LATE PLEISTOCENE GEOLOGY IN AN URBAN AREA

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Introduction

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The geology of South Florida presents a picture of a slowly subsiding plateau, warm tropical waters, and a great accumulation of carbonate sediments. The structure of the area is comparatively simple, but very difficult to examine. Almost all we know is based on cores from oil or artesian well drillings.

Investigation of the surface features combined with well studies have also shown that the geology is not as simple as it would appear. Subsidence must have virtually ceased near the end of the Miocene. The Tamiami Formation (Upper Miocene) outcrops some forty miles west of Miami, and represents either a long period of nondeposition in the area or the erosion of Pliocene sediments.

The Pinecrest, a sandy facies with shallow water fossils, appears to show a period of lowered sea level near the end of the Miocene. During much of Pliocene time, however, sea level was evidently considerably higher. The crest of the Tamiami Formation was then too deep to produce large amounts of sediments of biological origin, and probably supported a very sparse flora and fauna. The environment was probably similar to depths of around 100 feet or more off the west coast of Florida today. The water in this environment was crystal clear, but there was not much light due to depth. Much of the bottom was hard, and supported a scattered fauna of sponges and coelenterates (sea whips, small corals, etc.) Mollusks and echinoderms were the most conspicuous hard shelled motile organisms.

A more recent formation, the Fort Thompson, overlies the Tamiami in much of South Florida. It contains fossils of the modern South Florida fauna, and is apparently mostly Pleistocene in age. In the Miami area it is about 150 feet thick, but is much thinner to the north and northwest.

Overlying and forming a unit of the Fort Thompson in Dade County is the Miami Limestone. Although called the Miami Oolite for most of this century, Hoffmeister _et al_. (1967) have shown that this formation is made up of two units, a bryozoan facies and, overlying the southeastern part, an öolite facies. Fossils are rather rare in the öolite, and are mostly bryozoa in the bryozoan facies.

The Miami Öolite was formed during the Pamlico sea stand when sea level was approximately 23 feet higher than today. Students of sea level stands have found another, the Princess Anne, at 14 feet, and the Silver Bluff sea level was about 8 feet above the present sea level. We have not found the Princess Anne shore line in the Miami area, but the Silver Bluff can be seen along South Bayshore Drive.

The close of the Pliocene saw a vast change in ocean current systems. With the end of the Panamic Seaway, the Gulf Stream began, and a great warm current began to sweep by the southern end of Florida. This current and the lowering of sea level brought favorable conditions for coral reef development in what is now the Florida Keys. This formation, the Key Largo Limestone, interfingers with the Fort Thompson in the Biscayne Bay area, and is found under the surface deposits of the islands on the eastern edge of the bay.

This trip, then, will allow us to see Pleistocene equivalents of phenomenonal which are now taking place in the Recent sediments of the Bahamas. The main observable features will be those described from the Pleistocene of this area by Hoffmeister _et al_. (1967), and from the Recent of the Bahamas by Ball. Hoffmeister's Recent analogues are in the Bahamas sediment of today; Ball's Pleistocene analogues are to a large extent observable in the Pleistocene of South Florida. Both major studies are concerned with rock units whose recognizable criteria for interpretation of depositional milieu are very subtle and subject to very minor changes of environment and particularly, hydrologic conditions. These are the types of changes with which we are concerned in the Recent, and presumably also were in the Sangamon. They are instructive for a study of uniformitarianism over a short time basis; this is the single major advantage of this field trip.

The geology that we will see on our field trip may seem monotonous to those accustomed to seeing many formations revealed by erosion, faulting or other means. The clues to past events in the Miami area are concelaed by vegetation, urban development, and the nature of the sediments. It takes careful study to work out the history of the region, but the results are well worth the effort.

Carbonate Sand Bodies of Florida and the Bahamas

The following text and particularly the descriptions have been taken from a very excellent (and, indeed, award-winning) paper of the above title, written by Dr. Mahlon Ball of the Institute of Marine Sciences and published in the June 1967 issue of the Journal of Sedimentary Petrology. It is the purpose of this synopsis to present his main ideas on these subjects, stressing those features to be observed on this trip. Unfortunately we will not stop at any of Dr. Ball's type localities. The present writer feels, however, that many of Dr. Ball's phenomena can be seen at our stop locations. Such being the case, the danger of trying too hard to find the features sought for explanation may be real. Any failings of this kind are entirely to be blamed on the present writer.

Carbonate sand bodies are of four general types: 1) marine sand belts, 2) belts of tidal bars, 3) eolian ridges, and 4) platform interior sand bodies. Each is characterized by a rather unique set of properties including setting, geometry, internal structure, composition, and texture. All are indicative of depositional environments only a few feet below (or, in the case of eolian ridges, above) the strand line. Thus the fact that four distinct bodies do form is indicative of the fine degree of control of the various bottom topographic and hydrologic factors that determine the geometry, internal structure, composition, and texture of sand bodies.

Marine Sand Belts

Marine sand belts occur as linear features parallel to major slope breaks. They are formed by the predominant onshore movement of carbonate sand under the influence of currents which are themselves directed onshore by the vertical constriction exerted on waves moving onto the shallow slope. The best example of such a sand body is the belt of oolitic sand stretching from Cat Cay, Bahamas to the south, along the major slope break between the Florida Straits and the western edge of the Bahama Banks. While we will not observe this sand body, we will have occasion on several stops to view its Pleistocene equivalent, the oolitic Atlantic Coastal Ridge of southeast Florida. This equivalency of depositional environment has been stressed by Hoffmeister et al (1967) and will be discussed later.

The Cat Cay sand belt is about a mile wide and some tens of miles long. Adjacent water depths are about 10-15 feet, and parts of the belt are awash at low tide. There are several major external morphological features of the belt. The largest are ridges that trend at angles to the long axis of the belt, having amplitudes of some 10 feet and wavelengths of perhaps 3000 feet. Floridian Pleistocene analogues to these are the series of ridges and swales which can be seen to be trending generally northwesterly-southeasterly along the Atlantic Coastal Ridge, when viewed on the scale used in the USCGS chart series. Large spillover lobes rival the transverse ridges in size in the Cat Cay body. They are generally directed onto the Banks, bedding is convex upward (opposite to festoon bedding), and they nose out in steep foreset beds. These will not be seen in the Pleistocene equivalent. The transverse ridges and spillover lobes are controlled by the continuous onshore currents. Smaller features are common, ripples of medium size controlled by infrequent severe stroms, and smaller ripples controlled by daily tidal fluctuations. It is this constant tidal agitation of the grains in the $CaCO_3$- supersaturated water which allegedly causes the well-developed oolitic coatings.

Internal structure of the tidal bars has been studied; generalizing, the mean cross bed dip direction is perpendicular to the sand body trend. The cross-beds are well developed in the upper part of the sand body, and indicate deposition under shallow water conditions where current and wave agitation were strong and frequent enough to overcome any effects of organic burrowing. At places, sets of cross beds show a striking erosional beveling, no doubt a function of the periodic exposures at low tide mentioned earlier.

Cross bedding will be seen to excellent advantage at Stops 2, 5, and 6.

Compositionally and texturally, the upper zones of the sand belts are virtually pure oolite. The oolites typically show most of their diameter to be composed of very numerous discrete laminae, i.e. they are true oolites as opposed to 'pseudo-oolites' a term preferred by some to make the distinction between grains with only a single or several thin coating layers. The oolites are well sorted and medium grained. In the Pleistocene outcrops we will be examining, they are bound together by a cement of sparry calcite, formed when the oolite sand body was exposed to the subaerial environment. At the various stops mentioned, break off pieces of the oolite and examine them under the hand lens. Various degrees of diagenetic alteration may be seen. In some cases, the oolites are only rim-cemented together loosely, while in other cases the aragonitic oolites have been leached out, leaving only calcite cement, an "oomoldic porosity". Indeed, Robinson (1967) has described 7 different diagenetic stages within the oolitic facies of the Miami Limestone. This should be considered by those who tend to overemphasize the relationship between age and stage of diagenesis.

Underlying this well-bedded clean oolite, and still part of the same marine sand bar sequence, is a burrowed sand, which contains some oolitically coated grains, except the degree of oolitic coating is less complete. Sorting is poorer, and there is a high percentage of fine pelletoidal sand. Burrows of Callianassa and Upogebia are commonly preserved as positive features, perhaps because of the effect of organic material on cementation. This lower, non-bedded sand unit contains a sparse megafauna of pelecypods and gastropods, with some forams. Locally, pelecypod assemblages consist of large number of small individuals of a single species.

Excellent contacts between the bedded oolitic and non-bedded oolitic-skeletal subfacies of the marine sand belt will be seen at Stops 2 and 6.

Tidal Bar Belts

Tidal bar belts are similar to the marine sand belts in that they also develop at a relatively steep slope break. They differe in gross morphology, however, in that they are broken into a series of digitate bodies at roughly right angles to the main trend of the total feature, which parallels the slope break. The reason for this is a greater current velocity, set up on a tidal cycle. In Dr. Ball's type area, Schooner Cays at the northern terminus of Exuma Sound, these currents attain some 3 knots and are a result of the tidal currents being of the same frequency as the natural standing waves of this closed embayment. Internal structure and composition of the tidal bar belts are about the same as those of the oolite sand belt in the Cat Cay area, except now the well-developed crossbeds dip perpendicular to the digitate cusps, rather than to the strike of the major feature.

Tidal bar belts will not be seen on this trip, but the Safety Valve area of the flats of Biscayne Bay, just south of Stop #4, offers an example of such a phenomenon as the Schooner Cays, but on a smaller scale. Also, the southern Florida Keys are Pleistocene equivalents of tidal bar belts. These are the islands from Big Pine Key to Key West, which are elongated normal to the prevailing trend of the Keys, and which are composed of relatively pure oolite, as opposed to the Key Largo Limestone reef facies of the northern Keys.

Eolian Ridges

Eolian ridges are merely accumulations of submarine-derived carbonate particles which have been pushed up into dunes under the influence of prevailing onshore winds. Thus with a slight drop in sea level, the submarine sand accumulation mentioned earlier would be available as source material for dune construction. Composition reflects the composition of the source - hence the dunes of the eastern Bahamas are almost wholly oolitic, while those of non-oolitic areas, such as Bermuda, are almost entirely biogenic. In some cases low fossil dunes are difficult to distinguish from submarine bars, but in other cases such criteria as intercalations of fossil soils, fossil root casts, characteristic paper-thin cross laminae, and pulmonate gastropods such as Cerion are quite diagnostic. The matter will not be pursued further here, since fossil dunes will not be seen on this trip.

Platform Interior Sand Bodies

These extensive sand blankets occur in the lee of the sand belts and tidal belts, hence are of a lower energy environment. Burrowing is extensive. In some cases individual burrows may be preserved, in other areas burrowing has been so thorough as to obliterate individual burrows. In these cases, only the orientation of long axes of grains at all directions to be depositional horizon may be indicative of the burrowing. In the fossil record these sand bodies are generally thickly bedded (some 2 or more feet) and may be marked by lag horizons marking particularly severe storms or by cemented horizons formed under either submarine or subaerial conditions. Compositionally and texturally, platform interior sand blankets may vary within wide limits. Commonly they are poorly sorted, may contain a significant mud fraction, and may contain a significant macrofauna.

The bryozoan limestone facies of the Miami Limestone may be considered a platform interior sand body in that it lies in the lee of the Atlantic Coastal Ridge submarine oolite sand belt. This also is true of the Recent in the Bahamas, where an abundant bryozoan lagoonal deposit lies east (leeward) of the Cay Cay oolite bar. The fossil analogue will be examined and sampled at stops 7 and 8, and is described in detail in the paper by Hoffmeister, also in this Guidebook.

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Fossil Mangrove Reef of Key Biscayne, Florida

Abstract: A small rock reef, extending along the northeastern shore of Key Biscayne, Florida, for a distance of about 400 yards and seaward for 115 yards, has been found to be composed of a framework of fossilized mangrove roots belonging to the black mangrove, ***Avicennia nitida***. The roots, now turned into calcareous rods, are embedded in a friable calcareous-quartzitic sand which may be quickly washed away by wave action along the seaward edge of the reef. In this manner, a lattice of roots in their original position is exposed. It is believed that this may be the first reported occurrence of the fossilization of mangrove roots. Radiocarbon dating indicates the age of the rods to be between 1000 and 2000 years.

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INTRODUCTION

The geologic work of mangroves in creating land has long been recognized. Writers in many parts of the world where mangroves are found have described the sequence of events leading to the extension of land areas by these plants. The region of the southern tip of Florida, including the Florida Keys, Florida Bay, and the Ten Thousand Islands of the west coast offers excellent examples of this action. Vaughan's (1910) account of the events which lead to the formation of new land in this manner is one of the best of the older writers. It was his belief (p. 464) that mangroves "... are among the most important constructional geologic agents of southern Florida," and he estimated that one-third to one-half of the total area of the Florida Keys is occupied by them.

This type of geologic work is due to the thick tangle of roots which catch and hold sediments and other types of floating debris, organic and inorganic, until a mound of accumulated material is built up to and above sea level. The inference has been that the mangrove roots act merely as a catchment mechanism and add little, if anything, to the substance of the new land itself, since the woody material disintegrates and eventually disappears entirely.

This paper records a different type of geologic work of mangroves: the transformation of the roots and pneumatophores of a species of the plant (*Avicennia nitida*) into indurated rock material, which at present forms a reef on the northeast tip of Key Biscayne, Miami, Florida. Thus the roots not only serve as collecting agents of extraneous materials, but are themselves turned into hard rock. In other words, reefs of fossil mangroves may develop under certain conditions.

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DESCRIPTION OF REEF

The sand beach which fringes the northern tip of Key Biscayne is bordered on its eastern side by a small rock reef (Pl. 1, fig. 1; Fig. 1). This adjoins the passage known as Bear Cut which separates Key Biscayne from Virginia Key. The total width of the reef as measured along the shore is about 425 yards, and it extends seaward for a maximum distance of 115 yards. It presents an irregular and jagged outer edge, as can be seen from the diagram (Fig. 2). Its surface, although originally smooth, is now rough and contains numerous shallow pits and basins where solution and boring organisms have worn through a crust averaging about 3 inches in thickness. Some of the pits are only a few inches in diameter, and others are several feet. They become enlarged and elongated by gradual encroachment on each other; some attain a length of 75 feet and a width of 10 feet.

