Final Report to the South Florida Water Management District

PRELIMINARY HYDROGEOLOGIC ANALYSIS OF THE SUNNILAND NO. 1 COREHOLE, COLLIER COUNTY, FLORIDA

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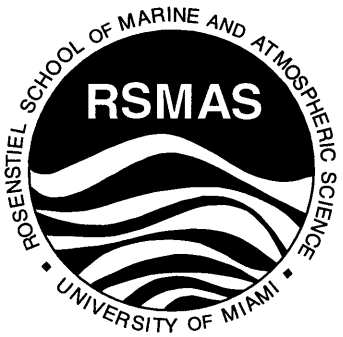

Final Report for Purchase Order No. PC P605169

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Executive Summary

Understanding the geologic framework of northcentral Collier County is critical for constraining the Surficial, Intermediate and Floridan Aquifer Systems. A new 815' core from Collier County provides key data on these aquifer systems (Fig. 1). This data is an important addition to the hydrogeologic framework of Collier County because it is the first continuous core from northcentral Collier County that contains a record of the upper Floridan Aquifer System through the Surficial Aquifer System (Fig. 2). The corehole is located in the central axis of a thick coarse sand of Pliocene and possibly younger age, which has been mapped by Cunningham et al. (in press) to span across the southern peninsula of Florida from southern Glades County to the middle and upper Florida Keys (Fig. 1).

The purpose of the joint University of Miami, South Florida Water Management District (SFWMD), and Florida Geological Survey (FGS) core hole was to collect new subsurface geologic data and test the water supply potential of Neogene sands of the Intermediate Aquifer System (Fig. 2). This report is the results of analyses of lithology, mineralogy, stratigraphy, and permeability, and the results of measurements of permeability conducted at the University of Miami. The SFWMD will collect and analyze water samples collected from the completed corehole.

Introduction

The UM/SFWMD/FGS Sunniland No. 1 corehole (FGS well ascension number W-17534) was completed in March, 1997, by the Florida Geological Survey. The corehole penetrated 815 feet of Oligocene, Neogene, and Quaternary rocks and sediments. The purpose of the core hole was to collect new subsurface geologic data and test the water supply potential of Neogene sands of the Intermediate Aquifer System. This report presents the results of analyses of lithology, mineralogy and stratigraphy, and of measurements of permeability conducted at the University of Miami. The SFWMD will collect and analyze water samples collected from the completed corehole.

Previous geologic studies (Peacock, 1983; Knapp et al., 1986; Brown et al., 1996) of the Intermediate Aquifer System (Fig. 2) in Collier County were based on drill cuttings derived from water wells. In this study the sample quality is improved by drilling a continuous core through the Surficial Aquifer System, Intermediate Aquifer System, and top of the Floridan Aquifer System.

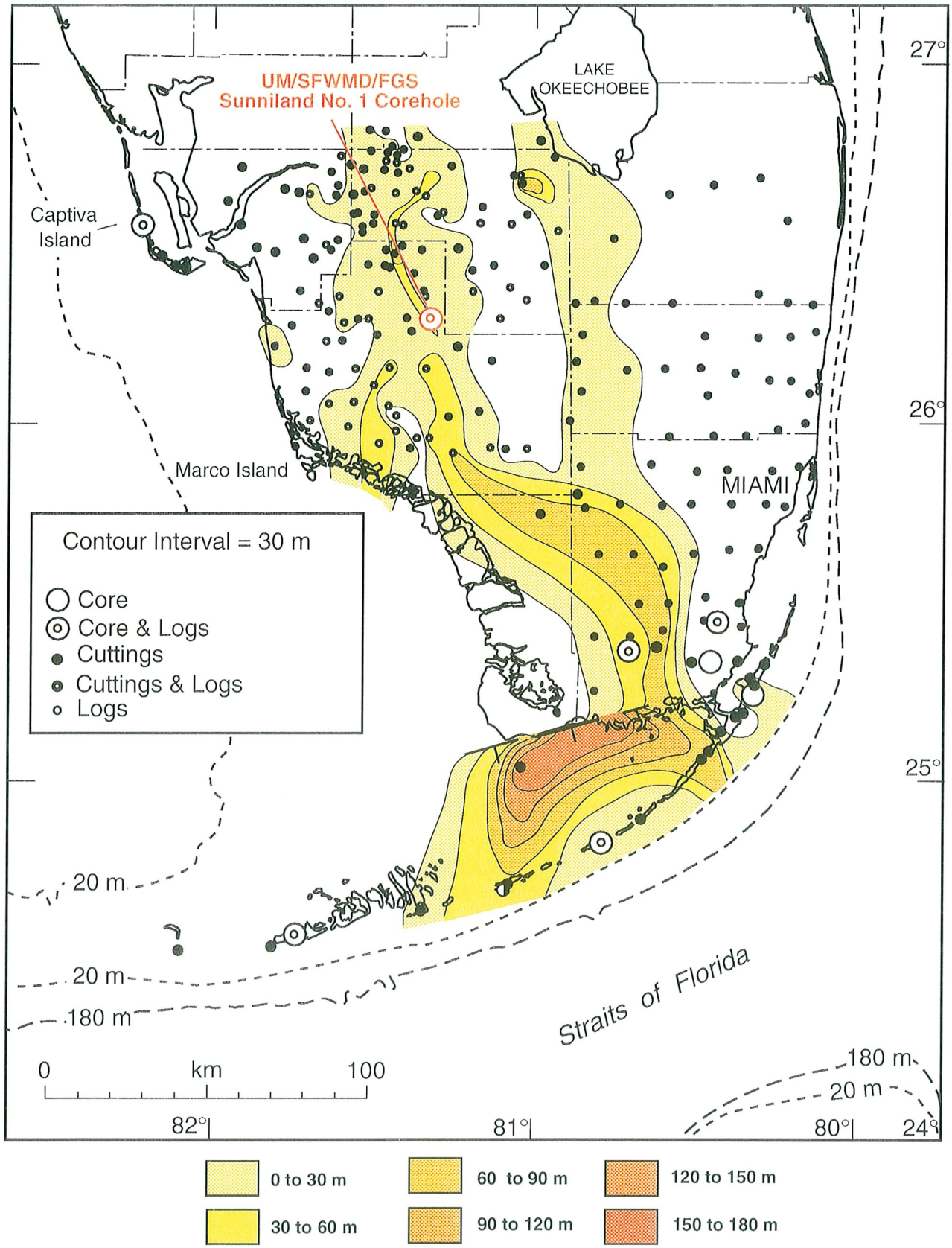

Figure 1. Location of UM/SFWMD/FGS Sunniland No. 1 and net thickness of coarse-grained (>1 mm) Miocene-to-Pliocene siliciclastic sands (after Cunningham et al., in press).

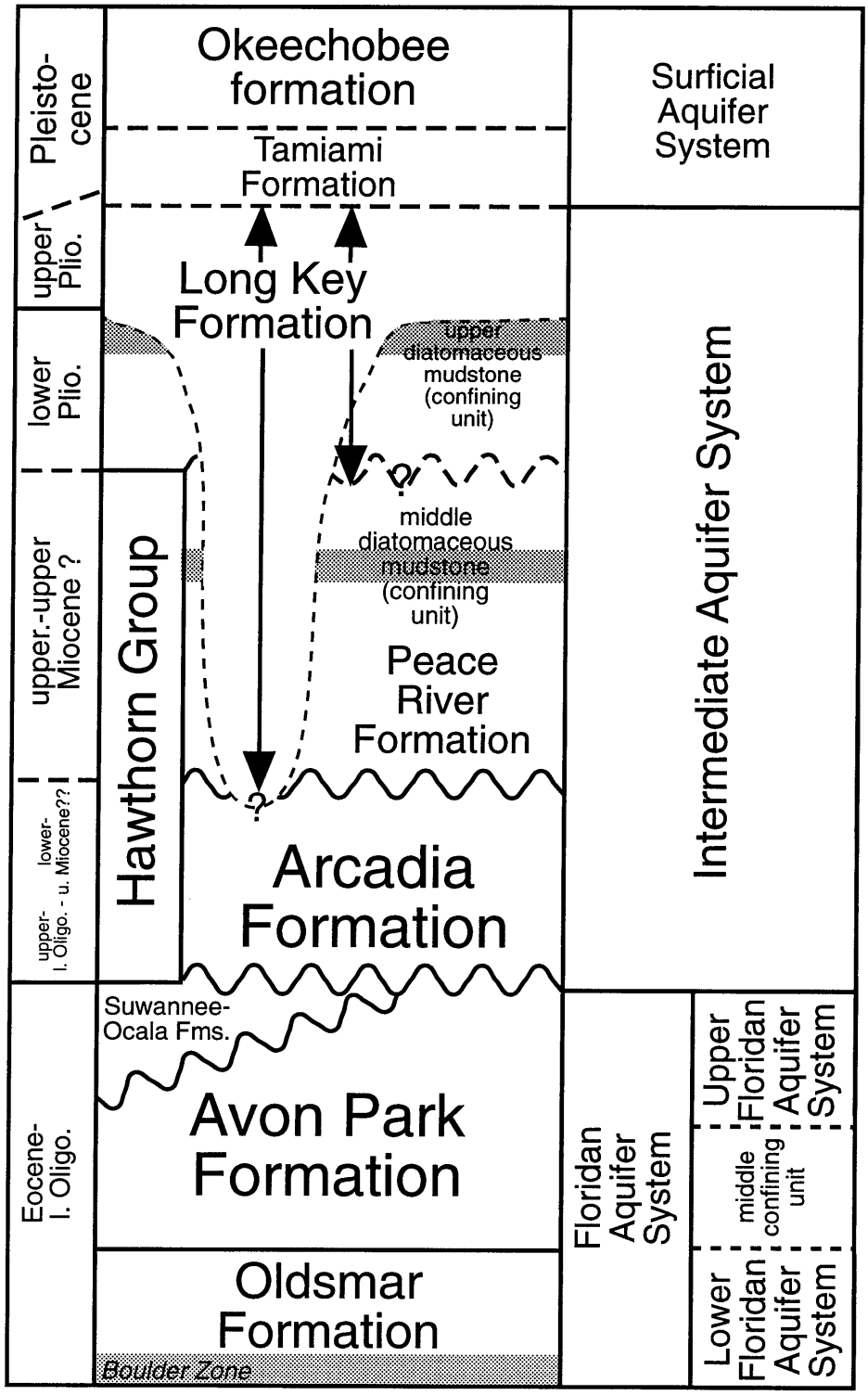

Figure 2. Working generalized stratigraphic nomenclature for South Florida. After Scott (1988), Scott and Wingard (1995), and Cunningham et al. (in press).

Location and Drilling History

The UM/SFWMD/FGS Sunniland No. 1 (W-17534) was drilled by the Florida Geological Survey (FGS) approximately 1/2 mile from the intersection of county highway 858 and state highway 29, approximately 9 miles southeast of the town of Immokalee in Collier County (Fig. 1). The corehole is located in the SW1/4, Section 17, T48S, R30E (latitude 26D, 17M, 51S and longitude 81D, 20M, 57S).

