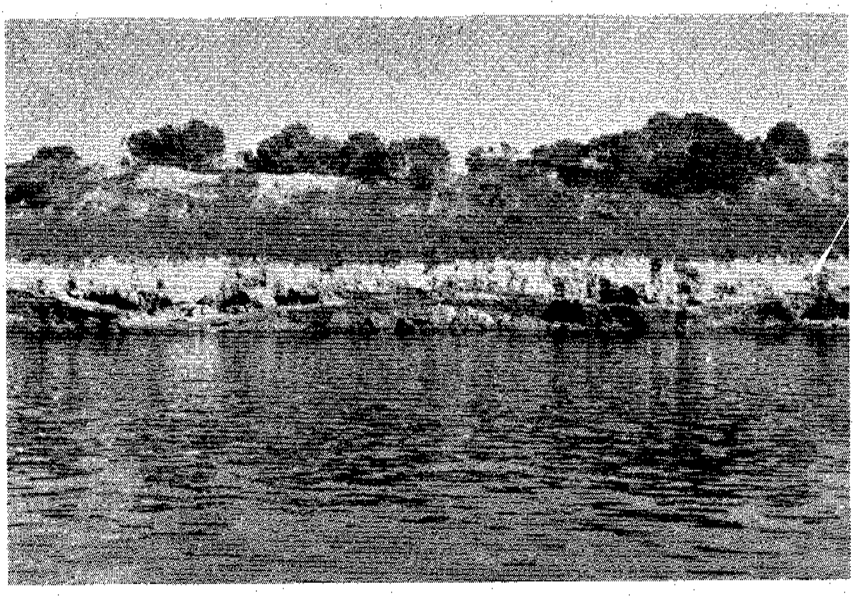

Figure 11. —Dredge-cut in Caloosahatchee River showing small undulations in Fort Thompson formation.

exposed on the surface in eastern Collier County, the Fort Thompson formation is a grayish-white to tan calcareous sandstone containing an abundance of *Chione cancellata* shells. It is riddled with solution holes commonly filled with marly soil. To the east and south of the outcrop area (see pl. 4), beds of the Fort Thompson formation slope gradually under the Miami oolite, and for several miles the contact of these two formations is visible in big pieces of rock dredged from the Tamiami Canal. Similar pieces of rock are visible along the banks of the South New River Canal (see fig. 12) where at times of extreme low water this contact can be seen along the banks west of State Route 25 in western Broward County.

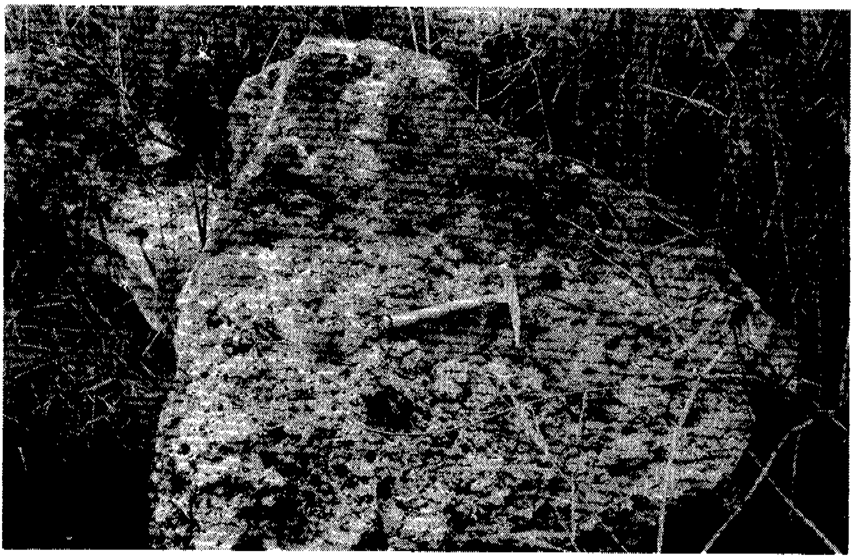

Figure 12. —View of contact of Miami oolite and Fort Thompson formation.

The southern part of the Fort Thompson formation is, in general, a wedge-shaped deposit that thickens toward the Atlantic Ocean. This is graphically shown in some of the following geologic cross sections, especially those trending in an east-west direction. Plate 5 is an index map showing the location of the sections, and plate 8, section *G-G'*, and plate 9, sections *F-F'* and *J-J'*, are most illustrative of this eastward thickening.

Three strike sections, *A-A'* (pl. 6), *B–B'* (pl. 7) and *I-I'* (pl. 8) trend in a direction generally parallel to the coast. These indicate that the Fort Thompson formation thickens somewhat toward the northeast (about 80 feet thick in the Miami area but only about 60 feet thick near Homestead). The block diagram of the Miami area (fig. 13) presents a three-dimensional picture of the Fort

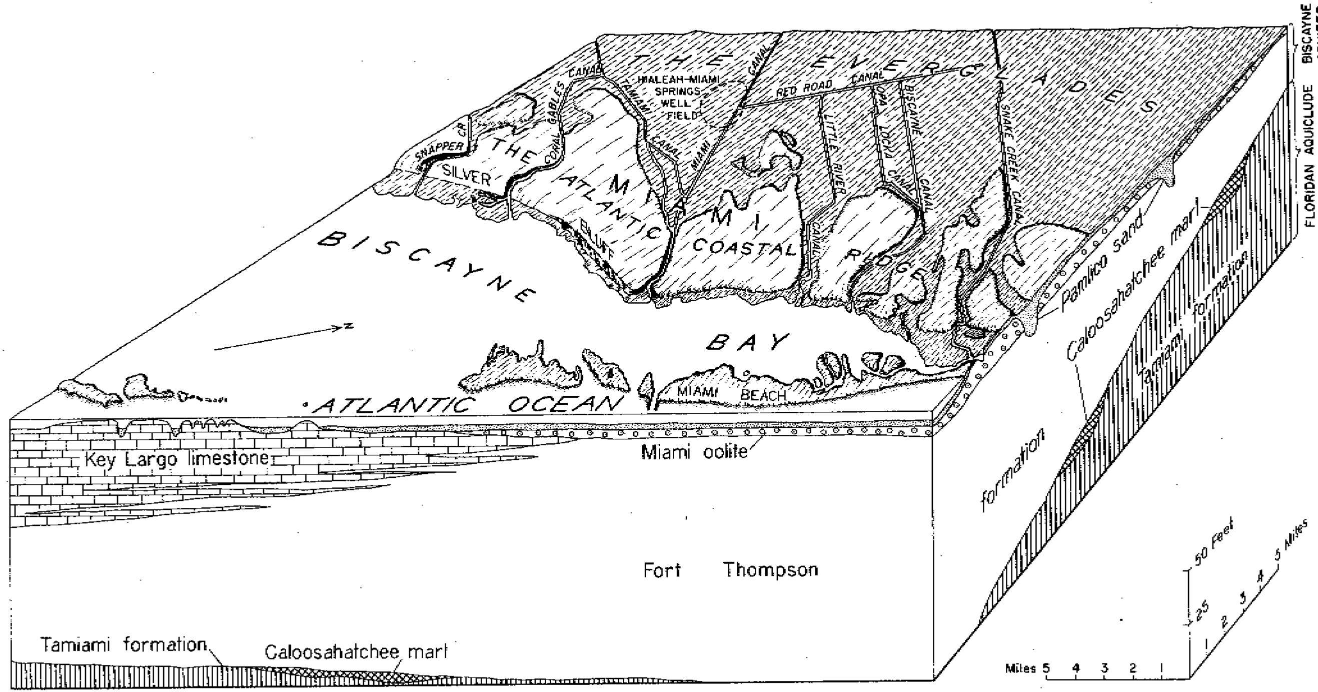

Figure 13. —Block diagram of the Miami area.

Thompson and associated formations, which together comprise the Biscayne aquifer.

This wedge of Pleistocene marine limestones and intercalated fresh-water limestones was deposited in a topographic depression, which was in all probability, bounded on the east by a slightly higher offshore bar and fringing reef composed of the Anastasia formation to the north of Fort Lauderdale, and the coral reefs and their wastage, which now comprise the Key Largo limestone to the south of that area. During the low sea levels of the glacial ages this depression was a land area having one or more large, shallow, fresh-water lakes in which fresh-water deposits, chiefly soft limy muds, were deposited. During the high sea levels of the interglacial ages the depression was flooded with sea water, and marine limestone, sand, and shells were deposited. At the same time, with adjustment to changed sea level, the offshore bars and the Key Largo reefs continued to grow. This concept of Pleistocene sedimentation in southeastern Florida is supported by the occurrence of the fresh-water limestones and by the interfingering of the Anastasia formation and the Key Largo limestone with the Fort Thompson formation along the coastal areas.

The filling of this shallow trough and the contemporaneous development of the bars and reefs along the shore produced a unit of rocks underlying the lower Everglades and the coastal area of southeastern Florida that now forms the major part of the highly permeable part of the Biscayne aquifer. This part of the aquifer was previously correlated with the Tamiami formation by Parker and Cooke (1944), largely on the basis of lithology as interpreted from cable-tool drill cuttings, and partly on the basis of an inconclusive fauna of both microfossils and macrofossils. The comminuted condition of the cuttings prevented the discernment of fresh-water limestones in which most of the fossils are preserved by casts and molds. Recent core borings, which have been reported by Hoy and Schroeder (1952), indicate that there are several beds, a few inches to a foot or more in thickness, of fresh-water limestone intercalated with the very permeable, sandy, marine limestone. Some of these fresh-water limestones come from depths as great as 55 feet below present sea level. They are probably the correlatives of the fresh-water beds in the Fort Thompson formation that may be seen in its outcrop area along the Caloosahatchee River east of La Belle and as part of the North New River Canal spoil banks from Lake Okeechobee to 20-Mile Bend.

