HYDROGEOLOGY
OF
SOUTH - CENTRAL FLORIDA
WEST PALM BEACH, FLORIDA
TWENTY - SECOND FIELD CONFERENCE
1978
Southeastern Geological Society
Publication No. 20

COMPILED BY
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Guidebook Cover taken from
U. S. Geological Survey ERTS-1 Imagery of Florida

SOUTHEASTERN GEOLOGICAL SOCIETY FIELD TRIP
"Hydrogeology of South-Central Florida"
November 10, 11 & 12, 1978

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Vincent Amey (Geraghty & Miller, Inc.).

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Telemetry Monitoring and Control Stations". Site Leader:
Richard Slyfield (SFWMD).

STOP 4: "Paleoenvironmental Implications of the Area's Peat Deposits, South Shore of Lake Okeechobee". Site Leader:
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STOP 10: "Caloosahatchee, Fort Thompson and Coffee Mill Hammock Stratigraphic Section". Site Leader: H. K. Brooks (Univ. of Florida).
SOUTHEASTERN GEOLOGICAL SOCIETY

Guidebook No. 20

"HYDROGEOLOGY OF SOUTH-CENTRAL FLORIDA"

Twenty-Second Field Conference
West Palm Beach, Florida
November 10, 11 & 12

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Coconut Grove, Florida
SCHEDULE OF 22nd FIELD CONFERENCE

Friday, November 10, 1978

4:00 - 5:00 pm  Registration
                Check in at Sheraton Ocean Inn, 3200
                North Ocean Drive, Riviera Beach (Singer
                Island)

5:00 - 6:00 pm  Garald G. Parker, speaking on "Water
                Resources Exploration in South Florida,
                1939-43"

6:00 - 7:00 pm  Social hour

7:00 - 8:00 pm  Banquet Dinner

8:00 - 9:00 pm  Abe Kreitman, speaking on "Present and
                Future Hydrogeologic Studies in the
                South Florida Water Management District"

Saturday, November 11, 1978

8:00 am  Bus leaves from Sheraton Ocean Inn
          parking lot

approx. 12:00 pm  Lunch at S-5A

5:00 pm  Spend night in Ft. Myers Sheraton Motor
          Lodge, U.S. 41 and Collage Road

Sunday, November 12, 1978

8:00 am  Bus leaves from Sheraton Motor Lodge
          parking lot

12:00 pm  Lunch at Ortona Lock

3:00 pm  Sheraton Ocean Inn parking lot. End of
          Field Trip
ACKNOWLEDGMENTS

Cooperation of the South Florida Water Management District is greatly appreciated for whom many people generously gave their time in preparing and printing of this guidebook. I am particularly grateful to Peter Rhoads, Director, Resource Planning Department and to Abe Kreitman, Director, Groundwater Division (SFWMD) for their complete support of this project. A special note of thanks goes to Sharon Hynes for her review and drafting efforts on many parts of this guidebook. Also acknowledgments go to Muriel Hunter and Joe Banks for their time spent in lengthy discussions on field trip topics along with Sam Upchurch and Tom Scott for their review of this guidebook.
FOREWORD

It is amazing how much we have learned and how little we really know about our world. The earth holds so many secrets of how and why it works that it is vital that we constantly look for new ways to unlock those secrets. The study of hydrology, for instance, takes on an entirely new dimension when it is linked with the study of geology.

In South Florida, and throughout the world, this link means life, since the supply of water for people, agricultural production, commerce, and the environment cannot be separated from the understanding of how the earth holds our water.

The South Florida Water Management District, and others interested in the use and protection of our resources, is pleased and excited that the 1978 Field Conference of the Southeastern Geological Society is taking this "hydro-geologic look" at South Florida's resources. This focus adds a new depth to these earth sciences, giving them practical applications which affect the lives of every man, woman and child living in South Florida.

With the passage of the Water Resources Act of 1972, the South Florida Water Management District was charged with the management and protection of the vast water resources of this region. This has proven a real challenge with the limited amount of information available on the hydrogeology of Central and South Florida. Developments in locating new water bearing formations, such as those in Palm Beach and Lee Counties, will be discussed at this conference, along with advancements in hydrogeologic studies which have made the job of guaranteeing a water supply into the future for the people of these areas much brighter.

John R. Maloy, Executive Director
South Florida Water Management District
INTRODUCTION

Water, its availability, quality and use is perhaps the most pertinent issue facing Florida today. It is the responsibility of all water managers, regional or local, to analyze the existing data base using that information to initiate preliminary policies or plans, and more importantly, to form a basis for detailed quantitative studies leading to the adoption of a long range water use plan or policy.

The water resources now available in south Florida are the result of many natural and man-made occurrences. Features such as natural surface elevations, landforms and subsurface conditions all interact and greatly affect water resource availability. It is the intent of this field conference to bring to the conference these interactions by presenting original works by south Florida's hydrogeologists working with State, private and Federal agencies on developments that affect south-central Florida's water resources. In addition to the hydrological oriented topics, Caloosahatchee basin stratigraphy will also be addressed adding to this year's field conference. We consider it to be of great value that these works are presented in this guidebook and will be discussed by the respective authors at selected sites. An overview of south Florida's historic, present and future water resources investigations to be given during the banquet by Messrs. Gerald G. Parker and Abe Kreitman will serve as an introduction to south Florida's hydrological environments.

On behalf of the Conference Committee, I gratefully acknowledge the efforts of all those that contributed to what we believe will be a successful conference.

Michael P. Brown
Vice President
EVALUATION OF THE HIGH PERMEABILITY ZONE
OF THE
SHALLOW AQUIFER, PALM BEACH COUNTY, FLORIDA

By

John N. Fischer
U. S. Geological Survey

INTRODUCTION

The population of Palm Beach County grew from slightly less than 369,000 in 1971 to more than 557,000 in 1977, an increase of almost 34 percent. Freshwater pumpage over the same period increased by approximately 32 percent (Miller, 1978). Similar trends in population growth and freshwater pumpage are expected in the future. Coastal municipalities have met increased demands for freshwater in the past by augmenting pumping rates from nearby wellfields. However, a recent report by the U. S. Geological Survey (Scott, Rodis and Land, 1977) revealed that saltwater intrusion into the shallow aquifer is occurring in coastal areas of the County due at least in part to increased freshwater withdrawals. Therefore, further increases in pumping from coastal wells to meet demand is not a practical alternative. New freshwater supplies are needed from sources further inland where the threat of saltwater intrusion is reduced. One such source is an hypothesized zone of high permeability within Anastasia Formation materials of the Shallow aquifer. Investigation of the shallow aquifer was prompted by the reports of Rodis and Land (1976) and Land (1977), both of which refer explicitly or by implication to the existence of a high-permeability zone within the aquifer. Because the zone is described by Rodis and Land as offering "excellent potential for the development of future groundwater supplies", the Palm Beach County Board of Commissioners, the South Florida Water Management District and the Riviera Beach City Commission requested more detailed information for planning and management of future development. An investigation was designed, therefore, to: 1) define the areal extent, 2) define the hydrologic characteristics of the zone; 3) determine the impact of waste disposal leachates on the groundwater system; and 4) determine the impact that extensive development of water supplies in the high permeability zone would have on the regional groundwater system. A subsidiary objective was to evaluate the usefulness of surface electrical resistivity data to hydrologic investigations in South Florida.

The investigation is divided into two parts, designated Phase I and Phase II. Phase I covers an area of 9-square miles and lies within the area of Phase II which includes approximately 130-square miles. Both areas are outlined in figure 1. The Phase I investigation commenced in June 1977 and will conclude in December 1978. Phase II commences at that time and will continue for 3 years.

GEOLOGY

The Anastasia Formation forms the backbone of the Atlantic Coastal Ridge on the eastern coast of Southern Florida north of Boca Raton. It is composed

Figure 1. Map of Palm Beach County showing location of investigation areas.
chiefly of calcareous sandstone, sandy limestone and coquina with lesser amounts of sand and shell. The formation is wedge-shaped, thick toward the coast and thinning westward into the Lake Okeechobee-Everglades depression.

The Anastasia Formation developed in a marine environment largely as an offshore bar during the Pleistocene interglacial age when the Lake Okeechobee-Everglades depression was a wide marine shoal. Many of the materials in the formation were deposited under water but in places low dunes of calcareous sandy and shelly materials were heaped on the surface of the bar above high-tide level (Parker and others, 1955, p. 100-101).

Geologic information was derived from analyses or driller's logs, surface resistivity and borehole geophysical data. Figure 2 shows the locations of all test holes within the Phase I area. Locations of general geologic sections of the Phase I investigation area are shown in figure 3 with the east-west and north-south geologic cross sections shown in figures 4 and 5.

The aquifer material of the high permeability (cavity-riddled) zone is composed primarily of gray calcareous sandstone mixed with fine tan to gray quartz sand. Gray sandy limestone is interbedded with the sandstone particularly near the bottom of the zone; the distinction between the two is frequently difficult to make.

Cavities were encountered at depths from approximately 55 to 100 feet of depth in test holes throughout the investigation area. The zone of highest permeability lies beneath the coquina and sandstone layer shown in figure 4. In drilling beneath this zone, circulation was frequently lost, 6-10 inch drops of the drilling bit were common. Both these phenomena are indicative of cavity-riddled zones.

Borehole televiwer data collected in testhole PB1065 confirmed the existence of cavities in that hole between 55 and 95 feet of depth. The driller's log from that hole, shown in table 1, is typical of those from holes located in the high permeability zone.

Based upon the relatively large quantity of fine gray quartz sand indicated by the driller's log, it is probable that the cavities of that hole are sand filled.

In western test holes, such as PB1026, aquifer material within the cavity zone is similar to that beneath the coquina and sandstone layer. However, circulation losses and bit drops were less frequent indicating a decrease in cavity size and/or frequency of occurrence. In the eastern portion of the area, consolidated aquifer material is absent to a depth of over 120 feet.

The high permeability zone is overlain by 5 to 7 feet of thin beds of green clay, fine gray sand and weakly consolidated grey calcareous sandstone. The beds are non-uniform and provide varying degrees of confinement to the high permeability zone. Immediately below the clay beds and directly above the cavity-riddled zone is a thin bed of hard sandstone. These two lithological features identify the top of the high permeability zone throughout the Phase I investigation area.
Figure 2. Map showing location of test holes extending more than 100 feet below land surface.
Figure 3. Map showing location of geologic sections.
Figure 4. Geologic section of the shallow aquifer along line A-A', Figure 4.
Figure 5. Geologic section of the shallow aquifer along line B-B', Figure 4.
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<th>Depth</th>
<th>Hardness</th>
<th>Description of Formation</th>
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<tr>
<td>0-3</td>
<td>Soft</td>
<td>Sand, fine to med., lt. gray</td>
</tr>
<tr>
<td>3-5</td>
<td>Med. Soft</td>
<td>Sand, fine to med., dark brown</td>
</tr>
<tr>
<td>5-8</td>
<td>Soft</td>
<td>Sand, fine to med., tan</td>
</tr>
<tr>
<td>8-10½</td>
<td>Med. Soft</td>
<td>Sand &amp; shell, dark brown, 9½-10½</td>
</tr>
<tr>
<td>10½-21½</td>
<td>Med. Soft</td>
<td>Sandstone &amp; shell, lt gray &amp; buff, loose shells, dark last 3 ft (gray)</td>
</tr>
<tr>
<td>21½-28</td>
<td>Med. Soft</td>
<td>Sandstone, fine to med., lt. gray, buckshot</td>
</tr>
<tr>
<td>28-29</td>
<td>Soft</td>
<td>Shells, fine, broken, white</td>
</tr>
<tr>
<td>29-31</td>
<td>Medium</td>
<td>Sandstone, fine to med. (some small shell 2%)</td>
</tr>
<tr>
<td>31-44</td>
<td>Hard</td>
<td>Sandstone, fine to med., (some shell 2%) lt gray</td>
</tr>
<tr>
<td>41-47</td>
<td>Hard</td>
<td>Same as above (med. gray color)</td>
</tr>
<tr>
<td>47-49</td>
<td>Hard</td>
<td>Same as above with greenish gray clay streaks</td>
</tr>
<tr>
<td>49-50</td>
<td>Hard</td>
<td>Sandstone and siltstone, green gray</td>
</tr>
<tr>
<td>50-54</td>
<td>Med. Soft</td>
<td>Clay and sandstone layered, gray-green</td>
</tr>
<tr>
<td>54-57</td>
<td>Very Hard</td>
<td>Sandstone, 1t gray cemented, broken shell</td>
</tr>
<tr>
<td>57-61</td>
<td>Very Hard</td>
<td>Sandstone, very fine grained, gray green (Momentary loss of circulation)</td>
</tr>
<tr>
<td>61-68</td>
<td>Very Hard</td>
<td>Sandstone, very fine grained, gray, (Lost circulation @ 67 ft), fine gray sand</td>
</tr>
<tr>
<td>68-71</td>
<td>Very Hard</td>
<td>Limestone, white to dk gray, bit jumped a lot</td>
</tr>
<tr>
<td>71-74</td>
<td>Very Hard</td>
<td>Sandstone or limestone, cemented, dk gray</td>
</tr>
<tr>
<td>74-86</td>
<td>Hard</td>
<td>Sandstone with some shell cemented with calcite crystals present, few nodular SS cuttings,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>most cuttings angular (Momentary loss of circulation @ 75-77 ft), fine gray quartz sand</td>
</tr>
<tr>
<td>86-96</td>
<td>Very Hard</td>
<td>Sandstone and shells, with thin white marly streaks, gray and calcite cemented</td>
</tr>
<tr>
<td>96-101</td>
<td>Hd to Med.</td>
<td>Sandstone, gray &amp; brown with marl, white</td>
</tr>
<tr>
<td>101-106</td>
<td>Hard</td>
<td>Sandstone, gray &amp; brown with marl, white</td>
</tr>
<tr>
<td>106-110</td>
<td>Medium</td>
<td>Sandstone, gray to buff with fine broken shell</td>
</tr>
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Figure 6. Natural gamma WG of test hole PB1026.
The bottom of the zone is bounded by beds of sandy limestone with streaks of white marl. Figure 6 shows a natural gamma log of well PB1026. The clay and marl at depths of approximately 40 and 95 feet, respectively, are indicated by the increase in gamma radiation shown at those depths. The overall increasing trend of gamma radiation with depth is due to the settling in the borehole of drilling mud, a source of relatively high gamma radiation.

The use of surface electrical resistivity data provides a method for subsurface exploration by means of electrical measurements taken at the surface of the earth. The technique was applied to the investigation of the high permeability zone to assist in determining the east-west boundaries and depths of the zone. A small, portable field instrument with a current source of 20 milliamperes was used. Both resistivity soundings (variations of resistivity with depth) and profiles (variations of areal resistivity) were conducted at sites indicated in figure 7.

Surface resistivity data proved useful in determining the eastern boundary of the cavity zone. High resistances in that area coincided with a decrease in consolidation of aquifer material. Water quality decreases to the west in the Phase I investigation area and because resistance is effected by water quality as well as by aquifer material, conclusions as to boundary location in this area based upon resistivity data alone were not possible. The top of the cavity zone (approximately 55 feet below land surface) was identified by surface resistivity soundings in the areas where clay content in the confining beds was high. Where clay was absent or present in only small quantities the zone was not detected. Resistivity soundings were unsuccessful in locating the bottom of the cavity zone probably because of limited current output of the field instrument.

**HYDROLOGY**

An aquifer test of the high-permeability zone was conducted on May 3-5, 1978. In conducting such tests, water is withdrawn from an aquifer and the effect of the withdrawal on water levels in adjacent areas is observed. Test site and well locations are shown in figure 8a and 8b. The 6-inch production well and 2-inch observation wells drilled to 95 feet below ground level are screened from 55 to 95 feet, fully penetrating the producing zone. Observation wells 2 inches in diameter were installed at 10 and 45 feet of depth to determine the confining nature of clay at depths of 5-12 and 47-54 feet. Each of these wells is screened in the final 5 feet of depth.

The pumping portion of the test was conducted at a rate of 220 gallons per minute for 24 hours. Water was withdrawn from the production well by introducing compressed air into the well via a 3/4-inch PVC pipe perforated at well depths of 75 through 95 feet. Drawdown and recovery of water levels in the observation wells were recorded for 54 hours following test initiation.

The aquifer test was designed to determine values for transmissivity and storage coefficient, hydrologic parameters which together describe the potential of an aquifer to yield water to wells. Transmissivity is a measure of the volume of water that can move through a one-foot-wide strip of the aquifer over its entire saturated thickness under a hydraulic gradient of one. The storage coefficient is the volume of water taken into or released from storage per unit area of the aquifer per unit change in head (Lohman, 1972, p. 6-8).
Figure 7. Map showing surface resistivity data collection sites.
Figure 8a. Map showing aquifer test site location.

Figure 8b. Map showing aquifer test well locations.
Aquifer test data were analyzed using the modified Hantush method for leaky confined aquifers. The Hantush equations are based upon the assumption of a permeable aquifer overlain by semipermeable beds through which water can infiltrate to recharge the aquifer. Aquifer characteristics obtained by this method apply to the permeable aquifer. Preliminary analysis of aquifer test data show the values of transmissivity and storage coefficient for the Phase I area to be approximately 100,000 GPD/FT and $1 \times 10^{-4}$, respectively.

The test showed drawdown in wells of 10 and 45 feet in depth to be closely related. Therefore, the clayey sand 5-12 feet below land surface does not significantly influence the vertical movement of groundwater. Comparisons of drawdown in wells open to the aquifer from 40-45 feet of depth to those open from 55-95 feet, however, show significant differences. For example, after 12.5 hours of pumping, drawdown in the wells 100 feet from the production well was 1.12 feet in the well open to the aquifer at a depth of 55 feet but only 0.12 at the well open at 45 feet. Similar differences existed in other pairs of observation wells. The difference in drawdown is due to thin-bedded clays which retard vertical water movement in the profile between those depths.

Another indication of the effectiveness of the clay beds in confining the high permeability zone in the southern portion of the Phase I area is that under natural conditions there, water in the zone beneath the clay exists at a head approximately one foot higher than that in the zone above. In the central portion of the investigation area, however, the differences in head between the two zones is less than 0.1 foot. The variation in head differences shows that the clay beds do not provide uniform confinement throughout the Phase I area probably due to thinning or non-continuity.

In summary, to date, the areal extent, thickness, lithology and hydrologic characteristics of the high permeability zone within the Phase I area of the investigation have been determined. The remaining investigation elements, determining impacts on the groundwater system of 1) waste disposal leachates, and 2) extensive development, are currently being assessed using computer models. Complete results of the investigation will be published in the U. S. Geological Survey Water Resources Investigation series.
REFERENCES


UTILIZATION OF THE BOULDER ZONE
PALM BEACH COUNTY, FLORIDA
A CASE HISTORY

by

Vincent P. Amy
Executive Vice President
Geraghty & Miller, Inc.
West Palm Beach, Florida

INTRODUCTION

In recent years, the so-called Boulder Zone, a cavernous dolomite present throughout much of southern peninsular Florida, has received considerable attention due to its potential for the disposal of treated waste waters. The name "Boulder Zone" was coined by oil well drillers: Because of its highly cavernous nature and the presence of fractures and unconsolidated debris. This section is prone to collapse when it is penetrated by the drill--whereas it causes very difficult driling due to lost circulation and debris and "boulders" falling in on top of the drilling tools. Initially, the Boulder Zone was utilized by the oil industry for brine disposal (Vernon, 1970); more recently, it has been used to dispose acidic wastes at Belle Glade, and secondary-treated effluent from plants located in Broward, Dade, and Palm Beach counties.

In 1974, the City of West Palm Beach, Florida, began construction of a regional pollution control facility designed to treat sewage from that city and a number of surrounding communities. Initial plant capacity was designed to be 20 mgd (million gallons daily); a second phase of construction raised the capacity to 44 mgd. The plant is designed to accommodate a total capacity of 68 mgd, although enough property was acquired by the City to eventually treat and dispose of 128 mgd.

At about the time treatment plant construction began, the City of West Palm Beach initiated a test program to determine the presence of the Boulder Zone, its hydrologic characteristics, and its suitability for the disposal of treated effluent.

In January 1976, shortly after the completion of the test program, construction was started on three 24-inch-diameter permanent disposal wells (Figure 1). These wells were completed in the Fall of 1977 and have been in operation since December 1977. Two more injection wells are presently under construction. The wells have been used to dispose secondary-treated effluent at an average rate of about 10 mgd; peak injection rates of 17,000 gpm have been observed.

REQUIREMENTS FOR INJECTION WELL DISPOSAL

Certain natural conditions must be present in order for an injection well disposal system to be workable. Proper utilization of these conditions
FIGURE 1

LOCATIONS OF DISPOSAL WELLS

WEST PALM BEACH, FLA.

Scale: 1' = 200'
forms the basis for the criteria used in the design of disposal wells and their operation. These criteria are as follows.

- Testing to determine the presence of suitable geologic conditions.
- A highly transmissive zone capable of accepting large volumes of treated waste at high rates and economically low pressures must be present.
- The injection zone must be overlain by beds having little or no vertical permeability (confining sequence), to prevent the upward movement of injected waste into zones containing potable, or otherwise useable, water.
- A permeable, salt-water-bearing zone overlying the confining sequence must be present. This zone is reserved for monitoring.
- Zones containing water with less than 10,000 mg/l (milli-grams per liter) of total dissolved solids must be protected and cannot be used for waste disposal. The presence of zones containing water with less than 10,000 mg/l should be delineated. Monitoring of this zone also is required.
- Once proper conditions are found, wells must be constructed to take advantage of these natural conditions using materials that will provide a long and useful life.

THE BOULDER ZONE

The Boulder Zone is a highly porous and permeable section of interconnected vugs and cavities (occasionally cavern-sized openings are present) found in dolomite beds of Eocene Age. This unit and others have been referred to as zones of high transmissivity (Puri and Winston 1974), because of the well-developed system of solution features and the degree of interconnection. The transmissivity of the Boulder Zone is truly enormous; based on tidal responses and fluctuations, estimates of the transmissivity are on the order of one to six million feet squared per day (Meyer, 1974).