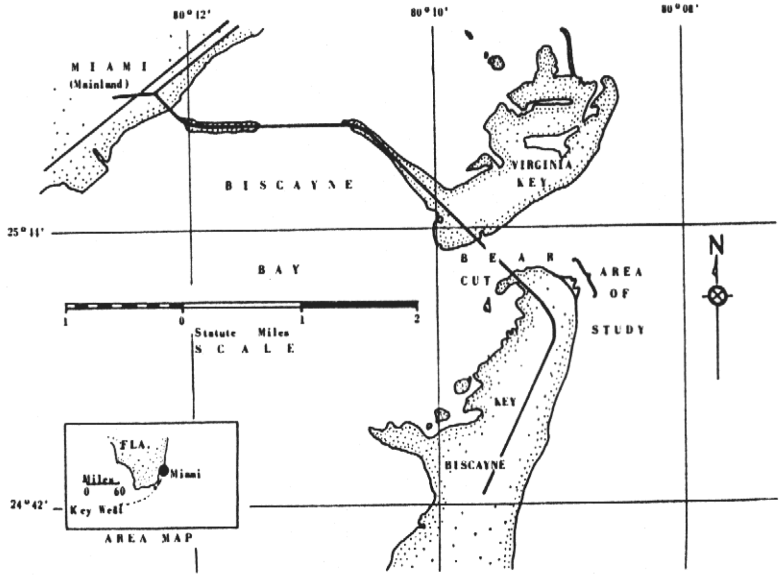

Figure 1. Index map of Biscayne Bay and Bear Cut, Florida, showing location of mangrove reef

Figure 1. General view of reef at low tide, looking north

Figure 2. Edge of reef showing lattice structure made by horizontal and vertical rods

MANGROVE REEF OF KEY BISCAYNE, FLORIDA, AT LOW TIDE

Figure 1. Black mangrove with roots exposed at low tide

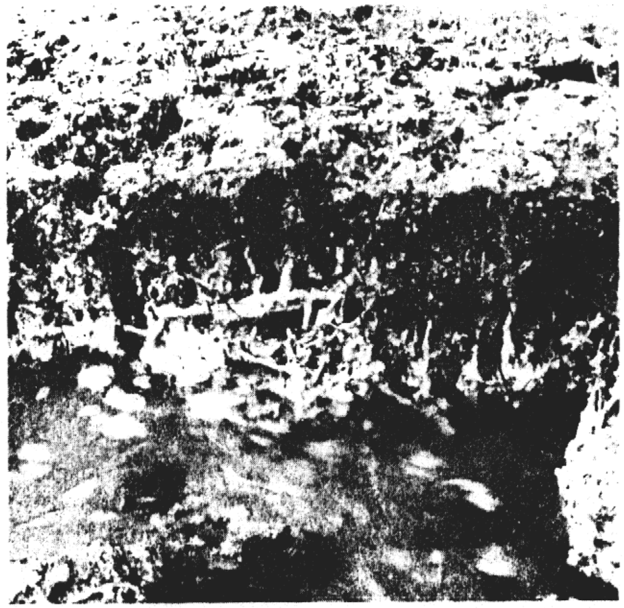

Figure 2. Edge of reef showing platform and rods after sand has been removed by wave erosion

COMPARISON OF LIVING BLACK MANGROVE ROOTS WITH FOSSIL ROOTS OF REEF, KEY BISCAYNE, FLORIDA

The reef platform is barely awash at high tide, and at low tide the reef face is exposed along its edge for a height of about 2 feet. This exposure reveals an interesting and unusual rock formation. Beneath the crust cylindrical rods, averaging about half an inch in diameter, extend downward a few inches to 1 foot or more. Many are attached at their lower ends to a layer of horizontal rods which can be traced along the exposure for several feet. Other vertical rods extend downward from the horizontal rods until they reach a lower layer of the latter. The waves breaking against the exposed cliff face quickly remove the soft sand and etch out the harder rods. The result is the formation of porous reef rock with large cavities, such as those shown in Figure 2 of Plate 1 and Figure 2 of Plate 2. The porous rock is thus limited chiefly to the areas which have been affected by wave action. The remainder is a soft sand formation with the embedded rods.

The reef itself is being eroded very rapidly. It is evident from its irregular edge that some parts are eroding much faster than others. This

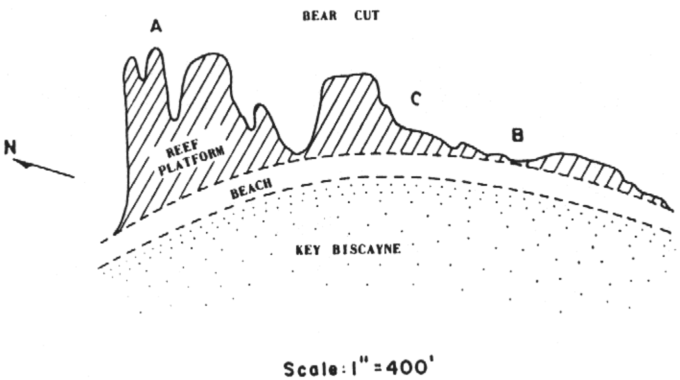

Figure 2. Diagrammatic sketch of the mangrove reef, Key Biscayne, Florida

In most exposures only one layer of horizontal rods is visible, but in some two or even three are present for limited distances (Pl. 1, fig. 2).

Most of the vertical rods are separated from each other by an average distance of 1.5 inches, but others may be joined together to form multiple rods. In general, it can be said that the horizontal rods, some of which are 2 inches thick, have a greater diameter than those which run vertically. This unique rock structure results in an irregular lattice at the outer edge of the reef and a veritable forest of rods inward from the edge.

In places where the reef is only a few feet wide, such as at *B* in Figure 2, the part played by wave erosion in producing the structure described heretofore can be easily observed at low tide. Here it is clear that the rods are embedded in a friable sand deposit (Table 1). In other words, the rods are an integral part of the sand formation which is topped by the hard reef platform or crust. The waves breaking is due to the fact that the platform and rods in such places as *A* in Figure 2 have been protected and hardened by coatings of barnacles, worms, and algae. Once these gain a foothold the erosion is greatly retarded. The barnacles form a solid veneer on the surface and sides of the platform. The chief species is *Tetracleta squamosa*, although *Balamis amphitrite*, *Chthamalus stellatus*, and *C. fragilis* are also present.

Marine algae cover the rods, and although they are not as effective as the barnacles in impeding erosion, they undoubtedly are a significant factor in this action. One of the most important algal deterrents is the red *Centroceras clavulatum*. *Gelidium corneum* and the green alga, *Ulva lactuca*, are less important. The surface of the platform in many places is covered by a species of the green algae *Enteromoplia* with long grasslike blades. The speed at which the algae settle on the rods is worthy of note. It is estimated that within 2 or 3 hours algae can be observed on the newly exposed

rods, and that within a day the latter have become covered in many places with a dense coating of the red algae.

In places, such as *B* in Figure 2, where the platform is not protected by encrusting animal and plant life, the reef is eroding at the alarming rate of about 6 feet per month.

An examination of the reef platform or crust reveals that it is composed of a basal framework of horizontal rods embedded in a matrix of calcareous sandstone (Pl. 3, fig. 2). More horizontally placed brown and black, partly decayed root material, counterparts of which can be traced to local living vegetation, and woody tubes, 0.5–8 mm in diameter, either hollow or filled with secondary calcite.

COMPARISON OF RODS AND ROOTS OF MANGROVES

The origin of this reef has for some time been a matter of interest and speculation. The realization by the writers that the shape and

TABLE 1. PARTIAL CHEMICAL ANALYSES (IN PER CENT) OF COMPACT SAND FROM BETWEEN BURIED RODS AT INDICATED DEPTHS BELOW BASE OF REEF PLATFORM, LOOSE SURFACE BEACH SAND, AND SAMPLES OF CALCAREOUS "PASTE" FROM WITHIN INDURATED, INDIVIDUAL RODS

Samples taken from points B and C (Fig. 2) along edge of exposed reef rock. Balance of each sample analyzed consists dominantly of organic material, moisture, and salts. Analyses by O. Joensuu, Institute of Marine Science, University of Miami, Florida

Sample	Depth below base of platform (inches)	Location	Total $CaCO_3$	SiO_2	SrO	MgO	Fe_2O_3
Sand	0.5–4	B	19.5	65.0	0.14	0.9	0.09
Sand	4–10	B	35.0	62.0	0.16	0.6	0.25
Sand	4–8	C	23.0	72.0	0.095	0.35	0.3
Loose beach sand		C	24.8	72.0	0.095	0.35	0.16
Paste	6–12	B	60.5	10.0	0.12	0.8	0.16
Paste	1–4	B	70.4	13.0	0.11	0.76	0.192
Paste	4–8	C	64.7	20.0	0.25	1.1	0.10
Paste	12	C	70.0	20.0	0.12	1.5	0.08

specifically, the sandstone is a very pale orange (10 YR 8/2)[1], firm to poorly friable calcareous sandstone consisting of fine, subangular quartz grains in a dense calcareous matrix (Table 1). Insoluble residues show an average of 60 per cent quartz grains and a small amount of organic scum.

The horizontal rods are found concentrated mostly in the lower third of the platform. The rock also contains a highly variable amount of calcitic tubes of plant and animal origin which range in diameter from 0.5 mm to 8 mm and which are predominantly filled with calcite. Orientation of the tubes within the platform rock is highly variable, but for the most part they are parallel to the reef surface.

Evidence of recent plant and animal action is also present, mostly in the upper part of the platform. Here are found matlike masses of

[1] Numbers in parentheses refer to the Rock Color Chart, available from The Geological Society of America, Inc.

arrangement of the rods were superficially similar to the roots and pneumatophores of a type of mangrove led them to examine this lead in more detail (*see* Pl. 1, fig. 2; Pl. 2; Pl. 3, fig. 1).

Four species of the plants are associated in mangrove swamps in southern Florida. The commonest is the red mangrove *Rhizophora mangle* with its distinctive "prop" roots. The black mangrove *Avicennia nitida*, the white mangrove *Laguncularia racemosa*, and the buttonwood *Conocarpus erectus* are also well known. It was soon evident that the roots of *Avicennia nitida* are identical in shape, size, and arrangement to the rods of the reef. *A. nitida* grows, in general, slightly landward of *Rhizophora mangle*.

The adult *Avicennia nitida* possesses several types of rootlike structures, three of which are important in this study (Fig. 3). At about the level of high tide or lower, a ring of lateral roots extends outward from the trunk, similar to the spokes of a wheel. These may be as

Figure 1. Living black mangrove showing lateral roots and pneumatophores

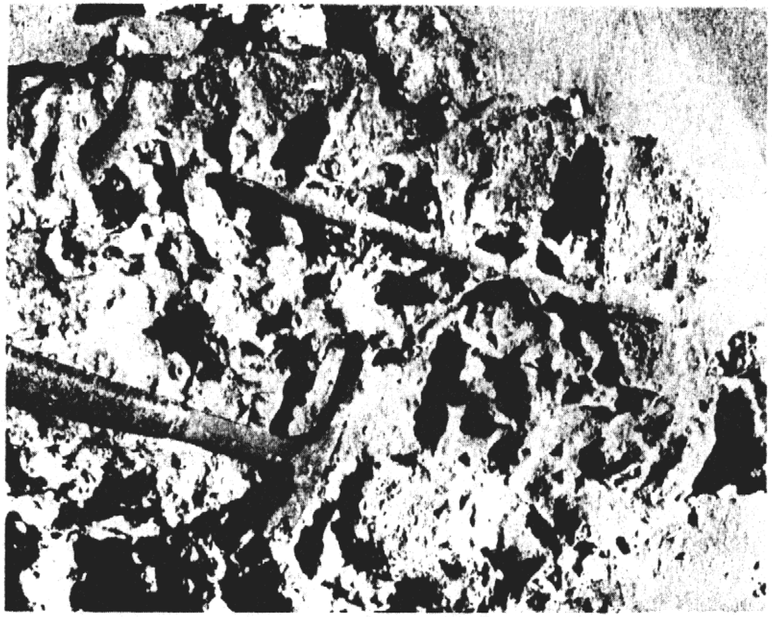

Figure 2. Surface of reef platform showing horizontal rods

LIVING AND FOSSIL ROOTS AND PNEUMATOPHORES, KEY BISCAYNE, FLORIDA

HOFFMEISTER AND MULTER, PLATE 3
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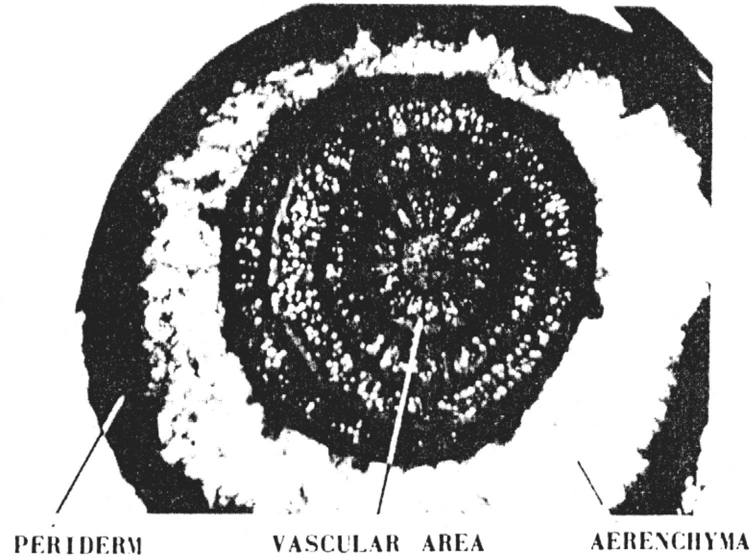

Figure 1. Cross section of pneumatophore of black mangrove (× 10)

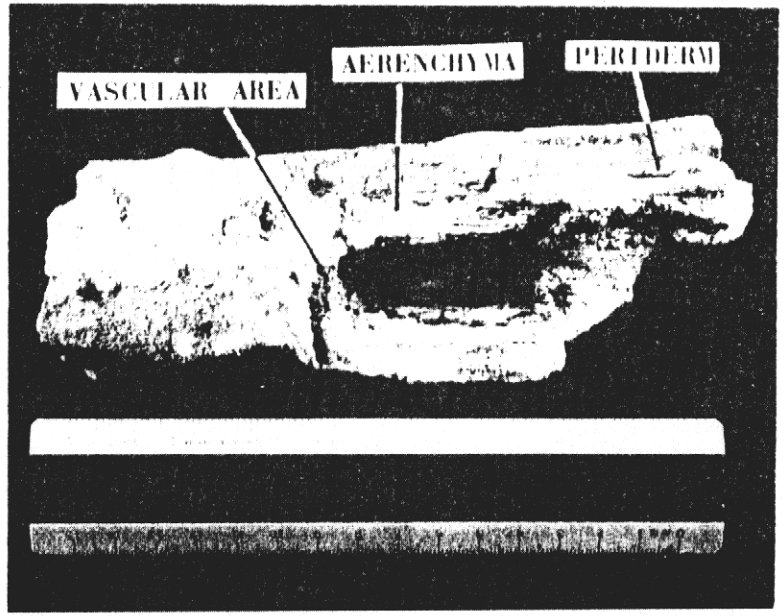

Figure 2. Fossil lateral root of black mangrove of Key Biscayne reef

COMPARISON OF CROSS SECTION OF PNEUMATOPHORE OF LIVING MANGROVE WITH INTERNAL STRUCTURE OF FOSSIL ROOT

HOFFMEISTER AND MULTER, PLATE 4
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much as 15 feet long, tapering slightly toward their tips and branching dicotomously at infrequent intervals. For most of their length they are embedded under several inches of sand or mud. From these grow rows of pneumatophores, which extend above the surface of the ground and which probably aid in plant aeration (Pl. 3, fig. 1). The pneumatophores average about 10 inches in length and are spaced along the horizontal roots at intervals of about 6 inches. Extending downward from the lateral roots are geotrophic roots spaced about the same distance from each other as are the pneumatophores. The geotrophic roots branch near their tips, giving rise to thin branchlets which are used for anchoring and absorbing. They are about the same size as the pneumatophores except that they may be somewhat longer.

The structural similarities between the roots of a living *Avicennia nitida* and the shapes and arrangement of the rods of the reef may be summarized as follows:

(1) Rods are similar in size to roots.
  a. Vertical rods are equivalent in size to the pneumatophores.
  b. Horizontal rods are larger than vertical rods and equivalent in size to lateral roots.
  c. Some horizontal rods are as much as 2 inches in diameter and equivalent in size to some of the larger lateral roots. Rods of this size have not been found in a vertical position.
(2) Rods are similar in shape to the roots and pneumatophores.
(3) Rods and roots are placed about the same distance apart.
(4) Roots, as is usual in plants, give rise to smaller roots. The same applies to the rods.
(5) Lateral roots extend from the tree trunk at certain definite levels. Horizontal rods are also concentrated at specific levels.
(6) Lateral roots give rise to the pneumatophores and geotrophic roots. The same condition can be seen in the rods.