The fresh-water limestone beds occur in many places at or near the base of the highly permeable limestones and sandstones of the Biscayne aquifer. Only rocks containing upper Miocene fossils occur immediately below this boundary. This knowledge has been used in establishing the boundary between deposits of

Pleistocene and upper Miocene ages (see pls. 6–9), although it is recognized that possibly there are places where upper Miocene (Tamiami formation) has been included in the base of the Fort Thompson formation. A comparable situation exists in the Kendall area west of U. S. Route 1, where Pliocene materials (Caloosahatchee marl) may be included above the inferred base of the Fort Thompson formation. A collection of macrofossils from test wells in the interval of 50 to 90 feet below sea level in the Biscayne aquifer west of Kendall includes the following fossils:

Mollusca:

Turbo?
Turritella cf. *T. subannulata* Heilprin
Epitonium sp.
Strombus sp. (internal mold)
Fasciolaria? sp. (internal mold)
Ostrea frons Linne (mangrove oyster)
Pecten ziczac Linne
Pecten (Plagioctenium) gibbus var. cf. P. *evergladensis* Mansfield
Chalmys fuscopurpureus Conrad
Chalmys n. sp. aff. *C. eboreus buckinghamensis* Mansfield
Plicatella aff. *P. marginata* Say
Pseudomiltha floridana (Conrad)
Cardium (Fragum) medium Linne
Chionne cancellata Linne

Cirripedia:

Pyrgoma sp. (a coral-boring barnacle)
Balanus sp.

Echinodermata:

Metalis cf. *M. pectoralis* Lamark

Other:

Unidentified head coral
Bryozoa (2 genera)
Shark teeth

Concerning this fauna F. Stearns MacNeil (personal communication) states: "There is nothing to indicate an age older than Pliocene. *Turritella subannulata* Heilprin is believed to be restricted to the Pliocene. If any of this interval is Pleistocene, it is not possible to say so definitely on the basis of this material. The presence of reef-building corals may indicate a Pleistocene age for part of this interval, but we have no information that would eliminate Pliocene reefs."

A fragment of an *Encope* was recovered between 59 and 63 feet below mean sea level in this same area. MacNeil further reports that: "It is not identifiable, but the absence of a depressed area between the petals and the margin suggests that it is not the upper Miocene species. Age - Post Miocene?"

The paleontological data suggest that in the Kendall area (see cross section *E-E'*, pl. 8) there may be some Pliocene (Caloosahatchee marl) included in the rocks mapped as belonging to the lower part of the Fort Thompson formation. Scattered and relatively thin Pliocene materials may also be present elsewhere in southeastern Florida.

Stringfield (1933a) first reported on the water-bearing characteristics of the Fort Thompson formation in the Lake Okeechobee area. As mentioned above, this part of the formation makes a very poor aquifer; its limestones are dense and hard, and the intercalated calcareous mud and fine-sand layers have very low coefficients of permeability. The freest movement of water is in the sand and shell beds, but these commonly are of relatively low permeability because of the admixture of fine sand, silt, and clay. The water is likely to be of poor quality because of residual mineralization from the several invasions of this area by the sea during Pleistocene interglacial ages. (See p. 106–107, and p. 184–185 of the section on Ground water occurrence and p. 821–822 of the section on Quality of ground and surface waters.) Chloride ranging from 16 to 3,150 ppm has been found in test wells in the Everglades. As means of comparison, the U. S. Public Health Service standards allow a maximum chloride concentration of 250 ppm in public supplies for common carriers in interstate traffic, and most people can definitely taste 400 to 500 ppm of chloride.

The fact that some wells in the Fort Thompson formation of the Lake Okeechobee area supply usable water is due to their having been drilled in more permeable beds that have been flushed of their highly mineralized waters. Heavy or long-continued pumping of certain of these wells, however, has caused mineralized water to be drawn in from adjacent shallow zones, and some wells have been abandoned.

The Fort Thompson formation in Dade County is the major part of one of the most permeable aquifers (Biscayne aquifer) ever investigated by the U. S. Geological Survey, and it ranks with clean, well-sorted gravel in its ability to transmit water. (See the section on Ground water [Quantitative studies].) This high permeability is due to the solution-riddled nature of the limestone and calcareous sandstone. The development of the cavities is caused by the solvent activity of percolating ground water. Note in the geologic cross sections (pls. 6-9) the numerous cavities found during exploratory test-well drilling. Such cavities are usually partly filled, and sometines are entirely filled, with quartz sand. The sand is of two origins: (1) Residual, left behind when the calcareous materials are removed by solution of either sandy limestone or calcareous sandstone, and (2) introduced from above through connecting vertical cavities. The presence of sand in the cavities diminishes the permeability of the formation.

Numerous cores were taken during late phases of the test-well drilling program. These help greatly in visualizing the reason for the extremely high permeability of calcareous rocks of southeastern Florida. Photographs of a few of these cores are reproduced

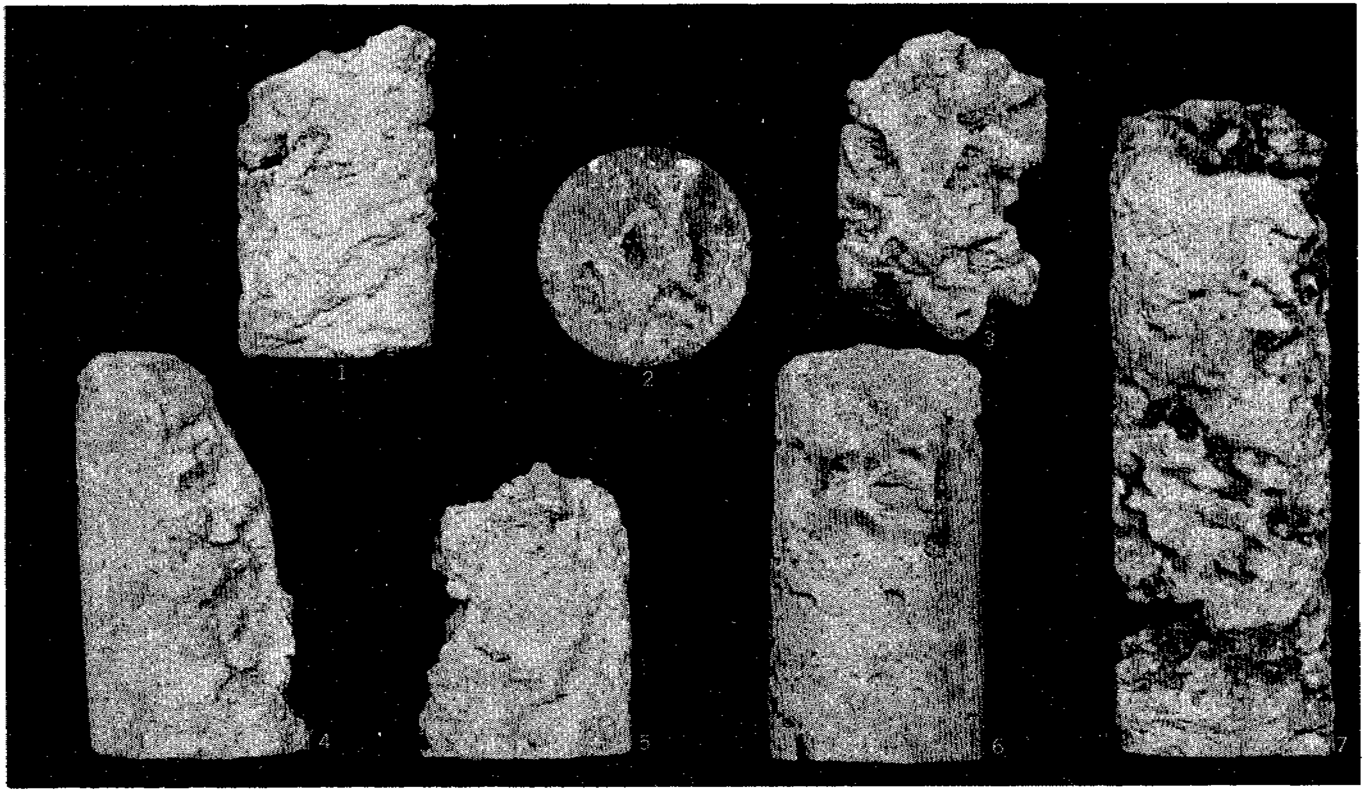

Figure 14. --Cores from test wells in Dade County. Numbers 1-3 are from the Miami oolite; numbers 4-7 are from the Fort Thompson formation.

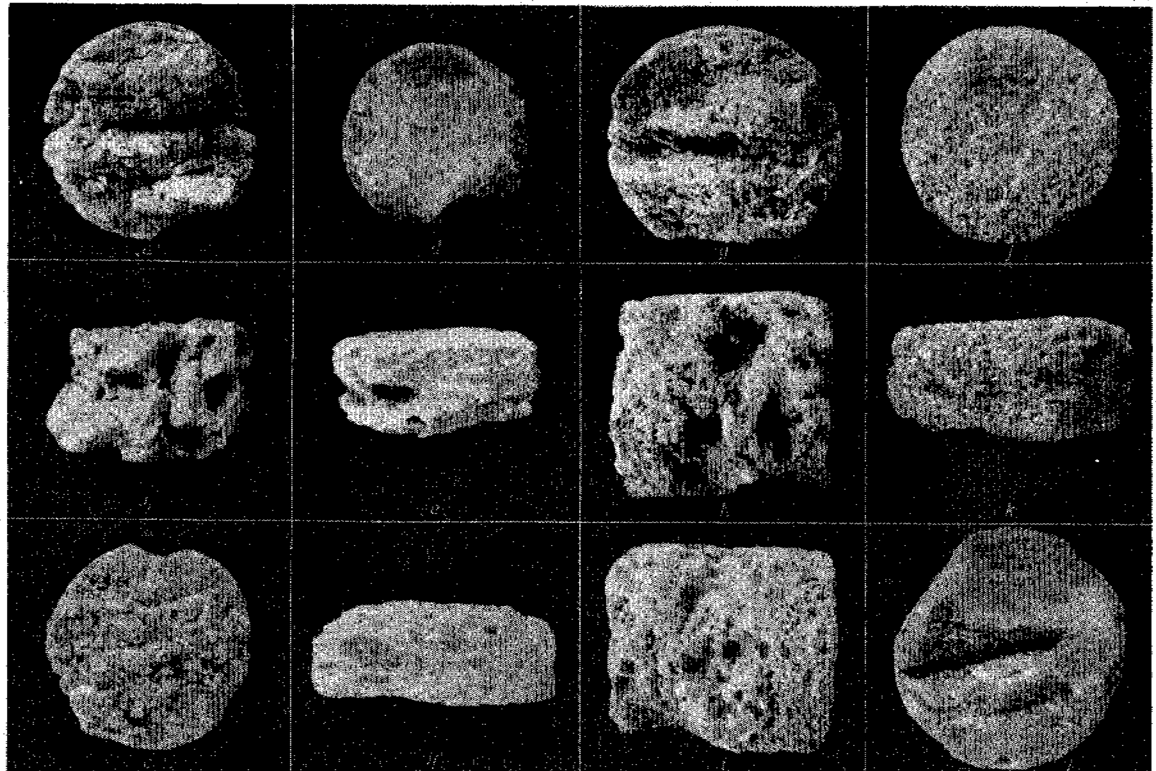

Figure 15.—Cores from test well S 394 at Delray Beach.