At the West Palm Beach plant, the top of the Boulder Zone was found at -3132 feet MSL. At Wells 1R, 2, and 3, located 900, 1440, and 1480 feet to the west, respectively (Figure 1), the Boulder Zone was found at successively greater depths owing to the southwesterly dip of the beds. The test well terminated at 3578 feet after having penetrated 58 feet of dense, massive dolomite. From this information, the thickness of the Boulder Zone is estimated to be 370 feet.

Water contained in the Boulder Zone has basically the same composition as sea water, with an average temperature of about 17°C (62.6°F). Interestingly, the water is considerably cooler than would be expected. Temperature data collected indicate that borehole water temperature becomes cooler with depth, rather than warmer. This gradient appears to be closely related to the thermal gradient observed to occur in the ocean to the east (Meyer, 1974). This anomaly suggests an interconnection of the Boulder Zone with the ocean at depth, and its occurrence is the subject of a hypothesis discussed by Kohout (1967).
Lithology

The following description of subsurface conditions is based on data from one of the permanent disposal wells and the test well (Figure 2), and illustrates general conditions present in the area. Emphasis is placed on physical properties of the rocks. No attempts have been made to "pick" formational tops on the basis of fossil content.

Cuttings were used to describe the various rock types. Sets of cuttings from each of the wells drilled are on file with the Florida Bureau of Geology. The various geophysical logs also were used; of particular value were the electric induction, caliper, and 3-D velocity logs.

The upper 260 feet of material consists of sand, shells, coquina, and limestone. Sand and shells are found to 50 feet; the first limestone is present at that depth. The limestone, coquina, shells, and sand sequence persists to 260 feet, with increasing amounts of sand in the lower portion of this section. Permeable portions of the sequence yield large quantities of fresh water and form the so-called "Turnpike Aquifer."

The characteristic green clay of the Miocene (possibly Hawthorn Formation) is first encountered at 260 feet. This material persists to a depth of 890 feet, along with varying amounts of silt and sand. Sections of this clay are quite plastic and have a tendency to squeeze in and close open boreholes. Analysis of cores taken in the more permeable, siltier sections of the clay gives values of vertical permeability of 10⁻⁵ cm/sec (centimeters per second). Phosphatic minerals are also present. Clay beds of the Miocene act as the confining beds for the Floridan Aquifer (Parker, 1955) and prevent brackish water from migrating upward and into the shallow aquifer system.

The first limestone beds penetrated were found at 890 feet. These beds are intermixed with lenses of shells and marl and extend to approximately 1000 feet.

Based on the physical properties of the rocks, the sequence below 1000 feet extending to the top of the Boulder Zone (at 3520 feet in Disposal Well 1R) can be subdivided into three parts. From 1000 to 1550 feet, a fairly soft, light-colored, porous, fossiliferous, poorly cemented limestone is present. Some harder zones are present. The bulk of the limestone in this section corresponds to the "grainstone" described by Puri and Winston (1974). It also has been strongly affected by solution activity, making it highly permeable.

At 1550 feet, the nature of the rocks changes. From this depth to 2425 feet, the rock is more competent. Dolomite first appears at 1600 feet. Thereafter, limestone, dolomitic limestone, and dolomite are present. The limestone varies in nature from crystalline to porous, poorly cemented grainstone. Beds of finer-grained limestone with considerable micrite also are present. These latter materials correspond to the packstone described by Puri and Winston (1974). The limestone is light colored, usually white, tan or cream; the dolomite is usually brown. This section contains both "tight"
GENERALIZED GEOLOGIC LOG

0'
SAND, CLAY,
LIMESTONE & SHELLS
(Shallow Aquifer)

322'
MARL (CLAY), GREEN
WITH TRACES OF
SAND, SHELLS, LIMESTONE

700'
MARL (CLAY), GREEN
WHITE TO GRAY
LIMESTONE & SILT

1000'
LIMESTONE, BUFF,
Porous, Permeable
First Highly Permeable
Zone at 1015 Feet

1300'
LIMESTONE, BUFF, PERMEABLE
WITH INTERBEDDED GRAY
DENSE LIMESTONE,
HARD DENSE DOLOMITE
1316 to 1358 Feet

1500'
LIMESTONE, BUFF, GYAL
WHITE, PERMEABLE

1700'
LIMESTONE, SOFT TO HARD
DENSE TO POROUS
Lost Circulation at 1359 Feet

2096'
LIMESTONE, DOLomite, DENSE,
To Soft, Traces of Porosity
Interspersed with Limestone

2170'
LIMESTONE, DOLomite, DENSE
2180'
LIMESTONE, DOLomite, DENSE

2300'
LIMESTONE, DENSE, UNPENETRABLE

2340'
LIMESTONE, DENSE, UNPENETRABLE

2490'
DOLOMITE, BROWN, DENSE,
To Soft, Trace of Porosity
Interspersed With Limestone

2705'
DOLOMITE, BROWN, DENSE

2976'
DOLOMITE, BROWN, DENSE

3190'
DOLOMITE, BROWN, DENSE,
INTERBEDDING WITH SOFT
MASSIVE LIMESTONE / HARD DENSE CHERT

3216'
DOLOMITE, BROWN, DENSE

3528'
DOLOMITE, VERY HARD
DENSE, HIGHLY PENETRABLE
Numerous Cavities
(Boulder Zone)

T.O 3528'

Note:
Depths referenced to Top
Of Concrete Drilling Pad

GENERALIZED GEOLOGIC LOG & Construction Details
Of Test Injection Well

City of West Palm Beach, Florida

May 1975

Geraughty/Miller, Inc., Palm Beach, FLA.

Vertical Scale:
1" = 200'

Figure 2
and permeable zones. The transition between brackish water contained in the Floridan aquifer and salt water contained in deeper beds occurs in the interval between 1900 and 2100 feet. Permeable horizons below approximately 2100 feet are tapped by annular monitor tubes at each disposal well.

Beginning at 2425 feet, a distinct change in the nature of the rocks can be observed. Generally, they become more massive and uniform in nature. The top of this section is marked by a ten-foot-thick bed of dolomite overlying a fairly uniform limestone present in the interval between 2435 and 2520 feet. From 2520 to 2780 feet, an off-white to cream-colored limestone is present, along with beds of dolomite. This sequence is generally finer-grained than the overlying rocks and contains a greater percentage of cementing material.

At 2780 feet, cherty limestone, limestone, and dolomite are encountered. The chert is dark colored, usually brown, and occurs as surprisingly large nodules, which can be easily seen in videotapes collected in the open borehole. Ghost fossils can occasionally be seen in the nodules. The dolomite is tan to brown, while the limestone is white to cream-colored. At each of the wells, the cherty-limestone-dolomite sequence is present, but the percentage of chert varies. The chert also appears to be fractured.

A section of soft, white limestone, dolomitic limestone, and soft, marly limestone occurs at 3040 to 3250 feet, where it overlies the Boulder Zone. From 2425 feet to the top of the Boulder Zone (3250) the dolomite sequence forms the upper confining unit. These beds are generally finer-grained and have a much higher percentage of interstitial cement. An analysis of a limestone core taken from 2750 feet in the test well gave a porosity of approximately 30 percent. The vertical permeability was found to be only $10^{-6}$ cm/sec.

The top of the Boulder Zone is marked by the occurrence of a hard, brown dolomite. The rock can be solid or highly fractured. Samples of the rock exhibit a wide variation in character. It can be massive, dense, or vuggy. Crystalline material also is present. Fractured zones are common throughout, although there appears to be no correlation of these zones between wells. During drilling, it was a rather common occurrence for large fragments to be removed from the borehole. These are the result of fracturing, judging from their angular nature. Also, many of the fracture surfaces exhibit deposits of small, well-formed dolomite rhombs. Numerous cavities also are present, although none was as large as has been reported at other locations in southern Florida. These, too, do not correlate from one well to another.

On-Site Structure & Stratigraphy

Correlation of the electric induction logs for the three disposal wells, which are laid out in a triangular pattern roughly 500 feet on a side, clearly shows the beds dipping roughly to the southwest. The dolomite beds between 1600 feet and the top of the Boulder Zone form distinctive markers on the induction logs and make correlation between wells quite simple. Similarly, there are several distinctive limestone beds above 1600 feet which also can be correlated without difficulty.
A correlation was made between nine distinctive marker beds, beginning at depths of approximately 2880 feet and extending up to 1150 feet. The correlated depths, and calculated values for true dip and strike of each horizon are listed in the following table.

<table>
<thead>
<tr>
<th>Marker Bed</th>
<th>Well 1R</th>
<th>Well 2</th>
<th>Well 3</th>
<th>Depth (Ft.)</th>
<th>Dip (°)</th>
<th>Strike</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2786</td>
<td>2878</td>
<td>2882</td>
<td>10.6</td>
<td>N22°W</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>2658</td>
<td>2747</td>
<td>2748</td>
<td>10.1</td>
<td>N23°W</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>2547</td>
<td>2635</td>
<td>2637</td>
<td>10.0</td>
<td>N23°W</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>2231</td>
<td>2301</td>
<td>2312</td>
<td>8.6</td>
<td>N17°W</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>1714</td>
<td>1783</td>
<td>1794</td>
<td>8.5</td>
<td>N16°W</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>1646</td>
<td>1734</td>
<td>1720</td>
<td>9.4</td>
<td>N14°W</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>1609</td>
<td>1672</td>
<td>1683</td>
<td>7.9</td>
<td>N15°W</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>1245</td>
<td>1275</td>
<td>1287</td>
<td>4.4</td>
<td>N05°W</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>1130</td>
<td>1151</td>
<td>1174</td>
<td>4.7</td>
<td>N13°W</td>
<td></td>
</tr>
</tbody>
</table>

Examination of the table reveals some interesting facts and raises a number of questions. First, the dip of the deeper beds is quite high, much greater than data on regional geology would indicate. However, it should be noted that the largest dips are associated with the dolomite beds, presumably of secondary origin, whereas dips of the shallower limestone beds are significantly less. The difference could be due to the presence of an unconformity below Marker Bed H or to dolomitization subsequent to deposition which has given rise to an apparent dip. In this case, these secondary features do not reflect the "true" dip of the beds; the dip values recorded for the limestone may be a more accurate reflection of the dip. Perhaps this question could be answered by detailed analysis of the cuttings and correlation on the basis of fossil content.

The dolomite beds, particularly those forming the Boulder Zone, are severely fractured in some places, although the limestone has not been affected by fracturing. The difference is noticeable on the videotapes of the boreholes. The cause is unknown. Perhaps it is due to the reduction in volume which can accompany dolomitization, or maybe it was the result of a response to stresses. The dolomite is a harder and more brittle rock and may have responded to stresses by fracturing, whereas the limestone would have behaved as a more ductile material and has not fractured. This question may be answered by the regional studies presently being conducted by the U. S. Geologic Survey.

CONCLUSIONS

The drilling and testing of the West Palm Beach disposal wells have demonstrated the capability of the Boulder Zone to accept wastes and have added considerably to the growing body of knowledge. Utilization of data collected is making it possible to design better testing and data collection programs, improve well design, and formulate monitor programs. In addition, the data collected during this operation clearly indicate that site-specific data for each well must be collected in order to properly assess conditions and properly construct facilities capable of operating as safely as possible.
ACKNOWLEDGEMENTS

The successful completion of the disposal well system is largely due to the cooperative efforts of many individuals representing a number of organizations. The author expresses his thanks to John Simmons, Director of Utilities for the City of West Palm Beach, and J. H. "Buck" Weaver, Vice President of Robert and Company Associates, consultants to the City of West Palm Beach and designers of the treatment facility. The efforts and assistance of personnel of the USGS is acknowledged and appreciated, especially that of Frederick W. Meyer, who shared his store of knowledge freely. Finally, thanks are due to the various Geraghty & Miller staff members who collected and analyzed much of the data, and to the officers and personnel of the Alsay-Pippin Corporation for their cooperation and assistance.
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MANAGEMENT OF URBAN RUNOFF
BY REMOTE SENSING IN SOUTH FLORIDA

By
Richard E. Slyfield
Director of Operations
South Florida Water Management District

INTRODUCTION

Description of the South Florida Water Management District

Physical Description. The District covers an area of 18,000 square miles, or about the southern third of the Florida peninsula. The urban development along the southeast coast is known as the Gold Coast. This area, because of the mild climate of south Florida, has experienced an explosive population growth, particularly since World War II until today the narrow coastal strip constitutes a continuous metropolitan area with a population of about 3,000,000. Figure 1 shows the District boundaries, the Gold Coast and various features described subsequently.

The intensive development together with the very flat terrain and the abundant rainfall, often in the form of tropical hurricanes, combine to create unique problems in water management. Annual rainfall varies from 31 to 117 inches, with about 60% of the rain occurring in the four summer months. The high figure occurred in 1947 when two hurricanes attacked the region in that one year.

Motivated by the destruction from these hurricanes, Congress authorized the design and construction of the Central and Southern Florida Flood Control Project, (henceforth referred to as the Project) and the Florida legislature created what is now known as the South Florida Water Management District.

A very brief description of the Project will be given to facilitate an understanding of the existing operation and the innovations being instituted.

Flood waters are placed either by gravity flow or by pumping into four large flood retention areas - Lake Okeechobee, a shallow natural lake, and three natural marsh areas, known as Conservation Areas 1, 2, and 3. These four areas are completely encircled by levees. The flood retention areas also serve as a source of water supply during dry periods. A network of arterial canals covers most of the District and permits flood or water supply flows to be discharged either into or out of the storage areas or to tidewater. Innumerable secondary canals, administered by local jurisdictions, connect to the primary system. Gated control structures on the primary canals maintain optimum levels and even during the design storm limit discharge to non-erosive velocities. Each canal has a control structure near the coast line. These coastal structures serve the added function

1 Excerpted from International Symposium on urban storm water management, July 1978.
FIGURE 1 - Boundaries of the South Florida Water Management District and Communication & Control System
of preventing salinity intrusion, during periods of high tide and low natural runoff. Control of salinity intrusion is very important because 90% of the municipal water supply is from groundwater.

Present Operations. The physical facilities operated by the District consist of over 1,400 miles of canals and levees, 125 major water control structures, 15 major pumping stations and several hundred minor structures. To operate this system, an up-to-the-minute picture is required of the state of the system including the state of all control structures, the hydrometeorological conditions throughout the system, and a prediction of weather conditions in the immediate future.

The state of the system is ever changing, so the picture must be constantly updated. This updating is accomplished normally by daily sending observers to report by radio on hydrometeorological conditions to headquarters. During periods of stress, such as drought or flood events, more frequent observations are made. An estimated 20,000 man-hours are spent annually on this data collection program, exclusive of the time so spent at the pump stations.

Similar data are collected by the Corps of Engineers, the National Weather Service, various local water related agencies and cooperating private interests. Data from these other sources are received at headquarters by radio, telephone and teletype. On the basis of all these data, operational decisions are made by the District's engineering staff. Personnel are dispatched when required to make the appropriate changes in the control structures.

Hurricanes present special conditions of such a unique nature that special operational procedures are required. These procedures consist essentially of training District personnel to know how each structure is to be operated before, during and after such an event. These trained personnel are assigned to each major water control structure to operate it throughout the storm. The danger inherent in this procedure is obvious, especially at structures in vulnerable locations.

Having read thus far, the reader is probably aware of some of the weaknesses in the operational procedure and possible improvements that might be made. For example, the state of the system is ever changing and the present method develops a picture which can be as much as several days old (on a long weekend). Serious conditions can develop in such a time. These problem conditions can result from a number of sources - for example, from unexpected rain or high winds. Vandalism too is a very serious problem in the District. Vandals often break in and change gate settings, thus permitting waste of valuable water, salt intrusion, perhaps even flooding. During hurricanes, some control structures become too dangerous to man, so they must be abandoned, at which time all control is lost.

Background and History of the Communications and Control System

Because of these and other considerations, the District contracted with the General Dynamics Corporation in late 1970 to conduct a study of
its communications needs and how a modern communication system could be employed as an operational tool. This study was completed in March 1971.

Because of a previous unfavorable experience, the District elected to implement the recommendations of the General Dynamics' study in the form of a turnkey contract. This contract was of the performance type, in which the contractor was required to design and construct the facilities, being constrained only to obtain a specified level of performance.

Proposals were requested from qualified contractors, and in March 1973, five such proposals were received, one of which was judged non-responsive. The highest proposed price exceeded the lowest, which was $3,236,000, by only 10%.

Since the costs were so close, the District established a set of evaluation criteria by which each proposal was judged. The objective was to determine which proposal was most cost effective. The evaluation determined that General Dynamics (which incidentally submitted the lowest cost proposal) should be awarded the contract, which in fact they were, on June 29, 1973.

System Description

The objectives of the Communication and Control System are as follows:

1. To provide a dedicated, reliable, and cost-beneficial intra-District voice communication network.

2. To reduce costs and improve operation efficiency through centralized collection, communication, and processing of administrative data such as payroll, stores and inventory, vehicle utilization, etc.

3. To handle day-to-day routine functions associated with data collection and the operation of water control structures and equipment.

4. To provide real-time "state-of-the-system" reports on hydrometeorological conditions in the physical system on a 24-hour/day schedule.

5. To improve reaction time under emergency conditions, in order to prevent or minimize the impact of natural hazards such as hurricanes.

6. To provide a continuous uniform historical record of the operational, meteorological, and hydrological data collected, and to build this record into a readily accessible data base.

7. To generate management and technical reports in a timely manner.

8. To aid in the development and testing of new management strategies for improved water control utilizing computerized models of the physical system.

9. To develop as the ultimate objective a fully automated real-time water management system.
10. To provide continuous security surveillance of remote facilities.

11. To provide a vehicle by which data can be exchanged with other agencies such as the National Weather Service, the Corps of Engineers and the U. S. Geological Survey.

Functional Design Concept

The system consists of two major functional subsystems - the Voice/ Administrative Data Communications Subsystem (VADC) and the Data Acquisition and Supervisory Control Subsystem (DASC). Both subsystems employ a common microwave transmission backbone, described subsequently.

The VADC subsystem interconnects all District field stations, pump stations and headquarters with reliable communications channels. At District headquarters in West Palm Beach, the system connects with the PBX facilities, which have lines to the District's central computer as well as to voice telephones.

The DASC subsystem is a fully automated, real-time water management information system and a semi-automated water resource control system. This subsystem provides computer-controlled collection of water management data from remote acquisition stations to a central DASC computer that logs, processes, and stores this data for use in formulation of management decisions. This subsystem also provides centralized control of District water equipment and structures (e.g., pumps and gates) through manually initiated commands that are automatically relayed to and executed by remote control stations. It is expected that the control functions will be largely automated at some future date when the interaction among all the natural water variables is better understood.

Hardware Design Concept

A symbolic diagram of the Communication and Control System is shown in Figure 2. Basically, the system consists of:

1. A multi-channel, full duplex, 2 GHz microwave transmission system, referred to as the Microwave Backbone.

2. The elements of the microwave backbone are relays and Master Concentrator Units (MCU's).

3. Field data acquisition and control elements, referred to as Remote Acquisition and Control Units (RACU's).

4. A half-duplex VHF transmission system, referred to as the VHF Feeder Network, which connects the microwave backbone to the RACU's.

5. Field sensors and actuators.

6. Central computers.

7. Voice communication equipment.
Microwave Backbone. The microwave backbone, the primary communication network in the Communication and Control System, is configured as shown in Figures 1 and 2. The backbone consists of stations that have been located appropriately to assure reliable communication at an average spacing of 15.3 miles. The microwave backbone provides route redundancy for the DASC Sub-system because of the closed-loop configuration, where hardware is provided which permits bi-directional propagation of signals around the loop.

The microwave radios have been implemented for 54 voice grade channels at 200 KHz per channel deviation. Calculations show that the worst link has a reliability of 99.995%, or an anticipated total outage of 24 minutes per year.

Microwave Station. As noted previously, microwave stations are of two types, MCU's or repeaters. The MCU's function as message switching and relay elements between the backbone and VHF feeder network, as well as message repeaters. The MCU's are controlled from the central computer by coded digital messages. Circuits within each MCU decode these messages and determine which of the following tasks to perform:

a. Set up a data path to the central computer.

b. Terminate a data path to the central computer.

c. Transfer local status and summary alarm data to the central computer.

d. Establish a VHF link with an assigned RACU and relay all DASC messages subsequently exchanged between the RACU and the central computer.

e. Terminate a VHF link with an assigned RACU.

f. Send only an echo of the received message in the direction of the initiating computer.

In addition to a 200-foot guyed steel tower with 6-foot diameter parabolic microwave antennas and associated hardware, equipment at each repeater is housed in a concrete block building and consists of the following:

1. Farinon FM 2000 microwave transmitters and receivers operating at a frequency of about 2 GHz with transmitter RF power output of 5 watts.

2. Air conditioning equipment.

3. Batteries, battery charger, emergency power generator, and automatic transfer switch.

4. Channel MUX equipment if an MCU or voice drop.

5. Fault alarm equipment.

6. Order wire equipment.
FIGURE 2 - Symbolic Diagram of Communication & Control System
MCU sites also have the following equipment:

1. Master concentrator unit.

2. Canadian Marconi transmitters and receivers for DASC data, operating at a frequency of about 170 MHz with transmitter RF power output of 30 watts.

3. A similar radio for voice data for maintenance purposes, operating at a frequency of about 170 MHz.

4. Side mounted VHF antennas, with diplexer to both radios.

Remote Acquisition and Control Unit (RACU). The RACU's are the terminal acquisition and control elements in the DASC subsystem. They are hard-wired to the sensors and controllers that provide the raw input data to the system and effect control over District water equipment and structures. A RACU and associated sensors and controllers constitute a remote station.

RACU's are of flexible configuration with a channel for each installed sensor, but typically expandable to 30 channels, each of which may be analog or 12-bit digital, and with up to eight control channels.

All RACU's are battery operated. The batteries are recharged automatically by a battery charger which is powered at most stations by commercial electricity, or by solar panels at remote sites where commercial power is unavailable.