MICROSCOPIC DESCRIPTION OF THE ROOTS OF *AVICENNIA NITIDA*

A cross section of a pneumatophore is shown in Figure 1 of Plate 4. The parts with which this study is chiefly concerned are the periderm, the cortex, and the vascular area.

The periderm, or hard outer coating, is made of several layers of small, closely packed cells. The number of layers varies with the age—fewer near the tip (the younger area) and increasing to 20 or more near the base.

The cortex is composed of twisting, serpentine chains of small cells. The chains join each other at intervals, enclosing spaces which may be wider than the chains themselves, and producing a porous meshwork. This type of cortex, known as aerenchyma, is believed to serve in the aeration of the plant. It is spongy in texture and is the softest part of the section.

The vascular tissue, used as a conveyor of plant fluids, occupies the space between the aerenchyma and the center. It is composed of several layers of cells surrounding a core or pith. The cells are closely packed and result in a relatively firm substance.

In general, the make up of the lateral roots and the geotrophic roots is similar to that of the pneumatophores. The chief differences are that the periderm of the lateral roots is thicker than that of the others and that the vascular system is greater in diameter in proprotion to the aerenchyma.

MICROSCOPIC DESCRIPTION OF THE RODS AND COMPARISON TO MANGROVE ROOT STRUCTURE

The rods consist of a rim enclosing a softer carbonate "paste" interior. The rim is hard and is composed of subangular, fine to very fine quartz grains with a limited amount of calcite grains, unidentified dark-brown organic material, and mollusk and algal fragments in a cryptocrystalline calcite bond. Insoluble residues show an average of 55 per cent quartz grains plus some organic scum. Small voids within the hard rim are lined with crystals of secondary cryptocrystalline calcite.

Within the rim of the rod is a white homogeneous "paste" composed of calcium carbonate with a trace of fine-grained quartz and organic matter. This paste is soft and plastic when wet and hard and crumbly when dry. A freshly broken longitudinal cross section through the center of the rod in places shows a series of roughly parallel, undulating ridges and grooves in the dry carbonate "paste" core.

The nature of the structure of the rods is best illustrated by an unusually large specimen of a horizontal rod found about 12 inches below the surface of the reef platform (Pl. 4, fig. 2). This rod measures 2.5 inches in diameter and is of unknown length. In cross section three distinct areas can be seen—a hard outer layer or

rim, and two inner layers. The rim is about half an inch in thickness and corresponds in petrology and texture to the description given heretofore. Immediately within and adjoining the rim is a layer of white calcareous paste about half an inch in thickness. This is a porous structure, with the general flow of the texture running parallel with the long axis of the rod. It is believed that this texture is largely primary, *i.e.*, owing to the character of the original material of the rod. It is also known that it has been subsequently affected by the action of boring animals and plant roots. Many round and flattened tubes 0.2-1 mm in diameter run parallel with the long axis of the rod and are composed of cryptocrystalline calcite, with concentric rings of dark-brown organic material outlining each tube. Most are hollow and show secondary calcite crystals lining the voids.

A second inner layer occupies the central section of the rod and is about one-quarter inch thick. It is similar petrologically to the outer white layer but differs in several respects: It is somewhat darker in color and more compact, less porous, and with fewer tubes.

It is clear that there is much similarity between this rod and a root of the mangrove. Although it is made chiefly of calcite it possesses the woody texture of the plant. In addition the three major components of the root—periderm, aerenchyma, and vascular system—can be recognized in the rod.

The hard outer layer or rim of the rod is equivalent to the periderm of the root, although it is considerably thicker than the latter. The first inner layer has a remarkable likeness to the cortex or aerenchyma of the mangrove root. It has the same general texture and degree of porosity. The second inner layer or central section of the rod is similar to the vascular section of the plant. Like the latter it is tighter, less porous, and somewhat darker than the aerenchyma.

Microscopic examination of thin sections of the internal parts of the rods have failed as yet to reveal any cellular structure. Apparently the woody cells of the original plant have been obliterated during the process of fossilization.

AGE OF THE REEF

The age of the fossil roots and pneumatophores and of the enclosing sand, obtained by

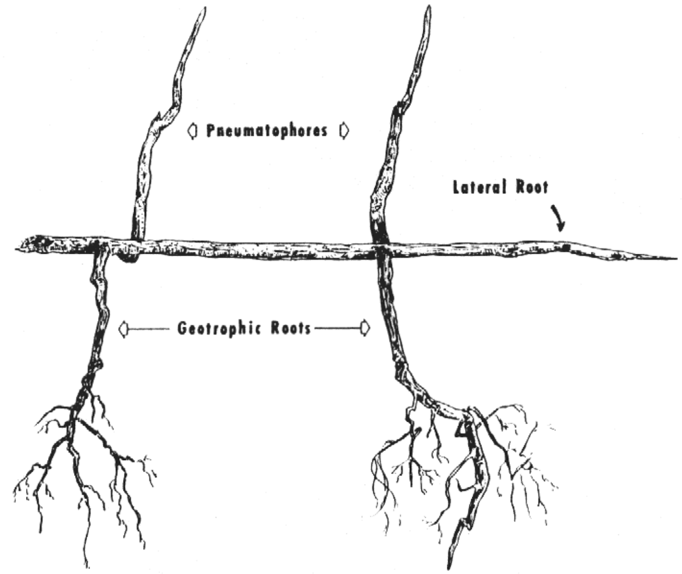

Figure 3. Basic root structure of *Avicennia nitida*

the radiocarbon method, is of considerable interest. Samples of the calcareous "paste" from one of the rods yield an age of 1960 ± 180 years, and from another, 1000 ± 140 years. On the other hand, one sample of the carbonate fraction of the sand indicates an age of 6020 ± 180 years, and another of 5690 ± 200 years. Consequently the sand, as might be expected, is considerably older, by three or more times, than the rods. Both, however, are relatively young as compared to the Pleistocene limestone upon which they rest.

SEQUENCE OF EVENTS

It is believed that the exposed reef rock as described in this paper is a remnant of a swamp of black mangroves which at one time extended seaward beyond the present edge of the reef and landward over at least the northern part of what is now Key Biscayne.

The substrate in which the roots were embedded was a calcareous-quartzitic sand of the intertidal zone. The trees were subsequently destroyed, and the woody material of the buried roots subjected to slow decomposition. This action released CO_2 which combined with available water, forming H_2CO_3. This in turn dissolved calcite and produced calcium carbonate-bearing solutions which percolated through the pore spaces of the sand.

Reprecipitation of $CaCO_3$ in the sand immediately adjacent to the rotting root cemented quartz grains together, forming a hard cylindrical rim around the root. This slowly grew outward as the action continued and resulted in a coating considerably thicker than the original periderm. At the same time continued decay of the organic material, surrounded by the hard but still porous rim, provided an environment for calçification within the woody structure and for replacement of the tissue itself by $CaCO_3$.

It is difficult to determine the exact cause of precipitation of the $CaCO_3$. It is believed, however, that microbial action was a significant factor in the process. Sisler (1962, p. 68, 69) discussed the various hypotheses for bacterial precipitation of $CaCO_3$. He endorsed (p. 69) the views of Bavendamm (1932) that no single species of bacteria could be solely responsible for $CaCO_3$ precipitation but "... that bacteria may be considered as biochemical agents which influence the carbon dioxide and calcium equilibria in a variety of ways, depending on the environment." He also inclined (p. 68) toward Bavendamm's (1932) conclusion "... that if sulphate-reducing bacteria should play a key role in the precipitation of $CaCO_3$ their main scene of action would be the mangrove swamps."

Oppenheimer (1964, personal communication) inspected the fossil mangrove reef of Key Biscayne and found that the H_2O saturated sediment is anaerobic a few millimeters below the surface and that H_2S and black hydrotroilite are present. It is possible that microbial activity during the decomposition of the roots altered the chemical condition of the area surrounding the roots, producing the necessary change in carbonate equilibrium through pH transition which resulted in the precipitation of the $CaCO_3$. Such pH changes have been shown to occur between aerobic and anaerobic environments (Oppenheimer and Kornicker, 1958).

GEOLOGICAL IMPLICATIONS

The following results of the study are worthy of mention:

(1) Mangroves themselves do not adapt easily to fossilization, and it may be that this is the first time they have been reported in this condition. Bowman (1917, p. 666) who has written one of the most authoritative papers on mangroves, reported, "... it may be well to state that there are no fossil evidences of mangroves, but this is only to be expected, since the conditions of a mangrove swamp are very favorable to decay on account of the heat and the very large numbers of bacteria of all kinds in the water and swampmud." He further stated (p. 666), "The water here has no preservative action on woody tissues, such as the water of peat formations," and concludes that this, aided by the erosive activity of small marine animals, results in the disintegration of the organic material.

Although Bowman seems to have included all mangroves in his comments, his paper dealt primarily with the red mangrove, *Rhizophora mangle*. It is true that the red mangrove, although it must have grown in close proximity to the black mangrove which made the rods, has never been recognized as a fossil in this reef. In other words, it would seem that of the two, the black mangrove alone is capable of fossilization under the conditions which produced the reef. It should, however, be noted that the white mangrove, *Laguncularia*, which is structurally somewhat similar to the black, may have had a small part in its formation.

(2) The fact that the woody material of the

roots of some mangroves is capable of being converted into a rock substance opens up the possibility that other marine and brackish water plants of similar organic structure might do likewise. For example, rock structures which are of doubtful origin and which have tentatively been assigned to worm tubes and burrows of various animals may actually have originated in some type of marine vegetation.

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Miami Limestone of Florida and Its Recent Bahamian Counterpart

Abstract: The Miami Oölite, named by Sanford (1909) for the oölitic limestone of Pleistocene age which covers a large part of the southern tip of Florida, has been found to consist of two separate units—an upper unit, herein designated the oölitic facies, and a lower unit, called here the bryozoan facies. In this paper the two units are combined as the Miami Limestone,[1] a formational name which now seems more appropriate than the Miami Oölite. The bryozoan facies, the dominant constituents of which are massive compound colonies of the cheilostome bryozoan *Schizoporella floridana* Osburn surrounded by ooids and pellets, covers the greater part of Dade County and extends in places into adjoining counties—a total area of about 2000 square miles. It averages 10 feet in thickness in southeastern Florida and thins to 1 foot or so westward to the Gulf of Mexico. It is the surface rock of the southern Everglades and is one of the most extensive bryozoan limestones in the country. In southeastern Florida it is covered by an elongated mound of cross-bedded oölitic limestone, the upper unit or oölitic facies. This is the rock of the southern end of the Atlantic Coastal Ridge, with a maximum thickness of 35 feet under the Ridge summit thinning westward toward the low-lying Everglades as it encroaches over the bryozoan facies.

Interest in the origin of the two units has been heightened recently by the recognition of similar deposits that are being actively produced in a nearby area. Immediately east of Miami on the western edge of the Great Bahama Bank, strung in a north–south line, are the islands of Bimini, Cat Cay, Sandy Cay, *etc.*, the region described by Newell and others (1959). East of the Cays and parallel to them, a large underwater mound of unstable oölite is forming, and east of the mound in the shallow lagoon, massive, tubular bryozoans (*Schizoporella floridana* Osburn) are growing. The oölite from the mound is slowly encroaching over the bryozoan beds. The bathymetric and ecologic conditions now extant in this area are probably similar to those which existed during the Pleistocene to form the units of the Miami Limestone.

The eastern slope of the unstable oölite mound of the Cat Cay and Sandy Cay area is cut by tidal channels which run normal to the direction of the mound itself. Narrow valleys, similar to these channels, can be found in the indurated rock of the oölitic facies of the Atlantic Coastal Ridge. The valleys probably had their origin as channels produced by tidal currents at the time the oölitic mound of the Ridge was in an unstable condition. It is also believed that the shape and orientation of the Lower Keys of Florida originated in a similar fashion.

[1] The Miami Limestone refers to the formation which has been called the Miami Oölite by previous writers.

CONTENTS

Geological Society of America Bulletin, v. 78, p. 175–190, 5 figs., 6 pls., February 1967

INTRODUCTION

The large area of oölitic limestone of Pleistocene age which occupies the southern tip of the Florida peninsula was named the Miami Oölite by Sanford (1909, p. 211–214). It is the most prominent stratigraphic unit of southeastern Florida. Upon it are located the main cities of the area, including Fort Lauderdale, metropolitan Miami, and Homestead. In addition, it underlies the extensive area of the southern Everglades. Sanford's original description, although brief, covers the essential points which could be discerned at that time. Later workers have considerably increased our knowledge of the formation in dealing with the region as a whole, but no careful study of the unit *per se* has ever been made.

This paper calls attention to several important features of the rock which hitherto have not been reported. The writers have determined that the formation possesses two distinct units. The purpose of the paper is to describe these units and outline the conditions under which they were formed. One rather unique aspect of the study was the realization that similar rocks are now being formed in an area in the nearby Bahamas and that the conditions now existing there must be nearly identical to those which prevailed in southern Florida during the late Pleistocene.

The Miami Oölite is located in the southern part of the topographic division originally described by Cooke (1939, p. 14) as the Coastal Lowlands. Several subdivisions of this area were later created by Parker and Cooke (1944, Pl. 8), and in these the oölite occupies large areas of the Atlantic Coastal Ridge, the Everglades, the Sandy Flats, the Coastal Marshes and Mangrove Swamps, and a smaller section of the Big Cypress Swamp.

The highest, and therefore the most prominent, subdivision, the Atlantic Coastal Ridge (Fig. 1), borders the Atlantic shore as a narrow ridge with a smooth to slightly undulating surface. For most of its length this ridge has a surface of indurated rock although it is veneered in places by Pleistocene sands as far south as Miami. North of Boca Raton, which is 34 miles north of Miami near the border of Palm Beach and Broward counties, the bedrock is the sandy limestone of the Anastasia Formation. South of Boca Raton and extending to the point where it disappears southwest of Homestead, its surface is the Miami Oölite.

The highest point on the Atlantic Coastal Ridge in the Miami Oölite section is about 24 feet in the Coconut Grove area of Miami. From the ridge, the land slopes eastward to the nearby Atlantic and westward more gently to the Everglades. The low, broad expanse of the Everglades is about 10 feet above sea level in southern Broward County and drops imperceptibly southward to a 5-foot level in Dade and Monroe counties. This large, flat area with its cover of muck, organic soils, and calcareous muds is underlain by the Miami Oölite.

The geologic map of southern Florida (Parker and others, 1955, Pl. 4) outlines the territory covered by the Miami Oölite. Figure 1 is a somewhat modified version of the map. The chief difference is the inclusion of an area along the southwest coast between Cape Sable and Lostmans River.