in figures 14 and 15. In figure 14, core Nos. 4 to 7 are from the Fort Thompson formation in Dade County and were selected as being typical of the formation; they were not selected to illustrate extreme or special conditions. Core Nos. 4 and 5 are medium-hard sandy limestone. Each core shows, by a ragged and irregular outline, that it was cut through a part of the formation containing relatively large solution holes. No. 6 is a dense, hard, once fossiliferous limy sandstone from which fossil shells have been removed by solution, thus leaving numerous small cavities. No. 7 is taken from a part of the formation that shows some evidence of bedding planes, and it is along the softer of these planes that solution has been most active. The dark color of the solution channels of this core is caused by a deposit of iron oxide. Core Nos. 1 to 3 are from the Miami oolite and will be discussed later.

Without exception, all of the cores in figure 15 are from the Biscayne aquifer at Delray Beach, in Palm Beach County, which is very near the northernmost extent of the aquifer. The cores are chiefly sandy limestone and calcareous sandstone of the Anastasia formation and show by the alinement of solution channels evidence of the solvent activity of percolating ground water moving principally in one direction. Although no means of obtaining oriented cores were available, it is believed that the solution channels developed principally in a west-east direction, because ground-water movement is now, and probably always has been, directed mainly toward the Atlantic Ocean on the east.

As in Dade County, the Fort Thompson formation in coastal Broward and Palm Beach Counties is highly permeable, and where thick enough, it yields large quantities of water with very little lowering of the water level.

KEY LARGO LIMESTONE

The Florida Keys, from Soldier Key, off Miami, to and including Bahia Honda, are parts of a dead coral reef. This reef is about 90 miles long, has a maximum width at sea level of about 3 miles, and is known to be at least 60 feet thick; its base, however, is much wider and possibly much longer.

The Key Largo limestone interfingers in some places with the Miami oolite, and in the Silver Bluff area of Miami it underlies the oolite. It is partly contemporaneous with the oolite, but its lower portion is older and interfingers with the Fort Thompson formation.

This latter relationship is shown by the occurrence of coralline limestone as deep as 48 feet below sea level in well G 189 (see pl. 9), and by fragments of similar marine limestone in the cuttings from wells G 101 and G 224 as deep as 55 feet below mean sea level.

Recent core boring in the Kendall area, west of U. S. Route 1, contained similar limestone (largely reef detrital materials). F. S. MacNeil examined a length of core from about 39 feet below mean sea level that contained a bed of fresh-water limestone. MacNeil states: "The marine limestone with which the fresh-water limestone is interbedded is highly coralline and contains *Chione cancellata* and some other unidentifiable mollusks. *Chione cancellata* occurs in both the Pliocene and Pleistocene, but the semi-crystalline, coralline nature of this rock does not suggest any Pliocene deposits with which I am familiar. I am inclined to believe that Hoy's assignment (Hoy and Schroeder, 1951) of it (limestone of the Fort Thompson formation formerly referred to the Tamiami formation) to the Pleistocene is correct. The similarity of it to the Key Largo limestone suggests the presence of one or several tongues of the formation."

The Key Largo limestone contains a large amount of coral, and the spaces between and around the coral heads are filled with amorphous limestone or detritus from wastage of the reef. Much limestone breccia is present on the surface of the Keys and is incorporated within former caverns or crevices of the reef. The breccia on the surface is of the same origin as that described on page 102.

On the Florida Keys fresh-water supplies from the Key Largo limestone cannot be obtained except in extremely limited quantities from just above sea level. The formation is so open and permeable that fresh water readily escapes laterally to the sea, and ocean water finds access to the interstices, caverns, and crevices of the rock just as easily. Substantial Ghyben-Herzerg lenses (see section on salt-water encroachment, p. 591–593) of fresh water do not occur in these keys. Wells in the Key Largo limestone of the Florida Keys yield unlimited quantities of salty water with practically no measurable drawdown, but this water is used only for fire-fighting or flushing purposes.

ANASTASIA FORMATION

On the eastern coast of southern Florida the Anastasia formation comprises the backbone of the Atlantic Coastal Ridge north of Boca Raton, and extends westward into the Lake Okeechobee–Everglades depression, where it forms the marine members of the Fort Thompson formation. Near Boca Raton the upper part of the Anastasia formation grades into the Miami oolite, which forms the southern portion of the Atlantic Coastal Ridge. (See Miami oolite, below.)

The Anastasia formation may exceed 100 feet in thickness and is composed chiefly of sandy limestone, calcareous, sandstone, sand, shells, and coquina. It, like the Miami oolite, is wedge-shaped, thick toward the coast and thin toward the interior. Like the oolite, it was formed in a marine environment largely as an offshore bar during times when the Lake Okeechobee–Everglades depression was a wide marine shoal. Many, if not most, of the materials composing these two formations were deposited under water, but at times, and in places, low dunes of calcareous, sandy, and shelly materials were heaped on the surface of the bar above high-tide level. There are many exposures of both the marine and aeolian types of deposits.

One of the thickest outcrops of the Anastasia formation is in a road cut in Palm Beach at the south end of the Palm Beach golf course, one block north of Ridgeview Avenue, where 18 feet is exposed (see fig. 16). Here, an unconformity exists within the Anastasia, separating sediments of two different ages in **Pleistocene** time.

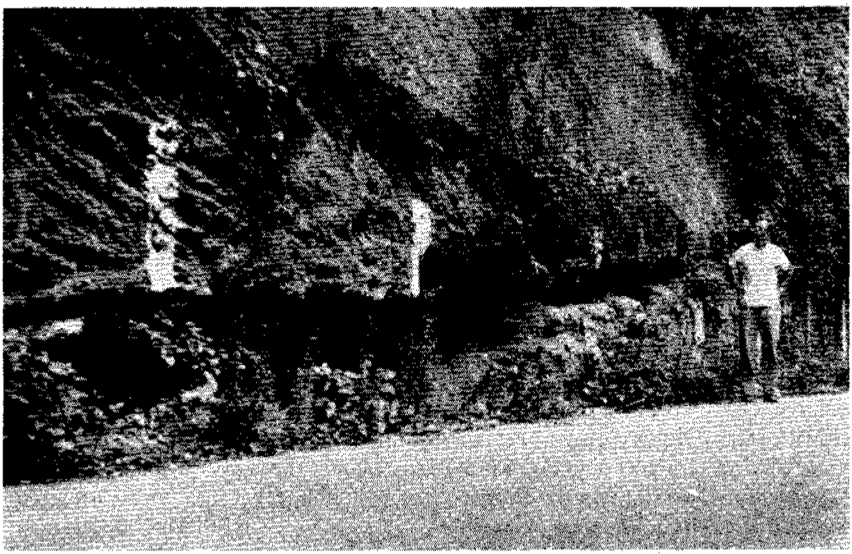

Figure 16.—Anastasia formation in road cut at south side of West Palm Beach golf course.

It is possible that the Anastasia formation contains deposits laid down during most, if not all, of the Pleistocene interglacial ages. Subsurface studies indicate that each of the several marine beds of the Fort Thompson formation, which are possibly representative of the high sea levels of Pleistocene time (Parker and Cooke, 1944, p. 20, 73–74, 89–90), is an extension of the main mass of the Anastasia formation.

Throughout most of its distribution in southern Florida the Anastasia formation yields potable water to wells and may be considered a fair to good aquifer. In the consolidated portions of the formation, open-hole (unscreened) wells of exceedingly high yield and low drawdown may be developed. In the sandier portions, wells must be finished with screens, well points, or gravel packs. The yield varies with the lithologic character and can be ascertained locally only by construction of wells.

In those zones within the Anastasia formation that contain old mangrove-swamp or salt-marsh deposits, there is usually so much fine sand, silt, and clay along with black silty muck and organic remains that the yield is very low and the quality of the water is poor. The Anastasia formation along the coast, from southern Palm Beach County to central St. Lucie County, has a considerable amount of these old swamp deposits. To date, not enough exploration has been done to map their boundaries, either areally or vertically.

MIAMI OOLITE

From a transition zone near Boca Raton, the Miami oolite underlies the Atlantic Coastal Ridge south to, and beyond, Florida City; it floors the Bay of Florida and reappears above water level in the lower Florida Keys from Big Pine Key to Key West. It is thickest along the coast, possibly reaching a maximum thickness of 40 feet, but its base seldom is lower than 20 feet below sea level. Inland from the ocean the oolite thins out, and on the eastern margin of the Big Cypress Swamp it finally disappears entirely. (See geologic map, pl. 4.)

The Miami oolite makes visible contact with the underlying Fort Thompson formation along some of the Everglades canals, as evidenced by rocks in the spoil banks (figs. 11, 12) and in the canal walls. The contact is often on a clean, solution-riddled surface of calcareous sandstone, but in many places a limestone breccia or conglomerate separates the two formations. At first glance this breccia appears to be the result of erosion with later sedimentation and consolidation. Closer examination, however, shows it to be the product of differential chemical deposition of water-borne minerals (principally iron oxide and silica) in the limestone. These secondary minerals penetrate the original limestone irregularly, often producing angular boundaries within the matrix. Later, solvent action may remove the softer matrix between these harder mineralized areas and leave a rough, irregular surface similar to breccia. Proof that this interpretation is correct is shown by numerous examples of fossils, or original structures, in the limestone that are traceable across boundaries between the angular, hard "fragments" and the matrix.

