Hydrogeologic Investigation of the Floridan Aquifer System

Big Cypress Preserve
Collier County, Florida
Technical Publication WS-18

Title: BICY-TW Quad-Zone Monitor Well

Prepared by:
Michael W. Bennett, P.G.

February 2004

South Florida Water Management District
3301 Gun Club Road
West Palm Beach, FL 33406
(561) 686-8800
www.sfwmd.gov

EXECUTIVE SUMMARY

The Lower West Coast Planning Area (LWCPA) includes Collier and Lee counties and portions of Hendry, Charlotte, and Glades counties. A combination of natural drainage basins and political boundaries define the extent of this planning area. Water supply plans developed for the LWCPA have identified the Floridan aquifer system (FAS) as a possible water supply alternative. Based on these plans, the South Florida Water Management District (SFWMD) initiated a program of exploratory well drilling and construction, aquifer testing, and long-term monitoring (water quality and hydraulic heads) to provide data needed to assess the FAS underlying this area. These wells will supply information needed to characterize the water supply potential of the FAS and for use in the development of ground water flow models, which will support future planning and regulatory decisions.

Four previous FAS test sites located in the LWCPA were completed under this program (Bennett, 2001a, 2001b, 2002, and 2003). **Figure 1** shows the location of the Floridan aquifer test site completed by SFWMD in the LWCPA and south Florida. The fifth and final site under this program and the focus of this report is located in the Big Cypress Preserve of south central Collier County and identified on **Figure 1** as the "Study Area."

This report documents the results of two Floridan aquifer wells constructed and tested under the direction of the SFWMD. The Big Cypress Preserve site was selected to augment existing hydrogeologic data and to provide broad, spatial coverage within the LWCPA.

The scope of the investigation consisted of constructing and testing two FAS wells. The first well identified as BICY-TW was drilled to a total depth of 2,505 feet below land surface (bls). The Contractor constructed a telescoping type well in various stages, completing it into the middle portion of the intermediate aquifer system (IAS) and three distinct hydrogeologic zones within the FAS. The second well, a dual-zone production well identified as BICY-PW, is located 350 feet south of well BICY-TW and was constructed to facilitate aquifer testing in the middle part of the IAS and upper Floridan aquifer.

SFWMD provided oversight during all well drilling, well construction, and aquifer testing operations. Diversified Drilling Corporation (DDC), a Tampa based firm was responsible for all drilling, construction, and testing services associated with the two FAS wells (BICY-TW and BICY-PW) under SFWMD Contract C-7663.

The main findings of the exploratory drilling and testing program at the site are as follows:

- The top of the FAS as defined by the Southeastern Geological Society AdHoc Committee on Florida Hydrostratigraphic Unit Definition (1986) was identified at approximately 820 feet bls.
- Lithologic and geophysical logs, specific capacity and packer test results, and petrophysical data indicate excellent production capacity in the middle part of the IAS (mid-Hawthorn aquifer) and moderate production capacity in the upper Floridan aquifer.
- Water quality data from packer tests and completed monitor zones indicate that chloride and total dissolved solids (TDS) in the upper Floridan aquifer waters exceed potable drinking

water standards. Chloride and TDS concentrations from 460 to 1,000 feet bls average 2,375 and 3,655 micrograms per liter (mg/L), respectively.

- The base of the Underground Source of Drinking Water (USDW), those waters having TDS concentrations less than 10,000 mg/L, occurs at approximately 1,375 feet bls.
- Stable isotope data from the Big Cypress Preserve site indicate that the middle IAS (BICY MZ-1) and upper Floridan aquifer (BICY MZ-2) are depleted in both ^{18}Oxygen (^{18}O) and deuterium as compared to the reference standard of Standard Mean Ocean Water (SMOW). The corrected radiocarbon ages from these two monitor intervals are 17,002 and 26,149 years bp, respectively, using the Fontes-Granier method.
- Stable isotope data also suggest that water in the middle Floridan confining unit is enriched in both ^{18}O and deuterium as compared to SMOW. The inorganic water quality results from samples obtained from 1,550 to 1,785 feet bls are saline in composition suggesting that the middle part of Floridan aquifer has been intruded by seawater.
- The lower Floridan aquifer waters at the BICY site are enriched in both ^{18}O and deuterium compared to SMOW and produced a corrected radiocarbon age of 8,460 years bp using the Fontes-Granier method.
- The petrophysical data suggest a moderate linear relationship between horizontal permeability and porosity with a correlation coefficient of 0.76.
- The highest mean horizontal permeability measurements of 11,069 and 4,707 millidarcys (md) correspond to cored sections at approximately 900 and 985 feet bls, respectively. These two intervals consist of coral and pelecypod boundstones, likely deposited in an open shoal environment.
- Future petrology work, in conjunction with the magnetic susceptibility data, are needed to refine the Nuclear Magnetic Resonance (NMR) permeability model for carbonate units of the FAS.
- A productive horizon in the middle IAS from 460 to 540 feet bls yielded a transmissivity value of 502,100 gallons per day per foot (gpd/ft), a storage coefficient of 6.8×10^{-5}, a (r/B) value of 0.06, and a leakance value of 1.51×10^{-2} gpd/ft^3.
- A productive horizon in the upper Floridan aquifer from 830 to 1,010 feet bls yielded a transmissivity value of 82,720 gpd/ft, a storage coefficient of 5.0×10^{-6}, an (r/B) value of 0.03, and a leakance value of 6.25×10^{-4} gpd/ft^3.
- The average measured hydraulic heads for the FAS monitoring intervals are as follows:
  37.89 feet above mean sea level for the 460 to 540 feet bls monitor interval
  37.56 feet above mean sea level for the 838 to 996 feet bls monitor interval
  20.65 feet above mean sea level for the 1,550 to 1,785 feet bls monitor interval
  9.20 feet above mean sea level for the 2,260 to 2,505 feet bls monitor interval
- Water levels in the FAS respond to external stresses such as tidal loading, earth tides, and barometric pressure variations.
- The inorganic chemistry, stable isotopes, radiocarbon, and hydraulic head data summarized in this report suggest that the horizons between 460 to 550 and 830 to 1,010 feet bls are hydraulically connected.
- The inorganic, stable isotope, radiocarbon, and noble gas data suggest the ground water in the middle part of the intermediate and upper Floridan aquifers are composed of Pleistocene-aged meteoric water. Whereas water in the lower Floridan aquifer appears to be Holocene-aged seawater.

- Noble gas temperatures from the middle portion of the IAS (BICY MZ-1) and upper Floridan aquifer (BICY MZ-2) averaged 18.7°C, about 5°C cooler than the present-day south Florida mean annual air temperature of 23.6° C.
- The stable isotope data from lower Floridan aquifer samples (BICY MZ-4) are similar to seawater samples collected in the Straits of Florida (off the coast of Ft. Pierce at 27° 0.445N, 79° 26.789W) at depths greater than 1,700 feet, inferring a connection with the Atlantic Ocean at depth. The ^{14}Carbon data suggests these waters entered the lower Floridan aquifer during the Holocene epoch (approximately 8,500 years before present).
- Noble gas temperatures from the lower Floridan aquifer (BICY MZ-4) was 8.7° C, about 10° C cooler than waters in the upper Floridan aquifer and 14.9° C cooler than the present-day mean annual air temperature of south Florida, suggesting cooler ocean waters have intruded the lower Floridan aquifer.

TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

ACKNOWLEDGEMENTS

The author gratefully acknowledges the many people that aided in the successful completion of this project. I would like to thank those outside the District who reviewed the manuscript or lent technical expertise to the writing of the report. They include Ronald Reese of the United States Geological Survey, Jonathan Arthur and Will Evans of the Florida Geological Survey, and W. Kirk Martin of CDM.

Appreciation is also extended to the technical and professional staff of the South Florida Water Management District who assisted in the compilation and analysis of data and the production of this report. They include Emily Hopkins, Linda Lindstrom, John Lukasiewicz, E. Edward Rectenwald, and Keith Smith. I appreciate Debra Bennett and Janet Wise for their graphics expertise. I thank Sorrel Hoover from Orion Consulting Inc. for her editorial assistance and expertise in bringing this document to publication. I would also like to thank David Demonstranti of Electronic Support and Data Acquisition at the SFWMD for the excellent field support and coordination during testing operations.

INTRODUCTION

Background

The Lower West Coast Planning Area (LWCPA) includes Collier and Lee counties and portions of Hendry, Charlotte, and Glades counties. A combination of natural drainage basins and political boundaries define the extent of this planning area. Water supply plans developed for the LWCPA identified the Floridan aquifer system (FAS) as a possible water supply alternative. Based on these plans, the South Florida Water Management District (SFWMD) initiated a program of exploratory well construction, aquifer testing, and long-term monitoring (water quality and hydraulic heads) to provide data needed to assess the FAS underlying this area. These wells will supply information needed to characterize the water supply potential of the FAS and for use in the development of a ground water flow model, which will support future planning and regulatory decisions.

Four previous FAS test sites located in the LWCPA were completed under this program (Bennett, 2001a, 2001b, 2002, and 2003). The fifth site and final site is the focus of this report and is located in the Big Cypress Preserve (BICY) in south central Collier County **(Figure 1)**. These wells are in the southwest quadrant of Section 34 of Township 52 South, Range 30 East **(Figure 2).** The geographic coordinates of the Big Cypress Preserve test/monitor well identified as BICY-TW are 25° 53’ 35.7” North latitude and 81° 18’ 33.8” West longitude (North American Datum of 1927 – NAD, 27). A survey elevation of 4.4 feet relative to the National Geodetic Vertical Datum of 1929 (NGVD, 29 - sea level) was determined for land surface.

Purpose

The purpose of this report is to document the hydrogeologic data collected during the SFWMD-initiated Floridan aquifer system well drilling and construction, aquifer testing and monitoring program at the Big Cypress Preserve site. This report includes a summary of: 1) well drilling and construction details; 2) lithostratigraphy and hydrogeology; 3) water quality and productive capacity; 4) stable isotope, ^{14}Carbon, and noble gas data; 5) petrophysical and petrologic data; 6) aquifer performance test data and analyses; and 7) short-term hydraulic head data.

Project Description

SFWMD provided oversight during all well drilling, construction, and testing operations. Diversified Drilling Corporation (DDC), a Tampa based firm was the water well contractor responsible for all drilling, construction, and testing services associated with the two FAS wells (BICY-TW and BICY-PW) under SFWMD Contract C-7663.

Site preparation and equipment mobilization at the project site began January 20, 1997. Two Floridan aquifer wells were constructed to facilitate aquifer testing and long-term monitoring of the FAS. The first well, a telescoping style, multi-zone well (referred to as BICY-TW) was drilled to a total depth of 2,505 feet below land surface (bls) and completed in four distinct hydrogeologic units. The second well, a dual-zone, test-production well (referred to as BICY-PW) was completed to 1,010 feet bls with a 12-inch diameter steel casing set at 830 feet in depth.

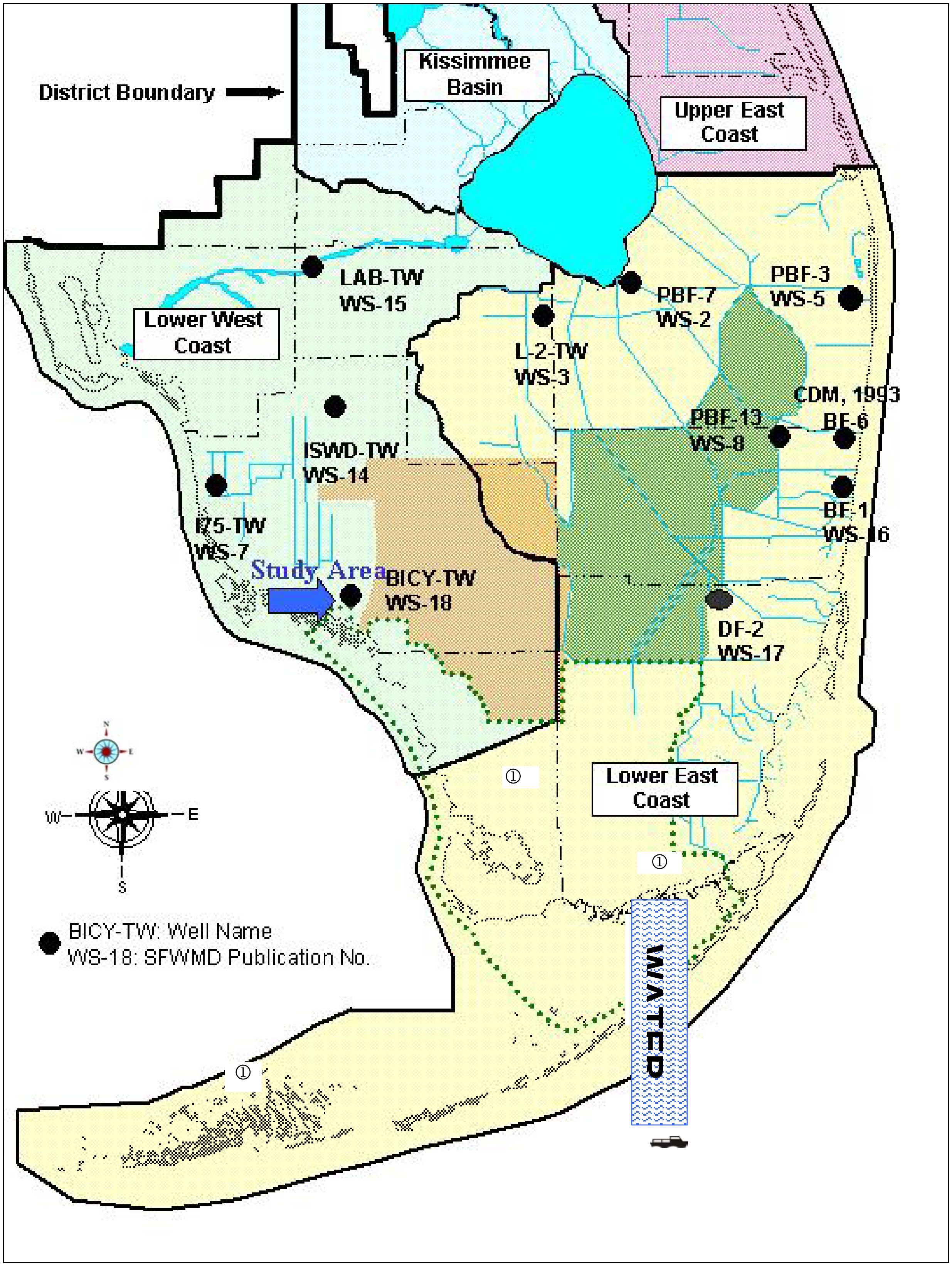


Figure 1. Study Area and Locations of SFWMD Floridan Aquifer System Test Sites.

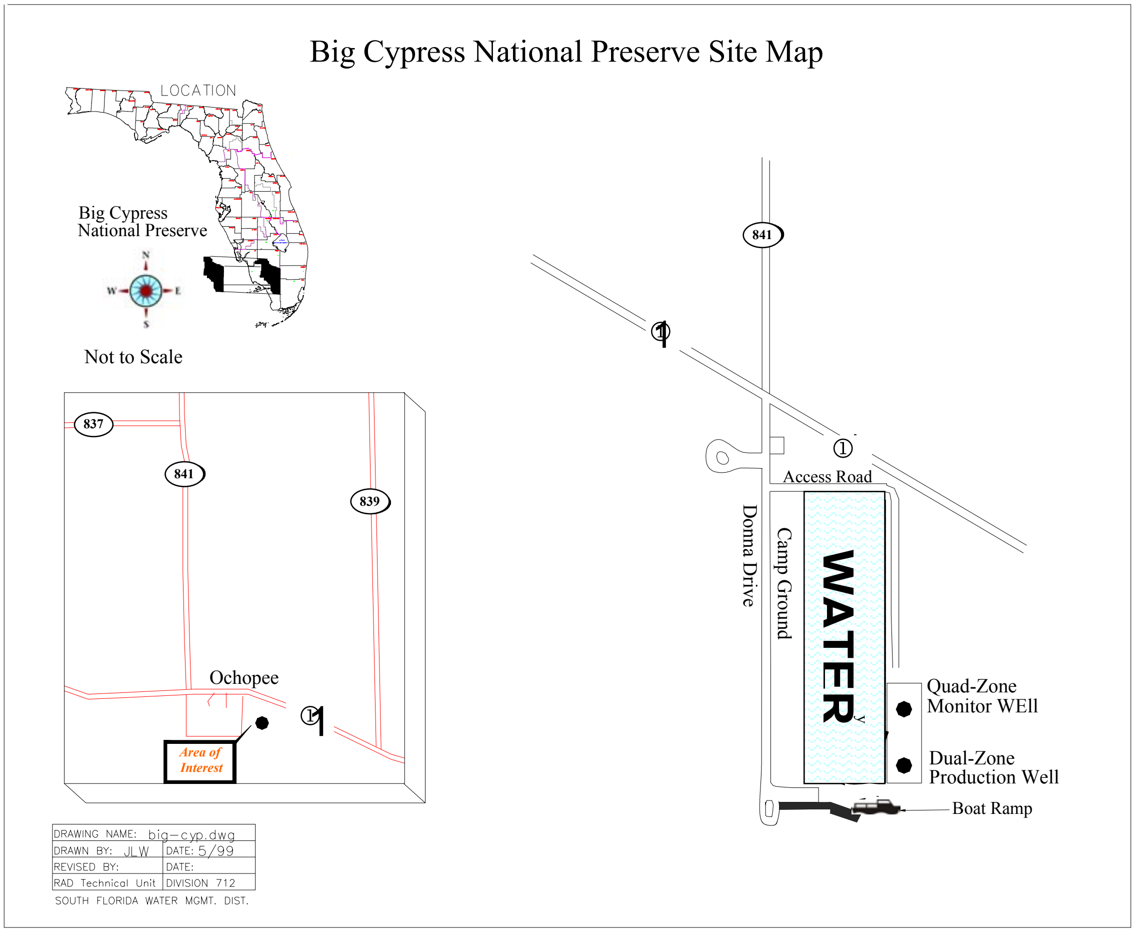


Figure 2. Project Location Map and Site Plan with Detailed Well Locations.

EXPLORATORY DRILLING AND WELL CONSTRUCTION

Big Cypress Preserve Quad-Zone Monitor Well (BICY-TW)

On September 27, 1997, DDC delivered drilling and support equipment to begin site preparation for drilling and construction of the FAS test-monitor well (referred to as BICY-TW). DDC cleared and rough graded the site and lined the ground surface beneath the temporary drilling pad with a high-density polyethylene (HDPE) membrane. DDC then constructed a two-foot thick drilling pad using crushed limestone with an earthen wall two feet high around the perimeter of the rig and settling tanks. The drilling pad served to contain drilling fluids and/or formation waters produced during well drilling, construction, and testing activities.

Mud rotary and reverse-air techniques were used during drilling operations. Closed-circulation mud rotary drilling was used to advance a nominal 10-inch diameter pilot-hole from land surface to 1,500 feet bls. DDC employed the reverse-air, open circulation method to drill the pilot-hole from 1,500 to 2,505 feet bls.

SFWMD used formation samples (well cuttings), packer tests results, and geophysical logs to determine casing setting depths. Once a suitable aquifer horizon was identified for long-term monitoring, DDC reamed the pilot-hole to the specified diameter and depth for the selected casing. Five concentric casings (30-, 24-, 18-, 12-, and 2-inch diameter) were used in the construction of the telescoping style monitor well. **Figure 3** shows the well construction details of the quad-zone monitor well identified as BICY-TW.

On October 7, 1997, DDC began drilling operations by advancing a 36-inch diameter borehole to a depth of 35 feet bls. DDC then installed a 30-inch diameter, steel pit casing, (ASTM A53, Grade B) to 30 feet bls and pressure grouted the annulus to land surface using 65 cubic feet (ft^3) of ASTM Type II neat cement.

After installing the 30-inch diameter steel pit casing, DDC advanced a nominal 10-inch diameter pilot-hole using the mud-rotary method from 35 to 460 feet bls. During pilot-hole drilling, DDC reported numerous minor lost circulation horizons between 35 and 400 feet bls with complete loss of drilling fluids at 435 feet bls. Consequently, DDC reamed the pilot-hole using the reverse-air drilling method due to the lost circulation horizons. On November 5, 1997, CH2M Hill caliper logged (4-arm caliper) the nominal 29-inch borehole **(Appendix A).** The caliper log showed no unusual borehole conditions that would prohibit proper installation of the 24-inch diameter surface casing (ASTM A53, Grade B), but it identified numerous borehole enlargement “wash-outs”, which exceeded 35 inches in diameter. DDC installed the 24-inch diameter casing to a depth of 460 feet bls, then pressure grouted it back to 53 feet bls using 1,295 ft^3 of ASTM Type II neat cement. On November 6, 1997, DDC pumped an additional stage (235 ft^3) of ASTM Type II neat cement causing cement returns at land surface.

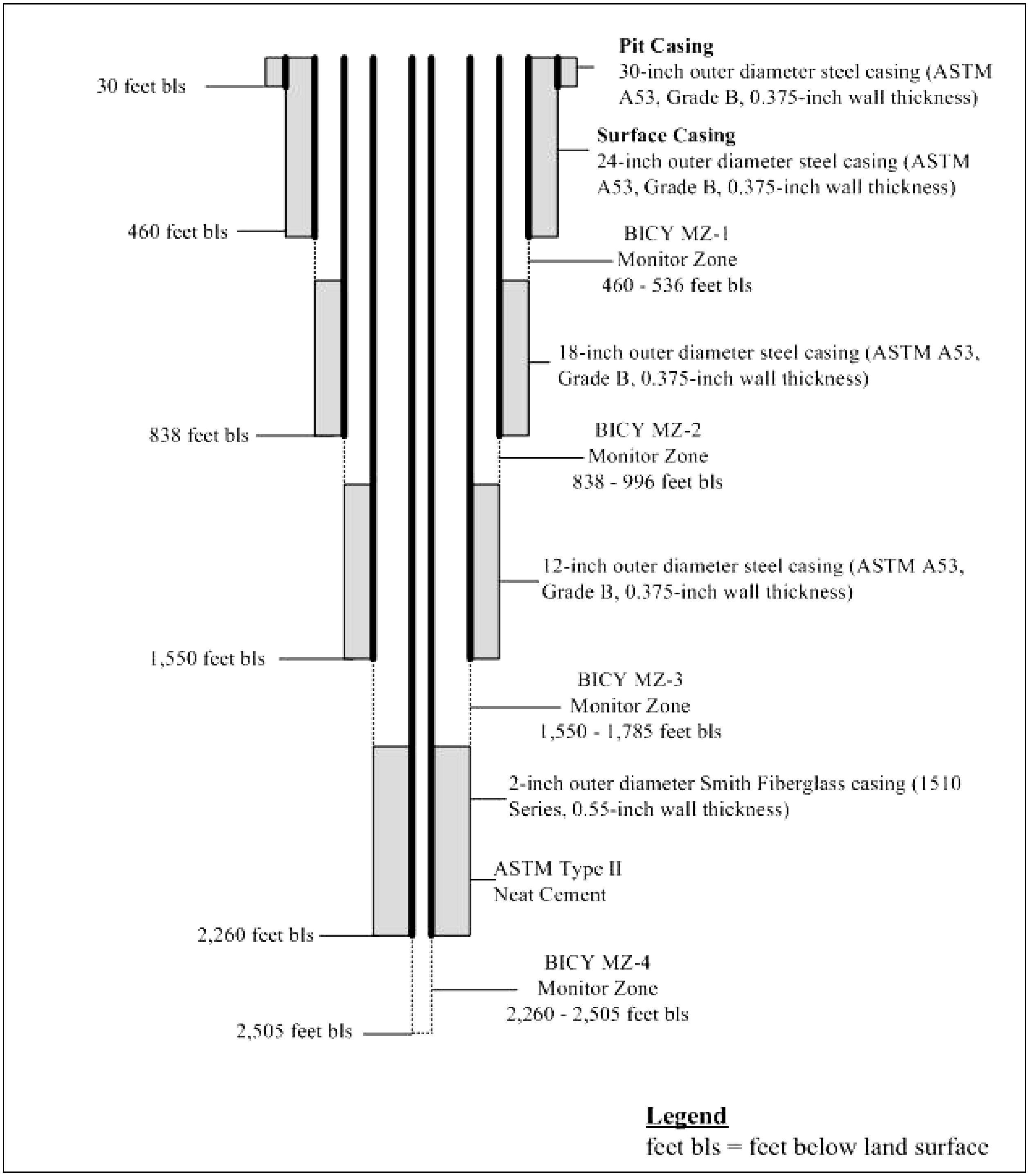


Figure 3. Well Completion Diagram, Quad-Zone Monitor Well (BICY-TW).

DDC installed a blow-off preventer (BOP) onto the 24-inch diameter casing to control potential artesian conditions while drilling through the intermediate and Floridan aquifer systems. On November 18, 1997, DDC resumed pilot-hole drilling via mud rotary through unconsolidated to semi-consolidated, Miocene-aged sediments and Oligocene/Eocene-aged carbonates. On November 21, 1997, DDC drilled to a depth of 1,500 feet bls, with no noticeable fluid losses. DDC circulated the nominal 10-inch diameter borehole to prepare it for geophysical logging operations. Western Atlas Logging Service (WALS) geophysically logged the mud-filled pilot-hole from 460 to 1,500 feet bls on November 23, 1997. Formation evaluation logs consisted of the following:

- Caliper Log, Gamma Ray Log
- Spectralog®
- Dual Induction-Focused Log
- Multipole Array Acoustilog℠
- Compensated Z-Densilog℠
- Compensated Neutron Log

In addition, WALS conducted a Magnetic Resonance Imaging Log (MRIL) to provide information on the subsurface permeability distribution within the open hole section (460 to 1,500 feet bls). After WALS completed the MRIL, they began rotary sidewall-coring operations to obtain 1-inch diameter rock plugs (plug dimensions are 1-inch in diameter and 3-inches in length). The objective of the core plugs was to provide samples for hydraulic permeability and porosity analyses along the entire length of the open hole. The laboratory determined permeability and porosity data would aid in the modeling of the MRIL data. WALS however recovered only 4 out of 22 core plugs at surface due to the high porosity, mixed lithology (e.g. sand and carbonates), and friable nature of the carbonate section.

After WALS completed the formation evaluation logs, DDC pumped the drilling fluids from the borehole and began to air develop the open-hole section (460 to 1,500 feet bls). On December 4, 1997, CH2M Hill completed the production type logs that included:

- high-resolution temperature
- fluid resistivity
- flowmeter conducted under both static (non-flowing) and dynamic (natural artesian) conditions
- borehole video survey was conducted to visually inspect the installed 24-inch diameter casing and open hole section.

Appendix A contains the individual log traces from Geophysical Run No. 2.

DDC re-entered the borehole and began to develop the open-hole interval using the reverse-air method for subsequent packer testing activities. On December 8, 1997, SFWMD began to conduct a series of packer tests within the open-hole section. The purpose of these tests was to gain hydraulic and water quality data from the middle portion of the IAS and upper portion of the FAS. See *"Packer Tests"* section of this report for further details and results.

SFWMD reviewed the geophysical logs (**Appendix A**) and lithologic data (**Appendix B**), and identified the top of the FAS at a depth of approximately 820 feet bls. However, the 18-inch diameter casing was set at a depth of 838 feet bls in order to:

1. Seal off overlying silty clays of the Hawthorn Group and carbonate mud stringers and fine quartz and phosphatic sands within the lower portion of the Arcadia Formation between 770 and 830 feet bls to avoid future drilling problems.
2. Locate the casing in a competent, well-indurated rock unit to reduce undermining (erosion) at its base as a result of natural and induced high-velocity upward flow.
3. Facilitate reverse-air drilling operations through the underlying permeable horizons of the FAS to the anticipated depth of 2,500 feet bls.
4. Evaluate flow characteristics of the FAS within the anticipated open-hole interval of 838 to 2,500 feet bls.

DDC installed temporary backfill material consisting of clean 3/8-inch diameter crushed limestone in the nominal 10-inch diameter pilot-hole to 830 feet bls. SFWMD chose this elevation based on the proposed setting depth of 840 feet bls. The temporary backfill material provided a competent base for subsequent pressure grouting operations. DDC then reamed a nominal 23-inch diameter borehole to 840 feet bls via reverse-air rotary method. On December 26, 1997, CH2M Hill caliper logged the nominal 23-inch diameter borehole to 840 feet bls without incident. The caliper log trace showed no unusual borehole conditions that would prohibit proper installation of the 18-inch diameter steel casing (see **Appendix A** for Geophysical Log Run No. 3). DDC installed the 18-inch diameter steel casing (ASTM A53, Grade B) to a depth of 838 feet bls and pressure grouted the annular space using 415 ft^3 of ASTM Type II neat cement. Steel tubing was then used to physically locate (hard tag) cement levels within the annulus. The physical hard tag indicated cement levels at 710 feet bls, which was in close agreement to calculated theoretical volumes using the caliper log data. DDC pumped an additional 605 ft^3 of ASTM Type II neat cement via the tremie method in three stages. This volume brought cement levels to 536 feet bls, which formed the base of the first monitor interval (referred to as BICY MZ-1).

DDC drilled out the cement plug at the base of the 18-inch diameter casing (a result of pressure grouting) using a nominal 17-inch diameter bit. DDC reconfigured the drill bit assembly using a 10-inch diameter bit and removed the temporary backfill material (crushed limestone) from 840 feet to 1,500 feet bls. Once DDC removed the temporary backfill material, then continued to advance a nominal 10-inch diameter pilot-hole via reverse-air method through moderately to well-indurated wackestones, packstones, and dolostones of the Ocala Limestone and Avon Park Formation. On January 18, 1998, DDC completed drilling operations to a depth of 2,505 feet bls.

DDC reverse-air developed the borehole and CH2M Hill successfully ran production evaluation logs under artesian flow (dynamic) conditions. These production logs included a flowmeter, high-resolution temperature log, and fluid resistivity log. On January 23, 1998, WALS geophysically logged the water-filled nominal 10-inch diameter pilot-hole from 838 to 2,505 feet bls.

The logging suite included:

- Caliper Log
- Gamma Ray Log
- Spectralog®
- Dual Induction-Focused Log
- Multipole Array Acoustilog[SM]
- Compensated Z-Densilog[SM] (Z-denotes electron density)
- Compensated Neutron Log.

The MRIL was not conducted on this section because the borehole exceeded the tool design limit of 13-inches over 90% of the proposed logged section.

SFWMD selected packer test intervals based on information provided by analysis of the geophysical logs, video survey, and formation samples (well cuttings). The first of two tests began on January 29, 1998. The purpose of these tests was to characterize the water quality and production capacities of specific intervals within the lower portion of the FAS (1,790 to 2,505 feet bls). SFWMD completed packer testing operations on February 2, 1998.

Following packer testing, all available information was compiled and used to select the open-hole sections for the two lower monitor zones. SFWMD selected 1,550 feet bls as the casing setting depth for the nominal 12-inch diameter steel casing. DDC used a nominal 17-inch diameter bit to ream the pilot-hole from 838 feet bls (base of the 18-inch diameter casing) to 1,550 feet bls. On February 6, 1998, the reamed borehole was caliper logged to evaluate borehole configuration/stability and to calculate cement volumes for grouting operations. DDC attached three steel cement baskets and centralizers to the nominal 12-inch diameter steel casing and installed it at 1,550 feet bls. DDC then grouted the annular space using 620 ft^3 of ASTM Type II neat cement using the tremie method in seven stages. This volume brought cement levels to 996 feet bls, which formed the base of the second monitor interval (referred to as BICY MZ-2).

Next, DDC re-entered the borehole and reverse-air developed the remaining open-hole section from 1,550 to 2,505 feet bls. A portion of the borehole (1,550 – 2,260 feet bls) was also caliper logged to evaluate borehole configuration/stability and to calculate cement volumes for grouting operations on February 27, 1998. Once the borehole was cleaned-out, DDC installed threaded-and-coupled nominal 2-inch diameter fiberglass reinforced pipe (FRP-Smith Fiberglass, SDT 1510 series) to a depth of 2,260 feet bls. DDC cement-grouted the FRP by the tremie method using 225 ft^3 of ASTM Type II neat cement pumped in multiple stages. Stage grouting operations caused cement levels to rise to 1,785 feet bls, which formed the base of the third monitor interval (referred to as BICY MZ-3). On February 28, 1998, DDC completed cement grouting of the nominal 2-inch diameter FRP. The open-hole section below the 2-inch FRP formed the fourth monitor interval (referred to as BICY MZ-4).

DDC installed four, 2-inch diameter, stainless steel extensions equipped with 2-inch inner diameter stainless steel ball valves at the surface to complete the wellhead for the quad-zone monitor well. The completed telescoped-style well allows SFWMD to monitor water levels and water quality in the middle portion of the intermediate aquifer system and three distinct FAS intervals. The uppermost monitor zone (BICY MZ-1) was constructed using 24-inch diameter casing and completed with an annular zone between 460 to 536 feet bls. The next zone (BICY MZ-2) was completed within the first productive interval in the FAS from 838 to 996 feet bls. The intermediate zone identified as BICY MZ-3 was completed in the middle confining unit below the USDW from 1,550 to 1,785 feet bls. The lowermost well (BICY MZ-4) constructed of 2-inch diameter threaded FRP was completed in the lower Floridan aquifer with an open hole of 2,260 to 2,505 feet bls. **Table 1** lists the monitor intervals and completion methods for the quad-zone monitor well.

Identifier	Monitor Interval (feet bls)	Completion Method	Aquifer
BICY MZ-1	460 to 536	Annular Zone	Intermediate Aquifer
BICY MZ-2	838 to 996	Annular Zone	Upper Floridan
BICY MZ-3	1,550 to 1,785	Annular Zone	Middle Confining Unit
BICY MZ-4	2,260 to 2,505	Open-Hole	Lower Floridan

Table 1. Summary of Monitor Interval and Completion Method for Quad-Zone FAS Monitor Well.

DDC developed the four monitor intervals via over-pumping and artesian flow techniques until the sediment concentration of the produced formation waters were 5 mg/L or less (using an Imhoff cone). DDC then constructed a 5-foot by 5-foot reinforced concrete pad at the surface of the monitor well head and placed traffic bumpers at its corners. DDC completed well construction operations related to BICY-TW on April 1, 1998. **Figure 4** is a photograph of the completed quad-zone monitor wellhead.

Figure 4. Photograph of Completed Test Monitor Wellhead (BICY-TW).

Big Cypress Preserve Test-Production Well (BICY-PW)

DDC cleared and rough graded the proposed location of the test-production well, identified as BICY-PW, to begin construction of a 60-foot by 40-foot temporary drilling pad. The drilling pad consisted of two feet of crushed limestone, lined with a high-density polyethylene (HDPE) membrane. DDC then moved the drill rig and support equipment from the monitor well pad and configured the equipment on the newly constructed drilling pad to begin construction of the dual-zone, test-production well. Once DDC moved their equipment, they constructed an earthen wall two feet high around the perimeter of the drilling pad that surrounded the rig and settling tanks. The purpose of the temporary drilling pad was to contain drilling fluids and/or formation waters produced during well drilling, testing, and well construction activities.

Construction of this well would facilitate aquifer testing of the middle portion of the intermediate aquifer system and upper Floridan aquifer between 460 and 1,010 feet bls. DDC began construction of the test-production well on March 24, 1998. **Figure 5** illustrates the well construction details of the dual-zone test-production well.

SFWMD designed the dual-zone, test-production well using three concentric steel casings (24-, 18- and 12-inch diameter). DDC installed 24-inch diameter pit casing to 40 feet bls. Once completed, DDC advanced a nominal 23-inch diameter borehole via the mud rotary method to a depth of 470 feet bls. On April 2, 1998, CH2M Hill ran a caliper log in the nominal 23-inch diameter borehole to evaluate stability and to calculate cement volumes for grouting operations. DDC then installed the first production casing, which consisted of 18-inch diameter steel pipe (ASTM A53, Grade B, and 0.375-inch wall thickness) to 465 feet bls. This casing was pressure-grouted using 678 ft^3 of ASTM Type II neat cement. Steel tubing was then used to physically locate (hard tag) cement levels within the annulus at 146 feet bls. DDC pumped an additional 200 ft^3 of neat cement, which caused returns at land surface.

On April 7, 1998, DDC re-configured the drill bit assembly and began to drill-out the cement plug at the base of the 18-inch diameter casing (a result of pressure grouting) using a nominal 17-inch diameter bit. DDC continued to advance the nominal 17-inch diameter borehole through the intermediate aquifer system to 550 feet bls using the reverse-air method. DDC developed the production interval via using reverse-air method and tripped out the drill bit assembly to set-up for an aquifer performance test (APT). On April 13, 1998, SFWMD began the first APT on the middle part of the intermediate aquifer system (see "*Aquifer Performance Test"* section for details and results).

After successfully completing the first APT, DDC advanced the borehole via the reverse-air drilling method using a nominal 17-inch diameter bit to the top of the second test horizon at 840 feet bls. CH2M Hill ran a caliper log to help SFWMD evaluate borehole diameter variability and stability and to calculate cement volumes for subsequent grouting operations. The second stage of well construction consisted of DDC installing 12-inch diameter steel casing (ASTM A53, Grade B, and 0.375-inch wall thickness) to 840 feet bls. The second production casing was grouted to land surface using 1,593 ft^3 of ASTM Type II neat cement using both pressure and tremie grouting methods. DDC completed installation of the 12-inch diameter, steel production casing on May 25, 1998.