The RACU's are placed either in a specially built shelter or in an existing building located at District structures, containing the structure operational controls. The specially built structures are large diameter concrete pipes, placed on end, supported about 3 feet above the ground on steel pipes, and capped by a concrete lid, as shown in Figure 3.

Additionally, all equipment in the RACU's is housed in steel boxes designed to protect the contents from vandalism and from the elements.

Equipment at the RACU's consists of the following:

1. Antenna pole, side mounted, yagi antenna, and solar panel (at sites without commercial power).

2. Repco FM VHF transmitter and receiver, operating at a frequency of about 170 MHz with transmitter RF power output of about 8 watts or 25 watts in a few sites.

3. Modem - to convert radio FSK signals to digital.

4. Analog and digital multiplexer.

5. Alarm and status circuits.
FIGURE 3 - RACU Shelter

7. Batteries and battery charger.

8. Diplexer - to provide isolation between data and maintenance frequencies.

9. Signal conditioners - to match outputs of both analog and digital sensors to their respective multiplexers.

VHF Feeder Network. The VHF Feeder Network connects the microwave backbone at MCU (Master Concentrator Unit) sites to the RACU's. It provides the communication links for eventually tying up to about 300 remote stations into the DASC subsystem, though only 37 are being implemented in this first phase contract. The VHF feeder network consists of a series of independent sub-networks, or families, each centered on an MCU site. Each MCU contains a master VHF transmitter and receiver that provides radio communication with a family of satellite VHF transmitter-receiver units located at the remote stations. Each master is capable of serving up to 64 satellite units.

The VHF family sub-networks associated with the present microwave backbone all operate on the same pair of frequencies, one for transmit and one for receive. All of the associated RACU's are dealt with consecutively, one RACU at a time.

Though not implemented in this first phase contract, the VHF feeder network may be modified in the future to provide link redundancy between the microwave backbone and the remote stations. Such a modification will require only a modification of the software.

A theoretical analysis indicated VHF coverage at a reliability level of 99.95% for the least reliable station - a level somewhat below that of the microwave backbone. The calculated outage for the least reliable station is 43 seconds per day.

Sensors and Actuators. There are four types of sensors which interface directly with the physical system:


b. Meteorological: Rain, air temperature, wind speed, wind direction.


d. Operation and Maintenance: Gate position, battery voltage, AC voltage, fuel level, intrusion.

These devices provide either analog or digital outputs. Signal conditioners in the RACU match the output of each sensor to a standard analog or digital interface, as applicable, for digitizing and transmission. These sensors are designed for use anywhere within the District and are independent of the RACU configuration. Four types of sensors, beyond those used for operation and maintenance, are being installed in this first phase contract - water level, gate position, rain, and conductivity.
The accuracy of all sensors was stringently detailed in the specifications, and extensive testing was conducted during the contract period to verify that the required accuracy was met. Overall accuracy requirements were specified for the entire system. That is, the error in the value of the parameter being tested, is defined as the difference between the value as reported to the system operator and the actual value of that parameter.

Water level sensors are modified model VR-2 variable resistance gages manufactured by Hersey Manufacturing Co. See Figure 4. This device is essentially a linear potentiometer, the voltage output of which is directly proportioned to the water level. The device consists of a wire wound resistive strip and a parallel many-fingered strip sealed in a stainless tube and suspended vertically in a stilling well; the length of the tube equals the maximum water level fluctuation. A donut shaped, coated polyurethane float with embedded permanent magnet surrounds the tube and floats on the water in the stilling well. The magnet bends the adjacent fingers of the reed strip so that they contact the resistive strip. Thus the electrical path and hence the output voltage is proportioned to the position of the float and hence the water level.

The gate position sensors are the same as the water level sensors except the stainless tube with the linear potentiometer assembly is mounted on the gate, and the magnet is placed on a fixed arm adjacent to the gate instead of in the float.

The permissible error of the water level sensor is 0.01 foot plus 0.4% of the difference in the actual water level from the level at the center of the range. The permissible error of the gate position sensor is 0.01 foot plus 0.4% of the actual gate opening.

The rain gage is a specially constructed device designed and manufactured by the contractor. It consists of a chamber fed by rain falling through a funnel, which has a top diameter of 12 inches. See Figure 5. When the volume of rainfall in the chamber reaches an equivalent of 0.01 inches of rain across the top of the funnel, a float operated switch closes a valve in the top of the chamber and opens a valve in the bottom of the chamber. As the water leaves the chamber, the float drops to the elevation of the bottom of the chamber and reverses the position of the valves. Every time the bottom valve opens, a counter is incremented in the RACU. This counter thus retains a digital record of the amount of rain that has passed through the raingage.

The permissible error of the rainfall recorded by the rain gage is .02 inches plus 2% of the actual rainfall occurring during the period being sensed.

The conductivity sensors employ an inductively coupled transformer sensing element. This element consists of an annular ring in which are located two coils, coil number one carries a primary, fixed alternating current. The other coil is a secondary, sensing coil, in which a current is induced. The strength of the induced current is a function of the field through which the lines of force from the primary coil pass. The
FIGURE 4 - Schematic of Hersey Water Level Sensor
FIGURE 5 - Rain Gage
element is fully immersed in water, the conductivity of which determines the field. As the conductivity of the water varies, so does the strength of the induced current.

The permissible recorded conductivity error is 1 micromho/cm plus 4% of the actual conductivity.

Actuators are the control elements that interface with the motor controllers of District equipment and structures. They are operated by control modules in the RACU on command from the central station. In this first phase contract, they are used only to control gates.

Central Computers. The central station contains two Control Data Corp. Tower-3000 computer systems. One of these computers is used principally for handling the data acquisition and control functions of the District, and the other for handling its EDP functions. The second computer also serves as a backup unit for the DASC computer, to provide the requisite system reliability.

The contractor is providing two Hewlett-Packard 2100 mini-computers which function as front-end communication controllers to the larger CDC computers. The central station contains two DASC input-output cathode ray tube (CRT) terminals which also serve as the human interface and by which the operator issues commands and which display operator selected data from the DASC subsystem. Finally, a printer makes a hard copy of (1) operator selected data (2) alarms generated by the system (3) various housekeeping information such as log-in, etc.

The DASC computer exercises control over the operation of all RACU's and MCU's in the system. It has override capability to redirect a RACU that is carrying on an autonomous operation.

Voice Communication Equipment. Voice and administrative data communication use conventional telephone equipment and procedures. Two types of circuits are included in the system-administrative and maintenance. This equipment will not be described in detail. It functions to maintain the system and to provide a private communication system.

Warnings. The system automatically notifies the system operator of various abnormal conditions. There are two classes of such conditions, classified and handled according to their severity - alarms and status reports. Alarms are transmitted immediately to the nearest MCU, and to the central site via a special alarm scan initiated by the computer at five-minute intervals. A status report is made up and held where an abnormal condition occurs, at an MCU or RACU, until a normal interrogation of the site. Such interrogations might occur automatically, daily, hourly, or at any other regular interval, or they might occur as the result of an unscheduled operator directed scan. All warnings are brought to the operator's attention by the sounding of a bell. They are printed on hard copy for his appropriate action and are stored in the computer. Alarms are caused by intrusions, loss of commercial power, and certain activities related to the water control gates.
Status reports are made to the operator in the same manner. They report on abnormal conditions, but of less critical a nature than those treated as alarms. Consequently, they are not transmitted with the urgency of the alarms.

Operational Concept

In order for any communications over the DASC subsystem to occur, a link must first be established. This link is established by the central computer either through timing built into the software or in response to an instruction from the system operator. Following the establishment of the data link, equipment commands, or warnings may be transmitted over the subsystem.

Data/Control Link Establishment. Data acquisition and control communication routes are established between the central computer and a remote station in a two step process. The first step is the establishment of communications via the microwave link between the computer and the MCU site that is a master to the remote station of interest. The next step is the establishment of a VHF link between the MCU site and the destination RACU. Once the communication route between the central computer and the remote station is set up and verified, exchange of data and control commands and instructions can be effected.

All communication routes are established by the central computer. The computer transmits a coded digital message bit-serially in one direction around the loop. Every MCU in the loop decodes the message to determine its internal and external response. Only that MCU for which the message was addressed responds with a retransmission of the received message back to the central computer. The addressed MCU decodes the set-up message to determine what internal action it is to perform and if an additional external response is requested. The central computer uses the response message to determine if the signal path quality for the selected communication route is adequate to achieve reliable data transfer. It makes this determination by comparing the response message, which is of known format and content, to the original message to see if the message was altered in transmission. Failing to establish a quality path, the computer attempts other available communication routes, in a prescribed priority schedule, before aborting the operation.

The message sequence which establishes the microwave link also activates appropriate internal circuitry in the MCU, such as the VHF equipment. All RACU's within "hearing" of that MCU transmitter decode the message address. Another link set-up message brings only the addressed RACU up to full operating status whereby it can perform data scans and control tasks as instructed.

Data Scans. Data scans of MCU's and RACU's are automatically executed under software control on a schedule that varies with (1) natural changes in District field conditions, (2) the update requirements for remote control of different water level control equipment, and (3) the needs of District operations and maintenance personnel. These data scans are effected on a polling basis. Normally, all MCU's and RACU's are polled on a regular schedule, normally once every five minutes for MCU's and at
various predetermined time intervals for RACU's. The MCU's when polled provide local status and RACU alarm information, and the RACU's when polled provide raw digitized field data, local status detail, and active control set-points (see equipment control below).

Additionally, an unscheduled data scan of a RACU which caused an alarm is made automatically wherever RACU alarm information is detected during a regular MCU status/alarm scan. The unscheduled scan is required because the MCU report does not contain the actual cause for the alarm but only the identity of the reporting remote station. Unscheduled data scans of MCU's and RACU's are also requested by the system operator at random times; these scans are manually initiated through the system control terminal at the central station. Some of the acquired data from data/alarm scans are processed, displayed, and logged as directed by the system operator through options provided by the software. Most of these data are automatically logged and stored in predetermined configurations established by the software. All data for at least the past 24 hours are kept readily accessible in disk storage in the computer. Older data are kept on archival tapes.

Equipment Control. There are three basic methods by which District water control equipment and sensors will be remotely controlled:

a. Adjust to Set-Point Control
b. Servo on Set-Point Control
c. Binary Control

Adjust to Set-Point Control. - In this method, the computer issues to the remote stations instructions that define the end point for a control function. The set-point control is the normal operational mode used by the system. After a control operation is initiated, the execution is autonomous and the computer is free to terminate communication with the remote station or to set up other control functions at the same station. Local sensors continuously monitor the parameter being acted upon; and when the measured value of the parameter attains the prescribed set-point value, the operation automatically terminates. Where desired as a safety feature, to preclude runaway control which can result from loss of communication with the computer, the remote station is equipped with an on-site timer that can be used to automatically de-activate any control operation after a 1\(\frac{1}{4}\) minute time interval has elapsed, if the operation has not already terminated. The computer can reset this timer approximately every minute to maintain continuity of the control operation throughout the desired "on" period.

The set-point values are derived off-line and commanded by the system operator through the DASC terminal equipment at the central station. After the computer initiates local control of the field equipment it then assumes a supervisory role over the operation. This method of control is envisioned initially for setting gate positions only.
Servo On Set-Point Control. - This type of control is slated for future implementation. It is similar to the adjust to set-point except that it is on-site autonomous, not using the timer; moreover, the set-point need not be directly related to the equipment being controlled. For example, a gate may be positioned by a water level set-point.

Binary Control. - This method consists of opening and closing sets of contacts at a remote station in obedience to commands issued to the computer by the system operator. The contacts will provide on/off, up/down, and other control signals which are equivalent to manual push-button operations. The period during which the controlled equipment functions may be commanded by the system operator and they are automatically effected by the computer as a safeguard against overtravel; however, the on-site timer, previously described, terminates the operation unless reset by the computer at one minute intervals.

Control Safeguards. - Accuracy in transfer of control messages and checking of all operations in control loops are essential system requirements. For example, if a gate is opened either too high or for too long, downstream erosion, flooding, or loss of a vital water supply may result. To preclude damage to the physical system, the DASC Subsystem provides built-in safeguards against control errors or failures. All messages sent by the computer require confirmation from the addressed remote station that the message was properly received and interpreted, before an execution order is issued. Moreover, if the system operator issues a command to open the gate farther than it is safe to do, he is given a warning by the computer. He may then elect to heed or ignore the warning.

Special Reliability Features

Because of the critical nature of water control in south Florida and because an error in remote operation could result in a condition which could not be corrected for a considerable period of time, various special features, in addition to the general requirement of high quality materials and workmanship, have been built into the system to increase its reliability. These fall into five general categories which are described in some detail.

Some of these features have been described previously, but they will be discussed here to show their importance in system reliability.

Redundancies. Wherever possible redundant features have been built into the system especially in those phases of the system with the most commonality such as the microwave backbone. With these redundancies, if one element of the system breaks down, the system will still be functional.

Beginning at the center of the system, two fully redundant computers with two interchangeable front-end mini-computers are incorporated in the system. The system operator has two CRT consoles, which, though they have different functions, can be used interchangeably if one breaks down. The microwave backbone is loop configured so that if one radio breaks down or even if one microwave tower is destroyed, communications can be
routed by another route around the loop. Each station on the microwave backbone is battery powered so as to be independent of commercial power which might be lost in case of a hurricane. The system can function for several days on the batteries alone. The batteries, however, are recharged by commercial power (at all but one of the 16 stations). Even if commercial power is lost, each station has a diesel operated motor generator with automatic transfer switch. In the future, each RACU can be reached from at least two MCU's.

Because the RACU's are at the "end of the line", the extensive redundancies were not considered cost effective there. Nevertheless, all RACU's are also battery operated and can operate without commercial power for several days. The batteries are charged by commercial power where it is available and by solar panels where it is not.

Environmental Design. In many ways the environment in which the system is required to operate is very severe. Consequently, special care has been taken to design a system suitable to anticipated environmental extremes.

South Florida is the only portion of the Continental United States which possesses a tropical climate. The long months of high temperatures and high humidity are very conducive to growth of mold which can be devastating to delicate electronic components. Such high temperature and humidity are also very conducive to corrosion of metal parts. Many off-the-shelf components are not capable of prolonged operation in such an environment. Consequently, stainless steel or other non-corrosive and fungus resistant parts were employed throughout the system, or else carefully controlled protective coatings were used. To protect the microwave equipment from the rigorous environment, each of the 16 microwave buildings was air conditioned to maintain temperature and humidity within normal ranges. Since this equipment might fail, however, all electronic components were required to perform for extended time periods at 110°F and 95% relative humidity.

The time the system is most needed is during hurricanes, when most public utilities are expected to suffer interruption. Consequently, all outdoor components of the system were designed to perform during winds of 150 miles per hour, and to stand under winds of 175 miles per hour.

South Florida is also the most lightning prone area in the country. Consequently, extensive grounding and electric surge protection has been built into the system. This has been done because the District has had much experience with lost communications from near or direct lightning strikes with more conventional equipment.

Vandalism Protection. As previously noted, vandalism is a major problem in this area. Consequently, extreme measures have been taken to mitigate against this senseless destruction; a few of which will be noted. First, though not always possible, equipment has been designed to maintain as low a profile as possible. This principle is expressed by such techniques as burying all electric conduit as much as possible and encasing all other in galvanized steel pipe. Even outdoor steel boxes are considered
vandal prone. Consequently, RACU's are placed indoors where possible and where no structures exist, they are placed in % inch thick steel boxes. These essentially bullet-proof boxes are then mounted on the inside of a large concrete pipe, set upright. See Figure 3. Water level sensors are placed indoors or in wells, the top of which protrudes about a foot above ground. But even this foot is encased in concrete and capped with a double-locked lid. All the instrumentation is in the well and the "readings" are transmitted via buried cable to the RACU for transmission to the computer. Similarly, the gate position sensors are mounted in galvanized structural steel channels on the water control structure.

Of course, it is quite difficult to maintain a low profile with a 200-foot tower. Consequently, because the most vulnerable element on the tower is the central element of the antenna, which makes an excellent target, the entire dish has been enclosed in a radome. The radome can be penetrated easily by rifle fire, but hopefully, the vital central element will not be hit since it cannot be seen.

Fail Safe Design. Since it is not possible to design anything which cannot fail, effort has been put into producing a system which if it does fail, the consequent damage will be minimized. It has already been noted that remotely operated gates will stop operating if messages are not received every minute from the central computer. Thus, if the communications break down, remote operation of gates will cease. This was felt the safest alternative - preferred over opening full or closing full.

Another fail-safe feature is that all gates are equipped with limit switches which will cause gate motion to stop when the gate reaches the limit of its motion even if the remote command tells the gate to go further. This feature will preclude burning up a gate motor or bending a lead screw if the gate sensor reading is erroneous.

Finally, to protect against erroneous messages, each message from the operator is addressed to a particular MCU or RACU. The receiving unit repeats that address back to the CPU before any task is commanded for it to perform.

Testing. To make certain that all the special reliability features specified were actually incorporated into the system as constructed, an extensive test procedure was incorporated in the contract.

Three types of acceptance tests were incorporated in the contract - design, factory, and field. The contract payments were tied to the first and last of these tests, and the payments were dependent on District approval of the test results.

The design acceptance tests were a series of tests under the most severe environmental conditions envisioned on one element of each type of equipment employed in the system.

The factory acceptance tests were the contractors tests on purchased equipment or on that of his own manufacture. These tests were performed.
on each major component of the system. For instance, each water level sensor was tested for accuracy over its entire range of travel by the Hersey Manufacturing Co., but under ambient conditions. These tests did not require District approval.

The field acceptance tests were performed on the completed system. These tests were a prerequisite to the buy-off. At their conclusion, the District received title to the system. To pass these tests, the system had to perform over a three-week period, under fully exercised conditions with a specified but very limited number of failures.
BOTTOM SEDIMENTS OF LAKE OKEECHOBEE

by

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METHODS

Bottom samples in Lake Okeechobee were collected using two types of equipment. The first type, a Peterson dredge or clam-shell was used for procuring grab samples. The second type, a 3 inch piston corer was used for collecting undisturbed samples of bottom mud as well as peat. Thirty cores of bottom mud were obtained from several locations; 2 cores were also contributed to this study by H. Kelly Brooks of the University of Florida. Eighty grab samples were collected.

Positioning was accomplished during the initial phase of this study by triangulation off of markers and towers using a Brunton compass. During the latter phase, navigational accuracy was improved by calibrating the speed of the boat between markers and then running from a known position to a sampling point along a compass bearing for a carefully measured length of time. Distance to the sampling location was calculated by multiplying the calibrated speed of the boat by travel time. Speed of the boat was calibrated at an engine RPM of 4000; time was measured using a stopwatch; distances between markers were taken from nautical charts. The overall accuracy of our sampling points was believed to be ± 3/8 mile.

The thickness and areal extent of several sediment types was determined in a separate effort using continuous reflection profiling and coring. Methods used in this study were as follows: Bottom samples were taken with a piston corer to provide thickness calibration for the subbottom record. Samples were taken at approximately 2 nautical mile intervals.
Continuous Reflection Profiling (C.R.P.) was accomplished with a 7 KH z system modified for high resolution shallow water profiling. Previous experience with shallow water organic mud deposits (Dinner Key Marina, Miami, Florida) was used to establish initial equipment adjustment. No variation in adjustment was required during the entire survey with the exception of record displacement on the record. The results of the C.R.P. records were used to provide qualitative continuity in data between core stations. In most cases (80%) the presence of muds produced a medium to strong 1st and 2nd multiple. In some cases the bottom muds showed up well as a semi-transparent bottom layer in the record. Harder bottom of sand or shell produced a bottom multiple, and a clean bottom/subbottom first return. Using these general acoustic responses, caused by characteristics material response and water column filtering, tracking of the thin mud veneers was made possible. A chart speed of 1" per minute was used at a boat speed of approximately 5 knots.

Bathmetry was run simultaneous with the C.R.P. using a high precision 200 KH z system. A Raytheon DE 719 Recorder was employed. This high frequency does not penetrate solid muds and the system provides an accurate record of depth and bottom topography. Since a common recorder was used for bottom and C.R.P. records, a slight vertical displacement was introduced between the bottom and C.R.P. trace on the record. Core samples were taken to provide a quantitative determination of mud thickness and the nature of bottom materials. A specially constructed, light weight, 6' piston core assembly was mounted on an aluminum extension handle. Viewing slots were cut in the side of the aluminum core tube and a scale marked on its side. This system permitted a rapid length of core evaluation. The sample was then extruded to examine the bottom materials. In each case the core was driven in to refusal. Positioning was accomplished by utilizing known departure and terminal points where possible. Lines were run by ship's compass at constant speed and stations established at measured time intervals. Bearings were taken from obvious landmarks, towers, and marine navigation aids, at every station when range and visibility permitted. Angles between reference points were measured with a sextant and plotted with a three arm protractor. Selected transect lines were run as close as possible. Actual lines are recorded, and final positions are accurate to within ±1/4 nautical mile.

Analyses of Lake Okeechobee muds for Ca O, Mg O, Fe₂O₃, and SiO₂ were performed using the LiBO₂ technique of Medlin, et al. (1969). NBS standards 633, 634, 982, 915, 1b, 91 and G. Frederick Smith Chemical Co. limestone and dolomite standards 400, 401, 402, 403 were used in the analyses. Results are reported as percent of the dry weight at 110°C. Accuracy and precision are ±5% of the amount present. Forty-eight samples were analyzed.

Sediment samples were sent out to the United States Bureau of Mines (Pittsburgh) for determination of percentage, nitrogen, sulfur and ash. The methods used were those in the 1974 Annual Book of ASTM Standards, Designations D3174-73, D3176-74, D3177-73, D3178-73, D3179-73. The nitrogen determination was based on a Kjeldahl type analysis. The ash determination at a temperature of 700-750°C did not involve a loss of carbon dioxide from carbonates. Sixty-two grab samples and about twenty other miscellaneous samples were analyzed in this manner.