The corehole was drilled to a depth of 815'. Drilling required setting 4" PVC casing to a depth of 355'. Full recovery of the 4" casing was not possible, preventing completion of the corehole throughout sands and sandstones of the Long Key Formation (Figs. 2 and 3). A monitor well was rotary drilled to a depth of 273.5', located approximately 30' east of the corehole. Two-inch diameter PVC was set in the monitor well, screened through an interval between depths of 48.5' and 270'. An FGS accession number was not assigned to the monitor well because of its close proximity to the Sunniland No. 1 corehole. Core recovery was best in the Arcadia Formation and poorest in the sands and sandstones of the Long Key Formation (Fig. 4).

Core W-17534 is temporally stored at the University of Miami Core Repository in Miami, but will be moved for permanent archival to Tallahassee, Florida as part of the Florida Geological Survey Core Repository.

Methods

One corehole, the UM/SFWMD/FGS Sunniland No. 1, was drilled for this study using a Failing 1500 drill rig operated by the Florida Geological Survey. The core was described at the University of Miami Core Repository to determine the vertical pattern of lithology, sedimentary features, and depositional sequence boundaries. Twenty thin sections were examined using standard transmitted-light petrography to identify lithofacies type and to estimate visual porosity. Rock colors were recorded by comparison to the Geological Society of America (1991) rock-color chart with Munsell color chips. Mineral concentrations (low- and high-magnesium calcite, aragonite, dolomite, and quartz) were calculated for 124 bulk specimens from peak-area ratios produced by a Scintag XDS-2000 X-ray diffraction unit. Visual permeabilty was estimated by examination of core and comparison to approximate ranges of hydraulic conductivity produced by Fish and Stewart (1991). Approximately 220 measurements of permeability were taken using a probe permeameter. Probe measurements on slabbed core were produced by using a 12.7 mm outer diameter and 6.35 mm inner diameter, flat, neoprene, washer-tip seal with a constant nitrogen injection flow rate of 200 ml/min. The instrument is capable of excellent reproducibility (typically $\pm$5% relative error) over a range of 0.2 to 2000 md. The reproducibility for samples with >3000 md had greater error, with 3000 $\pm$1000 md and 5000 $\pm$2000 md typical. Water quality (pH, specific conductance, salinity, and dissolved oxygen) was measured with a Hydrolab on groundwater samples collected during drilling of the core hole. Geophysical logs (gamma ray, neutron density, single point resistivity, 16" and 64" resistivity, caliper, temperature differential, and temperature gradient) were recorded by SFWMD and Geophex, Ltd (sonic log).

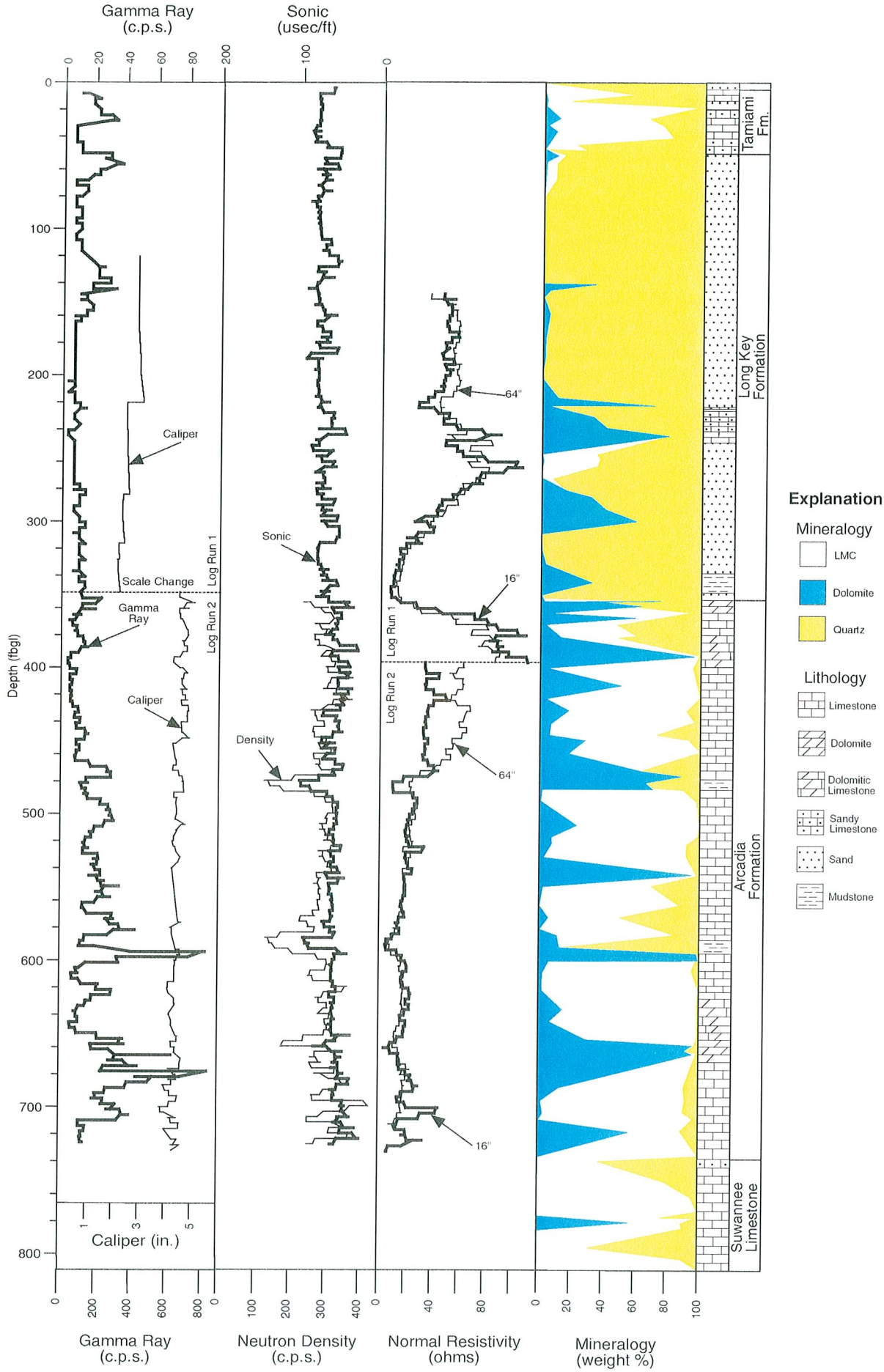

Figure 3. Comparison of geophysical, mineralogic, and lithologic data from the Sunniland No. 1 corehole.

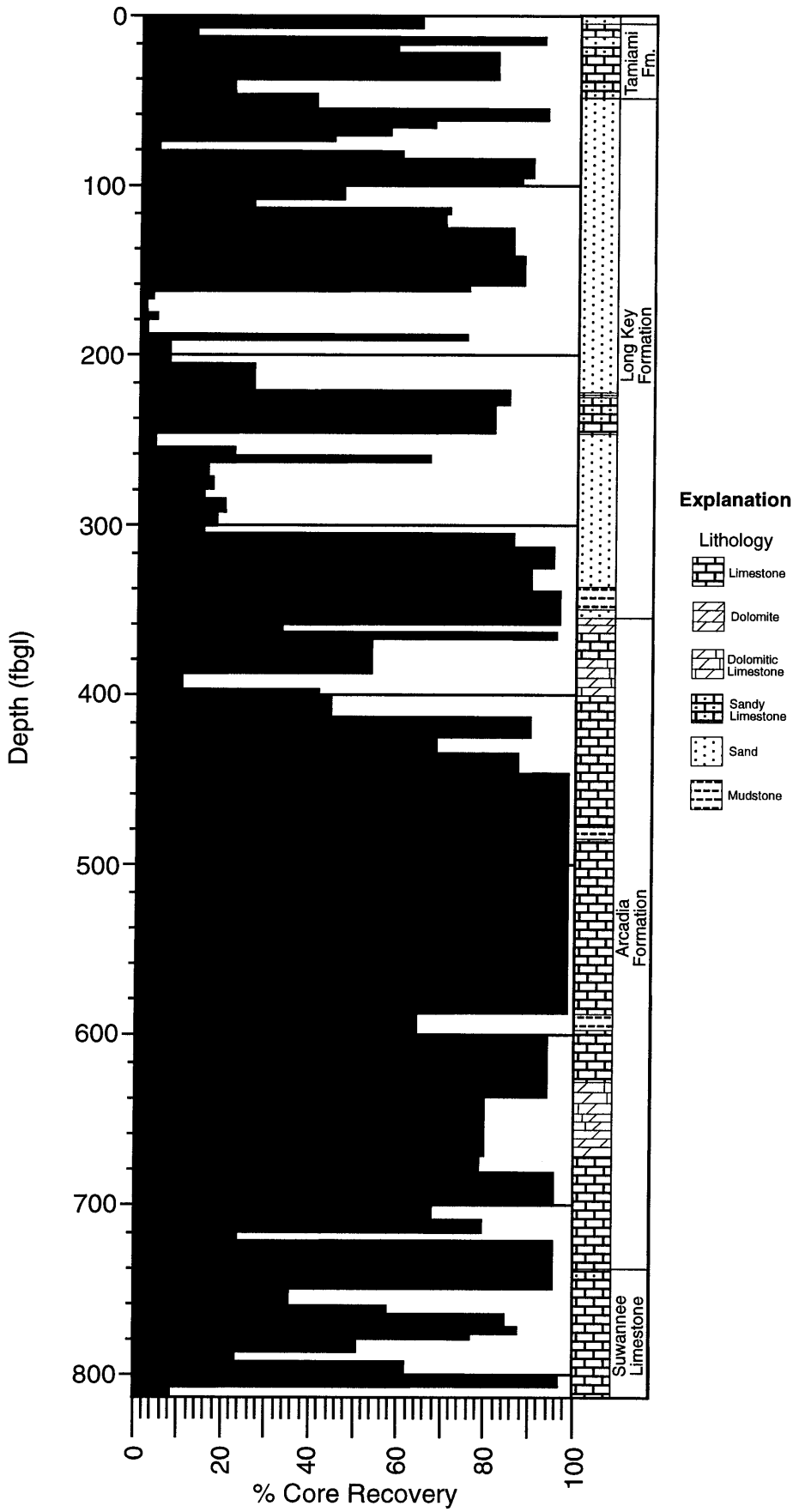

Figure 4. Percent core recovery from the Sunniland No. 1 core hole.

Geologic Interpretation

Lithology. In the Sunniland No. 1 core, the Surficial Aquifer System is composed of a mixed carbonate and siliciclastic deposit of the Tamiami Formation (Fig. 3). The most permeable portion of the aquifer system is in the uppermost 8.5 feet of the Tamiami were limestones contain mainly moldic and vuggy pososity and moderate to high hydraulic conductivities.