The oolite is crossbedded to massive, white to yellow, and often contains considerable fine to medium quartz sand that fills solution holes and channels. These solution holes occupy so much of the total volume of the oolite (figs. 14, 26) that they give it an exceedingly high permeability in a vertical direction. The horizontal permeability, however, is considerably lower.

In some places along the western shore of Biscayne Bay, as at SW. 13th Street and First Avenue and in the adjacent Florida East Coast Railway cut, large angular blocks and rounded cobbles of oolite, as much as 2 feet long, are embedded in both structureless and crossbedded oolite and lie on old erosion planes (see fig. 17). These erosion planes were formed by wave planation, and

Figure 17.—Details in the Miami oolite, Dade County.

the cobbles are part of the beach shingle that washed back and forth with the tides and waves, aiding the erosion of the previously formed oolite deposit.

There are a number of such erosion planes in the oolite at this locality and elsewhere in southern Florida, some of which are overlain by a coquina composed mainly of immature forms of shore- or near-shore-dwelling marine pelecypods and gastropods. Commonest among these are *Donax variabilis, Chione cancellata, Crassatellites* sp., *Venus mercenaria, Corbula* sp., *Fasciolara* sp., *Cerithium* sp., *Potamides* sp., *Cardium* sp., and others.

The evidence at this locality indicates interrupted deposition of oolite by changing levels of the sea. At times, these changes brought about conditions favorable for the development of a shallow-water, near-shore marine fauna; at other times, beach-shingle development occurred and a wave-planed bench was developed in the older part of the deposit; at still other times, dune-type and marine-bar deposits of crossbedded oolite were laid down.

346881 O—55——9

These changing levels all may have occurred within one interglacial age, but they also may have occurred during other interglacial ages at times when sea level was at the proper elevation. It is likely that conditions that were responsible for development of the oolite at any one time (as during the Sangamon interglacial age) could have been duplicated again and again during the Pleistocene as the sea level slowly rose and fell, ranging through the altitude at which the oolite is now found; therefore, the problem of dating the oolite is considerably complicated.

The writers are inclined to believe that the Miami oolite, like the Anastasia, Fort Thompson, and Key Largo, formations, may not be entirely the product of one interglacial age, though most of its development may have so occurred.

Core Nos. 1, 2, and 3, of figure 14, were taken from the Miami oolite. Core No. 1 is typical of the crossbedded rock where, for one reason or another, solution by percolating acidic ground water has had little effect. The alternating slanting layers are of hard crystalline limestone containing ooliths, and of soft unconsolidated oolitic sand. The origin of these alternating hard and soft layers, ordinarily developed in crossbedded structure, is not understood. The layers occur both in deposits that appear to be of marine origin (shallow, offshore bar, as judged by the enclosed fossil assemblage) and in those of aeolian (dune) origin.

Core Nos. 2 and 3 are from a part of the formation where solution has been very active and where a large percentage of the original rock material has been leached away, thus altering both the appearance and the water-bearing properties of the oolite. This solvent activity is not confined to the production of small cavities as shown in the cores; instead, it often produces underground cavities of considerable size and extent. Biggest of the solution channels found in the Miami area is in well G 189, in the Silver Bluff area of Miami (see pl. 9 section *F-F'*), where a vertical cavity 11 feet deep was measured. The length, width, and continuity of these solution channels are not known; however, some probably are of considerable extent and are the cause of foundation failures of many structures—including buildings, houses, roadways, dams, and airplane runways. In certain areas of Miami, for example near SW. 12th Avenue and the Tamiami Trail, apparently solid foundations have been known to give way beneath buildings. The area is one of very active underground solution and erosion. In such a place, after rainstorms, water may be heard trickling underground, and rain water vanishes quickly into the underground channels, sometimes carrying away cubic yards of soil and other surface materials.

Water supplies are often developed in the Miami oolite either by driving an "open-hole" well into the limestone, or by driving casing equipped with a well point into the sandier portions. Such a screened well driven into the soft limy oolite itself soon becomes clogged, and open-hole wells developed in it often produce impractical yields. However, in most instances, high yields of water are obtained by driving or drilling through the oolite into the underlying Fort Thompson formation.

HIGH TERRACE DEPOSITS (PENHOLOWAY AND TALBOT FORMATIONS)

Cooke (1945, p. 286), in describing the character of the Penholoway terrace deposits, says: "The Penholoway formation is supposed to consist chiefly of sand, but little is really known about its actual composition. The muck and peat associated with the many lakes and swamps on it do not logically form part of the Penholoway but are younger. The formation may, however, include considerable bodies of salt-marsh deposits, for some of it accumulated in lagoons nearly surrounded by islands, where marshes might be expected to prevail." In his description of the Talbot formation, Cooke (1945, p. 292) remarks: "Little is known about the detailed composition of the Talbot formation. Presumably it consists chiefly of fine sand except in former estuaries, where clay or silt may prevail. It probably exceeds 20 feet in thickness only in northwestern Florida, where there was an abundant supply of sand."

In the geologic map accompanying his report, Cooke (1945) does not attempt to map these two "formations" in Florida; instead, he groups them, with deposits of several other Pleistocene terraces, under the heading "Late Pleistocene deposits." This seems to be a more practical thing to do, because in the field it is impossible to separate these high marine terrace deposits except on the basis of the altitude of their respective shorelines. Parker and Hoy[5] (in press), working with these sands of the Kissimmee River—Lake Okeechobee area in 1943—1944, discovered the futility of attempting to separate these higher terrace deposits and stated: "Since these terrace sands are all so similar it is believed best to group them together under one heading and consider them as one formation, realizing, however, that several interglacial ages are represented."

Generally, the sands are white to gray at the surface and grade into tan, orange, and red below. In some places enough organic materials are admixed to make a mucky sand, and in other places enough iron oxide (limonite) is deposited around the sand grains to form a scabby ferric sandstone.

Although diligent search has been made in terrace deposits of southern Florida that lie at altitudes higher than the Pamlico ter-

[5] Parker, Garald G. and Hoy, N. D., Geology and ground water of the Kissimmee River-Lake Okeechobee area, Florida: Florida Soil Sci. Soc. Proc., 7-A, (now with publisher).

race (see p. 140—145), no fossils ever have been found. The sand grains are quartz, sharp to subrounded, generally nonfrosted, very fine to coarse in size but averaging less than medium, and have the usual characteristics of marine (not aeolian) sand. If fossils ever were present in these higher terrace deposits—and it seems likely that they were—it is probable that they were leached out by percolating acidic ground water (pH values as low as 6 are not uncommon in these siliceous materials today).

In some places, notably the northern end of the Kissimmee River watershed, the terrace deposits contain varying amounts of silt and clay. This reduces the permeability and in some areas makes it difficult to develop shallow wells. Generally, however, small-diameter wells finished with a sand point driven deep enough to be considerably below dry-season low levels of the water table will furnish potable water for domestic use throughout the year. Batteries of such shallow wells will yield water for public supply systems of small communities—Indian Town, Martin County, is a good example, although the Indian Town wells are developed in a semiconsolidated permeable sandstone and thus require no screens.

The permeability of these terrace sands has not been intensively investigated. Permeameter tests made in the southern part of the Kissimmee River watershed indicate that coefficients of permeability (P) ranging from 800 to 10 are about average (see footnote, p. 107). Some of the better-sorted sands, however, may exceed the average high value (800) by 3 or 4 times. (See p. 236—237 of section on Ground water [Quantitative studies] for the definition of coefficient of permeability.)

PAMLICO SAND

The Pamlico sand is composed chiefly of gray-white to black or brown carbonaceous quartz sand locally consolidated to sandstone, and in many places it is highly fossiliferous. It mantles the underlying rocks of southern Florida along the Atlantic Coastal Ridge and along the Gulf coast to about the latitude of Miami. It does not extend far out into the Lake Okeechobee—Everglades depression and seldom is found higher than 25 feet above present sea level, the altitude of the Pamlico seashore (Cooke, 1930, p. 389—395). Locally, however, Pamlico sand is heaped into beach ridge and dune deposits at altitudes higher than 25 feet. Pine Island (a dune deposit on the edge of the Everglades southwest of Fort Lauderdale) and Marco Island (northernmost of the Ten Thousand Islands on the Gulf coast) are examples of high dune deposits of Pamlico sand in southern Florida.

The Pamlico sand is generally of medium to low permeability. Where the sand is clean and well sorted the coefficient of permeability is high; usually, however, the sorting is poor, and the interstices between larger sand grains are filled either with finer grains, or with silt and organic materials intermixed with the sand, thus reducing permeability. A striking example of the effect of low permeability on ground-water flow is shown by studies made in the Lake Okeechobee area.

It had long been a local belief that a considerable amount of water in Lake Okeechobee and the Everglades is derived from ground-water seepage from geologic formations underlying the Kissimmee River watershed. However, Wallace (Cross, Love, Parker, and Wallace, 1940) came to the tentative conclusion, as a result of a brief study of Lake Okeechobee, that there could be no substantial gain or loss by the lake through underground flow. Furthermore, detailed studies in 1942 and 1943 (Parker and Hoy, in press) in cooperation with the Soil Conservation Service bear out Wallace's conclusions.[6]

The majority of wells developed in the Pamlico sand are small-diameter driven wells equipped with well points. In some places relatively large supplies are made available by driving numerous wells of this kind as part of a single water-supply system.

LATE PLEISTOCENE AND RECENT DEPOSITS

LAKE FLIRT MARL

The Lake Flirt marl, principally a light-gray, fresh-water, calcareous mud deposit, has its thickest and most typical development in the basin of now-drained Lake Flirt, between old Fort Thompson and Coffee Mill Hammock on the Caloosahatchee River east of La Belle. There, the formation ranges in thickness from a feather edge to 6 feet. The formation was first named and described by Sellards (1919, p. 73—74) who thought that it "may be quite recent in age." Sellards did not describe it as occurring

[6] The U. S. Geological Survey—Soil Conservation Service studies were designed to check on Wallace's conclusions. Fourteen test wells were sunk in the area of investigation and valuable geologic and hydrologic data were obtained. Coefficients of permeability ranging from about 800 to 10 were common. These were not field coefficients established by pumping tests; instead, they were made with a permeameter on typical samples of the sandy materials.