Total phosphorus content of bottom sediments was determined using the LiBO₂ fusion technique of Medlin, et al. (1969). A 100 mg sample of sediment
mechanically mixed with 500 mg of LiBO₂ flux, placed in a graphic crucible, and heated to 1000°C for ten minutes. The molten mixture was then poured into a nalgene beaker containing 40 ml of 3% HNO₃ and stirred until dissolution of the fluxed sample. The resulting solution was analyzed for phosphorus with a Technicon Autoanalyzer.

Using this method, standard orchard leaves, NBS 1571, gave a phosphorus concentration of .193% or 91% of the preliminary National Bureau of Standards value. The maximum standard deviation from the mean of any of the samples analyzed was ± 1.4 μg/gm.

Microscopic examination of all sediments was performed using a Leitz Ortholux Pol II and micrography, using an Orthomat W accessory.

DATA AND RESULTS

Sediments

Control points for sediment distribution and chemistry maps are given in Figures 1, 2 and 3. Four types of bottom were found as pictured in Figure 4: sand, mud, rock-marl, and peat. Boundaries between different facies were generally sharp with little intergradation. A quartz sand was found in a rectangular-shaped area towards the marsh on the northwest side of the lake; the interface of this deposit with other facies paralleled the NE-SW trending boundary of the lake. The sand was relatively devoid of other constituents but did contain marine shells, notably Chione cancellata. Rock and semi-consolidated marl were found over a large section of the lake parallel with the Rocky Reef extending up the northeast side past Chancy Bay. Peat appears to comprise that part of the bottom located south of a line drawn between Pahokee and Clewiston; the peat rises in elevation towards the south and appears to thicken towards Ritta and Kreamer islands. An eighth of a mile north of Ritta Island, the peat exceeded four feet in thickness whereas half a mile out, the peat approximated two feet in thickness. The surface of the peat at Station I (Fig. 1) north of Ritta Island was under 5.1 feet of water when the lake was at an elevation of 12.92 feet above MSL.

Mud, a black to dark grey, fine-grained sediment covered most of the interior deeper-water areas in the form of a sack-shaped deposit (Fig. 4). A contour map of the copropeel was constructed on the basis of CRP recordings and coring and is presented in Figure 5. The mud varied from a feather edge to a maximum of about 32 inches. Two discrete areas of maximum thickness occurred towards the lower end of the sack-like configuration (Fig. 5). Rangia cuneata (Sowerby) valves regularly occurred mixed with mud in a small area of thin mud as an appendix to the deposit towards its southwestern extremity. Rangia is a brackish water clam; within the lake it is definitely fossil and is a primary component of an unconsolidated marl that underlies the mud. Flocculent mud usually less than two inches thick sometimes occurred in the rock-marl province on the north flank of the Rocky Reef in proximity to the mud.

The total volume of the mud was determined in the following manner. An area of the mud was established which excluded the province in Figure 4 labeled "thin mud on Rangia shells." The deposit was assumed to take the general cross-section of a biconvex lens. Contour lines were plotted at six inch intervals and each interval was assigned an average thickness equal to
Figure 6 - ERTS Multispectral imagery showing distinct pattern in northeastern quadrant where mud is located. Radiance imagery from Bands 5 and 6.
the sum of the lower contour plus one-half of the contour interval. Areas of intervals between contour lines were established by planimeter. Volume was determined by multiplying an interval area by its average thickness; volumes of all intervals were summed to obtain a total volume of the mud. The closure of the zero inch thickness contour located near the mouth of the Kissimmee River was assumed to be more narrow than is actually pictured in Fig. 5 and the zero inch line was also moved in closer to the 6 inch contour along the southern end of the deposit in order to achieve a conservative estimate of volume. Considerable variation in thickness existed in the northern portion of the map and here a best fit was made on all available data. Errors in contouring north of latitude 27°05' would have a small effect upon the total volume due to the smaller area and thickness involved. The total area of the deposit was calculated as 128 square nautical miles; total volume of mud was calculated as 263 x 10^6 cubic yards or 201 x 10^6 cubic meters.

Particle size analysis of the mud was different because of its high organic content. Analysis of material collected at Station 78 indicates that 93% of mud by weight was less than 74 μm. Calcium carbonate was present as a fine silt in the size range of 2-5 μm. Quartz grains appeared to be slightly larger.

ERTS multispectral imagery evidenced a pattern which closely resembled the distribution of the mud (Figure 6). Possibly this reflects turbidity created by wind driven waves stirring up the fine flocculent material comprising the mud.

The mud extends south from the Kissimmee River - Nubbin Slough area covering the deeper portions of the lake bottom. Elevations of surface mud are greater at the north end of the lake than at the latitude of Canal Point. The mud does not occur in deep water (1 ft. above MSL) north of Pahokee yet it does occur in slightly shallower (3-4 ft. above MSL) water east of the North Lake Shoal. The distribution of the sediment towards the north end of the lake particularly towards the mouth of the Kissimmee River, the presence of mud at higher elevations at the north end and the absence of mud at slightly lower elevations off of Pahokee suggest that the source of some of the detrital components of the mud may have been the Kissimmee River.

Examination and Chemical Analysis of Mud (Copropel)

The mud possesses both allochthonous and autochthonous characteristics. It contains pollen grains, primarily pine and chenoam; plant fragments including water lily scleroids, sclerified xylem cell walls, leaf fragments containing stomata, sawgrass leaf parts, and roots. It contains humic material, sponge spicules and phytoplankton remains, abundant fecal pellets and aquatic arthropod fragments, shell fragments, ostracod valves, quartz grains and CaCO₃ silt. Seeds of two types have been found as well as seed coats. Chara oogonia have also been recognized. Pyrite (FeS₂) granules are present within some of the plant material.

Examination of the presence or absence of these constituents with depth in core L0 29 (Table 1) shows that the mud is copropellic, using the description provided by Cole (1974), to a depth of 50 cm; fecal pellets fade out below this depth. Pediastrum simplex, the alga used by Joyner (1974) as an index of eutrophic condition is present throughout the core to a depth of 73 cm. Scenedesmus quadricauda and Pediastrum boryanum are both present at depth in the core.
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<tr>
<td><strong>Pediasastrum borvanum</strong></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td>X</td>
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<tr>
<td><strong>Scenedesmus quadricauda</strong></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Rock present on the highest portions of the Rocky Reef appeared to be solution weathered and bored extensively by the isopod, *Sphaeroma terebras*, which drills numerous small pits 6 mm in diameter. Sponges and periphyton were found coating the rock in abundance.

*Rangia cuneata* (Sowerby) valves found mixed with the mud show signs of chemical corrosion and possibly some mechanical abrasion. Numerous valves show shell material removed from beaks of the valves but not clear cut mechanical abrasion along the shell edges. Some valves appear to be chemically etched with dissolution either widening a gastropod drill hole and/or directly causing an aperture in the shell in a biased, apparently weak, position. Valves present in the carbonate marl underlying the mud do not exhibit these characteristics.

*Rangia* flourished in the lake in geologic time when the lake was still slightly saline. It is present in the lake only as a fossil. It is found at present as an extant form in the St. Johns River as far south as Palatka, where the water is nearly fresh for all practical purposes (letter, Fred G. Thompson, June 6, 1975).

The lignin-humus fraction of the mud, which represents resistant organic material, forms a significant portion of the material on a weight basis (Table 2). Lignin-humus varies from 17.3% to 25.1% of the mud weight. This data suggests that a large portion of the organic matter was transported into the basin rather than deposited in situ by phytoplankton.

The mud is nitrogen and phosphorus rich compared with other bottom types (Figures 7 and 8). Surprisingly, it is two to three times richer in phosphorus than surface peats at the south end of the lake though organic material is in greater abundance in the peats. The rank of phosphorus concentrations in various bottom types if mud > peat > sand. Rock-marl was not analysed. Nitrogen concentrations are relatively high in the mud considering its high ash content; about one-half to one-third the concentration in peats. The ranking of nitrogen concentrations according to sediment types is peat > mud > sand.

Percent ash (Figure 9) and sulfur (Figure 10), in bottom sediments can be grouped according to sediment type. As expected the ash content of sand is nearly 100%, whereas that of mud averages about 60%; peat contains the smallest amount 19 - 37%. Sulfur is highest in the most organic sediment type, peat, and decreases with increasing ash; mud contains about four-tenths of one percent S, and the sand contains none.

Forty-eight samples of mud, collected at the surface and at depth, revealed the following mean oxide concentrations (Table 3): SiO$_2$, 36.5%; Al$_2$O$_3$, 3.2%; Fe$_2$O$_3$, 2.71%; CaO, 19.7%; MgO, 4.6%. The geographic distributions of values for each component are shown in Figures 11-15. CaO principally reflects CaCO$_3$ and the mean value for all samples represents about 35% calcium carbonate.

The calcium oxide concentration of the mud appears to be considerably less near the mouth of the Kissimmee than in the main body of the mud farther south. SiO$_2$ on the other hand is higher at the north end than below the latitude of North Lake Shoal. MgO, which may be present in organic matter,
TABLE 2

Ash-free lignin-humus composition of copropel or mud on an oven dried (105° C) weight basis.

<table>
<thead>
<tr>
<th>Sample Station</th>
<th>% Lignin-humus</th>
</tr>
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<tbody>
<tr>
<td>28</td>
<td>21.2</td>
</tr>
<tr>
<td>36</td>
<td>25.1</td>
</tr>
<tr>
<td>44</td>
<td>20.6</td>
</tr>
<tr>
<td>51</td>
<td>17.3</td>
</tr>
<tr>
<td>53</td>
<td>21.6</td>
</tr>
<tr>
<td>54</td>
<td>18.9</td>
</tr>
</tbody>
</table>

Figure 15

PERCENT ALUMINUM (Al₂O₃)
IN ORGANIC MUD SAMPLES
© Pahokee
<table>
<thead>
<tr>
<th>Sample No.</th>
<th>SiO$_2$%</th>
<th>Al$_2$O$_3$%</th>
<th>Fe$_2$O$_3$%</th>
<th>CaO%</th>
<th>MgO%</th>
</tr>
</thead>
<tbody>
<tr>
<td>LO Core 26, 59-64 cm (Q)</td>
<td>34.7</td>
<td>3.2</td>
<td>2.50</td>
<td>12.8</td>
<td>3.6</td>
</tr>
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<td>2.63</td>
<td>20.6</td>
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<td>L078</td>
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<td>4.0</td>
<td>3.25</td>
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<td>4.8</td>
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<td>3.10</td>
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<td>1.74</td>
<td>14.0</td>
<td>3.1</td>
</tr>
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<td>4.0</td>
<td>3.41</td>
<td>20.9</td>
<td>6.3</td>
</tr>
<tr>
<td>L028</td>
<td>34.6</td>
<td>4.4</td>
<td>3.28</td>
<td>14.2</td>
<td>4.4</td>
</tr>
<tr>
<td>L056</td>
<td>39.0</td>
<td>3.0</td>
<td>2.76</td>
<td>17.0</td>
<td>4.3</td>
</tr>
<tr>
<td>LO Core 22, 22-24 cm (F)</td>
<td>27.0</td>
<td>2.7</td>
<td>2.83</td>
<td>30.2</td>
<td>6.0</td>
</tr>
<tr>
<td>L038</td>
<td>69.8</td>
<td>1.8</td>
<td>2.04</td>
<td>3.0</td>
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<tr>
<td>L074</td>
<td>36.5</td>
<td>3.4</td>
<td>3.20</td>
<td>15.0</td>
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<td>84.2</td>
<td>1.2</td>
<td>1.40</td>
<td>3.8</td>
<td>1.4</td>
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<tr>
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<td>29.0</td>
<td>3.3</td>
<td>2.94</td>
<td>26.2</td>
<td>5.8</td>
</tr>
<tr>
<td>LO Core 22, 46-48 cm (I)</td>
<td>26.8</td>
<td>2.7</td>
<td>2.66</td>
<td>18.2</td>
<td>7.4</td>
</tr>
<tr>
<td>LO Core 26, 46-49 1/2 (O)</td>
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<td>2.7</td>
<td>2.24</td>
<td>21.2</td>
<td>5.2</td>
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<td>3.8</td>
<td>2.85</td>
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<td>4.2</td>
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<td>LO Core 26, 31-34 1/2 cm+</td>
<td>31.2</td>
<td>2.8</td>
<td>2.62</td>
<td>20.6</td>
<td>8.2</td>
</tr>
<tr>
<td>36 1/2-40 cm</td>
<td></td>
<td></td>
<td></td>
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<td>L032</td>
<td>41.7</td>
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<td>2.72</td>
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<td>3.3</td>
<td>3.34</td>
<td>19.5</td>
<td>6.2</td>
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<td>29.1</td>
<td>4.2</td>
<td>3.00</td>
<td>23.6</td>
<td>4.5</td>
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<td>LO Core 26, 0-9 cm (J)</td>
<td>32.8</td>
<td>3.8</td>
<td>3.06</td>
<td>15.0</td>
<td>4.4</td>
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<tr>
<td>L044</td>
<td>33.4</td>
<td>3.8</td>
<td>3.33</td>
<td>16.0</td>
<td>5.2</td>
</tr>
<tr>
<td>L052</td>
<td>37.8</td>
<td>3.0</td>
<td>2.72</td>
<td>21.2</td>
<td>4.4</td>
</tr>
<tr>
<td>L010</td>
<td>28.3</td>
<td>4.2</td>
<td>2.97</td>
<td>24.0</td>
<td>5.5</td>
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<td>29.0</td>
<td>3.4</td>
<td>2.74</td>
<td>18.7</td>
<td>4.3</td>
</tr>
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<td>L076</td>
<td>34.4</td>
<td>3.0</td>
<td>2.96</td>
<td>20.1</td>
<td>4.4</td>
</tr>
<tr>
<td>LO Core 26, 40-44 (N)</td>
<td>30.8</td>
<td>2.6</td>
<td>2.72</td>
<td>19.2</td>
<td>6.1</td>
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<td>L039</td>
<td>46.6</td>
<td>3.3</td>
<td>3.42</td>
<td>5.8</td>
<td>2.9</td>
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<td>LO Core 26, 9-16 cm (K)</td>
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<td>3.1</td>
<td>3.08</td>
<td>18.0</td>
<td>3.8</td>
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<td>L054</td>
<td>34.0</td>
<td>3.3</td>
<td>2.98</td>
<td>20.0</td>
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<tr>
<td>L012</td>
<td>66.3</td>
<td>1.7</td>
<td>1.53</td>
<td>15.8</td>
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<tr>
<td>LO Core 22, 39-41 cm (H)</td>
<td>21.6</td>
<td>1.6</td>
<td>1.50</td>
<td>41.0</td>
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<tr>
<td>LO Core 12 0-20 1/2 cm (C)</td>
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<td>L030</td>
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<td>3.8</td>
<td>3.50</td>
<td>16.0</td>
<td>5.5</td>
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<tr>
<td>LO Core 22, 31-34 cm (G)</td>
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<td>2.7</td>
<td>2.44</td>
<td>26.5</td>
<td>8.5</td>
</tr>
<tr>
<td>L055</td>
<td>35.0</td>
<td>3.4</td>
<td>2.95</td>
<td>19.8</td>
<td>4.8</td>
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<td>35.1</td>
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<td>3.22</td>
<td>17.6</td>
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<td>2.20</td>
<td>37.4</td>
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<td>LO Core 22, 39-41 cm (H)</td>
<td>22.6</td>
<td>2.0</td>
<td>1.73</td>
<td>38.9</td>
<td>6.1</td>
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<td>33.9</td>
<td>4.3</td>
<td>2.93</td>
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<td>5.9</td>
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<tr>
<td>L05</td>
<td>22.9</td>
<td>3.5</td>
<td>2.14</td>
<td>37.0</td>
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<td>L031</td>
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<td>3.0</td>
<td>2.45</td>
<td>21.5</td>
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<td>LO Core 22, 10-13 cm (E)</td>
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<td>4.0</td>
<td>3.05</td>
<td>14.4</td>
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<td>L037</td>
<td>52.6</td>
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<td>2.84</td>
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<td>2.4</td>
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<td>L077</td>
<td>31.4</td>
<td>2.9</td>
<td>2.44</td>
<td>18.8</td>
<td>4.1</td>
</tr>
<tr>
<td>LO Core 26, 52-56 cm (P)</td>
<td>31.2</td>
<td>2.6</td>
<td>2.47</td>
<td>11.6</td>
<td>3.5</td>
</tr>
<tr>
<td>L053</td>
<td>33.2</td>
<td>3.3</td>
<td>2.92</td>
<td>16.8</td>
<td>4.2</td>
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<tr>
<td><strong>Avg.</strong></td>
<td><strong>36.5</strong></td>
<td><strong>3.2</strong></td>
<td><strong>2.71</strong></td>
<td><strong>19.7</strong></td>
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</tr>
<tr>
<td><strong>SD</strong></td>
<td><strong>11.5</strong></td>
<td><strong>.76</strong></td>
<td><strong>.52</strong></td>
<td><strong>8.53</strong></td>
<td><strong>1.5</strong></td>
</tr>
</tbody>
</table>
silicate clays, and calcium carbonate, appears to be slightly lower in concentration towards the mouth of the Kissimmee. This pattern is not so clear cut with iron which may be present in organic material, clays, calcium carbonate and as an iron oxide precipitate. The average concentration of Fe$_2$O$_3$, 2.7% indicates that iron is relatively abundant in the sediments. Al$_2$O$_3$ represents the silicate clay fraction of the sediments, though the actual clay content would be higher than the average Al$_2$O$_3$ content, 3.2%, because of the weight of other components in the clay.

Analysis of Mud Cores

The number of stratifications in the cores of the mud varies with the thickness of mud and its location in the lake. Core L0 26 (location on Fig. 3) which exhibits 82 cm of mud (Fig. 16), has eight stratifications in contrast with Core L0 22, which exhibits 50 cm of mud and has only three stratifications. The stratifications are of two types; first lag deposits of coarse shells and sand and second, sharply defined compositional changes in fine grained constituents. The lag deposits consist of abundant hydrobiid shells of the species Hyalopyrgus aequicostatus (Pilsbry) (Fig. 17), fragments of Helisoma duryni (Weatherby), and, generally, well preserved shells of Viviparus georgianus (Say). A lens of Viviparus shells was commonly found directly above the marl at the base of the mud. Hydrobiids were most abundant in the upper parts of cores taken in the vicinity of Core 26 than in the lower part. The number and position of lenses of coarse shell material were not always consistent in cores taken only a few yards apart; for example the shell-hash at 20 cm was not found in other cores from that location. Lenses of sand frequently showed graded bedding. All of the lag deposits suggest hurricane or lower-energy storm formation.

Texturally and chemically, Core 26 can be divided into three zones (Table 4). From 0 to 18 cm the mud possesses a fluid texture, and an intermediate CaO and MgO content ranging from 15 - 18% and 4.4 - 3.8%, respectively. From 18 - 51 cm, the color of the mud lightens, the mud becomes more compact, and the CaO and MgO are high, ranging from 19.5 to 21.2% and 6.2 - 5.2%, respectively. From 51 cm to the bottom of the core, the mud darkens in color, appears granular and compacted, and the CaO drops strikingly to low concentrations, 11.6 - 14.0%, and MgO also decreases to its lowest values in the core, 3.1 - 3.6%. Core 22 also shows considerable chemical variation with depth but textural variations are not as clear cut as in Core 26.
Figure 16 - Core L026 showing eight stratifications.
Exhibit 17 - Photomicrograph of hydrobiid gastropod shells, *Hyalopyrgns aequicostatus* (Pilsbry); hydrobiids function both as primary consumers of algae particularly periphyton and no detritus feeders.
<table>
<thead>
<tr>
<th>Depth</th>
<th>SiO₂%</th>
<th>Al₂O₃%</th>
<th>Fe₂O₃%</th>
<th>CaO%</th>
<th>MgO%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-9 cm</td>
<td>32.8</td>
<td>3.8</td>
<td>3.1</td>
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<td>9-16 cm</td>
<td>33.7</td>
<td>3.1</td>
<td>3.1</td>
<td>18.0</td>
<td>3.8</td>
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<tr>
<td>24-27 cm</td>
<td>33.0</td>
<td>3.3</td>
<td>3.3</td>
<td>19.5</td>
<td>6.2</td>
</tr>
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<td>31-34 ½ + 36 ½-40 cm</td>
<td>31.2</td>
<td>2.6</td>
<td>2.62</td>
<td>20.6</td>
<td>8.2</td>
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<td>40-44</td>
<td>30.8</td>
<td>2.6</td>
<td>2.7</td>
<td>19.2</td>
<td>6.1</td>
</tr>
<tr>
<td>46-49 ½</td>
<td>38.0</td>
<td>2.7</td>
<td>2.24</td>
<td>21.2</td>
<td>5.2</td>
</tr>
<tr>
<td>57-56</td>
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<td>2.6</td>
<td>2.5</td>
<td>11.6</td>
<td>3.5</td>
</tr>
<tr>
<td>59-64</td>
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<td>3.2</td>
<td>2.5</td>
<td>12.8</td>
<td>3.6</td>
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<tr>
<td>67-75</td>
<td>44.8</td>
<td>2.0</td>
<td>1.7</td>
<td>14.0</td>
<td>3.1</td>
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</table>
REFERENCES


WHAT IS THE CALOOSAHATCHEE MARL?

By

Muriel E. Hunter
Coastal Petroleum Co.
Tallahassee, Fla.

INTRODUCTION

The Caloosahatchee controversy over the stratigraphic position of certain shell beds involves numerous strata occurring in southern parts of the Florida peninsula; various geologic names, some of which are now obsolescent; and a prolific accumulation of literature that is filled with conflicting interpretations and data. Involved are incomplete river outcrops; radiometric, vertebrate and mollusk dates; also typical localities that have been cut away by dredging or inundated by controlled water levels behind dams. Required is a review of confusing facts and ideas accumulated over a 90-year period. The task is to present a short, meaningful, and understandable answer to the question, "What is, or what can be done with, the Caloosahatchee marl?"

This paper, then, will

1. Outline the current stratigraphic terminology;
2. Discuss the major boundary problems; and
3. Suggest for discussion a stratigraphic column that recognizes the destruction or flooding of the surface outcrops in typical areas, and the difficulties involved in identifying very thin, patchy, surface units, especially in the subsurface.