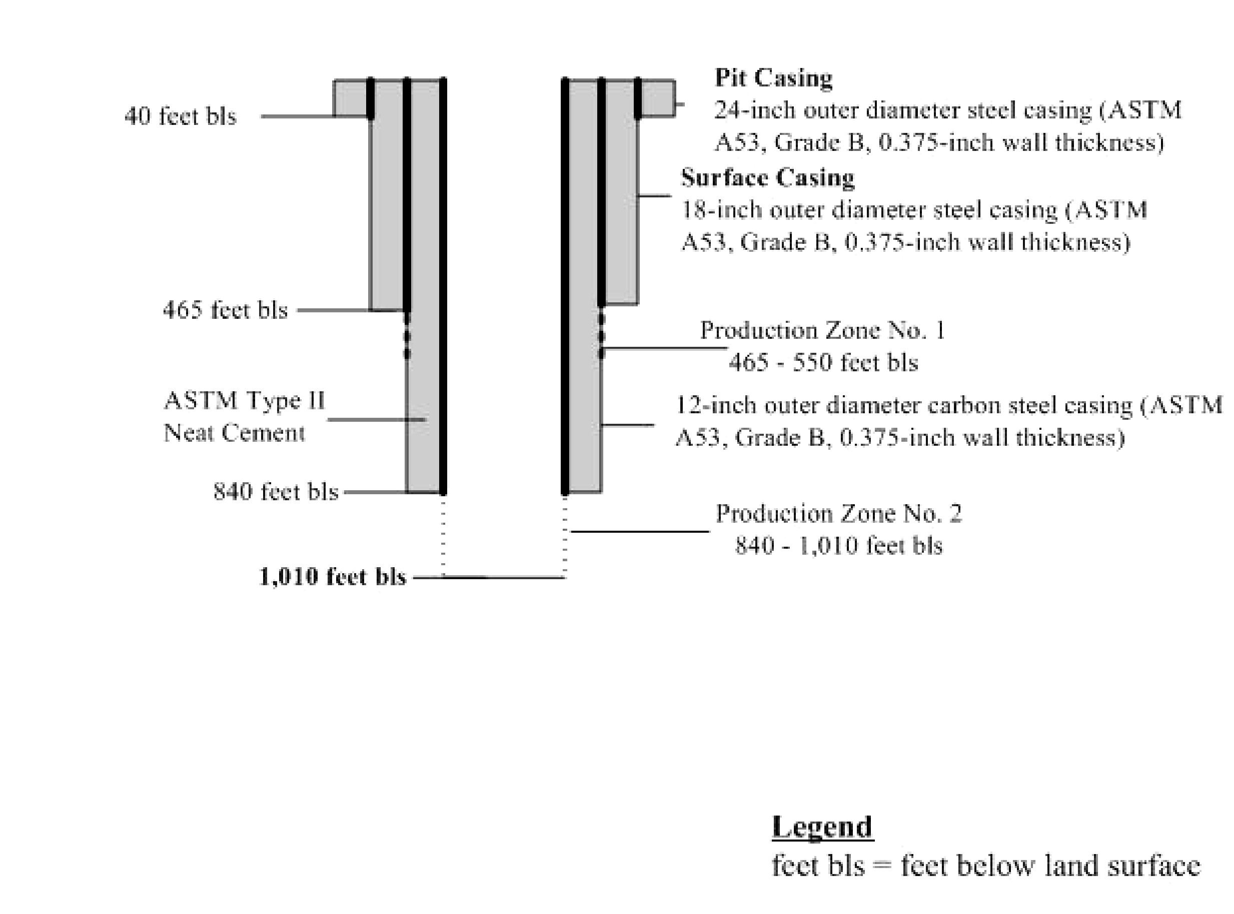


Figure 5. Well Completion Diagram, Dual-Zone Test Production Well (BICY-PW).

DDC retrieved full-diameter rock cores (4-inch diameter) from the second production interval (840 to 1,010 feet bls – Suwannee Limestone) with a recovery efficiency of only 23 percent. These cores were sent to Core Laboratories in Midland, Texas for petrophysical, petrologic, and magnetic resonance analyses (see *"Petrophysical/Petrologic"* section for further information). DDC completed drilling of the second production interval to a depth of 1,010 feet bls on July 2, 1998.

The production interval was developed using the reverse-air and artesian flow techniques. Once sufficiently developed, CH2MHill geophysically logged the open-hole section (840 to 1,010 feet bls). SFWMD conducted and successfully completed the second APT on July 22, 1998 (see "*Aquifer Performance Test"* section for test details and results).

DDC installed a standard 12-inch diameter wellhead, which consisted of an iron body, bronze-mounted valves with flanged ends, solid wedge gate, and outside screw and yoke gate valves with an 8-inch diameter side discharge port. DDC then constructed a 5-foot by 5-foot reinforced concrete pad at the surface to complete the construction of the test-production well.

STRATIGRAPHIC FRAMEWORK

SFWMD collected geologic formation samples (well cuttings) from the pilot-hole during drilling operations for the quad-zone monitor well (BICY-TW) and separated them based on their dominant lithologic or textural characteristics, and, to a lesser extent, color. Formation samples were washed and split into two sets with one set shipped to the Florida Geological Survey (FGS) for analysis and long-term storage. **Appendix B** contains a copy of the FGS's detailed lithologic description for the pilot-hole/monitor well BICY-TW (reference no. W-17801). An electronic version of the lithologic description can be downloaded directly from Florida Geological Survey's Internet site. A lithologic summary of the site is illustrated on **Figure 6**.

Pliocene Series

Limestone sediments occur from land surface to a depth of 100 feet at this site. These sediments consist of poorly to well-indurated packstones and unconsolidated yellowish-gray shell beds with 10 to 40% quartz sand content. The well-indurated packstones from 0 to 35 feet bls represent the Pliocene-aged Ochopee Limestone member of the Tamaimi Formation. Unconsolidated, fine to very coarse-grained quartz sands with varying percentages of silt, clay, and shell material occur from 35 to 305 feet bls. These sediments may be the Miocene-Pliocene aged "unnamed formation" designated by Weedman et al., (1999) or part of the Long Key Formation described by Cunningham et al., (1998). Cunningham (1997) identified similar coarse-grained siliciclastics sands from 15 to 300 feet bls as the Miocene-Pliocene Long Key Formation in a corehole located approximately 20 miles north of the BICY site. Cunningham (1997) suggests that these siliciclastic sands were deposited in a fluvial-deltaic environment that extends southward towards Florida Bay.

Miocene Series

Hawthorn Group

The Hawthorn Group is composed of a heterogeneous mixture of silt, clay, calcareous clay, dolosilt, quartz sand, phosphate, limestone, and dolomite. The Hawthorn Group can be subdivided into two lithostratigraphic units. The upper unit, the Peace River Formation is composed of predominantly siliciclastic material from approximately 305 to 470 feet bls at the BICY site. The lower unit, the Arcadia Formation is composed principally of carbonates (Scott, 1988) and is approximately 470 to 845 feet bls. A major regional disconformity separates these two units (Scott, 1988 and Missimer, 1997, 2002). The contact between these two units can often be identified by the occurrence of a rubble bed of coarse to pebble-size quartz sand and phosphatic sand and gravel. This unit generally produces a distinctive response ("peak") on natural gamma ray logs.

Peace River Formation

The top of the Peace River formation is recognized as the first appearance of an olive-gray to yellowish-gray, poorly indurated clayey silt unit with a minor phosphate component. These poorly indurated silts occur at a depth of 305 feet bls. These low permeable sediments are approximately 70 feet thick and extend to a depth of 375 feet bls. The lower portion of the Peace River Formation from 375 to 470 feet bls consist of unconsolidated yellowish-gray, silty quartz sands (375 to 430 feet bls) and olive-gray, sandy silts with minor limestone stringers (430 to 470 feet bls).

Arcadia Formation

Generally, the Arcadia Formation is separated from the Peace River Formation by a lithologic change from predominately siliciclastic to mixed siliciclastic-carbonate sediments. At this site, a distinctive lithologic break occurs at 470 feet bls, where a yellowish-gray to light-gray, moderately indurated, packstone with dolomitic and sparry calcite cement is encountered. This lithologic unit is noted on the geophysical logs by relatively low gamma-ray emissions, lower sonic transit times, and lower log-derived density/neutron porosity values. This moderately indurated packstone unit continues to a depth of 570 feet bls.

The lithology below 570 feet bls shifts to a moderately indurated phosphatic wackestone-packstone inter-bedded with well-indurated crystalline limestone. This interval is marked by higher formation resistivity and bulk density readings, and decreased sonic transit times. The inter-bedded nature of this interval is noted by irregularly shaped sonic and formation resistivity log traces. The bulk density (ZDEN) and log-derived porosity (PORZ and CNCF curves) from 570 to 700 feet bls support the inter-bedded nature of this carbonate sequence. Between 700 and 760 feet in depth, a clean, moderately indurated, porous, yellowish-gray packstone is found. This unit correlates with the “Marker Unit” in the basal Hawthorn unit identified by Reese (2000). Reese found this “Marker Unit” to be laterally continuous throughout much of Collier County

The lowermost section of the Arcadia Formation (continuation of the basal Hawthorn unit from above – Reese, 2000) at this site is composed primarily of moderately indurated, sandy, phosphatic packstones that occur from 760 to 845 feet bls. The top of this interval is identified by an over-gauged borehole, a slight increase in formation resistivity and bulk density values, and lower natural gamma ray activity and sonic transit times (see BICY-TW Geophysical Log Run No.2 - **Appendix A**). A well-indurated limestone unit (from 820 to 845 feet bls) provided a suitable location for the 18-inch diameter casing, which served as the uppermost FAS monitor interval for the BICY quad-zone well.

Oligocene Series

<u>Suwannee Limestone</u>

The FGS and SFWMD identified the contact between the Arcadia Formation and the Suwannee Limestone at depth of 845 feet bls based on lithologic considerations and changes in physical characteristics recorded on the geophysical logs. Lithologically, the basal portion of the Arcadia Formation is composed of a yellowish-gray sandy (5% quartz sand), phosphatic (8%) wackestone. The Suwannee Limestone, however, is a yellowish-gray, packstone containing considerably less quartz (1%) and phosphatic (<1%) sands than above. Geophysically, this contact is marked by an attenuation of the natural gamma activity primarily due to the decrease in phosphate content in the upper Suwannee Limestone. In addition, the Suwannee Limestone at this site is characterized by higher sonic transit times, lower bulk density values and higher density and neutron log-derived porosity as compared to the basal facies of the Arcadia Formation.

The Suwannee Limestone occurs from 845 to 1,265 feet bls and consists predominantly of packstone and grainstone units. Through this interval, the photoelectric log values average 3.5 b/e indicating a carbonate lithology with a minor silt/sand component (Hallenburg, 1998) that produce higher density and neutron log-derived porosity values (average 36 porosity units). A poorly indurated, light-gray, high porosity, sandy packstone occurs from 970 feet to 995 feet bls. This unit is identified by decreased formation resistivity, increased sonic transit times and increased log-derived porosity values. In addition, the photoelectric values decrease to 2.5 b/e (quartz sand = 1.8 b/e, whereas carbonates = 5.0 b/e), consistent with the unit's higher siliciclastic content.

The lower portion of the Suwannee Limestone (995 to 1,265 feet bls) consists of high porosity, yellowish-gray, moderately indurated packstones with a minor quartz sand component. The geophysical log traces are fairly consistent through this interval, characterized by slightly over-gauged borehole, formation resistivity between 5 to 10 ohm-m, average sonic transit time of 110 µsec, and log-derived porosity values of 35 to 42 porosity units. The medium induction log curve produced similar values to that of the deep induction log curve. This log response indicates that fairly substantial drilling fluid invasion occurred while drilling through these highly porous units via mud rotary.

Eocene Series

Ocala Limestone

The Ocala Limestone is identified at a depth of 1,265 feet bls. The lithologic character of the upper portion of the Ocala Limestone is very similar to the yellowish-gray packstones of the lower Suwannee Limestone as seen in the well cuttings and geophysical log responses. The FGS identified the top the Ocala Limestone at a depth of 1,265 feet bls, with the first occurrence of the diagnostic microfossil Lepidocycina ocalana (primarily a biostratigraphic designation, Applin and Applin, 1944). The lack of lithologic differences between the two lithostratigraphic units may indicate similar depositional environments were present at this location.

At this site, the Ocala Limestone occurs from 1,265 to 1,545 feet bls, consisting primarily of yellowish-gray, moderately indurated packstone and grainstone units. The allochemical constituent consists primarily of larger foraminiferal tests such as Lepidocyclina sp., Nummulites sp., and mollusks. Through this lithostratigraphic unit, the natural gamma log recorded low emissions, the photoelectric log values averaged 4 b/e, and the log-derived neutron/density porosity curves produced similar values (see Geophysical Log Run No 3 - **Appendix A**). These geophysical log responses indicate a uniform and relatively clean (free of detrital material) limestone unit.

Avon Park Formation

The FGS identified the top of the Avon Park Formation at a depth of 1,545 feet bls. At this depth, a lithologic change from a yellow-gray packstone to a yellowish-gray to grayish-brown dolostone occurs. In addition, this formation boundary coincides with a change in fossil assemblage, higher formation resistivity, lower bulk density and neutron porosity values and an increase in natural gamma activity. The first occurrence of Dictyoconus americanus, a diagnostic microfossil (used extensively as a bio-stratigraphic indicator for the Avon Park Formation) occurs at 1,555 feet bls, 10 feet below the identified top of the formation.

The Avon Park Formation from 1,545 to 2,505 feet bls consists predominantly of moderately indurated, tan to yellowish-gray wackestone and grainstone units that exhibit the effects of minor to moderate recrystallization. The formation resistivity, photoelectric, density, neutron, sonic, and caliper log responses remain fairly consistent throughout this limestone sequence, noting minor variations in lithology, porosity, and structure as seen in their individual log traces obtained from Geophysical Log Run No. 3 (**Appendix A**). Within the interval from 1,545 to 2,505 feet bls, the presence of individual dolostone units is limited, comprising only 4% of this 960 foot section, which is unusual for the lower Avon Park Formation, where thicker and higher number of dolostone units are generally found.

<u>Oldsmar Formation</u>

The top of the Oldsmar Formation is often difficult to identify. Its diagnostic microfossils are often obliterated by diagenetic effects and its lithologic character is similar to the overlying Avon Park Formation. A review of the borehole data indicates that the Oldsmar Formation was not present to depth of 2,505 feet bls, based on established lithologic and paleontologic criteria (Applin and Applin, 1944; Chen, 1965; Miller, 1986; Duncan et al., 1994).

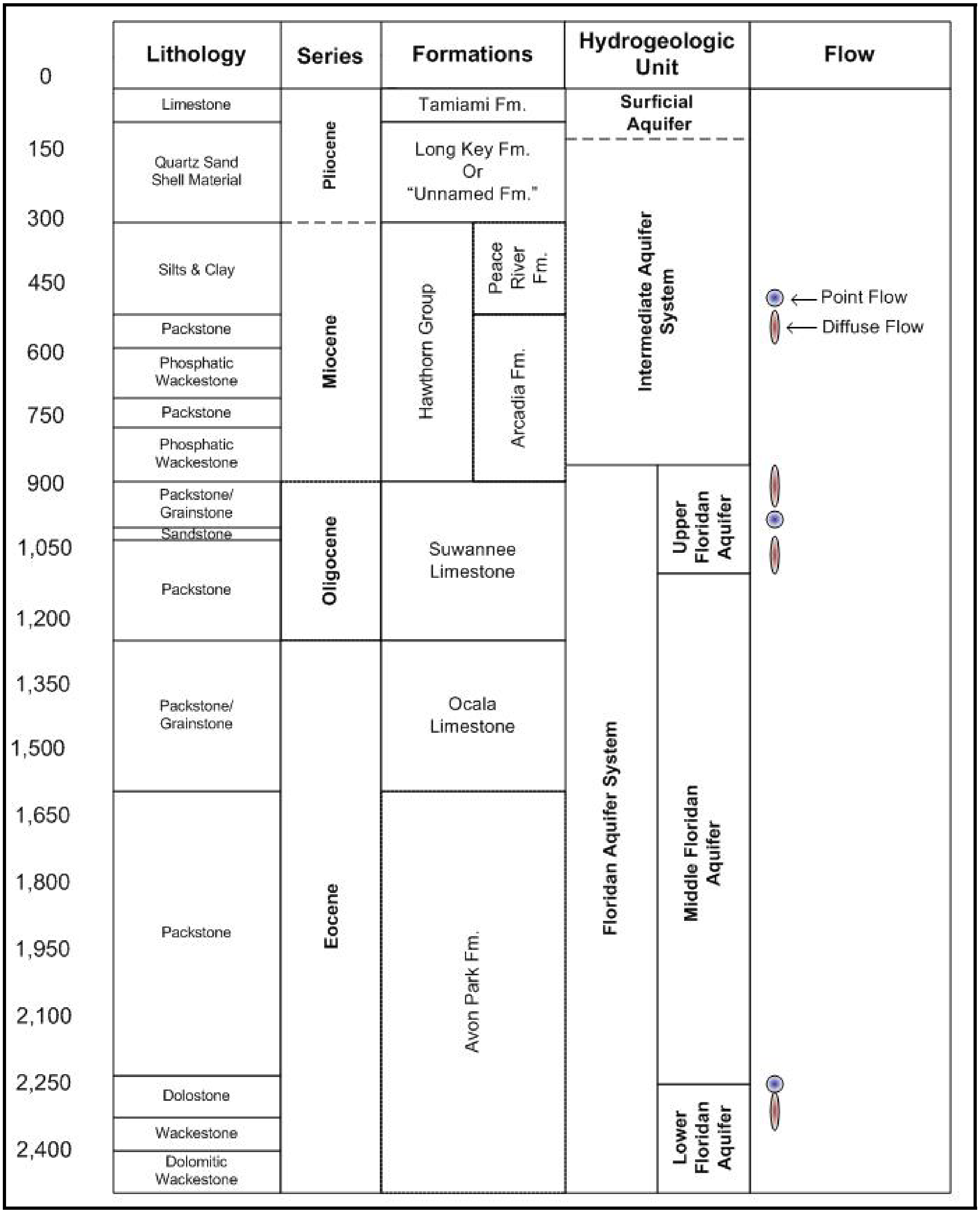


Figure 6. Generalized Hydrogeologic Section.

HYDROGEOLOGIC FRAMEWORK

Three major aquifer systems underlie this site, the surficial aquifer system, the intermediate aquifer system, and the Floridan aquifer system with the Floridan aquifer system being the focus of this test well program. These aquifer systems are composed of multiple, discrete aquifers separated by low permeability "confining" units that occur throughout this Tertiary/Quaternary-aged sequence. **Figure 6** shows the generalized lithologic and hydrogeologic sections underlying the Big Cypress Preserve site.

Surficial Aquifer System

At this location, the surficial aquifer system (SAS) consists of the Pliocene-aged Tamiami Formation (Ochopee Limestone Member) and the upper part of the Pliocene-Miocene-aged "Unnamed Formation" (Weedman, 1999) or Long Key Formation (Cunningham, 1997). An intervening confining unit from 100 feet to 150 feet bls, consisting of an unconsolidated, light olive-gray clay-rich shell bed and poorly indurated wackestone, was used to delineate the base of the SAS.

Intermediate Aquifer System

Below the SAS is the intermediate aquifer system (IAS), which extends from 150 to 820 feet bls. The Pliocene-Miocene-aged "Unnamed Formation or the Long Key Formation, and the Miocene-aged Hawthorn Group (Scott, 1988) act as confining units, separating the FAS from the SAS. Lithologic information obtained from drill cuttings from BICY-TW indicates that the "Unnamed Formation or Long Key Formation consist of unconsolidated quartz sand containing shell material, silt and clay. The Hawthorn Group sediments consist of unconsolidated shell beds, soft non-indurated clay, silt and quartz-phosphatic sand units, and poorly to moderately indurated mudstones/wackestones (see FGS lithologic description in **Appendix B**).

The IAS underlying the LWCPA contains multiple productive horizons separated by low permeable inter-aquifer confining units. The top of the IAS is marked by low permeable unconsolidated, clay-rich, shell beds and poorly indurated wackestone from 100 to 150 feet bls. A moderately productive unit occurs from 150 to 285 feet bls and consists of unconsolidated quartz sand units with varying percentages of detrital and phosphate clay/silt and shell material. Below this productive interval is a relatively thick, inter-aquifer confining unit that extends from 285 to 470 feet bls. This confining unit consists of low permeable, yellowish to light-gray, unconsolidated to poorly-indurated clayey silt to silty sand units with minor biogenic limestone stringers and poorly indurated olive-gray to dark greenish-gray clay.

A distinctive lithologic break occurs at 470 feet bls where a yellowish-gray, moderately indurated, dolomitic packstone is encountered that continues to 545 feet bls. Well cuttings and moderate drilling fluid loss through this interval indicated moderate to good production capacity. A subsequent step-drawdown test conducted on this interval yielded 95 gallons per minute per foot (gpm/ft) of drawdown at a flow rate of 2,700 gpm. Based on moderate to good productivity, SFWMD identified this interval (referred to as BICY MZ-1; 460 to 536 feet bls – "mid-Hawthorn aquifer") for long-term monitoring and aquifer testing.

The lithology from 545 to 820 feet bls remains fairly consistent in character as described above (consisting of a moderately indurated packstone), but formation samples show only minor primary or secondary porosity development. This interval is identified by an irregular sonic log trace, decreased sonic transit times and computed porosity values, and higher bulk density and resistivity values. In addition, the production logs indicate only minor water production through this interval. These low permeability carbonate sediments form the lower confining unit of the IAS at 820 feet bls.

Floridan Aquifer System

The Floridan aquifer system (FAS) consists of a series Tertiary Age limestone and dolostone units. The FAS includes permeable sediments of the lower Arcadia Formation, Suwannee and Ocala Limestones, Avon Park Formation, and the Oldsmar Formation. The Paleocene age, Cedar Keys Formation with evaporitic gypsum and anhydrite forms the lower boundary of the FAS (Miller, 1986).

Upper Floridan Aquifer

The top of the FAS, as defined by the Southeastern Geological Society AdHoc Committee on Florida Hydrostratigraphic Unit Definition (1986), coincides with the top of a vertically continuous permeable carbonate sequence. The upper Floridan aquifer consists of thin water bearing horizons with high permeability interspersed within thick units of late Miocene to middle-Eocene age sediments with low permeability, including the basal Arcadia Formation, Suwannee and Ocala Limestones, and the Avon Park Formation. At this site, the top of the FAS occurs at a depth of 820 feet bls, which coincides with the lower portion of the Arcadia Formation (Basal Hawthorn Unit, Reese, 2000).

On a regional scale, two zones of high permeability exist within the upper Floridan aquifer and typically occurs between 700 and 1,300 feet bls. The most transmissive part of this upper zone usually occurs near the top, coincident with zones of dissolution in association with unconformities of the Oligocene or Eocene-aged formations (Miller, 1986). The first transmissive horizon in the FAS at the Big Cypress Preserve site occurs from 820 to 1,000 feet bls, and includes the basal Arcadia Formation and Suwannee Limestone. This productive unit is composed of yellowish to medium-gray, poorly to moderately indurated wackestone to packstone units. While drilling, minor drilling fluid losses were noted in the on-site drilling log within an interval from 820 to 990 feet bls - indicative of a porous/permeable horizon. The flowmeter log data indicated that the majority of the water production within this interval was found at 980 feet bls with smaller discrete flow zones at 850, 900 and 950 feet bls) with the fluid resistivity log data suggesting poorer water quality below 980 feet bls (refer to Geophysical Log Run No. 3 – **Appendix A)**. SFWMD selected the depth interval of 838 to 996 feet bls for long-term monitoring and hydraulic testing based on moderate to good water production potential and similar water characteristics. Formation water samples obtained from this completed monitor zone (838 to 996 feet bls) yielded chloride and TDS concentrations of 2,946 and 5,460 mg/L, respectively. The production logs indicate minor production in a sandy packstone unit from 1,000 to 1,100 feet, but higher TDS waters appear to be present based on the fluid resisitivity log. The objective of this study was to identify productive horizons of similar water quality in the upper portion of the FAS, so only the 838 to 996 foot interval was identified for that purpose and did not include the depth interval of 996 to 1,100 feet bls. Using the current hydrogeologic nomenclature of hydraulically connected permeable unit, the interval from 820 to 1,100 feet bls can be considered as part of the "upper Floridan aquifer".

Middle Floridan Confining Unit

Below this productive horizon is a thick, low permeable, inter-aquifer semi-confining carbonate unit that extends from 1,100 to 2,240 feet bls. The lower Suwannee and Ocala Limestones form the upper portion of this inter-aquifer confining unit from 1,100 to 1,545 feet bls. It consists of poorly to moderately indurated "chalky" wackestone and packstone units. Formation samples from this interval do not show evidence of large-scale secondary porosity development (e.g., good pinhole, or moldic porosity). In addition, the production type geophysical log traces indicate no significant productive horizons, as seen by smooth temperature and flowmeter log traces (after correcting for borehole diameter), which support the confining nature of this interval. SFWMD conducted two separate packer tests from 1,195 to 1,295 feet bls and 1,402 to 1,525 feet bls, which yielded specific capacity values of 1.0 gal/min/foot and 0.01 gal/min/foot, respectively. Permeability data from rock cores obtained between 1,350 and 1,500 feet bls yielded an average value of 83 millidarcy (md) as compared to 1,775 md in the upper Floridan production horizon (830 to 1,010 feet bls).

The signature of the deep induction log indicates that a water quality transition occurs below 1,350 feet bls. Between 1,350 and 1,500 feet bls, formation resistivity values decrease from 8 ohm-m to 2 ohm-m with minor changes in lithology or porosity (as noted in the well cuttings and computed porosity curves) indicative of a change in the quality (TDS concentration) of the pore fluids. Reese (2000) suggests that deep induction resistivity values of 2 ohm-m or less are indicative of saline-water, those defined as TDS concentrations of 35,000 mg/L or greater. A log-derived formation water salinity (TDS concentration) log **(Figure 8)** indicates waters below 1,375 feet bls exceed a concentration of 10,000 mg/L. Formation water with TDS concentrations less than 10,000 mg/L are considered an underground source of drinking water (USDW).

At this site, SFWMD identified minor productive intervals that contained waters of similar TDS concentration from 1,550 to 1,785 feet bls (Avon Park Formation). This interval consists of moderately indurated dolomitic packstones to grainstones with minor dolostone units. Within this interval, limited secondary porosity development (primarily pinhole porosity) was observed in the formation samples. In addition, the geophysical log data shows a general increase in bulk density and a decrease in sonic transit times, and log-derived porosity values **(Appendix A)**. The flowmeter log was of limited use due to the enlarged borehole muting evidence of water production. Deflections, however, in the temperature log (gradient and differential) indicated minor production. Based on minor production capacity and similar water characteristics, SFWMD identified this interval for long-term monitoring. Formation water samples obtained from this completed monitor zone (1,550 to 1,785 feet bls) yielded chloride and TDS concentrations of 15,244 and 26,500 mg/L, respectively.

The Avon Park Formation from 1,775 to 2,240 feet bls consists of low permeable moderately indurated wackestone and packstone units. Through this interval formation resistivity values range between 1.5 and 2.0 ohm-m, bulk density average 2.15 gram per centimeter, sonic transit time average 90 micro-seconds, and log-derived porosity averages 28 porosity units. The formation evaluation logs indicate fairly uniform physical attributes (e.g. bulk density and porosity) through this depth interval. Formation samples do not show evidence of large-scale secondary porosity development, and the temperature and flowmeter log traces indicate limited water production, which supports the overall confining nature of this interval.

Lower Floridan Aquifer

A low to moderately permeable dolostone unit occurs from 2,240 to 2,280 feet bls. The change in lithology from a packstone to dolostone is noted by individual geophysical log traces. The induction and sonic logs show a slight increase in formation resistivity and lower sonic transit times, which are indicative of well-indurated dolostones. A minor flow zone, present near the top of this dolostone sequence was initially identified during reverse-air drilling when flow rates from the well bore increased. Minor deflections in the temperature log and information from the borehole video log confirmed small productive horizons from 2,240 to 2,300 feet bls. Based on Meyer's (1989) and Reese (2000), SFWMD identified the interval from 2,240 to 2,300 feet bls as the upper dolostone units of the lower Floridan aquifer. Wackestone and dolomitic wackestone units are present from 2,300 feet bls to a total depth of 2,505 feet bls. This lowermost interval was identified for long-term water level and quality monitoring (BICY-MZ4; 2,260 to 2,505 feet bls)

HYDROGEOLOGIC TESTING

SFWMD collected specific information during the drilling program to determine the lithologic, hydraulic, and water-quality characteristics of the FAS at this site. These data were to be used in the final design of both the Floridan aquifer monitor and test-production wells for use in site-specific aquifer tests, and a long-term water level and water quality monitoring program.

Geophysical Logging

Geophysical logging was conducted in the pilot-holes after each stage of drilling and before reaming of the boreholes for casing installations. The resulting logs provide a continuous record of the physical properties of the subsurface formations and their respective fluids. These logs were later used to assist in the interpretation of lithology, provide estimates of permeability, porosity, bulk density, and resistivity of the aquifer and to determine the salinity profile of the ground water (using Archie's equation, Archie, 1942). In addition, the extent of confinement of discrete intervals can be discerned from the individual logs. **Table 2** lists the formation evaluation logs conducted at the BICY site, their physical characteristics, and properties measured.

Log Name	Log Type	Principal Application	Maximum Hole Size	Benefit to Ground Water Studies
4-arm Caliper	Mechanical (inches)	Determines borehole diameter and rugosity in two horizontal planes and used to correct other logs	22 inches	Used to correct flowmeter logs and aids in identifying suitable inflatable packer and casing placement
Gamma Ray (GR)	Natural Radioactive Nuclear reported in American Petroleum Institute Units (API)	Correlation, stratigraphic boundaries	24 inches	Correlation, used to estimate shale and clay volume
Spectralog® (SL)	Nuclear –Natural Gamma Emissions of the 256 Mineral spectrum reported in API units.	Correlation, mineral identification – U, Th, and K and clay content	22 inches	Correlation, defines clay type and aids in mineral identification and fracture detection
Dual Induction-Focused Log (DIFL)	Conductivity converted to Resistivity. Bedding resolution to 2 feet in smooth borehole values reported in ohm-meter (ohm-m)	Provides invasion profile and accurate water resistivity (Rw) determination	20 inches	Water Quality – determination of R_w via Archie Equation, and provides estimates of permeability from invasion profile

Compensated Z-Density with Photoelectric absorption	Nuclear – Induced Radioactive – Pad mounted, reports bulk density in grams per cubic centimeters (gm/cc) and porosity in porosity units (p.u)	Porosity analysis, bulk density and lithologic and fluid determination	14 inches affected by rugose borehole	Porosity estimates and lithologic indicator – porosity may be used in Archie Equation.
Compensated Neutron (CN)	Nuclear – Induced Radioactive reports porosity in porosity units (p.u)	Porosity analysis, and lithologic determination	14 inches good in rough or washed out borehole	Porosity estimates, porosity may be used in Archie Equation.
Multipole Array Acoustilog^{SM} (MAC)	Acoustic Sonic - Full wave form records the primary, secondary and tube wave velocities and reports travel times in microseconds per foot (usec/ft)	Porosity and permeability analysis, dynamic and mechanical properties	15 inches sensitive to washouts	Evaluates porosity and permeability plus rock mechanical properties - aids in fracture and lithology estimates
Magnetic Resonance Imaging Log (MRIL) ®	Uses the principle of nuclear magnetic relaxation	Porosity and permeability analysis	13 inches sensitive to washouts	Provides porosity, permeability measurements and grain-size and pore-size distribution

Table 2. Summary of Formation Evaluation Logging.

The geophysical logging contractor(s) downloaded the data directly from the onsite logging processor onto diskettes using log ASCII standard (LAS) version 1.2 or 2.0 format. SFWMD and CH2M Hill provided supplemental geophysical logging services. **Appendix A** contains the geophysical log traces from the various log runs for BICY-TW. The original geophysical logs and video surveys from the BICY site are archived (SFWMD reference no. 021-000100) and available for review at the SFWMD headquarters in West Palm Beach, Florida. **Table 3** is a summary of the geophysical logging program conducted at this site.

Run #	Date	Logging Company	Logged Interval (feet bls)	Caliper	Natural Gamma Ray	SP	Dual Induction	Sonic	Density-Neutron	Magnetic Resonance	Flow-Meter	Temp	Fluid Resist	Video
1	11/05/97	CH2M Hill	0-460	x	x									
2a	11/23/97	Western-Atlas	460-1500	x	x	x	x	x	x	x	x	x		
2b	12/04/97	CH2M Hill	460-1500	x	x						x	x	x	x
3	12/26/97	CH2M Hill	460-840	x	x									
4.a	01/19/98	CH2M Hill	840-2505	x	x						x	x	x	
4.b	01/23/98	Western-Atlas	840-2505	x	x	x	x	x	x					
4.c	01/27/98	SFWMD	840-2505											x
5	02/06/98	CH2M Hill	840-1550	x	x									
6	02/27/98	CH2M Hill	1550-2260	x	x									
feet bls = feet below land surface														
Mesuring point elevation is land surface at 4.4 feet NGVD, 1929														

Table 3. Summary of Geophysical Logging Operations.

A new wireline technology using nuclear MRIL® was conducted at the BICY site. The objective of conducting the MRIL® was to determine the in-situ permeability distribution within the upper Floridan and to provide calculated depth specific permeability and porosity values over the open-hole section. If successful, this information would be used to determine zones of high (aquifers) and low permeability (confining units) for subsequent use in future ground water flow models. The initial MRIL® derived data provided the gross permeability distribution based on a T_2 cutoff of 90 milliseconds (ms) for the logged interval of 460 to 1,500 feet bls. A nuclear magnetic relaxation (NMR) measurement referred to as T_2 is defined as the time for the hydrogen proton to come to rest after being excited by an induced magnetic field. MRIL® derived permeability values, however, did not correlate well with the laboratory derived values produced from whole-diameter core analysis. A subsequent nuclear magnetic resonance calibration study on rock samples from the BICY site produced T_2 cutoff values between 40 and 152 ms. The results of the calibration study indicate a single T_2 cutoff of 90 ms may not be appropriate to determine permeability values for the highly porous, mixed carbonates of the Floridan aquifer system. The NMR calibration study results from the BICY site are presented in **Appendix C.**

SFWMD also used the geophysical log data to identify water quality changes (specifically TDS concentration) within the FAS to assist in determining the depth of the base of the Underground Source of Drinking Water (USDW) were TDS concentrations are less than 10,000 mg/L. In addition, these data were used to determine salinity concentrations within lower middle confining unit and lower Floridan aquifer where direct measurements on formation water samples were limited. In an effort to meet these objectives, a salinity profile of the FAS was generated using a method devised by Archie in 1942, referred to as "Archie Equation."

Archie (1942) discovered that the resistivity of a water-saturated rock (R_o) varies by a constant value as the resistivity of the formation water (R_w) changes. He qualified the relationship as:

$$R_o = F * R_w \qquad \textit{(Equation 1)}$$

Where:

R_o = the resistivity in ohm-meters of the 100% water saturated formation
F = the formation factor, a proportionality constant
R_w = the resistivity in ohm-meters of the water saturating the formation

Archie derived the equation by saturating core samples of different porosity (10 to 50%) with water of various salinity (1,000 to 20,000 mg/L) then measuring R_o. He found that the equation was valid for the entire range of porosity and salinity. Archie also observed that R_o, and consequently F, decreased as porosity increased and inferred that F was a function of porosity and derived an empirical relationship between the two as;

$$F = 1/\phi^m \qquad \textit{(Equation 2)}$$

Where:

F = formation factor
ϕ = porosity in decimal form
m = cementation factor

A subsequent investigation by Winsauer et al., (1952) led to the addition of the variable “a” in the numerator:

$$F = a/\phi^{m} \qquad \textit{(Equation 3)}$$

Where:

a = tortuosity factor

Chombart (1960) noted that “m” generally had values of 1.8 to 2.0 for chalky limestone and 2.1 to 2.6 for vugular carbonates, while “a” ranged between 0.85 and 1.3 for carbonates.

Therefore, to determine the resistivity of the formation water, the Archie’s equation can be rearranged as $R_w = R_o/F$. The deep induction (RILD) resistivity log values corrected to standard temperature (77°F), were substituted for R_o and the formation factor (F) determined using the empirical relationship of $F = a/\phi^m$ (with a = 1, m = 1.95 and ϕ = sonic derived porosity values – Wyllie, 19--). The resulting resistivity values (R_w in ohm-m) were converted to specific conductance by taking the inverse of R_o ($1/R_o$) then multiplying by 10,000 to produce values in micromhos per centimeters. SFWMD translated the calculated specific conductance values to TDS using a two step approach described in Reese (1994). **Figure 7** shows the calculated formation water TDS log compared to measured TDS concentrations of water samples taken during packer tests and from completed monitor zones. The base of the USDW is identified at approximately 1,375 feet bls, which is in close agreement with laboratory determined TDS concentrations of water samples taken from similar depths.