There are numerous outcrops of the formation, and the most prominent natural exposures are along the Atlantic Coastal Ridge. Probably the most famous of these is at Silver Bluff (Fig. 1, between Stations 205 and 206) in Coconut Grove, bordering Biscayne Bay, where a wave-cut bench about 8 feet above mean sea level has been cut in a cliff of the cross-bedded oölite. Numerous canals and road burrows have been cut in all directions across the Everglades, especially along the eastern side. Many reach the sea through the Coastal Ridge. The high spoil banks lining the canals afford excellent opportunities to examine the bedrock to depths of 15 feet or more below sea level. In addition, numerous quarries, some as much as 30 or 40 feet in depth, are scattered over the terrain. Even in the undisturbed sections of the Everglades Na-

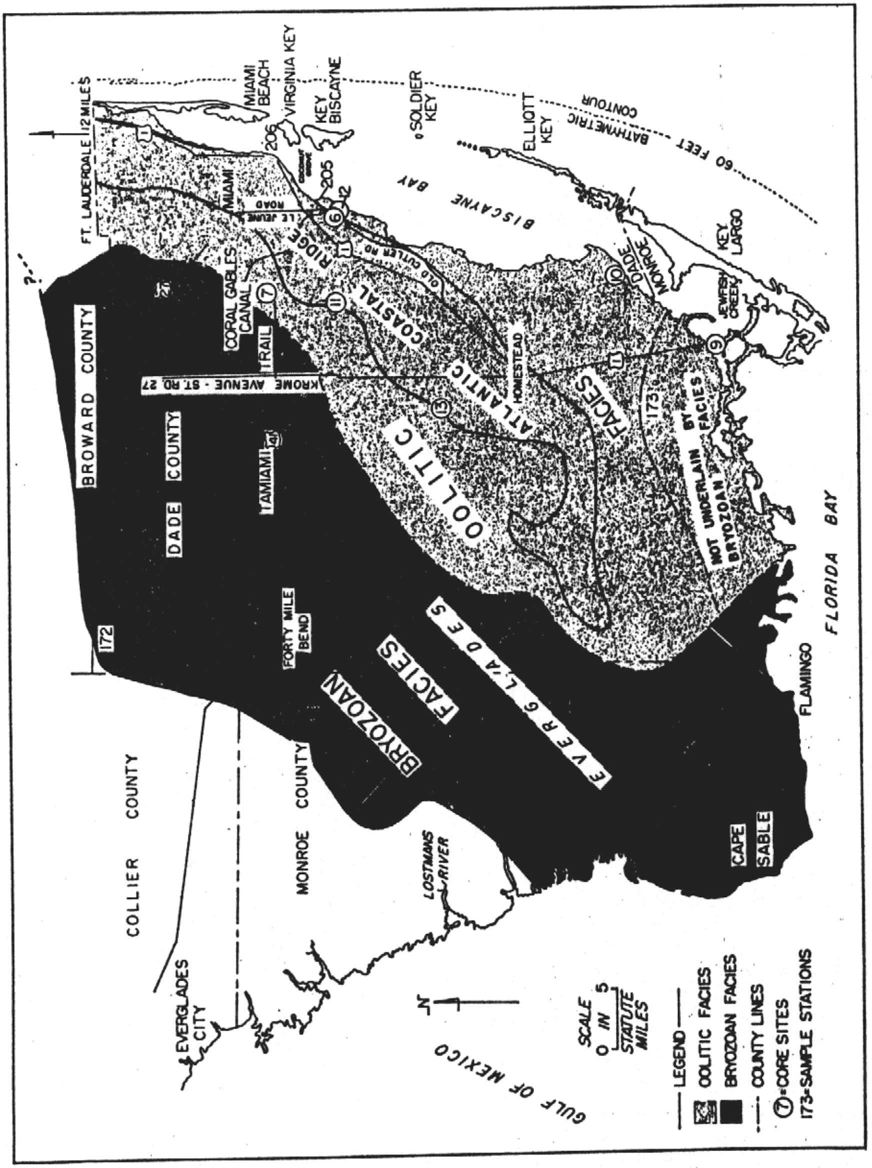

Figure 1. Main physiographic features and geology of the southern tip of Florida showing area underlain by the oölitic facies and bryozoan facies of the Miami Limestone. The oölitic facies covers the bryozoan facies except for the southern border as outlined.

tional Park many patches of bedrock appear a few inches above the soil. Only in the mangrove swamp sections of the south and southwestern shores are outcrops difficult to locate, but even here bedrock can be discovered at depths of 3 feet or so below low tide in some of the many small creeks which drain the glades.

Examination of the Miami Oölite of the Coastal Ridge in the Miami area shows that it is made of two rather distinct units. An upper part includes the typical, locally well-known cross-bedded oölitic rock such as that exposed at Silver Bluff. Here it has a maximum thickness of 34 feet, and its base reaches to about 10 feet below sea level. Beneath it lies a unit, about 10 feet thick, which contains large numbers of massive tubular bryozoans in an oölitic and pelletoidal matrix. Although both units are oölitic, they are sufficiently different to be considered as separate facies of one formation. Accordingly the upper unit has been designated the oölitic facies and the lower unit the bryozoan facies. Together they are here referred to as the Miami Limestone, a name which now seems more appropriate than the Miami Oölite of Sanford.

ACKNOWLEDGMENTS

The writers gratefully acknowledge their indebtedness to the National Science Foundation for making possible their studies on the Florida Coral Reef Tract. In addition, they have received aid from many specialists. They particularly wish to thank Dr. Alan Cheetham of Louisiana State University who spent some time with them in the field and who studied specimens of bryozoans from a large area. Drs. B. F. Howell of Princeton University and Olga Hartman of the University of Southern California and Mr. Kenneth Ebbs, Jr., of the Institute of Marine Science were especially helpful in examination of fossil worm tubes. Dr. Axel Olsson aided greatly in examination of the bryozoan facies and in identifying fossil mollusks. Drs. Norman Newell and John Imbrie of the American Museum of Natural History and Dr. E. G. Purdy of the Esso Production Research Laboratory were generous in their aid and encouragement in the comparison of the Bahama area with its Florida counterpart. The writers are most grateful to Dr. Robert Ginsburg of The Johns Hopkins University for his many suggestions which improved the paper. Messrs. Terry Thomas, John A. Jones, Durbin Tabb, Robert Work, Wayne Bock, and Dr. Donald Moore of the Institute of Marine Science were tireless in their efforts to collect living bryozoans from the Florida coasts for comparative purposes. Among the many persons with whom the writers held fruitful discussions and who, in some cases, reviewed the paper critically were Drs. Helen Duncan, Harry S. Ladd, Cesare Emiliani, James I. Jones, F. W. Meyer, R. J. Dunham, Harbans Puri, William S. Hoffmeister, and John Milliman.

THE UPPER UNIT OR OÖLITIC FACIES

This part of the formation is confined largely to the Coastal Ridge although it extends as a thin sheet several miles westward into the Everglades (Figs. 1 and 2). It is evident that it has been greatly modified by solution. In many places, it is indented by small circular sink holes which lead to numerous channel-ways of irregular shape and varying size.

Where it is exposed along canal cuts and in quarries in the Coastal Ridge the oölitic facies exhibits an intricately cross-bedded structure (Pl. 1, fig. 1). The beds may dip as much as 30 degrees and strike in all directions. Groups of dipping beds are commonly separated from each other by thin, nearly horizontal layers about 1 inch thick characterized by small mollusk shells, *Halimeda*, and a few bryozoans. The mollusks which seem to be the most numerous are *Transennella stimpsoni* Dall, *Chione cancellata* (Linné), *Columbella mercatoria* (Linné), and *Thericium* sp. The bryozoan is *Schizoporella floridana* Osburn. All are shallow-water types.

Soon after exposure the rock becomes surface-hardened, and directly below the hardened layer the material is softer, more friable, and the ooids and other particles can be separated by the fingers. Except for the surface the rock is poorly cemented down to the water table. It is so highly permeable that there is practically no runoff and no standing water even immediately after heavy rains.

The chief constituent particles of the oölitic facies are ooids, pellets, and skeletal sand. In this paper, the term "pellet" follows the usage of Newell and others (1959, p. 220): it refers to grains which are ellipsoidal in shape and carries no implication of origin. A rough examination indicates that ooids (concentrically laminated spherical to subspherical grains) are by far the dominant constituent of the Atlantic Coastal Ridge. West and northwest of the Ridge summit, on the sides which slope toward the Everglades, and extending to the border of the facies, ooids decrease to approximately 10 per cent of the rock and varying amounts of pellets

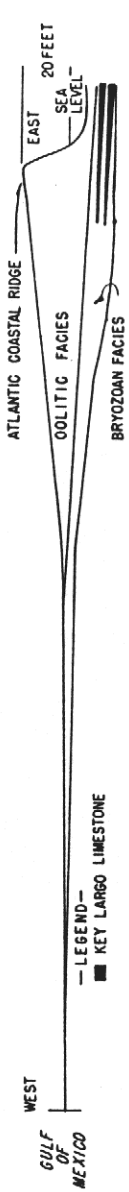

Figure 2. Generalized east-west cross section of Miami Limestone, Florida, showing stratigraphic relationship between the two facies of the Miami Limestone and interfingering of the upper part of the Key Largo coral reef limestone of the Florida Keys with the bryozoan facies of the Miami Limestone.

and skeletal material compose the remainder.

By far the most comprehensive description of the rock is that by R. N. Ginsburg (1953, Ph.D. thesis, University of Chicago). He has shown that many aragonitic ooids and pellets have been entirely or partially replaced by calcite and that with depth these have become increasingly embedded in a matrix of crystalline calcite. In addition, in the lower levels, especially below the water table, the ooids and pellets have been completely dissolved away, leaving only spherical and ellipsoidal cavities in the calcitic cement which bound them together (Pl. 1, fig. 2). In other words, the rock has assumed an oömoldic condition. Ginsburg has demonstrated that the calcitic matrix is a postdepositional precipitation filling the empty interstices.

The Coastal Ridge shows some interesting aspects concerning its structure and topography. There is a decided difference in the amount and intricacy of the cross-bedding in different parts of the Ridge. Beneath the Ridge summit, which in general occupies the eastern side of the mound, the cross-bedding is distinct and decidedly complicated. This can be seen in many places where the rock is exposed in small cliffs along the eastern or seaward slope, such as the Silver Bluff area of Coconut Grove (Fig. 1). It can also be seen along the sides of several canals which have been cut through the Ridge, especially the Coral Gables Canal at the southern end of LeJeune Road (Fig. 1, Station 205). Farther south along old Cutler Road, which follows the Ridge summit on its eastern side, there are many outcrops of cross-bedded oölite.

There is a gradual change in the rock structure along the western side of the Ridge. Underlying the gentle slope in this direction the cross-bedding at existing outcrops becomes less noticeable. The thin layers extend for long distances without change in the direction of dip. Where observed, the low dip is in a western direction toward the Everglades.

The low relief on the Ridge makes it difficult to observe topographic features or patterns. However, topographic maps bring out some interesting details. Figure 3, part of which is reproduced from map NG178 of the U. S. Geological Survey, shows a number of narrow, flat-bottomed valleys which extend northwest-southeast and normal to the trend of the Ridge. These are no more than 4 or 5 feet lower than the bedrock divides which separate them. The valleys are filled to a depth of 4 or 5 feet with unconsolidated organic soil, marl, and quartz sand. Consequently, the depth of the valleys in

the bedrock may be as much as 8 to 10 feet. The U. S. Geological Survey quadrangle maps bring out the details more clearly.

These valleys are significant in the interpretation of the origin of the Ridge. The origin of the valleys poses an interesting question. It is doubtful that they were made by streams, as no naturally running water occurs in the region, for all the rain water immediately seeps underground into the porous oölite. The cause of this topographic pattern will be considered in more detail later in the paper.

Westward from the Coastal Ridge the rock of the upper unit thins as it extends into the low-lying Everglades (*see* Fig. 2). Over most of the eastern half of the Everglades National Park it is only 1 foot or more in thickness; farther west it disappears entirely.

THE LOWER UNIT OR BRYOZOAN FACIES

The Bryozoa

Beneath the upper unit of the Coastal Ridge there is a rather unique rock layer which is about 10 feet thick. It consists of large numbers of massive tubular cheilostome bryozoan compound colonies (Pl. 2, fig. 1; Pl. 5, fig. 1), many of which are 1 foot or more in diameter. These are mixed with ooids, pellets, and skeletal sand. Most of the ooids and pellets have been dissolved away but the hard calcitic matrix which enveloped them now forms a cellular or vesicular structure. The material which surrounds the bryozoans is sufficiently fragile so that the zoaria can commonly be easily separated from it and from each other. However, surfaces of the zoaria in most places are plastered by a layer of cellular calcite which adheres strongly to the colonies and therefore covers the minute structure of the bryozoans. In many other places, the zoaria are free of this material and the anatomical structure is beautifully revealed (Pl. 2, fig. 2).

The entire facies is below the ground-water level here, and is not exposed to view. Examination can be made only by core drilling and by study of rock material dredged from the many canals which empty into Biscayne Bay. Because the rock is relatively easily broken, coring produces only fragments of the original large bryozoan zoaria and recovery is far from satisfactory; dredging has broken the zoaria into smaller pieces. Spoil banks along the sides of the canals, however, afford an excellent opportunity to observe the size and growth forms of the species as well as the relative abundance of the specimens (Pl. 4, fig. 1).

It should be emphasized that this is not a facies which contains bryozoans sufficiently numerous merely to make them the outstanding or dominant organism. This is a rock which is made largely of bryozoan zoaria. It has been estimated that bryozoans occupy at least 70 per cent of the rock by volume in many places, and they are so numerous that some of the unfinished roads near canal banks are paved largely with their fragments. Along some of the canals of the eastern Everglades, where the rock is close to the surface, spoil banks 4 and 5 feet high, made chiefly of bryozoans, can be traced for 2 or more miles. The relative abundance of bryozoans in the facies can best be seen from large boulders dredged from canals. Some of these, which measure 3 by 4 feet, are estimated to contain from 60 to 80 per cent of bryozoans by volume (Pl. 4, fig. 2).

The colonies vary tremendously in shape but seem to fall into two main growth forms. Specimens of the more important group, from the point of numbers and zoarial size, are rough, irregular masses with knobby projections. The latter are subcylindrical and vary greatly in length (to a maximum of 2–3 inches) and thickness (to as much as 2 inches). The ends are commonly flattened domes and many are bulbous. Where the knobs are broken they reveal a central hollow tubelike interior which varies in diameter from knob to knob and which tapers in each knob from its base toward its end. The thickness of the knob depends on the number of laminae it possesses. In one specimen (Pl. 3, fig. 1), as many as 46 laminae could be seen in cross section; this super-multilaminate type has a diameter of 1½ inches.

The zoaria of the second growth form are smaller than the first, commonly no more than 4–5 inches in their largest dimension. They also are irregular in shape, with crooked branches emanating from a massive, bumpy surfaced base. The tubes have a tendency to flange out near the top and thus produce wide, gaping tube openings with irregular edges. In other words, instead of tapering with length to make a closed top, as in the first group, they grow outward near the top to increase the size of the interior opening. There is also a smaller number of laminar layers, commonly five or six as a maximum, so this is a more delicate form than the first type mentioned. There has not been much

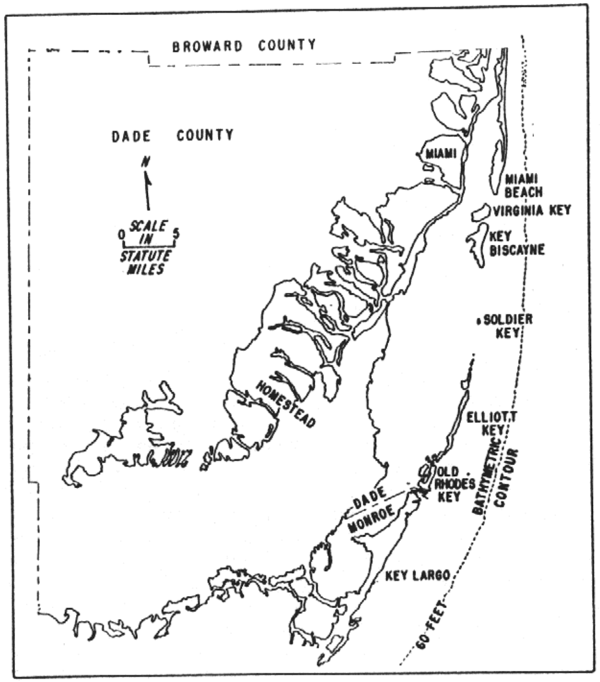

Figure 3. Map showing transverse valleys or "glades" in the Atlantic Coastal Ridge. The valleys are comparable to the tidal channels of the unstable oölite ridge of the Bahama area (*see* Pl. 6).

mixing between the two types; each seems to be more common in certain localities although not necessarily limited to these localities.