The Long Key Formation and the Arcadia Formation combine to form the Intermediate Aquifer System. The upper portion of the Long Key Formation (49'-221' core depth) is predominately very fine sand to pebble sized quartz sands and sandstones, which have moderate to high hydraulic conductivities. Marine bivalves occur in several thick intervals of this succession of sands and sandstones and may indicate fluctuation between fluvial and deltaic depositional systems. A 26-foot thick sandy limestone occurs within the middle Long Key Formation between core depths of 221' and 247' (Fig. 3). This limestone suggests a restricted marine depositional system in which the supply of siliciclastics has been reduced. The lower portion of the Long Key Formation, from 247' to 354.5' core depth, is composed of very fine to fine sands and interbedded mudstones that coarsen upward to very fine to pebble sized sands. The lower, finer-grained portion of this succession yields very low to moderate hydraulic conductivities and the upper coarse-grained portion moderate to high hydraulic conductivities. This coarsening upward sequence suggests progradation of an inner deltaic depositional environment over an outer deltaic depositional environment. Approximately 110 feet of coarse sand (>1mm diameter) was encountered in the Sunniland No. 1 corehole, confirming the presence of thick coarse sands of Pliocene and possibly younger that are shown in Figure 1.

The Arcadia Formation is composed of marine limestones with minor dolomites, dolosilts, mudstones, quartz grains, and phosphorite grains. The dolosilts and mudstones have very low hydraulic conductivities. Concentration of phosphorite is localized into bed-scale units and can be as high as 80%. Beds containing quartz are not common but can contain up to 40% quartz grains. Visual estimates of hydraulic conductivities within the Arcadia Limestone are typically low.

The Suwannee Limestone is characterized by numerous vertically-stacked, exposure-capped, shallowing-upward successions. Each shallowing-upward succession is capped by a laminated calcrete, which typically contains root molds, an indicator of subaerial exposure. Similar shallowing upward successions were described in the Suwannee Limestone of the Florida Keys (Cunningham et al., in press) and southwestern Florida (Hammes, 1992). A thick, bed-scale calcrete at the top of the Suwannee forms a sequence boundary between the top of the Suwannee Limestone and the base of the Arcadia Formation. Quartz sand is estimated to comprise up to 50% of quartz-rich units within the Suwannee Limestone. These quartz-rich units can contain up to 5% phosphorite grains. Visual estimates of hydraulic conductivity within the Suwannee Limestone are typically low to moderate, somewhat higher than those estimated for limestones of the Arcadia (Appendix 1).

Geophysical logs. The gamma-ray log is most useful in distinguishing formations in the Sunniland No. 1 corehole (Fig. 3). An increase in gamma ray that occurs at a log depth of 354' is attributed to uranium associated with phosphorite sand and pebbles at a core depth of 354.33' to 354.5'. The gamma-ray response over the Arcadia interval shows numerous increases in activity due to thin intervals containing high

concentrations of phosphorite sand and pebbles or mudstones. The Long Key Formation shows little high gamma-ray activity due to its overall low concentration of phosphorite grains. The Suwannee Limestone was not logged.

The sonic log displays slightly higher interval transit times throughout the sands and sandstones of the Long Key Formation relative to the sonic response logged over the Arcadia Formation. The higher interval transit times throughout the Long Key Formation are likely due to higher porosity associated with the relatively unconsolidated sands and sandstones as compared to well consolidated limestones of the Arcadia Formation.

A neutron density log was run through the Arcadia Formation only. Three zones containing the lowest neutron densities (Fig. 3) correspond to mudstone or dolosilt lithologies.

Permeability. Permeability measurements with a probe permeameter were conducted on slabbed core of a limestone from the middle of the Long Key Formation, the Arcadia Formation and the Suwannee Limestone (Fig. 5). Permeability measurements were not collected from the sands and sandstones of the Long Key Formation because the sands and sandstones are not cohesive enough. Visual estimates of hydraulic conductivity of the entire core are included in a lithologic description in Appendix 1.

Permeabilities sampled from the middle limestone of the Long Key Formation were poor to good, ranging from 2 to 131 millidarcies. Permeabilities collected from the Arcadia Formation were poor to excellent, ranging from 0.02 to 5480 millidarcies. Permeabilities measured from the Suwannee Limestone were also poor to excellent but averaged somewhat higher than the Arcadia Limestone, ranging from 0.8 to 5229 millidarcies.

Hydrolab Results. Groundwater flowed to the surface upon penetration of the upper 50' of the Arcadia Formation. This flow continued throughout drilling of the corehole to a total depth of 815'. It is presumed the source of the groundwater is a highly permeable zone within the upper Arcadia. This ground water was sampled from the surface at three separate time intervals during drilling of the corehole. Temperature, pH, specific conductance, salinity, and dissolved oxygen was measured with a portable Hydrolab at the University of Miami. Results are shown below in Table 1.

Sample Interval	Date Collected	Temp. (^{o}C)	pH	Specific Conductance (mS/cm)	Salinity (ppt)	Dissolved Oxygen (mg/l)
140-399'	12/4/96	22	8.2	0.75	~0.3	----------
355-815'	2/8/97	23	7.6	1.90	1.0	2.8
355-815'	3/8/97	24	7.1	5.24	2.9	0.8

Table 1. Results from Hydrolab measurements conducted at the University of Miami on samples collected from the UM/SFGWMD/FGS Sunniland No. 1.

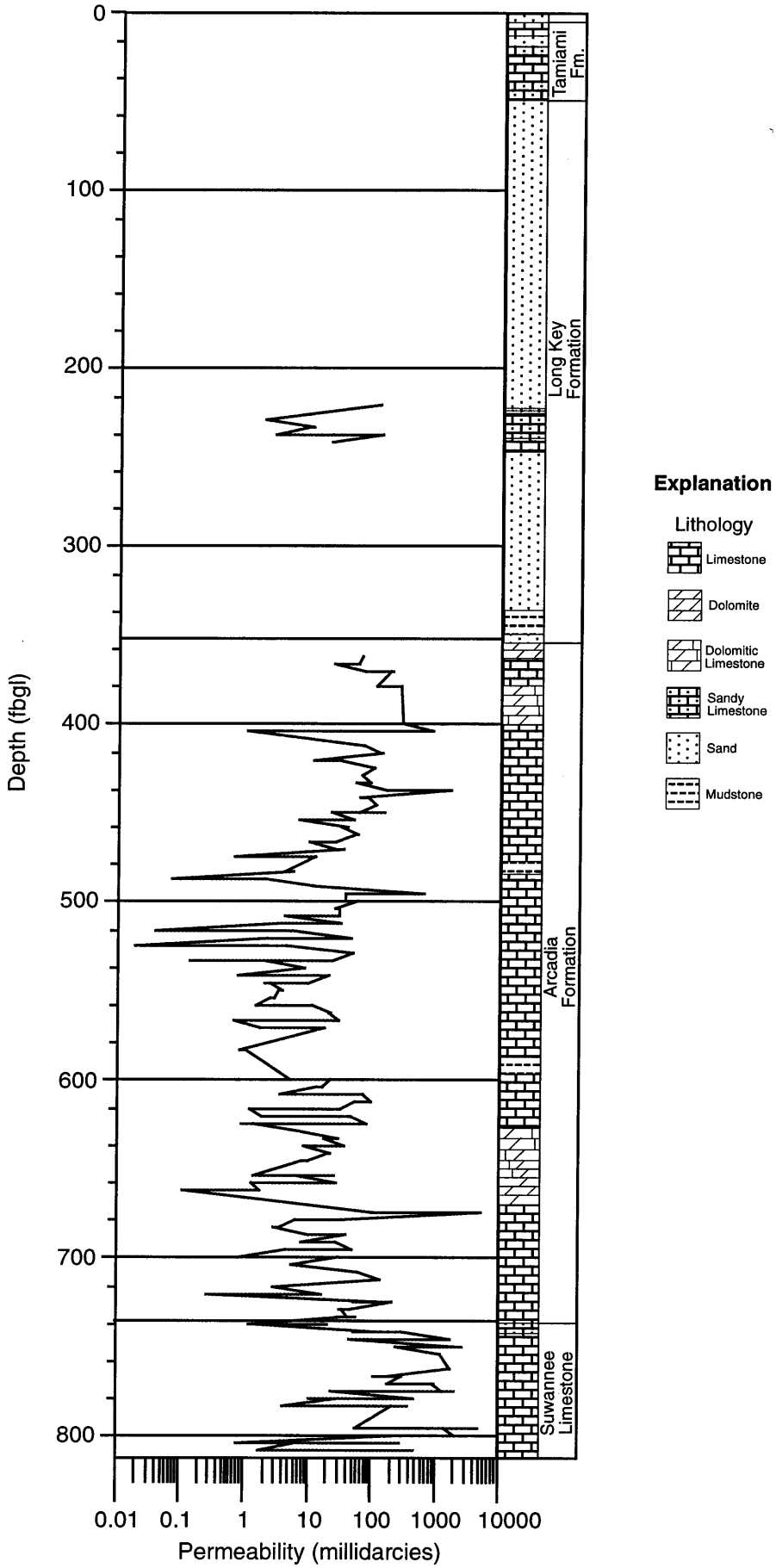

Figure 5. Comparison of permeability and lithology.

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Appendix 1

Core Description

UM-SFWMD-FGS Sunniland Corehole
W-17534
SW1/4, SW1/4, Sec. 17, T48S, R30E, Collier Co., Florida
Lat. 26D 17M 51S Long. 81D 20M 57S
Described by Kevin J. Cunningham, Ph.D., P.G., University of Miami, Rosenstiel School of Marine & Atmospheric Science, Division of Marine Geology & Geophysics, 27 August 1997.
Colors described dry by comparison to the Geological Society of America Rock-Color Chart (1991) with genuine Munsell color chips. Horizontal hydraulic conductivity (feet per day) estimated by comparison to Fish and Stewart (1991).

0-4'	Undifferentiated sand
4-49'	Tamiami Formation
49-354.5'	Long Key Formation
354.5- 738.83'	Arcadia Formation
738-815'	Suwannee Limestone

0-4' Lithology: sand
Color: pale yellowish brown (10YR 6/2) and dark yellowish orange (10YR 6/6)
Porosity: intergranular
Hydraulic Conductivity: moderate to high (10-1,000)
Grain Size: very fine to fine; range: very fine to fine
Roundness: subrounded to rounded; Sorting: well sorted
Very poor induration
Cement: clay matrix
Other Features: loose unconsolidated sand

4-8.5' Lithology: lime rudstone with packstone matrix
Color: grayish orange (10YR 7/4)
Porosity: moldic, vuggy and intraparticle
Hydraulic Conductivity: moderate to high (10-1,000)
Allochemical Constituents: 60%
Grain Size: very coarse and very large pebble size; range: mud to small pebble size
Moderate to well induration
Cement: lime mudstone matrix
Fossils: bivalves and broken fossil fragments
Other Features: poor recovery, most recovery broken rubble

8.5-10.5' No samples

10.5 12.5' Lithology: lime rudstone with packstone matrix
Color: grayish orange (10YR 7/4)
Porosity: moldic, vuggy and intraparticle

Hydraulic Conductivity: moderate to high (10-1,000)
Allochemical Constituents: 60%
Grain Size: very coarse and very large pebble size; range: mud to small pebble size
Moderate to well induration
Cement: lime mudstone matrix
Fossils: bivalves, broken fossil fragments
Other Features: poor recovery, most recovery broken rubble

12.5-19' Lithology: sandstone
Color: yellowish gray (5Y8/1)
Porosity: intergranular
Hydraulic Conductivity: very low (<0.1)
Grain Size: very fine; range: mud to very fine
Roundness: subangular to subrounded; Sorting: well sorted
Moderate induration
Cement: lime mud matrix
Accessory Minerals: 2% phosphorite
Fossils: bivalves, broken fossil fragments
Other Features: bioturbated(?)