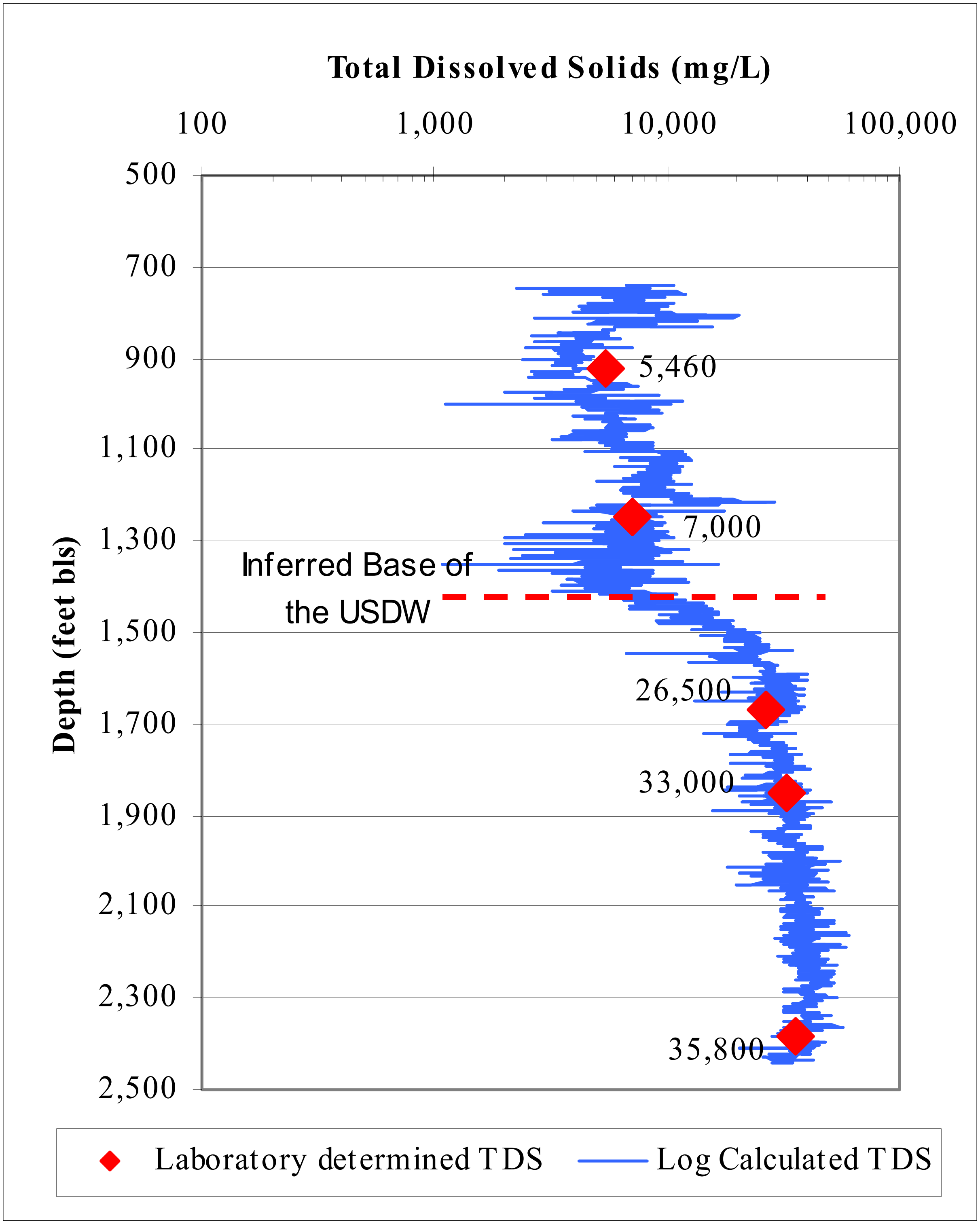


Figure 7. Calculated Formation Water Resistivity Log – BICY-TW (830-2,450 feet bls).

Packer Tests

The packer tests were conducted in the middle portion of the IAS between 455 and 540 feet bls and in the FAS between 850 and 2,505 feet bls. The purpose of these tests was to gain water quality and production capacity data on discrete intervals. SFWMD selected intervals based on lithologic, hydraulic and water quality considerations using all available data.

The procedures listed below were used to conduct individual packer tests in well BICY-TW at the BICY preserve site:

1) Lower packer assembly to the test interval based on geophysical and lithologic logs.
2) Set and inflate packers and open the ports between the packers.
3) Install a 4-inch diameter submersible pump to a depth of 60 to 120 feet below the drill floor.
4) Install two 50-psig-pressure transducers inside the drill pipe and one 10-psig transducer in the annulus.
5) Purge a minimum of three drill-stem volumes.
6) Monitor pressure transducer readings and field parameters (e.g., temperature, specific conductance, and pH) from the purged formation water until stable. These parameters were used to determine the quality of isolation of the "packed-off" interval.
7) Perform constant pumping rate drawdown and recovery tests, once the interval was effectively isolated.
8) Collect formation water samples per SFWMD sampling protocol for laboratory analyses.
9) Record recovery data until water level return to static (pre-pumping) conditions.

The Contractor purged the packer intervals a minimum of three borehole volumes or until field parameters of samples collected from the discharge pipe had stabilized then SFWMD obtained individual ground water samples. A limit of +/-5% variation in consecutive field parameter readings was used to determine chemical stability. SFWMD staff used a Hydrolab® multi-parameter probe to measure field parameters including temperature, specific conductance, and pH on each sample. Chloride concentrations were determined using a field titration method (Hach® Kit). SFWMD personnel collected unfiltered and filtered water in accordance with sampling SFWMD protocol. The water samples were placed on ice and transported to the SFWMD water quality laboratory where they were analyzed for major cations and anions using EPA and/or Standard Method Procedures (SFWMD, Comprehensive Quality Assurance Plan, 1995). **Table 4** lists the field parameters and laboratory results for the individual packer tests.

Inorganic Water Quality Data from Big Cypress Preserve Drill Site (BICY), Collier County, Florida.															
				Cations				Anions					Field Parameters		
Identifer	**Depth Interval (ft. bls)**	**Aquifer**	**Sample Date**	**Na^+ mg/L**	**K^+ mg/L**	**Ca^{2+} mg/L**	**Mg^{2+} mg/L**	**Cl^- mg/L**	**Alka as $CaCO_3$ mg/L**	**SO_4^{2-} mg/L**	**F- mg/L**	**TDS mg/L**	**Specific Conduct. umhos/cm**	**Temp ^{o} C**	**pH s.u.**
BICY-PT2	455-532	IAS	12/12/97	1,100	49	120.0	150	1,850	150	500	0.96	4,000	6,428	25.45	7.46
BICY-PT3	1195-1295	MCU	12/18/97	2,200	99	170.0	260	3,600	170	730	0.93	7,000	11,828	26.71	7.46
BICY-PT5	1790-1910	MCU	02/02/98	11,000	470	660.0	1,100	19,000	130	2,400	0.16	33,000	50,941	28.32	7.13
BICY-PT4	2260-2505	LFA	01/29/98	12,000	490	670.0	1,200	20,000	130	2,500	2.00	34,000	51,767	26.74	7.28

mg/L = milligrams per liter
umhos/cm = microumhos per centimeter
^{o} C = degree Celisus
s.u = standard unit
ft. bls = feet below land surface
PT = Packer Test
IAS = intermediate aquifer system
UFA = upper Floridan aquifer
MCU = middle confining unit
LFA = lower Floridan aquifer

Table 4. Summary of Water Quality Data from Packer Tests.

The Hazen-Williams equation was used to calculate the friction (head) losses for all drawdown data because of induced flow up the drill pipe. These head losses were then used to correct the drawdown data for specific capacity determinations. Curve-matching techniques were not used to determine transmissivity values from the drawdown or recovery data. These tests generally involve partial penetration, have significant friction loss due to small pipe diameter, and have short pumping periods, which violate the various analytical method's basic assumptions.

Packer Test No. 1 (1,402 to 1,525 feet bls):

The purpose of this packer test was to obtain water samples for analyses and to determine the confining nature of the interval. The main intent of this packer test was to gather pertinent hydraulic information before setting casing through this interval. DDC conducted this test on December 8, 1997, which consisted of pumping an interval between 1,402 and 1,525 feet bls (part of the Ocala Limestone).

During this test, DDC pumped this interval for 5 hours at 1.5 gallons per minute (gpm), which produced a sustained drawdown of 154.9 feet. The results of the drawdown test indicated extremely poor yield, with a specific capacity of 0.01 gpm/ft of drawdown. The specific capacity (SC) was calculated using the following method:

SC = Q / Drawdown *(Equation 4)*

1.5 gpm/ (155 feet) = 0.01 gpm/ft of drawdown

Q = pumping rate in gpm as measured by an in-line flowmeter

Drawdown = aquifer head loss in feet: measured drawdown minus negligible pipe friction losses

SFWMD determined the static water level at the end of the recovery phase at 34.2 feet above sea level based on a surveyed land surface reference elevation of 4.4 feet NGVD, 1929. No water quality samples were taken because of very low pump rate, which was insufficient to meet sampling protocol (requires a minimum of three pipe volumes), therefore, it is not reflected on **Table 4**.

Packer Test No. 2 (455 to 532 feet bls):

The purpose of this packer test was to determine the hydraulic properties and water quality characteristics of a productive interval within the middle part of the IAS. DDC set a dual packer assembly to isolate an interval between 455 and 532 feet bls. SFWMD conducted and successfully completed a drawdown/recovery test on December 12, 1997.

During the drawdown phase, DDC pumped this interval for approximately 130 minutes at an average rate of 210 gpm, which produced a maximum drawdown of 32.5 feet. The results of the drawdown test indicate moderate to good productivity, with a specific capacity (SC) of 36.2 gpm/ft-drawdown calculated using the following method:

SC	=	Q / Drawdown 210 gpm/ (32.5 ft – 26.7 ft) = 36.2 gpm/ft-drawdown
Q	=	pumping rate in gpm as measured by an in-line flowmeter
Drawdown	=	aquifer head loss in feet: measured drawdown minus the pipe friction losses (5.00 feet per 100 feet of pipe for a 3.5-inch inside diameter pipe with a flow rate of 210 gpm). The pipe extended to 532 feet bls which resulted in a pipe frictional loss of 26.7 feet. (Friction loss coefficient determined from Appendix 17.A. Ground Water and Wells, 1989).

SFWMD calculated the static water level at the end of the recovery phase at 36.10 feet above sea level using a surveyed land surface reference elevation of 4.40 feet (NGVD, 1929).

Packer Test No. 3 (1,195 to 1,295 feet bls):

The purpose of this packer test was to evaluate the hydraulic and water quality characteristics of middle Floridan confining unit at this site. DDC set a dual packer assembly, which isolated an interval between 1,195 and 1,295 feet bls. SFWMD conducted and successfully completed a drawdown/recovery test at this depth on December 18-19, 1997.

During the drawdown phase, DDC pumped the interval for 135 minutes at 110 gpm that produced a recorded average drawdown of 44.7 feet. The results of the drawdown test indicate low productivity, with a specific capacity of 3.6 gpm/ft-drawdown calculated using the following method:

SC	=	Q / Drawdown 110 gpm/ (44.7 ft – 14.1 ft) = 3.6 gpm/ft-drawdown
Q	=	pumping rate in gpm as measured by an in-line flowmeter
Drawdown	=	aquifer head loss in feet: measured drawdown minus the pipe friction losses (1.18 feet per 100 feet of pipe for a 3.5-inch inside diameter pipe with a flow rate of 110 gpm). The pipe extended to 1,295 feet bls which resulted in a pipe frictional loss of 5.4 feet. (Friction loss coefficient determined from Appendix 17.A. Ground Water and Wells, 1989).

SFWMD determine the static water level at the end of the recovery phase at 37.08 feet above sea level using a surveyed land surface reference elevation of 4.40 feet (NGVD, 1929).

Packer Test No. 4 (2,260 to 2,505 feet bls):

The purpose of this packer test was to evaluate the hydraulic and water quality characteristics of the lower Floridan aquifer at this site. DDC set a single packer at 2,260 feet bls, which isolated an interval between 2,260 and 2,505 feet bls. SFWMD conducted and successfully completed a drawdown/recovery test at this depth on January 29-30, 1998

During the drawdown phase, DDC pumped the interval for 331 minutes at 62 gpm that produced a recorded drawdown of 75.1 feet. The results of the drawdown test indicate low productivity, with a specific capacity of 1.0 gpm/ft of drawdown calculated using the following method:

SC	=	Q / Drawdown 62 gpm/ (75.1ft – 11.3 ft) = 1.0 gpm/ft of drawdown
Q	=	pumping rate in gpm as measured by an in-line flowmeter
Drawdown	=	aquifer head loss in feet: measured drawdown minus the pipe friction losses (0.5 feet per 100 feet of pipe for a 3.5-inch inside diameter pipe with a flow rate of 62 gpm). The pipe extended to 2,260 feet bls, which resulted in a pipe frictional loss of 11.3 feet. (Friction loss coefficient determined from Appendix 17.A. Ground Water and Wells, 1989)

SFWMD determined the static water level at the end of the recovery phase at 9.28 feet above sea level using a surveyed land surface reference elevation of 4.40 feet (NGVD, 1929).

Packer Test No. 5 (1,790 to 1,910 feet bls):

The purpose of this packer test was to evaluate the hydraulic and water quality characteristics of lower portion of middle confining unit at this site. DDC set a dual packer assembly, which isolated an interval between 1,790 and 1,910 feet bls. SFWMD conducted and successfully completed a drawdown/recovery test at this depth on February 2-3, 1998,

During the drawdown phase, DDC pumped the interval for 121 minutes at 90 gpm that produced a recorded drawdown of 49.7 feet. The results of the drawdown test indicate low productivity, with a specific capacity of 3.0 gpm/ft of drawdown calculated using the following method:

SC	=	Q / Drawdown 90 gpm/ (49.7ft – 20.1 ft) = 3.0 gpm/ft of drawdown
Q	=	pumping rate in gpm as measured by an in-line flowmeter,
Drawdown	=	aquifer head loss in feet: measured drawdown minus the pipe friction losses (0.96 feet per 100 feet of pipe for a 3.5-inch inside diameter pipe with a flow rate of 90 gpm. The pipe extended to 1,910 feet bls, which resulted in a pipe frictional loss of 20.1 feet. (Friction loss coefficient determined from Appendix 17.A. Ground Water and Wells, 1989).

SFWMD determined the static water level at the end of the recovery phase at 17.59 feet above sea level using a surveyed land surface reference elevation of 4.40 feet (NGVD, 1929).

Inorganic Chemistry

The water samples for packer tests and completed monitor zones were analyzed by SFWMD water quality laboratory for major cations and anions using EPA and/or Standard Method Procedures (SFWMD, Comprehensive Quality Assurance Plan, 1995). The Piper trilinear diagram **(Figure 8)** indicated that sodium and chloride are the dominant ions and that the concentrations of dissolved constituents increase with depth. Below a depth of 1,400 feet, the dissolved constituents are similar in concentration to seawater. The inorganic data suggest sea water as a dominant source but stable isotope and noble gas data provided additional information on the recharge sources to the middle part of IAS and upper, middle and lower segments of the FAS as discussed below.

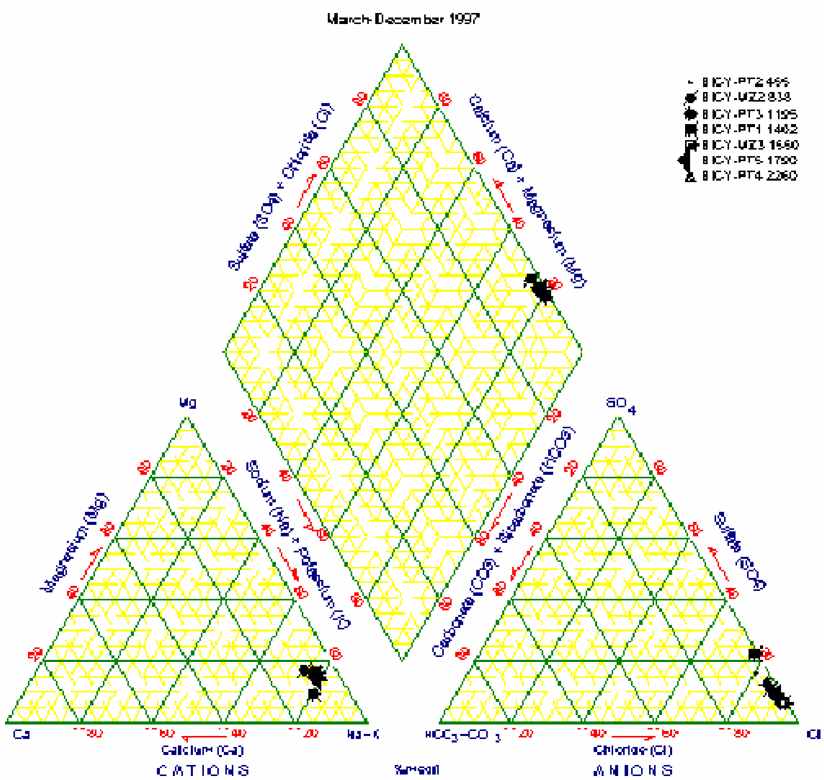


Figure 8. Piper Trilinear Diagram of Inorganic Constituents of the Floridan Aquifer System.

Stable Isotope, Radiocarbon, and Noble Gases

Stable isotope data complements inorganic geochemistry and physical hydrogeology investigations. SFWMD plans to use the isotopic data collected at this site in a regional investigation to better understand the ground water circulation patterns of the Floridan aquifer system (Kohout, 1965, 1967) and to identify recharge and discharge areas.

Geochemical data can be used to estimate ground water ages and help to discern circulation patterns within a hydrologic system. A multi-tracer approach using inorganic, stable isotopes, radiocarbon, and noble gases can be successfully applied in unraveling complicated hydrologic systems with travel time of thousands of years (Bottomley et al., 1984; Clark et al., 1997 and

1998; Stute et al., 1995). The chemical composition of ground water reflects both the source(s) of water and process(es) that modify the inorganic and isotopic compositions; each source and process leaves a distinctive geochemical "signature" on the water. If water from an interval produces a particular isotopic signature, it can be used to identify and map the lateral extent of aquifer storage and recovery (ASR) and reverse osmosis (RO) horizons within the Floridan aquifer. Radiocarbon often complements the stable isotope data and is used to estimate regional flow velocities (Hanshaw et al., 1964). Noble gas paleo-thermometry has become an acceptable method for determining continental temperatures of past climates archived in the ground water systems based on the temperature dependence of the solubility of noble gases in water. This method can help to determine the paleo-temperatures of water entering the Floridan aquifer (Stute et al., 1995 and Clark et al., 1997) thus providing constraints to the determined radiocarbon ages.

Stable Isotopes

SFWMD collected water samples during packer tests and from completed monitor intervals from well BICY-TW and sent them to the Environmental Isotope Laboratory (EIL) at the University of Waterloo for stable isotope determinations. The analytical services included the determination of the stable isotope compositions for the following parameters: ^{18}Oxygen ($\delta^{18}O$), deuterium (δD), ^{13}Carbon ($\delta^{13}C$), and ^{34}Sulfer ($\delta^{34}S$).

$\delta^{18}O$ values were determined by CO_2 equilibration using standard procedures outlined by Epstein and Mayeda (1953), and Drimmie and Heemskerk (1993). Hydrogen isotope compositions were determined using the methods of Coleman et al., (1982) and Drimmie et al., (1991). The results are presented as per mil (‰) derivations from a water standard using the δ-notation (delta):

$$\delta_{x} = \delta_{x-\text{std}} = \left(\frac{Rx}{R_{S\tan dard}} - 1 \right) \text{x } 1000 \qquad \textit{(Equation 5)}$$

Where:

Rx = the isotope ratio of the sample (e.g., $^{2}H/^{1}H$)

$R_{Standard}$ = the isotopic standard.

The standard related to deuterium and ^{18}O is Standard Mean Ocean Water (SMOW). The reproducibility for $\delta^{18}O$ and δD were ± 0.05‰ and ±0.5‰, respectively.

The reporting of the sulfur ratios in natural water is as follows:

$$\delta^{34}\text{ S (CDT)} = \left(\frac{{}^{34}C/{}^{32}C_{sample}}{{}^{34}C/{}^{32}C_{s\tan dard}} - 1 \right) \text{x } 1000 \qquad \textit{(Equation 6)}$$

Where:

Sample = ^{34}S /^{32}S ratio

Standard = sulfur isotope ratio of reduced sulfur (FeS; Troilite) in the Canyon Diablo Meteorite (CDT).

Water samples received by EIL for $\delta^{13}C$ determinations are acidified under vacuum with phosphoric acid. The released CO_2 produced from dissolved inorganic carbon (DIC) in the sample is then purified using cold distillation and analyzed by a mass spectrometry (Drimmie et al., 1990). These results are then compared to a carbon standard. The carbon standard is the isotope ratio derived from CO_2 liberated from beleminites of the Cretaceous-aged Pee Dee Formation (PDB) of South Carolina. The results are presented as per mil (‰) derivations with respect to the standard using the δ-notation (delta):

$$\delta^{13}\text{C (‰, PDB)} = \left(\frac{{}^{13}C/{}^{12}C_{sample}}{{}^{13}C/{}^{12}C_{s\tan dard}} - 1 \right) \text{x } 1000 \qquad \textit{(Equation 7)}$$

Radiocarbon

An accelerator mass spectrometer (AMS) at the Rafter Radiocarbon Laboratory (Institute of Geological and Nuclear Sciences, New Zealand) was used to determine radiocarbon age, delta ^{14}C, and percent modern carbon (pmC). The ^{14}C activities or pmC values are absolute percent of modern carbon, relative to the National Bureau of Standards (NBS) oxalic acid standard (HOxI) corrected for decay since 1950. The activity of "modern carbon" is 95 % of the ^{14}C in the 1950 NBS oxalic acid standard, which is close to the activity of 1890 wood produced in a fossil-fuel free environment (Clark and Fritz, 1997). Del ^{14}C is the relative difference between the absolute standard activity and the sample activity.

$$\text{Del } {}^{14}\text{C} = (A_s/A_{abs} - 1) \text{ x } 1000 \qquad \textit{(Equation 8)}$$

Where:

$A_{s\,=}$ activity of the sample

$A_{abs\,=}$ activity of the standard.

The modern activity of ^{14}C is set as 13.56 decays-per-minute per gram of carbon. The "zero year" for this activity is 1950 AD (pre thermonuclear testing) with an activity of 100 pmC. The conventional radiocarbon age (^{14}C Age) is determined in the following manner:

$$T = -8033 \ln (A_{sn}/A_{on}) \qquad \textit{(Equation 9)}$$

Where:

A_{sn} = normalized sample activity
A_{on} = normalized oxalic acid activity (count rate).
T = calculated time that elapsed represented by the difference in activities between the standard and sample.

Time (T) however is not the actual date of recharge because ^{14}C is either removed or added as the water moves through the system. In order to calculate time since recharge, equation 9 is modified to:

$$t = -8267 \ln (A_t/A_o) \qquad \textit{(Equation 10)}$$

Where:

t = the time since recharge,
A_t = the current ^{14}C activity of the sample
A_o = the initial ^{14}C activity.

Calculating time since recharge requires the current ^{14}C activity of the sample, which is measured, and the initial activity (A_o), which must be estimated.

Radiocarbon ages are reported in years before present (1950) and ^{14}C activities are reported as pmC with reproducibility of ± 1 pmC. Fontes and Garnier (1981) developed a correction model that considers soil processes, carbonate dissolution, and cation exchange. Equation 11 presents the Fontes-Garnier correction equation.

$$A_o = [(A_g - A_c)(\delta_T - \delta_c)/ (\delta_g - \delta_c)] + A_c \qquad \textit{(Equation 11)}$$

Where:

(A) represents ^{14}C activity,
(δ) represents $\delta^{13}C$ stable isotope ratio,
(g) stands for soil gas,
(c) stands for solid carbonate,
(T) stands for total dissolved inorganic carbon.

Table 5 summarizes the stable isotope and radiocarbon results for the BICY site.

Identifier	Aquifer	Sample Interval ft. bls	Sample Date	δ 18 O ‰ SMOW	δ2H ‰ SMOW	δ 37Cl ‰ SMOC	δ 13C ‰ PDB	δ 34S ‰ CDT	δ 14C ‰	14C pmC	Uncorrected 14C Yr. B.P	Corrected 14 C Yr. B.P
BICY PT-2	IAS	460-550	12/15/97	-1.54	-10.71	-0.01	-2.35	22.50	-990.4	0.92	37,650	25,119
BICY MZ-1	IAS	455-540	05/27/98	-1.52	-7.13	0.08	-3.40	21.50	-978.7	1.93	31,670	17,002
BICY MZ-2	UFA	838-996	05/27/98	-1.31	-8.65	-0.06	-2.70	23.20	-990.9	0.91	37,730	26,149
BICY PT-3	MCU	1195-1295	12/18/97	-1.20	-4.55	-0.26	-2.10	21.45	-995.2	0.45	43,310	30,285
BICY MZ-3	MCU	1550-1785	05/27/98	0.25	-0.16	0.21	-1.10	20.64	-995.5	0.45	43,340	30,475
BICY PT-5	MCU	1790-1910	02/02/98	0.68	1.22	0.05	-1.47	20.30	-996.8	0.31	46,500	9,330
BICY PT-4	LFA	2260-2500	01/29/98	0.74	1.06	-0.13	-2.03	20.30	-996.3	0.35	45,400	7,400
BICY MZ-4	LFA	2260-2500	01/28/99	0.71	1.17	ND	0.34	20.28	-998.1	0.18	46,100	8,460

ft. bls - feet below land surface
‰ - per mil
SMOW - Standard Mean Ocean Water Standard
SMOC - Standard Mean Ocean Chloride Standard
δ = delta
* 14C Dates were corrected using Pearson & Hanshaw Method, 13 C Correction for Closed System
PDB - Pee Dee Belemnitella Standard
CDT- Canyon Diablo Meteorite Standard
pmC - percent modern Carbon
Yr. B.P. - Years Before Present -1950
MZ = Monitor Zone
PT = Packer Test
IAS = intermediate aquifer system
UFA = upper Floridan aquifer
MCU = middle confining unit
LFA = lower Floridan aquifer

Table 5. Summary of Stable Isotope and ^{14}Carbon Results.

Noble Gases

Noble gas samples were collected from the IAS and upper and lower portion of the FAS at the BICY site on October 26, 2000. These samples were collected in 15 ml copper tubes connected to a peristaltic pump and regulator, which reduced aeration of the sample. Once the copper tubing was flushed with formation water at high pressure, it was sealed at each end with steel pinch-off clamps. The samples were sent to the Lamont-Doherty Observatory of Columbia University and noble gas concentrations including Helium (He), Neon (Ne), Argon (Ar), Krypton (Kr), and Xenon (Xe) were determined on a MAP 215-50 noble gas mass spectrometer using the method outlined by Stute et al., 1995. The system was calibrated using known quantities of air and water standards. Absolute noble gas concentrations were determined with a precision of +/- 1% for Ar and Xe and +/- 2% for He, Ne and Kr.

As water recharges and flows down gradient within the aquifer, there is no longer exchange with other fluid phases and the heavier noble gas concentrations remain unchanged, making them suitable for paleoclimate studies. Helium concentrations in ground water however change due to radioactive decay of uranium/thorium nuclides within the aquifer (Bottomley et al., 1984; Torgersen and Ivey, 1985) Helium concentrations increase with time and vary between aquifers making it a useful tool as an approximate chronometer (Clark, 2002). **Table 6** contains the noble gas data and calculated paleo-temperatures of the ground water samples.

Identifier	Aquifer	Sample Interval ft. bls	Sample Date	Helium (cc stp/g)	Neon (cc stp/g)	Argon (cc stp/g)	Krypton (cc stp/g)	Xeon (cc stp/g)	Temp 0 C
BICY MZ-1	IAS	460-536	10/26/00	2.97E-07	2.20E-07	3.39E-04	7.31E-08	9.77E-09	19.2
BICY MZ-2	UFA	838-996	10/26/00	2.77E-07	2.54E-07	3.73E-04	7.31E-08	1.02E-08	18.0
BICY MZ-4	LFA	2260-2505	10/26/00	1.56E-07	1.82E-07	3.18E-04	7.36E-08	1.05E-08	8.7

ft. bls - feet below land surface
cc stp/g =
0 C - degree Celisus
MZ = Monitor Zone
IAS = intermediate aquifer system
UFA = upper Floridan aquifer
LFA = lower Floridan aquifer

Table 6. Summary of Noble Gas Results and Calculated Paleo-Temperatures.

Discussion

Precipitation or meteoric water contains very little dissolved constituents and the oxygen and hydrogen isotope composition of world-wide rainfall fall along a documented line called the Global Meteoric Water Line (GMWL, Craig, 1961). The stable isotope results from BICY-TW indicate that waters in the upper Floridan aquifer are depleted in both ^{18}O and D compared to Standard Mean Ocean Water (SMOW), where $\delta^{18}O = 0\ ^0/_{00}$ and $\delta D = 0\ ^0/_{00}$. **Figure 9** shows that the isotopic composition of upper Floridan aquifer deviates slightly from the GMWL and mean isotopic composition of recent Everglades rainfall ($\delta^{18}O = -2.2^0/_{00}$; $\delta D = -7.6\ ^0/_{00}$, Meyers et. al., 1993). Stable isotope results from other locations in south Florida (Meyer, 1989, Bennett, 2001a, and 2001b, 2002) produce similar results whereby waters within the upper Floridan aquifer are depleted and plot near the GMWL. The occurrence of $\delta^{18}O$ and δD values near the GWML suggest that these waters are likely meteoric in origin modified by evaporation prior to infiltration.

The ^{14}C activity in pmC of ground water samples from the mid-Hawthorn aquifer, part of the intermediate aquifer system (BICY MZ-1; 460 to 536 feet bls), and upper Floridan aquifer (BICY MZ-2; 838 to 996 feet bls) produced values of 1.93 and 0.91, respectively. The uncorrected radiocarbon ages of these waters were reported as 31,670 and 37,730 years before present (bp), respectively. In order to be meaningful, the reported radiocarbon ages were corrected using the Fontes and Granier method *(Equation 11),* which accounts for carbonate dissolution and CO_2 gas in the soil (open system). The corrected radiocarbon ages from these two monitor intervals are 17,002 and 26,149 years bp, respectively.

The corrected radiocarbon ages suggest that recharge to the hydrologic system from 460 to 996 feet in depth occurred during the late Pleistocene epoch. The noble gas data supports this assertion. Noble gas temperatures from the middle portion of the intermediate aquifer system (BICY MZ-1) and upper Floridan aquifer (BICY MZ-2) averaged 18.7° C, about 5° C cooler than the present-day south Florida mean annual air temperature of 23.6° C. The reported noble gas temperature suggests that freshwater recharge occurred during the cooler glacial period from 15,000 to 25,000 years bp (Clark, 2002).

The lower Floridan aquifer waters at the BICY site are enriched in both ^{18}O and D and plot near but to the right of the ocean water standard SMOW **(Figure 9)** suggesting a marine source. The stable isotope data from lower Floridan aquifer samples are similar to seawater samples collected in the Strait of Florida (off the coast of Ft. Pierce – 27° 0.445N, 79° 26.789W) at depths greater than 1,700 feet (Clark, 2002). In addition, the $\delta^{18}O$ data from the LFA is different from glacial ocean water where the isotopic composition of glacial ocean water was significantly different than SMOW, $\delta^{18}O$ was 1 $^0/_{00}$ heavier than present (Schrag et al., 1996 and Mashisotta et al., 1999), suggesting seawater probably entered the LFA at the end of the last glacial period (less than 10,000 years bp).

The ^{14}C activities of ground water samples from the lower Floridan aquifer (BICY MZ-4; 2,260 to 2,505 feet bls) generated values of 0.18 pmC. The uncorrected radiocarbon age for this interval was approximately 46,100 years bp age, corrected to 8,460 years bp using the Fontes-Granier method. Noble gas temperatures from the lower Floridan aquifer (BICY MZ-4) was 8.7° C, about 10° C cooler than waters in the upper Floridan aquifer and 14.9° C cooler than the present-day mean annual air temperature of south Florida. The stable isotope, noble gas and radiocarbon data suggest that seawater entered the lower Floridan aquifer near the end of the last glacial period and have been circulating for about 10,000 years.

The isotopic composition, radiocarbon dates, and noble gas temperatures indicate that the ground water in the upper and lower Floridan aquifers are distinct. In addition, the data suggest that within this hydrologic system relatively old meteoric water circulates over relatively younger seawater. Similar data has been reported from other locations in south Florida that suggests that two different water masses may be present in the Floridan aquifer system (Meyer, 1989; Kaufmann and Bennett, 1997; Bennett, 2001a, 2001b, and 2002; Clark, 2002). The upper Floridan waters appear to be meteoric in origin with recharge having occurred during the last glacial period between 15,000 and 30,000 years ago when sea levels were approximately 300 feet lower than present (Milliman and Emery, 1968; Fairbanks 1989). The lower Floridan waters appear to be younger intruded seawater that may have entered somewhere along the Florida Straits. That water moved inland through the "Boulder Zone" (or other highly permeable rock units of the lower Floridan) to its present position some 10,000 years bp as sea levels began to rise during the Holocene epoch.

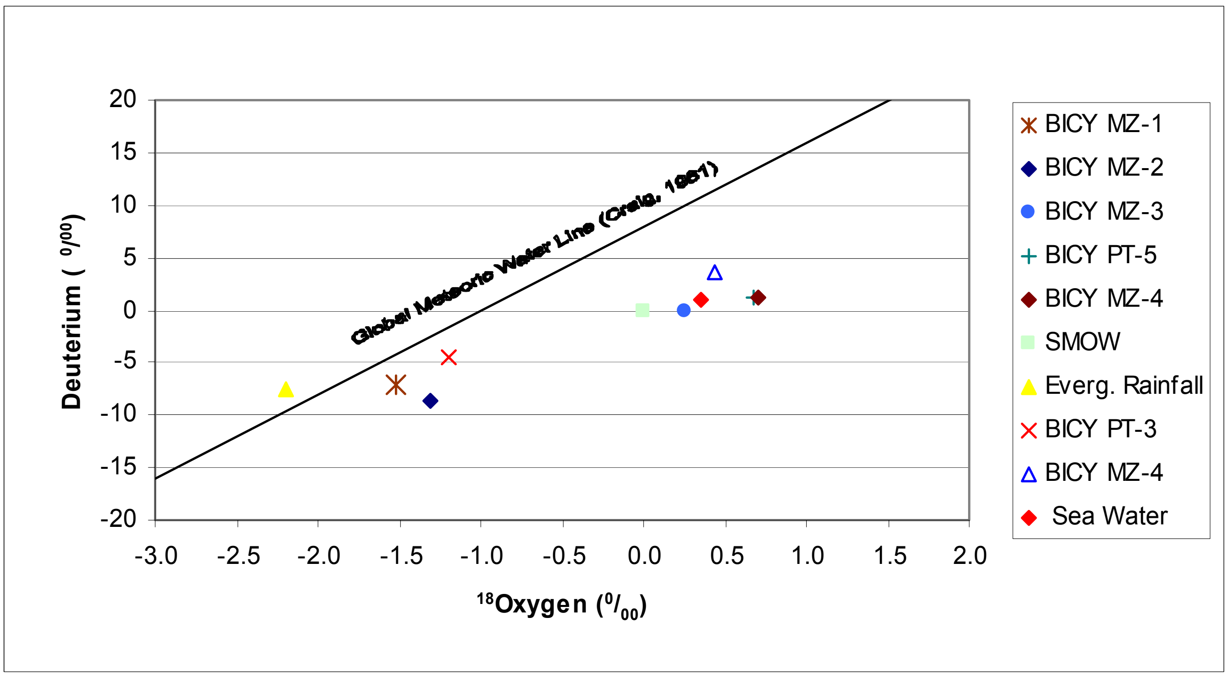


Figure 9. Cross-Plot of Deuterium and ^{18}Oxygen – Stable Isotopes.

Petrophysical and Petrologic Data

Upon completion of the formation evaluation logs, SFWMD identified 22 core points from 460 to 1,500 feet bls in the open-hole section of BICY-TW. The purpose of these cores was to constrain log-derived porosity and permeability values from a carbonate aquifer with laboratory determined values. WALS operated their down-hole rotary sidewall tool (RCOR^{SM}) and cored at the 22 depth-specific points. WALS however retrieved only 4 out of 22 core plugs (18% recovery efficiency). Low core recovery may be the result of an inexperienced operator, unfamiliar subsurface conditions, or the friable nature of the carbonate section due to its high intergranular porosity and mixed lithology (i.e., carbonate and siliciclastics).

As a result of low core recovery of sidewall cores from BICY-TW not providing sufficient rock samples for laboratory testing, SFWMD instructed DDC to obtain full-diameter conventional cores during the drilling of the test-production well identified as BICY-PW. Per the technical specifications and as directed by SFWMD, DDC cored the entire production interval in the upper Floridan aquifer between 830 and 1,010 feet bls using a 4-inch diameter, 20-foot long, diamond-tipped core barrel. Core recoveries from the 11 core runs ranged between 0 and 80 percent with an average of only 20 percent. **Table 7** is a summary of the full-diameter coring program conducted at this site.

Core No.	Core Interval (feet bls)	Core Footage (feet)	Core Recovered (feet)	Percent Recovery
1	850-859	9	0.0	0.0
2	859-879	20	5.0	25.0
3	879-899	20	2.0	10.0
4	899-919	20	3.0	15.0
5	919-939	20	4.0	20.0
6	939-949	10	1.5	15.0
7	950-970	20	0.0	0.0
8	970-980	10	7.0	70.0
9	980-990	10	8.0	80.0
10	990-1000	10	2.0	20.0
11	1000-1010	10	0.0	0.0
Totals:		**159**	**32.5**	**20.4**

Table 7. Summary of Conventional Rock Coring Program.

SFWMD sent the core plugs and full-diameter cores to Core Laboratories (CL) located in Midland, Texas to determine the following parameters: horizontal permeability, porosity, grain density, and lithologic character. Initially, CL recorded a spectral gamma log on each core for downhole correlation. SFWMD identified various intervals from the total core footage for detailed analyses. CL then cleaned and dried the selected core samples using a convection oven to remove any residual fluid.

CL used Boyle's Law Helium Expansion Method to determine full diameter porosity values. Once the samples were cleaned and dried, they determined bulk volume by Archimedes Principle with grain density calculated from the dry weight, bulk volume and pore volume measurements using Equation No. 12 (American Petroleum Institute, 1998).