The shape of the zoaria generally depends on the character of the encrusted organisms of the substrate. Bryozoans of the Cheilostome type encrust a wide variety of animals and plants. Some common living examples in this region are colonies of the green alga *Halimeda*, gorgonian fronds, and various types of grasses, especially *Thalassia*. Each of these produce zoaria which are rather distinct from each other and which roughly simulate the form of the encrusted material.

In practically all specimens of the fossil zoaria, the knobs and more elongated branches have hollow centers. The encrusted material must have disappeared by decomposition. *Halimeda* or any other calcareous organism would still be preserved and could easily be identified. The hard axes of gorgonians might under some conditions remain intact but in most cases they would have disintegrated. Even if they were no longer present, the shape of the encrusting zoaria would reveal their former presence.

The most plausible explanation for the shapes and hollow tubes of the zoaria is that the bryozoans formerly encrusted clumps of some type of marine vegetation. In the shallow waters around the shores of the Keys and in places in Florida Bay, excellent examples of bryozoan-encrusted *Thalassia* may be found. Figure 2 of Plate 3 shows a recent specimen of the same species as that found in the bryozoan facies encrusting a *Thalassia* clump. It is believed that most of the fossil zoaria were formed in a similar manner. The zoecia form layer after layer around the grass blades or rhizomes. They do not, however, always extend only the length of the branch, but may grow beyond it so that the bryozoan knob is longer than the encrusted branch. In such cases the central hollow in the

knob of a fossil specimen ends where the branch ended. Beyond this, the laminae become closed and encircle a center as growth continues.

Other Constituents of the Bryozoan Facies

In addition to the bryozoans, calcareous worm tubes are numerous and in places comprise as much as 10–20 per cent of the rock by volume. The tubes average about 1½ mm in diameter and are for the most part only slightly tortuous. They commonly lie parallel to each other in tightly packed groups and may be as much as 3 cm long. Most have been broken into smaller fragments 1 cm or less in length. Some, especially those isolated from the mass, are tortuous in form. The tubes possess sides which are roughened by irregularly arranged minute pits of various shapes.

Identification of the species is difficult because of the absence of the living organisms. Dr. Olga Hartman (personal communication) has likened them to the filograne serpulid genus *Salmacina* but states that ". . . without preserved specimens it is not possible to determine either the genus or species." Dr. B. F. Howell (personal communication) has recognized two species of *Serpula* and one of *Dodecaceria* in rock specimens from a different locality in the bed, but has been unable to designate specific names.

There is no doubt that the worm tubes in the bryozoan facies have been made by many species. At the present time, it is safe to say only that most of them were produced by polychaetes and that serpulids seem to have been dominant.

Other recognizable lime-secreting organisms are few and far between. However, several poorly preserved specimens of a species of *Strombus* have been observed (Pl. 4, fig. 2).

As mentioned earlier, the grains of the facies are composed of ooids, pellets, and skeletal sand. Of these, pellets are the most important constituent. A rough estimate indicates that beneath the Atlantic Ridge the facies contains no more than about 15 per cent of ooids and larger amounts of pellets and skeletal material. Southeast and south of the Ridge the ooids are very scarce, the pellets comprise about 15 per cent of the grains, and the skeletal material about 80 per cent. West and north of the Ridge and beyond the cover of the oölitic facies the ooids are scarce and the pellet content varies from 25 to 75 per cent of the indurated sand.

Areal Extent of the Bryozoan Facies

Figures 1 and 2 show the approximate area underlain by the bryozoan facies. The northeastern end in the vicinity of Fort Lauderdale is hard to map because of the abundance of loose sand which tends to cover the rock. It is safe to say, however, that it extends as far north as Fort Lauderdale. West of Fort Lauderdale, in the Everglades, the north-central boundary of the formation is obscure. It has been traced to a point about 2 miles east of the intersection of Dade, Broward, and Collier counties. How far north it extends into Broward County is not known, but this is probably near its northern limit. Along its western side, it can be traced for over 10 miles west of the 40-mile bend of the Tamiami Trail and thence to the southwest where it reaches the Gulf of Mexico at a point about 10 miles south of Lostmans River.

The swampy, mangrove character of the Gulf Coast makes it very difficult to locate bedrock, but sufficient information has been obtained to make it possible to approximate the boundary of the formation. It is not known whether it underlies all of Cape Sable, but Flamingo is one of the most prolific bryozoan localities. Here the surface layer is a hard, almost flinty textured oölitic limestone which contains a few bryozoans. This overlies the main bryozoan layer which has been dredged from the shallow bank immediately off shore and piled in large mounds preparatory for road building. By far the most important organism in these mounds is the large knobby type bryozoan.

Eastward from Flamingo the mangrove shore line of Florida Bay again makes mapping difficult. However, an east-west strip bordering Florida Bay, about 5 miles wide, is probably composed of oölite and skeletal sand with very few bryozoans present (Fig. 1). This type of sediment is clearly exposed along canal banks which extend from the Aerojet site (Station 173) southeastward to the coast just east of Jewfish Creek. This is also true of the canal exposure along U. S. 1 in the same direction. In addition, a core from a drill site at Jewfish Creek (no. 9) shows a paucity of bryozoans. This strip apparently does not seem to be underlain by the typical bryozoan facies. It should also be noted that a fair number of corals, especially branching *Porites*, are found in this area. North of the 5-mile strip, bryozoans appear in greater numbers.

The entire eastern coast is underlain by the bryozoan facies upon which lies a cover of varying thickness of the oölitic facies limestone, as determined by several core borings (Fig. 1, nos. 6, 7, 10, 11, 12, and 13) and material from numerous canal dumps. It is believed that the area which lies within the borders just outlined is underlain by the bryozoan facies. Surface outcrops, canal and quarry dumps, and cores scattered over the territory confirm this. It is safe to conclude that the facies covers an area of at least 2000 square miles and that it is one of the most extensive bryozoan limestones in the country.

Geographic Distribution of Bryozoans According to Zoarial Growth Forms

There seems to be a definite relationship between the major growth forms and their geographic location. The large knobby, super-multilaminar specimens are confined chiefly to the eastern part of the facies. They border the eastern coast line and underlie the oölitic facies of the Coastal Ridge. They also extend west and northwest of the Ridge for at least 10–15 miles into the Everglades, and are also found in the Flamingo section of Cape Sable. From these areas the colonies become smaller and are gradually replaced by the type with short, thin walls and wide-open funnel-shaped ends. This is the main growth form of the greater part of the Everglades.

A thin-walled variety which has long, twisting, anastomosing branches is found in a few places around the periphery of the areas with thick, knobby forms. Examples are found along the south border (Station 173) and the north border (Station 172). Also, in various places along the western bank of the Coastal Ridge, where there is a noticeable amount of quartz sand mixed with the oölite, the tubes are thinner and inclined to be scraggly in shape.

Along the eastern coast line and underlying the Atlantic Coastal Ridge the bryozoan facies has a rather consistent thickness of about 10 feet. Farther west and north of the Ridge, underlying its western slope, the facies increases somewhat in thickness and reaches a maximum of 15 feet at core site 11.

Where the facies is thickest, the large multilaminar, knobby type is most prevalent. Where it is thin, as in the western part of the Everglades and along the Gulf Coast, the thin type of tube is common. Apparently the eastern section of the area was optimal for bryozoan growth.

RESUMÉ

In summary, the chief topographic and geologic features of the southern tip of Florida are the following:

(1) The eastern coast is bordered by a gentle ridge (the Atlantic Coastal Ridge, Fig. 1), with a maximum height of 24 feet above sea level. This ridge swings to the southwest and west at its southern end and disappears about 22 miles west of Homestead.

(2) The eastern side of the Ridge is somewhat steeper than the western side which grades almost imperceptibly into the low level of the Everglades.

(3) The gentle western slope is cut by a number of narrow valleys which run normal to the direction of the Ridge itself (Fig. 3). The relief is very slight (average 4 feet) but they can be clearly recognized on the contour quadrangle maps of the area.

(4) West of the Ridge and occupying the entire remainder of the southern tip of the peninsula is the low, flat country of the Everglades bordered by the coastal swamps of the Gulf and the Bay of Florida.

(5) The rocks of the Coastal Ridge are composed of oölite. They are intricately crossbedded on the crest and eastern side. On the western side the oölitic layers are less crossbedded, with beds dipping gently away from the Ridge crest in the direction of the Everglades.

(6) The maximum thickness of the oölite (oölitic facies) beneath the Ridge crest is about 34 feet, the lower 10 of which are beneath sea level.

(7) Beneath the oölitic facies of the Coastal Ridge lies a limestone which is made predominantly of zoaria of the bryozoan *Schizoporella floridana* (bryozoan facies). Mixed with these are ooids, pellets, and skeletal grains of which pellets are the most numerous, as well as tubes of polychaete worms. A few specimens of the gastropod *Strombus* have also been observed.

(8) The bryozoan layer extends in all directions so that it covers the major part of the southern tip of Florida. It is overlain by the oölitic facies in the east and is the surface rock of the western part of the Everglades.

INTERPRETATION

Oölitic Deposits of Northwestern Part of the Great Bahama Bank

The next step in the study of the region is to try to understand the conditions which gave rise to the features just outlined. Knowing that the present is a great help in understanding the past, it was natural to look for a place where conditions similar to those which existed in southern Florida during the Pleistocene are now producing corresponding rock formations. Such a place is relatively close at hand.

Directly east of Miami on the opposite side of

the Florida straits lies the Great Bahama Bank (Fig. 4). On its western edge are the islands of Bimini, Cat Cay, Sandy Cay, Brown's Cay, and others extending in a north-south line. This is the area so well described by Newell and his coworkers (1959). On the northwestern part of

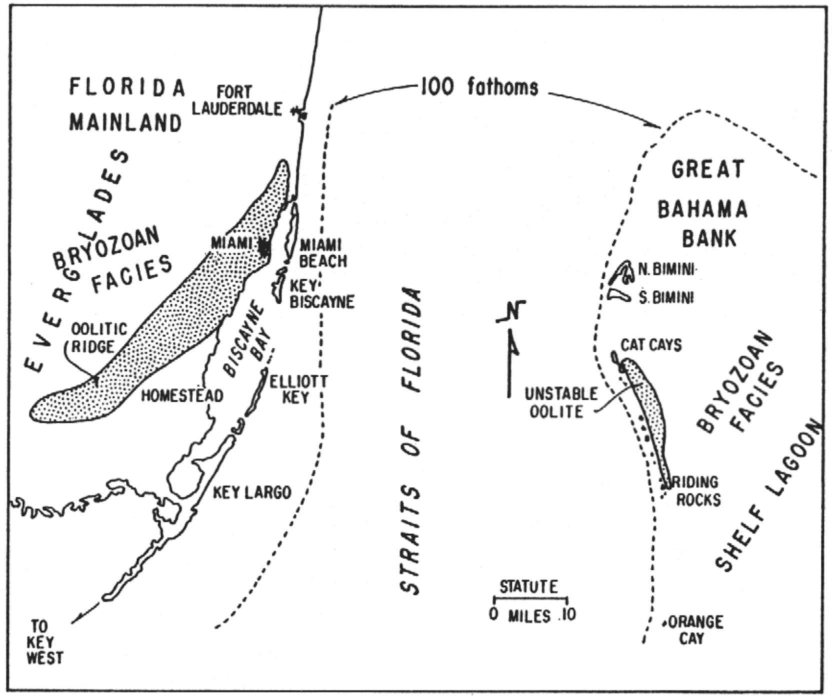

Figure 4. Map of southeastern Florida and the northwestern section of the Great Bahama Bank showing the chief topographic and stratigraphic features of southern Florida and the mirror image relationship to their Recent Bahamian counterparts

the bank is a conspicuous underwater physiographic feature immediately east of the line of Cays. This is a ridge (or bore) of unstable oölite approximately 20 miles in length and ¾ mile wide, lying parallel to the edge of the bank. It begins at the southern end of North Cat Cay and extends southward to the vicinity of South Riding Rock (Fig. 4; Pl. 6).

In places the ridge rises to near the low-tide level. The ridge crest for the most part is closer to the western side of the ridge, and the slope to the Outer Platform of the Bank is generally steeper on this side. Eastward from the crest a relatively gentle slope leads to the level of the shelf lagoon. The eastern slope is characterized by numerous channels which run normal to the direction of the ridge and which, in some cases, cut through the ridge crest (Pl. 6). The bankward ends of many of the channels are terminated by small deltas (Newell and Rigby, 1957, Pl. XI; Newell and others, 1959, Pl. 60). The channels have been formed by tidal currents flowing bankward and depositing deltas upon reaching the deeper water of the Bank.

According to Newell and others (1959), the optimum conditions for oölite growth occur along this ridge. At the ridge crest where the water is shallowest, the sand is constantly moving and consequently lacks a protective vegetative cover. In general (Newell and others, 1960,

Figure 1. Cross-bedded oölite of oölitic facies at Silver Bluff (between stations 205 and 206, Fig. 1), Coconut Grove, Miami

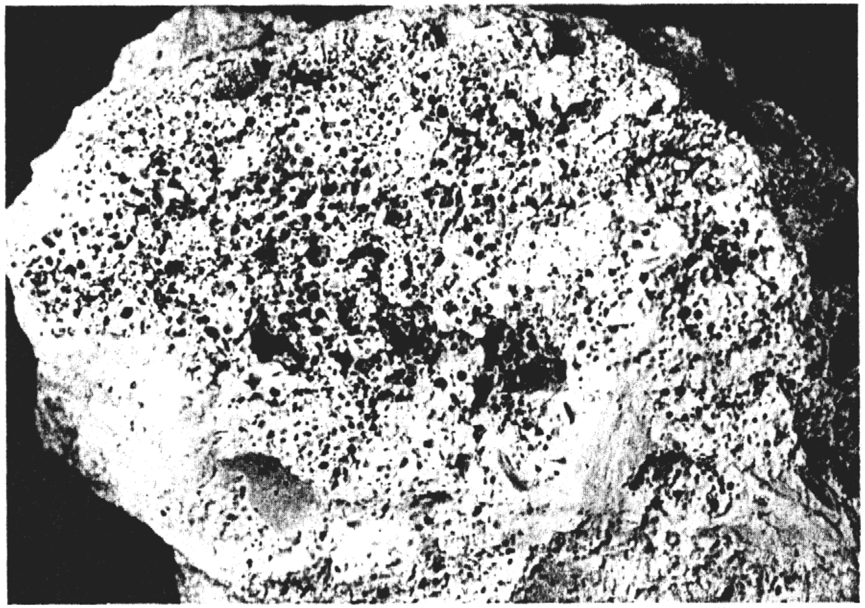

Figure 2. Oömoldic structure, commonly found in bryozoan facies. Ooids and pellets dissolved away and calcitic matrix remains. (× 3)

TYPES OF OÖLITIC ROCK OF MIAMI LIMESTONE, FLORIDA

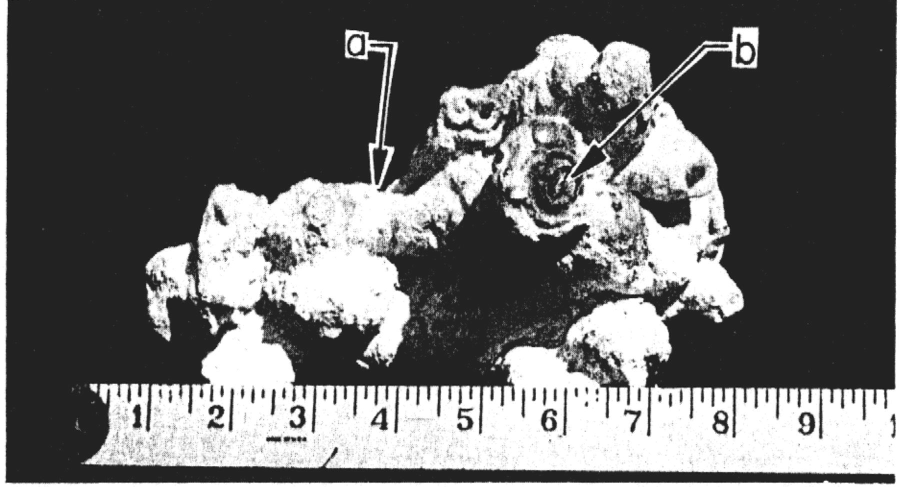

Figure 1. Typical knobby specimen from bryozoan facies of Miami Limestone. Knobs and tubes commonly hollow