19-27' Lithology: sandy lime mudstone
Color: yellowish gray (5Y 8/1)
Porosity: intergranular
Hydraulic Conductivity: very low (<0.1)
Allochemical constituents: trace
Grain Size: silt to very fine; range: clay
Moderate induration
Cement: lime mudstone matrix
Accessory Minerals: 20% quartz sand
Fossils: trace bivalves
Other Features: mottled texture due to bioturbation

27-30' Lithology: lime floatstone with mudstone matrix
Color: very pale orange (10YR 8/2)
Porosity: moldic
Hydraulic Conductivity: low (0.1-10)
Allochemical constituents: 50%
Grain Size: bimodal, clay and large pebble size; range: clay to large pebble size
Poor induration
Cement: mudstone matrix
Accessory Minerals: clay
Fossils: broken fossil fragments, bivalves
Other Features: very rubbly recovery

30-35.5' Lithology: lime rudstone with lime packstone matrix
Color: very light gray (N8) and very pale orange (10YR 8/2)
Porosity: moldic
Hydraulic Conductivity: low to moderate (0.1-100)

Allochemical constituents: 60%
Grain Size: bimodal, coarse sand and large pebble size; range: clay to very large pebble size
Well indurated
Cement: lime mud matrix
Accessory Minerals: trace heavy minerals
Fossils: bivalves, broken fossil fragments, bryozoans
Other Features: bioturbated; poor recovery; rock mainly rubble

35.5-41' Lithology: lime rudstone with lime packstone matrix
Color: very light gray (N8) and very pale orange (10YR 8/2)
Porosity: moldic
Hydraulic Conductivity: low to moderate (0.1-100)
Allochemical Constituents: 60%
Grain Size: bimodal, coarse sand and large pebble size; range: clay to very large pebble size
Well indurated
Cement: lime mud matrix
Accessory Minerals: trace heavy minerals
Fossils: bivalves, broken fossil fragments
Other Features: bioturbated

41-47' Lithology: lime rudstone with sandstone matrix
Color: very light gray (N8) and very pale orange (10YR 8/2)
Porosity: moldic
Hydraulic Conductivity: low to moderate (0.1-100)
Allochemical Constituents: 60%
Grain Size: bimodal, fine sand and large pebble size; range: clay to very large pebble size
Moderate to well induration
Cement: lime mud matrix
Accessory Minerals: 30% quartz sand; 2% phosphorite
Fossils: bivalves
Other Features: very poor recovery

47-49' Lithology: lime rudstone with sandstone matrix
Color: very light gray (N8) and very pale orange (10YR 8/2)
Porosity: moldic
Hydraulic Conductivity: low to moderate (0.1-100)
Allochemical Constituents: 60%
Grain Size: bimodal, fine sand and large pebble size; range: clay to very large pebble size
Moderate to well induration
Cement: lime mud matrix
Accessory Minerals: 30% quartz sand; 2% phosphorite
Fossils: gastropods, bivalves

49-69' Lithology: sand
Color: yellowish gray (5Y8/1)

Porosity: intergranular
Hydraulic Conductivity: moderate to high (10-1,000)
Grain Size: very fine; range: very fine to coarse
Roundness: subangular to rounded; Sorting: well sorted
Poor induration
Cement: trace clay matrix
Accessory Minerals: trace mica; ≤5% phosphorite
Fossils: trace bivalves
Other Features: poor recovery

69-70.5' Lithology: sand
Color: yellowish gray (5Y8/1)
Porosity: intergranular
Hydraulic Conductivity: moderate to high (10-1,000)
Grain Size: very fine to medium; range: very fine to medium pebble size
Roundness: subangular to rounded; Sorting: moderate to well sorted
Poor induration
Cement: none
Accessory Minerals: trace mica; ≤5% phosphorite
Fossils: ≤2% broken bivalves
Other Features: massive and structureless

70.5-77' Lithology: sand
Color: yellowish gray (5Y8/1)
Porosity: intergranular
Hydraulic Conductivity: moderate to high (10-1,000)
Grain Size: very fine to coarse; range: very fine to coarse
Roundness: subangular to rounded; Sorting: moderate to well sorted
Poor induration
Cement: none
Accessory Minerals: ≤2% phosphorite
Other Features: poor recovery

77-81' No samples

81-86' Lithology: sand
Color: yellowish gray (5Y8/1)
Porosity: intergranular
Hydraulic Conductivity: moderate to high (10-1,000)
Grain Size: very fine to coarse; range: very fine to coarse
Roundness: subangular to rounded; Sorting: moderate to well sorted
Poor induration
Cement: none
Accessory Minerals: ≤2% phosphorite
Other Features: poor recovery

86-91.83' Lithology: sand
Color: yellowish gray (5Y8/1)
Porosity: intergranular

Hydraulic Conductivity: moderate to high (10-1,000)
Grain Size: very fine to fine; range: very fine to coarse
Roundness: subangular to rounded; Sorting: well sorted
Poor induration
Cement: none
Accessory Minerals: ≤5% mica; ≤1% phosphorite

91.83-102.6' Lithology: sand
Color: yellowish gray (5Y8/1)
Porosity: intergranular
Hydraulic Conductivity: moderate to high (10-1,000)
Grain Size: very fine; range: very fine to fine
Roundness: subangular to rounded; Sorting: well sorted
Poor induration
Cement: none
Accessory Minerals: trace mica; ≤5% phosphorite
Other Features: poor recovery

102.6-103.6' No samples

103.6-107.5 Lithology: sand
Color: yellowish gray (5Y8/1)
Porosity: intergranular
Hydraulic Conductivity: moderate to high (10-1,000)
Grain Size: very fine; range: very fine to fine
Roundness: subangular to rounded; Sorting: well sorted
Poor induration
Cement: none
Accessory Minerals: trace mica; ≤5% phosphorite
Other Features: poor recovery

107.5-109' No samples

109-114.5' Lithology: sand
Color: yellowish gray (5Y8/1)
Porosity: intergranular
Hydraulic Conductivity: moderate to high (10-1,000)
Grain Size: very fine; range: very fine to fine
Roundness: subangular to rounded; Sorting: well sorted
Poor induration
Cement: none
Accessory Minerals: trace mica; ≤5% phosphorite
Other Features: poor recovery

114.5-115' No samples

115-128' Lithology: sand
Color: yellowish gray (5Y8/1)
Porosity: intergranular

Hydraulic Conductivity: moderate to high (10-1,000)
Grain Size: very fine; range: very fine to very coarse
Roundness: subangular to rounded; Sorting: well sorted
Poor induration
Cement: trace clay
Accessory Minerals: trace mica; ≤2% phosphorite
Fossils: trace fossil fragments
Other Features: bioturbated

128-140' Lithology: sandstone
Color: yellowish gray (5Y8/1) to light olive gray (5Y 5/2)
Porosity: intergranular
Hydraulic Conductivity: moderate (10-100)
Grain Size: very fine; range: very fine to very coarse
Roundness: subangular to rounded; Sorting: well sorted
Moderate induration
Cement: clay matrix
Accessory Minerals: 1% mica; trace phosphorite
Fossils: trace bivalves
Other Features: minor layers containing very coarse sand grains floating in very fine sand

140-140.5' Lithology: lime floatstone with sandstone matrix
Color: yellowish gray (5Y8/1)
Porosity: intergranular
Hydraulic Conductivity: moderate (10-100)
Grain Size: bimodal, very fine sand and very large pebble sized; range: very fine sand to very large pebble size
Roundness: subangular to rounded; Sorting: well sorted
Well indurated
Cement: calcite
Accessory Minerals: trace phosphorite
Fossils: trace bivalves
Other Features: recovery mainly rubble

140.5-154.5' Lithology: sandstone
Color: medium light gray (N6) to very light gray (N8)
Porosity: intergranular
Hydraulic Conductivity: moderate to high (10-1,000)
Grain Size: very fine to coarse sand; range: very fine sand to large pebble size
Roundness: subangular to rounded; Sorting: poor to moderate
Poor to moderate induration
Cement: clay matrix
Accessory Minerals: 2% phosphorite
Fossils: 10-20% bivalves and gastropods

154.5-158' Lithology: sand
Color: very light gray (N8)

Porosity: intergranular
Hydraulic Conductivity: moderate to high (10-1,000)
Grain Size: fine to medium sand; range: fine sand to small pebble size
Roundness: subangular to rounded; Sorting: moderate
Poor induration
Cement: none
Accessory Minerals: 2% phosphorite
Fossils: 5% bivalves fragments
Other Features: massive and structureless

158-160' No samples

160-162.5' Lithology: sand
Color: very light gray (N8)
Porosity: intergranular
Hydraulic Conductivity: moderate to high (10-1,000)
Grain Size: fine to medium sand; range: fine sand to small pebble size
Roundness: subangular to rounded; Sorting: moderate
Poor induration
Cement: none
Accessory Minerals: 1% phosphorite
Fossils: broken bivalves and broken fossil fragments
Other Features: poor recovery

162.5-167' No samples

167-170' Lithology: sand
Color: yellowish gray (5Y 8/1)
Porosity: intergranular
Hydraulic Conductivity: moderate to high (10-1,000)
Grain Size: medium sand; range: fine sand to very coarse size
Roundness: subangular to rounded; Sorting: moderate
Poor induration
Cement: none
Accessory Minerals: $\leq$3% phosphorite
Fossils: trace bivalves fragments
Other Features: very poor recovery

170-173' No samples

173-191' Lithology: sand
Color: yellowish gray (5Y 8/1)
Porosity: intergranular
Hydraulic Conductivity: moderate to high (10-1,000)
Grain Size: medium sand; range: fine sand to very coarse size
Roundness: subangular to rounded; Sorting: moderate
Poor induration
Cement: none
Accessory Minerals: $\leq$3% phosphorite

Fossils: trace bivalves fragments
Other Features: very poor recovery

191-196.5' Lithology: sand
Color: very light gray (N8)
Porosity: intergranular
Hydraulic Conductivity: moderate to high (10-1,000)
Grain Size: medium to coarse sand; range: fine sand to very coarse size
Roundness: subangular to rounded; Sorting: moderate
Poor induration
Cement: none
Accessory Minerals: ≤3% phosphorite
Fossils: trace bivalves fragments
Other Features: poor recovery