The nonconsolidated terrace sand borders Lake Okeechobee on the east, west, and north for a total shoreline distance of about 60 miles. Assuming that the coefficient of permeability of the sand bordering Lake Okeechobee is 800 (a generous figure), that the length of the permeable section contributing ground-water flow around the lake is 60 miles (measured from a point about 6 miles south of Lakeport on the west shore to a point about opposite Lakeport on the east shore), that the average saturated thickness of the permeable sand is 10 feet (based on test-well data), and that the slope of the water table is 1.5 feet to the mile (about equivalent to land-surface slope to the northwest as measured along Indian Prairie Canal), the amount of ground water seeping into Lake Okeechobee was computed by Parker to be about 720,000 gpd or 1.1 cfs per day. This is equivalent to about 730 acre-feet per year—a relatively negligible amount—and bears out Wallace's conclusions.

outside the Lake Flirt basin, which is about 8 miles long. The formation is widely distributed in the Everglades, however, and usually lies in direct contact with the surficial rocks of the underlying Fort Thompson formation; it fills and rather effectively seals the solution holes of these rocks.

Over large areas of southern Florida, particularly in the lower Everglades and in the coastal marshes, deposits of this light-gray calcareous mud, rich in the remains of fresh-water gastropod shells (principally *Planobis* and *Ameria*), are present; their thickness ranges from a feather edge to several feet. These marl deposits, valuable as agricultural lands where more than 2 feet thick, are here classed as part of the Lake Flirt marl.

Generally, in its occurrence in the Everglades, the Lake Flirt marl lies between the organic soils and the rock floor, but layers of it often are intercalated with layers of organic material, peat or muck. These marl layers pinch out or grade into the organic layers both horizontally and vertically, thus indicating an origin closely related to the deposition of the peat and muck (see fig. 18).

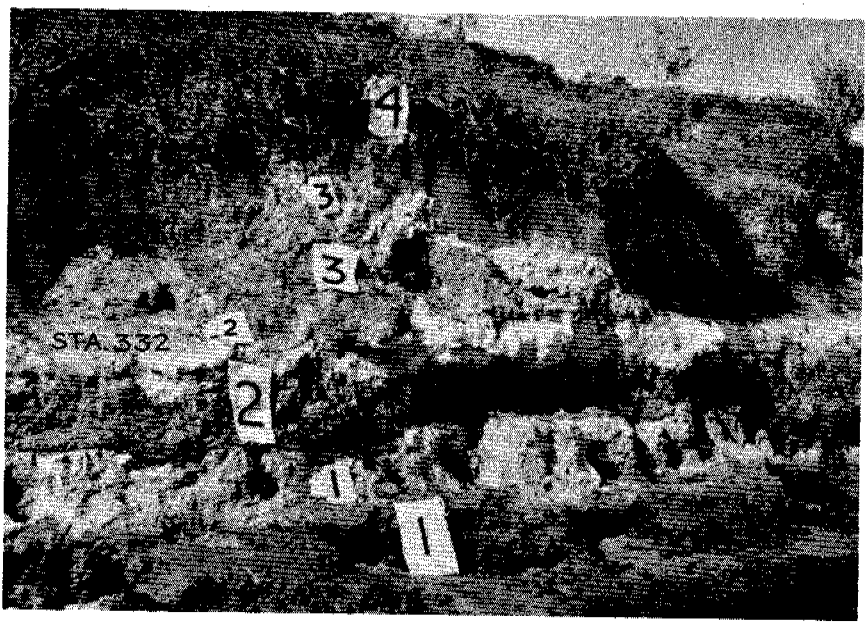

Figure 18. —Lake Flirt marl.

The Lake Flirt marl is relatively impermeable and acts as a seal that prevents movement of water through it to underlying more permeable rock. Where present in thicknesses of a foot or more, it is an important aid in controlling water levels, especially above the highly permeable parts of the Fort Thompson formation and the Miami oolite.

ORGANIC SOILS

The peats and mucks of the Everglades range in thickness from a feather edge around the borders and in the south to 8 or 10 feet in the north near Lake Okeechobee.

These organic deposits were formed since the last high-level sea of the Climatic Optimum (see p. 124—125) in marshy areas where large amounts of vegetative matter were annually growing, dying, and sinking below the water surface. Under such conditions the organic material did not decay and dissipate but underwent change slowly. Where little or no inorganic matter was incorporated into the deposit, it became a peat; where considerable amounts of mineral matter were deposited with the organic materials, it became a muck. In the Everglades all types are found—from purely aquatic and semiaquatic peats to highly inorganic mucks.

In order to determine the age of the peat deposits, three samples from the upper Everglades were checked by the Carbon 14 method by J. L. Culp, of Lamont Laboratories, with results given in the following table:

Survey No.	Lamont No.	Description	Age (years)
WR 3-4a	141-A	Peat, south pasture line of Everglades Exp. Sta., 2½ miles southeast of Belle Glade, Fla. Depth, 5.5 to 6.0 ft below land surface. Peaty muck.	4900 ± 200
WR 3-4b	141-B	Peat, as above area, but north line. Fibrous peat.	3800 ± 200
WR 2-7	141-C	Peat 10 miles south of Lake Okeechobee, Fla. 5.0 to 5.5 ft below land surface.	5050 ± 200

In the past, under normal conditions, these organic materials were accumulating slowly and building up the body of Everglades soils. At present, with the drainage canals in operation (since about 1909), the organic soils are being lost rapidly. This dissipation takes place principally because of drainage that allows fires, natural oxidation, shrinkage, and compaction. As a result of compaction, "subsidence valleys" (Evans and Allison, 1942, p. 38) have developed along all major Everglades drainage canals.

The organic soils of the Everglades have a comparatively low coefficient of permeability. Water moves through them very slowly under the low gradients existing there. In a test pit 5 feet square and 3 feet deep, with the water table standing only about 1 foot below land surface, the ground water seeped in so slowly that the pit could be emptied by slow bailing with a pint can.

LATERITE OF THE REDLANDS DISTRICT

Harper (1927, p. 57-58) was the first to mention these clayey soils, apparently residually derived from weathering of the Miami oolite. The soil is reddish, contains only a minor amount of quartz sand, and usually fills solution holes and crevices in the oolite (see fig. 19). It is most common on that part of the Atlantic Coastal Ridge near Homestead, in southern Dade County, but it occurs at least as far north as the Miami River. Harper tentatively classified the deposit as a laterite, an interpretation with which the present writers concur.

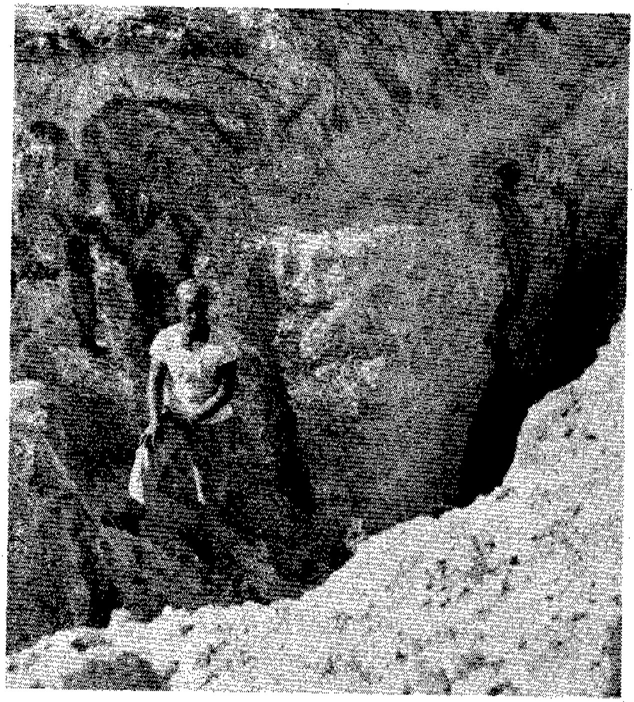

Figure 19. —Miami oolite in cut at Florida Power and Light Company's Cutler plant.

The laterite is not a continuous bedded deposit, nor does it have a wide areal extent; it probably has little effect on ground water, inasmuch as there is an ample amount of bare limestone surface through which rainwater can readily percolate to the water table below. Agriculturally, it is valuable and is used especially for the growing of citrus fruits, avocados, mangoes, papayas, and other subtropical fruits.

BEACH SAND

Recent sand is confined almost solely to the modern beaches, although in some instances hurricane tides have deposited present-day beach and shallow ocean or bay-bottom sand inland beyond the beaches.

Recent sand in southeastern Florida is generally tan to brown and is composed principally of shell particles, possibly derived largely from reworking of coquina deposits (Anastasia formation) near Boca Raton, Jupiter, and elsewhere along the present shore to the north. Generally, the farther south in Florida that beach sands are traced the calcareous content is greater and the silica content is smaller. Beach sand varies in mechanical and chemical character from time to time and from place to place. There is relatively little quartz sand at or south of Miami Beach; and Cape Florida, on Key Biscayne, marks the southern terminus of migrating quartz sand in notable quantities.

Considerable sand is present along the beaches of the Florida Keys, but it is almost entirely calcareous; in many instances it is composed of 75 percent or more of foraminiferal tests. Only minor amounts of true coral sand have been noted on the Florida Keys, though the term is commonly used by local residents in speaking of foraminiferal and shell-fragment sand deposits.

LATE CENOZOIC HISTORY

GENERAL STATEMENT

In southern Florida only relatively young rocks are penetrated in the drilling of the deepest water wells, and the oldest of these rocks does not antedate the Eocene, which was deposited possibly 50 to 60 million years ago. A minor number of wells reach into the Miocene rocks, some into the Pliocene, but most are developed in the Pleistocene formations.

The following table gives the approximate dates that have been derived from the epoches of the Cenozoic era (National Research Council, 1949—1950).