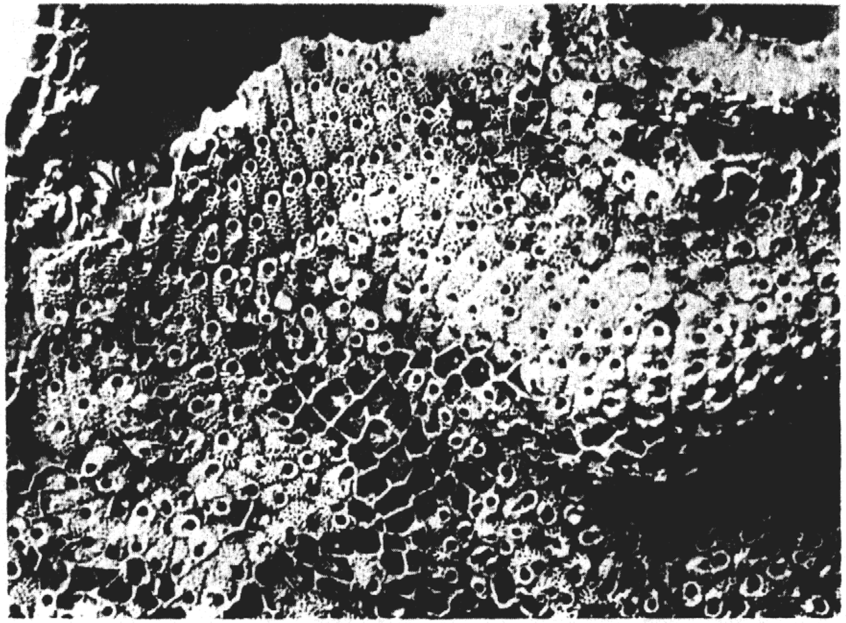

Figure 2. Well-preserved cellular structure as seen along portion of surface at a. (× 9)

MULTILAMINATE BRYOZOAN COLONY OF *SCHIZOPORELLA FLORIDANA* OSBURN

Figure 1. Enlarged view of transverse section of knob (b in Pl. 2, fig. 1). Central hollow tube filled with calcareous debris and surrounded by 46 laminae

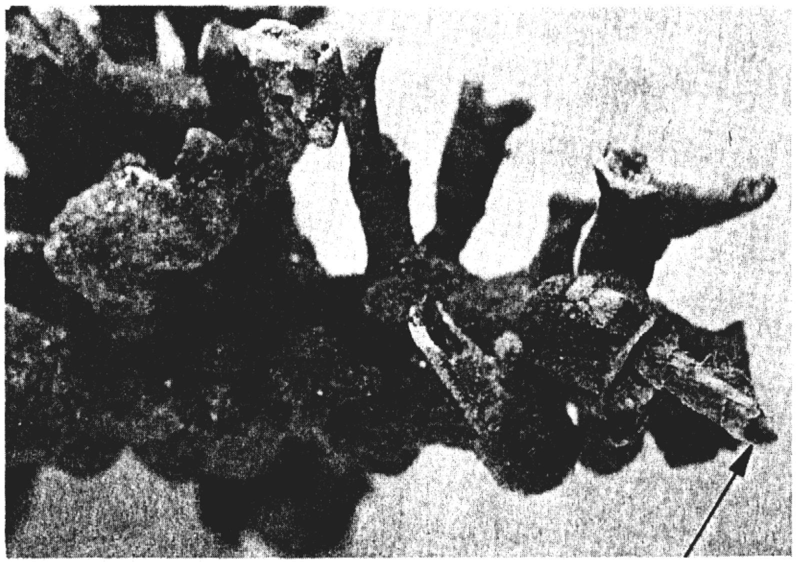

Figure 2. Recent specimen from Florida Bay, Florida. Arrow points to rhizome of *Thalassia* around which colony encrusted. Natural size

PLEISTOCENE AND RECENT SPECIMENS OF *SCHIZOPORELLA FLORIDANA*

Figure 1. Spoil bank along canal near Dade County–Broward County line. At least 70 per cent of the rock specimens are fragments of bryozoan colonies.

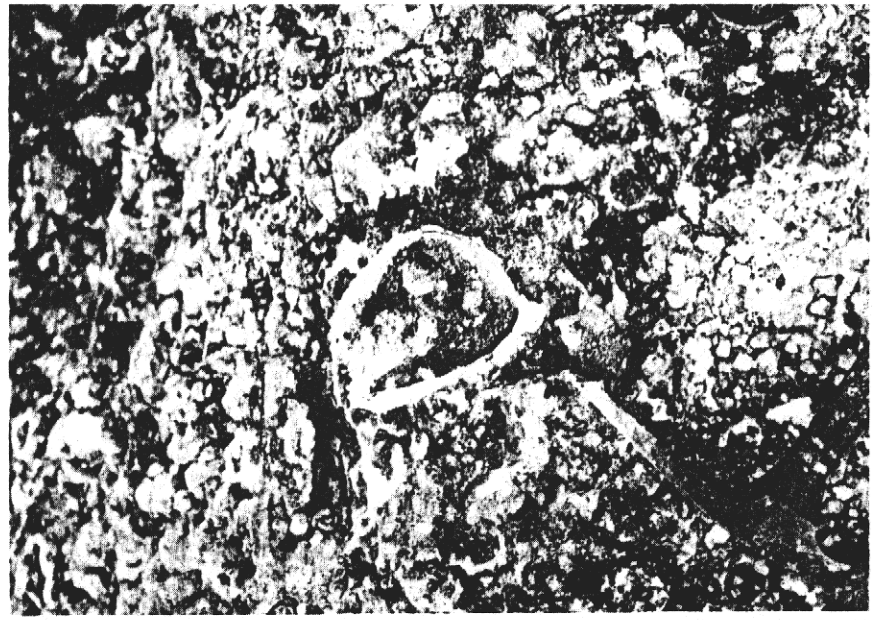

Figure 2. Surface view of large boulder made chiefly of bryozoan fragments surrounding *Strombus* shell (at point of hammer)

ILLUSTRATIONS OF ABUNDANCE OF BRYOZOAN COLONIES IN BRYOZOAN FACIES OF MIAMI LIMESTONE

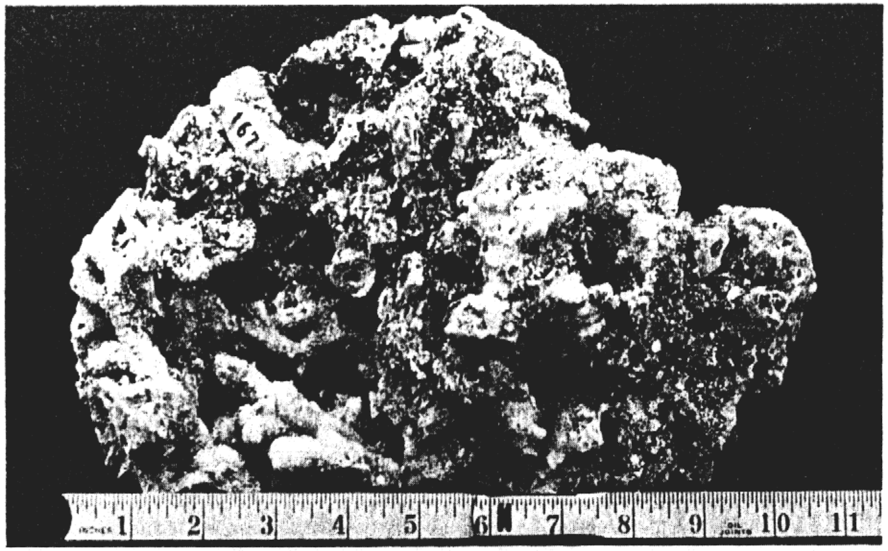

Figure 1. Typical tubular fossil growth form from the bryozoan facies of the Miami Limestone

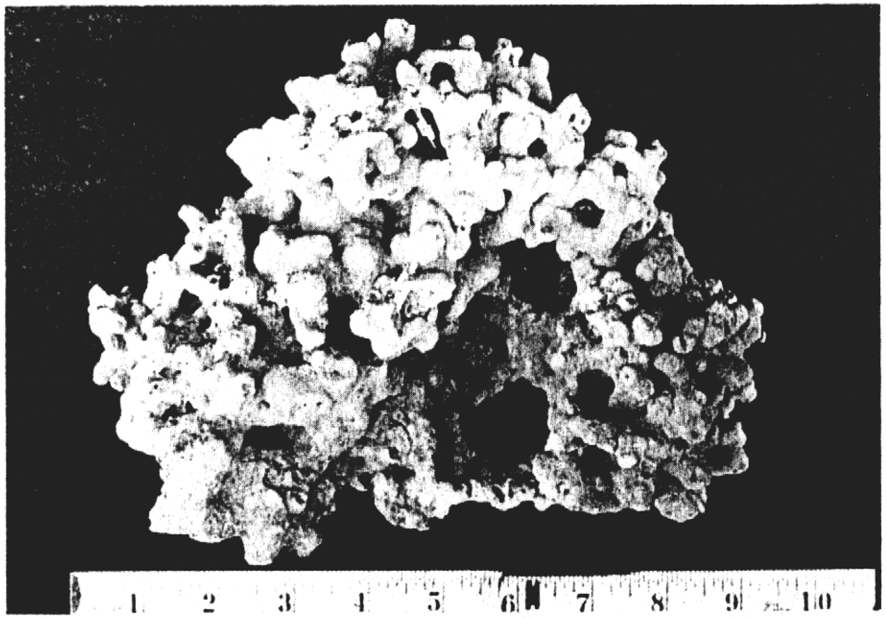

Figure 2. Similar tubular growth form of recent specimen from Great Bahama Bank

COMPARISON OF A COLONY OF *SCHIZOPORELLA FLORIDANA* FROM THE MIAMI LIMESTONE OF FLORIDA WITH ONE FROM THE SHELF LAGOON OF THE GREAT BAHAMA BANK

NINE-LENS AERIAL PHOTOGRAPH OF UNSTABLE OÖLITE RIDGE, GREAT BAHAMA BANK

Northern part of ridge from South Cat Cay at top of photograph to Sandy Cay in south — distance about 9 miles. Transverse tidal channels with deltaic ends show clearly. Bryozoans grow in somewhat deeper water (darker area) east of ridge. U.S.C. and G. Survey, Aerial photograph 48386

p. 487), "... the shoaler the water the greater the percentage of oolitically coated grains in the sediment." Thus it is their belief that the oölite grains are growing more rapidly over the upper surface of the ridge in waters which are rarely more than 6 feet deep at low tide. There is no doubt that intricate cross-bedding is produced by wave and current action in the upper part of the mound. According to Newell and others (1960, p. 485), Prof. E. Seibold obtained core samples from the sloping borders of the ridge and found that they were characterized by small-scale cross-bedding. It would seem doubtful that the border slopes which are considered analogous to foreslopes of tidal deltas would be underlain by sands as intricately cross-bedded as are those in the shoaler more turbulent areas higher up.

Newell and others (1959) have described and mapped the main habitat communities of the shelf lagoon which lies to the east of the western rim of the Bank. Immediately east of the oölitic ridge in water 12–15 feet deep is a bottom type mapped as pellet sand. Although this type of sediment is dominant here it is mixed with lesser amounts of skeletal grains, oölite, and grapestones. The bottom is sheltered from storm waves by the oölite ridge and subjected to vigorous tidal flow and waves and currents caused by average winds. Its surface is protected by marine grasses which exert a stabilizing influence on the bottom. Newell and others (1959, p. 220) point out that "... this situation may reflect combined advantages of shelter and availability of fresh supplies of sea water rich in nutrients as compared with the depleted Bank waters of the interior." It has also been observed that rippling of the surface is not so common here as in the more exposed seaward zones.

The pellet sands are differentiated from others on the Bank by the presence of ellipsoidal grains in excess of 25 per cent and with a maximum content of 80 per cent. Although these have been considered fecal pellets, the term as used by Newell and others (1959, p. 220) refers only to their ellipsoidal shape and does not take into account their origin.

It has long been recognized that in the Bahamas and elsewhere there is a close connection between habitat and organism communities, and that the substrate exerts an important influence on the latter. Newell and others (1959, p. 220) have identified the pellet-sand bottom type with a biotic community which they designate the *Strombus costatus* community. This is "... characterized especially by many echinoderms and mollusks living in a moderately heavy plant cover of grass and algae." In addition, they point out that a conspicuous element of the community is a branching cheilostome bryozoan (*Schizoporella pungens*) which encrusts a species of *Halimeda*. Dr. Alan Cheetham, who identified the bryozoan as *S. pungens*, now considers it a synonym of *S. floridana*. According to Purdy (personal communication), "... the colonies are rather widespread in occurrence on the Bank but are particularly numerous and large (approximately one foot in height) on the east side of South Cat Cay–Sandy Cay oolite shoal." A moderate degree of substrate mobility is suggested by the rippled sand bottom. It is his belief that an environment such as this is optimal for *Schizoporella* because the oölite shoal provides a shelter from large waves from the Florida Straits and also because tidal currents are strong enough to provide a good food supply. Newell (personal communication) has told the writers that, in view of the large number of bryozoans in this community, if he had it to do over again, he would call it the bryozoan community instead of the *Strombus costatus*.

The writers have examined the shelf lagoon from Bimini to Brown's Cay, south of Sandy Cay, and agree with Purdy that an environment of this type seems to afford excellent conditions for bryozoan growth. Tidal currents are unusually strong and the oölitic mound provides protection from storm waves from the Straits. In all probability, however, occasional hurricanes have created their usual amount of damage. Patches of living bryozoans seem to be sparsely distributed over the bottom. In many places well-developed, partially buried dead colonies protrude above the pellet sand and are evidence of the widespread occurrence of the organisms during the present and very recent past.

Comparison of Great Bahama Bank Deposits with the Miami Limestone

A paper entitled, "Bryozoan Limestone of Southeast Florida" (Hoffmeister and Multer, 1965), was presented at the Miami meeting of The Geological Society of America in 1964. During the ensuing discussion John Imbrie commented on the similarity between the recent Bahamian occurrence of *Schizoporella floridana* and the Pleistocene occurrence in Florida. This led the writers to examine the two situations in more detail.

It was soon evident that the two areas were alike not only in respect to bryozoans but in many other features as well. In fact, it might be

stated that one is almost the mirror image of the other. A mirror placed in the middle of the Straits of Florida, between Miami and Bimini, would reveal similar features in reverse order (*see* Fig. 4).

Starting from the coast line and progressing eastward, the outstanding features in the Bahama area are: (1) The Cays; (2) The underwater mound of unstable oölite; and (3) The shelf lagoon. On the Florida side from east to west are: (1) The Keys; (2) The Atlantic Coastal Ridge; and (3) The low-lying Everglades.

A brief comparison will be made of the features which correspond to each other on the two sides of the Florida Straits.