196.5-206' No samples

206-207.2' Lithology: sand
Color: very light gray (N8)
Porosity: intergranular
Hydraulic Conductivity: moderate to high (10-1,000)
Grain Size: medium to coarse sand; range: fine to very coarse sand size
Roundness: subangular to rounded; Sorting: moderate
Poor induration
Cement: none
Accessory Minerals: ≤3% phosphorite
Fossils: trace bivalves fragments
Other Features: poor recovery

207.2-221' Lithology: sand
Color: very light gray (N8)
Porosity: intergranular
Hydraulic Conductivity: moderate to high (10-1,000)
Grain Size: very coarse sand; range: coarse to large pebble size
Roundness: subangular to rounded; Sorting: moderate
Poor induration
Cement: none
Accessory Minerals: ≤2% phosphorite
Fossils: 5% bivalves fragments
Other Features: very poor recovery

221-223' Lithology: sandy lime mudstone
Color: yellowish gray (5Y 8/1) and light gray (N8)
Porosity: intergranular
Hydraulic Conductivity: very low (<0.1)
Allochemical Constituents: none
Grain Size: bimodal, mud and medium sand; range: mud to medium sand size
Roundness: subangular to rounded; Sorting: moderate
Moderate induration

Cement: lime mudstone matrix
Accessory Minerals: ≤15% quartz sand
Fossils: trace bivalves
Other Features: mottled texture

223-226' Lithology: sandstone
Color: yellowish gray (5Y 8/1)
Porosity: intergranular
Hydraulic Conductivity: very low to low (<0.1-10)
Grain Size: medium to coarse sand; range: mud to coarse sand size
Roundness: subangular to rounded; Sorting: moderate
Moderate induration
Cement: lime mudstone matrix
Accessory Minerals: ≤1% phosporite
Other Features: bioturbated(?)

226-228' Lithology: sandy lime mudstone
Color: yellowish gray (5Y 8/1)
Porosity: intergranular
Hydraulic Conductivity: very low (<0.1)
Allochemical Constituents: trace
Grain Size: bimodal, mud and coarse sand; range: mud to large pebble size
Roundness: subangular to rounded; Sorting: moderate
Moderate induration
Cement: lime mudstone matrix
Accessory Minerals: ≤40% quartz sand and pebbles
Fossils: broken fossil fragments
Other Features: heavily bioturbated

228-241.75' Lithology: sandy lime wackestone
Color: yellowish gray (5Y 8/1)
Porosity: moldic
Hydraulic Conductivity: very low (<0.1)
Allochemical Constituents: trace
Grain Size: very fine to medium sand; range: mud to coarse sand size
Roundness: subangular to rounded; Sorting: moderate
Well indurated
Cement: lime mudstone matrix
Accessory Minerals: ≤25% quartz grains; trace phosphorite
Fossils: broken fossil fragments, bivalves
Other Features: heavily bioturbated

241.75-247' Lithology: lime rudstone with packstone matrix
Color: very pale orange (10YR 8/2)
Porosity: moldic
Hydraulic Conductivity: low (0.1-100)
Allochemical Constituents: 75%
Grain Size: medium pebble size; range: mud to very large pebble size
Roundness: subround to rounded; Sorting: moderate

Well indurated
Cement: lime mudstone matrix
Accessory Minerals: 10% quartz grains; trace phosphorite
Fossils: bivalves, broken fossil fragments, gastropods
Other Features: bioturbated

247-261' Lithology: sand
Color: yellowish gray (5Y 8/1)
Porosity: intergranular
Hydraulic Conductivity: moderate to high (10-1,000)
Grain Size: fine to coarse sand size; range: fine sand to small pebble size
Roundness: subround to rounded; Sorting: moderate to well
Poor induration
Cement: none
Accessory Minerals: 5% phosphorite
Fossils: bivalves fragments
Other Features: massive structureless

261-272.58' Lithology: sandstone
Color: yellowish gray (5Y 8/1)
Porosity: intergranular and moldic
Hydraulic Conductivity: moderate to high (10-1,000)
Grain Size: very fine to fine sand size; range: very fine sand to very large pebble size
Roundness: subangular to rounded; Sorting: moderate
Moderate induration
Cement: calcite cement
Accessory Minerals: trace mica; 5% phosphorite
Fossils: bivalves

272.58-301' Lithology: sand
Color: yellowish gray (5Y 8/1)
Porosity: intergranular
Hydraulic Conductivity: moderate to high (10-1,000)
Grain Size: very fine to fine sand size; range: very fine to very coarse sand size
Roundness: subangular to subrounded; Sorting: moderate
Poor induration
Cement: none
Accessory Minerals: trace mica; 5% phosphorite
Other Features: massive structureless

301-301.25' Lithology: mudstone
Color: light olive gray (5Y 6/1)
Porosity: intergranular
Hydraulic Conductivity: very low (<0.1)
Grain Size: clay; range: clay to very fine sand size
Roundness: subangular to subrounded; Sorting: very well
Moderate induration
Cement: clay matrix

Accessory Minerals: ≤1% mica; ≤1% phosphorite
Other Features: minor very fine sand laminations; bioturbated

301.25-310.75' Lithology: sand
Color: yellowish gray (5Y 8/1)
Porosity: intergranular
Hydraulic Conductivity: moderate (10-100)
Grain Size: very fine to fine sand size; range: very fine to fine sand size
Roundness: subangular to subrounded; Sorting: very well
Poor induration
Cement: trace clay
Accessory Minerals: trace mica; 5% phosphorite
Other Features: bioturbated(?)

310.75-325.42' Lithology: interbedded sand and mudstone
Color: sand yellowish gray (5Y 8/1) and mudstone pale olive (10Y 6/2)
Porosity: intergranular
Hydraulic Conductivity: very low to moderate (<0.1-100)
Grain Size: very fine to fine sand size; range: clay to fine sand size
Roundness: subangular to subrounded; Sorting: well to very well
Poorly indurated sand and moderately indurated mudstone
Cement: clay matrix
Accessory Minerals: trace mica; 5% phosphorite
Other Features: sand:mudstone ratio=50:50; heavily bioturbated

325.42-338' Lithology: interbedded sand and mudstone
Color: sand yellowish gray (5Y 8/1) and mudstone pale olive (10Y 6/2)
Porosity: intergranular
Hydraulic Conductivity: very low to moderate (<0.1-100)
Grain Size: very fine sand size; range: clay to very fine sand size
Roundness: subangular to subrounded; Sorting: very well
Poorly indurated sand and moderately indurated mudstone
Cement: clay matrix
Accessory Minerals: trace mica; 5% phosphorite
Other Features: heavily bioturbated

338-342.58' Lithology: mudstone
Color: light olive gray (5Y 6/1)
Porosity: intergranular
Hydraulic Conductivity: very low (<0.1)
Grain Size: clay; range: clay to very fine sand size
Roundness: subangular to subrounded; Sorting: very well
Moderate induration
Cement: clay matrix
Accessory Minerals: ≤1% mica; ≤1% phosphorite
Other Features: minor very fine sand laminations; bioturbated

342.58-344.75' Lithology: interbedded sand and sandstone
Color: yellowish gray (5Y 8/1) and light olive gray (5Y 6/1)

Porosity: intergranular
Hydraulic Conductivity: very low to moderate (<0.1-100)
Grain Size: very fine to fine sand size; range: clay to fine sand size
Roundness: subangular to subrounded; Sorting: well
Poor to moderate induration
Cement: minor clay matrix
Accessory Minerals: ≤2% mica; 5% phosphorite
Other Features: bioturbated; minor mudstone laminations

344.75-349.83' Lithology: mudstone
Color: light olive gray (5Y 6/1)
Porosity: intergranular
Hydraulic Conductivity: very low (<0.1)
Grain Size: clay; range: clay to very fine sand size
Roundness: subangular to subrounded; Sorting: very well
Moderate induration
Cement: clay matrix
Accessory Minerals: ≤1% mica; ≤1% phosphorite
Other Features: minor very fine sand laminations; bioturbated

349.83-353' Lithology: interbedded sand and sandstone
Color: yellowish gray (5Y 8/1) and light olive gray (5Y 6/1)
Porosity: intergranular
Hydraulic Conductivity: very low to moderate (<0.1-100)
Grain Size: very fine to fine sand size; range: clay to fine sand size
Roundness: subangular to subrounded; Sorting: well
Poor to moderate induration
Cement: minor clay matrix
Accessory Minerals: ≤2% mica; 5% phosphorite
Other Features: bioturbated; minor mudstone laminations

353-354.33' Lithology: sandstone
Color: light olive gray (5Y 6/1)
Porosity: intergranular
Hydraulic Conductivity: low (0.1-10)
Grain Size: very fine to fine sand size; range: clay to fine sand size
Roundness: subangular to subrounded; Sorting: well
Moderate induration
Cement: clay matrix
Accessory Minerals: ≤5% phosphorite
Other Features: bioturbated; interval capped by 6" thick mudstone

354.33-354.5' Lithology: phosphatic sand and pebbles
Color: medium dark gray (N4)
Porosity: intergranular
Hydraulic Conductivity: low (0.1-10)
Grain Size: coarse to very coarse sand size; range: very fine sand to medium pebble size
Roundness: subrounded; Sorting: moderate

Poor induration
Cement: clay matrix
Accessory Minerals: 90% phosphorite

354.5-363' Lithology: dolosilt
Color: yellowish gray (5Y 7/2)
Porosity: intercrystalline
Hydraulic Conductivity: very low (<0.1)
Allochemical Constituents: none
Grain Size: clay to silt size; range: clay to very fine sand size
Well indurated
Cement: clay and dolosilt matrix
Accessory Minerals: trace mica; ≤5% phosphorite
Fossils: none
Other Features: heavily bioturbated

363-365' Lithology: lime rudstone with lime packstone matrix
Color: yellowish gray (5Y 7/2) to very light gray (N8)
Porosity: moldic
Hydraulic Conductivity: low to moderate (0.1-100)
Allochemical Constituents: 80%
Grain Size: medium pebble to very large pebble; range: clay to very large pebble size
Moderate to well induration
Cement: lime mud matrix
Accessory Minerals: trace mica; ≤2% phosphorite
Fossils: bivalves, broken fossil fragments, bryozoans, gastropods
Other Features: heavily bioturbated

365-367.33' Lithology: lime floatstone with dolomitized wackestone matrix
Color: light olive gray (5Y 6/1)
Porosity: intercrystalline
Hydraulic Conductivity: low to moderate (0.1-100)
Allochemical Constituents: 50%
Grain Size: bimodal, fine and large pebble to very large pebble; range: clay to very large pebble size
Well indurated
Cement: dolomite matrix
Accessory Minerals: ≤80% dolomite; ≤10% phosphorite
Fossils: bivalves, broken fossil fragments
Other Features: heavily bioturbated

367.33-370.67' Lithology: lime rudstone and floatstone with packstone matrix
Color: yellowish gray (5Y 8/1)
Porosity: intraparticle
Hydraulic Conductivity: low (0.1-10)
Allochemical Constituents: 80%
Grain Size: bimodal, fine and very large pebble; range: clay to very large pebble size