Grain Density = Dry Weight / (Bulk Volume – Pore Volume) *(Equation 12)*

Porosity as a percent was calculated using bulk volume and grain volume measurements using Equation No. 13.

Porosity = ((Bulk Volume – Grain Volume)/ Bulk Volume) x 100 *(Equation 13)*

CL measured direct grain volume on the 1-inch diameter plugs also using Boyle's Law Helium Expansion Method. After cleaning, they measured bulk volume on the individual plug samples by Archimedes Principle with porosity calculated using the bulk volume and grain volume data in Equation No. 13.

Steady-state air permeability was measured on the full diameter core samples in two horizontal directions and vertically while confined in a Hassler rubber sleeve at a net confining stress of 400 psi.

Upon completion of petrophysical testing, CL slabbed and boxed the rock cores, photographed them under natural and ultraviolet light then scanned the negatives of the core photographs and stored the digital images on a compact disc. These photographs are reproduced in Figures 1 to 6 listed in **Appendix D**. **Appendix D, Table 1** lists the results of the petrophysical analyses. **Figure 10** shows a semi-log cross-plot of laboratory derived horizontal permeability versus (helium) porosity. The equation of the fitted linear regression model, which describes the relationship between the $\log_{10}$ transformed horizontal permeability (y) and porosity (x) is $\log_{10}(y) = 0.1451(x) – 2.6926$. The correlation coefficient equals 0.76 (a value of 1.0 suggests a strong positive relationship), indicating a moderately strong relationship between the two variables.

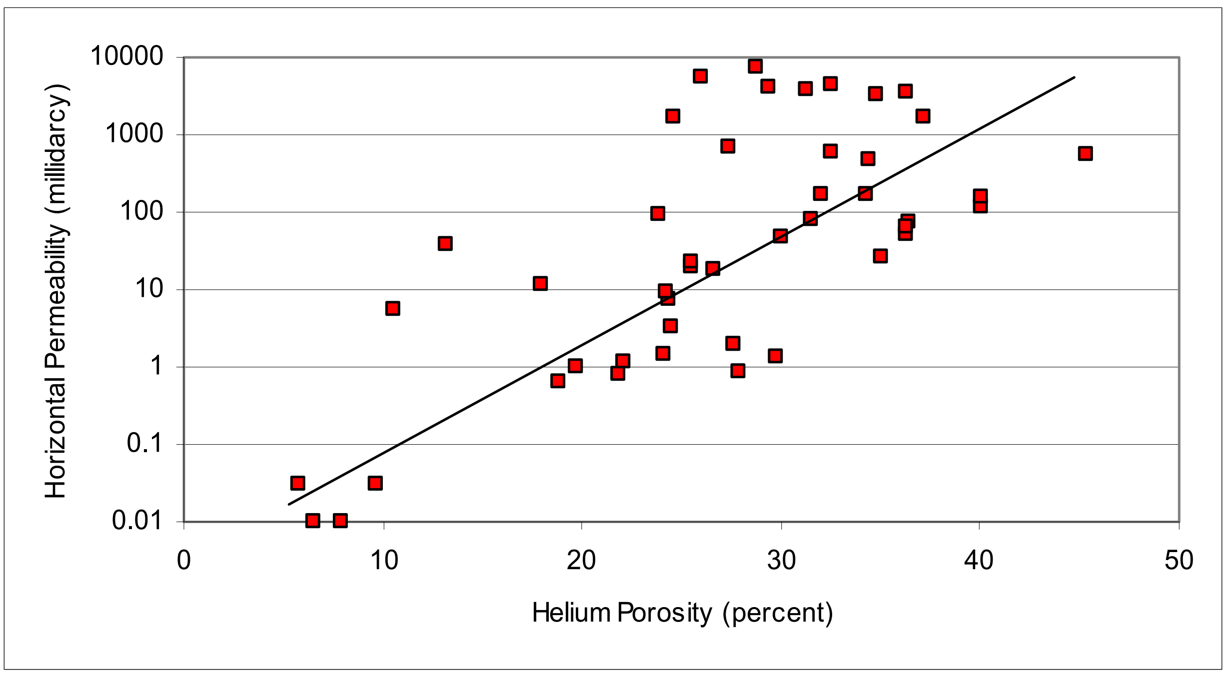


Figure 10. Cross-Plot of Laboratory Derived Horizontal Permeability and Porosity.

After CL measured the specified petrophysical attributes, Dr. Hughbert Collier of Collier Consulting, Inc (CCI) conducted a petrologic study to provide preliminary data on the gross reservoir heterogeneity and depositional environmental (facies) controls on porosity and permeability development within the FAS. As part of this study, Dr. Collier examined and described the slabbed cores in detail. He selected intervals from which to prepare thin-sections and stained the thin-sections with Alizarin Red S to determine dolomite content. Dr. Collier then examined the thin sections using both a Nikon SMZ-2T binocular microscope and Nikon petrographic microscope. Thin section analyses included the identification of porosity types, visual estimation of porosity, rock type, cement type, mineralogy, dominant allochems, fossil types, grain size, sorting, and sand content. Once compiled, this information was used to determine the lithofacies and depositional environment of the various core intervals. **Appendix D**, **Table 4** is a summary of the petrologic analysis generated by CCI. **Appendix E** contains individual photomicrographs of selected cores.

CCI conducted a detailed petrologic analysis of the cores obtained between 820 and 1,015 feet bls identifying 17 lithofacies associated with several trangressive-regressive sequences. **Table 7** shows the core interval recovered and percent recovered. The petrologic analyses combined with the petrophysical data indicate variations in horizontal permeability and porosity based on lithofacies and corresponding depositional environment. The highest mean horizontal permeability measurements of 11,069 and 4,707 md correspond to cored sections at approximately 900 and 985 feet bls, respectively. These two intervals consist of coral and pelecypod boundstones, likely deposited in an open shoal environment. Petrologic analyses of four other SFWMD-owned Floridan aquifer wells, two located in Hendry County (L2-TW and LAB-TW) and two others in Collier County (I75-TW and ISWD-TW) had similar results with the highest mean horizontal permeability occurring in packstone to boundstone units. These units were all thought to be deposited in an open shoal environment (Bennett, 2001a, 2001b, 2002, and 2003). The lowest horizontal permeability (0.02 md) corresponds to a molluscan-interclastic-wackestone at a depth of 855 feet bls. **Figure 11** shows the horizontal permeability distribution and variation through the upper Floridan production horizon at this site. **Appendix E** contains a detailed summary of the individual lithofacies and transgressive-regressive sequences identified by CCI between 820 and 1,015 feet in depth.

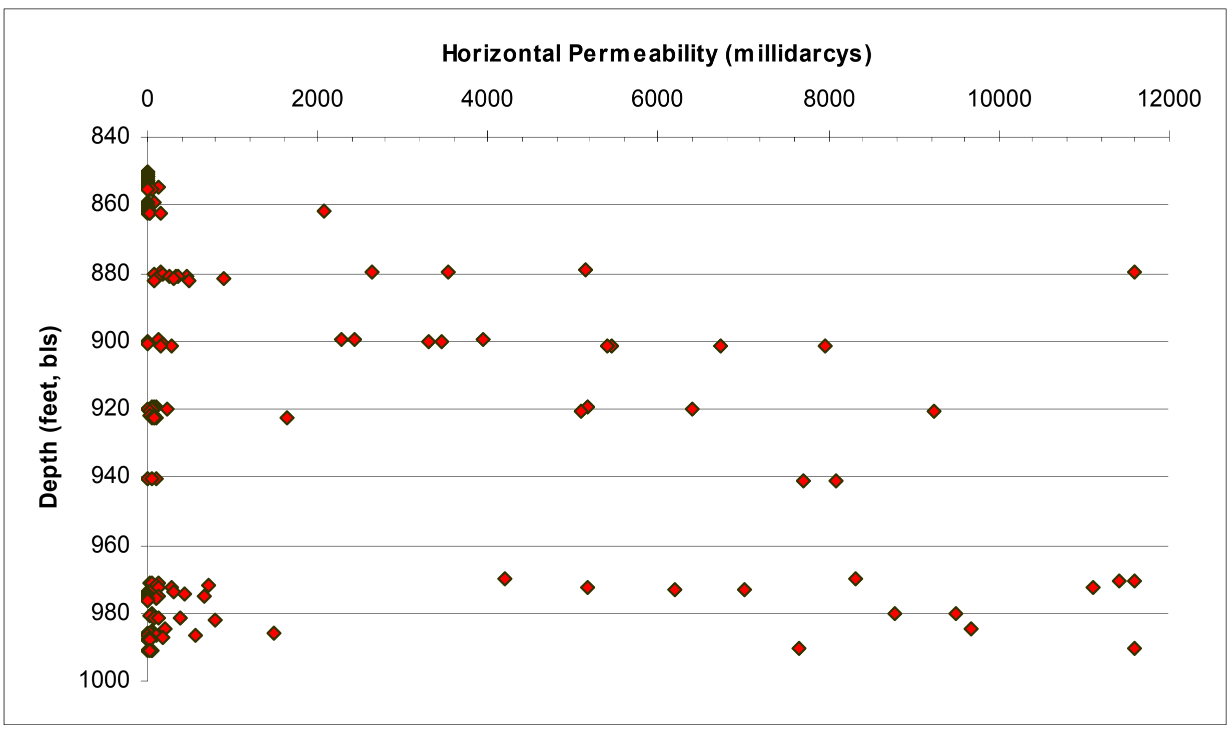


Figure 11. Laboratory Permeability Distribution of Upper Floridan Production Zone.

Once CCI completed the lithofacies analysis, 9 core samples were submitted to CL for Nuclear Magnetic Resonance (NMR) spectrometry to gain calibration data for effective interpretation of MRIL log-derived porosity and permeability values. These values were determined using a standard relaxation T_2 cutoff of 90 milliseconds (ms); however, the core data showed that several relaxation constant (T_2 cutoff) that ranged between 42 and 150 ms were determined for a 170 foot section of the upper Floridan aquifer. Future petrology work in conjunction with the magnetic susceptibility from these analyses will be used to study the difference in the relaxation groups and refine the NMR permeability model for carbonate units in the FAS. Pertinent information from the NMR calibration report submitted by CL is provided in **Appendix C. Figure 12** summarizes the hydrogeologic testing and data collection activities at the BICY site.

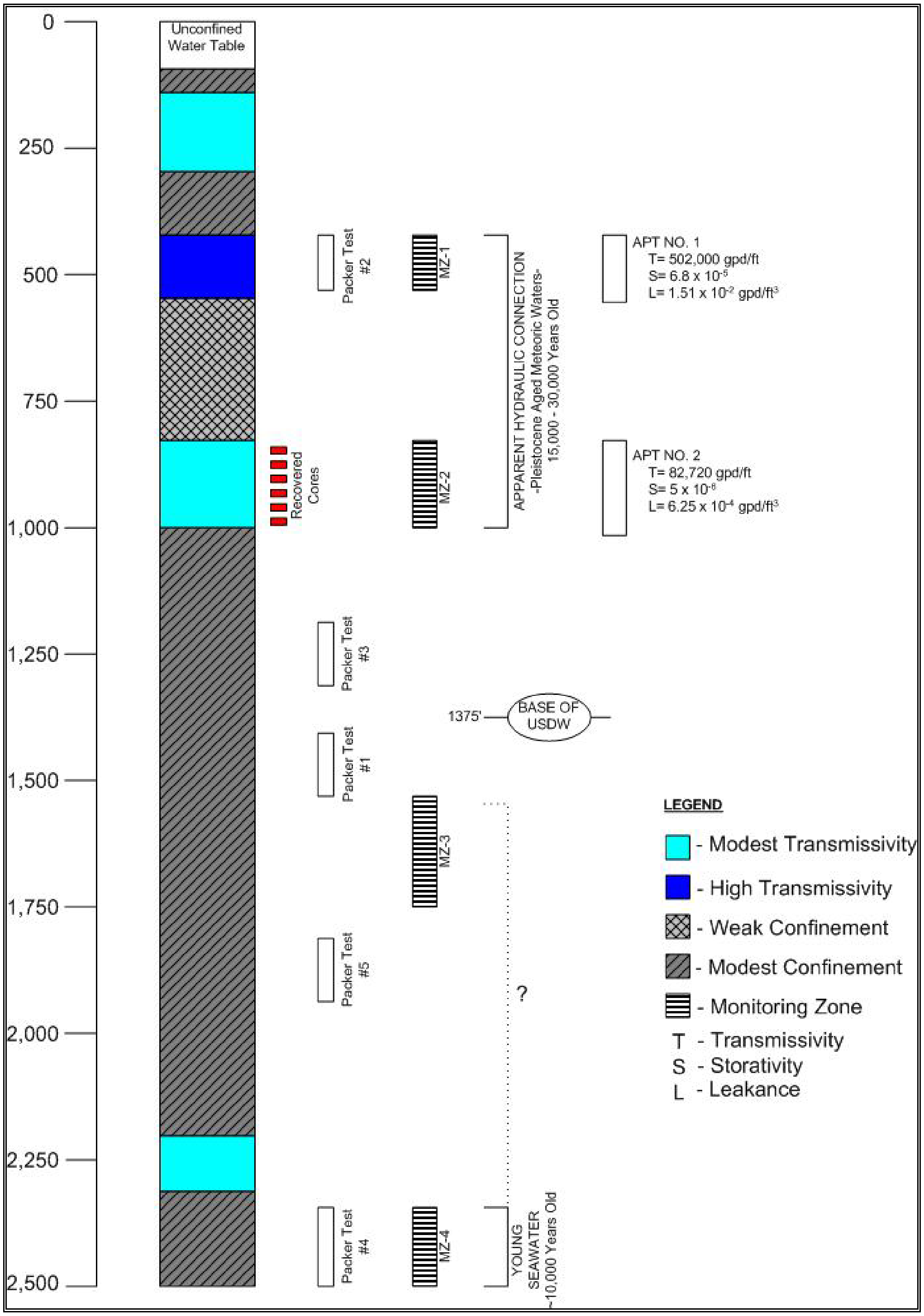


Figure 12. Hydrogeologic Testing – Data Summary Diagram.

Aquifer Performance Testing

Aquifer Performance Test No. 1

SFWMD conducted the first of two aquifer performance tests (APTs) to determine the hydraulic performance of the middle portion of the IAS from 465 to 550 feet bls within the lower Peace River and upper Arcadia Formations (mid-Hawthorn aquifer). The principle factors of aquifer performance, such as transmissivity and storage coefficients, can be calculated from the drawdown and/or recovery data obtained from the proximal monitor well completed in the same interval (BICY MZ-1). If the aquifer tested is semi-confined, the hydraulic parameter of leakance of the semi-pervious layer(s) can also be determined.

The drawdown phase consisted of allowing the test-production well (BICY-PW) to flow naturally at a sustained rate of 2,700 gallons per minute for 4 hours while recording water level changes in the proximal (located 330 feet north) quad-zone monitor well (BICY-TW). The drawdown phase was followed by a 14-hour recovery period, where natural flow was stopped and water levels were allowed to return to background condition. **Figure 13** shows configuration of the quad-zone monitor and test-production wells, identified as BICY-PW1, used in the first APT.

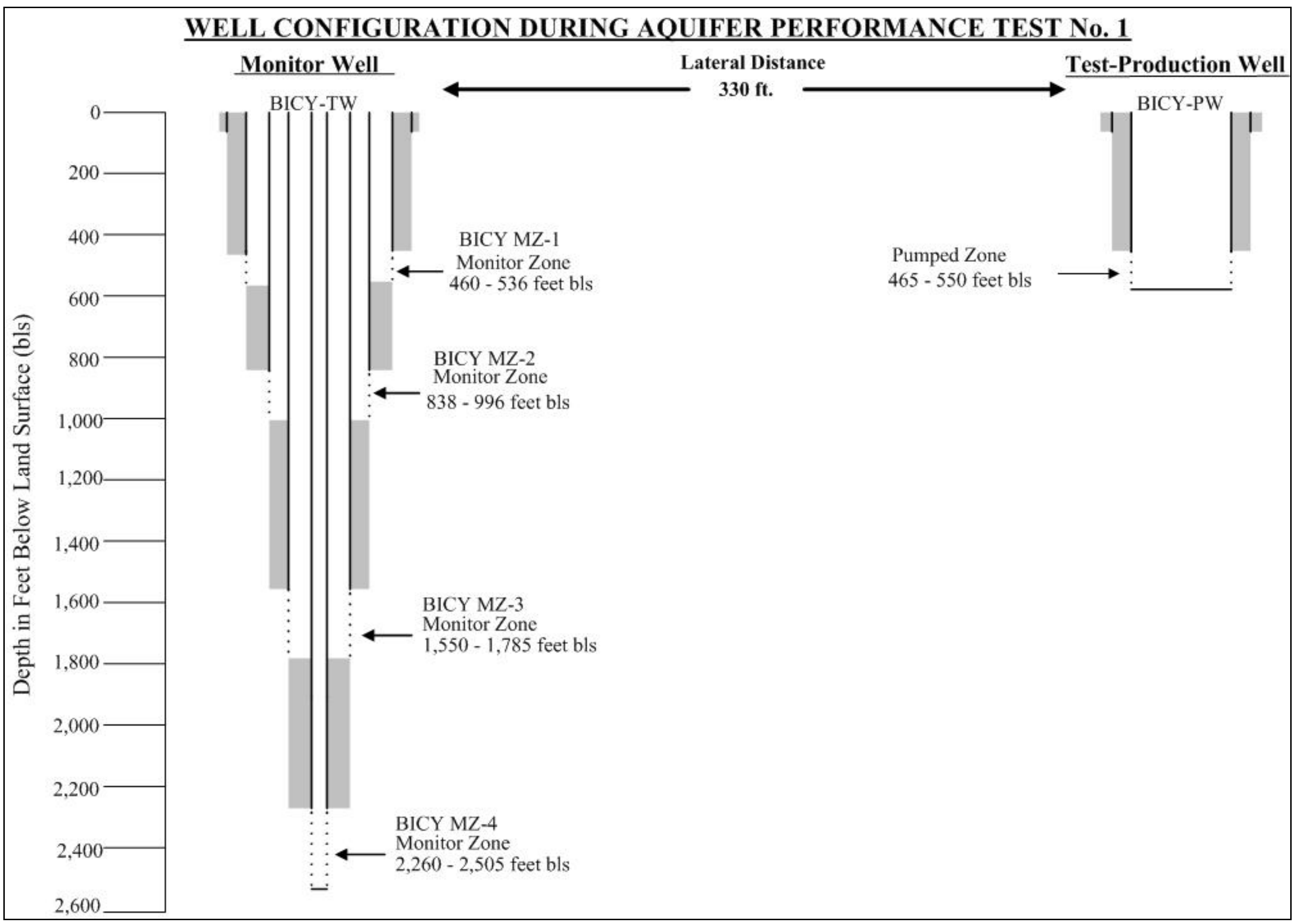


Figure 13. Aquifer Performance Test – Well Configuration APT No. 1.

The wellhead appurtenances consisted of a shut-off valve, discharge pressure gauge, and wellhead pressure transducer. A 16-inch diameter circular orifice weir with a 12-inch diameter orifice plate was used to measure discharge rates, verified by an in-line flowmeter. SFWMD personnel installed a pressure transducer on the orifice weir to record discharge rates during the pump test at 2-minute intervals. Additional pressure transducers were installed on/in both BICY-PW1 and monitor zones (BICY MZ-1 and BICY MZ-2) connected to a Hermit® 2000 (Insitu, Inc) data logger via electronic cables. The transducers and data logger were used to measure and record water-level changes at pre-determined intervals during testing operations.

On April 13, 1998, the drawdown phase of the APT started by allowing the test-production well to flow naturally at a rate 2,700 gpm. SFWMD maintained the installed electronic devices, which continuously measured and recorded water levels and flow rates during the drawdown phase. Maximum drawdown in BICY MZ-1 was 3.5 feet (1.5 psi).

Before the production well was shut-in, SFWMD reconfigured the various data loggers to record the recovery data. DDC manually closed the discharge port and water levels slowly recovered to static conditions. The recovery phase of the APT continued for 14 hours, ending on April 14, 1998. **Figure 14** is a semi-log plot of the drawdown and recovery data for the tested monitor zone (BICY MZ-1). Electronic copies of the original drawdown, recovery and orifice weir (flow rate) data for the APT are archived and available for review at the SFWMD's headquarters in West Palm Beach, Florida.

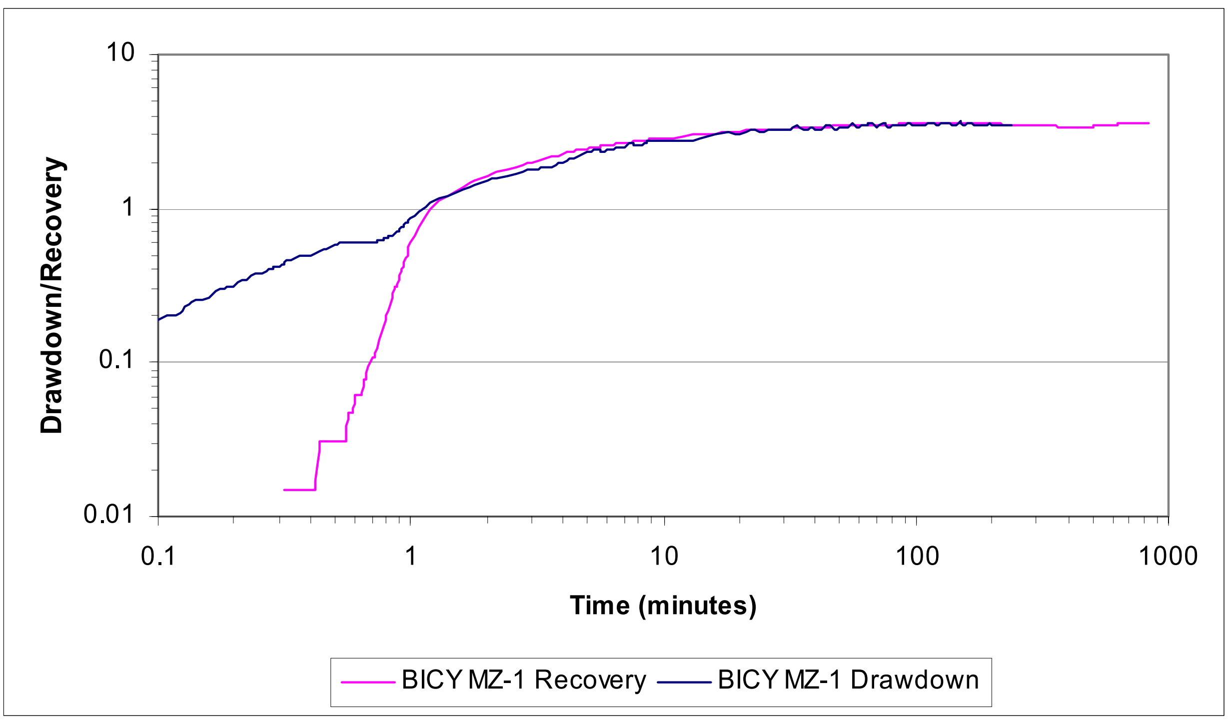


Figure 14. Time Series Plot of Drawdown and Recovery Data from BICY MZ-1, APT No. 1.

Figure 15 is a time-series plot of the drawdown data for the production well (BICY-PW1) and discharge rates (manometer readings) during the pumping phase of the APT No. 1. Maximum drawdown in BICY-PW1 was 28.6 feet (12.4 psi) with flow rates varying about 6 % during the test. Water-level changes during the drawdown phase for the lower monitor zone BICY MZ-2 (838 to 996 feet bls) showed no effect and varied only by +/- 0.1 feet.

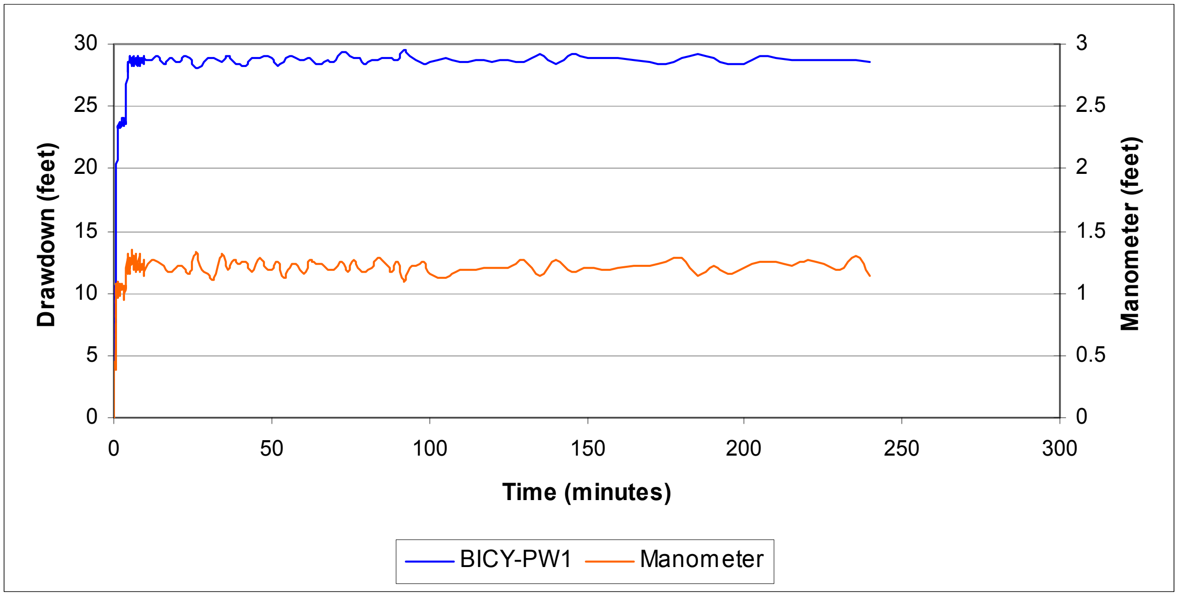


Figure 15. Time Series Plot of Drawdown Data from BICY-PW1 and Manometer Readings from Discharge Orifice Weir, APT No. 1.

SFWMD applied various analytical models to the drawdown data collected during the APT to determine the hydraulic properties of the aquifer and aquitard(s) at this site. The analytical methods included both confined and semi-confined "leaky" solutions. The confined transient analytical solutions include the Theis (1935) non-equilibrium method and the Cooper Jacob (1946) approximation. The semi-confined "leaky" analytical models include the Hantush-Jacob (1955), Hantush (1960), and Moench (1985). The methods referenced are based on various assumptions and interested readers should refer to the original articles for further details. Data analyses of the recovery produced similar hydraulic results. In general, drawdown data from a single observation well only provides an estimate of aquifer and confining unit properties because many of the type curves are similar in shape to one another and do not necessarily provide a unique match to a given data set.

Figure 16 is a log/log plot of drawdown versus time for the pumped monitor zone (BICY MZ-1). The shape of the drawdown curve of BICY MZ-1 indicates a leaky-type aquifer. A leaky (semi-confined) aquifer is one that loses or gains water (depending on the pressure gradients) through a semi-confining unit. If a semi-confining unit(s) is composed of a thick layer of unconsolidated or poorly indurated, high porosity sediments, it may provide water to the pumped interval. The lithologic data indicates that the overlying units are composed of porous (25% to 40% porosity), unconsolidated siliciclastic sediments, which have the potential to transmit water through them, and to supply additional water released from storage to the tested interval. A proximal monitor well completed above the test interval of 465 to 560 feet bls was not available for monitoring during the

APT to quantify the relative contribution of the overlying semi-confining unit. During the drawdown (flow test), water levels in the FAS monitor well identified as BICY MZ-2 (completed from 838 to 996 feet bls) did not decline, but remained fairly static (+/- 0.1 feet).

Moench (1985) derived an analytical solution for predicting water-level displacements in response to pumping a large diameter well that takes into account well bore storage in a leaky confined aquifer and assumes storage in the aquitard(s) and well bore skin effects. Moench (1985) also builds upon several previously established analytical solutions such as Hantush (1960), Papadopulos and Cooper (1967), Agarwal et al (1970). Based on these considerations and the site-specific hydrogeologic data collected during drilling and aquifer testing, the Moench analytical model appears to best represent the conditions present at this site. Model results yielded a transmissivity value of 502,000 gpd/ft, storage coefficient of 6.8 x 10^{-5}, and an (r/B) value of 0.06. The dimensionless parameter r/B characterizes the leakage across the semi-confining unit(s) to the pumped aquifer, from this value a leakance value of 1.51 x 10 $^{-2}$ gpd/ft^3 was calculated (Walton, 1960).

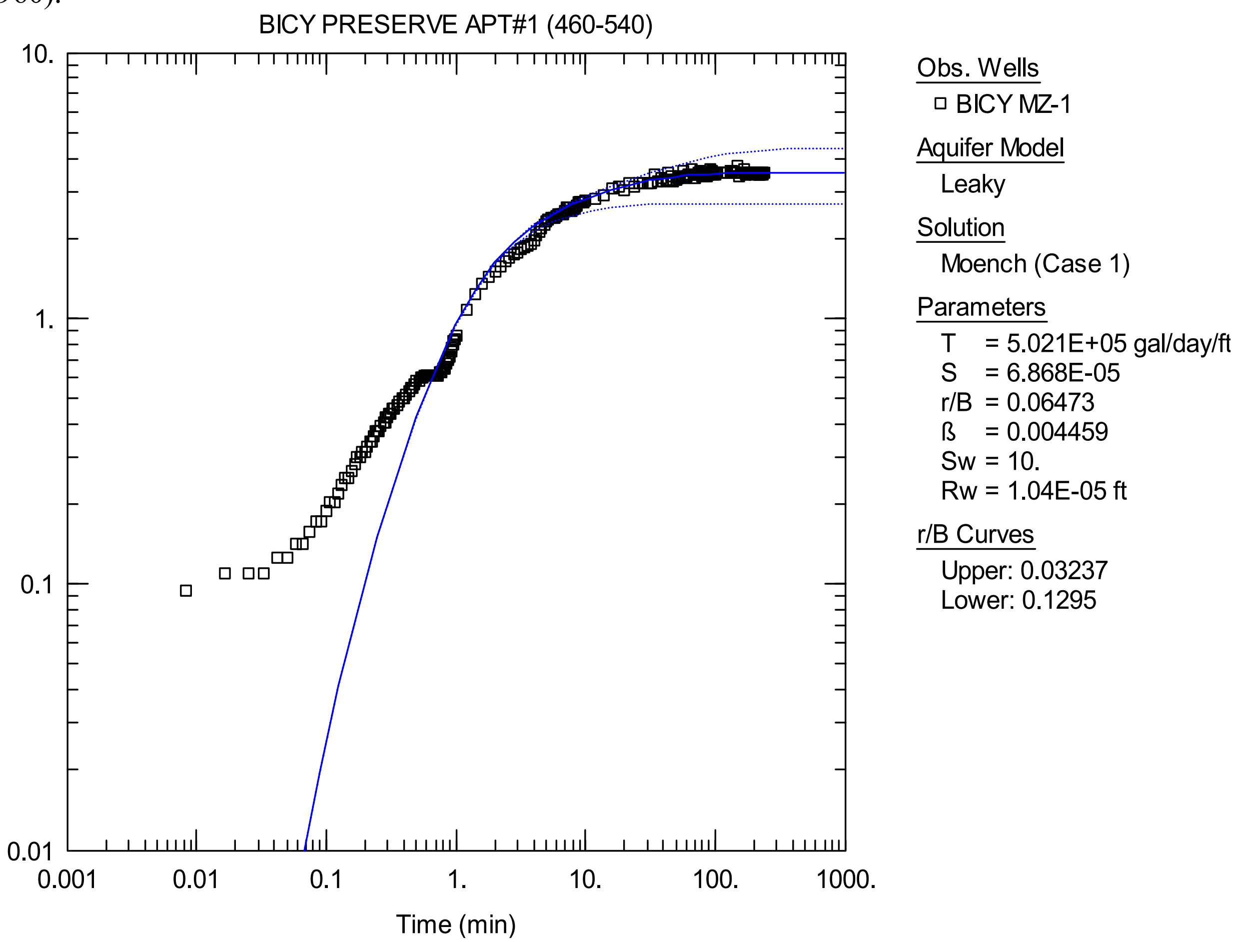


Figure 16. Log-Log Plot of Drawdown versus Time for Monitor Well BICY MZ-1, APT No. 1.

Aquifer Performance Test No. 2

SFWMD conducted a second APT to determine in-situ hydraulic characteristics of the FAS from 840 to 1,010 feet bls within the lower Arcadia Formation and upper Suwannee Limestone. The drawdown phase consisted of pumping this interval at a constant rate of 820 gpm for 50 hours.

Figure 17 shows the well configuration of the quad-zone monitor well (BICY MZ-2) and test-production well (BICY PW-2) used in the APT. The drawdown phase was followed by a 24-hour recovery period, where water levels were allowed to return to background conditions.

DDC installed an 8-inch diameter submersible pump in the test-production well with the pumping bowl set at 120 feet bls. SFWMD chose this depth based on preliminary data indicating that moderate drawdown would occur. The wellhead was re-installed with appurtenances consisting of a shut-off valve, discharge pressure gauge, and wellhead pressure transducer. A 6-inch diameter circular orifice weir with a 4-inch diameter orifice plate was used to measure discharge rates during pumping, verified by an in-line flowmeter. SFWMD personnel installed a pressure transducer on the orifice weir to record discharge rates during the pump test at 2-minute intervals. Additional pressure transducers were installed on/in both the test-production (BICY PW-2) and monitor wells (BICY MZ-1, BICY MZ-2, and BICY MZ-3) connected to a newly acquired Hermit® 3000 (Insitu, Inc) data logger via electronic cables. The transducers and data logger were used to measure and record water level and barometric pressure changes at pre-determined intervals during testing operations.

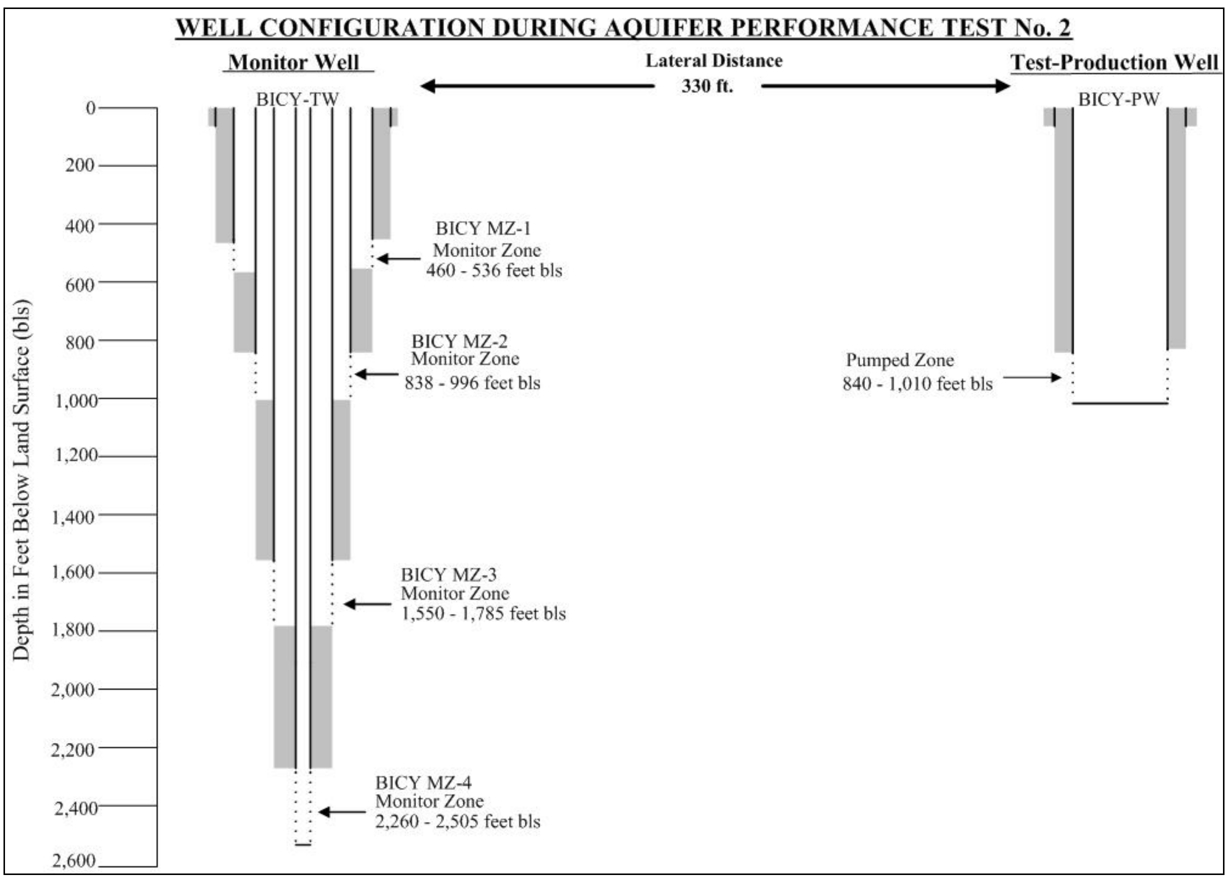


Figure 17. Aquifer Performance Test – Well Configuration APT No. 2.