Surface units described by the early authors were defined as genetic units: a group of strata that were related by their fossils, or by age, or by elevation, and/or any other characteristics that might be noticeable. Sedimentary units considered equivalent in age were usually given a formation name, and the name was often extended far from its original area to strata believed to contain the same fauna, or to be of the same age, regardless of lithology or the sequence of beds. This same principal has been used as recently as the 1960's, and has resulted in many of our present formation definitions (such as "all beds of 'x' age...", or, "all beds above 'x' formation and below 'y' formation...") which lack boundary or internal definition. This early terminology has probably been the source of most of the controversy discussed here: "How do we tell one from the other?"; "How old is an isolated shell bed?", or, "Where shall we place the boundary between the two aged formations that look alike?"

CURRENT AND SUGGESTED STRATIGRAPHIC TERMINOLOGY

Figure 1 shows the composite stratigraphic terminology currently approved by the Florida Bureau of Geology for Quaternary strata exposed in
<table>
<thead>
<tr>
<th>System</th>
<th>Series</th>
<th>Formation</th>
<th>Member</th>
<th>Stratigraphic Units</th>
<th>Lithologic Character</th>
<th>Maximum Thickness</th>
<th>Faunal Composition Key Species, Dominant Forms</th>
</tr>
</thead>
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<tr>
<td>QUATERNARY</td>
<td>PLEISTOCENE</td>
<td>FORT THOMPSON</td>
<td>COFFEE MILL HAMMOCK MARL</td>
<td>LIGHT GRAY to TAN SANDY SHELL MARL</td>
<td>6 FT</td>
<td>Haliotis siliqua (JAY)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Upper Fresh-Water MARL</td>
<td>GRAY, HARD SANDY LIMESTONE</td>
<td>2 FT</td>
<td>Haliotis siliqua (JAY)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lower Fresh-Water MARL</td>
<td>LIGHT CREAM to BUFF to TAN MARL</td>
<td>2 FT</td>
<td>Haliotis siliqua (JAY)</td>
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<tr>
<td></td>
<td></td>
<td>COFFEE MILL HAMMOCK MARL</td>
<td>SANDY SHELL MARL</td>
<td>1 FT</td>
<td>Chamaeleolus collaris</td>
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<td></td>
<td></td>
<td>Lower Fresh-Water MARL</td>
<td>LIGHT CREAM to BUFF or TAN MARL</td>
<td>2 FT</td>
<td>Haliotis siliqua (JAY)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Panope FAUNIZONE</td>
<td>CREAM to TAN SANDY SHELL MARL</td>
<td>1.5 FT</td>
<td>Panope flustra (HEILPRIN)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MARINE LIMESTONE</td>
<td>CREAM to YELLOW, SANDY MARL, LIMESTONE LIGHT to BUFF</td>
<td>1 FT</td>
<td>Chamaeleolus collaris (LINNE')</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SHELL BED</td>
<td>ARENASCOUS SHELL MARL and TAN to YELLOW-BROWN SAND</td>
<td>10 FT</td>
<td>Chamaeleolus collaris (LINNE')</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>BEE BRANCH MEMBER</td>
<td>HARD, SOLUTION-RIDDLED MARINE LIMESTONE or MARL</td>
<td>5 FT</td>
<td>Chamaeleolus collaris (LINNE')</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FRESH-WATER MARL and BRACKISH-WATER MARL</td>
<td>GRAY HARD DENSE CALCAREOUS MARL, MARINE CALCAREOUS MARL</td>
<td>1 FT</td>
<td>Chamaeleolus collaris (LINNE')</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CALOSAHATCHEE</td>
<td>FORT THOMPSON</td>
<td>OYSTER BISTROME</td>
<td>UPPER UNIT, SOFT CREAM to GRAY MARINE MARL with Spondylus lebini and Fasciolitapa saltvina LOWER UNIT, SOFT CREAM to GRAY MARL</td>
<td>2 FT</td>
<td>Various species of Palagrostylis, Vermeturia recta OLSSON, and HARRISON</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CYTRANTELA COSTATA FAUNIZONE</td>
<td>SOFT SANDY, CALCAREOUS</td>
<td>1 FT</td>
<td>Various species of Palagrostylis, Vermeturia recta OLSSON, and HARRISON</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MARINE MARL</td>
<td>WHITE to LIGHT GRAY, FLAT, CONCRETIONARY, CHALKY MARL</td>
<td>2.5 FT</td>
<td>Anadara Scalarina (HEILPRIN)</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1 - Composite stratigraphic section of the Quaternary showing stratigraphic terminology in the Caloosa-hatchee River area. (Copied from Puri & Vernon, 1964, fig. 35)
the area of the Caloosahatchee River (Puri and Vernon, 1964, fig. 35). Not shown by this composite figure is the fact that no such continuous section has ever been found, nor has any evidence been recorded for a maximum total thickness of over 60 feet of Quaternary strata near the river. Not shown are the many thin outcrops, in which exposures of only two or three thin beds are usual.

Also not evident is the fact that not all geologists agree on the State-approved divisions of the Caloosahatchee River strata, nor on the placement of boundaries within them. Figure 2 shows an attempt to reconcile three different interpretations in one guide book (Miami Geological Society, 1968, addendum). Similar variations in geologic opinions about the Caloosahatchee River outcrops have become traditional.

I have discussed with several local geologists the problem of identifying and correlating the various thin shell beds found in the subsurface of southern Florida contiguous to the Caloosahatchee River, and all of these men indicated that division of the beds into the present number of formation and member units is a major problem when attempting to do shallow subsurface stratigraphic work. My own experience with 10-foot samples and/or small diameter cores supports their viewpoint.

Since most of the type or typical exposures have been destroyed or covered, presumably future emphasis will have to be on subsurface work. Figure 3 suggests one way in which such work can be done with reasonable accuracy. The extension of the Fort Thompson Formation upward and downward in the column to include all interbedded marine, brackish, and fresh water deposits of roughly Pleistocene age will still involve only a thin rock interval, and will permit the subsurface geologist to map one instead of 8 or 9 discontinuous units in a section that may be no more than 9 or 10 feet in total thickness. For those whose work requires finer detail, the original major units are retained as members, while strata of minor importance or of local occurrence are shown as beds. All units still remain available for use whenever they can be identified — only their stratigraphic ranks have been changed.

The suggested terminology is as follows:

Surface sands, soils, and mucks

Fort Thompson Formation

Lake Flirt member
Pamlico sand beds
Coffee Mill Hammock Member
Okaloacoochee member)
Belle Glade member ) More or less equivalent and
interfingering
Caloosahatchee member
Ayers Landing beds
Bee Branch beds
Fig. 2 - Chart reconciling three interpretations of the Caloosahatchee River strata by three authors in one publication (after addendum to "Miami Geological Society Guidebook. "Late Cenozoic stratigraphy of southern Florida", 1963).
Fort Denaud beds

Tamiami Formation (upper part)

Pinecrest Sand Member *  }  More or less  
Buckingham Limestone Member*  }  equivalent &  
interfingering

Tamiami Formation (lower part)

LaBelle clay member *
Ortona sand member *

* = Other members are known from other areas in which the Tamiami Formation is present, but only the four shown above have been recognized along the Caloosahatchee River to date.

Figure 3 also shows a number of radiometric dates obtained on samples from a few of the units and published by several authors during recent years. The Pleistocene/Recent, Pliocene/Pleistocene, and Miocene/Pliocene boundaries are given radiometric ages currently in use: about 10,000, 1,800,000, and approximately 5,000,000 years respectively. The reader should note that Figure 3 is not drawn to scale, and both horizontal and vertical distances are distorted.

Two major unconformities are shown in Figure 3:

(1) The older, between the lower and upper parts of the Tamiami Formation, appears to represent a time span of as much as perhaps 3.5 to 4 million years, and is correlated with a major regional unconformity that may be global in extent. Articulated and disarticulated remains of land vertebrates of Hemphillian age found near present sea level at the Manatee Dam site in Manatee County (Webb and Tessman, 1968) support other evidence for this unconformity, and indicate a stand of the sea at or below its present level during a part of Hemphillian time. The Hemphillian land mammal age is now correlated with a position of about 4 to about 10 million years B.P. on the widely used radiometric scale (Evernden et al., 1964), or roughly from within the upper part of planktonic zone N.16 to within the lower part of zone N. 19 (of Blow, 1969). This time interval includes most of the Late Miocene and a small part of the Early Pliocene (Van Couvering and Berggren, 1977, Fig. 1, p. 289).

(2) The younger, between the eroded top of the Tamiami Formation and the expanded Fort Thompson Formation (Fig. 3) appears to represent a time span of perhaps as much as 2 to 2.5 million years, indicating that an upper part of the Pliocene and roughly 65% to 75% of Pleistocene deposition are unrecorded or have not been recognized in the area of southern Florida. A search for the missing section seems indicated.

Three still younger unconformities shown within the Fort Thompson Formation on Figure 3 are of more or less minor nature, and may be merely local in extent. An average duration of about 50,000 to 75,000 years is postulated for each of these three gaps in the geologic record.
Fig. 3 - West to east schematic geologic cross-section of Caloosahatchee River outcrops in the area near Fort Denaud, Fort Thompson and Ortona Lock. NOT TO SCALE.
A series of thin, discontinuous crusts at the top of many beds within the Fort Thompson might suggest short periods of weathering. These are not shown in Figure 3, but they are typical of many of the erosional contacts at many of the outcrops along the river, including the Fort Thompson type locality (Fig. 4). It is impossible to trace the crusts continuously from one outcrop to another, and even at one locality the crust on any one bed may be discontinuous. These crusts are here accepted as evidence of short-term weathering intervals - periods of minor, local unconformity.

This paper contains no correlations of the Caloosahatchee River strata with the North American glacial and interglacial events, because I believe that we lack firm evidence for such correlations. The only available data are (a) the few radiometric dates that have been obtained from a few parts of the section, and (b) the estimated time of origin for disarticulated fragmentary remains of land mammals. As presently accepted, the animals may have lived during the time of deposition of the sediments in which their remains have been found. However, they may also have lived during an earlier time when the land was exposed, and their remains may have worked up the section into younger beds. For the present, about all that can be concluded from the radiometric dates and the animal remains is an approximate depositional sequence, and the probability that deposition of the Caloosahatchee and younger strata took place during the last one-third or so of Pleistocene time. To me, it therefore seems preferable to delay further age assignments (such as Kansan, Sangamon, etc.) until firm data are available, rather than to postulate such correlations by means of extrapolation.

The expanded Fort Thompson Formation of this paper (Fig. 3) is underlain at shallow depths by strata of either the upper or lower parts of the Tamiami Formation, and it appears to thin over the Tamiami highs. Two of the upper members of the Tamiami have been recognized in the river area: the Buckingham Limestone and the Pinecrest Sand. These members are given a middle to late Pliocene stratigraphic position in Fig. 3, based on Akers report of nannofossils of zone N. 20 (of Blow, 1969) in the Pinecrest Sand in a pit near Sarasota (1974, p. 119). Correlation between the Pinecrest and Buckingham was established by mollusks (Hunter, 1968). Planktonic zone N. 20 has been given an age of about 3.3 million years on the radiometric scale (Steininger, 1977, p. 251), and this age has been assigned to the upper Tamiami sediments in the Caloosahatchee River area.

Two members of the lower part of the Tamiami Formation have also been recognized along the river: the LaBelle clay of Puri, and a new member for which the informal name, Ortona sand member, is here suggested. Although the LaBelle clay has no described fossils, Puri believed it to be more or less equivalent to the Arca zone of northern Florida. Megafossils present in the Ortona sand indicate a closely similar age for this new unit. The Arca zone has been correlated by Huddleston and Wright (1977) with planktonic zone N.17 and perhaps the youngest part of N.16. On the radiometric scale, this interval is given an age of about 8,000,000 years (Van Couvering and Berggren, 1977).

FORT THOMPSON FORMATION

Sellards (1919) restricted the top of the Caloosahatchee marl ("the Pliocene") of earlier authors by removing from its strata which he believed
to be of Pleistocene age, and for which he proposed two names: the Coffee Mill Hammock Marl and the Fort Thompson Beds. Cooke and Mossom (1929) raised the Fort Thompson to formation rank and included the Coffee Mill Hammock as its uppermost member.

As presently defined, the Fort Thompson Formation consists of marine limestones and marls interbedded with fresh or brackish water marls and limestones. It has a type locality at the site of old Fort Thompson, about 1.5 to 1.75 miles upstream from the bridge at the present city of LaBelle in Hendry County, Florida. In 1944, Parker and Cooke (p. 89-90 and Fig. 4) published a detailed description of this outcrop and a figure showing the relationship of the beds (reproduced here as Fig. 4 of this paper). Their figure of only 25 feet along the river bank at the type locality illustrates various reasons why beds in more widely separated outcrops have been so difficult to correlate. Parker and Cooke's formal section for the Fort Thompson overlies the Caloosahatchee marl and underlies the Lake Flirt marl and Pamlico formation as follows:

Lake Flirt marl:

8. Black carbonaceous sand ½ to 1

Pamlico formation:

7. Gray quartz sand with freshwater and land shells mixed in ½ to 1

Fort Thompson Formation:

6. (Coffee Mill Hammock marl member) Marine shell bed usually preserved only in solution holes or caves in lower beds but in places is a few inches thick over the top of the underlying rock 0 to 3

5b. Hard freshwater limestone riddled with solution holes usually filled with overlying marine shells 2 to 3

5a. Soft freshwater calcareous marl cut through by solution holes and usually filled with overlying marine shells 1 to 2

4. Marine shell bed 0 to ½

3. Freshwater shell marl locally hardened in top 6 inches to a hard limestone 1½ to 2

2. Marine shells, present only in low and protected areas in the underlying bed. Probably remnants of a once much thicker bed. Associated with the shells is a thin basal conglomerate 0 to ¼
Fig. 4 - Retouched copy of illustration of Fort Thompson type locality by Parker and Cooke, 1944, p. 89, fig. 4. Note erosional and solution features.
Caloosahatchee marl:

1. Creamy-gray shell marl with an oyster zone at top. To low tide level. 0 to 1

The Fort Thompson has been mapped over most of southern Florida. Its thinly interbedded marine and freshwater limestones have been reported beneath the Miami Oolite in the subsurface under the city of Miami (Parker et al., 1955, p. 85) to a depth of 55 feet below sea level. It has been mapped around Lake Okeechobee, through the Everglades, and north along the Gulf Coast to Pinellas County. Many cemented and sandy shell beds now being referred to the Anastasia Formation along the east coast of Florida are considered to merge westward into the Fort Thompson Formation (Parker et al., 1955, p. 100).

Two members have already been described within the Fort Thompson; the Coffee Mill Hammock Member (Sellards, 1919) and one which DuBar (1958b) described as the Okaloaoochhee Member. Several new members are suggested in this paper for the expanded formation, and other undescribed members may also occur.

Described Members

The Coffee Mill Hammock Member

The Coffee Mill Hammock Member is a fossiliferous marine sand, usually yellowish in color, with many white shells representing numerous species of nearshore mollusks. The most noticeable fossil in this unit is Chione cancellata, which is extremely abundant. In its type area, on the Caloosahatchee River just downstream from Ortona Lock, the Coffee Mill Hammock is usually unconsolidated, but elsewhere it may be cemented with the shells still remaining, or leached to a point where only the fossil molds remain. An average thickness of less than 10 feet and a maximum of probably not over 20 feet has been reported by Parker and Cooke (1944, p. 73). This member is mappable over a wide area from east of Lake Okeechobee to Fort Myers, and north and south of the Caloosahatchee River into Sarasota and Dade counties. Heilprin (1887) referred to this unit as the "Venus cancellata bed" and reported that he found no extinct species in it. However, Pyrazisinus scalatus is now known to occur in it, and it is possible that one or two of the smaller species of bivalves may also be extinct. Turritella subannulata, which has been reported from this unit, was formerly thought to be extinct, but is now known to be still living offshore in the Gulf of Mexico.

Puri and Vanstrum (1971) report Th234/U238 ages of 120,000 to 140,000 years B.P. for three samples taken from the Coffee Mill Hammock Member at DuBar's locality A58 (1958a), which is reportedly at or very close to the original type locality for this unit, in the SE/4, Sec. 27, T.42S., R30E., Glades County.

The Coffee Mill Hammock is usually correlated with the Key Largo Limestone, the Anastasia Formation and the Miami Oolite or Formation. Published dates of 120,000 to 130,000 for the Miami Oolite suggest that this correlation is reasonably close. However, one date on the Key Largo
Limestone of 95,000 years suggests that the part of this unit from which the dated sample came may be as much as 35,000 years younger than the Coffee Mill Hammock. This is a considerable difference when dealing with beds deposited within such a short interval of time, and might be a warning signal that the correlation of the Key Largo and the Coffee Mill Hammock should be re-examined.

The Okaloacoochee Member

The Okaloacoochee member (Dubar, 1958b) consists of two freshwater beds separated by a thin discontinuous marine bed which DuBar (1958a) called the Chlamys bed. According to DuBar, where the Chlamys bed is missing, the freshwater beds appear to be one unit.

No published radiometric date has been found for this unit.

DuBar also restricted the bottom of the Fort Thompson Formation, by removing from it Bed 2 (Fig. 4) described by Parker and Cooke in 1944. In doing so, he said, "...the marine marl thought by Parker and Cooke to represent the base of the Fort Thompson at the type locality is considered by the writer to be an erosional remnant of the upper Caloosahatchee shell bed. Thus the lowest Fort Thompson bed in the type section is a freshwater marl." (1958a, p. 143)

This change in boundary has been the source of a number of divergent opinions. In 1968, the Miami Geological Society field trip visited the Caloosahatchee River area and, among others, papers by Brooks, DuBar and Olsson were published in the field guide. The trip was designed to compare different viewpoints, and a comparison chart issued with the field guide indicated that each of these authors placed this boundary at a different place in the section (Figure 2).

Marine bed #2 of Figure 4, which Parker and Cooke considered the basal Fort Thompson bed and which DuBar considered Caloosahatchee marl, is thin (0 to 3 inches) and discontinuous, and appears to be an erosional remnant. However, there appears to be no sound reason to correlate it with the well preserved fossiliferous upper shell bed downstream to which DuBar gave the name Ayers Landing member, or with his Bee Branch member. It may be equivalent, but it may also be a remnant of a bed that has no equivalent in the outcrop area of the Ayers Landing.

Both outcrops have been destroyed and covered with water, and there now seems to be no way to settle this long-standing controversy. The thin beds described from the outcrop are presumably unrecognizable in subsurface samples, since the cross-sections made by Puri from Corps of Engineers' core holes along the river (1964, Fig. 31-32) show only the Fort Thompson Formation near the type locality, although the Caloosahatchee marl has been seen there at the surface. An arbitrary solution now seems needed.

It is therefore suggested here that the member boundary be placed between the lower two marine beds (Beds 1 and 2) as originally done by Parker and Cooke in 1944. It is also suggested that the Okaloacoochee member be extended to include Bed 2 as a basin marine marl, as formerly exposed at the type locality of the Fort Thompson Formation and the Okaloacoochee member.
Suggested New Members

Expansion of the Fort Thompson Formation as shown in Figure 3 is suggested to simplify stratigraphic terminology in the subsurface and in outcrops away from the Caloosahatchee River. An effort has been made to emphasize lithology, rather than identification solely by means of fossil faunas. As expanded, the formation would include a number of well known formations which have been demoted to member rank. Rock units formerly referred to as members are here considered beds. Each is discussed in more detail below.

Lake Flirt member

Sellards (1919) first used the name Lake Flirt marl to describe a "calcareous mud" of freshwater origin in the area of Lake Flirt, a shallow depression (now drained) along the Caloosahatchee River between Ortona Lock and Fort Thompson.

In 1954, Schroeder (p.20-22) described the unit as being composed of beds of "gray freshwater marl, dark-brown to black sticky muck, sandy muck, and carbonaceous sand", with an average thickness of about 6 feet and a maximum thickness of about 8 feet. He gave a generalized composite section for this member in the Lake Flirt area. He commented that channeling and diastems are common, and considered the organic soils of the Everglades and the Lake Flirt to be in part time equivalents that interfinger. He also gave Carbon-14 determinations for peats from near the base of the organic soils of the Everglades as ranging from 3,800 to 5,050±200 years.

In 1968, Brooks discussed the Lake Flirt. He gave the following section of the Lake Flirt in its type area, (1968, p. 104), and included the Recent soil, saying that is was impractical to separate it.

South bank of Caloosahatchee Canal, 4 miles west of Ortona Lock, Sec. 30, T.42 S., R.30 E., Glades County, Fla.

<table>
<thead>
<tr>
<th>Bed #</th>
<th>Thickness (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Flirt formation</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Sand, mucky, brownish black 7&quot;</td>
</tr>
<tr>
<td>8</td>
<td>Sand, fine, no fossils 6 to 8&quot;</td>
</tr>
<tr>
<td>7</td>
<td>Marl, very sandy, abundant fresh water snails, light olive gray 2 to 8&quot;</td>
</tr>
<tr>
<td>6</td>
<td>Sand, mucky, olive gray to brownish black 8 to 12&quot;</td>
</tr>
<tr>
<td>5</td>
<td>Marl, minor sand, plastic, abundant freshwater snails 0 to 8&quot;</td>
</tr>
<tr>
<td>4</td>
<td>Muck, sandy, plastic, brownish black 8 to 12&quot;</td>
</tr>
<tr>
<td>3</td>
<td>Marl, clayey, minor sand, plastic, yellowish gray, abundant freshwater snails 6 to 10&quot;</td>
</tr>
</tbody>
</table>
Sand, mucky Unconformity

Sand and shell

Below the top two beds of his Lake Flirt Formation, Brooks recognized three divisions: beds 6 and 7; beds 4 and 5; and beds 2 and 3, each consisting of a lower sand or muck overlain by shelly freshwater marls. He reported a C-14 age for the uppermost muck (bed 9) of 7,000 years, well within the Holocene. A second determination reported by Brooks indicated a C-14 age of 20,900 (+1400 or -1600) years for the muck in bed 4. In addition, he tentatively correlated the freshwater marls of beds 5 and 7 at Lake Flirt with similar marls in northern Florida for which ages of 18,000 to 17,000 and 12,500 to 11,000 C-14 years respectively had been obtained.