Well indurated
Cement: lime mud matrix
Accessory Minerals: ≤20% dolomite; ≤2% phosphorite
Fossils: broken fossil fragments, bivalves, oysters, bryozoans
Other Features: heavily bioturbated

370.67-375' Lithology: dolomitic lime wackestone
Color: yellowish gray (5Y 7/2)
Porosity: intercrystalline, intraparticle
Hydraulic Conductivity: low to moderate (0.1-100)
Allochemical Constituents: 70%
Grain Size: fine sand size; range: clay to small cobble size
Well indurated
Cement: dolomite matrix
Accessory Minerals: ≤50% dolomite; ≤2% phosphorite
Fossils: broken fossil fragments, bivalves, oysters, bryozoans, cheilostome bryozoans
Other Features: heavily bioturbated

375-379.67' Lithology: lime rudstone with packstone matrix
Color: yellowish gray (5Y 8/1)
Porosity: intraparticle, moldic
Hydraulic Conductivity: low (0.1-10)
Allochemical Constituents: 75%
Grain Size: bimodal, fine sand and large to very large pebble size; range: clay to small cobble size
Moderate to well induration
Cement: lime mud matrix
Accessory Minerals: ≤10% phosphorite
Fossils: broken fossil fragments, bivalves, oysters, bryozoans, cheilostome bryozoans, small benthic foraminifers
Other Features: heavily bioturbated

379.67-399' Lithology: dolomitized lime wackestone
Color: yellowish gray (5Y 7/2)
Porosity: intercrystalline, moldic, intraparticle
Hydraulic Conductivity: low to moderate (0.1-100)
Allochemical Constituents: 40%
Grain Size: bimodal, fine sand and large pebble size; range: clay to very large pebble size
Well indurated
Cement: dolomite matrix
Accessory Minerals: ≤80% dolomite; ≤10% phosphorite
Fossils: broken fossil fragments, bryozoans, cheilostome bryozoans, bivalves
Other Features: heavily bioturbated

399-424' Lithology: lime floatstone to rudstone with lime packstone matrix
Color: yellowish gray (5Y 8/1)
Porosity: moldic, intraparticle

Hydraulic Conductivity: low (0.1-10)
Allochemical Constituents: 80%
Grain Size: bimodal, medium to coarse sand and large pebble size; range: clay to very large pebble size
Well indurated
Cement: lime mud matrix
Accessory Minerals: ≤5% phosphorite
Fossils: broken fossil fragments, bivalves, bryozoans, gastropods
Other Features: heavily bioturbated

424-450.25' Lithology: lime packstone and wackestone with minor lime rudstone with lime packstone matrix
Color: yellowish gray (5Y 8/1)
Porosity: moldic, intraparticle
Hydraulic Conductivity: very low to low (<0.1-10)
Allochemical Constituents: 60%
Grain Size: fine to medium sand size; range: clay to very large pebble size
Well indurated
Cement: lime mud matrix
Accessory Minerals: ≤10% phosphorite
Fossils: broken fossil fragments, bivalves, bryozoans, gastropods
Other Features: heavily bioturbated

450.25-467' Lithology: lime wackestone with minor lime packstone
Color: yellowish gray (5Y 8/1)
Porosity: intraparticle, intergranular
Hydraulic Conductivity: very low (<0.1)
Allochemical Constituents: 20%
Grain Size: large pebble size; range: clay to very large pebble size
Well indurated
Cement: lime mud matrix
Accessory Minerals: ≤5% phosphorite
Fossils: broken fossil fragments, cheilostome bryozoans, bivalves
Other Features: heavily bioturbated

467-471.5' Lithology: dolomitized lime wackestone
Color: yellowish gray (5Y 7/2 to 5Y 8/1)
Porosity: intercrystalline, intraparticle
Hydraulic Conductivity: very low to low (<0.1-10)
Allochemical Constituents: 25%
Grain Size: coarse sand size; range: very fine sand to very large pebble size
Well indurated
Cement: dolomite matrix
Accessory Minerals: ≤90% dolomite, ≤25% phosphorite
Fossils: bivalves, bryozoans, broken fossil fragments
Other Features: heavily bioturbated

471.5-478.5' Lithology: lime floatstone with lime packstone and wackestone matrix
Color: yellowish gray (5Y 7/2 to 5Y 8/1)

Porosity: intraparticle, moldic
Hydraulic Conductivity: very low (<0.1)
Allochemical Constituents: 50%
Grain Size: bimodal, coarse sand and large pebble size; range: very fine sand to very large pebble size
Well indurated
Cement: lime mudstone matrix
Accessory Minerals: ≤20% phosphorite
Fossils: bivalves, broken fossil fragments, bryozoans, cheilostome bryozoans, cyclostomata bryozoans
Other Features: bioturbated

478.5-485.5' Lithology: silty mudstone
Color: pale olive (10Y 6/2)
Porosity: moldic
Hydraulic Conductivity: very low (<0.1)
Allochemical Constituents: trace
Grain Size: mud size; range: mud to silt size
Well indurated
Cement: clay matrix
Accessory Minerals: ≤20% quartz grains; ≤5% phosphorite
Fossils: trace bivalves
Other Features: fissile in part; bioturbated mainly

485.5-492.5' Lithology: lime wackestone
Color: yellowish gray (5Y 7/2)
Porosity: intraparticle, moldic
Hydraulic Conductivity: very low (<0.1)
Allochemical Constituents: 40%
Grain Size: fine to medium sand size; range: mud to large pebble size
Well indurated
Cement: lime mudstone matrix
Accessory Minerals: ≤10% phosphorite
Fossils: broken fossil fragments, bivalves, bryozoans, cheilostome bryozoans, cyclostomata bryozoans
Other Features: heavily bioturbated

492.5-500.58' Lithology: lime rudstone and floatstone with lime packstone and wackestone matrix
Color: yellowish gray (5Y 8/1)
Porosity: moldic, intraparticle
Hydraulic Conductivity: very low to low (<0.1-10)
Allochemical Constituents: 60%
Grain Size: very coarse sand to medium pebble size; range: mud to very large pebble size
Well indurated
Cement: lime mudstone matrix
Accessory Minerals: ≤40% phosphorite
Fossils: bryozoans, bivalves, broken fossil fragments, gastropods, red algae

Other Features: heavily bioturbated

500.58-515.25' Lithology: lime rudstone and floatstone with lime packstone and wackestone matrix
Color: yellowish gray (5Y 8/1)
Porosity: moldic, intraparticle
Hydraulic Conductivity: very low to low (<0.1-10)
Allochemical Constituents: 60%
Grain Size: very coarse sand to medium pebble size; range: mud to very large pebble size
Well indurated
Cement: lime mudstone matrix
Accessory Minerals: ≤10 quartz grains; ≤10% phosphorite
Fossils: bryozoans, bivalves, broken fossil fragments, gastropods, red algae
Other Features: heavily bioturbated

515.25-535' Lithology: lime wackestone
Color: yellowish gray (5Y 8/1)
Porosity: moldic, intraparticle
Hydraulic Conductivity: very low to low (<0.1-10)
Allochemical Constituents: 30%
Grain Size: mud size; range: mud to very large pebble size
Moderate to well induration
Cement: lime mudstone matrix
Accessory Minerals: ≤30% phosphorite
Fossils: broken fossil fragments, bryozoans, cheilostome bryozoans, bivalves, cyclostomata bryozoans
Other Features: heavily bioturbated

535-538.4' Lithology: lime wackestone
Color: yellowish gray (5Y 8/1)
Porosity: moldic, intraparticle
Hydraulic Conductivity: very low to low (<0.1-10)
Allochemical Constituents: 30%
Grain Size: mud size; range: mud to very large pebble size
Moderate to well induration
Cement: lime mudstone matrix
Accessory Minerals: ≤30% phosphorite
Fossils: cyclostomata bryozoans, broken fossil fragments, bryozoans, cheilostome bryozoans, bivalves
Other Features: heavily bioturbated

538.4-541' Lithology: lime wackestone
Color: yellowish gray (5Y 8/1)
Porosity: moldic, intraparticle
Hydraulic Conductivity: very low to low (<0.1-10)
Allochemical Constituents: 30%
Grain Size: mud size; range: mud to very large pebble size
Moderate to well induration

Cement: lime mudstone matrix
Accessory Minerals: ≤20% phosphorite
Fossils: broken fossil fragments, bryozoans, cheilostome bryozoans, bivalves, cyclostomata bryozoans
Other Features: heavily bioturbated

541-545.5' Lithology: lime wackestone
Color: yellowish gray (5Y 8/1)
Porosity: moldic, intraparticle
Hydraulic Conductivity: very low to low (<0.1-10)
Allochemical Constituents: 30%
Grain Size: mud size; range: mud to very large pebble size
Moderate to well induration
Cement: lime mudstone matrix
Accessory Minerals: ≤10% phosphorite
Fossils: broken fossil fragments, bryozoans, cheilostome bryozoans, bivalves, cyclostomata bryozoans
Other Features: heavily bioturbated

545.5-559.5' Lithology: lime wackestone
Color: yellowish gray (5Y 8/1)
Porosity: moldic, intraparticle
Hydraulic Conductivity: very low to low (<0.1-10)
Allochemical Constituents: 30%
Grain Size: mud size; range: mud to very large pebble size
Moderate to well induration
Cement: lime mudstone matrix
Accessory Minerals: ≤40% phosphorite
Fossils: broken fossil fragments, bryozoans, cheilostome bryozoans, bivalves, cyclostomata bryozoans
Other Features: heavily bioturbated

559.5-565' Lithology: lime wackestone
Color: yellowish gray (5Y 8/1)
Porosity: moldic, intraparticle
Hydraulic Conductivity: very low to low (<0.1-10)
Allochemical Constituents: 20%
Grain Size: mud size; range: clay to very large pebble size
Moderate to well induration
Cement: lime mudstone matrix
Accessory Minerals: ≤5% phosphorite
Fossils: broken fossil fragments, bivalves, cheilostome bryozoans
Other Features: heavily bioturbated

565-575' Lithology: lime packstone and wackestone
Color: light olive gray (5Y 6/1) and yellowish gray (5Y 8/1)
Porosity: moldic, intraparticle
Hydraulic Conductivity: very low to low (<0.1-10)
Allochemical Constituents: 30%

Grain Size: very fine to fine sand size; range: clay to very large pebble size
Moderate induration
Cement: lime mudstone matrix
Accessory Minerals: ≤50% quartz grains; ≤5% phosphorite
Fossils: bryozoans, broken fossil fragments, cheilostome bryozoans, bivalves
Other Features: heavily bioturbated

575-578' Lithology: dolomitic quartz sandstone
Color: light olive gray (5Y 6/1)
Porosity: intergranular
Hydraulic Conductivity: moderate (10-100)
Allochemical Constituents: 10%
Grain Size: very fine sand size; range: very fine to medium sand size
Roundness: subangular to subrounded Sorting: well
Poor induration
Cement: lime mudstone matrix
Accessory Minerals: 10% clay; 20% dolosilt; 10% limestone; 30% phosphorite
Fossils: bryozoans, bivalves
Other Features: heavily bioturbated with minor burrows filled with lime mudstone