Following equipment setup, SFWMD conducted a step-drawdown test on July 13, 1998 to determine an appropriate pumping rate for the planned drawdown test. Once completed, SFWMD allowed water levels to recover to static conditions before starting the APT. On July 14, 1998, SFWMD started the drawdown phase of the second APT by initating pumping of BICY PW-2 at 820 gpm. SFWMD maintained the installed electronic devices, which continuously measured and recorded water levels, and pump rates during the drawdown phase. DDC operated the pump uninterrupted for the next 50 hours at an average pumping rate of 820 gpm, completing the drawdown phase on July 16, 1998. The drawdown phase was limited to 50 hours due to elevated specific conductance levels in the adjacent surface water body resulting from brackish formation water discharges during aquifer testing. **Figure 18** is a time-series plot of the drawdown data for the production well (BICY-PW2) and discharge rates (manometer readings) from the 6-inch diameter, circular orifice weir during the pumping phase of the APT No. 2. This figure shows that maximum drawdown in BICY-PW2 was 35.8 feet (15.3 psi) and pump rate variations during the course of the APT No. 2 were small (less than +/- 5%) to be inconsequential to the overall test results. **Figure 19** is a semi-log plot of the drawdown data for the pumped monitor zone (BICY MZ-2) and show a maximum drawdown of 8.8 feet (3.8 psi).

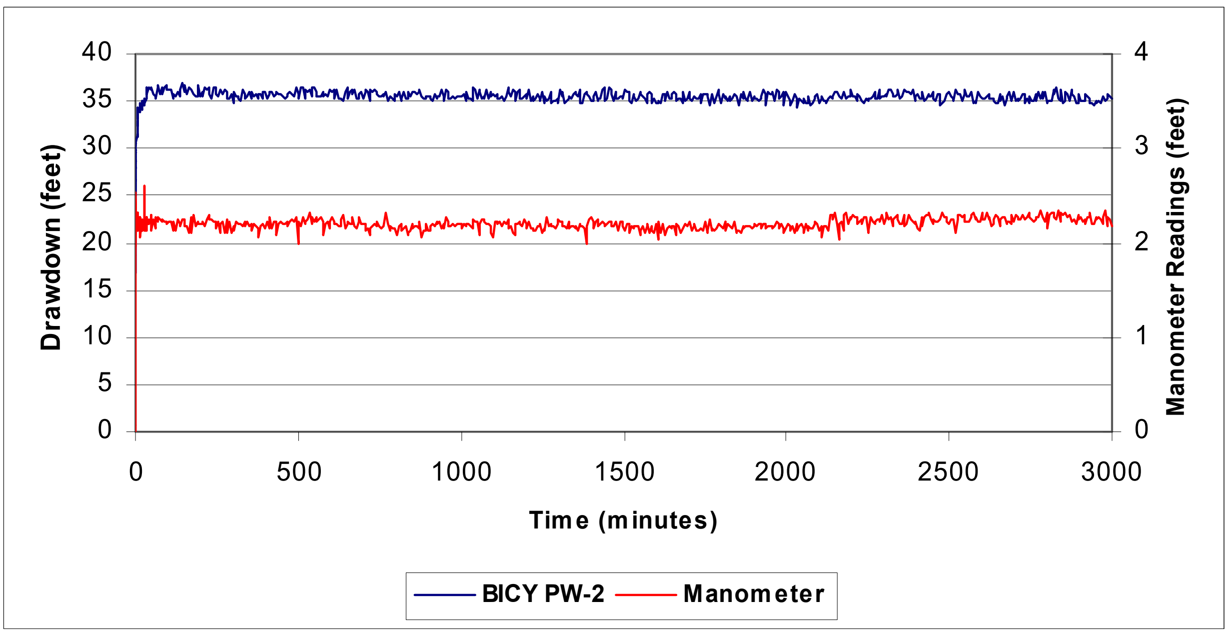


Figure 18. Time Series Plot of Drawdown Data from BICY-PW2 and Manometer Readings from Discharge Orifice Weir, APT No. 2.

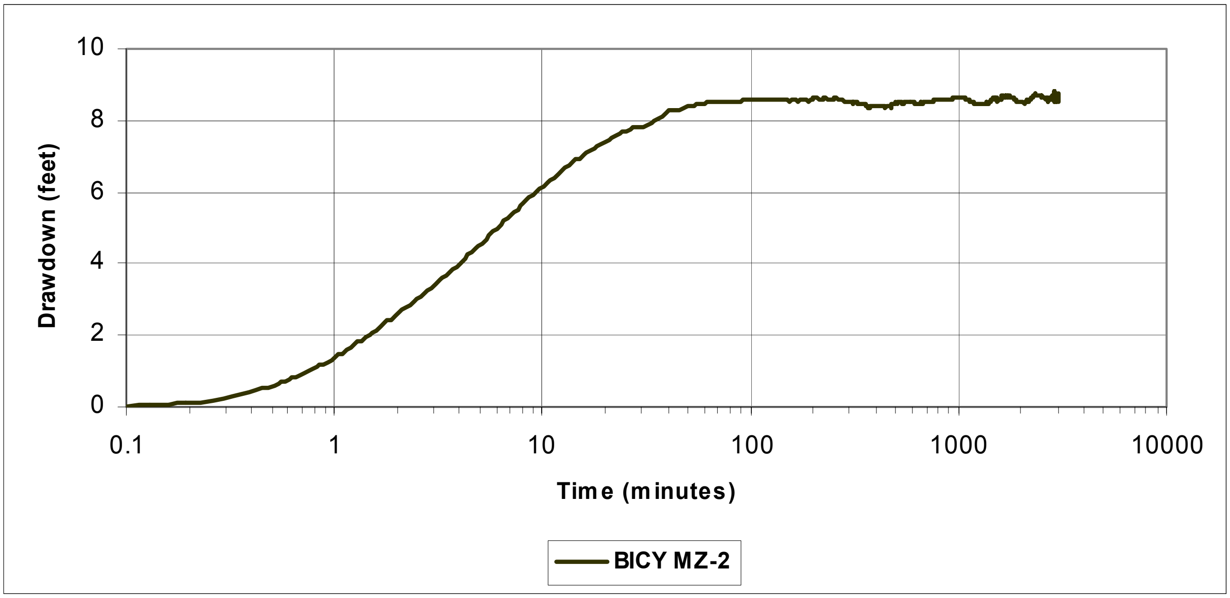


Figure 19. Semi-Log Plot of Drawdown Data from BICY MZ-2, APT No. 2.

Figure 20 is a time-series plot of water-level changes during the drawdown phase for the IAS monitor zone BICY MZ-1 (460 to 536 feet bls), middle Floridan aquifer monitor zone BICY MZ-3 (1,550 to 1,785 feet bls) and barometric pressure. Water-level changes in the monitor zone above and below the pumped interval declined (0.2 feet) during pumping, which indicates leakage across the semi-confining units.

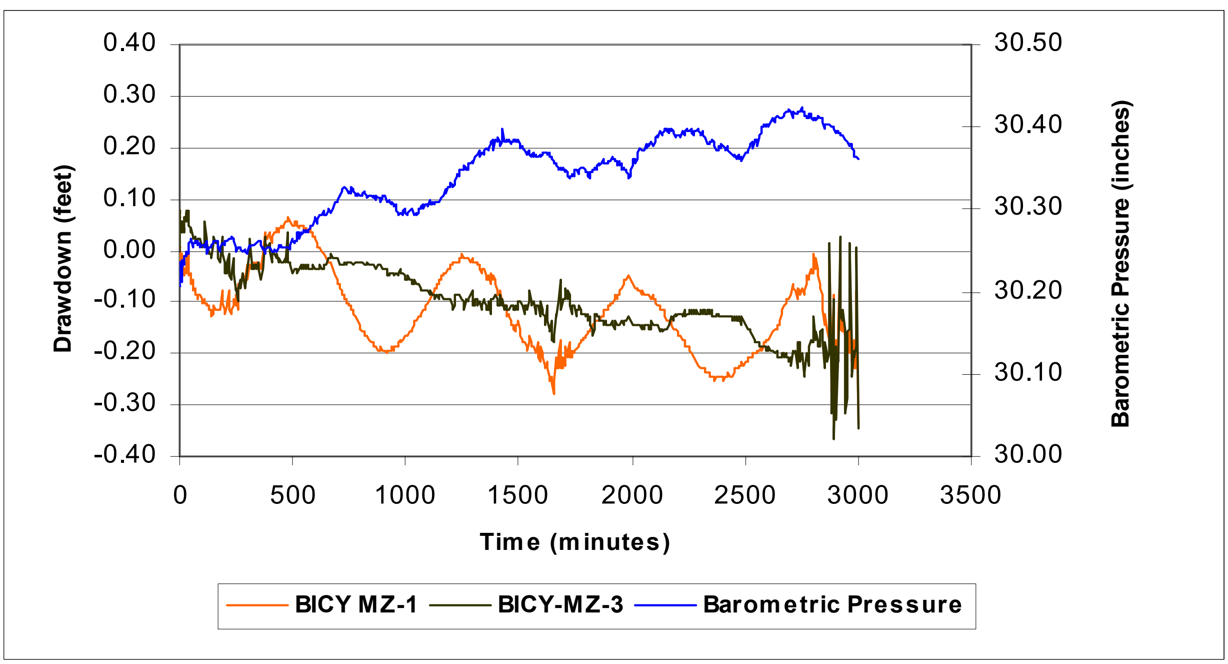


Figure 20. Time Series Plot of Water Levels from BICY MZ-1, BICY MZ-3, and Barometric Pressure During Pumping Phase of APT No. 2.

Before pumping stopped, SFWMD reconfigured the various data loggers to record the recovery data. DDC manually stopped the pump and water levels slowly recovered to static conditions. The recovery phase of the APT continued for 24 hours, ending on July 18, 1998. Electronic copies of the original drawdown, recovery and orifice weir (pump rate) data for the APT are archived and available for review at the SFWMD headquarters in West Palm Beach, Florida.

Again, SFWMD applied various analytical models to the drawdown data collected during the second APT to determine the hydraulic properties of the aquifer and confining unit(s) consistent with those used to analyze data from APT No. 1. Data analyses of the recovery produced similar hydraulic results. As previously mentioned, drawdown data from a single observation well only provides an estimate of aquifer and confining unit properties because many of the type curves are similar in shape to one another and do not necessarily provide a unique match to a given data set, this is stated to qualify the presented values.

Figure 21 is a log/log plot of drawdown versus time for the pumped monitor zone (BICY MZ-2). The shape of the drawdown curve from BICY MZ-2 is indicative of a leaky-type aquifer. The lithologic data shows that the overlying and underlying units are composed of porous (25% to 45% porosity) sediments that have the potential to transmit water and to supply additional water released from storage to the pumping interval. Water levels from both the monitor zones completed above (BICY MZ-1) and below (BICY MZ-3) the test interval of 830 to 1,010 feet bls declined a maximum of 0.25 feet. Similar water level declines in the upper and lower monitor zones during pumping indicates proportional leakage across the upper and lower semi-confining units.

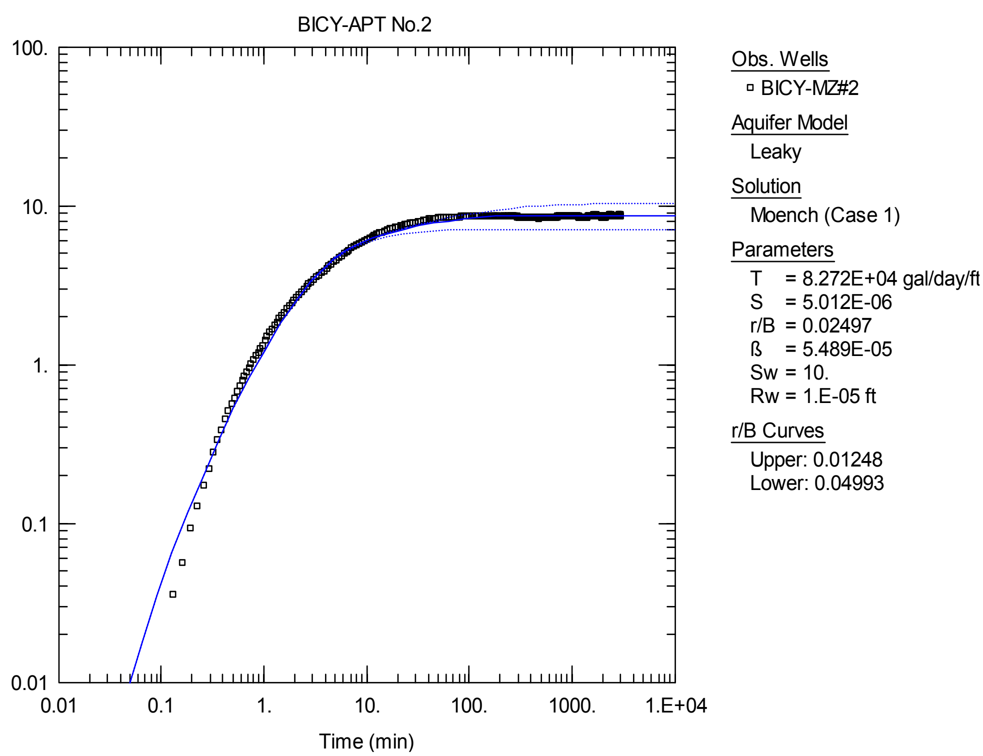


Figure 21. Log-Log Plot of Drawdown versus Time for Monitor Well BICY MZ-2, APT No. 2.

Based on these analytical considerations and the site-specific hydrogeologic data collected during drilling and aquifer testing, the Moench analytical model appears to best represent the conditions present at this site. The analytical solution yielded a transmissivity of 82,720 gpd/ft, a storage coefficient of 5.0 x 10^{-6}, and an (r/B) value of 0.02. The dimensionless parameter r/B characterizes the leakage across the aquitard(s) to the pumped aquifer, from this value a leakance value of 6.25 x 10^{-4} gpd/ft^3 was calculated (Walton, 1960).

Long-Term Ground Water Level/Quality Monitoring Program

Shortly after the construction of the quad-zone FAS monitor well (BICY-TW), SFWMD collected water samples to establish baseline water quality conditions. Unfiltered and filtered water samples were taken directly from the discharge point into a Teflon bailer, which was placed on a stand where the sample bottles filled slowly, minimizing aeration. As part of SFWMD's water quality sampling protocol, duplicate samples were collected from consecutive bailers with sample splits collected from the same bailer. Once collected, all water samples were preserved and immediately placed on ice in a closed container and transported to SFWMD water quality laboratory. The laboratory analyzed the samples using EPA and/or Standard Method Procedures (SFWMD, Comprehensive Quality Assurance Plan, 1995). **Table 8** summarizes the analytical results.

Inorganic Water Quality Data from Big Cypress Preserve Drill Site (BICY), Collier County, Florida.

				Cations				Anions					Field Parameters		
Identifer	Depth Interval (ft. bls)		Sample Date	Na^+ mg/L	K^+ mg/L	Ca^{2+} mg/L	Mg^{2+} mg/L	Cl^- mg/L	Alka as $CaCO_3$ mg/L	SO_4^{2-} mg/L	F- mg/L	TDS mg/L	Specific Conduct. umhos/cm	Temp °C	pH s.u.
BICY MZ-1	455-540	IAS	05/27/98	1,080	45	116.0	140	1,807	153	505	0.99	3,800	5,976	27.73	7.41
BICY MZ-2	838-996	UFA	05/27/98	1,550	61	165.0	195	2,946	140	611	0.94	5,460	8,647	28.02	7.50
BICY MZ-3	1550-1785	MCU	06/05/98	8,490	268	587.0	923	15,244	138	1,422	1.14	26,500	42,225	28.69	7.50
BICY MZ-4	2260-2505	LFAS	01/28/99	11,300	400	794.0	1,180	20,790	191	2,479	1.12	35,800	52,647	26.86	6.08

mg/L = milligrams per liter
umhos/cm = microumhos per centimeter
o C = degree Celisus
s.u = standard unit
ft. bls = feet below land surface

MZ - Monitor Zone
IAS = intermediate aquifer system
UFA = upper Floridan aquifer
MCU = middle confining unit
LFA = lower Floridan aquifer

Table 8. Water Quality Data from Quad-Zone Monitor Intervals.

In addition, SFWMD established a monthly potentiometric-head monitoring program. A 30-psi transducer and a Hermit 3000® (Insitu, Inc.) data logger recorded pressures from the various monitor zones once a month. On March 10, 1999, SFWMD installed automated pressure recorders (Insitu® Troll 4000) on the FAS quad-zone monitor well (BICY-TW). The sample frequencies are set to hourly readings to identify short- and long-term stresses to the FAS.

The pressure transducer converted all pressure readings to equivalent fresh-water heads in feet using a conversion factor of 2.31 feet of head per psi. SFWMD then added the converted pressure readings to the surveyed measuring point elevation (located on the concrete well pad) to obtain a hydraulic head referenced to the National Geodetic Vertical Datum (NGVD) of 1929.

Figures 22 and 23 illustrates hourly water level data for middle IAS and FAS monitor intervals. **Table 9** lists the monitor intervals within the IAS and FAS, average measured hydraulic head, and standard deviation. SFWMD generated the hydrographs for these monitor zones using hourly pressure readings. These hydrographs show water level fluctuations that may be attributed to tidal loading, earth tides, and changes in atmospheric pressure (i.e., barometric effect).

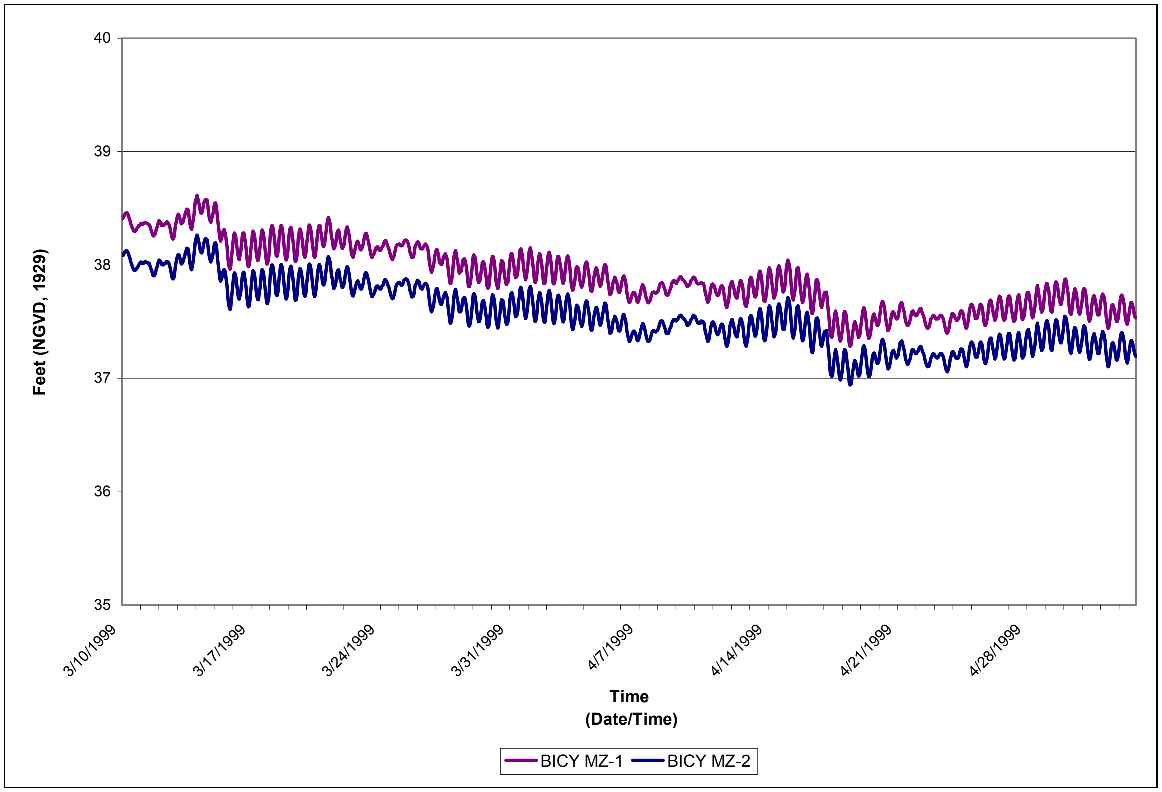


Figure 22. Long Term Hydrograph – Middle IAS and Upper FAS Monitor Zones.

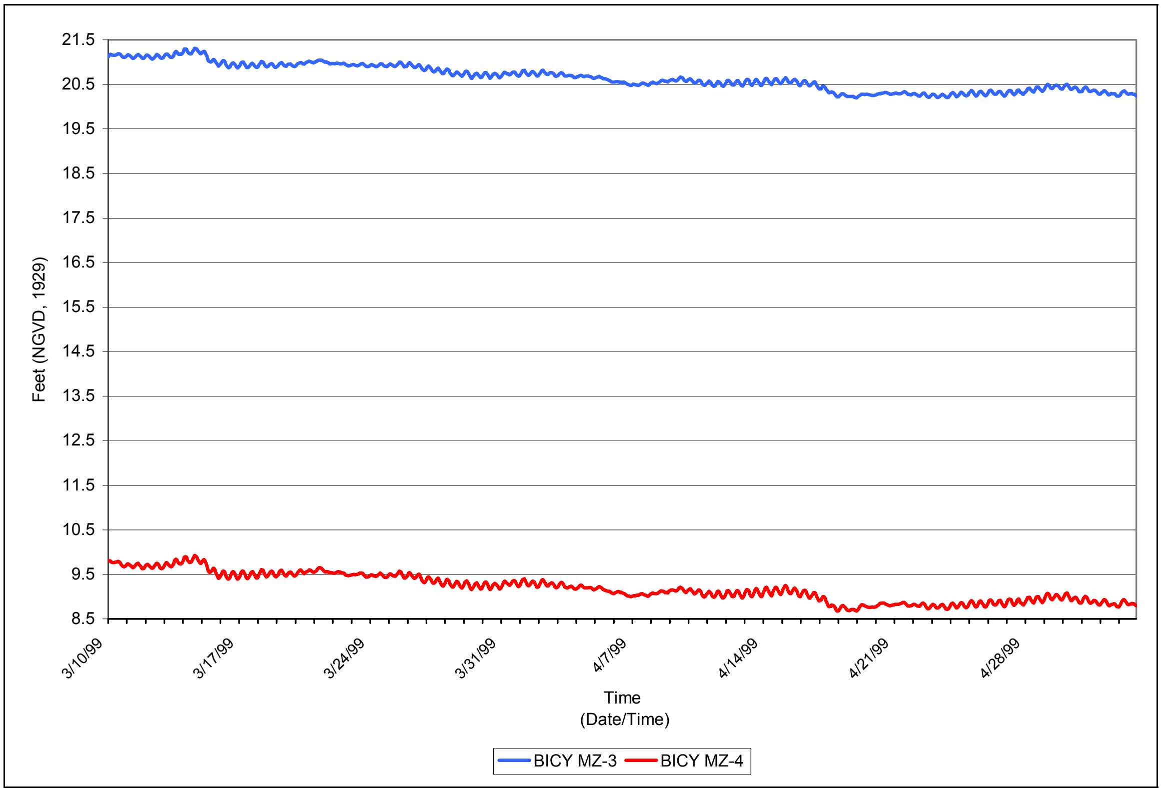


Figure 23. Long Term Hydrograph, Middle Confining Unit and Lower FAS Monitor Zones.

Identifier	Monitor Interval (feet bls)	Average Measured Hydraulic Head (feet NGVD, 1929)	Standard Deviation (feet)
BICY MZ-1	460 to 536	37.89	0.289
BICY MZ-2	838 to 996	37.56	0.286
BICY MZ-3	1,550 to 1,785	20.65	0.293
BICY MZ-4	2,260 to 2,505	9.20	0.309
Period of Record from 03/10/99 to 05/04/99			

Table 9. Average FAS Hydraulic Head Data from Quad-Zone Monitor Well.

SUMMARY

1. The top of the Floridan aquifer system (FAS) as defined by the Southeastern Geological Society AdHoc Committee on Florida Hydrostratigraphic Unit Definition (1986) was identified at a depth of approximately 820 feet bls.
2. Lithologic and geophysical logs, specific capacity and packer test results, and petrophysical data indicate excellent production capacity in the middle intermediate aquifer system, and moderate production capacity in the upper Floridan aquifer.
3. Water quality data from packer tests and completed monitor zones indicate that chloride and total dissolved solids in the upper Floridan aquifer waters exceed potable drinking water standards. Chloride and total dissolved solids concentrations between 460 and 1,000 feet bls average 2,375 and 3,655 mg/L, respectively.
4. The base of the Underground Source of Drinking Water, those waters having TDS concentrations less than 10,000 mg/L, occurs at an approximate depth of 1,375 feet bls.
5. The stable isotope data from the Big Cypress Preserve site indicate that the middle intermediate aquifer system (BICY MZ-1) and upper Floridan aquifer (BICY MZ-2) are depleted in both ^{18}O and deuterium as compared to the reference standard of Standard Mean Ocean Water (SMOW). The corrected radiocarbon ages from these two monitor intervals are 17,002 and 26,149 years before present (bp), respectively, using the Fontes-Granier method.
6. Stable isotope data also suggest that water in the middle Floridan confining unit water is enriched in both ^{18}O and deuterium as compared to SMOW. The inorganic water quality results from samples obtained from 1,550 to 1,785 feet bls are saline in composition suggesting that the middle part of the Floridan aquifer has been intruded by seawater.
7. The lower Floridan aquifer waters at the BICY site (BICY MZ-4) are enriched in both ^{18}O and deuterium compared to SMOW and produced a corrected radiocarbon age of 8,460 years bp using the Fontes-Granier method.
8. The petrophysical results from full-diameter core testing suggest a moderate linear relationship between horizontal permeability and porosity with a correlation coefficient of 0.76.
9. The highest mean horizontal permeability measurements of 11,069 and 4,707 md correspond to cored sections at approximately 900 and 985 feet bls, respectively. These two intervals consist of coral and pelecypod boundstones, likely deposited in an open shoal environment.
10. Future petrology work in conjunction with the magnetic susceptibility data are needed to refine the NMR permeability model for carbonate units of the Floridan aquifer system.
11. A productive horizon in the middle part of intermediate aquifer system from 465 to 550 feet bls yielded a transmissivity value of 502,000 gpd/ft, a storage coefficient of 6.8×10^{-5}, and a (r/B) value of 0.06 and a leakance value of 1.51×10^{-2} gpd/ft^3.
12. A productive horizon in the upper Floridan aquifer from 840 to 1,010 feet bls yielded a transmissivity value of 82,720 gpd/ft, a storage coefficient of 5.0×10^{-6}, and a (r/B) value of 0.02 and a leakance value of 6.25×10^{-4} gpd/ft^3.
13. The average measured hydraulic heads for the FAS monitoring intervals are as follows:
    - 37.89 feet above mean sea level for the 460 to 536 feet bls monitor interval
    - 37.56 feet above mean sea level for the 838 to 996 feet bls monitor interval
    - 20.65 feet above mean sea level for the 1,550 to 1,785 feet bls monitor interval
    - 9.20 feet above mean sea level for the 2,260 to 2,505 feet bls monitor interval

14. Water levels in the FAS respond to external stresses such as tidal loading and barometric pressure variations.
15. The inorganic chemistry, stable isotopes, radiocarbon, and hydraulic head data - summarized in this report suggests that the two horizons (460 to 550 and 830 to 1,010 feet bls) are hydraulically connected.
16. The inorganic, stable isotope, radiocarbon, and noble gas data suggest the ground water in the middle part of intermediate and upper Floridan aquifers is composed of Pleistocene-aged meteoric water.
17. Noble gas temperatures from the middle portion of the intermediate aquifer system (BICY MZ-1) and upper Floridan aquifer (BICY MZ-2) averaged 18.7° C, about 5° C cooler than the present-day south Florida mean annual air temperature of 23.6° C inferring freshwater recharge during cooler climatic conditions – possibly during the late Pleistocene.
18. The stable isotope data from lower Floridan aquifer samples (BICY MZ-4) are similar to seawater samples collected in the Strait of Florida (off the coast of Ft. Pierce – 27° 0.445N, 79° 26.789W) at depths greater than 1,700 feet. Corrected ^{14}Carbon data suggests these waters entered the lower Floridan aquifer during the Holocene epoch.
19. Noble gas temperatures from the lower Floridan aquifer (BICY MZ-4) was 8.7° C, about 10° C cooler than waters in the upper Floridan aquifer and 14.9° C cooler than the present-day mean annual air temperature of south Florida. This suggests circulation of cooler ocean waters into the lower Floridan aquifer in south Florida.

REFERENCES

Agarwal, R. G., R. Al-Hussainy, and H. J. Ramey, Jr. 1970. An investigation of well bore storage and skin effect in unsteady liquid flow – analytical treatment, Transaction of the Society of Petroleum Engineers AIME, v. 249, pp. 279-290.

American Petroleum Institute, 1998. Recommended Practices for Core Analysis. American Petroleum Institute

Applin, P.L. and E.R. Applin, 1944. Regional subsurface stratigraphy and structure of Florida and southern Georgia, American Association of Petroleum Geologist Bulletin v. 28 (12), pp.1673-1753.

Archie, G.E., 1942. The electrical resistivity log as an aid in determining some reservoir characteristics, A.I.M.E. Transaction, v. 146, pp.54-61.

Bennett, M.W., 2001a. Hydrogeologic investigation of the Floridan aquifer system at the L-2 Canal site Hendry County, Florida: South Florida Water Management District Technical Publication WS-3, 36 p.

Bennett, M.W., 2001b. Hydrogeologic investigation of the Floridan aquifer system at the I-75 Canal site Collier County, Florida: South Florida Water Management District Technical Publication WS-5, 46 p.

Bennett, M.W., 2002. Hydrogeologic investigation of the Floridan aquifer system – Immokalee Water & Sewer District Wastewater Treatment Plant, Collier County, Florida: South Florida Water Management District Technical Publication WS-14, 42 p.

Bottomley, D. E., J. D. Ross, and W. B. Clark, 1984. Helium and neon isotopes geochemistry of some ground waters form the Canadian Precambrian Shield. Geochim. Cosmochim. Acta, 1973 – 1985. 48 p.

Clark, J. F., 2002. Isotopic measurements from the Floridan aquifer. Phase I Final Report submitted to the South Florida Water Management District. 7 p.

Clark, J. F., M. Stute, P. Schlosser, S. Drenkard, and G. Bomini, 1997. An isotope study of the Floridan aquifer in Southeastern Georgia; Implication for groundwater flow and paleoclimate. Water Resource Research v. 33, pp. 281-289.

Clark, J. F., M. L. Davisson, G. B. Hudson, and P. A. Macfarlane, 1998. Noble gases, stable isotope and radiocarbon as traces of flow in the Dakota aquifer, Colorado and Kansas, Journal of Hydrology, v. 211, pp. 151-167.

Clark, I. and P. Fritz, (1997). Environmental Isotopes in Hydrogeology, Lewis Publishers. New York.

Chen, C.S., 1965. The regional lithostratigraphic analysis of Paleocene and Eocene rocks of Florida: Florida Geological Survey Bulletin No. 45, 105 p.

Chombart, L. J., 1960. Well logs in carbonate reservoirs, Geophysics, v. 25 (4), pp.779-853.

Coleman, M. L., Shepherd, T. J., Durham, J. J., Rouse, J. E. and Moore, G. R., 1982. Reduction of water with zinc for hydrogen isotope analysis. Analytical Chemistry, v. 54, pp. 993-995.

Cooper, H.H. and C.E. Jacob, 1946. A generalized graphical method for evaluating formation constants and summarizing well field history, Am. Geophys. Union Trans., v. 27, pp. 526-534.

Craig, H., 1961. Isotopic variations in meteoric waters: Science, v. 133, pp. 1702-1703.

Cunningham, K.J. and McNeill, D.F., (1997) Preliminary hydrogeologic analysis of the Sunniland No.1 core-hole, Collier County, Florida: Final Report submitted to the South Florida Water Management District, 39p.

Cunningham, K.J. and McNeill, D.F., Guertin, and others (1998) New Tertiary stratigraphy for the Florida Keys and southern peninsula of Florida: Geological Society of America Bulletin, v. 110 231-258.

Drimmie, R. J., Heemskerk, A. R., Mark, W. A. and Weber, R. M. 1991. Deuterium by zinc reduction, technical procedure 4.0, Rev. 02: Environmental Isotope Laboratory, Department of Earth Sciences, University of Waterloo, 6 p.

Drimmie, R.J. and Heemskerk, A.R., 1993. Water ^{18}O by CO_2 equilibration, technical procedure 13.0, Rev.02. Environmental Isotope Laboratory; Department of Earth Sciences, University of Waterloo, 11 p.

Drimmie, R.J., Heemskerk, A.R. and Aravena, R., 1990. Dissolved Inorganic Carbon (DIC), Technical Procedure 5.0, Rev. 01. Environmental Isotope Laboratory; Department of Earth Sciences, University of Waterloo, 3 p.

Driscoll, F.G., 1989. Ground water and wells 2nd Edition. Johnson Filtration Systems Inc., St Paul, Minnesota. 1089 p.

Duncan, J.C., Evans, W.L. III, and Taylor, K.L., 1994. The geologic framework of the lower Floridan aquifer system in Brevard County, Florida, Florida Geological Survey Bulletin No. 64, 90 p.

Epstein S. and Maeda, T.K., 1953. Variations of the $^{18}O/^{16}O$ ratio in natural waters. Geochimica et Cosmochimica Acta, v. 4, 213 p.

Fairbanks, R. G., 1989. A 17,000 year glacio-eustatic sea level record: Influence of glacial melting rates on the Younger Dryas event and deep ocean circulation, Nature, v. 342, pp. 637-642.

Fontes, J-Ch. 1990. Chemical and isotopic constraints on ^{14}C dating of groundwater. In: Taylor, R.E., Long, A., Kra, A. (eds.) Radiocarbon After Four Decades. Springer, New York, pp. 242-261.

Fontes, J.-Ch. and Garnier, J-M., (1979) Determination of the initial 14C activity of total dissolved carbon: A review of existing models and a new approach. Water Resources Research, v. 15 399-413.

Hallenburg, J.K., 1998. Standard Methods of Geophysical Formation Evaluation. CRC Press, Lewis Publishing, Boca Raton, Florida.

Hantush, M.S., 1960. Modification of the theory of leaky aquifers, Journal of Geophysical Research, v. 65 (11), pp. 3713-3725

Hantush, M.S., and C. E. Jacob, 1955. Nonsteady radial flow in an infinite leaky aquifer, Eos Trans. AGU, v. 36 (1), pp. 95-100.

Hanshaw, B.N., W. Back, and M. Rubin. 1964. Radiocarbon determinations for estimating flow velocities in Florida. Science, v. 143, pp. 494-495.

Kaufmann, R.S. and M.W. Bennett, 1997. The history of saltwater intrusion and flow in the Floridan aquifer, in the western Everglades, southern Florida. *Proceedings of the AWRA symposium Conjunctive Uses of Water Resources: Aquifer Storage and Recovery*, 407-416.

Kohout, F.A., 1965. A hypothesis concerning cyclic flow of salt water related to geothermal heating in the Floridan aquifer. New York Academy of Sciences Transaction, Ser.2, v.28 (1), p.11-15.

Kohout, F.A., 1967. Ground water flow and the geothermal regime of the Florida Plateau, *Trans. Gulf Coast Assoc. Geol. Soc. 17*, pp. 339-354.

Mashisotta, T. A., D. W. Lea, H. J. Spero (1999) Glacial-interglacial changes in Subantartic sea surface temperature and $\delta^{18}O$-water using foraminiferal Mg, *Earth Planet. Sci. Lett.*, 170, 417-432.

Meyer, F.W., 1989. Hydrogeology, ground water movement, and subsurface storage in the Floridan aquifer system in southern Florida, *USGS Professional Paper 1403-G*.

Meyers, J.B., P.K. Swart, J.L. Myers. 1993. Geochemical evidence for ground water behavior in an unconfined aquifer, south Florida. Journal of Hydrology, v.149, pp. 249-272.

Miller, J.A., 1986. Hydrogeologic framework of the Floridan aquifer system in Florida and in parts of Georgia, Alabama, and South Carolina, *USGS Professional Paper 1403-B*.

Milliman, J.D. and Emery, K.O. 1968. Sea levels during the past 35,000 years. *Science 162*, pp. 1121-1123.

Missimer, T.M., 1997. Paleogene and Neogene sea level history of the southern Florida platform based on seismic and sequence stratigraphy: University of Miami, Ph.D. dissertation, 942 p.

Missimer, T.M., 2002. Late Oligocene to Pliocene evolution of the central portion of the south Florida platform: Mixing of siliciclastic and carbonate sediments: Florida Geological Survey Bulletin No. 65, 184 p.

Moench, A.F., 1985. Transient flow to a large-diameter well in an aquifer with storative semi-confining layers, Water Resources Research v. 21(8), pp. 1121-1131.

Papadopulos, I. S., and H. H. Cooper, Jr., 1967. Drawdown in a well of large diameter, Water Resource Research, v. 3 (1), pp. 241-244.

Reese, R.S., 2000. Hydrogeology and the distribution of salinity in the Floridan aquifer system, southwestern Florida. United States Geological Survey Water-Resources Investigation Report 98-4253, 86 p., 10pls.

Sandal, H. M., R. N. Horne, H. J. Ramey Jr., and J. W. Williamson, 1978. Interference testing with well bore storage and skin effect at the produced well, paper presented at the 53rd Annual Fall Technical Conference and Exhibition, Society of Petroleum Engineers of AIME, Houston, Texas Oct 1-3, 1978.

Schrag, D. P.; G. Hampt, and D. W. Murray (1996) Pore fluid constraints on the temperature and oxygen isotopic composition of the glacial ocean, *Science*, 272, 1930-1932.

Scott, T.M. 1988. The lithostratigraphy of the Hawthorn Group (Miocene) of Florida. Florida Geological Survey Bulletin No.59.

Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986. Hydrogeologic unit of Florida: Florida Department of Natural Resources, Bureau of Geology, Special Publication No. 28, 9 p.

South Florida Water Management District. 1995. Comprehensive Quality Assurance Plan. South Florida Water Management Publication.

Stuiver, M, and H.A. Polach. 1977. Discussion, reporting of ^{14}C data. Radiocarbon v. 19 (3), pp. 355-363.