The Cays of the Bahama platform are made of indurated Pleistocene oölites. The Keys on the Florida side in the Miami area are made of several rock types, the most important of which is also of Pleistocene age. Miami Beach, Virginia Key, and Key Biscayne are topped by recent deposits much of which have been dredged from Biscayne Bay. Beneath this lies a thin layer of oölite which covers the relatively thick Key Largo Limestone. Farther to the south, the Keys, beginning with Soldier Key, are made entirely of Key Largo Limestone. Besides the differences in the composition of the rock, there is a difference in distance between the Keys or Cays and the second main physiographic feature. In the Bahamas, the Cays are close to or adjoin the mound of unstable oölite. In Florida, the Keys are separated from the Coastal Ridge by Biscayne Bay, a distance of only about 4 miles in the Miami area which increases to 10 miles farther south around Soldier Key (Figs. 3 and 4).

The Atlantic Coastal Ridge of southern Florida and the unstable oölite ridge of the Bahamas are remarkably similar. They are alike in height and shape, and both are made of oölite which seems to be more intricately cross-bedded on the seaward side than bankward. In both cases, the seaward side is somewhat steeper than the bankward side. The unstable oölite ridge is cut on the gently sloping eastern side by numerous channels which run normal to the direction of the mound and which in some cases cut through its crest. Commonly, the channels terminate in deltaic mounds made of oölitic sand deposited by tidal currents. The Atlantic Coastal Ridge is also cut by many narrow valleys (Parker and Cooke, 1944, p. 54, 55) which run normal to the direction of the ridge and which in many cases terminate in deltaic mounds of oölitic sand (Fig. 3). The eastern borders of the unstable oölite spread over the bottom of the shelf lagoon and cover its sediments and organic communities with a thin oölitic layer. Along its western side, the oölitic facies of the Miami Limestone encroaches on the bryozoan facies and spreads a thin veneer over the latter.

The rocks of the Everglades area also have much in common with the sand deposits and organisms of the shelf lagoon in the region under discussion. The dominant organisms in both are the numerous and well-developed bryozoan colonies of the species *Schizoporella floridana* Osburn (Pl. 5). Bryozoan facies of the Miami Limestone, however, contains a greater abundance of these organisms than does its Bahamian counterpart. Also, in the Bahamian area the colonies encrust branches of *Halimeda* as well as other marine vegetation, such as *Thalassia*.

Newell and others (1959, p. 220) have designated this the *Strombus costatus* community. Several specimens of this genus have been found in the bryozoan facies of the Miami Limestone. The sediments associated with the community have been listed by Newell and others as the pellet-sand type. Pellets also represent the dominant constituent of the sands of the bryozoan facies, especially in the area west of the Atlantic Coastal Ridge.

Purdy (1963, p. 334–355; 472–497) has made a careful statistical study of the constituent particles on the Great Bahama Bank and has defined several main calcium carbonate facies. His classification is somewhat different from the bottom types originally described by Newell and others (1959). Consequently, his map (Fig. 1, p. 473), showing the distribution of facies, is different from the reconnaissance map of bottom types of Newell and others. For the purpose of this paper the designations of the latter report are sufficiently accurate.

In summary, the reefs of the Florida Keys and the Cays of the Bimini region represent the forward bastions behind which the oölitic sediments were formed. This does not mean that they were essential to the accumulation of the oölites. Their presence, however, probably contributed to the geographic position and shape of the ridges in the two localities. The Atlantic Coastal Ridge or oölitic facies is the Pleistocene counterpart of the unstable oölite Ridge of the Bahamas. The bryozoan facies of the Miami Limestone is the ancient equivalent of the sediments and organic community now forming on the western part of the shelf lagoon. In conclusion it can be said that the two areas are so similar that the ecological conditions and events which gave rise to the Miami Limestone were probably nearly identical with those which are taking place now on the northwestern section of the Great Bahama Bank.

Main Events in the Origin of the Miami Limestone

During the last interglacial period, the coral reefs which today make up the Key Largo Limestone of the Florida Keys were flourishing. Broecker and Thurber (1965, p. 58–60) dated the Key Largo corals from the quarry at Windley Key as about 95,000 years old. The corals which underlie Miami Beach, Virginia Key, and Key Biscayne farther north are believed to be of similar age. West of these Pleistocene reefs, on what is presently the mainland of Florida, a broad shallow-water platform extended across what is today the entire southern tip of the state to the Gulf of Mexico. On this platform the multilaminate bryozoan *Schizoporella floridana* grew in great profusion. Other important invertebrates of the community were species of polychaete worms. Some mollusks, including the gastropod genus *Strombus*, were present. Pellets and some ooids accumulated on the bottom and filled in the spaces around the organic constituents.

The ecologic conditions which prevailed over the bank may be surmised by the organisms found in the limestone and a comparison with conditions now extant on the Great Bahama Bank. Dr. Alan Cheetham (personal communication) who has studied the bryozoans from both localities believes that the form and abundance of the zoaria of *S. floridana* in the limestone indicate a shoal-water substrate covered by marine grasses and protected from turbulence seaward and from turbidity landward. He also believes that the absence of other bryozoans and paucity of other fossils indicates a departure from normal marine salinity. His study of the occurrence and distribution of the species in other areas leads him to believe that the most plausible conclusion is ". . . that the Miami Limestone accumulations of *S. floridana* were produced in water of salinity analogous to that of the Great Bahama Bank, *i.e.*, about 37 to 39 ‰ throughout the year."

There were times when a change in the salinity of the water and other ecologic conditions along the eastern border of the bank made it possible for corals to encroach over the bryozoan community and extend westward to the area which today is overlain by the eastern part of the Atlantic Coastal Ridge. Somewhat later, conditions were reversed and the corals retreated eastward while the bryozoans took their place. This sequence occurred once again, as shown in Figure 2, so that two sheets of the Key Largo Limestone intrude the bryozoan facies. Thus the upper part of the Key Largo Limestone seems contemporaneous with rocks of the bryozoan facies.

After the sediments of the bryozoan facies had attained a thickness in the eastern section of about 10 feet, oölites began to form in larger amounts in the area which is now the Atlantic Coastal Ridge and pellets became relatively less important. As time went on, the oölitic sediments gradually accumulated until a northeast-southwest mound was built up to the level of the sea. The shoaler the mound became, the more abundant was the production of ooids.

Cross-bedding was more prevalent at the summit and on the eastern side of the mound than along its western slope. On the western slope tidal currents running down the slope created channels in the unstable oölite and deposited deltas at their western terminals over the bryozoan communities of the lagoonlike shelf.

While the mound was being formed, bryozoans continued to grow over the wide shelf to the west. Conditions were optimal for bryozoan growth in the area immediately west of the oölitic mound due to the protective character of the mound from storm waves and the strength of the tidal currents which produced an abundance of food. The result was that here the large, knobby, super-multilaminar zoaria lived in great numbers and formed a relatively thick deposit. Farther to the west, conditions were not so favorable and bryozoans having the thin-layered growth form with open-ended branches grew. They were also fewer in number and consequently produced here a thinner bryozoan deposit.

With the lowering of sea level, due to the ice age which followed, these deposits were subaerially exposed. During this time rain water flowing through the interstices of the rock eventually precipitated calcite around the grains and formed the indurated rock which is now present. It is believed that the eastern side of the oölitic mound was subjected to considerable wave erosion and that much material from this side thus has been removed.

The tidal channels, originally formed while the oölite was in its unstable condition, have been maintained in the indurated rock of the present day.

The Miami Limestone of the Lower Florida Keys

The Lower Keys, from Big Pine Key to Key West, differ in several aspects from those to the northeast. Instead of being strung out in a long, thin line they form an irregular, roughly triangular grouping with Key West at the apex and Big Pine at the base (Fig. 5). Most of the Keys are elongated in a northwest direction and lie parallel to each other, becoming progressively shorter from east to west.

Another major difference is that they are composed of oölite instead of Key Largo coral reef limestone. Sanford (1909, p. 218–221) named this rock the Key West Oölite. He recognized its great similarity to the Miami Oölite but gave it a different name because locally the latter contained more quartz sand. Cooke and Mossom (1929, p. 204) later considered this difference unimportant and combined them into one, the Miami Oölite.

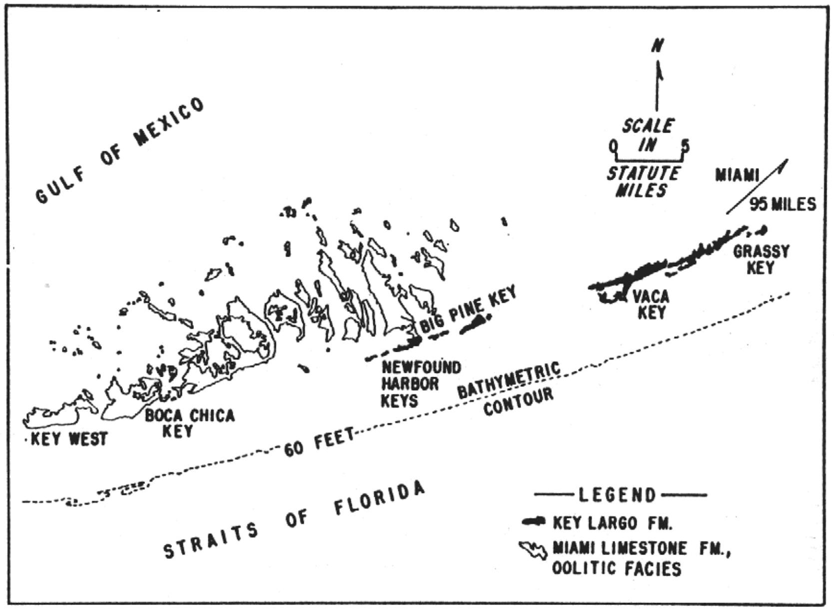

Figure 5. Geologic map of the Lower Keys of Florida composed of the oölitic facies of the Miami Limestone. The shape and orientation of these Keys owe their origin to tidal currents which cut transverse channels in the unstable oölitic ridge which formerly occupied the area.

All the Lower Keys, with their surface deposits of the oölitic facies of the Miami Limestone, are probably underlain by the Key Largo Limestone. The stratigraphic relationship between the two formations can be seen at a contact at the southeastern point of Big Pine Key (Hoffmeister and Multer, 1962, p. 199–200; Ginsburg and others, 1964, p. 60). Here the oölite gently overlaps the old coral reef to the south. The oölite cover of these Keys is relatively thin, particularly along their southern borders, and thickens in a northern direction as it extends into the Gulf of Mexico. For example, at the southern shore line of Boca Chica Key it is only about 6 feet thick and at about 1½ miles to the north it reaches a thickness of 35 feet. It is not known what happens to it beneath the waters of the Gulf.

In general, the Lower Keys are elongated in a northwestern direction and are separated from each other by shallow well-defined channels. The reason for the orientation of the Keys in this direction, so different from those to the east and north, has been a subject of interesting speculation. It has long been known that the Upper Keys are composed of the coral-reef Key Largo Limestone and their orientation, roughly parallel to the edge of the reef platform, can be easily understood. It is only natural to assume that the Lower Keys, made of a different rock, the Miami Limestone (oölitic facies), should have a different shape and orientation. But why this particular orientation and relationship to each other?

An understanding of the conditions now existing in the Cat Cay–Sandy Cay area of the Bahamas throws considerable light on the problem. Oölites probably formed on the platform behind, or north of, the coral reefs which now lie beneath the oölite cover of the Lower Keys. An east-west mound of unstable oölite with a thickness of at least 35 feet and extending the entire length of the Lower Keys was eventually built up. As the mound became higher than the reefs there was a tendency for the oölite to encroach over them and eventually to cover them entirely. As in the case of the Bahamas, tidal currents cut channels in the unstable oölite normal to the direction of the mound and probably deposited deltas in the slightly deeper waters to the north. When the land was exposed during the following glacial period, the rock became indurated as in the case of the Atlantic Coastal Ridge. Subsequent rise in sea level exposed the mound to erosion by waves and currents. These concentrated on the tidal channels originally formed while the mound was composed of loose ooids, and have eventually formed the narrow channels which today separate the Lower Keys from each other. This process continues at the present time. In summary, it is believed that the present shape and orientation of the Lower Keys had their start in the underwater topography created by tidal currents on an unstable oölitic mound.

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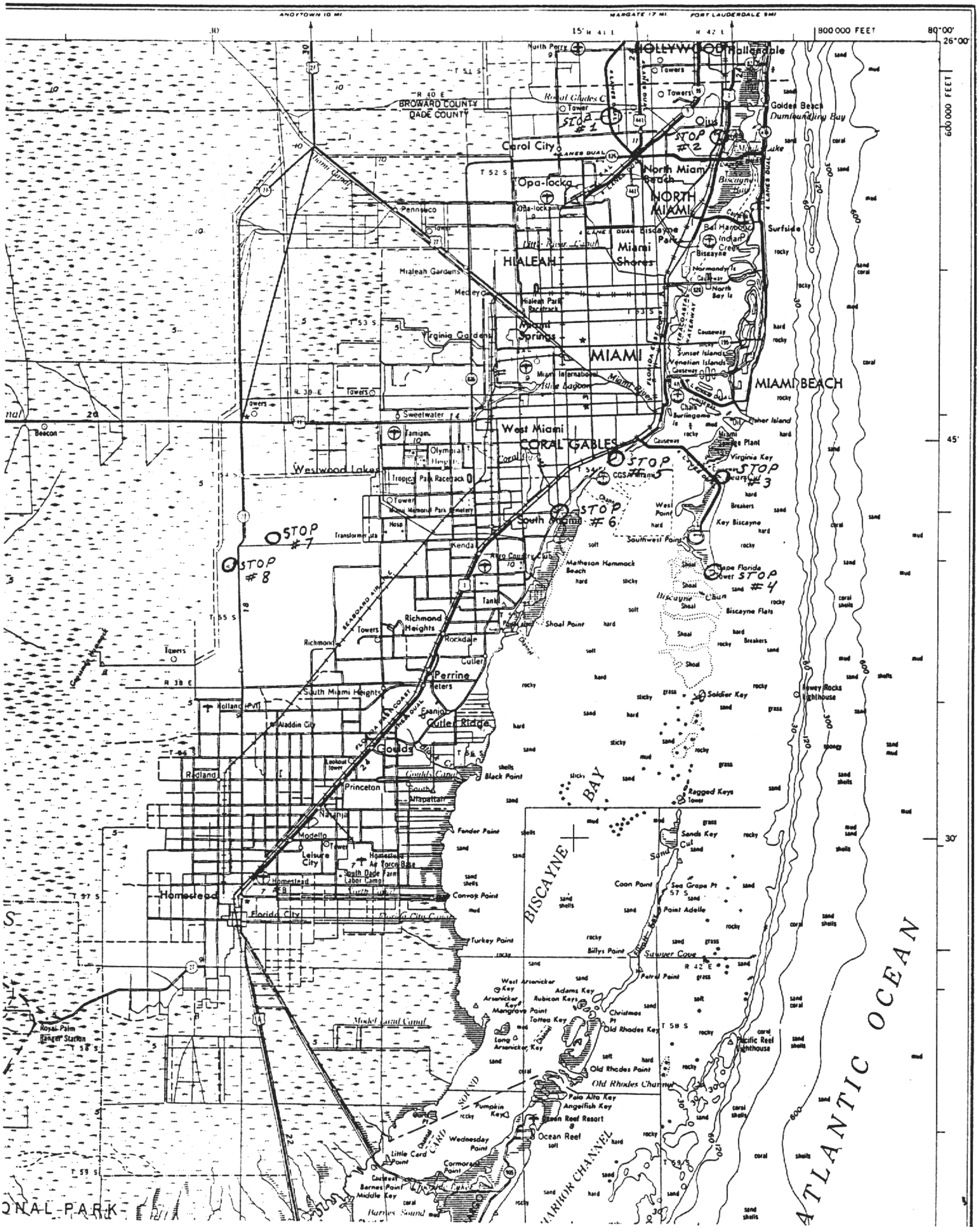


ANDYTOWN 10 MI
MARGATE 17 MI
FORT LAUDERDALE 9 MI
800 000 FEET
80°00'
26°00'
600 000 FEET
45'
30'
HOLLYWOOD
Hallandale
Golden Beach
BROWARD COUNTY
DADE COUNTY
STOP #1
STOP #2
STOP #3
STOP #4
STOP #5
STOP #6
STOP #7
STOP #8
Carol City
Opa-locka
North Miami Beach
NORTH MIAMI
Biscayne Park
Miami Shores
Bal Harbour
Indian Creek
Surfside
HIALEAH
Hialeah Gardens
Medley
Pennsuco
Hialeah Park Racetrack
Miami Springs
Virginia Gardens
MIAMI
MIAMI BEACH
Miami International
Sweetwater
Tamiami
West Miami
CORAL GABLES
Westwood Lakes
Olympia Heights
Tropical Park Racetrack
Virginia Key
Key Biscayne
Southwest Point
Cape Florida Tower
South Miami
Kendall
Matheson Hammock Beach
Richmond Heights
Richmond
Rockdale
Perrine
Cutler
South Miami Heights
Cutler Ridge
Goulds
Aladdin City
Redland
Princeton
Naranja
Modello
Leisure City
Homestead Air Force Base
Homestead
Florida City
Black Point
Convoy Point
Turkey Point
Fender Point
Soldier Key
Ragged Keys
Sands Key
Sea Grape Pt
Coon Point
Point Adelle
Billys Point
Sawyer Cove
Petrel Point
Adams Key
Rubicon Keys
Christmas Pt
Old Rhodes Key
Old Rhodes Point
Old Rhodes Channel
Palo Alto Key
Angelfish Key
Pumpkin Key
Ocean Reef
Little Card Point
Cormorant Point
Wednesday Point
Barnes Point
Barnes Sound
Royal Palm Ranger Station
Fowey Rocks Lighthouse
Pacific Reef Lighthouse
BISCAYNE BAY
CARD SOUND
HARBOR CHANNEL
ATLANTIC OCEAN
NAL PARK

ROAD LOG

Leave Un. of Miami Campus at 0800.