The problem involving the upper boundary of the Lake Flirt has not yet been resolved. In this paper, the boundary is arbitrarily placed below the Recent soils, based on Schroeder's priority of definition. However, Brooks' extension of the Lake Flirt to include the Recent soils seems reasonable from the viewpoints of practicality, lithology, and the present Code of Stratigraphic Nomenclature (AAPG, 1970).

In view of the thin bedding and the freshwater origin of the Lake Flirt, it is suggested that for practical purposes it should be considered the uppermost member of an extended Fort Thompson Formation. If this is accepted, then the unresolved upper boundary of the Lake Flirt member would also be the upper boundary of the Fort Thompson Formation (Figure 3).

As inferred by Schroeder, the organic material that accumulated at the top of the Pleistocene and Recent Lake Flirt member has been exposed in part to weathering as a result of drainage, and has been extensively converted into a rich organic soil of very recent age. According to the present Code (AAPG, 1970), this soil is not a rock stratigraphic unit. In other places, as illustrated by Parker and Cooke (1944, plate 7), certain lakes in southern Florida are "still adding to the humic mass" at the top of the Pleistocene and Recent Lake Flirt member.

Pamlico beds: According to Parker and Cooke (1944, p. 74), the name Pamlico originated in North Carolina, where Stephenson (1912, p. 286-290) used it for fine sandy loams, sands and clays, together with a few gravels, all at elevations seldom higher than 25 feet. Cooke, in his works on "marine terraces" (1931 and later) used the name Pamlico for his 25-foot "terrace deposit", and extended the name and "terrace" into South Carolina and Georgia under this definition. Parker and Cooke extended the name Pamlico into Florida to cover all Pleistocene marine deposits younger than the Anastasia Formation and, according to their belief, occurring at elevations at or below 25 feet. They included almost pure quartz sands to shelly sands, loose to locally consolidated, and described the sand as mostly white but locally stained black by an organic coating; varying in size from fine to coarse, but with most grains within the medium size range.

Thus, by definition, before including a sand bed in the Pamlico "Formation", we should know definitely that it is younger than the Anastasia
Formation but still of Pleistocene age. In actual practice, this is difficult (if not impossible) to determine. Lacking this criteria, we find there is no real definition of the Pamlico of Florida:

1. It has no type section or area.
2. It has no described boundaries, either upper or lower.
3. It is apparently not homotaxial with the type Pamlico Formation of North Carolina as described by Stephenson.
4. The Pamlico "Formation" has already been described in several ways, with the result that another redefinition can only lead to further confusion.
5. It would appear that the spotty nature of the Pamlico would make it unmappable, at least in the Caloosahatchee River area.
6. The inclusion of black organic-stained sands in the Pamlico can make it lithologically inseparable from the Lake Flirt where both units are present.

The last two items are supported by the fact that Puri (1964, fig. 31-32) mapped the Lake Flirt and Pamlico as undifferentiated in his cross-section along the Caloosahatchee River, thus indicating that no consistent difference was seen in core holes. Brooks (1968, p. 14) comments "It can readily be shown that the surficial sands of the coastal plain associated with the 'marine terraces' are heterogenetic and heterochronic. In some places they represent beach dune deposits, and regresional sand, but in many cases they are nothing more than soil profiles developed in the normal course of soil formation".

In the Caloosahatchee River area, many geologists refer the very light grey sands that occur locally just above the Coffee Mill Hammock Member to the Pamlico "Formation". It is not known whether these sands represent a separate marine unit, an upper regressive or leached part of the Coffee Mill Hammock, or a leached lower part of the Lake Flirt. Also unknown is their relationship to the Anastasia Formation. Lithologically they seem closest to the Lake Flirt.

It thus seems obvious that the Pamlico "Formation" of southern Florida has few, if any, of the characteristics of a formal lithostratigraphic unit. Perhaps the name should be abandoned completely, at least in the Caloosahatchee River area, or reduced in rank for informal use wherever it is separable, as shown in Figure 3.

Belle Glade member

Belle Glade member, including the Fusinus watermani assemblage zone (= Unit A of Olsson, 1964).

In the early part of 1961, a rock pit located a mile south of the city of Belle Glade in Palm Beach County had a maximum subsurface depth of 30 to 35 feet. In freshly dredged spoil piles, it was possible to
distinguish a number of different types of sediment, such as marine shell
marls, freshwater marls, and muddy brackish water sediments, parts of which
were indurated. However, the pit was never dewatered, and the actual number
and sequence of the beds in the pit remain unpublished.

Since the type of preservation and the matrix within fossils are often
indicative of the beds in which the fossils originated, it was possible
while spoil piles were present to ascertain that several marine units and
at least as many freshwater units were present in the pit, with the strong
probability that additional strata were also present but not separable. A
fairly comprehensive list of the fossils collected from spoil in the Belle
Glade pit was published by S. Hoerle (1970, p. 56 to 68). Material in spoil
contained fossils and matrix suggestive of the Coffee Mill Hammock Member of
the extended Fort Thompson Formation. Although the member was not exposed
at Belle Glade, it was seen above water level in another pit at the water
plant for the town of South Bay. It has thus been concluded that the Coffee
Mill Hammock is present in the Belle Glade area. Spoil at Belle Glade pit
also contained an abundance of the same species of pecten that is in the
Chlamys bed of the Okaloacoochee member of the extended Fort Thompson
Formation.

A third marine unit, which the pit operators said had come from the
bottom of the pit, contained a faunal assemblage that consisted mostly of
extant species of mollusks, but which also included a few extinct species
carried over from the Caloosahatchee Member and several other extinct species
that appear to be limited to this horizon (such as Fusinus watermani, Murex
anniae, and Anadara catasarca). The quality of preservation of the assemblage
at this pit is distinctive, and the fossils are easily recognizable by their
high gloss, ivory to gold or gray color, and the hard, very calcitic character
of the shell material. Many geologists and paleontologists who are know-
ledgeable about Florida marine fossils have agreed that this is a previously
unrecognized assemblage mapped as Caloosahatchee marl prior to about 1964
(Olsson).

For discussion in this paper, the informal name, Fusinus watermani
assemblage zone, is used in referring to this faunizone (i.e., this third
group of rocks identified by the fossil assemblage it contains) which Olsson
called Unit A in 1964.

The F. watermani assemblage zone has been identified in the shallow
subsurface at Fort Thompson and Ortona localities to the west; southeastward
along Route 27 as far south as the Palm Beach/Broward county line; north
along the eastern edge of Lake Okeechobee almost to the Martin/Okeechobee
county line; and at many scattered localities elsewhere. At many of the
places where the F. watermani zone was recognized, there was also some
evidence of the presence of freshwater beds. Only near Belle Glade and at
the new pit near South Bay did the fossils from this faunizone exhibit the
unusual preservation described above. Elsewhere, the zone appears as
unconsolidated sandy material with the fossils ordinarily preserved, or as
poorly to well indurated rock in which the fossils were partly or wholly
leached.

Unfortunately, at no place has the author been able to acquire the
data necessary for description of the lithostratigraphic unit containing the
F. watermani fauna. No section usable as a type section has been observed;
the upper and lower boundaries of the member are unknown. As discussed,
the lithology of the entire series of beds in the Belle Glade pit is that of
the Fort Thompson Formation, and the F. watermani zone is identifiable solely
by the fossils it contains - a biostratigraphic unit rather than a member

Nevertheless, it is suggested here that the undescribed lithostrati-
graphic unit that includes the F. watermani assemblage zone and closely
associated brackish or fresh water beds should be informally referred to as
the Belle Glade member of the Fort Thompson Formation. As demonstrated above,
the Belle Glade member, at least in part, is a correlative of the Okaloacoochee
Member.

Caloosahatchee Member

Compared with the Caloosahatchee River beds of Dall (1892) and the
widespread Florida "Caloosahatchee Formation" of Cooke (1945), the present
Caloosahatchee unit is greatly restricted in thickness and areal extent. In
the river outcrops, members of the Fort Thompson Formation are recognized
above it and members of the Tamiami Formation below it. I have seen equally
thin deposits of Caloosahatchee marl, and some even thinner, in the subsurface
at dewatered canal excavations around the western edge of Lake Okeechobee,
and at the site of Pump Station 8 on the Miami Canal at the Palm Beach/
Broward county line.

In a cross-section based on core samples taken by the Corps of Engineers
along the river, Puri (1964, fig. 31-32) shows the Caloosahatchee Formation
in its type area (W-6766 to AS277) as deposited in a low roughly four miles
wide between two erosional highs in the underlying Tamiami Formation. The
low occurs east of Fort Denaud and west of LaBelle. The maximum thickness
of the Caloosahatchee in these holes is about 15 feet, with exposures at
river level being about 8 or 9 feet in thickness. Further east, between
Ortona Lock and Lake Hicpochee, (W-6792 to W-6803), he also shows shell beds
(maximum thickness 24 feet) that he assigned to the Caloosahatchee Formation.
However, later recognition of the presence in this area of the Belle Glade
member (new) of the Fort Thompson and the Pinecrest Member of the Tamiami
suggests that both of these units may also be included in the 24 feet of
shell beds found in this series of cores.

The presently used interpretation of the Caloosahatchee Formation is
that made by DuBar and published in two articles (1958a and 1958b). He
identified a number of thin beds in the type area and proposed three members:
the discontinuous Ayers Landing shell bed at top, the most widespread Bee
Branch limestone and marl, and the discontinuous Fort Denaud shell beds at
the bottom, each having individual characteristics (Fig. 1). He also recog-
nized the presence throughout the Caloosahatchee Formation of beds of fresh
and brackish water origin, as well as mixtures of fresh, brackish and marine
shells in marine beds, indicative of nearby land areas.

Brooks (1968, and fig. 2 of this paper) suggested that the Ayers
Landing is a basal part of the Fort Thompson Formation. His interpretation
is reasonable, based on lithologic correlation with the Belle Glade member
(Unit A), the lack of definite stratigraphic limits (ranges) for Plio-
Pleistocene mollusks, and the probability of finding reworked mollusks in
channel deposits, especially if mixed fresh, brackish and marine species are
present together. This controversy can be somewhat diluted by placing all
of the Caloosahatchee sediments in the expanded Fort Thompson Formation as the lowest member.

DuBar's work (1958a) included the important discovery of land mammal remains of middle to late Pleistocene age throughout the section which he assigned to the Caloosahatchee marl. Prior to this discovery, the Caloosahatchee had been assigned a Pliocene age, based on Lyell's theory concerning percentages of extinction. Needless to say, DuBar's age assignment quickly became controversial, but today a Pleistocene age for the unit is generally accepted.

Important at this point in time is the question, "How can we identify the Caloosahatchee?" Most of the typical outcrops have been either destroyed or flooded, and it seems probable that they will remain that way, at least for many years. This means that identifications must now be made from subsurface cuttings or core samples, or by test pits in the type area.

The 90-year work product by many geologists does not give us sufficient information to maintain the Caloosahatchee's rank as a formation:

1. Neither an upper or a lower boundary can be called clear, concise, or well described.

2. No internal lithologic description clearly separates the Caloosahatchee from the overlying Fort Thompson or underlying Tamiami Formation.

3. As a result of the many changes and restrictions, the Caloosahatchee no longer seems mappable.

4. DuBar's recognition of the Pleistocene age of the Caloosahatchee has rendered the old definition of "all beds of Pliocene age" obsolete.

5. The Caloosahatchee is dependent for identification on recognition of a particular group of fossils - it is, in effect, a biostratigraphic assemblage zone, based on mollusks.

There, I suggest that the Caloosahatchee marl should be reduced to member status and be included in the Fort Thompson Formation as the lowest member.

Three other factors enter into identification of the Caloosahatchee member in the subsurface:

1. At one time, it was thought that all of the interbedded marine and freshwater strata were included in the Fort Thompson Formation. DuBar's work (1958) indicated that such interbedding continued to the bottom of the Caloosahatchee. My work indicates that both the Fort Thompson and Caloosahatchee might now be defined as interbedded marine, brackish and freshwater strata. Up dip, north of the river, the Tamiami Formation contains fresh and brackish water mollusks.

2. The present fine zonation of the surface into very thin beds and formations is useless in the subsurface unless two-foot samples are caught or, preferable, cores recovered having a three to four inch diameter.
3. It is a well-known fact that subsurface samples, whether cuttings or cures, seldom contain enough recognizable megafossils to identify mollusk faunizones. The time between the Caloosahatchee assemblage and that of the younger Belle Glade or the older Pinecrest Sand is too short to have permitted drastic evolutionary changes, and the differences between the three faunas are so small that the chance of finding identifiable species of restricted range in well samples is slight. It is much more likely that the samples will contain numerous species that are common in all three units. Thus, it is probable that the Caloosahatchee assemblage cannot be separated in the subsurface in many holes with any degree of accuracy, even though the bed can be locally identified. Nevertheless, expert knowledge of mollusk ranges can greatly increase the number of holes in which the Caloosahatchee assemblage is identified as present or definitely absent, as demonstrated by Fig. 5, a cross-section through shallow holes along the west side of Lake Okeechobee.

THE CHARLOTTE HARBOR AREA AND THE BERMONT FORMATION

Dall (1892) first recognized a faunal assemblage between beds exposed along the Caloosahatchee River and those along Alligator and Shell Creeks in the Charlotte Harbor area about 25 to 30 miles northwest of the Caloosahatchee. Matson and Clapp (1909) mapped the Charlotte Harbor beds as Caloosahatchee marl, and they have been included in that unit ever since.

DuBar (1962) continued to use the name Caloosahatchee for the fossiliferous strata at Shell and Alligator Creeks, and interpreted the overlying, mostly unfossiliferous sands as being representative of the Fort Thompson Formation. If the terminology suggested in this paper were used, the sands might have been included in the Pamlico beds of the Lake Flirt member of the Fort Thompson. Regarding the underlying limestone and marl units, he commented that the formational subdivisions that he had identified along the Caloosahatchee River were not recognizable in this area, and he reported no fresh or brackish water beds. Instead, he described a sequence of marine marls and limestones which he separated as Units A through F.

I have not seen the outcrops along these two creeks, and understand that they are no longer readily accessible. However, DuBar's comments, and his well-described measured sections, indicate that the sequence of beds is not lithologically the same as the sequence of beds exposed along the Caloosahatchee River - i.e., they are not homotaxial as required by the American Code of Stratigraphic Nomenclature for inclusion under the same formation name (Code, Art. 4-b, 1970) - and it is therefore suggested here that the limestones and marls in the Charlotte Harbor section deserve their own lithostratigraphic name, even though their faunas may be the same or nearly the same as the assemblages present in the beds along the Caloosahatchee River.

Later (1974, p. 221), DuBar proposed the informal name Bermont Formation, for his Unit F (1962) in the Shell Creek outcrops which he and others believed equivalent to Unit A of Olsson (1964). He states "...The formation, or apparent time-equivalent units, extends eastward through southern DeSoto and Highlands counties, and through the Lake Okeechobee region into Martin and Palm Beach counties. It is probable, but not established, that the formation underlies parts of the Everglades...", and later that the Caloosahatchee and
Bermont units "...cannot be distinguished by their lithologic characteristics, and locally it is difficult to establish the presence of an unconformity between the units. As a consequence formational differentiation generally is based on comparative faunal analysis."

As discussed above under the Belle Glade member, a body of strata recognizable only by its fossils should be described as a biostratigraphic zone, and the rank of formation should be retained solely for units distinguishable by lithology alone. It was with this thought in mind that the Belle Glade member and the Fusinus watermani zone within it were proposed in this paper, and the same thought leads to the suggestion that the use of the name Bermont formation be restricted to the area in which the unit is mappable by lithology. Perhaps the name Bermont might be more useful if expanded to include the entire all-marine section at Shell Creek, to provide these strata with their own distinctive name that indicates a lithologic separation from the interbedded marine and freshwater sediments of the Caloosahatchee and Okeechobee areas.

In addition, published faunal lists raise a question about the correlatives of Bed F, or the Bermont formation, at Shell Creek: Does it correlate faunally with the bed(s) which Olsson referred to as Unit A, and which are termed F. watermani zone in this paper? DuBar (1974, Table 8, p. 222) lists some characteristic fossils of the Bermont formation and has marked some as "not known to occur in the Caloosahatchee Formation". These marked species have been reported from the sediments of the F. watermani zone, or from undifferentiated strata of the Belle Glade member. However, none of the species considered diagnostic are included in DuBar's 1962 list of fossils found in Bed F at Shell Creek (1962, p.60-81), indicating that the age and stratigraphic position of Bed F is not well enough known to be correlated.

THE TAMIA MI FORMATION

The Tamiami limestone was proposed by Mansfield in 1939 for a shallow limestone penetrated in roadside ditches along the Tamiami Trail over a distance of about 34 miles in Collier and Monroe counties, Florida. The limestone is thin, 25 feet more or less, with no measurable dip along the 34 miles of type area. In 1955, Parker extended the unit into the Miami area and included in it a thick lower section of greenish clay, shelly sand, and impure limestone, thus increasing the thickness (p.84, well G220) to about 135 feet and giving a heterogeneous or formational character to the unit. The lower part had previously been mapped at the surface and in the subsurface as an upper part of the Hawthorn formation. Parker et al. intended by definition to include "all the Upper Miocene materials in southern Florida" (p.85) in this formation.

As we now realize, Parker's Tamiami Formation has a major regional unconformity within it, separating the upper and lower units. The thin upper unit is now known to contain Pliocene sediments (Akers, 1974) above this regional unconformity. Evidence based on vertebrates, foraminifera and mollusks indicates a much older age for sediments below this unconformity. See discussion of Figure 3, above.

It is obvious that the Tamiami and Hawthorn formations need formal definitions in accordance with present-day standards. To do so will require
a group effort, not limited to one county or part of a county, but statewide in scope and coordinated with stratigraphic work in the adjoining state of Georgia.

Several lithologic members, some formal (Hunter, 1968) and some informal (Puri and Vernon, 1964), have already been recognized as parts of the Tamiami Formation. In this paper, a new informal name is added to the lower part of this formation: the Ortona sand member.

Along the Caloosahatchee River, the following members are known to be present, although others may eventually be recognized. The Buckingham Limestone Member and the Pinecrest Sand Member are part of the upper Tamiami and are more or less lateral equivalents. The Ortona sand member and the LaBelle clay are considered to be part of the lower Tamiami, but with uncertain relationships. The Alva clay member and phosphatic sand units have uncertain positions. These units are discussed individually below.

**Buckingham Limestone Member**

In 1939, W. C. Mansfield proposed the name Buckingham limestone for beds exposed on and near the Caloosahatchee River in the northeastern part of Lee County, Florida. Later workers referred to this limestone as a clay or marl, because the material is actually a soft, light gray to white calcareous clay or calcitutte that weathers to a buff color. Parker et al (1955, p.87) included it in the Tamiami Formation as an equivalent of Mansfield's limestone (now called the Ochoppee Limestone Member). The Buckingham contains, in addition to carbonates, some quartz sand, a few brown phosphate grains, a few bone fragments, and shark teeth. Well-preserved pectens, oysters, echinoids and barnacles are present, but molds of aragonitic mollusk species are mostly poor and mostly unidentifiable. The type locality is at a rock pit near State Highway 25, half a mile west of Orange Creek, near the town of Buckingham, in Lee County. Several years ago the pit had become badly weathered and overgrown.

Along the Caloosahatchee River, the Buckingham is exposed at a number of localities downstream from Fort Denaud, at least as far as Alva in Lee County. Descriptions of some of these outcrops were given by Parker and Cooke in 1944. The cross-section by Puri (1964, fig. 32) indicates an erosional high in the Tamiami Formation in this area, with the Caloosahatchee member pinching out against the high just west of Fort Denaud.

**Pinecrest Sand Member**

The shelly sands in the upper Tamiami Formation were first noted near Pinecrest, on State Road 94, Monroe County, Florida, by W. C. Mansfield who described several new species of mollusks but did not describe or name the lithologic unit (1931). In the early 1960's, extensive work on flood control canals and levees exposed the same shelly sands, but this time at different localities scattered over a large part of southern Florida. Fossils were collected from spoil and studied. In a number of dewatered sections the same shelly sands were observed. Since then, these sands have been recognized on the Gulf Coast as far north as Pinellas County, on the northwest side of Lake Okeechobee, on the east coast through Kissimmee to Orlando, and a few other areas.
Olsson (1964) proposed an informal name - Pinecrest beds - for this biostratigraphic assemblage zone. To establish his unit, Hunter (1968) formally described a lithostratigraphic unit - Pinecrest Sand Member of the Tamiami Formation. It should be noted that the term "Pinecrest formation" has been used by several authors, but the term appears to lack definition and description, and is apparently invalid. Hunter also described the Pecten tamiamiensis assemblage zone, which was called the Pinecrest beds by Olsson. Hunter also correlated the Pinecrest Sand, the Buckingham Limestone and the Ochopee Limestone as lateral equivalents, because the same mollusk assemblage is present in all three of these members of the upper Tamiami formation.

The Pinecrest Sand has not been seen in outcrop along the Caloosahatchee River, but is known to be present in the shallow subsurface because aragonitic (white) fossils known to be a part of the P. tamiamiensis zone have been identified in material dredged from the bottom of the river. Venericardia olga, described by Mansfield from river dredgings in the area around Olga, has often been found in Pinecrest Sand, but occurs only as molds in the interfingered Buckingham Limestone. Further upstream, beyond Ortona Lock and near Lake Hicpochee, aragonitic fossils of the Pinecrest assemblage were also found on spoil banks at two or three localities.

The Alva Clay Member

The Alva clay member was informally described by Puri and Vernon (1964) as a white clay barren of fossils. Core samples of it were taken in the area along the river between LaBelle and a point a little downstream from Alva (1964, p. 213, fig. 31-32). Puri shows a limestone member overlying the Alva clay in core holes W-6735 to W-6762, W-6737, W-6766 and W-6767. He considered the limestone to be similar to the typical Tamiami limestone, now called the Ochopee Limestone.