Stute, M., J. F. Clark, P. Schlosser, W. S. Broecker, and G. Bonani, 1995. A 30,000 yr continental paleotemperature record derived form noble gases dissolved in groundwater from the San Juan Basin, New Mexico. Quaternary Research, v. 43, pp. 209 – 220.

Theis, C.V., 1935. The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground water storage, American Geophysical Union Transactions, v. 16, pp. 519-524.

Torgersen, T. and G. N. Ivey (1985) Helium accumulation in groundwater: II. A model for the accumulation of the crustal ^{4}He degassing flux. *Geochim. Cosmochim. Acta*, 49: 2445-2452.

Weedman, S.D., Paillet. F.L., Edwards. L.E., and others (1999) Lithostratigraphy geophysics, biostratigraphy, and strontium-isotope stratigraphy of the surficial aquifer system of eastern Collier County and northern Monroe County, Florida U.S. Geological Survey Open-File Report 99-432, 125p.

Winsauer, W.O., Shearin, H.M. Jr., Masson, P.H., and Williams, M., 1952. Resistivity of brine-saturated sand in relation to pore geometry, Bulletin of the American Association of Petroleum Geologists, v. 36 (2), pp. 253-277.

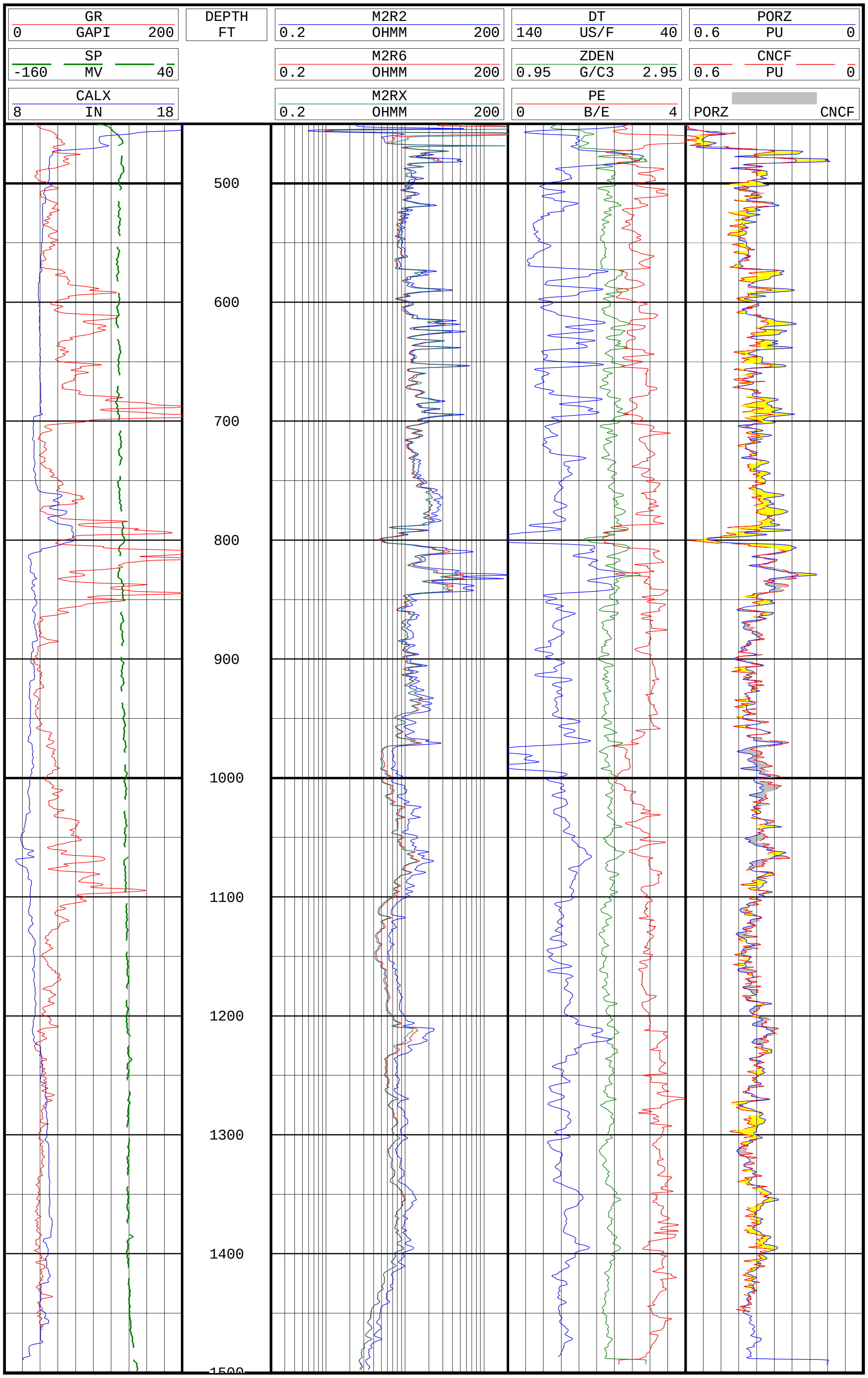
Wyllie, M. R. J., Gregory, A. R., and Gardner, L. W., 1956, Elastic wave velocities in heterogeneous and porous media: Geophysics, 21, no. 1, 41-70.

APPENDIX A

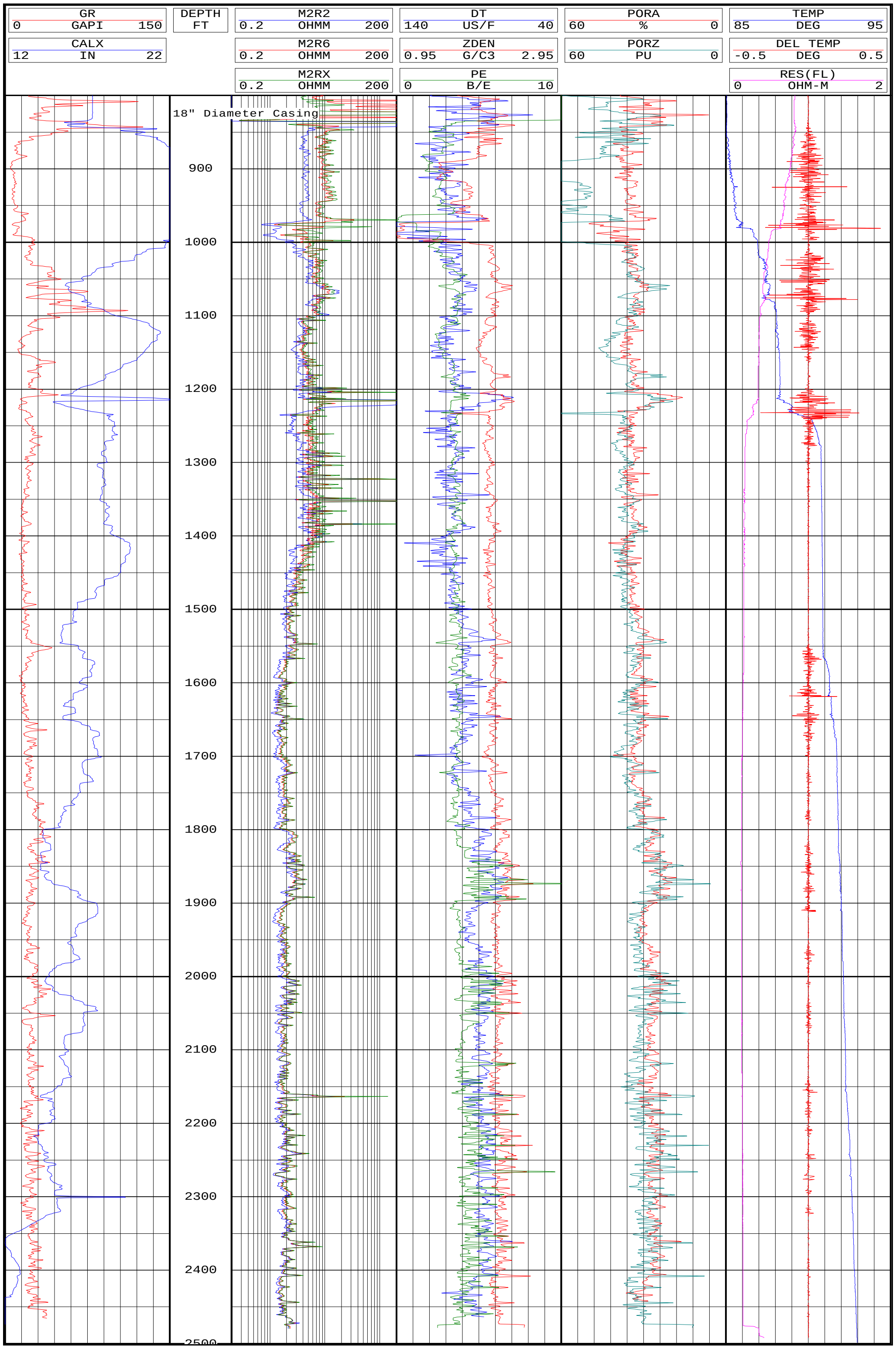
GEOPHYSICAL LOGS

Legend for Geophysical Log Traces

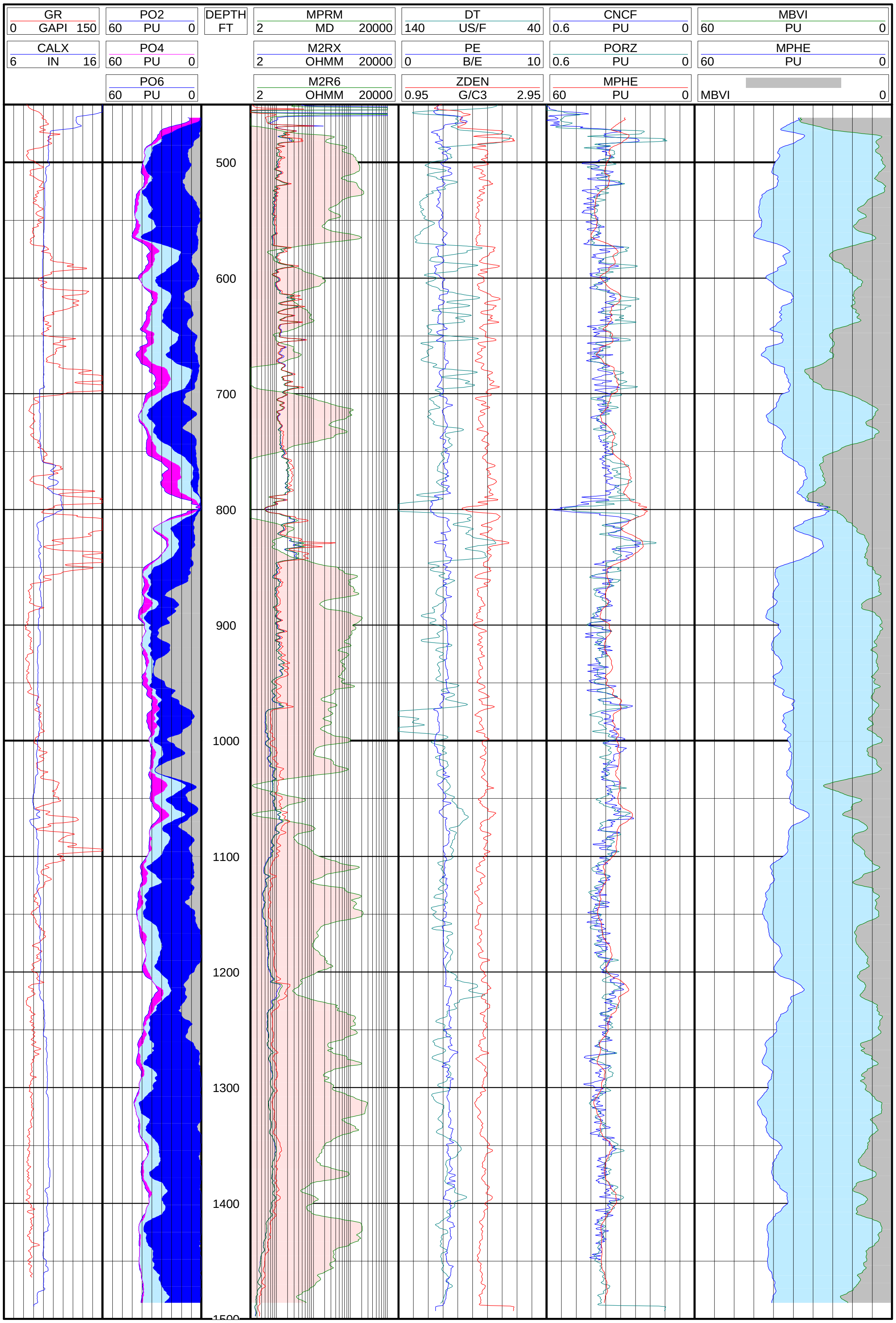
B/E	**Barnes per Electron**
CALI	**caliper**
CALX	**x-caliper**
CNCF	**neutron porosity**
cps	**counts per second**
dec	**decimal fraction**
DegF	**degrees Fahrenheit**
DelTemp	**delta temperature**
DFLOW	**flowmeter (down)**
DT	**delta transient time**
FLOWD	**flowmeter dynamic**
FT	**feet**
g/c^3	**grams per cubic centimeter**
GAPI	**gamma American Petroleum Institute units**
GR	**gamma ray**
in	**inches**
LAT6	**lateral – 6-foot resistivity**
M2R2	**shallow focused resistivity**
M2RX	**deep induction log**
M2R6	**medium induction log**
NPHI	**neutron porosity**
OHMM	**ohm-meters**
PORA	**sonic porosity**
PORZ	**density porosity**
PU	**porosity units**
RES16	**normal resistivity (16-inch)**
RES64	**normal resistivity (64-inch)**
RES(FL)	**fluid resistivity**
SP	**Spontaneous Potential**
TEMP	**temperature gradient**
US/F	**microseconds per foot**
ZDEN	**bulk density**



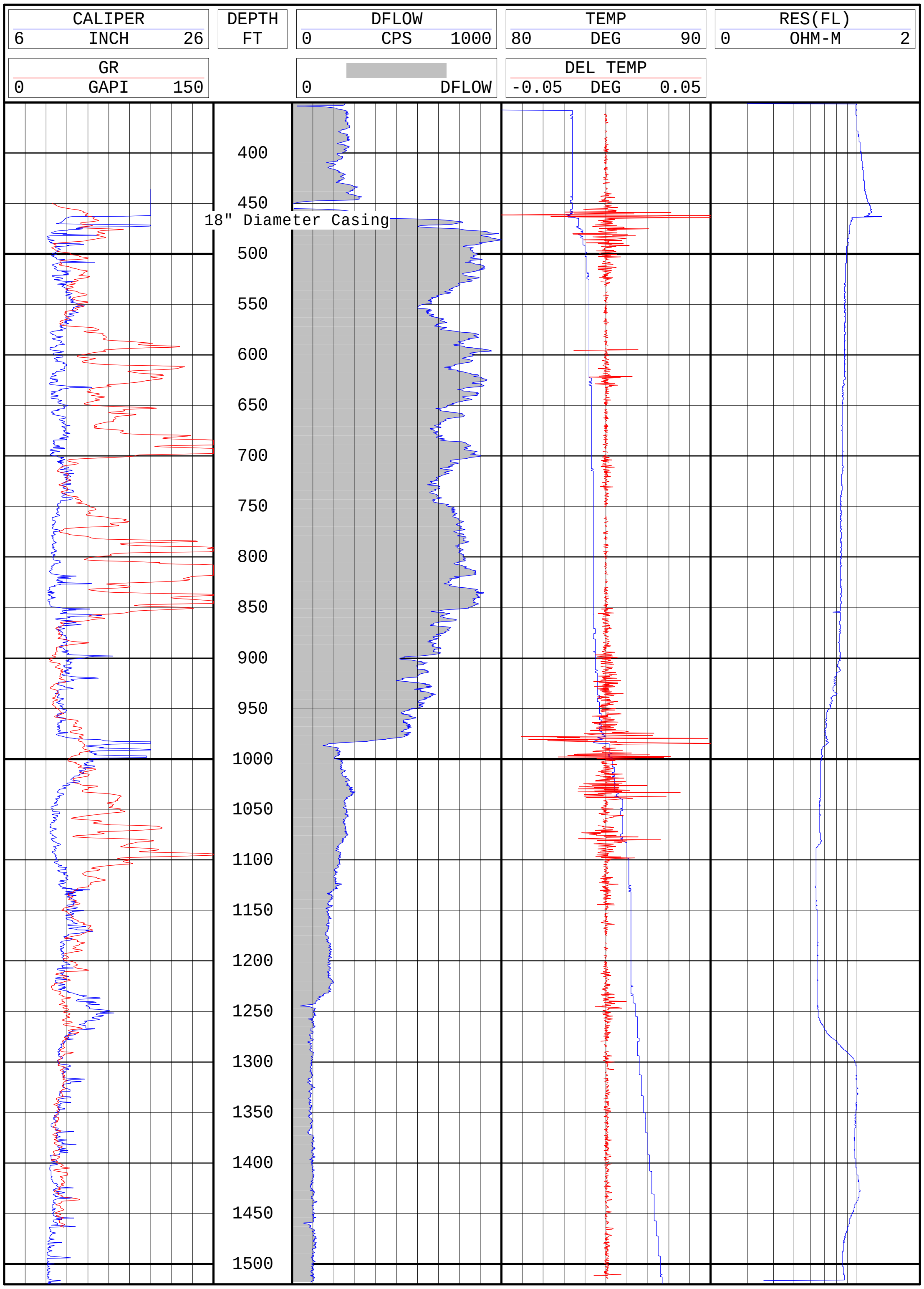
Geophysical Log Run No.1 - Big Cypress Preserve Site



Geophysical Log Data Run No. 2 – Big Cypress Preserve Site



Magnetic Resonance Log Data – Geophysical Run No. 1



Production Log Data – Geophysical Run No. 1

APPENDIX B
FLORIDA GEOLOGICAL SURVEY
LITHOLOGIC DESCRIPTIONS

LITHOLOGIC WELL LOG PRINTOUT SOURCE - FGS

WELL NUMBER: W-17801
TOTAL DEPTH: 2505 FT.
495 SAMPLES FROM 0 TO 2505 FT.
COMPLETION DATE: 14/04/98
OTHER TYPES OF LOGS AVAILABLE - NONE

COUNTY - COLLIER
LOCATION: T.52S R.30E S.34
LAT = 25D 53M 36S
LON = 81D 18M 34S
ELEVATION: 5 FT

OWNER/DRILLER:SOUTH FLORIDA WATER MANAGEMENT DISTRICT

WORKED BY:C. FISCHLER 5FT INTERVALS. COMPLETED MARCH 1999.
021-37 BICY-TW SFWMD GEOPHY #21000091 EVERGLADE CITY
FLORIDA PLANAR X 398287
0 135 121PCPC PLIO-PLEISTOCENE UNITS
135 870 122HTRN HAWTHORN GROUP
870 1265 123SWNN SUWANNEE LIMESTONE
1265 1545 124OCAL OCALA LIMESTONE
1545 2505 124AVPK AVON PARK FORMATION
NOTE: PICKS ABOVE ARE C. FISCHLER'S ORIGINAL PICKS, WHILE PICKS BELOW WERE MA
BY RICK GREEN/ TOMS SCOTT/ JON ARTHUR 6/01

0.	-100	.	121PCPC	PLIOCENE-PLEISTOCENE
100.	-470	.	122PCRV	PEACE RIVER FM.
470.	-840	.	122ARCA	ARCADIA FM.
840.	-1265	.	123SWNN	SUWANNEE LIMESTONE
1265.	-1545	.	124OCAL	OCALA GROUP
1545.	-TD	.	124AVPK	AVON PARK FM.

0 - 15 PACKSTONE; DARK YELLOWISH ORANGE TO YELLOWISH GRAY
10% POROSITY: INTERGRANULAR, MOLDIC, VUGULAR
GRAIN TYPE: PELLET, CALCILUTITE, SKELETAL
80% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: MEDIUM; RANGE: FINE TO GRANULE
GOOD INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, CALCILUTITE MATRIX
DOLOMITE CEMENT
ACCESSORY MINERALS: CALCITE-10%, SPAR-20%, QUARTZ SAND-10%
SHELL- 8%
OTHER FEATURES: DOLOMITIC, MEDIUM RECRYSTALLIZATION
FOSSILS: PLANT REMAINS, ALGAE, MOLLUSKS, CORAL
BENTHIC FORAMINIFERA
GASTROPOD CAST UP TO 4CM. WACKESTONE TO PACKSTONE. TRACE OF
SILT AND CLAY. TRACE OF PHOSPHATE. IRON STAINING. ABOUT 5%
LOOSE QUARTZ SAND. <1% CALCAREOUS SANDSTONE. LESS SHELL
WITH DEPTH.

15 - 20 LIMESTONE; YELLOWISH GRAY TO MODERATE YELLOWISH BROWN
20% POROSITY: INTERGRANULAR
GRAIN TYPE: SKELETAL, CALCILUTITE, CRYSTALS
80% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: MEDIUM; RANGE: VERY FINE TO GRANULE
POOR INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, CALCILUTITE MATRIX
DOLOMITE CEMENT
ACCESSORY MINERALS: CALCITE-20%, SPAR-15%, QUARTZ SAND-<2%

SHELL- 2%
OTHER FEATURES: MEDIUM RECRYSTALLIZATION
FOSSILS: FOSSIL FRAGMENTS, BRYOZOA, MOLLUSKS
BENTHIC FORAMINIFERA
CLAM AND GASTROPOD CAST. NUMMULITES. IRON STAINING.

20 - 35 LIMESTONE; YELLOWISH GRAY
20% POROSITY: INTERGRANULAR, MOLDIC
GRAIN TYPE: SKELETAL, CALCILUTITE, CRYSTALS
90% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: MEDIUM; RANGE: FINE TO GRANULE
POOR INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, CALCILUTITE MATRIX
DOLOMITE CEMENT
ACCESSORY MINERALS: CALCITE-15%, SPAR- 7%, QUARTZ SAND- 5%
SHELL-30%
OTHER FEATURES: LOW RECRYSTALLIZATION
FOSSILS: BENTHIC FORAMINIFERA, BRYOZOA, WORM TRACES
BARNACLES, ECHINOID
CLAM AND GASTROPOD CAST. SLIGHTLY DOLOMITIC. CORAL
NUMMULITES, PLANT REMAINS.

35 - 65 SHELL BED; YELLOWISH GRAY TO LIGHT GRAY
30% POROSITY: INTERGRANULAR; UNCONSOLIDATED
ACCESSORY MINERALS: QUARTZ SAND-10%
FOSSILS: MOLLUSKS, FOSSIL FRAGMENTS
GASTROPODS, CORAL. SAND IS SUBANGULAR TO ROUNDED, COARSE
GRAINED. TRACE OF IRON STAINED LIMESTONE(CAVINGS). TRACE OF
SANDY LIMESTONE.<1% PHOSPHATIZED SHELLS AND BRYOZOANS.TRACE
OF SANDY CLAY.

65 - 70 SHELL BED; YELLOWISH GRAY TO LIGHT OLIVE GRAY
30% POROSITY: INTERGRANULAR; UNCONSOLIDATED
ACCESSORY MINERALS: QUARTZ SAND-40%, PHOSPHATIC SAND- 2%
OTHER FEATURES: DOLOMITIC
FOSSILS: MOLLUSKS, BARNACLES
GASTROPODS. SAND IS COARSE TO GRANULE, SUBANGULAR TO
SUBROUNDED, LOW SPHERICITY AND FROSTED. TRACE OF SANDY
LIMESTONE WITH MEDIUM SIZE QUARTZ GRAINS (CAVINGS?).

70 - 95 SHELL BED; YELLOWISH GRAY TO LIGHT OLIVE GRAY
30% POROSITY: INTERGRANULAR; UNCONSOLIDATED
ACCESSORY MINERALS: QUARTZ SAND-25%, PHOSPHATIC SAND- 2%
LIMESTONE-10%
OTHER FEATURES: DOLOMITIC
FOSSILS: MOLLUSKS, BARNACLES, CORAL
GASTROPODS UP TO 2CM. PELIODAL, MOLDIC LIMESTONE WITH TRACE
OF IRON STAINING; SANDY LIMESTONE; SOME OF THE LIMESTONE IS
RECRYSTALLIZED AND COATED WITH SPAR. SAND IS POORLY SORTED
FINE TO GRANULE, FROSTED AND SUBROUNDED. TRACE OF SANDY
CLAY. TRACE OF SANDSTONE WITH PHOSPHATE MATRIX. SLIGHT
INCREASE IN PHOSPHATE AND SANDY CLAY WITH DEPTH.

95 - 120 SHELL BED; LIGHT OLIVE GRAY TO YELLOWISH GRAY
30% POROSITY: INTERGRANULAR; UNCONSOLIDATED
CEMENT TYPE(S): CLAY MATRIX
ACCESSORY MINERALS: CLAY-25%, SILT-15%, QUARTZ SAND-20%

LIMESTONE- 2%
FOSSILS: ECHINOID, MOLLUSKS, BARNACLES
BENTHIC FORAMINIFERA, SPICULES
CLAY IS SILTY AND SANDY(FINE GRAINED). LOOSE SAND IS POORLY SORTED FINE TO GRANULE. <1% PHOSPHATE. GASTROPODS SPICULES.

120 - 135 SHELL BED; VERY LIGHT ORANGE TO YELLOWISH GRAY
30% POROSITY: INTERGRANULAR; UNCONSOLIDATED
ACCESSORY MINERALS: QUARTZ SAND-10%, PHOSPHATIC SAND- 2%
LIMESTONE-25%, CALCITE-<2%
OTHER FEATURES: REEFAL
FOSSILS: CORAL, BARNACLES, MOLLUSKS, BRYOZOA
GASTROPODS, ABUNDANT BARNACLES AND CORAL. 10% SANDY SILTY CLAY-LESS WITH DEPTH. SOME IRON STAINING. SHELL DECREASES WITH DEPTH AND LIMESTONE INCREASES.

135 - 150 LIMESTONE; YELLOWISH GRAY
10% POROSITY: INTERGRANULAR
GRAIN TYPE: SKELETAL, CALCILUTITE, CRYSTALS
60% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: VERY FINE TO COARSE
POOR INDURATION
CEMENT TYPE(S): CALCILUTITE MATRIX, SPARRY CALCITE CEMENT
ACCESSORY MINERALS: QUARTZ SAND-10%, PHOSPHATIC SAND- 2%
CALCITE- 5%, SHELL-35%
OTHER FEATURES: REEFAL
FOSSILS: CORAL, WORM TRACES, BARNACLES, MOLLUSKS
BIOMICRITE AND SANDY LIMESTONE. TRACE OF PINK GRAINS. ABOUT 2% SANDY SILTY CLAY. TRACE OF QUARTZ AND PHOSPHATE GRAVEL.

150 - 180 WACKESTONE; YELLOWISH GRAY TO LIGHT OLIVE GRAY
25% POROSITY: INTERGRANULAR, MOLDIC
GRAIN TYPE: SKELETAL, CALCILUTITE, BIOGENIC
70% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: MEDIUM; RANGE: VERY FINE TO GRANULE
POOR INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, CALCILUTITE MATRIX
ACCESSORY MINERALS: QUARTZ SAND-10%, SHELL-15%
CALCITE-<3%
OTHER FEATURES: DOLOMITIC
FOSSILS: BENTHIC FORAMINIFERA, MOLLUSKS, BARNACLES, CORAL
TRACE OF SANDSTONE WITH PHOSPHATE MATRIX, AND SOME CALCAREOUS SANDSTONE. TRACE OF PHOSPHATE. SLIGHTLY DOLOMITIC. GASTROPOD AND CLAM CAST. SILTY, SANDY, FRIABLE LIMESTONE. TRACE OF ORGANICS. TRACE OF WELL-ROUNDED GRAVEL.

180 - 190 SAND; LIGHT OLIVE GRAY TO YELLOWISH GRAY
30% POROSITY: INTERGRANULAR
GRAIN SIZE: VERY COARSE; RANGE: FINE TO GRANULE
ROUNDNESS: SUB-ANGULAR TO ROUNDED; MEDIUM SPHERICITY
UNCONSOLIDATED
CEMENT TYPE(S): CLAY MATRIX, CALCILUTITE MATRIX
ACCESSORY MINERALS: LIMESTONE-15%, SHELL-20%, SILT-10%
FOSSILS: MOLLUSKS, BARNACLES, ECHINOID
TRACE OF PHOSPHATE. SAND COATED WITH SILT AND SOME POORLY INDURATED WITH SILTY CALCAREOUS MUD. TRACE OF PYRITE.

190 - 205 SAND; GRAYISH BROWN TO YELLOWISH GRAY
35% POROSITY: INTERGRANULAR, POSSIBLY HIGH PERMEABILITY
GRAIN SIZE: VERY COARSE; RANGE: MEDIUM TO GRAVEL
ROUNDNESS: SUB-ANGULAR TO ROUNDED; MEDIUM SPHERICITY
UNCONSOLIDATED
CEMENT TYPE(S): CLAY MATRIX, CALCILUTITE MATRIX
ACCESSORY MINERALS: LIMESTONE-15%, SHELL- 5%
PHOSPHATIC SAND- 5%, CLAY- 3%
FOSSILS: MOLLUSKS
LIMESTONE MAY BE CAVINGS - FRIABLE, SANDY, SHELLY, MUD
SAND IS MEDIUM TO COARSE. 30% OF SAMPLE IS >2MM WHICH
INCREASES TO ABOUT 45% WITH DEPTH. CLAY IS IN THE FORM OF
IRON STAINED CLAY BALLS CONTAINING FINE GRAINED SAND
POSSIBLY FROM BURROWS OR FECAL PELLETS. TRACE OF PYRITE.
SHELL AND LIMESTONE DECREASE WITH DEPTH.

205 - 215 SAND; YELLOWISH GRAY TO LIGHT OLIVE GRAY
30% POROSITY: INTERGRANULAR, POSSIBLY HIGH PERMEABILITY
GRAIN SIZE: COARSE; RANGE: FINE TO GRAVEL
ROUNDNESS: SUB-ANGULAR TO SUB-ROUNDED; MEDIUM SPHERICITY
UNCONSOLIDATED
ACCESSORY MINERALS: LIMESTONE-20%, SHELL-20%, CALCITE- 7%
PHOSPHATIC SAND-<3%
FOSSILS: BRYOZOA, MOLLUSKS, ECHINOID, BARNACLES
SHARKS TEETH
TRACE OF PYRITE. GASTROPODS. <1% PALE OLIVE CLAY.

215 - 240 SAND; YELLOWISH GRAY
30% POROSITY: INTERGRANULAR, POSSIBLY HIGH PERMEABILITY
GRAIN SIZE: COARSE; RANGE: MEDIUM TO GRANULE
ROUNDNESS: SUB-ANGULAR TO ROUNDED; MEDIUM SPHERICITY
UNCONSOLIDATED
ACCESSORY MINERALS: LIMESTONE- 5%, SHELL- 5%, CALCITE-<2%
PHOSPHATIC SAND- 3%
FOSSILS: ECHINOID, MOLLUSKS, BRYOZOA, BARNACLES
<1% PINK GRAINS MAYBE ROSE QUARTZ. LIMESTONE IS A
BIOMICRITE. TRACE OF REDDISH BROWN GRAINS - HEAVIES?
LIMESTONE AND SHELL DECREASE WITH DEPTH. TRACE OF PALE
OLIVE CALY.

240 - 245 SAND; YELLOWISH GRAY
30% POROSITY: INTERGRANULAR, POSSIBLY HIGH PERMEABILITY
GRAIN SIZE: COARSE; RANGE: MEDIUM TO GRAVEL
ROUNDNESS: SUB-ANGULAR TO ROUNDED; LOW SPHERICITY
UNCONSOLIDATED
ACCESSORY MINERALS: SHELL-20%, LIMESTONE-10%
PHOSPHATIC SAND- 3%, CALCITE-<1%
FOSSILS: BRYOZOA, BARNACLES, MOLLUSKS, CORAL
GASTROPOD CAST. ABOUT 10% OF SAMPLE IS QUARTZ GRAINS >2MM.
<5% FINE TO MEDIUM GRAINED QUARTZ SANDSTONE. LIMESTONE
VARIES FROM BIOMICRITE TO SANDY LIMESTONE.

245 - 270 SAND; YELLOWISH GRAY TO LIGHT OLIVE GRAY
25% POROSITY: INTERGRANULAR
GRAIN SIZE: VERY COARSE; RANGE: COARSE TO GRAVEL
ROUNDNESS: SUB-ANGULAR TO ROUNDED; MEDIUM SPHERICITY

UNCONSOLIDATED
ACCESSORY MINERALS: SHELL-35%, PHOSPHATIC SAND- 5%
SILT-<2%, LIMESTONE- 3%
FOSSILS: MOLLUSKS, BARNACLES, WORM TRACES
GASTROPODS. %PHOSPHATE INCLUDES PHOSPHATIC GRAVEL AND
SANDSTONE WITH PHOSPHATE MATRIX. TRACE OF PYRITE. SOME
SHELL FRAGMENTS ARE PARTIALLY PHOSPHATIZED. SHELL INCREASES
TO ABOUT 40%. SAND BECOMES COARSER WITH MORE GRAVEL IN THE
260-265 FT. INTERVAL.

270 - 285 SAND; YELLOWISH GRAY TO LIGHT OLIVE GRAY
25% POROSITY: INTERGRANULAR
GRAIN SIZE: COARSE; RANGE: FINE TO GRAVEL
ROUNDNESS: SUB-ANGULAR TO ROUNDED; MEDIUM SPHERICITY
UNCONSOLIDATED
ACCESSORY MINERALS: SHELL-35%, PHOSPHATIC SAND- 5%
SILT-10%, LIMESTONE-10%
FOSSILS: MOLLUSKS, BARNACLES, WORM TRACES, BRYOZOA
GASTROPODS. % SILT INCLUDES SILT AND CLAY. TRACE OF MICA.
<1% CALCAREOUS SANDSTONE. TRACE OF SANDSTONE WITH PHOSPHATE
MATRIX. ABOUT 2% PALE OLIVE CLAY. SILT INCREASES TO 15%
WITH DEPTH.

285 - 305 SHELL BED; LIGHT OLIVE GRAY TO LIGHT OLIVE
20% POROSITY: INTERGRANULAR; UNCONSOLIDATED
ACCESSORY MINERALS: PHOSPHATIC SAND- 3%, LIMESTONE-20%
QUARTZ SAND-25%, SILT-25%
FOSSILS: CORAL, MOLLUSKS, BARNACLES, WORM TRACES
CRUSTACEA
SANDY, SILTY, CLAYEY SHELL BED. % SILT INCLUDES SILT AND
CLAY. TRACE OF MICA. SAND IS COARSE GRAINED RANGE FROM FINE
TO GRAVEL AND FROSTED. SILT AND CLAY INCREASES SLIGHTLY
WITH DEPTH.

305 - 335 SILT; YELLOWISH GRAY TO LIGHT OLIVE GRAY
POOR INDURATION
CEMENT TYPE(S): CALCILUTITE MATRIX, CLAY MATRIX
ACCESSORY MINERALS: PHOSPHATIC SAND- 3%, QUARTZ SAND-35%
SHELL- 3%
OTHER FEATURES: DOLOMITIC
FOSSILS: BRYOZOA, BARNACLES, SHARKS TEETH
CALCAREOUS, SANDY, PHOSPHATIC SILT WITH FRAGMENTS OF
LIMESTONE AND SHELL POSSIBLY SOME DOLOSILT. SAND IS FINE TO
VERY FINE. PHOSPHATE IS VERY FINE GRAINED. 1% PALE OLIVE
CLAY. <1% MICA. 10% OF SAMPLE IS LOOSE MEDIUM TO COARSE
GRAINED SAND PROBABLY CAVINGS. TRACE OF PHOSPHATIC GRAVEL.
TRACE OF CALCAREOUS SANDSTONE.

335 - 355 SILT; LIGHT OLIVE GRAY TO YELLOWISH GRAY
POOR INDURATION
CEMENT TYPE(S): CALCILUTITE MATRIX, CLAY MATRIX
ACCESSORY MINERALS: QUARTZ SAND-35%, PHOSPHATIC SAND- 3%
SHELL- 5%
OTHER FEATURES: DOLOMITIC
FOSSILS: BARNACLES, PLANT REMAINS, BRYOZOA
1% PALE OLIVE CLAY. <1% CALCAREOUS SANDSTONE. <1% MICA.
ABOUT 15% LIMESTONE IS A FOSSILIFEROUS, MOLDIC

CALCILUTITE. SANDY, PHOSPHATIC, CALCAREOUS SILT (PHOSPHATE IS VERY FINE GRAINED) WITH SOME DOLOSILT. MEDIUM TO COARSE GRAINED LOOSE SAND. SHELL INCREASES WITH DEPTH TO 15%.

355 - 360 SILT; YELLOWISH GRAY TO LIGHT OLIVE GRAY
POOR INDURATION
CEMENT TYPE(S): CALCILUTITE MATRIX, CLAY MATRIX
ACCESSORY MINERALS: PHOSPHATIC SAND- 3%, SHELL-25%
QUARTZ SAND-20%
FOSSILS: MOLLUSKS
SAND VARIES FROM VERY FINE TO GRAVEL. TRACE OF MICA. ABOUT 15% LIMESTONE IS FRAGMENTED.

360 - 375 SILT; LIGHT OLIVE GRAY
POOR INDURATION
CEMENT TYPE(S): CALCILUTITE MATRIX, CLAY MATRIX
ACCESSORY MINERALS: SHELL- 5%, QUARTZ SAND-25%
PHOSPHATIC SAND- 3%, LIMESTONE- 5%
FOSSILS: MOLLUSKS, ECHINOID
SANDY SHELLY CALCAREOUS SILT. SLIGHTLY DOLOMITIC. TRACE OF WHITE CALCAREOUS SANDSTONE. <1% QUARTZ GRAVEL AND PEBBLE. TRACE OF MICA.