Table 13.—*Cenozoic time correlations*

Era	Period	Epoch	Duration in millions of years	Time since beginning of each epoch in millions of years
Cenozoic	Quaternary	Recent	0.01	0.01
		Pleistocene	1	1
	Tertiary	Pliocene	11	12
		Miocene	16	28
		Oligocene	12	40
		Eocene and Paleocene	20	60

THE PLEISTOCENE OR "GREAT ICE AGE"

At the close of the Pliocene epoch a marked change took place in the earth's climate—a change that brought about the development of great systems of continental and alpine glaciers. The continental glacial sheets covered about one-third of the land area in the northern hemisphere and a somewhat smaller area in the southern hemisphere. The North American glacial sheets, including the Cordilleran complex, reached from Labrador to Alaska and pushed down from Canada until they covered the part of the northern United States that extends south to an irregular line stretching, roughly, from Long Island, N. Y., through Cairo, Ill., to the southern tip of Puget Sound in western Washington. The Scandinavian sheet extended across the Baltic Sea into the plains of northern Germany and western Russia and covered all of Holland and Belgium and most of the British Isles—an area about half as great as the glaciated region in North America. The extent of the glaciation in the southern hemisphere is not yet well known; at least it covered Patagonia and parts of Australia and New Zealand. In addition to the continental ice sheets, extensive and well-developed alpine glacial systems existed. Valley glaciers often extended far beyond the termini of modern glaciers and even spread beyond the foothills to coalesce into piedmont glaciers, often of considerable extent.

The continental ice sheets were tremendously thick. Schuchert and Dunbar (1933, p. 422) estimate the North American sheet to have been "at least 5,000 or 6,000 feet thick at the center of dispersal and it may have been as much as 10,000 feet. It has been found (Wegener, 1933) that the Greenland ice sheet reaches a thickness of 8,800 feet near its center in latitude 72° north, and averages over 4,500 feet thick over a large area." The North American glacial sheets stripped a large part of Canada to bedrock, and deposited much of Canada's surficial materials as rich soil in north-central United States.

The Pleistocene epoch, however, was not a time of continuous glaciation; rather, it was a time of alternate glaciation and deglaciation as the climate repeatedly changed from cold to warm. The times of glaciation are called glacial ages, and the times of deglaciation are called interglacial ages. The last major change in climate that brought about withdrawal of the major continental ice sheets marks the beginning of the Recent epoch. However, as a matter of fact, it is probable that our Recent epoch should not be ranked in this manner; instead, it should be regarded as another of the interglacial ages of the Pleistocene, even though large masses of ice on a continental scale (such as the Greenland sheet and the Antarctic sheet) still exist. Lobeck (1939, p. 299) has reckoned the extent of these sheets as totaling approximately 6,000,000 square miles, and he has stated that enough water is stored in this ice to raise the sea level about 150 feet if it were to be released to the ocean. Although all geologists do not agree on this figure, it is generally conceded that the amount is significant. Longwell, Knopf, and Flint (1932, p. 153) conservatively estimate that "the complete wastage of the polar ice sheets existing today would return enough water to the sea to raise its level about 80 feet. . . ."

The causes for the waxing and waning of the great ice sheets are not definitely known, but the existence of the several great glacial sheets cannot be doubted. Their distribution of rocks foreign to the regions where they are now found, their terminal and ground moraines, their gouging of deep lake basins, their rearrangement of stream patterns, and many other evidences are excellent proof of their existence. Furthermore, their effect on the life of man today, through control of topography, soil types, ground water, surface water, and certain mineral deposits, is of utmost importance. Their influence extended far beyond the confines of the glacial sheets themselves; even tropical areas of the world were influenced, principally as a result of glacial control of sea level. Daly (1934, p. 271) has pointed out that the occurrence of many coral reefs may thus be accounted for.

GENERAL EFFECT OF GLACIAL CONTROL OF SEA LEVEL

The sea level fell during times of glaciation because of the huge draft on the ocean waters needed to produce the massive continental glaciers; it rose again as the glaciers retreated during the warm interglacial stages and the water formerly stored on the land as ice returned to the sea. This fall and rise occurred several times with worldwide effects.

With each succeeding glacial age the ice front in North America did not advance as far to the south as it had previously; also, with each succeeding interglacial age the high-water mark of the ocean was lower. Whether the difference of ocean level in each succeeding interglacial age is due to successive enlargements in the capacity of the oceanic basins brought about by crustal movements in some distant parts of the earth, or whether it is due to more ice remaining locked on land during each subsequent interglacial age, or both, is not known. However, the changing ocean levels resulted in the formation of shorelines with their characteristic features wherever the ocean halted long enough for their development.

Some of these ancient shorelines are now beneath the surface of the ocean, and therefore they are very difficult to recognize; in some places, however, they have been detected and mapped (Cooke, 1939, p. 33–58; Stearns and Macdonald, 1942, p. 54–55, 153–154; Veatch and Smith, 1939; Upson, J. E., 1951). Where the shorelines lie above present ocean level they often may be located by those familiar with shorelines and shoreline processes despite subsequent modification by weathering, erosion, and solution. Eight such shorelines along the Atlantic seaboard alone have been described (Cooke, 1931, p. 503–515; Parker and Cooke, 1944, p. 21–27); and in Hawaii and the South Pacific, Stearns (Stearns and Macdonald, 1942, p. 54), has detected four corresponding ones and six others that are not apparent in southeastern United States. In Cuba, Meinzer (1933, p. 256–258) noted and described the occurrence of seven Pleistocene marine terraces, of which the one whose shoreline is about 40 feet above present sea level is the "most persistent and best-preserved throughout the region." Meinzer noted that "the terraces consist largely of benches cut into the older rocks and are mantled with soft, massive, coral limestone

As long ago as 1913 Matson (Matson and Sanford, 1913, p. 31–35) described and named three marine terraces in Florida with shorelines at elevations of approximately 100, 70, and 40 feet, respectively, above present sea level. In the lowest of these terraces, which he called the Pensacola, Matson recognized a second division with a shoreline at about 20 feet. He did not have adequate field data, however, to map this lowest shoreline, so he did little more than mention it. Many other geologists likewise have noted the occurrence of terraces in Florida, and a controversy has developed over whether or not their shorelines reflect westward tilting of the Florida peninsula (Leverett, 1931). Cooke, who has given much time to the study of the Pleistocene shorelines and their associated sea floors (the terraces) along the Atlantic coast, has traced the eroded remnants of the shorelines from New Jersey southward into Florida, has checked their elevations, and finds that they are approximately level. He therefore arrives at the conclusion that no great movements of land with respect to sea level have taken place in this area since the close of the Pliocene epoch. In addition, work of the writers on the younger Pleistocene shorelines in Florida south of Orange County has indicated that they are approximately horizontal, and if any late Pleistocene tilting of the Floridan Plateau is involved, it is of a very minor amount.

EFFECTS OF CHANGING SEA LEVELS IN SOUTHERN FLORIDA

Geologists have established, by their work in the glaciated parts of North America, that there were at least four major glacial ages (time units) and stages (rock units) separated by three major interglacial ages and stages, and possibly five major glacial ages and stages separated by four major interglacial ages and stages (Flint, 1941, p. 22–25). The writers adopt the former view and list them in table 14. In this interpretation the Iowan is regarded as a subage of the Wisconsin glacial age.

Table 14.—*Tentative correlation of Pleistocene and Pliocene formations in southern Florida*

Epoch	Age		Shoreline altitude (feet)	Upper Caloosahatchee River valley area	Central Everglades area	Southeastern coastal area
RECENT			0 5	In places no deposits (solution and erosion). Sand bars, dunes and old channel fills. Lake Flirt marl and organic soils of Everglades.	Organic soils of Everglades. Lake Flirt marl (upper part).	In places no deposits (solution and erosion). Formation of beach ridges, organic soils, and marl beds (Lake Flirt marl). Local dunes. Laterite of the Redlands district. Development of Silver Bluff terrace.
PLEISTOCENE	Wisconsin		-25	In places no deposits (solution and erosion).	In places no deposits (solution and erosion). River cuts and fills.	In places no deposits (solution and erosion). Laterite of the Redlands district.
	Wisconsin		25	Pamlico sand.	*Rangia cuneata* beds.	Pamlico sand.
	Wisconsin	Iowan Sub-stage	-?	In places no deposits (solution and erosion).	No deposits (solution and erosion).	In places no deposits (solution and erosion; especially deep cuts in Miami oolite). Laterite of the Redlands district.
	Sangamon interglacial		42 70 100	Fort Thompson fm.: Coffee Mill Hammock marl member (marine shell bed).	Fort Thompson fm.: Undifferentiated marine limestone, sand, and shell marl.	Fort Thompson fm.: Miami oolite and upper parts of Anastasia formation. Key Largo limestone.

Table 14.—*Tentative correlation of Pleistocene and Pliocene formations in southern Florida*—Continued

Epoch	Age	Shoreline altitude (feet)	Upper Caloosahatchee River valley area		Central Everglades area		Southeastern coastal area	
PLEISTOCENE	Illinoian glacial	-?	Fort Thompson formation	Highest fresh-water limestone ledge, merging into soft fresh-water marl below.	Fort Thompson formation	Hard fresh-water limestone.	Fort Thompson formation	Solution and erosion of coastal ridge. Deposition of fresh-water limestone behind coastal ridge.
	Yarmouth inter-glacial	170 215		Marine shell marl, "Pecten horizon."		Undifferentiated marine limestone, sand, and shell marl.		Undifferentiated, possibly middle and lower parts of the Miami oolite. Anastasia formation. Key Largo limestone.
	Kansan glacial	-?		Lowest fresh-water marl, locally indurated, making a shelf.		Hard, fresh-water limestone.		Solution and erosion of coastal ridge. Deposition of fresh-water limestone behind coastal ridge.
	Aftonian inter-glacial	270		Marine shells (local, often mixed with basal part of over-lying fresh-water shells).		Undifferentiated marine limestone, sand, and shell marl.		Undifferentiated. Basal part of Anastasia formation. Basal part of Key Largo limestone.
	Nebraskan glacial	-?	No deposits (solution and erosion).					
PLIOCENE			Caloosahatchee marl.		Caloosahatchee marl.		Caloosahatchee marl. In places no deposits.	

The following correlation of deposits in southern Florida with these glacial and interglacial ages is tentative and is to be regarded as a working hypothesis only. In part it is based upon the work of Cooke (1935, p. 331–333), who previously has assigned tentative ages to the Pleistocene shorelines in Southeastern United States.