In a pit at Alva, I saw a white clay that contained numerous fossils (pectens, barnacles and oysters) of the species found in the type Buckingham Limestone; in other parts of the Alva pit, fossils of the same species occurred in the typical calcilutite. Parker and Cooke noted a similar occurrence of Buckingham fossils in "marly clays" and "clayey marls" in the same general area, and decided the only difference was in varying percentages of clay in the sediments (1944, p. 83-84).

Whether or not these fossiliferous clays are actually the same as Puri's unfossiliferous Alva clay has not been determined, and a further study of these strata is indicated. For the present, pending such a study, the presence of the Alva clay is noted, and it is given an approximate position as a lateral equivalent of the Buckingham calcilutite, the Ochopee limestone and the Pinecrest sand.

Ortona Sand Member

The informal name, Ortona sand, for a member of the lower Tamiami Formation, is here suggested. The sands are typically coarse, and are being mined for fine aggregate a short distance east of Ortona Lock. The name is already in use in economic circles.

The Ortona sand member consists mostly of quartz grains and a few pebbles. At the Ortona mine, it is white to very light gray, somewhat black speckled with a little fine grained phosphate, and contains occasional
phosphate pebbles and bone fragments. Red sands with quartz pebbles near Brighton in southern Highlands County may be correlative strata. The Ortona sand is clean in the subsurface, containing a low percentage of clay and a few red quartz grains. Its maximum thickness in the Ortona area is uncertain, but exceeds 25 feet. Along the northwest edge of Lake Okeechobee (Fig. 5), a maximum thickness in excess of 50 feet was observed in Mineral Hole no. 4.

Fossils are not common in the Ortona sand. The assemblage is typical of the lower part of the Tamiami Formation and includes "Pecten" jeffersonius, "P." wendelli olgensis, Ephora quadricostata (the older, wide-ridged form), and fragments of oysters, pectens and large barnacles.

Correlatives of the Ortona sand are uncertain. In the Lake Okeechobee cross-section (fig. 5), the Ortona lies beneath the Bayshore Clay Member. In the area of the river, Puri (1964) suggested that the LaBelle clay grades eastward into the Ortona sand. However, because coarse sand beds of minor thickness can occur in any part of the Fort Thompson or Tamiami formations, the light green clays of the LaBelle member may yet be found above and the dark olive green clays below the Ortona sand, or in some other unsuspected relationship.

The LaBelle Clay Member

The LaBelle clay member was informally described by Puri and Vernon as including the greenish gray, blue gray, and dark olive green clays present in core holes along the Caloosahatchee River, where they formed the lowest cored part of the Tamiami Formation (1964, p.213 and fig. 32).

Puri compared the LaBelle clays to others under the Miami area that were in the lower part of the Tamiami Formation and contained a microfauna of the Arca zone. Whether part or all of the clays at LaBelle are lateral equivalents of the greenish clays of the Miami area has not yet been established, and the clays themselves along the Caloosahatchee River may not be lateral equivalents.

WESTERN SHORE OF LAKE OKEECHOBEE

The geologic cross-section (Figure 5) along the western shore of Lake Okeechobee shows the approximate positions of ten stratigraphic units above a suggested top of the Hawthorn Formation, using data obtained from six mineral holes drilled by Coastal Petroleum Company in search of minerals, a water well at Okeechobee City, two drainage canals, and four shallow pits. Although data collection occurred 15 to 20 years ago, the interpretation is new and prepared for this field trip to demonstrate the utility of detailed stratigraphy based on lithology, faunas and well logs. The author is grateful to Coastal Petroleum Company for release of the data.

No great degree of accuracy can be expected from old data assigned to only three known units instead of ten or more presently known units. Closer spaced holes would no doubt reveal many more channel deposits and relief features along the unconformities. The high position of the Bayshore and Ortona members under mineral holes 4, 5, and 6 is due in part to their projection on to the cross-section from a more westerly position.
Figure 5. Semi-diagramatic cross-section showing approximate relationship of members of the Fort Thompson and Tamiami Formations along the northwest shore of Lake Okeechobee between the towns of Moore Haven and Okeechobee, Florida.
Based on test holes, levee sections and probe holes for limestone deposits located near the margin of Lake Okeechobee, this body of water appears to be located in a structurally flat area of either non-deposition or erosion with a halo of Fort Thompson Formation, the members of which pinch out rapidly in a lakeward direction. Yet to be mapped are buried channels of the Kissimmee River across the lake.

The Pinecrest Sand in this area has upper and lower divisions separated by a zone of beach hash, which contains nassariids, Donax, and other taxa restricted to nearshore environments, together with shell pebbles and beach-worn shells and fragments. A similar zonation is present at Jackson Bluff in Leon County, where the Cancellaria zone (upper unit) is separated from the Ephora zone (lower unit) by an interval containing mostly broken pectens, oysters and a few other species of mollusks. The Pinecrest and the Jackson Bluff strata are correlatives.

The interval from 70 to 80 feet in Test Hole 7 contains materials similar to those found in underlying beds, including fine to coarse sand, quartz and phosphate pebbles, and barnacle fragments. Also present in the two 5-foot samples were a number of land snail fragments and remains of aragonitic fresh, brackish, and marine mollusks. The combination of aragonitic shells with the leached material from the underlying beds suggests that this deposit was the result of reworking by a river during the time of unconformity between the upper and lower parts of the Tamiami Formation, or that the deposit is a transgressive shoreline unit of earliest Pinecrest age. Its appearance in only one hole tends to favor the idea of a river channel.

The boundary between the Hawthorn and Tamiami Formations can at best be placed in a tentative manner. Prior to Parker's redefinition of the Tamiami in 1955, the boundary had been usually placed at the point of unconformity now included in the Tamiami Formation. Formal redefinition of the two formations is required before a boundary can be placed in any other than an arbitrary manner.

CONCLUSION

Minor stratigraphic changes are suggested. The grouping together of various laterally and vertically related but geographically restricted members into an expanded Fort Thompson Formation merely clarifies an established pattern of reconnaissance mapping based on identification of a few key beds and a minimum of biostratigraphic detail. When mapping formations in Florida, Cooke and others "lumped" diverse lithologies into mappable "formations" equivalent to series and stage rank. In addition, they provided detailed descriptions of outcrop sections at many localities that can be used for identification of present members. Some of their outcrop sections also contain useful biostratigraphic data.

Expansion of the Fort Thompson Formation as suggested provides a lithostratigraphic unit for surface reconnaissance and wellsite geology. The lithostratigraphic members and biostratigraphic zones provide criteria useful for determining the presence or absence of a part, parts, or all of the Fort Thompson Formation. Thus the few minor changes in the geologic column permit geologists of the future to relate their work to that done in the past, and the recognition of members preserves the 90-year effort on the part of many specialists to finely subdivide this and other formations into lithostratigraphic and biostratigraphic units.
Since 1970, the mollusk scale and the land mammal scale have been adjusted to correlate with planktonic, nanofossil and radiometric scales. These age adjustments, by many authors, have changed time intervals of members, unconformities, and the entire Fort Thompson several times. However, the lateral and/or vertical positioning of the members and their correlation with distant strata, all based on the ranges of mollusks and land mammals, have not changed.

New evidence provided by the planktonic and radiometric scales provides an approximate concept of the magnitude of the unconformities known to be present in the section, and indicates that recognized Late Tertiary and Quaternary strata in Florida record only a small part of this interval of geologic time.

During preparation of this paper, an effort was made to determine which "formations" whose rank was changed had the attributes of formal units (i.e., such things as lithologic description and individuality, boundary descriptions, type sections, etc.). It was found that the majority lacked one or more of the necessary requirements. The suggested new member rank of these data-deficient units is shown by small print to distinguish them from those which seem to have sufficient identification.

Much of the 90-year effort to unravel and understand the stratigraphic section along the Caloosahatchee River has been accomplished slowly, by amateurs and part-time stratigraphers with competence in other fields. Their results, reviewed in this paper, conflict with sound stratigraphic procedure and strongly suggest that help is needed, either from leaders in stratigraphic methods by specialists in the science of erecting a proper geologic column.

It could be recommended that these problems be called to the attention of the A.A.P.G., the S.E.P.M., the U.S.G.S., or the G.S.A. research groups by the Southeastern Geological Society with a request for the establishment of more type sections in Florida, especially for shallow sand, clay and limestone units located in southern and eastern Florida, but evidence of their willingness or concern is lacking. So, to the extent possible, this society must sponsor the study of reference sections for future use in Florida.
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FIGURE 1. REFERENCE MAP.
THE TAMIAI FORMATION

The Tamiami Formation is a regional geologic unit that covers all of Florida south of Lake Okeechobee. It was originally named the Tamiami Limestone by Mansfield (1939) for some limestone exposures located in Collier and Monroe counties. Mansfield assigned the formation to the Pliocene and placed it below the Caloosahatchee Marl. Parker et al., 1955 redefined the Tamiami Formation to include all upper Miocene sediments in south Florida. Parker included calcareous clays, quartz sands, and various other carbonate lithologies in the Tamiami Formation, which he believed was about 150 feet thick.

More recent works have more precisely defined the Tamiami Formation in terms of rock stratigraphic units and time (Bogges and Missimer, 1975; Peck, 1976; Missimer, 1978; Missimer and Associates, Inc., 1978a; 1978b). The Tamiami Formation contains lithologic units below the base of the Caloosahatchee Marl to the top of the Hawthorn Formation, which approximately marks the late Miocene-middle Miocene boundary. The top of the formation is marked by a disconformity between the Caloosahatchee Marl or younger sediments and the Buckingham Limestone, Ochopee Limestone, or one of the clay members of the Tamiami Formation. The base of the sequence is defined by a disconformity in western Lee County and an influx of coarse clastic sediment to the east (Missimer, 1978). Tamiami Formation sediments range from about 100 feet to about 450 feet in total thickness in parts of Lee and Collier counties (Missimer and Associates, Inc., 1978a; Bogges, Missimer, and O'Donnell, in preparation). The formation ranges from middle Pliocene to late Miocene in age (Peck, 1976).

A number of informal member names have been assigned to rock stratigraphy defined within the Tamiami Formation (Figure 2). These names are used strictly for discussion and should not be used formally. Several publications are presently being prepared on the detailed stratigraphy of the Tamiami Formation (Bogges, Missimer, and O'Donnell in preparation; Missimer and others, in preparation). The members which merit discussion are the Ochopee limestone and the Lehigh Acres sandstone.

Ochopee limestone member

The Ochopee limestone as originally termed (Hunter, 1968), is the uppermost member of the Tamiami Formation. This lithologic unit underlies more than 2000 square miles of south Florida. It occurs south of a line drawn from Fort Myers (Lee County) to LaBelle (Hendry County), and west of a line drawn from LaBelle to Miami (Dade County). It is quite probable that time-equivalent limestone units dip to the south beneath the Florida Keys. Equivalent limestone units may occur beneath the Miami Oolite and extend northward along the east coast into Palm Beach County.

The Ochopee limestone is a significant unit in south Lee County, where it is mined for construction materials and water is developed from it. A map showing the thickness of the unit in south Lee County is given in Figure 3. The new Lee County wellfield is located near the thickest part of that formation.
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**Figure 2.** Diagram showing the stratigraphic positions of the freshwater aquifers of South Lee County, Florida.
FIGURE 3.  ISOPACH MAP SHOWING THE THICKNESS OF THE OCHOPEE LIMESTONE IN SOUTH LEE COUNTY
Lehigh Acres sandstone member

The Lehigh Acres sandstone is a limestone-sandstone-sand facies of the Tamiami Formation. It is overlain by lime muds and sandy clays of the Cape Coral clay member. This unit ranges from about 10 to more than 90 feet thick in Lee County. It is limited in lateral extent to Lee, western Hendry, and western Collier counties. The Lehigh Acres sandstone is a very complex unit with thin beds of "clean" limestone alternating with coarse clastics (quartz sand and shell). It is water-bearing in most areas.

AQUIFER DESCRIPTIONS

Tamiami Aquifer System - Zone I

The Tamiami Formation contains several geologic units that are water-bearing. The uppermost aquifer in the system is termed Tamiami Aquifer System - Zone I (Missimer and Associates, Inc., 1978a; 1978b; 1978c). In most of central Lee County, the aquifer is unconfined and occurs in both the Pamlico Sand and the Ochopee limestone, which are hydraulically well-connected. In south Lee County and coastal Collier County, Zone I is confined to a variable degree by lime muds of Fort Thompson Formation - Caloosahatchee Marl age. The base of Zone I is formed by low permeability sediments of the Buckingham limestone and Cape Coral clay member.

Some confusion has arisen as to the definition of Tamiami Aquifer System - Zone I in Collier County. The aquifer has been termed the shallow aquifer (Klein, 1972) or the Coastal Ridge Aquifer with the implication that it is limited in lateral extent to the Naples area. As described in this paper, Zone I is a regionally extensive aquifer.

Several municipal wellfields tap Zone I for raw water supply. The San Carlos, Bonita Springs, Isle of Capri, and The Glades systems pump less than 1 MGD each from the aquifer, but large systems such as the City of Naples, and the new Lee County wellfield pump, or will pump, large volumes from the system.

Extensive aquifer tests have been performed on Zone I in three separate localities (Figure 1). These tests have shown that a large quantity of potable water is available from the aquifer. It has a conservative range in transmissivity from 115,000 to 216,000 gpd/ft, which may actually range up to 700,000 gpd/ft in certain locations (Table 1). Storage coefficients range from $5.2 \times 10^{-3}$ to $4 \times 10^{-5}$ and where confined, the leakance ranges from $3.2 \times 10^{-1}$ to $1 \times 10^{-2}$ gpd/ft³. In most areas the aquifer responds as a semi-unconfined system (see Kruseman and DeRidder, 1970).

Tamiami Aquifer System - Zone II

Tamiami Aquifer System - Zone II was originally defined as the "Sandstone Aquifer in eastern Lee County" (Sproul, Boggess, and Woodard, 1972; Boggess and Missimer, 1975). Zone II is a confined aquifer, which occurs beneath an area east of a line extending between Fort Myers and Naples and west of a line extending through LaBelle, Immokalee, and Marco Island. It is confined from Zone I by clays in the Cape Coral clay and Buckingham limestone members of the Tamiami Formation. Zone II ranges from about 10 to more than 80 feet thick. It occurs exclusively in the
<table>
<thead>
<tr>
<th>SITE</th>
<th>TRANSMISSIVITY (gpd/ft)</th>
<th>STORAGE COEFFICIENT</th>
<th>LEAKANCE (gpd/ft³)</th>
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</thead>
<tbody>
<tr>
<td>1. Lee County Well Field</td>
<td>205,000</td>
<td>5.2 x 10⁻³</td>
<td></td>
</tr>
<tr>
<td>2. Pelican Bay Well Field</td>
<td>115,000</td>
<td>4 x 10⁻⁵</td>
<td>1 x 10⁻²</td>
</tr>
<tr>
<td>3. The Glades Well Field</td>
<td>216,000</td>
<td>3.2 x 10⁻⁴</td>
<td>3.2 x 10⁻¹</td>
</tr>
</tbody>
</table>
Lehigh Acres sandstone member of the Tamiami Formation. It responds to stress as a semi-confined aquifer.

An aquifer test on Zone II at the new Lee County wellfield site (No. 2 on Fig. 1) yielded the following hydraulic properties: transmissivity = 20,000 gpd/ft, storage coefficient = $3 \times 10^{-5}$, and leakance = $4.7 \times 10^{-4}$ gpd/ft$^3$.

CONCEPT OF THE NEW LEE COUNTY WELLFIELD

Many municipal wellfields in Florida are overpumped or mismanaged. Excessive pumping concentrated in a relatively small area often causes a number of problems, including: saline-water intrusion; large drawdowns of water levels in areas surrounding the site; and extreme alteration of the surface environment.

The concept on which the Lee County wellfield will be managed is based on the water-supply paradox of south Florida's abundant rainfall during the 4-month wet season and lack of rainfall during the ensuing dry season. Storage of water over dry periods is the principal problem. The site is located in Section 22 of T. 46S. R. 22E.

Two separate fresh water aquifers underlie the Lee County wellfield site. The uppermost aquifer is Tamiami Aquifer System - Zone I, which is semi-unconfined (Dutch terminology) and has a transmissivity of more than 200,000 gpd/ft. Tamiami Aquifer System - Zone II lies below Zone I. It is a semi-confined aquifer with a transmissivity of 20,000 gpd/ft, and a leakance of $4.7 \times 10^{-4}$ gpd/ft$^3$.

An average of 5 MGD of water will initially be pumped from the wellfield. This volume will be pumped from 16 primary production wells - 6 tapping Zone II, and 10 tapping Zone I. A peak demand capacity of 10 MGD can be met. A general diagram of the wellfield is given in Figure 4.

In order to utilize the natural system to the maximum, water will be pumped from both aquifers. During the wet season when the area is partially flooded by surface water, all water will be pumped from Tamiami Aquifer System - Zone I. This will cause a slight depression of the water table, which will permit a greater quality of recharge. Less water will be lost to runoff and evapotranspiration. The predicted cone of depression of Zone I is shown in Figure 5. During the dry season, water will be pumped from both Zones I and II at 2.5 MGD each. This pumping scheme will prevent excessive lowering of the water table. A large cone of depression will be created in the Zone II potentiometric surface (Fig. 6). This drawdown will only be temporary because pumping from Zone II will be terminated at the beginning of the wet season. The potentiometric surface will recover back to the original level.

Conjunctive use of water from both aquifers with a proper management plan will minimize all impacts of pumping on surface wetlands environment and will effectively prevent lateral migration of saline water.
LEGEND

● TAMIAI MI AQUIFER SYSTEM - ZONE I PRODUCTION WELLS
✠ TAMIAI MI AQUIFER SYSTEM - ZONE II PRODUCTION WELLS
●● EXISTING OBSERVATION WELL PAIRS - ZONES I & II
✠✠ PROPOSED NEW OBSERVATION WELL PAIRS - ZONES I & II
✠✠✠ PROPOSED UPPER HAWTHORN AQUIFER OBSERVATION WELL

FIGURE 4. LOCATIONS OF PROPOSED PRODUCT WELLS, EXISTING OBSERVATION WELLS, AND PROPOSED ADDITIONAL OBSERVATION WELLS
FIGURE 5. MAP SHOWING THE CONE OF DEPRESSION IN THE POTENTIOMETRIC SURFACE OF TAMIAMI AQUIFER SYSTEM - ZONE 1 AT EQUILIBRIUM FOR 5 MGD AVERAGE PUMPAGE.
FIGURE 6. MAP SHOWING THE CONE OF DEPRESSION IN THE POTENTIOMETRIC SURFACE OF TAMIAI AQUIFER SYSTEM - ZONE II AT EQUILIBRIUM FOR 2.5 MGD OF AVERAGE PUMPAGE.
ACKNOWLEDGMENTS

The author wishes to express thanks to the following persons: Mr. Durward H. Boggess of the U. S. Geological Survey; Mr. P. Fred Biery and Mr. Robert Wright of Post, Buckley, Schuh, & Jernigan, Inc.; Dr. Sherwood Wise and Mr. Douglas Peck of Florida State University; Mr. Sam Hubschman of The Glades, Naples, Florida; Mr. Larry Holland, Mr. Richard Holzinger, Mr. Lloyd Horvath, and Mr. David Hire of Missimer and Associates, Inc.
REFERENCES


Missimer, T.M., and others, in preparation, Regional extent of the Ochoppee Limestone Member of the Tamiami Formation in South Florida.


REFERENCES (CON'T.)


ROAD LOG
Southeastern Geological Society Field Trip
Hydrogeology of South-Central Florida
November 11 & 12, 1978

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<tr>
<td>.3</td>
<td>.3</td>
<td>Turn west on Blue Heron Blvd.</td>
</tr>
<tr>
<td>.3</td>
<td>.6</td>
<td>Cross bridge over Lake Worth.</td>
</tr>
<tr>
<td>.9</td>
<td>1.5</td>
<td>Intersection Blue Heron and U.S. 1 (Broadway). Proceed south on U.S. 1.</td>
</tr>
<tr>
<td>.9</td>
<td>2.4</td>
<td>Port of Palm Beach on east side of U.S. 1.</td>
</tr>
<tr>
<td>.5</td>
<td>2.9</td>
<td>West Palm Beach City limits, continue south on U.S. 1.</td>
</tr>
<tr>
<td>.7</td>
<td>3.6</td>
<td>Intersection U.S. 1 and 45th St., continue south on U.S. 1.</td>
</tr>
<tr>
<td>2.7</td>
<td>6.3</td>
<td>Junction U.S. 1 (N. Dixie Hwy.) and Poinciana Way (AIW), turn east on Poinciana Way.</td>
</tr>
<tr>
<td>.6</td>
<td>6.9</td>
<td>Cross Causeway (Flagler Memorial Bridge) over Lake Worth.</td>
</tr>
</tbody>
</table>

An old map dated between 1830 and 1833 labeled Lake Worth as a "large freshwater lake," however, now Lake Worth is brackish.

Captain Armour in his memoirs of the mid 1800's described Lake Worth as a large lake, some twenty two miles long and in some places more than a mile wide. At that time only two people were settled into this area, a German named Lang and his wife. Now the waters of Lake Worth are used for sport fishing, navigation (Intracoastal Waterway), general recreation, industrial cooling and deposition of effluents.

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<td>17.9</td>
</tr>
<tr>
<td>.8</td>
<td>18.7</td>
</tr>
</tbody>
</table>

- Palm Beach Lakes Blvd. merges with Okeechobee Rd. Proceed west on Okeechobee Rd.
- Intersection of Okeechobee Rd. and Military Trail. Continue west on Okeechobee Rd.
- Intersection of Okeechobee Rd. and Haverhill Rd. Proceed north on Haverhill Rd.
- Intersection of Haverhill Rd. and Earnest St. Proceed west on Earnest St.
- Entrance to Palm Beach County Regional Sewage Disposal Facility.