375 - 405 SAND; YELLOWISH GRAY TO LIGHT OLIVE GRAY
30% POROSITY: INTERGRANULAR
GRAIN SIZE: COARSE; RANGE: MEDIUM TO GRANULE
ROUNDNESS: SUB-ANGULAR TO ROUNDED; MEDIUM SPHERICITY
UNCONSOLIDATED
ACCESSORY MINERALS: SILT-20%, SHELL-10%, LIMESTONE- 5%
PHOSPHATIC SAND- 5%
FOSSILS: BRYOZOA, MOLLUSKS, SHARKS TEETH
BENTHIC FORAMINIFERA, BARNACLES
GASTROPODS. TRACE OF PHOSPHATIC GRAVEL AND QUARTZ GRAVEL. TRACE OF CALCAREOUS SANDSTONE. SLIGHTLY DOLOMITIC. TRACE OF MICA. CLAY BALLS.

405 - 415 SAND; YELLOWISH GRAY TO YELLOWISH GRAY
25% POROSITY: INTERGRANULAR
GRAIN SIZE: MEDIUM; RANGE: VERY FINE TO GRANULE
ROUNDNESS: SUB-ANGULAR TO ROUNDED; MEDIUM SPHERICITY
UNCONSOLIDATED
ACCESSORY MINERALS: LIMESTONE-30%, SILT-25%, SHELL-10%
PHOSPHATIC SAND- 5%
FOSSILS: MOLLUSKS, ECHINOID
TRACE OF QUARTZ AND PHOSPHATIC GRAVEL. <1% CLAY BALLS.

415 - 430 SAND; YELLOWISH GRAY
25% POROSITY: INTERGRANULAR
GRAIN SIZE: MEDIUM; RANGE: VERY FINE TO GRANULE
ROUNDNESS: SUB-ANGULAR TO ROUNDED; MEDIUM SPHERICITY
UNCONSOLIDATED
ACCESSORY MINERALS: LIMESTONE-15%, SILT-30%
PHOSPHATIC SAND- 5%, CLAY- 5%
OTHER FEATURES: DOLOMITIC
FOSSILS: MOLLUSKS, ECHINOID, BENTHIC FORAMINIFERA
PLANT REMAINS, CORAL
GASTROPODS, SHARK TEETH. TRACE OF PALE OLIVE CLAY. TRACE OF

MICA. SOME OF THE GRAVEL IS DISK SHAPED. 7% SHELL
FRAGMENTS. % PHOSPATE INCLUDES PHOSPHATIC GRAVEL.

430 - 435 SILT; LIGHT OLIVE GRAY
POOR INDURATION
CEMENT TYPE(S): CALCILUTITE MATRIX, CLAY MATRIX
ACCESSORY MINERALS: LIMESTONE-10%, QUARTZ SAND-30%
PHOSPHATIC SAND- 5%, SHELL- 8%
FOSSILS: SHARKS TEETH, MOLLUSKS, WORM TRACES
VARIES FROM SANDY PHOSPHATIC SILT TO SILTY PHOSPHATIC
SANDSTONE WITH SHELLS THROUGHOUT. SAND IS VERY FINE GRAINED
TO GRAVEL.

435 - 470 SILT; LIGHT OLIVE GRAY TO YELLOWISH GRAY
POOR INDURATION
CEMENT TYPE(S): CALCILUTITE MATRIX, CLAY MATRIX
ACCESSORY MINERALS: QUARTZ SAND-15%, CLAY- 5%, SHELL-25%
PHOSPHATIC SAND- 7%
OTHER FEATURES: DOLOMITIC
FOSSILS: MOLLUSKS, WORM TRACES, CORAL, BARNACLES, ALGAE
TRACE OF PYRITE. % PHOSPHATE INCLUDES PHOSPHATIC GRAVEL
MOST OF THE PHOSPHATE IS VERY FINE GRAINED. 15% LIMESTONE
WHICH INCREASES TO 25% AND SAND DECREASES TO 5% WITH DEPTH.

470 - 600 LIMESTONE; YELLOWISH GRAY
20% POROSITY: INTERGRANULAR
GRAIN TYPE: CRYSTALS, SKELETAL, CALCILUTITE
60% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRANULE
MODERATE INDURATION
CEMENT TYPE(S): DOLOMITE CEMENT, SPARRY CALCITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: PHOSPHATIC SAND- 3%, DOLOMITE-10%
QUARTZ SAND- 3%, CALCITE-<1%
OTHER FEATURES: MEDIUM RECRYSTALLIZATION, DOLOMITIC
FOSSILS: BENTHIC FORAMINIFERA, SHARKS TEETH, BRYOZOA
ECHINOID
NUMMULITES, CLAM AND GASTROPOD CAST. SMALL AMOUNT OF
DOLOSTONE HAS UP TO 25% PHOSPHATE. SHELL <3%. SAND
DECREASES TO A TRACE AND CALCITE INCREASES WITH DEPTH.

600 - 690 LIMESTONE; YELLOWISH GRAY
20% POROSITY: INTERGRANULAR, PIN POINT VUGS
GRAIN TYPE: CRYSTALS, CALCILUTITE, SKELETAL
60% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRANULE
MODERATE INDURATION
CEMENT TYPE(S): DOLOMITE CEMENT, SPARRY CALCITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: PHOSPHATIC SAND- 3%, CALCITE- 5%
SPAR- 5%
OTHER FEATURES: DOLOMITIC, MEDIUM RECRYSTALLIZATION
FOSSILS: ECHINOID, BENTHIC FORAMINIFERA, FOSSIL FRAGMENTS
CLAM AND GASTROPOD CAST. <1% SILTY CALCAREOUS CLAY.
DOLOMITIC MICROCRYSTALLINE LIMESTONE WITH FINE GRAINED
PHOSPHATE. CALCILUTITE WITH FINE GRAINED PHOSPHATE. MOLDIC
LIMESTONE. SHELL <2%. TRACE OF SAND. DECREASE IN PHOSPHATE

WITH DEPTH.

690 - 695 NO SAMPLES

695 - 770 LIMESTONE; YELLOWISH GRAY
15% POROSITY: INTERGRANULAR, PIN POINT VUGS
GRAIN TYPE: CRYSTALS, CALCILUTITE, BIOGENIC
60% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRANULE
MODERATE INDURATION
CEMENT TYPE(S): DOLOMITE CEMENT, SPARRY CALCITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: PHOSPHATIC SAND- 5%
OTHER FEATURES: DOLOMITIC, MEDIUM RECRYSTALLIZATION
FOSSILS: FOSSIL FRAGMENTS, BRYOZOA, CRUSTACEA
SHARKS TEETH, BENTHIC FORAMINIFERA
CLAM AND GASTROPOD CAST. DOLOMITIC MICROCRYSTALLINE
LIMESTONE WITH FINE GRAINED PHOSPHATE. FOSSILIFEROUS
CALCILUTITE. TRACE OF SAND. <1% SHELL. % PHOSPHATE VARIES
WITHIN SAMPLE.

770 - 830 LIMESTONE; YELLOWISH GRAY
15% POROSITY: INTERGRANULAR, PIN POINT VUGS
GRAIN TYPE: CRYSTALS, CALCILUTITE, SKELETAL
70% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRANULE
MODERATE INDURATION
CEMENT TYPE(S): DOLOMITE CEMENT, SPARRY CALCITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: PHOSPHATIC SAND- 8%, QUARTZ SAND- 3%
CALCITE- 2%, SILT-<2%
OTHER FEATURES: DOLOMITIC, MEDIUM RECRYSTALLIZATION
FOSSILS: BENTHIC FORAMINIFERA, ECHINOID, BRYOZOA
FOSSIL FRAGMENTS, BARNACLES
CLAM AND GASTROPOD CAST.LITHOLOGY VARIES: MICROCRYSTALLINE
LIMESTONE WITH VERY FINE GRAINED PHOSPHATE; VERY FINE
GRAINED, SANDY, PHOSPHATIC LIMESTONE; BIOMICRITE.PHOSPHATE
AND SAND DECREASE WITH DEPTH. <1% SHELL FRAGMENTS. LESS
INDURATED WITH DEPTH.

830 - 845 LIMESTONE; YELLOWISH GRAY
20% POROSITY: INTERGRANULAR
GRAIN TYPE: CALCILUTITE, SKELETAL, CRYSTALS
80% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRANULE
MODERATE INDURATION
CEMENT TYPE(S): DOLOMITE CEMENT, CALCILUTITE MATRIX
SPARRY CALCITE CEMENT
ACCESSORY MINERALS: PHOSPHATIC SAND- 1%, CALCITE- 5%
QUARTZ SAND-<1%
OTHER FEATURES: DOLOMITIC, LOW RECRYSTALLIZATION
FOSSILS: BENTHIC FORAMINIFERA, FOSSIL FRAGMENTS, ALGAE
PHOSPHATIZED DICTYOCONUS COOKEI. CLAM AND GASTROPOD CAST.
LITHOLOGY VARIES: POORLY INDURATED FOSSILIFEROUS
CALCILUTITE; RECRYSTALLIZED MICRITE; MICROCRYSTALLINE
FOSSILIFEROUS LIMESTONE WITH VERY FINE GRAINED PHOSPHATE.

845 - 870 LIMESTONE; YELLOWISH GRAY
20% POROSITY: INTERGRANULAR
GRAIN TYPE: SKELETAL, CALCILUTITE, CRYSTALS
80% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRANULE
MODERATE INDURATION
CEMENT TYPE(S): DOLOMITE CEMENT, SPARRY CALCITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: PHOSPHATIC SAND-<1%, SPAR- 2%
OTHER FEATURES: LOW RECRYSTALLIZATION, DOLOMITIC
FOSSILS: BRYOZOA, CRUSTACEA, BENTHIC FORAMINIFERA, CORAL
GASTROPOD AND CLAM CAST. NUMMULITES. LITHOLOGY VARIES:
FOSSILIFEROUS MICRITE; MICROCRYSTALLINE FOSSILIFEROUS
LIMESTONE. FEW GRAVEL SIZE PIECES OF PHOSPHATE AND COARSE
GRAINED PHOSPHATE.

870 - 995 LIMESTONE; YELLOWISH GRAY
15% POROSITY: INTERGRANULAR, PIN POINT VUGS, MOLDIC
GRAIN TYPE: CALCILUTITE, SKELETAL, CRYSTALS
80% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRANULE
MODERATE INDURATION
CEMENT TYPE(S): DOLOMITE CEMENT, SPARRY CALCITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: PHOSPHATIC SAND- 2%, SPAR- 5%
OTHER FEATURES: MEDIUM RECRYSTALLIZATION, DOLOMITIC
FOSSILS: FOSSIL FRAGMENTS, BENTHIC FORAMINIFERA, BRYOZOA
ALGAE, CORAL
WACKESTONE TO PACKSTONE. GASTROPOD AND CLAM CAST. CORAL
SPIROLINA, DICTYOCONUS. TRACE OF SAND. TRACE OF CLAY.
PHOSPHATE IN THE LIMESTONE VARIES FROM 0% TO 30%. LIMESTONE
WITH A HIGHER % OF PHOSPHATE PROBABLY IS CAVINGS. PHOSPHATE
DECREASES WITH DEPTH. LESS DOLOMITIC.

995 - 1020 LIMESTONE; YELLOWISH GRAY
15% POROSITY: INTERGRANULAR, MOLDIC
GRAIN TYPE: SKELETAL, CALCILUTITE, CRYSTALS
90% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: MEDIUM; RANGE: MICROCRYSTALLINE TO GRANULE
MODERATE INDURATION
CEMENT TYPE(S): CALCILUTITE MATRIX, SPARRY CALCITE CEMENT
ACCESSORY MINERALS: QUARTZ SAND- 5%, CALCITE- 3%, SPAR-<2%
OTHER FEATURES: LOW RECRYSTALLIZATION
FOSSILS: BRYOZOA, FOSSIL FRAGMENTS, BENTHIC FORAMINIFERA
CRUSTACEA
CLAM AND GASTROPOD CAST. SPIROLINA. WACKESTONE TO
PACKSTONE. TRACE OF PHOSPHATE.

1020 - 1070 PACKSTONE; YELLOWISH GRAY
20% POROSITY: INTERGRANULAR, PIN POINT VUGS, MOLDIC
GRAIN TYPE: SKELETAL, CALCILUTITE, CRYSTALS
90% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRANULE
MODERATE INDURATION
CEMENT TYPE(S): CALCILUTITE MATRIX, SPARRY CALCITE CEMENT
ACCESSORY MINERALS: QUARTZ SAND- 5%, SPAR- 2%, CLAY-<1%
CALCITE-<1%

OTHER FEATURES: LOW RECRYSTALLIZATION
FOSSILS: CORAL, BENTHIC FORAMINIFERA, BARNACLES, CRUSTACEA MILIOLIDS
CLAM AND GASTROPOD CAST. ECHINOID. SLIGHT INCREASE IN CLAY WITH DEPTH. MICROCRYSTALLINE MICRITE; FOSSILIFEROUS LIMESTONE; SANDY LIMESTONE. TRACE OF PHOSPHATE. PEBBLE SIZE PIECE OF PHOSPHATE. EUHEDRAL DOLOMITE CRYSTLS ON CLAM CAST.

1070 - 1105 PACKSTONE; YELLOWISH GRAY
15% POROSITY: INTERGRANULAR, MOLDIC, PIN POINT VUGS
GRAIN TYPE: CALCILUTITE, SKELETAL, CRYSTALS
70% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRANULE
MODERATE INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, CALCILUTITE MATRIX DOLOMITE CEMENT
ACCESSORY MINERALS: QUARTZ SAND- 3%, CALCITE- 1%, SPAR-<2% PHOSPHATIC SAND-<2%
OTHER FEATURES: LOW RECRYSTALLIZATION
FOSSILS: BENTHIC FORAMINIFERA, CRUSTACEA, SHARKS TEETH BRYOZOA
CLAM AND GASTROPOD CAST. MICROCRYSTALLINE LIMESTONE FOSSILIFEROUS MICRITE, SMALL AMOUNT OF SANDY MICRITE. WACKESTONE TO PACKSTONE. PHOSPHATE IS CONCENTRATED IN THE MICROCRYSTALLINE AND SANDY LIMESTONE (CAVINGS?). TRACE OF ORGANICS. TRACE OF CLAY. EUHEDRAL DOLOMITE CRYSTALS WITH CALCAREOUS MATRIX. SLIGHTLY LESS PHOSPHATE WITH DEPTH.

1105 - 1110 NO SAMPLES

1110 - 1160 LIMESTONE; YELLOWISH GRAY
15% POROSITY: INTERGRANULAR, MOLDIC
GRAIN TYPE: SKELETAL, CRYSTALS, CALCILUTITE
70% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: VERY FINE; RANGE: MICROCRYSTALLINE TO GRANULE
MODERATE INDURATION
CEMENT TYPE(S): CALCILUTITE MATRIX, SPARRY CALCITE CEMENT DOLOMITE CEMENT
ACCESSORY MINERALS: QUARTZ SAND- 3%, CALCITE- 2%, SPAR- 1% PHOSPHATIC SAND-<1%
FOSSILS: BENTHIC FORAMINIFERA, SHARKS TEETH, ECHINOID CRUSTACEA
CLAM AND GASTROPOD CAST. GYPSINA. MICROCRYSTALLINE LIMESTONE, FOSSILIFEROUS MICRITE, ABOUT 1% MICROCRYSTALLINE DOLOMITE WITH CALCAREOUS MATRIX. TRACE OF CLAY. TRACE OF SANDY LIMESTONE. CALCITE INCREASES WITH DEPTH. SAND DECREASES WITH DEPTH.

1160 - 1235 PACKSTONE; YELLOWISH GRAY
20% POROSITY: INTERGRANULAR, MOLDIC
GRAIN TYPE: SKELETAL, PELLET, CRYSTALS
80% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRANULE
MODERATE INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, CALCILUTITE MATRIX DOLOMITE CEMENT
ACCESSORY MINERALS: CALCITE- 3%, PHOSPHATIC SAND-<1%

QUARTZ SAND-<1%
FOSSILS: MILIOLIDS, BENTHIC FORAMINIFERA, ECHINOID
CRUSTACEA, BRYOZOA
CLAM AND GASTROPOD CAST. FOSSILIFEROUS MICRITE. PACKSTONE TO WACKESTONE. TRACE OF ORGANICS. TRACE OF CLAY. ABOUT 1% EUHEDRAL DOLOMITE WITH CALCAREOUS MATRIX. DECREASE IN CALCITE WITH DEPTH. DOLOMITE INCREASES TO ABOUT 3% THEN DECREASES AGAIN.

1235 - 1265 PACKSTONE; YELLOWISH GRAY
20% POROSITY: INTERGRANULAR, MOLDIC, PIN POINT VUGS
GRAIN TYPE: SKELETAL, PELLET, CRYSTALS
90% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRANULE
MODERATE INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, CALCILUTITE MATRIX
DOLOMITE CEMENT
ACCESSORY MINERALS: QUARTZ SAND-<1%, PHOSPHATIC SAND-<1%
CALCITE- 1%
FOSSILS: BRYOZOA, ECHINOID, WORM TRACES
BENTHIC FORAMINIFERA, MOLLUSKS
CLAM AND GASTROPOD CAST. NUMMULITES. TRACE OF CLAY.FOSSILIFEROUS LIMESTONE; MICROCRYSTALLINE LIMESTONE 1% DOLOMITE - EUHEDRAL CRYSTALS WITH CALCAREOUS MATRIX.

1265 - 1310 PACKSTONE; YELLOWISH GRAY
25% POROSITY: INTERGRANULAR, PIN POINT VUGS, MOLDIC
GRAIN TYPE: SKELETAL, PELLET, CRYSTALS
90% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRAVEL
MODERATE INDURATION
CEMENT TYPE(S): CALCILUTITE MATRIX, SPARRY CALCITE CEMENT
DOLOMITE CEMENT
ACCESSORY MINERALS: CALCITE-<1%
FOSSILS: BENTHIC FORAMINIFERA, CRUSTACEA, ECHINOID
BRYOZOA
CLAM AND GASTROPOD CAST. LEPIDOCYCLINA OCALANA SPHAEROGYPSINA GLOBULA. FOSSILIFEROUS LIMESTONE MICROCRYSTALLINE PARTIALLY DOLOMITIZED LIMESTONE. TRACE OF PHOSPHATE. TRACE OF QUARTZ SAND. TRACE OF ORGANICS. TRACE OF CLAY.

1310 - 1370 PACKSTONE; YELLOWISH GRAY
20% POROSITY: INTERGRANULAR, INTERCRYSTALLINE
PIN POINT VUGS
GRAIN TYPE: SKELETAL, CRYSTALS, CALCILUTITE
70% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRAVEL
MODERATE INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, DOLOMITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: CALCITE- 3%, DOLOMITE- 5%
FOSSILS: BENTHIC FORAMINIFERA, ECHINOID, BRYOZOA
CRUSTACEA
WACKESTONE TO PACKSTONE. SOME MOLDIC. SHARP DECREASE IN LEPIDOCYCLINA AT 1320 FT THEN AN INCREASE AT ABOUT 1335 FT. DOLOMITE IS EUHEDRAL TO SUBHEDRAL-FINE TO MEDIUM GRAINED

SUCROSIC AND FOSSILIFEROUS. TRACE OF QUARTZ SAND AND PHOSPHATE. CLAM AND GASTROPOD CAST. TRACE OF ORGANICS. LEPIDOCYCLINA (LARGE LEP FRAGMENTS), ABUNDANT NUMMULITES. SPHAEROGYPSINA GLOBULA. TRACE OF CLAY. PYRITIZED FORAM.

1370 - 1425 PACKSTONE; YELLOWISH GRAY
25% POROSITY: INTERGRANULAR
GRAIN TYPE: SKELETAL, BIOGENIC
90% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: MEDIUM; RANGE: MICROCRYSTALLINE TO GRAVEL
POOR INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, DOLOMITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: CALCITE- 5%, DOLOMITE- 1%, SHELL-<1%
OTHER FEATURES: LOW RECRYSTALLIZATION
FOSSILS: BENTHIC FORAMINIFERA, ECHINOID, BRYOZOA
CRUSTACEA
ABUNDANT LEPIDOCYCLINA AND NUMMULITES (LEP FRAGMENTS ARE LARGE). HETEROSTEGINA OCALANA, SPIROLINA, BONE FRAGMENT AND SAND DOLLAR (OLIGOPYGUS WHETHERBY). PACKSTONE TO CALCARENITE. MUCH OF SAMPLE IS LOOSE FORAMS (CALCARENITE). TRACE OF PHOSPHATE AND QUARTZ SAND. TRACE OF ORGANICS. TRACE OF CLAY. DOLOMITE IS MICROCRYSTALLINE FINE TO MEDIUM GRAINED AND SOME DOLOMITIZED FORAMS. SOME IRON STAINING STARTING AT 1415 FT.

1425 - 1535 LIMESTONE; YELLOWISH GRAY
25% POROSITY: INTERGRANULAR
GRAIN TYPE: SKELETAL, CRYSTALS, BIOGENIC
70% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRAVEL
POOR INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, DOLOMITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: CALCITE- 7%, SHELL-<1%
OTHER FEATURES: LOW RECRYSTALLIZATION
FOSSILS: BENTHIC FORAMINIFERA, ECHINOID, BRYOZOA
CLAM AND GASTROPOD CAST. ABUNDANT LEPIDOCYCLINA AND NUMMULITES. MUCH OF SAMPLE IS LOOSE FRAGMENTS OF FORAMS. ABOUT 5% OF SAMPLE IS DOLOMITIZED. TRACE OF ORGANICS. TRACE OF PHOSPHATE AND QUARTZ SAND. SMALL AMOUNT OF IRON STAINING THROUGHOUT INTERVAL. OLIVE GRAY COLORED CLAY BALLS AT 1515-1525 FT. RECRYSTALLIZATION INCREASES TOWARD BOTTOM.

1535 - 1545 LIMESTONE; YELLOWISH GRAY
25% POROSITY: INTERGRANULAR, INTERCRYSTALLINE
PIN POINT VUGS
GRAIN TYPE: SKELETAL, CRYSTALS, CALCILUTITE
60% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: MICROCRYSTALLINE
RANGE: MICROCRYSTALLINE TO GRAVEL; POOR INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, DOLOMITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: CALCITE- 7%, DOLOMITE-25%
OTHER FEATURES: LOW RECRYSTALLIZATION
FOSSILS: BENTHIC FORAMINIFERA, ECHINOID
DOLOMITE IS EUHEDRAL TO SUBHEDRAL, VERY FINE TO FINE

GRAINED, AND SUCROSIC. MUCH OF SAMPLE IS LOOSE FORAMS. LIMESTONE IS VERY FINE GRAINED PARTIALLY DOLOMITIZED. TRACE OF ORGANICS. LEPIDOCYCLINA AND NUMMULITES.

1545 - 1555 DOLOSTONE; YELLOWISH GRAY
20% POROSITY: INTERGRANULAR, INTERCRYSTALLINE
PIN POINT VUGS; 50-90% ALTERED; SUBHEDRAL
GRAIN SIZE: VERY FINE; RANGE: VERY FINE TO FINE
MODERATE INDURATION
CEMENT TYPE(S): DOLOMITE CEMENT, SPARRY CALCITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: CALCITE- 5%, LIMESTONE-30%
OTHER FEATURES: MEDIUM RECRYSTALLIZATION, SUCROSIC
FOSSILS: BENTHIC FORAMINIFERA, ECHINOID
LIMESTONE IS VERY FINE GRAINED. TRACE OF ORGANICS. LEPIDOCYCLINA, SPHAEROGYPSINA GLOBULA, ABUNDANT NUMMULITES.

1555 - 1580 LIMESTONE; YELLOWISH GRAY TO GRAYISH BROWN
15% POROSITY: INTERGRANULAR, INTERCRYSTALLINE, MOLDIC
GRAIN TYPE: SKELETAL, CRYSTALS, CALCILUTITE
80% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: MEDIUM; RANGE: FINE TO GRAVEL
MODERATE INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, DOLOMITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: DOLOMITE-30%, CALCITE-25%, SPAR- 7%
OTHER FEATURES: MEDIUM RECRYSTALLIZATION
FOSSILS: BENTHIC FORAMINIFERA, ECHINOID, ALGAE
WORM TRACES, CORAL
CLAM AND GASTROPOD CAST. ABUNDANT ECHINOID AND ECHINOID FRAGMENTS RECRYSTALLIZED. DICTYOCONUS AMERICANUS HETEROSTEGINA, LEPIDOCYCLINA, NUMMULITES. LIMESTONE IS FOSSILIFEROUS. DOLOMITE IS SUCROSIC AND FINE GRAINED. TRACE OF ORGANICS.

1580 - 1600 PACKSTONE; VERY LIGHT ORANGE TO YELLOWISH GRAY
20% POROSITY: INTERGRANULAR, MOLDIC, VUGULAR
GRAIN TYPE: SKELETAL, SKELTAL CAST, CALCILUTITE
95% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: MEDIUM; RANGE: VERY FINE TO GRAVEL
MODERATE INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, CALCILUTITE MATRIX
ACCESSORY MINERALS: CALCITE-25%, SPAR-10%, DOLOMITE-10%
OTHER FEATURES: MEDIUM RECRYSTALLIZATION
FOSSILS: BENTHIC FORAMINIFERA, CORAL, ECHINOID
FOSSIL FRAGMENTS
DICTYOCONUS, NUMMULITES, LEPIDOCYCLINA, SPIROLINA, ABUNDANT ECHINOID FRAGMENTS. CLAM AND GASTROPOD CAST. LIMESTONE IS FOSSILIFEROUS PACKSTONE TO GRAINSTONE. DOLOMITE IS FINE GRAINED AND SUCROSIC.

1600 - 1735 GRAINSTONE; VERY LIGHT ORANGE TO YELLOWISH GRAY
25% POROSITY: INTERGRANULAR, POSSIBLY HIGH PERMEABILITY
GRAIN TYPE: SKELETAL, SKELTAL CAST, CALCILUTITE
95% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: MEDIUM; RANGE: VERY FINE TO GRAVEL
MODERATE INDURATION

```
                  CEMENT TYPE(S): SPARRY CALCITE CEMENT, CALCILUTITE MATRIX
                  ACCESSORY MINERALS: CALCITE-10%, SPAR-10%, DOLOMITE- 2%
                  OTHER FEATURES: LOW RECRYSTALLIZATION
                  FOSSILS: BENTHIC FORAMINIFERA, ECHINOID, FOSSIL FRAGMENTS
                  CORAL, CRUSTACEA
                  CLAM AND GASTROPOD CAST. MANY DICTYOCONUS. NUMMULITES
                  LEPIDOCYCLINA, MILIOLIDS, HETEROSTEGINA, SPIROLINA, AND
                  BRYOZOANS. FEW PYRITIZED FORAMS. TRACE OF ORGANICS. SLIGHT
                  INCREASE IN DOLOMITE TOWARD BOTTOM. <1% CLAY POORLY
                  CONSOLIDATED CLAY IN 1675 FT. INTERVAL.

1735  - 1770      PACKSTONE; VERY LIGHT ORANGE TO WHITE
                  20% POROSITY: INTERGRANULAR, INTERCRYSTALLINE
                  GRAIN TYPE: SKELETAL, CALCILUTITE, CRYSTALS
                  75% ALLOCHEMICAL CONSTITUENTS
                  GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRAVEL
                  MODERATE INDURATION
                  CEMENT TYPE(S): SPARRY CALCITE CEMENT, DOLOMITE CEMENT
                  CALCILUTITE MATRIX
                  ACCESSORY MINERALS: CALCITE-10%, SPAR- 5%, DOLOMITE-10%
                  OTHER FEATURES: MEDIUM RECRYSTALLIZATION
                  FOSSILS: BENTHIC FORAMINIFERA, ECHINOID, BRYOZOA
                  FOSSIL FRAGMENTS
                  WACKESTONE TO PACKSTONE. DOLOMITE IS EUEDRAL TO SUBHEDRAL
                  FINE GRAINED, AND SUCROSIC. <1% ORGANICS. TRACE OF CLAY.
                  CLAM AND GASTROPOD CAST. DICTYOCONUS, NUMMULITES
                  LEPIDOCYCLINA, AND SPIROLINA.

1770  - 1775      NO SAMPLES

1775  - 1805      PACKSTONE; YELLOWISH GRAY
                  20% POROSITY: INTERGRANULAR, INTERCRYSTALLINE, MOLDIC
                  GRAIN TYPE: SKELETAL, CRYSTALS, CALCILUTITE
                  70% ALLOCHEMICAL CONSTITUENTS
                  GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRAVEL
                  MODERATE INDURATION
                  CEMENT TYPE(S): SPARRY CALCITE CEMENT, DOLOMITE CEMENT
                  CALCILUTITE MATRIX
                  SEDIMENTARY STRUCTURES: LAMINATED
                  ACCESSORY MINERALS: CALCITE-15%, SPAR- 7%, DOLOMITE-10%
                  FOSSILS: BENTHIC FORAMINIFERA, ECHINOID, FOSSIL FRAGMENTS
                  CORAL
                  WACKESTONE TO GRAINSTONE. CLAM AND GASTROPOD CAST.
                  NUMMULITES, LEPIDOCYCLINA, ABUNDANT DICTYOCONUS. <1%
                  ORGANICS. TRACE OF FOSSILIFEROUS CLAY POORLY INDURATED.

1805  - 1825      WACKESTONE; VERY LIGHT ORANGE
                  20% POROSITY: INTERGRANULAR, INTERCRYSTALLINE, MOLDIC
                  GRAIN TYPE: SKELETAL, CRYSTALS, CALCILUTITE
                  60% ALLOCHEMICAL CONSTITUENTS
                  GRAIN SIZE: VERY FINE; RANGE: MICROCRYSTALLINE TO GRAVEL
                  MODERATE INDURATION
                  CEMENT TYPE(S): SPARRY CALCITE CEMENT, DOLOMITE CEMENT
                  CALCILUTITE MATRIX
                  SEDIMENTARY STRUCTURES: LAMINATED
                  ACCESSORY MINERALS: CALCITE- 7%, SPAR-10%, DOLOMITE-10%
                  ORGANICS-<2%
```

FOSSILS: BENTHIC FORAMINIFERA, ECHINOID, FOSSIL FRAGMENTS
CRUSTACEA
WACKESTONE TO PACKSTONE. LEPIDOCYCLINA, NUMMULITES
DICTYOCONUS. TRACE OF POORLY INDURATED FOSSILIFEROUS CLAY.
DOLOMITE IS EUHEDRAL TO SUBHEDRAL FINE GRAINED WITH
CALCILUTITE MATRIX. DOLOMITE INCREASES TO 20% THEN
DECREASES.

1825 - 1920 PACKSTONE; VERY LIGHT ORANGE
20% POROSITY: INTERGRANULAR, MOLDIC, PIN POINT VUGS
GRAIN TYPE: SKELETAL, CRYSTALS, CALCILUTITE
90% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRAVEL
MODERATE INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, DOLOMITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: CALCITE- 5%, SPAR- 3%, DOLOMITE-<5%
ORGANICS-<2%
FOSSILS: BENTHIC FORAMINIFERA, FOSSIL FRAGMENTS
WACKESTONE TO GRAINSTONE. MANY DICTYOCONUS. DICTYOCONUS ARE
CORRODED AND SQUASHED. NUMMULITES, LEPIDOCYCLINA. TRACE OF
POORLY INDURATED FOSSILIFEROUS CLAY. TRACE OF ORGANICS.
LAMINATIONS PRESENT FOR TOP 20 FT. DOLOMITE DECREASES TO A
TRACE WITH DEPTH.

1920 - 1970 PACKSTONE; YELLOWISH GRAY
25% POROSITY: INTERGRANULAR
GRAIN TYPE: SKELETAL, CALCILUTITE
70% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRAVEL
MODERATE INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, CALCILUTITE MATRIX
ACCESSORY MINERALS: CALCITE-<2%, SPAR-<1%, SHELL-<1%
FOSSILS: BENTHIC FORAMINIFERA, FOSSIL FRAGMENTS, ECHINOID
CRUSTACEA
GRADUAL CHANGE FROM PREVIOUSLY DESCRIBED INTERVAL.
WACKESTONE TO PACKSTONE. ABUNDANT DICTYOCONUS-ERODED.
LEDIDOCYCLINA, NUMMULITES. <1% POORLY INDURATED CALCAREOUS
SILT. TRACE OF ORGANICS WHICH INCREASE SLIGHTLY WITH DEPTH.
TRACE OF PYRITE TOWARD BOTTOM.

1970 - 2010 PACKSTONE; VERY LIGHT ORANGE
20% POROSITY: INTERGRANULAR, MOLDIC
GRAIN TYPE: SKELETAL, CALCILUTITE
90% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: MEDIUM; RANGE: VERY FINE TO GRAVEL
MODERATE INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, DOLOMITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: CALCITE-<2%, SPAR- 5%, DOLOMITE-<1%
SHELL-<1%
OTHER FEATURES: LOW RECRYSTALLIZATION
FOSSILS: BENTHIC FORAMINIFERA, FOSSIL FRAGMENTS, CORAL
ALGAE
CLAM AND GASTROPOD CAST. ABUNDANT DICTYOCONUS. NUMMULITES
COSKINOLINA. WACKESTONE TO GRAINSTONE. MUCH OF THE
LIMESTONE HAS A VERY FINE COATING OF SPARRY CALCITE. TRACE

OF ORGANICS.

2010 - 2050 PACKSTONE; VERY LIGHT ORANGE
20% POROSITY: INTERGRANULAR
GRAIN TYPE: SKELETAL, CALCILUTITE, CRYSTALS
90% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: MEDIUM; RANGE: VERY FINE TO GRAVEL
MODERATE INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, DOLOMITE CEMENT
CALCILUTITE MATRIX
SEDIMENTARY STRUCTURES: LAMINATED
ACCESSORY MINERALS: CALCITE- 5%, SPAR- 5%, DOLOMITE- 5%
ORGANICS-<1%
FOSSILS: BENTHIC FORAMINIFERA, FOSSIL FRAGMENTS, CORAL
WACKESTONE TO GRAINSTONE WITH A VERY FINE COATING OF SPARRY CALCITE. ORGANICS FORM LAMINATIONS IN THE LIMESTONE. ABUNDANT DICTYOCONUS. LEPIDOCYCLINA, NUMMULITES. DOLOMITE IS EUHEDRAL TO SUBHEDRAL WITH CALCAREOUS MATRIX. TRACE OF POORLY INDURATED CALCAREOUS SILT.

2050 - 2095 PACKSTONE; VERY LIGHT ORANGE
15% POROSITY: INTERGRANULAR
GRAIN TYPE: SKELETAL, CRYSTALS, CALCILUTITE
85% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRAVEL
MODERATE INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, DOLOMITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: CALCITE- 5%, SPAR- 2%, DOLOMITE- 7%
ORGANICS-<1%
OTHER FEATURES: LOW RECRYSTALLIZATION
FOSSILS: BENTHIC FORAMINIFERA, FOSSIL FRAGMENTS
MUDSTONE TO PACKSTONE. TRACE OF CALCAREOUS SILT. ABUNDANT DICTYOCONUS.

2095 - 2180 PACKSTONE; VERY LIGHT ORANGE TO YELLOWISH GRAY
25% POROSITY: INTERGRANULAR, PIN POINT VUGS
GRAIN TYPE: SKELETAL, CALCILUTITE
90% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRAVEL
MODERATE INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, DOLOMITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: CALCITE-<2%, SPAR- 2%, ORGANICS-<1%
OTHER FEATURES: LOW RECRYSTALLIZATION
FOSSILS: BENTHIC FORAMINIFERA, ECHINOID, BRYOZOA, CORAL
WACKESTONE TO PACKSTONE. SLIGHTLY DOLOMITIC. SOME IRON STAINING. ABUNDANT DICTYOCONUS. LEPIDOCYCLINA, NUMMULITES HETEROSTEGINA. DOLOMITE INCREASES TO 5% WITH DEPTH - ANHEDRAL TO EUHEDRAL, SUCROSIC.

2180 - 2190 DOLOSTONE; GRAYISH BROWN TO MODERATE GRAY
10% POROSITY: INTERGRANULAR, PIN POINT VUGS
INTERCRYSTALLINE; 50-90% ALTERED; SUBHEDRAL
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO MEDIUM
GOOD INDURATION
CEMENT TYPE(S): DOLOMITE CEMENT, SPARRY CALCITE CEMENT

CALCILUTITE MATRIX
ACCESSORY MINERALS: LIMESTONE-35%
OTHER FEATURES: MEDIUM RECRYSTALLIZATION, SUCROSIC
FOSSILS: BENTHIC FORAMINIFERA
LIMESTONE SAME AS ABOVE COULD BE CAVINGS. DICTYOCONUS NUMMULITES.

2190 - 2195 WACKESTONE; VERY LIGHT ORANGE
15% POROSITY: INTERGRANULAR
GRAIN TYPE: SKELETAL, CALCILUTITE, BIOGENIC
70% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRAVEL
MODERATE INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, DOLOMITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: DOLOMITE-10%, ORGANICS-<1%
OTHER FEATURES: LOW RECRYSTALLIZATION
FOSSILS: BENTHIC FORAMINIFERA
WACKESTONE TO PACKSTONE. GASTROPOD CAST.