Table 15.—*Pleistocene terraces of Southeastern United States*

Terrace	Approximate altitude of shoreline (feet)	Tentative age
Brandywine	270	Aftonian interglacial
Coharie Sunderland	215 170	Yarmouth interglacial
Wicomico Penholoway Talbot	100 70 42	Sangamon interglacial
Pamlico Silver Bluff	25 5	Interglacial subage of Wisconsin Climatic Optimum

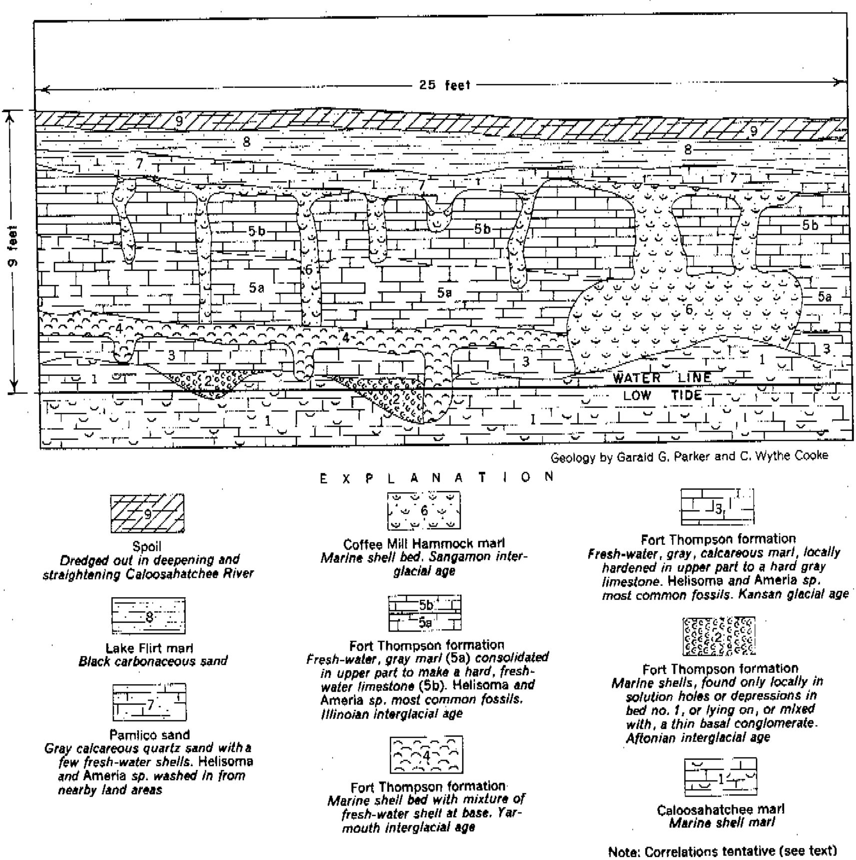

Figure 20. —Idealized geologic cross section at type locality of the Fort Thompson formation.

Inasmuch as the topography of southern Florida offers no opportunity to work on terraces having shorelines higher than 100 feet, the writers offer no suggestions for amending or changing Cooke's age assignment, except to add the Silver Bluff terrace and shoreline and to tentatively assign their development to the Climatic Optimum of Recent time—the lower shorelines and deposits appear to fit into Cooke's chronology. If the higher shorelines outside southern Florida are actually the product of Pleistocene marine environments, much of the earlier Pleistocene shoreline record is missing here; therefore, a sequence based on a complete set of Pleistocene shorelines cannot be made from evidence in southern Florida.

However, at Fort Thompson on the Caloosahatchee River, $1\frac{3}{4}$ miles east of La Belle, there is a sequence of Pleistocene deposits that records the effects of fluctuating sea level, and it is upon this occurrence and upon the tracing of related marine beds elsewhere in southern Florida that much of the correlation is based (see fig. 20).

The Caloosahatchee River section (illustrated in fig. 20) includes four Pleistocene marine beds (three in the Fort Thompson formation and one in the Pamlico sand) separated from one another by erosional unconformities and fresh-water deposits. If each of these marine beds represents an interglacial age and if the erosional unconformities and fresh-water deposits represent glacial ages, then the sequence of major ocean-level changes, postulated as a result of the several glaciations and deglaciations during the Pleistocene, is accounted for. However, there is nothing about these deposits to indicate, with any degree of certainty, the height of the ocean at its maximum altitude when the deposits were being formed. As a matter of fact, these marine beds may well have been laid down when the ocean level was comparatively low, either during advancing or retreating phases in the slow fluctuations of the ocean level at any time during the Pleistocene. Therefore, the marine beds of the Fort Thompson formation throw no light on the problem of the altitude of the shorelines of the higher terraces of the Southeastern United States. Likewise, the other low-lying Pleistocene marine deposits offer no aid in solving the problem of the altitude of the higher shorelines. Their stratigraphic relationships have been the bases for tentatively assigning them to the several interglacial ages listed in this report.

NEBRASKAN GLACIAL AGE

When the sea withdrew at the beginning of Nebraskan time, a gently southeastward-sloping area existed under the central and southern part of the present Everglades. Higher land lay to the west in the present area of the Devil's Garden and the Big Cypress Swamp, and to the north about in the latitude of Tampa Bay (see pl. 12). The deposits of the Pliocene sea were generally shelly, sandy, and silty, although in some places calcareous deposits were laid down.

This Pliocene surface became exposed to weathering and to the attacks of running surface water and percolating ground water. The latter was an especially important factor because it created a network of solution holes in the calcareous deposits and started the action which, repeated in subsequent glacial ages, has produced the best water-yielding parts of the Caloosahatchee marl. The shelly, sandy, and silty parts of the Caloosahatchee marl, however, were not so affected; instead, they were eroded, and in many places the Pliocene deposits were completely stripped away.

Ancestral Lake Okeechobee made its first appearance at this time, and in all probability other smaller lakes existed in the lower parts of the area to the south. If any fresh-water limestones were deposited in these early Everglades lakes they are not recognized as such.

AFTONIAN INTERGLACIAL AGE

After the close of Nebraskan time, there ensued a warm period called the Aftonian interglacial age, during which the great continental glaciers retreated, and the sea level may have risen to about 270 feet above its present level, forming the Brandywine terrace and associated deposits (Cooke, 1939, p. 33—35).

Only a few scattered local patches of marine shells, generally found in depressions in the underlying Caloosahatchee marl and often mixed with the basal part of the overlying bed of fresh-water marl, may be seen at Fort Thompson (bed 2, fig. 20). Elsewhere in southern Florida, extensive deposits of the Aftonian stage possibly are included in the lower part of the Fort Thompson and Anastasia formations. These deposits probably were once much thicker than they are now, but they have been thinned and in most places entirely removed by erosion and solution. The fact that the ocean probably was fairly deep here at its maximum during this age and that the sources of detritus were far distant, may be additional reasons in this area for a scarcity of deposits possibly assignable to the Aftonian interglacial stage.

This invasion of southern Florida by the sea during the Aftonian interglacial age probably distributed sand southward along the Atlantic coast, thus building up the early Pleistocene deposits (basal part of Anastasia formation) under the present area of the Atlantic Coastal Ridge. Also, it is likely that the basal portions of the Key Largo limestone were being formed by coral growth as

346881 O—55——10

a reef at or near the site of the present Florida Keys. The ocean water displaced the fresh ground water in much of the Pliocene and Miocene rocks, and it probably washed enough sand into many of the solution holes (developed during Nebraskan time) to partly or completely fill them.

KANSAN GLACIAL AGE

The cold Kansan glacial age succeeded the warm Aftonian interval, and again the sea fell below its present level. Once more, southern Florida became a wide land area with rivers, lakes, trees, grass, and strange animals (Simpson, 1929, p. 229–279). The sand, which had been washed southward in the vicinity of the present coastal ridge during Aftonian time, formed a low barrier and allowed a large shallow fresh-water marsh and lake to exist in the upper Everglades and the present Caloosahatchee River Valley. Fresh-water marl accumulated in this marsh.

Once again, fresh percolating ground water was at work flushing out the salt water and creating a network of solution holes in the calcareous marine rocks which were deposited during the Aftonian interval. The Caloosahatchee marl deposits may also have been flushed of salt water, but owing to the low permeability of these sediments and the very slow rate of ground-water movement through them, this flushing may not have been complete.

YARMOUTH INTERGLACIAL AGE

The Kansan glacial age was succeeded by the warm Yarmouth interglacial age. Cooke (1935, p. 331–333) has postulated that during this time the sea level may have risen to 215 feet above present sea level, that it stood there long enough to establish a definite shoreline and then fell to 170 feet, where it remained until the end of the age. None of these higher (270-, 215-, and 170-foot) shorelines or terraces are present in southern Florida, but Cooke describes them as occurring along the Atlantic coast from central Florida northward to New Jersey.

In the area of the Fort Thompson type locality the sea laid down a shell marl containing the shells of many scallops (*Pecten* sp.), marine jet-propelled pelecypods. Without doubt, this deposit was once much thicker than it is now, but, like earlier deposits, it was largely removed by subsequent erosion. In other areas of southeastern Florida the coral reef (Key Largo limestone) once more was being built upon; a very shelly limestone was deposited in the central and lower Everglades area; basal parts of the Miami oolite were probably being formed as a limy shore and bar deposit; and sand, a principal component of the Anastasia formation, continued to work southward, building up the present east-coast ridge, and together with the oolite bar and coral reef deposits it enclosed enough of the present Lake Okeechobee–Everglades depression to allow a large shallow lake and marsh to exist there in the succeeding interglacial age. This invasion by the sea once again filled the rocks with salt water and displaced the fresh water of the preceding age.

ILLINOIAN GLACIAL AGE

As the climate cooled again and the Illinoian glaciers spread far to the south of the dispersal centers, the ocean once more withdrew from the land and fell below present sea level. Land conditions again existed in southern Florida, and once more a wide, shallow lake and marsh came into existence in the Lake Okeechobee–Everglades depression. A widespread fresh-water limestone and marl deposit was laid down, which today is the most easily recognized member of the Fort Thompson formation. Solution and erosion took place on the higher land, and rivers wended their way from this shallow interior lake to the ocean. Fresh ground water again began displacing the salt water; it dissolved the more soluble limy rocks and extended the already existing solution network, thus making the Fort Thompson formation in the lower Everglades and coastal Broward and Dade Counties still more permeable.