578-586.93' Lithology: lime packstone
Color: very pale orange (10YR 8/2) and light olive gray (5Y 6/1)
Porosity: moldic, intraparticle
Hydraulic Conductivity: very low (<0.1)
Allochemical Constituents: 40%
Grain Size: bimodal, very fine to fine sand and very large pebble size; range: clay to very large pebble size
Moderate induration
Cement: lime mudstone matrix
Accessory Minerals: ≤40% quartz grains; ≤40% phosphorite; ≤30% dolomite
Fossils: bryozoans, broken fossil fragments, bivalves, gastropods
Other Features: heavily bioturbated

586.93-591.42' Lithology: mudstone
Color: greenish gray (5GY 6/1)
Porosity: nonporous
Hydraulic Conductivity: very low (<0.1)
Allochemical Constituents: none
Grain Size: clay size; range: clay size
Moderate induration
Cement: clay matrix
Accessory Minerals: trace phosphorite and mica
Fossils: none
Other Features: lower 1/2 of interval is fissile

591.42-596' Lithology: phosphatic mudstone
Color: light olive gray (5Y 6/1)
Porosity: nonporous

Hydraulic Conductivity: very low (<0.1)
Allochemical Constituents: none
Grain Size: bimodal, clay and fine to coarse sand size; range: clay to very coarse sand size
Poor to moderate induration
Cement: clay matrix
Accessory Minerals: ≤80% phosphorite
Fossils: none
Other Features: mottled texture due to bioturbation

596-601.42' Lithology: dolomitized rudstone and floatstone with dolosilt matrix
Color: yellowish gray (5Y 8/1) and light gray (N7)
Porosity: moldic and intercrystalline
Hydraulic Conductivity: very low (<0.1)
Allochemical Constituents: 60%
Grain Size: bimodal, coarse sand to large pebble size; range: clay to very large pebble size
Well indurated
Cement: lime mudstone matrix
Accessory Minerals: ≤80% dolosilt; ≤50% phosphorite
Fossils: bivalves, gastropods, broken fossil fragments
Other Features: mottled texture due to bioturbation

601.42-614' Lithology: lime packstone
Color: yellowish gray (5Y 8/1)
Porosity: intraparticle, intercrystalline
Hydraulic Conductivity: very low to low (<0.1-10)
Allochemical Constituents: 60%
Grain Size: bimodal, fine sand to large pebble size; range: clay to very large pebble size
Well indurated
Cement: lime mudstone matrix
Accessory Minerals: ≤80% dolosilt; ≤50% phosphorite
Fossils: bryozoans, broken fossil fragments, bivalves, small benthic forams
Other Features: mottled texture due to bioturbation

614-628' Lithology: lime floatstone with packstone matrix
Color: yellowish gray (5Y 8/1)
Porosity: intercrystalline, intraparticle
Hydraulic Conductivity: very low to low (<0.1-10)
Allochemical Constituents: 60%
Grain Size: bimodal, fine sand to large pebble size; range: clay to very large pebble size
Well indurated
Cement: lime mudstone matrix
Accessory Minerals: ≤70% dolosilt; ≤10% phosphorite
Fossils: broken fossil fragments, bryozoans, cheilostome bryozoans, bivalves
Other Features: mottled texture due to bioturbation

628-652' Lithology: dolomitic rudstone and floatstone with packstone matrix
Color: yellowish gray (5Y 8/1 to 5Y 7/2)
Porosity: intercrystalline, intraparticle
Hydraulic Conductivity: very low to low (<0.1-10)
Allochemical Constituents: 60%
Grain Size: bimodal, large to large pebble size; range: clay to very large pebble size
Well indurated
Cement: lime mudstone matrix
Accessory Minerals: ≤80% dolosilt; trace phosphorite
Fossils: cheilostome bryozoans, bivalves, broken fossil fragments
Other Features: mottled texture due to bioturbation

652-656.5' Lithology: dolomitic lime packstone
Color: yellowish gray (5Y 8/1 to 5Y 7/2)
Porosity: intercrystalline, intraparticle
Hydraulic Conductivity: very low to low (<0.1-10)
Allochemical Constituents: 60%
Grain Size: coarse sand size; range: clay to medium pebble size
Well indurated
Cement: lime mudstone matrix
Accessory Minerals: ≤15% phosphorite
Fossils: broken fossil fragments, bryozoans, cheilostome bryozoans, echinoderms, bivalves
Other Features: mottled texture due to bioturbation

656.5-671' Lithology: dolosilt
Color: pale olive (10Y 6/2)
Porosity: intercrystalline
Hydraulic Conductivity: very low to low (<0.1-10)
Allochemical Constituents: trace
Grain Size: silt sized dolomite crystals and clay sized mudstone
Well indurated
Cement: no cement
Accessory Minerals: upper 11/2" of interval contains ≤15% medium sand to large pebble sized phosphorite clasts
Fossils: broken fossil fragments, bryozoans, cheilostome bryozoans, echinoderms, bivalves
Other Features: mottled texture due to bioturbation

671-676.33' Lithology: lime rudstone with packstone matrix
Color: very pale orange (10YR 8/2) to yellowish gray (5Y 7/2)
Porosity: moldic, intraparticle
Hydraulic Conductivity: low to moderate (0.1-100)
Allochemical Constituents: 70%
Grain Size: medium to large pebble size; range: clay to very large pebble size
Well indurated
Cement: sparry calcite

Accessory Minerals: ≤2% phosporite (sourced from crust at top of interval 676.3-687.75')
Fossils: red algae, broken fossil fragments, bivalves, gastropods, *Sorities*
Other Features: mottled texture due to bioturbation

676.33-687.75' Lithology: lime floatstone to rudstone with packstone matrix
Color: very pale orange (10YR 8/2) to very light gray (N8)
Porosity: moldic, intraparticle
Hydraulic Conductivity: low to moderate (0.1-100)
Allochemical Constituents: 70%
Grain Size: bimodal, fine sand and large to very large pebble size; range: clay to very large pebble size
Well indurated
Cement: sparry calcite
Accessory Minerals: ≤10% phosporite
Fossils: broken fossil fragments, bivalves, *Sorities*, red algae, coral
Other Features: upper 8" phosphatic firmground; interval capped by a 1" thick pale yellowish brown (10YR 6/2) to moderate yellowish brown (10YR 5/4) phosphatic crust

687.75-693' Lithology: dolomitic lime packstone
Color: very pale orange (10YR 8/2) to very olive gray (5Y 6/1)
Porosity: moldic, intraparticle
Hydraulic Conductivity: low (0.1-10)
Allochemical Constituents: 70%
Grain Size: very fine to fine sand and very large pebble size; range: clay to very large pebble size
Moderate to well induration
Cement: sparry calcite
Accessory Minerals: <80% dolomite, ≤3% phosphorite
Fossils: broken fossil fragments, bivalves, cyclostomata bryozoans, gastropods

693-715' Lithology: lime floatstone to rudstone with lime packstone matrix
Color: very pale orange (10YR 8/2)
Porosity: moldic, intraparticle
Hydraulic Conductivity: low (0.1-10)
Allochemical Constituents: 75%
Grain Size: bimodal, fine sand and large pebble size; range: clay to very large pebble size
Moderate to well induration
Cement: sparry calcite
Accessory Minerals: ≤5% phosphorite
Fossils: broken fossil fragments, bivalves, gastropods, bryozoans, benthic forams

715-721' Lithology: lime grainstone
Color: light gray (N7)
Porosity: moldic

Hydraulic Conductivity: very low (≤0.1)
Allochemical Constituents: 80%
Grain Size: very fine to fine sand size; range: very fine to coarse sand size
Very well indurated
Cement: sparry calcite
Fossils: broken fossil fragments, bivalves, gastropods, echinoderms, small benthic forams
Other Features: very well cemented

721-726' Lithology: lime floatstone to rudstone with lime packstone matrix
Color: very pale orange (10YR 8/2)
Porosity: moldic, intraparticle
Hydraulic Conductivity: low (0.1-10)
Allochemical Constituents: 60%
Grain Size: bimodal, fine to medium sand and large pebble size; range: clay to very large pebble size
Well indurated
Cement: sparry calcite
Accessory Minerals: ≤2% phosphorite
Fossils: broken fossil fragments, bivalves, corals, bryozoans, gastropods, *Sorities*, oysters

726-738.83' lime wackestone and packstone, lower 2' contains lime floatstone with packstone matrix
Color: very pale orange (10YR 8/2)
Porosity: moldic, intraparticle
Hydraulic Conductivity: low (0.1-10)
Allochemical Constituents: 50%
Grain Size: very fine to fine sand size; range: clay to very large pebble size
Moderate to well induration
Cement: sparry calcite
Accessory Minerals: trace phosphorite
Fossils: broken fossil fragments, bivalves, bryozoans, corals (hermatypic)

738.83-743' sandy calcrete
Color: very pale orange (10YR 8/2)
Porosity: intergranular, moldic
Hydraulic Conductivity: low (0.1-10)
Allochemical Constituents: trace
Grain Size: very fine to fine sand size; range: clay to fine sand size
Moderate to well induration
Cement: lime mudstone matrix
Accessory Minerals: ≤50% quartz sand, ≤5% phosphorite
Fossils: broken fossil fragments
Other features: interval contains abundant root molds lined with laminated calcrete; interval possibly brecciated, as evidenced by vertical and other non-horizontal orientations of laminated calcretes

743-753' lime grainstone to lime floatstone with grainstone matrix

Color: very pale orange (10YR 8/2) and light gray (N7)
Porosity: intergranular, moldic, intraparticle
Hydraulic Conductivity: moderate (10-100)
Allochemical Constituents: 50%
Grain Size: fine to medium sand size; range: fine sand to very large pebble size
Moderate induration
Cement: sparry calcite
Accessory Minerals: ≤50% quartz sand, ≤5% phosphorite
Fossils: upper 2' contains abundant root molds lined with laminated calcrete.
Interval contains abundant inclined planar laminations.

753-766.83' lime rudstone and floatstone with packstone matrix and lime packstone
Color: very pale orange (10YR 8/2) and light gray (N7)
Porosity: moldic, intraparticle
Hydraulic Conductivity: low to moderate (0.1-100)
Allochemical Constituents: 75%
Grain Size: medium sand size; range: clay to large pebble size
Moderate to well induration
Cement: sparry calcite
Accessory Minerals: ≤50% quartz sand, ≤3% phosphorite
Fossils: broken fossil fragments, bivalves, gastropods
Other features: interval contains 1" thick laminated calcrete and also contains root molds lined with laminated calcretes.