In 1972 the Florida Department of Pollution Control extended their policy to Palm Beach County stating that "wastewater discharge to inland waters must cease." In 1973 the U.S. Environmental Protection Agency (EPA) issued a grant to the City of West Palm Beach to construct a secondary wastewater treatment plant on City owned property. This facility using bar screens and grit chambers removes 90% of 100 mesh particles at average flow. This is followed by secondary treatment by aeration and clarification. Present day treatment capacity is 44 MGD to be expanded to approximately 68 MGD.

**STOP 2**

Deep Well Injection of Treated Waste Water.
Site Leader: Vincent Amy
Location: Palm Beach County
SW1/4, SE1/4, NW1/4, Sec. 11, R 42E, T 43S
Latitude: 80° 07' 48.00"
Longitude: 26° 44' 30.00"

- Return to bus. Proceed to S-5A via Earnest St. to Haverhill Rd.
- Intersection of Earnest St. and Haverhill Rd. Proceed south on Haverhill Rd.
- Intersection of Haverhill Rd. and Okeechobee Rd. Proceed west on Okeechobee Rd. Continue on Okeechobee Rd. crossing the Florida Turnpike.
- Intersection of U.S. 441 and S.R. 80. Proceed west on S.R. 80. As we continue west on S.R. 80 we will parallel Canal-51 (West Palm Beach Canal).
The modification of overland flow in the Everglades started with drainage operations beginning in July 1882 (Leach, et. al., 1972). By early 1885 a shallow canal connected the Caloosahatchee River to Lake Okeechobee.

Prior to any development, water from Lake Okeechobee overflowed the south shores during high stages and fanned out overland. Because land slope for the Everglades during its natural state averaged .2 ft./mi. (Parker, et. al., 1955) and natural drainage channels were shallow, only small amounts of overflow from Lake Okeechobee left the Everglades.

From 1905 to 1927 the excavation of more than 400 miles of canals occurred for the purpose of draining lands for agricultural development. Four principal canals were constructed by the Everglades Drainage District. By 1921 these four canals: North New River, Hillsboro, West Palm Beach and the Miami Canals were in operation.

The West Palm Beach Canal (C-51) extends 42 miles from the southeast shore of Lake Okeechobee at Canal Point to Lake Worth. This primary canal is dug into muck soil from Canal Point to approximately 5 miles east of 20 mile bend where the muck grades into sand (Parker, et. al., 1955). The canal discharges into tide water at a coastal control structure near U.S. Hwy. 1, where it extends about 5 miles east and empties into Lake Worth. Secondary control facilities along the West Palm Beach Canal are used for winter and spring agricultural needs in addition to providing flood protection.

Royal Palm Beach City limits.

Entrance road to Structure-5A. Pumping Station No. S-5A is located in the West Palm Beach Canal, just east of twenty-mile bend, midway between the cities of West Palm Beach and Belle Glade on the northern edge of Conservation Area No. 1. Accepted by the South Florida Water Management District (formerly Central & Southern Florida Flood Control District) on May 2, 1955, it is designed to remove 3/4 inch of water in 24 hours from a 230 square mile area served by the West Palm Beach Canal. Pumping capacity of this station is 3,102,313,000 GPD. The principle function of this pumping station is to remove excess water from its drainage area and
discharge it into Conservation Area No. 1 for storage and future use during dry periods.

A weather station located on the northside of the access road east of the pumping station is used to gather rainfall, evaporation and wind data adjacent to the Conservation Area.

A two-way radio station located at the end of the access road through the gate enables personnel to have direct contact with District headquarters in West Palm Beach, along with other pumping stations throughout the District.

Structure-5A south is the spillway located off of the access road near the entrance of the S-5A facility on L-8 canal. This spillway allows water to flow into the Conservation Area through gravity from the West Palm Beach Canal which is controlled by culverts a few yards upstream. These structures enable the movement of water from the north, east and west when desired.

STOP 3
(a) **Tour of Structure-5A**
(b) **SFWMD Hydrologic Telemetry Monitoring and Control Station**

Site Leader: Richard Slyfield
Location: Palm Beach County
SW 34, NE 36, SE 36, Sec. 32, T 43S, R 40E
Latitude: 26° 41' 3.00"
Longitude: 80° 22' 5.00"

LUNCH

Board buses. Proceed to S.R. 80 and continue west on 80.

1.4 41.6

Bridge crossing West Palm Beach Canal. The Everglades Agricultural Area of western Palm Beach County and eastern Hendry County is by far the largest single block of land area within the SFWMD devoted to intensive agricultural use. Area-wide water control, for the most part, is provided by the levees, canals, pumping stations and control structures of the Water Management District Project system. Excess surface water runoff is removed and supplemental water requirements are introduced into the area by means of this system. Agriculture in the Everglades area is a major consumer of water. Supplemental water
requirements for crop growth vary depending upon the time and amount of natural water available from rainfall. The source of supplemental water for agricultural irrigation is Lake Okeechobee. Water is introduced from the lake via the four Project canals traversing the agricultural area (West Palm Beach, Hillsboro, North New River, and Miami Canals) by way of three Hurricane Gate structures on the south shore levees (HGS 3, 4, and 5). Individual agricultural operators or drainage districts then withdraw supplemental water from the primary canal system for irrigation.

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<tr>
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Pump Station.

North side of road, S-5A Remote Acquisition and Control Unit (RACU) Shelter.

Six mile bend (confluence of Hillsboro Canal with L-13 canal).

The Hillsboro Canal constructed by the Everglades Drainage District starts at the south end of Lake Okeechobee through a hurricane gate and extends 51 miles southeasterly to the coast. Near Lake Okeechobee, the canal cuts across the heart of the winter produce farming area (Everglades Agricultural Area). Here the canal was dug deep into the organic soil of the Everglades. Near Deerfield Beach the Hillsboro Canal discharges to tide water through an old control structure and lock (lock no longer in operation). Downstream of the structure the canal follows the meandering course of a natural stream finally discharging into the Intracoastal Waterway.

<table>
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<tbody>
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<td>3.5</td>
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Everglades Agricultural Research and Education Center.

The Everglades Experiment Station was created June 14, 1921 under the provisions of Chapter 844, Laws of Florida. The Experiment Station is a branch of the Florida Agricultural Experiment Station, Institute of Food and Agricultural Sciences, University of Florida. In 1926 research began on chemical and physical properties of peats. Research staff members were gradually added between 1930 and 1932 and investigations began for vegetable, forage and pasture crops, sugarcane and beef cattle. The Everglades Station holds a unique position among research facilities in that its efforts are almost entirely devoted to organic soils under semi-tropical conditions.
MILEAGE
Between Points Cumulative

STOP 4

Paleoenvironmental Implication of the Area's Peat Deposits
Site Leader: Michael Andrijko
Location: Palm Beach County
SE\(\frac{3}{4}\), NE\(\frac{3}{4}\), SW\(\frac{3}{4}\), Sec. 3, T 44S, R 37E
Latitude: 26° 40' 02"
Longitude: 80° 37' 58"

Board buses continue west on S.R. 80.

1.9  59.3
State Rd. 80 curves to the west into the city of Belle Glade. Continue south on S.R. 80, through southern Belle Glade. Two miles past Glades Hospital S.R. 80 heads due west.

.9  60.2

1.6  61.8
Bridge crossing the North New River Canal.

The North New River Canal starts with its confluence with the Hillsboro Canal near Lake Okeechobee and extends south and east 60 miles to tide water of the New River Canal near Fort Lauderdale. Near Lake Okeechobee the North New River cuts across the Everglades Agricultural Area for approximately 10 miles in a north-south course. The principal control facility on the North New River Canal is a coastal control structure, north of the town of Davie, 2 miles west of State Hwy. 7. Here the canal discharges into tide water.

.3  62.1
State Rd. 80 leads into U.S. Hwy. 27.

.2  62.3
Florida East Coast Railroad.

1.7  64.0
Hoover Dike on north side.

Lake Okeechobee not too long ago was not thought to be used as a water reservoir. On the contrary the Lake was a menace as it flooded its east and southeastern shores at unpredictable intervals. After channelization of the primary south Florida canals, development of both agriculture and east coast urbanization radically changed the approach to Lake Okeechobee water management. Regulation of the 740 square mile lake for storage and flood prevention has been in operation since the completion of the original levees, which were breached during the 1926 and 1928 hurricanes. The present levee system which has undergone various stages of enlargement was completed in December 1967.
The present lake regulation ranges between 14.5 to 16.0 ft. msl, capable of storing up to $2 \times 10^6$ acre-ft. of water. A planned increase in stage to 17.5 ft. msl will add 680,000 acre-ft. to the lake's storage capacity.

Crossing Miami Canal, entering Lake Harbor. Turn north onto entrance road for picnic area.

Miami Canal (L-25, L-24, L-23, C-123, C-304 and C-6) heads at the hurricane gate (HG-4) on the southern shore of Lake Okeechobee and extends to the east coast. The upper reach of the Miami Canal (L-25) runs south-southwest 6.5 miles to its confluence with Belles Canal where it was dug into deep muck with small amounts of limestone. South of the Belles Canal the Miami Canal (L-24, L-23) was dug into muck and runs south-southeast for approximately 19 miles to S-8 near the Palm Beach / Broward County line. The next 24 miles of Miami Canal (S-123) was reconstructed parallel to the old Miami Canal between 1967-1969 to route water from Lake Okeechobee to Miami. At this point, the Miami Canal heads the South New River Canal extending due east to Fort Lauderdale. The Miami Canal (C-304 and C-6) then runs southeast for 26 miles discharging to tide water at the northwest 36 Street control structure. The lower reach of the Miami Canal upstream of the structure drains the Hialeah and Miami Springs area and is an important source of recharge for the area's aquifer, supplying the Miami Springs / Hialeah wellfields.

Bottom Sediments of Lake Okeechobee
Site Leader: Patrick J. Gleason, Ph.D
Location: Palm Beach County
SW¼, SE¼, SE½, Sec. 35, T 43S, R 35E
Latitude: 26° 41' 50"
Longitude: 80° 48' 30"

Lake Okeechobee is located in the south-central portion of the Florida peninsula and occupies parts of Palm Beach, Glades, Martin, Okeechobee and Hendry Counties. The lake is approximately 35 miles across from north to south and 30 miles across from east to west. The lake has a surface area of about 750 square miles and a drainage basin of 4500 square miles.
MILEAGE
Between Points Cumulative

3.9  72.9  Board buses and return to S.R. 80. Proceed west on S.R. 80.
2.3  75.2  Pumping Station.
2.3  77.5  Palm Beach, Hendry County line.
2.6  80.1  Clewiston City limits, continue west on S.R. 80 through Clewiston.
7.5  87.6  R.R. Crossing.
1.1  88.7  Junction S.R. 80 separates from S.R. 27. Proceed north on S.R. 27.
2.5  91.2  Hendry, Glades County line.
2.1  93.3  Moore Haven. Sugar refinery on east side of S.R. 27.
1.9  95.2  Bridge crossing the Caloosahatchee River (Cross State Canal), Moore Haven City limits.
8.5  107.9  Intersection of S.R. 27 and W-78; Phillips 66 Station on southwest corner. Proceed west on W-78.
3.2  111.1  Entrance to Florida Rock Ind., Caloosa Mine. Proceed north on dirt road.

STOP 6
The Ortona Sand
Site Leader: Muriel Hunter
Location: Glades County
SE 1/4, NE 1/4, Sec. 15, T 42S, R 30E
Latitude: 26° 40' 15"
Longitude: 80° 18' 17"

0.0  111.1  Leave Sheraton Motor Inn for Florida Rock Ind. via U.S. 41, south.
4.2  115.3  Crossing Ten Mile Creek.
.6  115.9  Intersection U.S. 41 and Alico Rd. Proceed east on Alico Rd.
MILEAGE
Between Points Cumulative

.3 116.2 R.R. Crossing.
2.8 119.0 I-75 construction.
2.1 121.1 Entrance Florida Rock Ind., Turn south (right) towards office building.

STOP 7
Tamiami Aquifer, Zones 1 and 2 / Ochopee Limestone
Site Leader: Tom Missimer
Location: Collier County
NE¼, Sec. 12, T 46S, R 25E
Latitude: 26° 29' 23"
Longitude: 81° 45' 40"

Limestone is mined at this locality from the Ochopee limestone member of the Tamiami Formation. Molds and casts of various mollusks are common in the hard, light tan, limestone.

Board buses. Proceed to Site 8, Lee County Wellfield via Alico Rd., east.

.8 121.9 Pass through gate.
1.8 123.7 Alico Rd. curves to the southeast. Continue on Alico Rd.
2.2 125.9 Monitoring wells screened into the Tamiami aquifer(s) zones 1 and 2 can be observed east side of road.

.6 126.5 Intersection of Alico Rd. and Corkscrew Rd. Proceed east on Corkscrew Rd.

STOP 8
New Lee County Wellfield
Site Leader: Tom Missimer
Location: Lee County
SE¼, SW¼, Sec. 22, T 46S, R 26E
Latitude: 81° 41' 45"
Longitude: 26° 27' 10"

The new Lee County Wellfield will produce 5.0 MGD of raw water for municipal supply. Additional expansions of the system are expected in the future with an ultimate pumping rate of up to 25.00 MGD.

Board buses. Proceed west on Corkscrew Rd.
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<td>127.7</td>
<td>Intersection of Corkscrew Rd. and Alico Rd. Continue west on Corkscrew Rd. Along this stretch of road USGS test/monitoring wells can be observed.</td>
</tr>
<tr>
<td>3.4</td>
<td>131.1</td>
<td>Pass through cow gate.</td>
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<tr>
<td>1.4</td>
<td>132.5</td>
<td>I-75 construction.</td>
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<td>134.3</td>
<td>R.R. Crossing.</td>
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<td>Intersection of Corkscrew Rd. and U.S. 41. Proceed north on U.S. 41.</td>
</tr>
<tr>
<td>.2</td>
<td>134.8</td>
<td>Crossing Corkscrew River.</td>
</tr>
<tr>
<td>4.5</td>
<td>139.3</td>
<td>Intersection of U.S. 41 and Alico Rd. Continue north on U.S. 41 towards Ft. Myers.</td>
</tr>
<tr>
<td>6.1</td>
<td>145.4</td>
<td>Ft. Myers Airport.</td>
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<tr>
<td>.2</td>
<td>145.6</td>
<td>Ft. Myers City limits.</td>
</tr>
<tr>
<td>1.0</td>
<td>146.6</td>
<td>Intersection of U.S. 41 and North Airport Rd. Proceed east on North Airport.</td>
</tr>
<tr>
<td>.3</td>
<td>146.9</td>
<td>Yield to the north, continue north on Fowler</td>
</tr>
<tr>
<td>.4</td>
<td>147.3</td>
<td>Intersection of Fowler and Colonial. Proceed on Colonial.</td>
</tr>
<tr>
<td>.4</td>
<td>147.7</td>
<td>Cross R.R. Continue east on Colonial.</td>
</tr>
<tr>
<td>3.0</td>
<td>150.7</td>
<td>Intersection of Colonial and Oritz. Proceed north on Oritz.</td>
</tr>
<tr>
<td>4.6</td>
<td>155.3</td>
<td>Intersection of State Rd. 80 and Oritz. Proceed east on S.R. 80.</td>
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<tr>
<td>1.4</td>
<td>156.7</td>
<td>I-75 construction.</td>
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<tr>
<td>.3</td>
<td>157.0</td>
<td>Cross Orange River.</td>
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<td>7.6</td>
<td>164.6</td>
<td>Cross Hickory Creek.</td>
</tr>
<tr>
<td>4.5</td>
<td>169.1</td>
<td>Cross Bedman Creek.</td>
</tr>
<tr>
<td>2.0</td>
<td>171.1</td>
<td>Lee, Hendry County line.</td>
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MILEAGE
Between Points  Cumulative

STOP 9  
.5  171.6  

Buckingham Limestone
Site Leader: Tom Missimer & Muriel Hunter
Location: Hendry County
SW¼, SW¼, NE¼, Sec. 30, T 43S, R 28E
Latitude: 26° 42' 37"  
Longitude: 81° 33' 30"

The Buckingham Limestone, member of the Tamiami Formation, crops out beneath the bridge crossing the Townsend Canal. At this site, the Buckingham limestone is a lime mud with rock fragments containing large *Pectens*, oysters and vertebrate fossils.

1.6  179.2  
LaBelle City Limits.

1.1  180.3  

7.9  188.2  
R.R. Crossing.

.3  188.5  
Market on northwest corner of intersection. Turn north on paved road and proceed to Ortona Lock.

STOP 10  
1.4  189.9  

Stratigraphic Section: Caloosahatchee, Fort Thompson and Coffee Mill Hammock Formations
Location: Hendry County
SE¼, NE¼, SE¼, Sec. 27, T 42S, R 30E
Latitude: 26° 47' 17"
Longitude: 81° 18' 22"

Board buses, return to S.R. 80 and proceed east to West Palm Beach. End of Field Trip.
REFERENCES


APPENDICES

The plates and figures that follow were taken from "Late Cenozoic Stratigraphy of Southern Florida - A Reappraisal," Guidebook of the Second Annual Field Trip of the Miami Geological Society, compiled by R. D. Perkins, 1968.
STRIATIGRAPHIC SECTION

STOP 10 South bank Caloosahatchee Canal, 4 mi. W. of Ortona Lock, Sec. 30, R.30E., T.42S., Glades Co., Flo.

Sand, mucky, brownish-black, 7 in.
Sand, fine, no fossils, 6-8 in.
Marl, very sandy, abundant f.w. snails, light olive gray, 2-8 in.
Sand, mucky, olive gray to brownish-black, 8-12 in.

Marl, minor sand, plastic, abundant f.w. snails, 0-8 in.
Muck, sandy, plastic, brownish-black, 8-12 in.
Marl, clayey, minor sand, plastic, yellowish-gray, abundant f.w. snails, 6-10 in.
Sand, mucky, 12-24 in.

Unconformity
Sand and Shell.

Section by H.K. Brooks
Explanation of Plate 1

This plate shows a selection of fossils from the Tamiami, Pinecrest, Caloosahatchee, and Unit A. of special significance.

Figure 1.  *Pecten* (Nodipecten) *collierensis* Mansfield. About 1/1. Tamiami.

Figure 2. *Pecten* (Pecten) *hemicyclicus* Ravenel. About 1/1. Tamiami.

Figure 3. *Encopé tamiamiensis* Mansfield. About 1/1. Basal or ventral side. Tamiami.

Figure 4. *Ostrea* (Pycnodonta) *haitensis* (Sowerby). About 1/1. *O. monroensis* Mansfield. Often very large and thick. Both valves are plicated, and the shell texture is partly cellular. A Miocene species ranging through the Caribbean to South America. Tamiami.

Figure 5. *Spondylus bostrychites* Guppy. About 1/1. Inside of a large valve showing casts of boring in the inner layer (aragonitic) leacher away. A common Miocene species through the Caribbean to South America. Tamiami.

Figure 6. *Chione ulocyma leonensis* Mansfield. 1/1. Pinecrest. Alligator Alley. Also in north Florida.

Figure 7. *Anadara catasarca*. About 1/1. Index fossil for Unit A. Belle Glade.

Figure 8. *Anadara crassicosta* Heilprin. 1/1. Index fossil for Caloosahatchee. Caloosahatchee.

Figure 9. *Anadara* cf. *tuberculosa* (Sowerby) slightly reduced. This fossil is related or identical with *A. tuberculosa*, a mangrove-mud species along the Pacific coast of Mexico, Central America to Peru, the principal food clam in that region. Its discovery in Unit A was quite unexpected, as the last lingering occurrence of a purely Pacific element in the fauna. Slough's ditch.

Figure 10. *Pecten e boreus* darlingtonensis Dall, slightly reduced. Encrusted with a Miocene coral and worm-shells. Pinecrest. Fish Eating Creek.

Figures 11, 12. *Astartes*. Northern or Chesapeake elements in the south Florida Miocene. Fig. 11. *A. floridana* Dall. Also north Florida. St. Petersburg. Downdip Tamiami. Fig. 12. *A. symmetrica* Conrad. Pinecrest, Kissimmee.


*Personal communication with Hunter, 1978.*
Explanation of Plate 2

Figure 1  Ecphora quadricostata (Say) 2/3rd size. Murdock (Miss Hunter). Middle Miocene probably. An index fossil for the Chesapeake Miocene.

Figures 2 & 3  Vasum (Hystrivasum) 1/1 size. An endemic Florida group with about 4 species.
Fig. 2. V. locklini Olsson and Harbison. Pinecrest.
Fig. 3. V. horridum Heilprin. Caloosahatchee.

Figure 4  Cancellaria propevenusta Mansfield 1/1 size. Index fossil for the Pinecrest; also in north Florida and Duplin of North Carolina. Pinecrest.

Figures 5 - 8  Siphocypreea lineages. An endemic Eastern American genus beginning in the Chipola and became extinct at the end of Group C. Not in Unit A.
Fig. 5. S. carolinensis floridana Mansfield. About 2/3 size with simple apical sulcus. Pinecrest.
Fig. 6. S. problematica Heilprin. 1/1 size with fully developed spiral sulcus. Caloosahatchee.
Fig. 7, 8. S. transitoria Olsson and Petit. With transitional sulcus. Fig. 8 longitudinal section to show development of notch and Bulla stage whorls in the interior. Pinecrest. Brighton.

Figures 9- 12  Turritellas.
Fig. 9. T. evergladeensis Mansfield. Pinecrest. Slightly enlarged, notice scupture and inflated body whorl.
Fig. 10, 11. T. perattenuata Heilprin. About 1/1 size. Caloosahatchee.
Fig. 12. T. pontoni Mansfield. About 1/1 size. T. pontoni and evergladeensis are common Pinecrest species at all known stations.

Figures 13-14  Conus (Contraconus)
The left-handed cone, the only group of left-handed cones in the world and restricted to Group C or its equivalent beds in the Carolinas.
Fig. 13. Conus adversarius tryoni Heilprin. About 2/3 size. Caloosahatchee.
Fig. 14. Conus adversarius Conrad. A specimen showing fluorescent pattern. Pinecrest.

Figure 15  Fusinus watermani Maxwell Smith. 1/1 size.
Index fossil for Unit A. (Group B). Belle Glade.
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