SANGAMON INTERGLACIAL AGE

With the melting of the Illinoian ice the ocean slowly rose during the Sangamon interglacial age. Cooke (1935, p. 331–333) postulates that it reached an elevation of 100 feet above present sea level, then fell to 70 feet, and finally to about 42 feet by the end of the age. In each instance it remained long enough to produce marine terraces with well-preserved shorelines at those elevations. In southern Florida these shorelines show plainly on aerial photographs taken at 14,000 feet. They usually are difficult to see on the ground, but some features along these old shorelines are so little changed by erosion, that they are unmistakable when viewed even at close range. Best preserved of the three shorelines are those at 42 and 70 feet, and least well preserved is the one at 100 feet (the oldest). This is to be expected, because weathering has had more time to efface the features of the older ones.

At the beginning of the Sangamon age and again near its close (when sea level may have ranged between about -20 and +20 feet with reference to present mean sea level), conditions were very similar to those of the Yarmouth age, and an extensive bar of oolite (Miami oolite) was being built up along the eastern shore to the south of Boca Raton. North of this place the bar was sandy and shelly, and deposits of coquina, sand, and sandy limestone (the upper part of the Anastasia formation) were laid down (pl. 4). Outside this bar, southward from the latitude of Miami, the coral reef that makes up the present Upper Keys was once again growing (Key Largo limestone), and behind this bar and reef, in the Lake Okeechobee--Everglades depression, myriads of marine and brackish-water shells were accumulating, which today compose the uppermost member of the Fort Thompson formation (the Coffee Mill Hammock marl). Salt water again gained access to the rocks and displaced the fresh water, and sand worked into the solution holes.

On the higher terraces referred to the Sangamon interglacial age, especially on those that surround and underlie the Kissimmee River basin, the development of sand bars, beach ridges, and dunes took place. These features today dictate land usage through their control of drainage, ground water, vegetation, and soil types.

When the sea withdrew at the close of this interval it left many original depressions which today contain such consequent lakes as Istokpoga, Kissimmee, and the Tohopekaligas. The Kissimmee River is a consequent stream making use of the abandoned late Sangamon sea bottom north of Lake Okeechobee, which, itself, occupies a slightly modified original depression in the Pliocene sea bottom.

It is postulated that the deposits formed during Sangamon time largely gave southern Florida its modern appearance by building up the higher lands north, west, and east of the Lake Okeechobee--Everglades depression, and by constructing the major part of the coastal ridge along the Atlantic shore.

WISCONSIN GLACIAL AGE

Following Sangamon time, the Wisconsin glacial age occurred, consisting of early (Iowan) and late Wisconsin glacial subages, and an intermediate interglacial subage. The results, though much more complicated than here outlined, were about as follows: In the Iowan, or first glacial subage, the sea fell below its present level, and solution and erosion were common on the higher land. From the lakes that existed in the interior, cuts were made through low areas and abandoned tidal channels in the newly formed Atlantic Coastal Ridge, especially through the soft oolite between Miami and Fort Lauderdale. Dune building was common along the sandier shore areas, especially in St. Lucie, Martin, Palm Beach, and Collier Counties. Fresh water began to flush out the salt water left from the Sangamon invasion, but the interval was short, and the action may not have progressed very far, especially in the rocks of low permeability inland from the shore where very low water-table gradients probably existed.

Then, during the mid-Wisconsin interglacial subage, there followed a time of warm weather; the ocean rose to 25 feet above present sea level and remained long enough to produce the Pamlico terrace and formation (Pamlico sand), which, in southern Florida, is mainly quartz sand locally hardened into sandstone. This is the sand that mantles the Atlantic Coastal Ridge as far south as Coral Gables, often completely filling the channels cut through the oolite during the previous glacial subage. West of the Everglades this sand mantles the higher land that underlies the Big Cypress—Devil's Garden area (to as high as 25 feet above mean sea level, and higher where it was heaped into beach-ridge and dune deposits), and to the north it surrounds the higher terraces and generally encloses Lake Okeechobee—except on the southern and southeastern sides where the wide expanse of the Everglades meets the lake shore. Only a minor amount of the Pamlico sand found its way out into the present basin of the Everglades proper, because the longshore currents that carried it south were not effective in the quieter water of this great shoal area. Again, salt water displaced the fresh ground water, and sand worked its way down into solution holes.

Remnants of this Pleistocene salt water are still left in isolated patches in southern Florida; some of the patches are of considerable size, especially in the northern Everglades and around the southeastern side of Lake Okeechobee [see p. 183–185 in the section on Ground water (Occurrence) and p. 818–822 of the section on Quality of ground and surface waters]. This mid-Wisconsin invasion by the sea is believed to be largely responsible for salt water found in other places on the Pamlico terrace in Florida, notably in the St. Johns River valley and along the coast, as at Cocoa and Titusville, in Brevard County. Although these residual bodies of trapped sea water are still quite salty, the waters do not now have the characteristics of modern sea water. This is probably the result of modification by dilution with fresh water and by chemical reactions (mainly of the cation-exchange variety) with organic soils and enclosing calcareous rocks.

This mid-Wisconsin (Pamlico) stand of the sea over southern Florida was the last extensive one, and its marks are very evident today. The old bars and current-marked sand deposits are still noticeable and are being only partially obliterated by surficial drainage mainly in the vicinity of larger streams, where a dendritic drainage pattern is being imposed on the parallel pattern of old beach ridges, offshore bars, and intervening lagoons that characterizes some areas in the sandy flatlands in southern Florida, especially in St. Lucie, Palm Beach, and Martin Counties. The trend of the bars and swales parallels the present

Atlantic shoreline and is entirely confined to the sand land; it does not affect the surficial drainage in the organic soils of the Everglades, where one can see, from aerial photographs, a similar arrangement of the drainage pattern. This latter pattern is entirely confined to the peat and muck soils, and has no apparent relationship to the underlying floor of the Everglades.

As this warm mid-Wisconsin interglacial subage waned and as the continental glaciers made a relatively short but significant advance, the ocean level began to fall again. Probably it did not recede uniformly with respect to time but receded by halting stages. It may have remained long enough at 5 feet above present sea level in southern Florida to begin the development of a marine terrace and its associated shoreline, which in places in Dade County presently is marked by a low, wave-cut sea cliff in the Miami oolite. However it is more likely that these topographic features were developed in Recent time, during the Climatic Optimum. This will be considered subsequently.

In any event, the sea level fell at the close of the Wisconsin, to approximately 25 feet below present sea level (Cooke, 1937, p. 5), and a fresh-water regimen became dominant once again in southern Florida. Once again solution of the calcareous rocks and erosion of channels through the Atlantic Coastal Ridge became active, and it is quite likely that the re-excavation of former channels that had been choked with Pamlico sand was furthered. Fresh ground water began displacing the newly formed salt water body concentrated especially in the Lake Okeechobee—Everglades depression and may have cleared the more permeable and shoreward parts of the Biscayne aquifer of its saline water rather effectively.

During this time of lowered sea level it is likely that there was renewed sand-dune growth along both the Atlantic and Gulf coasts, and the major wind-blown sand deposits assumed in general their modern topographic expression.

RECENT EPOCH

The beginning of Recent time was marked by the climatic changes that brought about the withdrawal, through melting back, of the great Wisconsin ice sheets. The melt-water released from the continental glaciers partly refilled the oceanic basins, and sea level gradually rose. The rise must not be construed to have been uniform, for the climate is known to have been not uniform. Minor, but none-the-less effective, climatic fluctuations occurred that are revealed in several lines of evidence. Flint (1947, p. 487–535) and Brooks (1949, p. 359–378) have presented especially lucid and comprehensive accounts of the evidence and descriptions of post-glacial climates and their general geologic effects.

In southern Florida the sea level rose to, or very near, its present level and stood there until the interval known as the Climatic Optimum, which is believed to have occurred about 5000 B.C. (Brooks, 1949, p. 364). During the warm period, of which the Climatic Optimum was the peak, the sea rose to 5, and perhaps 8 feet, above its present level, and remained at this range of elevated stage for about 2,000 or 3,000 years, long enough to complete the carving of the wave-planed Silver Bluff Terrace (see pl. 13 and fig. 23), and to choke with sand the discharge channels through the Coastal Ridge as far south as Miami. During this time the entire present floor of the Everglades was a shoals area, situated between the low-lying Big Cypress-Devil's Garden area on the west and the Coastal Ridge to the east that stood out as a low series of islands and disconnected bars, as indicated by the Silver Bluff shoreline in pl. 13; Lake Okeechobee itself was an extension and slightly deeper part of this great shoal. The semi-diurnal sweep of the tides kept the floor of the shoal swept practically clean of what little sediment occurred there. The lack of marine sediment in such an environment is not at all surprising, because the surrounding low-lying limestone and quartz-sand terrain, under climatic conditions then existing, simply did not provide much detritus.

About 3,000 years ago, as the warm weather of the Climatic Optimum waned, the sea level began falling, and receded to its approximate present level, near which it has remained ever since. This resulted in the establishment, in essence, of our modern shoreline and its related topographic features.

In the great shoal area of the present Everglades, a fresh-water regimen replaced the salt and brackish water regimen of the Climatic Optimum, and in the deeper parts of the area, where the land was always submerged, plant remains accumulated until finally the peat and muck deposits of today were developed (p. 109). Gradually these materials accumulated over a greater and greater area, and as the basin became nearly filled, the water level rose, and some of the higher of the old tidal channels across the Coastal Ridge came into use as discharge channels; thus, modern natural drainage was effected. Short streams such as the Miami River, Arch Creek, New River, and many others established their modern form. The surface waters in the Everglades, slowly moving more or less as a sheet in high-water times and still more slowly in shallow channels in low-water times, came to flow toward these outlets. As they moved, the waters imposed a linearly arranged drainage pattern on the soft organic soils and flotant masses. Trees chose the higher of the areas between the "swales." and the "bays" or "tree islands" began to take form; sawgrass and the more aquatic plants chose the swales. (See the section on Geomorphology, p. 152–153).