766.83-784.25' lime rudstone and floatstone with packstone matrix and lime packstone and grainstone
Color: very pale orange (10YR 8/2) and light gray (N7)
Porosity: moldic, intraparticle, vuggy
Hydraulic Conductivity: low to moderate (0.1-100)
Allochemical Constituents: 75%
Grain Size: medium sand size; range: clay to very large pebble size
Moderate to well induration
Cement: sparry calcite
Accessory Minerals: trace quartz sand
Fossils: broken fossil fragments, small benthic foraminifers, miliolids, bivalves, gastropods
Other features: lower 1" contains several laminated calcretes; entire interval contains root molds lined with laminated calcretes; upper 1' contains several ≤2 cm thick laminated calcretes.

784.25-804.75' lime grainstones, packstones and floatstone with packstone matrix
Color: very pale orange (10YR 8/2)
Porosity: intergranular, moldic, intraparticle
Hydraulic Conductivity: low to moderate (0.1-100)
Allochemical Constituents: 75%
Grain Size: medium sand size; range: clay to very large pebble size
Moderate to well induration
Cement: sparry calcite

Accessory Minerals: ≤50% quartz sand and ≤3% phosphorite grains
Fossils: broken fossil fragments, miliolids, gastropods, bivalves, peneroplids
Other features: capped by a 2mm thick pale yellowish brown (10YR 6/2) laminated calcrete; lower 1" contains a very pale orange (10YR 8/2) 1/8" thick calcrete

804.75-812.3' lime packstone and floatstone with packstone matrix
Color: very pale orange (10YR 8/2)
Porosity: moldic, vuggy, intraparticle
Hydraulic Conductivity: low to moderate (0.1-100)
Allochemical Constituents: 60%
Grain Size: medium sand size; range: clay to very large pebble size
Moderate to well induration
Cement: sparry calcite
Accessory Minerals: trace quartz grains
Fossils: capped by an up to 1" thick laminated calcrete; root molds lined with laminated calcrete extend 31/2' below uppermost calcrete.

812.8-813' lime packstone
Color: very pale orange (10YR 8/2)
Porosity: vuggy, moldic, intraparticle
Hydraulic Conductivity: moderate (10-100)
Allochemical Constituents: 50%
Grain Size: medium sand size; range: clay to large pebble size
Moderate to well induration
Cement: sparry calcite
Accessory Minerals: none
Fossils: vertical to irregular dissolution pipes filled with sparry calcite; minor quartz sand partly infills solution cavities.

Appendix 2

Thin section descriptions

Long Key Formation

60.92 feet. Quartz sandstone with minor micrite cement. Quartz grains are silt to very coarse sand size, mainly very fine sand size; moderate sorting; angular to rounded, mainly angular to subangular; low to high sphericity, mainly moderate sphericity; common undulose extinction of quartz grains. Other clastic grains include 1% mica and feldspar, and 5% heavy minerals. Skeletal fragments include bivalves, benthic foraminifers, and echinoids spines. 30% visual intergranular porosity.

97.25 feet. Quartz sand, very poorly cemented by micrite cement. Quartz grains are silt to granule size, mainly very fine to fine sand size; moderate sorting; angular to rounded, mainly subangular; low to high sphericity, mainly moderate sphericity; common undulose extinction of quartz grains. Other clastic grains include 1% mica and feldspar, and 5% heavy minerals. No skeletal grains.

137.5 feet. Quartz sandstone. Quartz grains are silt to granule size, mainly very fine to fine sand size; moderate sorting; angular to rounded, mainly subangular; low to high sphericity, mainly moderate sphericity; common undulose extinction of quartz grains. Other clastic grains include 1% mica and feldspar. No skeletal grains.

150.67 feet. Quartz sand, very poorly cemented by micrite cement. Quartz grains are silt to granule size, mainly very fine to fine sand size; moderate sorting; angular to rounded, mainly angular to subangular; low to high sphericity, mainly moderate sphericity; common undulose extinction of quartz grains. Other clastic grains include trace feldspar. Skeletal fragments include bivalves.

235.62 feet. Sandy lime mudstone. Contains 40% quartz grains with a trace of feldspar grains. Quartz grains are silt to very coarse sand size, mainly fine sand size; moderate sorting; angular to subrounded, mainly angular to subangular; low to high sphericity, mainly moderate sphericity; common undulose extinction of quartz grains. Very low intergranular microporosity. No skeletal grains.

306.5 feet. Quartz sandstone. Quartz grains are very fine to fine sand size; well sorted; angular to subrounded, mainly subangular; low to high sphericity, mainly moderate sphericity; common undulose extinction of quartz grains. Other clastic grains include 2% feldspar and 4% heavy minerals. Contains 30% intergranular porosity.

331.58 feet. Dolomitic, silty mudstone. Quartz grains are very fine sand sized. 30% dolomite crystals floating in a mudstone matrix; silt to very fine sand-size dolomite crystals, mainly silt size.

Arcadia Formation

422.17 feet. Bivalve lime floatstone with lime wackestone and lime mudstone matrix. Carbonate grains include bivalves, bryozoans, small benthic foraminifers, and peloids. Most skeletal grains are broken. Carbonate grains are poorly sorted. 15% moldic porosity with a trace of vuggy porosity. Minor bladed calcite partly fills moldic and vuggy porosity. Trace quartz grains that are very fine sand size.

494.75 feet. Gastropod and bivalve lime floatstone with lime wackestone matrix. Carbonate grains include gastropods, bivalves, red algae, echinoids, ostracods, and peloids. Most skeletal grains are broken. 15% moldic porosity and 5% vuggy porosity. Burrows are common. 5% dolosilt; euhedral dolomite crystals floating in lime mudstone matrix. Quartz with undulose extinction replaces some skeletal grains. Clastic grains include 10% phosphorite and 5% quartz sand. Phosphorite grains are very fine to fine sand size; subrounded to rounded. Quartz grains are very fine to fine sand size; very poorly sorted. Both phosphorite and quartz grains are floating in lime mudstone matrix.

526.83 feet. Dolomitic, sandy, phosphatic, lime wackestone. Carbonate grains include undifferentiated broken skeletal fragments and bivalves. Minor intergranular microporosity. 40% euhedral dolomite crystals; silt to very fine sand size. Clastic grains include 20% phosphorite and 20% quartz sand. Phosphorite grains are very fine to fine sand size; subround to round; floating in a lime mudstone matrix. Quartz grains are silt to fine sand size; angular to subrounded floating in a lime mudstone matrix.

661.33 feet. Dolosilt. 50% euhedral crystals of silt-sized dolomite floating in a lime mudstone matrix. Very low intergranular microporosity. No skeletal grains.

676.5 feet. Sandy, phosphatic lime wackestone. Carbonate grains include undifferentiated broken skeletal fragments, bivalves, red algae, bryozoans, echinoids, gastropods, and ostracods. Skeletal fragments are poorly sorted. Burrowed. 10% moldic porosity. Bladed calcite cement partly fills moldic porosity. Clastic grains include 15% quartz sand and 10% phosphorite. Quartz grains are silt to fine sand size; angular to subrounded, mainly subangular; low to high sphericity, mainly moderate sphericity. Phosphorite grains are very fine to medium sand size; subrounded to rounded.

682.29 feet. Phosphatic, bivalve, *Sorities* lime floatstone with lime packstone matrix. Carbonate grains include undifferentiated skeletal fragments, bivalves, *Sorities*, echinoids, peloids, and *Halimeda*(?). 20% moldic and vuggy porosity. Minor bladed and sparry calcite partly fills moldic porosity. Carbonate grains are poorly sorted. Undifferentiated skeletal fragments, bivalves and echinoids are typically broken. Clastic grains include 30% phosphorite and 1% quartz sand. Phosphorite grains are silt to coarse sand size, mainly very fine to fine sand size; subrounded to rounded. Quartz grains are silt to fine sand size; angular to subangular, mainly angular; low to high sphericity, mainly moderate sphericity.

705.71 feet. Phosphorite, sandy lime packstone. Carbonate grains include broken undifferentiated skeletal fragments, miliolids, small benthic foraminifers, ostracods, *Sorities*, peloids, and echinoids. 5% moldic and intraparticle porosity. Sparry calcite partly fills moldic porosity. Clastic grains include 40% phosphorite and 5% quartz sand. Phosphorite grains are silt to medium sand size, mainly fine sand size; subrounded to rounded. Quartz grains are silt to coarse sand size, mainly very fine to fine sand size; angular to subrounded, mainly subangular; low to high sphericity, mainly moderate sphericity.

722.75 feet. Bivalve lime floatstone with sandy lime packstone matrix. Carbonate grains include bivalves, small benthic foraminifers, undifferentiated broken skeletal fragments, red algae, echinoids, *Sorities*, and peneroplids. 5% moldic and intraparticle porosity. Sparry calcite partly fills moldic porosity. Clastic grains include 15% quartz sand, and 1% phosphorite grains and heavy minerals. Quartz grains are silt to fine sand size, mainly very fine sand size; angular to subrounded, low to high sphericity, mainly moderate sphericity. Phosphorite grains are sand size, mainly very fine sand size.

Suwannee Limestone

740.25 feet. Sandy calcrete. 2% intergranular porosity. Clastic grains include 60% quartz sand and trace heavy minerals. Clastic grains are floating in a micrite matrix of laminated calcrete. Quartz grains are silt to coarse sand size, mainly very fine to fine sand size; angular to subrounded, mainly subangular; low to high sphericity, mainly moderate sphericity. No skeletal grains.

752.75 feet. Sandy intraclast bivalve lime packstone. Carbonate grains include intraclasts, bivalves, small benthic foraminifers, and bryozoans. 20% moldic and vuggy porosity. Minor bladed and micritic cement partly fills moldic porosity. Clastic grains include 40% quartz sand. Quartz grains are silt to very coarse sand size, mainly fine to medium sand size; angular to subround, mainly subangular; low to high sphericity, mainly moderate sphericity.

774.42 feet. Miliolid lime packstone. Carbonate grains include miliolids, small benthic foraminifers, and peloids. 10% intraparticle, intergranular and moldic porosity. Minor amount of root molds with laminated calcrete lining the molds. Clastic grains include 5% quartz sand and trace heavy minerals. Quartz grains are silt to fine sand size, mainly very fine sand; angular to subrounded, mainly subangular; low to high sphericity, mainly moderate sphericity.

798.08 feet. Sandy grainstone. Carbonate grains include miliolids, bryozoans, echinoids, bivalves, and gastropods. 25% intergranular and moldic porosity. Micritic cement partly fills intergranular and moldic porosity. Clastic grains include 50% quartz sand. Quartz grains are silt to medium sand size, mainly very fine to fine sand size; angular to subrounded, mainly subangular; low to high sphericity, mainly moderate sphericity.

811.5 feet. Lime wackestone and packstone. Carbonate grains include miliolids, small benthic foraminifers, bivalves, echinoids, and serpulid tubes. 20% moldic and

vuggy porosity. Clastic grains include 5% quartz sand and trace heavy minerals. Quartz grains are silt to medium sand size, mainly very fine to fine sand size; angular to subrounded quartz grains, mainly subangular; low to high sphericity, mainly moderate sphericity.