Take U.S. 1 to I 95 north to Golden Glades Interchange. Then take 441 north to 199th Street (Honey Hill Road). Go west on 199th to Sunshine Turnpike. Distance-23 miles. We will walk across an abandoned overpass. The outcrop lies alongside the road cut just south of the overpass. We will climb a fence (only one strand of barbed wire) and walk south along the cut.

The deposit is largely quartz sand inter-tonguing with thin layers of öolite. This thin bedded layer is about chest high along the path. At the top of the cut is a fairly thick layer of good clean öolite which is well consolidated where exposed. Fossils consist of the bivalves Chione cancellata, Trachycardium, etc., the gastropod Cerithium and the burrows of burrowing shrimp, Callianassa and Upogebia. Pellets from the burrows of the intertidal dwelling fiddler crab, Uca, have also been found.

Greynolds Park

We will return east on Honey Hill Road and turn south on 441. We then turn east on Miami Gardens Drive (183 Street) to Greynolds Park. Distance-6.3 miles.

We will park just beyond the castle (built during an ancient unknown civilization). This area has been mined for both rock and sand. Looking west, we see a ridge of oolitic rock on the right, and a higher ridge composed of some rock and a great deal of Pamlico sand. There are no fossils to speak of. The fact that the Pamlico here overlies the oolite (i.e. is stratigraphically higher) while at Honey Hill Road the Pamlico lies below the oolite substantiates the age contemporaneity. The intertonguing at Honey Hill Road is hard to see by itself.

To the southeast is a lagoon, on the right of this is an oolite outcrop with two distinct facies. The uppermost facies is bedded oolite. Below a sharp contact is a limestone containing a large amount of molluscan debris, forams, etc. There are several shrimp burrows in the upper facies plus a large burrow of unknown origin.

Bear Cut

We go west on Miami Gardens Drive to I 95, then south on I 95 to SW 25 Street. One block further (26th) we turn east and drive out on Rickenbacker Causeway. We cross Bear Cut Bridge and park on the east side. Distance-21.5 miles.

We will walk along the beach to northeast point. Along the way you will see two types of mangroves. The red mangrove (Rhizophora mangle) has an extensive prop root system. The black mangrove (Avicennia) lives just behind the red mangrove and has an extensive system of vertically projecting roots (pneumatophores.) In the shallow water just offshore are three species of sea grass which stabilize the bottom and provide a habitat for countless numbers of small invertebrates.

The beach rock at southeast point has preserved the root system of the black mangrove. It can be seen best when you stand back about 20 feet or so.

Cape Florida

Continue south on Key Biscayne to Cape Florida. Distance, 6.3 miles, Park at Lighthouse.

Cape Florida marks the southern terminous of quartz sand along the Florida east coast. Some quartz is found in sediments in the Florida Keys, but there it is relatively unimportant compared to the great mass of carbonates.

The quartz sand body which makes up Miami Beach, Va. Key and Key Biscayne is a barrier island complex. It ends at Cape Florida in a series of accreted spits which accounts for the widening at the southermost end (i.e. Key Biscayne). The quartzose sands extend as a submarine ridge southward and eastward from Cape Florida.

Silver Bluff

From Cape Florida we return to the mainland via Rickenbacker Causeway. We turn left when leaving the causeway and bear left a block further and continue on down South Miami Avenue. Our next stop is Silver Bluff, just beyond 17th Avenue. Distance-11 miles.

Please do not walk on the grass or attempt to chip off pieces of rock - this is private property!

Silver Bluff represents a higher stand of sea level (perhaps +8') during the last interglacial period (Sangamon). It is apparently contemporaneous with oolite formation in the Key West - Big Pine Key area. This was after oolite formation in the Miami area, and the Miami ridge had become somewhat indurated by exposure.

A short distance further southwest is another outcrop at the Everglades Schools for Girls. Here we can take a close look at the outcrop, but no hammers, please!

Sunset Circle

From Silver Bluff we proceed southwest on Bayshore Drive to the circle at Sunset and Le Jeune. Distance-4 miles.

Here the canal has cut through a section of the Miami ridge. You can see bedding planes from under the bridge. At the base of the oolite is a "holey" limestone, apparently part of the bryozoan facies.

Kendall Road

From Sunset Circle we proceed southwest to Kendall Road. We turn west on Kendall for 12 miles. This stop is at an open field. Distance-13 miles.

Here you can see an eroded limestone surface with small amounts of soil in the depressions. The surface rock is still oolite.

Krome Avenue and Canal

We continue west on Kendall and turn south on Krome Avenue. Two miles from the intersection is a canal with a high spoil bank. We will park on the west side of Krome. Distance-3 miles.

The rocks on the spoil bank contain an abundance of bryozoa (*Schizoporella floridana*), mollusks, forams, etc. This is Hoffmeister's bryozoan facies which is characterized by the presence of *Schizoporella*.

Return to University Campus by Kendall Road to 87th Avenue, then north to Miller Road (SW 56 Street). This will take us straight to the Campus.

TOTAL ACREAGE 232.74

GREYNOLDS PARK

THE SECOND DADE COUNTY PARK WAS BROUGHT INTO BEING IN SEPTEMBER, 1933, WHEN A. O. GREYNOLDS, FOR WHOM PARK WAS NAMED, DONATED 105.94 ACRES OF LAND, SUBJECT TO TAXES AND LIENS. ALSO IN 1933, 65 ACRES OF LAND WERE DEEDED TO DADE COUNTY BY PALM BEACH COUNTY ON AN EXCHANGE OF LAND.

IN 1935, H. B. GRAVES DEEDED 56.75 ACRES TO DADE COUNTY THROUGH THE CITY OF NORTH MIAMI BEACH, ALSO SUBJECT TO TAXES.

DURING 1938, THE COUNTY PURCHASED TWO ADDITIONAL TRACTS OF LAND, 2.7 ACRES AT COST OF $750, AND 2.35 ACRES AT COST OF $520.

GREYNOLDS PARK WAS SCENE OF SEMINOLE INDIAN FIELD AND TRADING POST OVER ONE HUNDRED YEARS AGO. THE OLD MILITARY ROAD FROM FORT LAUDERDALE TO FORT DALLAS IN MIAMI CROSSED THE OLETA RIVER AT THIS SAME POINT. IN 1878, THE COMMISSIONERS OF DADE COUNTY PURCHASED 60 ACRES AT JUNCTION OF LAUDERDALE TRAIL AND OLETA RIVER AS THE LOCATION FOR A COUNTY FARM. MAJOR PORTION OF THE ORIGINAL ACREAGE WAS SUBSEQUENTLY SOLD BUT A SMALL ROCK PIT AREA RETAINED BY DADE COUNTY FORMED NUCLEUS OF THE PARK.

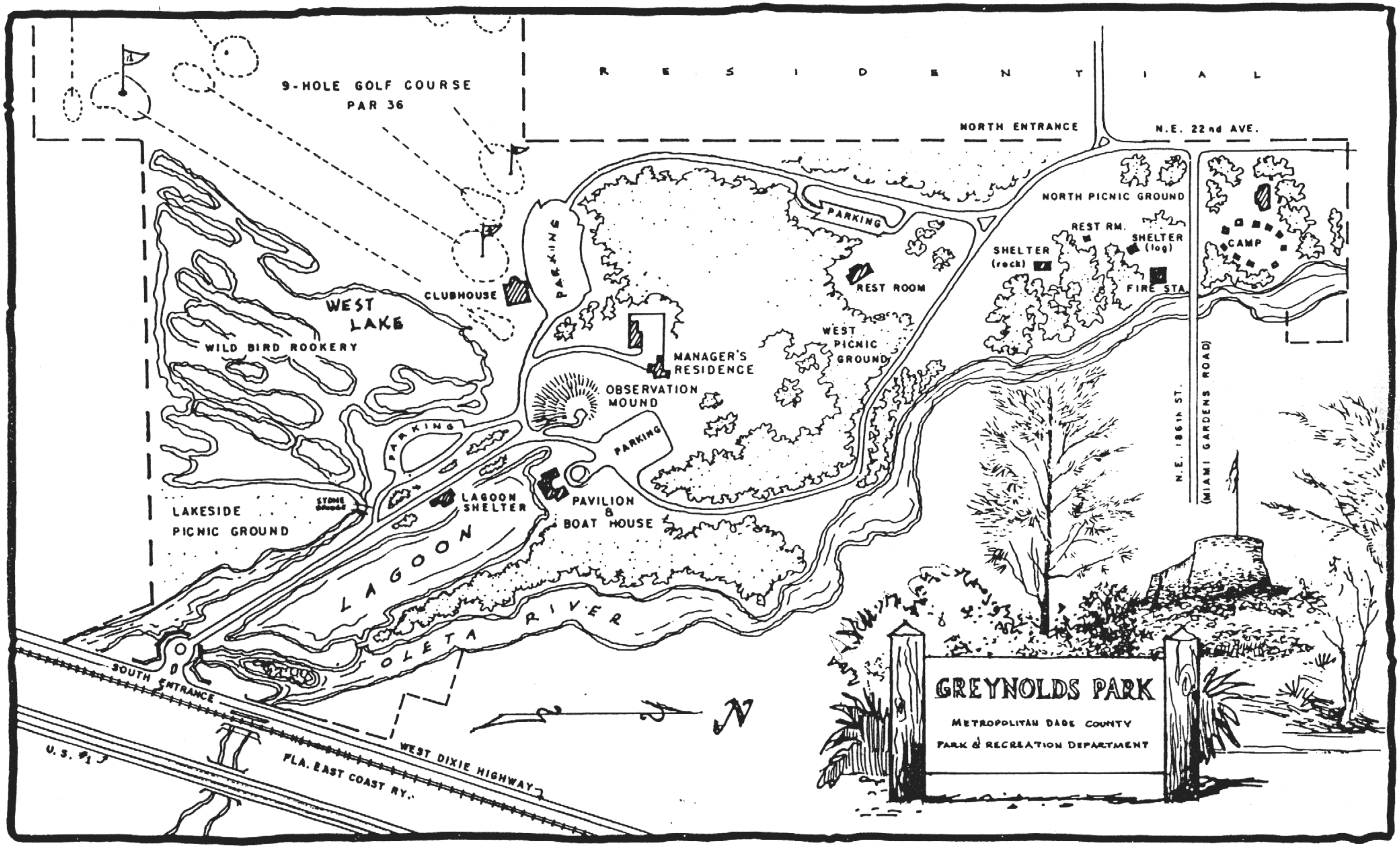
DEVELOPMENT STARTED IN 1933. ENTIRE ORIGINAL DEVELOPMENT OF THIS AREA WAS CARRIED OUT AS ONE OF THE FIRST C.C.C. CAMPS ASSIGNED TO THE STATE OF FLORIDA FOR DEVELOPMENT OF PARK AND RECREATIONAL AREAS. ALL IMPROVEMENTS AT BEGINNING OF THIS PARK WERE MADE AND PAID FOR FROM EMERGENCY CONSERVATION WORK FUNDS. DADE COUNTY CONTRIBUTED SOME HEAVY EQUIPMENT WHICH WAS AVAILABLE AT THE TIME.

MR. A. D. BARNES, WHO CONCEIVED AND DEVELOPED PLANS FOR A REGIONAL PARK IN NORTH DADE, WAS APPOINTED PROCUREMENT OFFICER FOR THE C.C.C.

BEFORE CONSTRUCTION BEGAN, THE PARK WAS ANYTHING BUT ATTRACTIVE. THE POOR ROCKY PINE LANDS HAD BEEN SCARRED BY BLEAK ROCKPITS PRESENTING A TOUGH PROBLEM IN LAND RECLAMATION AND BEAUTIFICATION. MR. BARNES ORDERED 120 SHOVELS AND HOES AND 40 AXES, AND WORK BEGAN WITH A CREW OF 170 MEN. THE ROCK PITS AND OLETA RIVER WERE CLEANED OUT AND QUARRIED STONE WAS USED TO BUILD WALLS, BRIDGES AND SERVICE BUILDINGS. PICNIC GROUNDS, DRIVES AND TRAILS WERE LAID OUT AND CONSTRUCTED ACCORDING TO A WELL DEVELOPED PLAN. AN OBSERVATION MOUND AND TOWER WERE BUILT ON THE HIGHEST POINT OF LAND IN DADE COUNTY WITH AN ELEVATION OF 42 FEET.

GREYNOLDS PARK WAS OFFICIALLY DEDICATED ON MARCH 29TH, 1936, BY DIRECTOR OF EMERGENCY CONSERVATION WORK, HONORABLE ROBERT FECHNER.

IN 1955, THE MANGROVE BOTTOM LAND EAST OF U.S. #1 WAS OPENED FOR CONSTRUCTION OF EAST GREYNOLDS.



9-HOLE GOLF COURSE
PAR 36
R E S I D E N T I A L
NORTH ENTRANCE
N.E. 22nd AVE.
PARKING
NORTH PICNIC GROUND
REST RM.
SHELTER (log)
SHELTER (rock)
CAMP
FIRE STA.
REST ROOM
CLUBHOUSE
PARKING
WEST LAKE
WILD BIRD ROOKERY
WEST PICNIC GROUND
MANAGER'S RESIDENCE
OBSERVATION MOUND
N.E. 186th ST.
(MIAMI GARDENS ROAD)
PARKING
PARKING
LAGOON SHELTER
PAVILION & BOAT HOUSE
STONE BRIDGE
LAKESIDE PICNIC GROUND
LAGOON
OLETA RIVER
SOUTH ENTRANCE
N
WEST DIXIE HIGHWAY
FLA. EAST COAST RY.
U.S. #1
GREYNOLDS PARK
METROPOLITAN DADE COUNTY
PARK & RECREATION DEPARTMENT