2195 - 2240 PACKSTONE; VERY LIGHT ORANGE
20% POROSITY: INTERGRANULAR, INTERCRYSTALLINE
GRAIN TYPE: SKELETAL, CALCILUTITE, BIOGENIC
90% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRAVEL
MODERATE INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, CALCILUTITE MATRIX
DOLOMITE CEMENT
ACCESSORY MINERALS: DOLOMITE-<2%, CALCITE-<1%
FOSSILS: BENTHIC FORAMINIFERA
DICTYOCONUS, NUMMULITES. WACKESTOE TO GRAINSTONE. TRACE OF ORGANICS. DOLOMITE INCREASES WITH DEPTH TO 8%.

2240 - 2245 LIMESTONE; YELLOWISH GRAY TO LIGHT OLIVE GRAY
10% POROSITY: INTERGRANULAR, INTERCRYSTALLINE
PIN POINT VUGS
GRAIN TYPE: SKELETAL, CALCILUTITE, CRYSTALS
60% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRAVEL
MODERATE INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, DOLOMITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: DOLOMITE-30%, CALCITE- 5%
FOSSILS: BENTHIC FORAMINIFERA
MUDSTONE TO GRAINSTONE.

2245 - 2250 DOLOSTONE; GRAYISH BROWN TO VERY LIGHT ORANGE
10% POROSITY: INTERGRANULAR, INTERCRYSTALLINE
50-90% ALTERED; ANHEDRAL
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO MEDIUM
GOOD INDURATION
CEMENT TYPE(S): DOLOMITE CEMENT, SPARRY CALCITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: LIMESTONE-30%, CALCITE- 5%
OTHER FEATURES: MEDIUM RECRYSTALLIZATION, SUCROSIC
FOSSILS: BENTHIC FORAMINIFERA, FOSSIL FRAGMENTS

2250 - 2265 LIMESTONE; GRAYISH BROWN TO VERY LIGHT ORANGE
15% POROSITY: INTERGRANULAR, PIN POINT VUGS
GRAIN TYPE: SKELETAL, CRYSTALS, CALCILUTITE
70% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRAVEL
MODERATE INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, DOLOMITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: DOLOMITE-45%, CALCITE- 5%
FOSSILS: BENTHIC FORAMINIFERA, FOSSIL FRAGMENTS
LEPIDOCYCLINA.

2265 - 2280 DOLOSTONE; VERY LIGHT ORANGE TO DARK YELLOWISH BROWN
10% POROSITY: INTERGRANULAR, INTERCRYSTALLINE, VUGULAR
50-90% ALTERED; SUBHEDRAL
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO MEDIUM
GOOD INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, DOLOMITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: LIMESTONE-20%
OTHER FEATURES: SUCROSIC, MEDIUM RECRYSTALLIZATION
FOSSILS: BENTHIC FORAMINIFERA, ECHINOID, FOSSIL FRAGMENTS
LIMESTONE IS MUDSTONE TO GRAINSTONE AND INCREASES TO 40% AT
BOTTOM.

2280 - 2310 LIMESTONE; VERY LIGHT ORANGE
20% POROSITY: INTERGRANULAR
GRAIN TYPE: SKELETAL, BIOGENIC, CALCILUTITE
85% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: MEDIUM; RANGE: MICROCRYSTALLINE TO GRAVEL
POOR INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, CALCILUTITE MATRIX
ACCESSORY MINERALS: CALCITE- 3%, DOLOMITE-<1%
FOSSILS: BENTHIC FORAMINIFERA, CRUSTACEA
LIMESTONE IS FRAGMENTED AND FOSSILIFEROUS AND SLIGHTLY
DOLOMITIC. ABUNDANT DICTYOCONUS. LEPIDOCYCLINA, NUMMULITES.
FISH TOOTH AT 2300 FT.

2310 - 2345 LIMESTONE; VERY LIGHT ORANGE TO YELLOWISH GRAY
20% POROSITY: INTERGRANULAR, PIN POINT VUGS
GRAIN TYPE: SKELETAL, CALCILUTITE, BIOGENIC
85% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: MEDIUM; RANGE: MICROCRYSTALLINE TO GRAVEL
MODERATE INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, CALCILUTITE MATRIX
SEDIMENTARY STRUCTURES: LAMINATED
ACCESSORY MINERALS: SPAR-<2%, CALCITE- 2%, DOLOMITE-<5%
OTHER FEATURES: LOW RECRYSTALLIZATION
FOSSILS: BENTHIC FORAMINIFERA, ECHINOID, FOSSIL FRAGMENTS
ALGAE
WACKESTONE TO GRAINSTONE. <1% ORGANICS. DICTYOCONUS
NUMMULITES.

2345 - 2375 LIMESTONE; VERY LIGHT ORANGE
20% POROSITY: INTERGRANULAR, PIN POINT VUGS
GRAIN TYPE: SKELETAL, CALCILUTITE, CRYSTALS
70% ALLOCHEMICAL CONSTITUENTS

GRAIN SIZE: MEDIUM; RANGE: MICROCRYSTALLINE TO GRAVEL
MODERATE INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, CALCILUTITE MATRIX
SEDIMENTARY STRUCTURES: LAMINATED
ACCESSORY MINERALS: SPAR- 5%, CALCITE- 5%, DOLOMITE-<5%
SHELL-<1%
OTHER FEATURES: LOW RECRYSTALLIZATION
FOSSILS: BENTHIC FORAMINIFERA, ECHINOID, CRUSTACEA
BRYOZOA
DICTYOCONUS, NUMMULITES, LEPIDOCYCLINA. <1% ORGANICS.
DOLOMITE INCREASES TO 10% WITH DEPTH.

2375 - 2390 GRAINSTONE; VERY LIGHT ORANGE
25% POROSITY: INTERGRANULAR, POSSIBLY HIGH PERMEABILITY
GRAIN TYPE: SKELETAL, CALCILUTITE
90% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRAVEL
MODERATE INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, CALCILUTITE MATRIX
DOLOMITE CEMENT
ACCESSORY MINERALS: CALCITE-<1%, SPAR- 3%, DOLOMITE-<1%
OTHER FEATURES: LOW RECRYSTALLIZATION
FOSSILS: FOSSIL FRAGMENTS, ECHINOID, BENTHIC FORAMINIFERA
WACKESTONE TO GRAINSTONE. DOLOMITE INCREASES WITH DEPTH.
LEPIDOCYCLINA, NUMMULITES, HETEROSTEGINA, DICTYOCONUS.

2390 - 2405 LIMESTONE; VERY LIGHT ORANGE TO GRAYISH BROWN
15% POROSITY: INTERGRANULAR, PIN POINT VUGS
GRAIN TYPE: SKELETAL, CALCILUTITE, CRYSTALS
80% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRAVEL
MODERATE INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, CALCILUTITE MATRIX
DOLOMITE CEMENT
SEDIMENTARY STRUCTURES: LAMINATED
ACCESSORY MINERALS: CALCITE- 3%, SPAR- 3%, DOLOMITE-15%
OTHER FEATURES: MEDIUM RECRYSTALLIZATION
FOSSILS: FOSSIL FRAGMENTS, BENTHIC FORAMINIFERA
WACKESTONE TO GRAINSTONE. DOLOMITE IS SUCROSIC. <1%
ORGANICS. NUMMULITES, DICTYOCONUS, LEPIDOCYCLINA.

2405 - 2415 LIMESTONE; VERY LIGHT ORANGE TO GRAYISH BROWN
15% POROSITY: INTERGRANULAR, PIN POINT VUGS
GRAIN TYPE: SKELETAL, CRYSTALS, CALCILUTITE
85% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRAVEL
MODERATE INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, DOLOMITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: DOLOMITE-30%, CALCITE- 5%, SPAR- 3%
OTHER FEATURES: MEDIUM RECRYSTALLIZATION
FOSSILS: FOSSIL FRAGMENTS, BENTHIC FORAMINIFERA
WACKESTONE TO GRAINSTONE. DOLOMITE IS SUCROSIC, CALCAREOUS
ANHEDRAL TO EUHEDRAL. <1% ORGANICS. DICTYOCONUS
NUMMULITES.

2415 - 2450 PACKSTONE; VERY LIGHT ORANGE

20% POROSITY: INTERGRANULAR, PIN POINT VUGS
GRAIN TYPE: SKELETAL, CALCILUTITE
90% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO GRAVEL
MODERATE INDURATION
CEMENT TYPE(S): SPARRY CALCITE CEMENT, DOLOMITE CEMENT
CALCILUTITE MATRIX
ACCESSORY MINERALS: DOLOMITE- 5%, CALCITE- 3%, SPAR- 3%
OTHER FEATURES: LOW RECRYSTALLIZATION
FOSSILS: FOSSIL FRAGMENTS, BENTHIC FORAMINIFERA, ECHINOID
WACKESTONE TO GRAINSTONE. LIMESTONE IS MORE FRAGMENTED
TOWARD BOTTOM. TRACE OF ORGANICS. NUMMULITES, DICTYOCONUS
LEPIDOCYCLINA.

2450 - 2455 PACKSTONE; YELLOWISH GRAY
20% POROSITY: INTERGRANULAR, PIN POINT VUGS
GRAIN TYPE: SKELETAL, CALCILUTITE, CRYSTALS
75% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO COARSE
MODERATE INDURATION
CEMENT TYPE(S): CALCILUTITE MATRIX, SPARRY CALCITE CEMENT
DOLOMITE CEMENT
SEDIMENTARY STRUCTURES: LAMINATED
ACCESSORY MINERALS: DOLOMITE- 3%
OTHER FEATURES: LOW RECRYSTALLIZATION
FOSSILS: FOSSIL FRAGMENTS
WACKESTONE TO GRAINSTONE. <1% ORGANICS.

2455 - 2505 PACKSTONE; YELLOWISH GRAY TO MODERATE GRAY
20% POROSITY: INTERGRANULAR
GRAIN TYPE: SKELETAL, CALCILUTITE, CRYSTALS
90% ALLOCHEMICAL CONSTITUENTS
GRAIN SIZE: FINE; RANGE: MICROCRYSTALLINE TO COARSE
MODERATE INDURATION
CEMENT TYPE(S): CALCILUTITE MATRIX, SPARRY CALCITE CEMENT
DOLOMITE CEMENT
ACCESSORY MINERALS: DOLOMITE-15%, CALCITE- 3%
OTHER FEATURES: LOW RECRYSTALLIZATION, SUCROSIC
FOSSILS: BENTHIC FORAMINIFERA
DOLOMITE DECREASES TO ABOUT 7% WITH DEPTH. TRACE OF
ORGANICS. DICTYOCONUS, LEPIDOCYCLINA, NUMMULITES.

2505 TOTAL DEPTH

APPENDIX C
MAGNETIC RESONANCE CALIBRATION REPORT

CORELAB

CORE LABORATORIES

NMR CALIBRATION STUDY

Performed for:

South Florida Water Management

BICY - PW
Big Cypress Preserve
Collier County, Florida

Core Laboratories File No.: 57151-18806

February 15, 1999

CORE LABORATORIES

Table of Contents

Section

CORE LAB

PETROLEUM SERVICES

15 February 1999

South Florida Water Management
3301 Gun Club Road
West Palm Beach, Florida 33416

Attention: Mr. Michael Bennett:

Subject: NMR Calibration Study

Company:	South Florida Water Management
Well:	BICY – PW
Project:	Floridian Aquifer System
Location:	Big Cypress Preserve

Dear Mr. Bennett:

Presented in the following Final Report are the results of the NMR calibration study performed on nine fully saturated core samples from the above referenced wells. Seven copies of this report have been generated.

Should there be any questions, or if I may be of further assistance, please do not hesitate to contact me personally at (713) 460-8113 or at the address below.

Sincerely,

Robert Lee

Robert Lee
NMR Technology Specialist
Core Laboratories - Houston

CORE LABORATORIES

1. SUMMARY

South Florida Water Management, requires calibration data on conventional core samples for the BICY-PW Well from Core Spectrometry for the effective interpretation of their logs. Core Laboratories was requested to carry out the calibration study. The results of the study are presented in this report.

NMR measurements were requested by South Florida Water Management on only 12 samples from this well. Three of these samples failed during the cleaning process leaving nine samples for NMR Spectrometry.

The original samples provided were of 1.0 inch diameter. These were wrapped in Teflon wrap to prevent grain loss. The rock samples (1.0 inch in diameter and 1-1.5 inches in length) were saturated with 2% KCl brine of density 1.016 g/cm^3. Then NMR measurements were made on the samples in a CoreSpec-1000^{TM} instrument operating at a proton Lamor frequency of 1 MHz. The experiments measure the transverse relaxation time (T_2), with interecho spacing time of 500 ms with no applied gradient. The Carr-Purcell-Meiboom-Gill (CPMG) pulse was used.

T_2 Spectrometry is performed on fully and partially saturated core plugs to obtain magnetization amplitude versus recovery time using the CoreSpec-1000. The output from CoreSpec-1000 was processed using an internally developed[1] multi-exponential fit using a modified form of the Levenberg-Marquardt non linear optimization algorithm with a regularization term. NMR Porosity and relaxation time distributions are obtained from this process.

CORE LABORATORIES

2. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. All of the nine samples were found to possess varying degrees of paramagnetic properties. It has been shown in subsequent NMR Calibration Studies that paramagnetic minerals in core samples have produced low T_{2C} and subsequently BVI for a given sample.
2. NMR measurements and data analysis indicate the existence of four relaxation groups in the well. The actual number of relaxation groups may differ if more core data were used.
3. The cutoff transverse relaxation time T_2c for the samples range from 33 ms. to 150 ms. Relaxation group 1 has an average T_2c = 150 ms., group 2 an average T_2c = 88 ms., group 3 an average T_2c = 80 ms. and group 4 an average T_{2C} = 42, (Table 6.1).
4. The relaxivity constant ρ expressed in combination with the specific surface area S_{gv} varies from 0.0021305 ms^{-1} to 0.003556424 ms^{-1} in the nine samples, averaging 0.00021305 ms^{-1} for group one, 0.00073772 ms^{-1} in group 2, 0.00124966 ms^{-1} in group 3 and 0.00321756 ms^{-1} for group 4, (Table 6.1).
5. The core NMR porosities and Helium porosities correlate fairly well in this particlular study. Where core NMR porosity and Helium porosity do not match, indicates that the total and effective porosities may be different in these rocks, hence the NMR log porosities in this field should be treated as effective porosity. NMR porosity has been measured at .50 ms echo-spacing to maximize the captured NMR relaxation data. In some samples, some fraction of the early time data may not be captured evidended by core and NMR porosities not being equal. The second explanation for the lack of an exact match between core analysis and NMR porosities can be the presence of paramagnetic properties.
6. The presence of vugular pore geometries have necessitated the formulation of two permeabilitiy models to effectively model flow through these two unique pore systems.

Recommendations

Apply the core data to NMR logs run in this well as follows:

1. Find the relaxation group for the logged zone by dividing its log NMR T_2 at 50 percentile (median) expressed in seconds by the NMR-derived porosity group $\phi_{NMR} = \phi_{NMR}/(1-\phi_{NMR})$.

- If the $T_2/\phi_Z = 1/\rho Sgv$ falls within the range $1/\rho Sgv$ = 4.6937-1.5592 s, the zone belongs to Relaxation Group 1, use T_{2C} = 150 ms. Note that these cutoff T_2 values are based on limited data and may be different if a higher number of samples were tested.

- If the $T_2/\phi_Z = 1/\rho Sgv$ falls within the range $1/\rho Sgv$ = 1.5592 - 1.0622 s, the zone belongs to Relaxation Group 2, use T_{2C} = 88 ms.

- If the $T_2/\phi_Z = 1/\rho Sgv$ falls within the range $1/\rho Sgv$ = 1.0622 - 0.34898 s, the zone belongs to Relaxation Group 3, use T_{2C} = 80 ms.

CORE LABORATORIES

- If the T_2/ϕ_Z = 1/ρSgv falls at or below 1/ρSgv = 0.34898 s, the zone belongs to Relaxation Group 4, use T_{2C} = 42 ms.

2. As seen in figures 6.3.1 and 6.3.2 the permeability models developed for this well should be used by first determining FZI from BVI using the two following equations:

   If the zone falls into Relaxivity Group 1 *or* 2

$$FZI = \left[\frac{0.03226(1.0-\frac{BVI}{\phi_{NMR}})}{1.0-1.10993(1.0-\frac{BVI}{\phi_{NMR}})}\right]^{0.48212}$$

   If the zone falls into Relaxivity Group 3 or 4

$$FZI = \left[\frac{0.59719(1.0-\frac{BVI}{\phi_{NMR}})}{1.0-1.20731(1.0-\frac{BVI}{\phi_{NMR}})}\right]^{1.16139}$$

Then obtain permeability using the FZI_{NMR} value and the NMR porosity as:

$$K = 1014 \times FZI^2 \frac{\phi_{NMR}^{\ 3}}{(1-\phi_{NMR})^2}$$

3. Future petrology work in conjunction with the magnetic susceptibility data contained within to further study the differences in the relaxation groups and thus refine the permeability model.

CORE LABORATORIES

3. BASIC ANALYSIS

Sample Preparation and NMR procedure.

The following summarizes the process of sample preparation and the procedure for obtaining the calibration data for NMR log from core analysis and Core Spectrometry.

1. Wrap samples in teflon tape.
2. Clean samples in toluene.
3. Methanol leach samples 3 days.
4. Place samples in low humidity oven at 140 °F to confirm that samples are fully dry by checking for about 72 hours until stable weight. No change in weight was observed.
5. Measure bulk volume with calipers.
6. Measure porosity and permeability of plugs in CMS - 300 at ambient conditions.
7. Fully saturate the plugs with minimum stress using 2% KCl brine at concentration as requested by South Florida Water Management.
8. Weigh each saturated sample in the brine (immersed weight) and in air. Record the weights.
9. Wipe off excess brine from the sample surface and wrap each in Seran Wrap to prevent loss of brine before and during NMR measurement.
10. Measure NMR T_2 on all 9 fully saturated samples.
11. Perform Gas Displacing Water High Speed Centrifuge Capillary Pressure on second set of "sister samples" to determine desaturation pressures.
12. Desaturate samples in a high speed centrifuge at speeds corresponding to S_{wirr} from capillary pressure data. Samples are desaturated to .01 cm^3 fluid stabilization for a minimum of 24 hours.
13. Measure NMR optimum (cut-off) transverse relaxation times T_{2c} of the desaturated samples.
14. Between centrifuging and moving each sample to the NMR instrument, the sample was wrapped in Seran Wrap to prevent loss of brine. The sample is weighed immediately after removal from the centrifuge and before the T_2 measurement to confirm no weight change.

Brine Preparation

The 2% (weight percent) Potassium Chloride is the saturating brine solution of choice for the core plugs so as not to disturb intact clays. Four liters of filtered de ionized water was weighed. Then 80 grams of KCl was added to the water and mixed until dissolved. The brine was filtered through a No. 3 Watman filter and then placed under vacuum with a vacuum pump for approximately 10 minutes to remove trapped air. The density of the filtered and de-aerated brine was measured (1.016 g/cm^3) at room temperature of 19° C.

Brine Density

The density of the brine was measured using a hydrometer. A graduated cylinder was 3/4 filled with brine. The temperature was measured and recorded. A hydrometer of the appropriate density range was chosen and allowed to float free in the brine. The density was then read off the scale. No correction for temperature was made.

CORE LABORATORIES

Bulk Volume in Brine

Bulk volumes were measured on fully brine-saturated samples by Archimedes method at ambient conditions. An Archimedes bulk volume of a saturated sample was measured using the saturating brine as the displaced fluid. The sample was weighted while submerged in the brine, without touching the sides of the container. Next the saturated weight of the sample was measured in air after carefully blotting off excess brine. Samples remained submerged in the brine, unless removed to make a measurement. The following equations were used to calculate saturated pore and bulk volumes.

$$\text{Saturated Bulk Volume} = \frac{\text{Saturated Weight - Immersed Weight}}{\text{Fluid Density}}$$

$$\text{Saturated Pore Volume} = \frac{\text{Saturated Weight - Dry Weight}}{\text{Fluid Density}}$$

Saturating the Samples

The samples cooled in a desiccator, were weighed, and then placed in a pressure vessel. Vacuum was applied in the vessel to evacuate air from the plugs and vessel. The vessel was isolated from the vacuum pump and vacuum pressure monitored for at least 30 minutes. No loss of vacuum pressure was observed during the 30 minutes, then a vacuum was reestablished and left overnight.

After vacuuming, the prepared brine was drawn into the pressure vessel using the vacuum pump. The pressure vessel was held vertical while filling to assist in displacing all the air. Once brine had reached the outlet line, the brine supply was turned off and the vacuum left on for about 30 minutes. After 30 minutes the brine valve was opened again with the pressure vessel held vertical until brine again reached the outlet line displacing all the remaining air from the vessel.

With the pressure vessel filled with brine, the vacuum valve was closed. The vessel was pressured to 2,000 psig with the hand pump. After closing all the valves, the pressure was monitored on the vessel to ensure a tight seal. The brine-filled vessel remained under pressure for a minimum of 12 hours in order to fully saturate samples.

The pressure was released through the vacuum line and about 1 liter of brine was drawn off using the vacuum pump. The pressure vessel was open at an angle to prevent brine from leaking out of the cap when removed. Once opened the remaining brine in the pressure vessel was poured off into a container. The samples were removed from the vessel and submerged in the brine-filled container.

CORE LABORATORIES

4. CENTRIFUGE CAPILLARY PRESSURE

- A second set of the original NMR samples were taken from the same depth. These nine, dry samples were placed into a stainless steel saturation cell and evacuated overnight, then pressure saturated with synthetic formation brine.
- Saturated and immersed weights were obtained so that saturated pore volumes could be compared to helium measured values. The helium pore volumes were verified by the saturated values.
- Testing was performed with the samples under ambient pressure in a Beckman L5-40 centrifuge.
- The sample/coreholder assemblies were placed into the centrifuge and subjected to nonstop centrifugation at rotational rates thet were increased incrementally to generate equivalent displacement pressures ranging from 0 to 400 psig in a gas-displacing-water system.
- Sufficient time was allowed at each rate of rotation for saturation equilibrium within the samples to be established. Equilibrium at each speed was determined by monitoring brine displacement until the rate of diplacement was reduce to 0.001 or less pore volumes per hour over a nominal period of eight hours. Each speed took 24-48 hours. Diplaced brine volumes were read during centrifugation using a General Radio 1531-AB Strobotac.
- Capillary pressure- saturation relationships were calculated for each sample using equilibrium displacement volumes and equivalent pressure data. Inlet-face saturation values calculated based on the methods of Hassler and Brunner ("measurement of Capillary Pressure in Small Core Samples" T.P. 1817, Petroleum Technology, March 1945, P. 114-123).

5. NMR MEASUREMENT

Fully Saturated Samples

NMR measurements were performed using the CoreSpec-1000. First a calibration curve was established using 4 water samples of known volume. The water samples were loaded in the instrument and measured using 10 trains. The results were plotted as water volume vs. gain corrected amplitude. The slope of the curve is the correction factor used in the computer program used in this work to process the NMR data from saturated (fully and partially) rock samples.

With the correction factor established, each fully saturated sample was blotted to remove excess brine and loaded into the instrument. The measurements were made with a current gain of 100 and a signal gain of 2 (total gain = 100 × 2 = 200). The fully saturated samples were measured with 0.5 ms echo time spacing and various trains to achieve a high NMR signal-to-noise ratio. Once a sample was unloaded, a saturated weight was again recorded to confirm no loss of weight. Measurements were made on the nine samples.

CORE LABORATORIES

Measurement of Desaturated Samples

The nine samples were loaded into the Beckman High Speed Centrifuge and desaturated to .001 cm^3 stabilization. Approximately 36 hours per sample was needed to desaturate using speeds corresponding to 200 and 300 and 400 psig. capillary pressure, (Table 4.1). Immediately after unloading them from the centrifuge, they were wrapped in Seran Wrap ready for NMR measurement. The samples were then stripped of Saran Wrap, weighed again and individually loaded in the CoreSpec 1000 for NMR T_2 measurement. Each sample was weighed again immediately after NMR measurement. These measurements serve to check the material balance data from the samples.

Results of the NMR tests showing the match between the measured and filtered transverse magnetization decay versus recovery time and the multi-exponential fits are presented in the Appendix. The results are displayed in plots for each sample as follows:

The first page consists of the multi-exponential fit of the signal and the T_2 relaxation distribution. The second page contains the distribution converted to porosity (top), and the T_2 relaxation distributions for both desaturated and fully saturated sample overlaid on one plot (bottom). Optimum cut-off T_2 relaxation time (T_{2c}) for use in logs can be estimated by comparing the overlaid distribution curves.

Magnetic Susceptibility

A sample from each plug was introduced into the Johnson Matthey Magnetic Susceptibility Balance to assess the paramagnetic content of each NMR sample. If in fact a sample is found to have paramagnetic properties, then the rock grains probably are coated with paramagnetic minerals which have been found to reduce the NMR relaxation characteristics(T_2).
To calculate magnetic susceptibility the following formula is used:

$$Xg = \frac{C_{bal} * L(R - Ro)}{10^9 m} \quad \text{------------(Table 6.6)}$$

Where L = sample length (cm)
m = sample mass (gm)
R = reading for tube plus sample
Ro = empty tube reading
C_{bal} = balance calibration constant

The four of the nine samples in this study were found to possess paramagnetic properties.

6. DATA EVALUATION

Porosity

The core analysis porosity and permeability data are presented in Table 5.1. Porosity was also calculated from NMR measurements and from Archimedes method (saturated porosity) on fully water-saturated samples. Figure 5.1 shows the relationship between NMR-derived porosity and helium porosity at .50 ms echo spacing. The figure shows a reasonably good match. As expected NMR-derived porosity is lower than the core analysis porosities of the samples because NMR only 'sees' the effective porosity. In samples where total and effective porosities are the same, NMR should match core analysis porosity.

Non-Movable Fluid Determination

Because of the different relaxation rate associated with the different rock groups in the well, different T_2 cut off (T_{2c}) are needed to obtain the appropriate BVI. As shown in Figure 6.2, the non-movable brine saturation obtained by material balance (MB) is compared with that ($Sw = BVI/\phi$) obtained from the T_2 distribution curves using the appropriate NMR T_{2c}. The T_{2c} values serve as calibration data for BVI determination in NMR logs[1].

Relaxation Groups[2]

$$\log T_2 = \alpha \log \Phi_z + \log\left(\frac{1}{\rho S_{gv}}\right) \quad \text{----------------------(Table 6.1)}$$

It has been shown that a plot of Log T_2 versus Φz based on above equation would separate samples into their relaxation groups. Where α can take values from 1.0 to 10.0 (1.0 in this case, as Figure 6.1 indicates) and the intercept defines the relaxation groups. Hence

$$\left(\frac{1}{\rho S_{gv}}\right) = \frac{T_2(\sec s)}{\Phi_z} \quad \text{--------------------(Figure 6.1)}$$

Where,

$$\Phi_z = \frac{\phi}{1-\phi} \quad \text{----------------------------------(Table 6.1)}^3$$

As shown in Figure 6.1, there are four distinctive relaxation groups in the well. Group 1 has intercept $1/\rho S_{gv}$ = 4.6937 seconds; for Group 2 $1/\rho S_{gv}$ = 1.3556 seconds, for Group 3 $1/\rho S_{gv}$ = 0.8003 seconds and for Group 4 $1/\rho S_{gv}$ = 0.3108 seconds. As presented in Table 6.1, the samples in Group 1 have T_{2c} averaging 150 ms, Group 2 samples average T_{2c} 88 ms, Group 3 average T_{2c} of 80 ms and Group 4 T_{2C} averaging 42 ms.

CORE LABORATORIES

7. REFERENCES

1. Ohen H. O., Ajufo A. O & Enwere, P. M.: "Laboratories NMR Relaxation Measurements for the Acquisition of Calibration Data for NMR Logging Tools", SPE 35683.

2. Ohen H. O., et al.: "A Hydraulic (Flow) Unit Based Model For The Determination of Petrophysical Properties From NMR Relaxation Measurements", SPE 030626, 1995.

3. Amaefule, J.O. et al.: "Enhanced Reservoir Description: Using Core and Log Data to Identify Hydraulic (Flow) units and predict permeability in uncored Intervals/Wells", SPE 26436, 68th Annual SPE conference and exhibition, Houston, Texas, October 3rd - 6th, 1993.

TABLES AND FIGURES

Table 5.1: NMR and CMS - 300 Core Analysis Data

South Florida Water Management

BICY-PW

Collier County, Florida

Sample ID	Depth	Reservoir NOB	Permeability		Porosity He	Porosity NMR	T_2 median	Desaturation Pressure	Grain Density
			Klinkenburg	Kair					
	feet	psig	mD		%	%	ms	psig.	g/cm^3
3	851.6	800	38.0	88.7	19.9	16.8	62.5	400	2.69
7	855.2	800	20.0	22.9	20.0	17.1	58.0	400	2.80
10	861.4	800	0.10	0.13	8.2	6.0	299.6	400	2.79
12	880.1	800	150	178	33.2	32.3	166.5	400	2.67
16	901.6	800	302	322	24.5	22.6	452.7	300	2.68
20	921.1	800	1827	2124	37.4	34.5	559.5	300	2.68
21	921.9	800	69.0	86.2	36.2	32.2	740.5	400	2.67
29	981.7	800	3296	4345	31.5	26.8	506.3	200	2.66
33	984.9	800	1289	1952	27.2	21.1	214.0	200	2.67

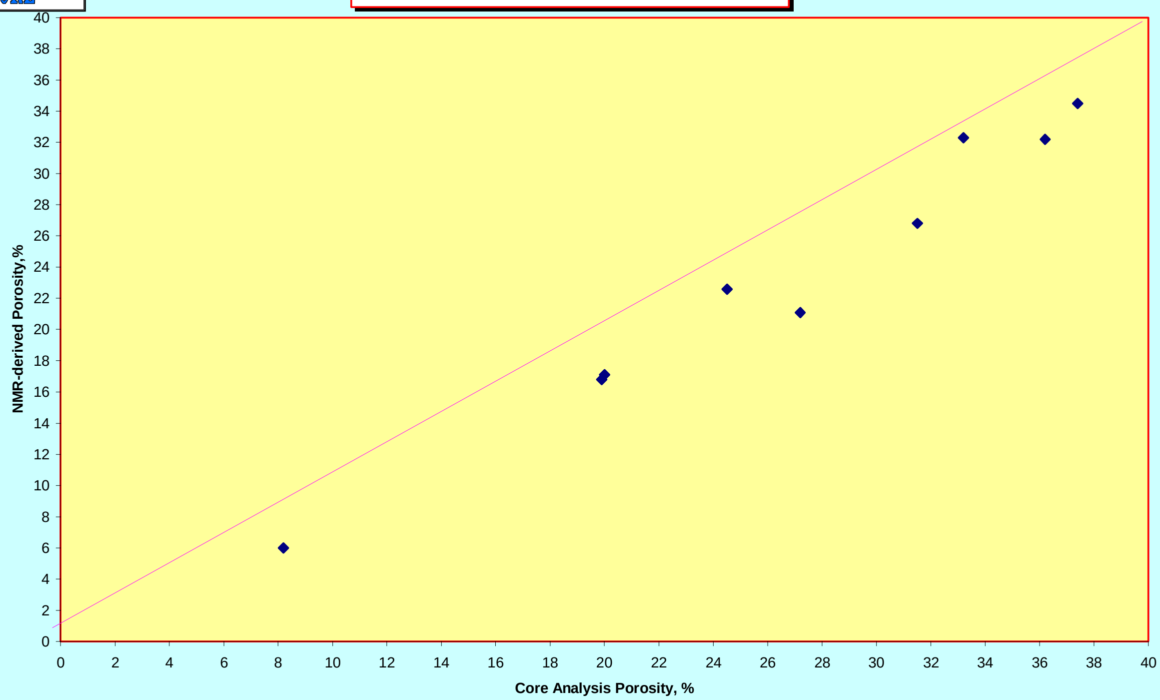


Figure 5.1: Core Analysis versus NMR Porosities

Table 6.1: Relaxation Groups for NMR Log Interpretation

Relaxivity Group	DEPTH (m)	Sample I.D.	NOB (500 psi) K_{inf} (mD)	NOB (500 psi) ϕ_{He} (%)	Models K_{NMR} (mD)	Models $K_{Coates'}$ (mD)	Swirr nmr (%)	Swirr (material balance) (%)	NMR ϕ (%)	FZIcore (µm)	FZInmr (µm)
1	861.4	10	0.10	8.2	0.04	100768	25.35	33.67	6.0	0.3881964	0.3881822
2	921.9	21	69.0	36.2	43	102693	14.26	11.47	32.2	0.7640328	0.7639760
2	901.6	16	302	24.5	7.3	56622	16.66	13.55	22.6	3.3972769	0.6098715
2	981.7	29	3296	31.5	10.8	41058	18.26	21.53	26.8	6.9847037	0.5453486
2	921.1	20	1827	37.4	1310	56622	10.08	14.34	34.5	3.6733800	3.6743256
3	984.9	33	1289	27.2	512	135454	25.32	29.91	21.1	5.7854098	5.7855341
4	880.1	12	150	33.2	0.001	112783	16.88	22.02	32.3	1.3429029	0.0037049
4	851.6	3	38.0	19.9	21.2	52058	36.58	41.46	16.8	1.7465232	1.7465272
4	855.2	7	20.0	20.0	11.6	59026	41.11	35.03	17.1	1.2560000	1.2559991

Relaxivity Group	DEPTH (m)	Sample I.D.	T_2median (ms)	ΦzCore Analysis	Φznmr	RQI_{nmr} (µm)	1/ρSgv (ms)	ρSgv (ms^{-1})	ρSgv Average (ms^{-1})	T2C (ms)	T2C Average (ms)
1	861.4	10	299.6	0.089324619	0.0638298	0.04778522	4693.733333	0.00021305	**0.0002131**	150	**150**
2	921.9	21	740.5	0.567398119	0.4749263	0.868220360	1559.189441	0.000641359		100	
2	901.6	16	452.7	0.324503311	0.2919897	0.443203876	1550.397345	0.000644996		70	
2	981.7	29	506.3	0.459854015	0.3661202	0.489906432	1382.879104	0.000723129		100	
2	921.1	20	559.5	0.597444089	0.5267176	1.320230432	1062.23913	0.000941408	**0.0007377**	80	**88**
3	984.9	33	214.0	0.373626374	0.2674271	1.547025724	800.2180095	0.001249659	**0.0012497**	80	**80**
4	880.1	12	166.5	0.497005988	0.4771049	0.001767437	348.9798762	0.002865495		33	
4	851.6	3	62.5	0.248439451	0.2019231	0.352622436	309.5238095	0.003230769		42	
4	855.2	7	58.0	0.2500000	0.2062726	0.259047570	281.1812865	0.003556424	**0.0032176**	50	**42**

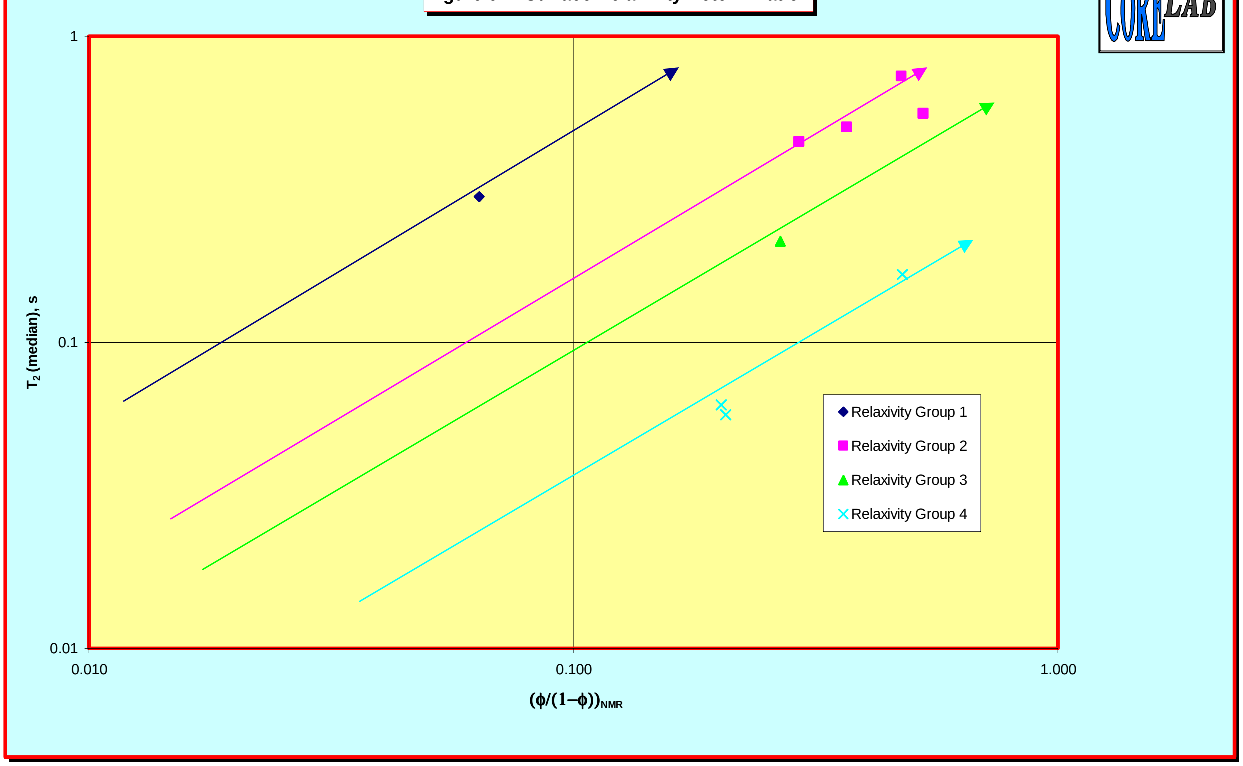


Figure 6.1: Surface Relaxivity Determination

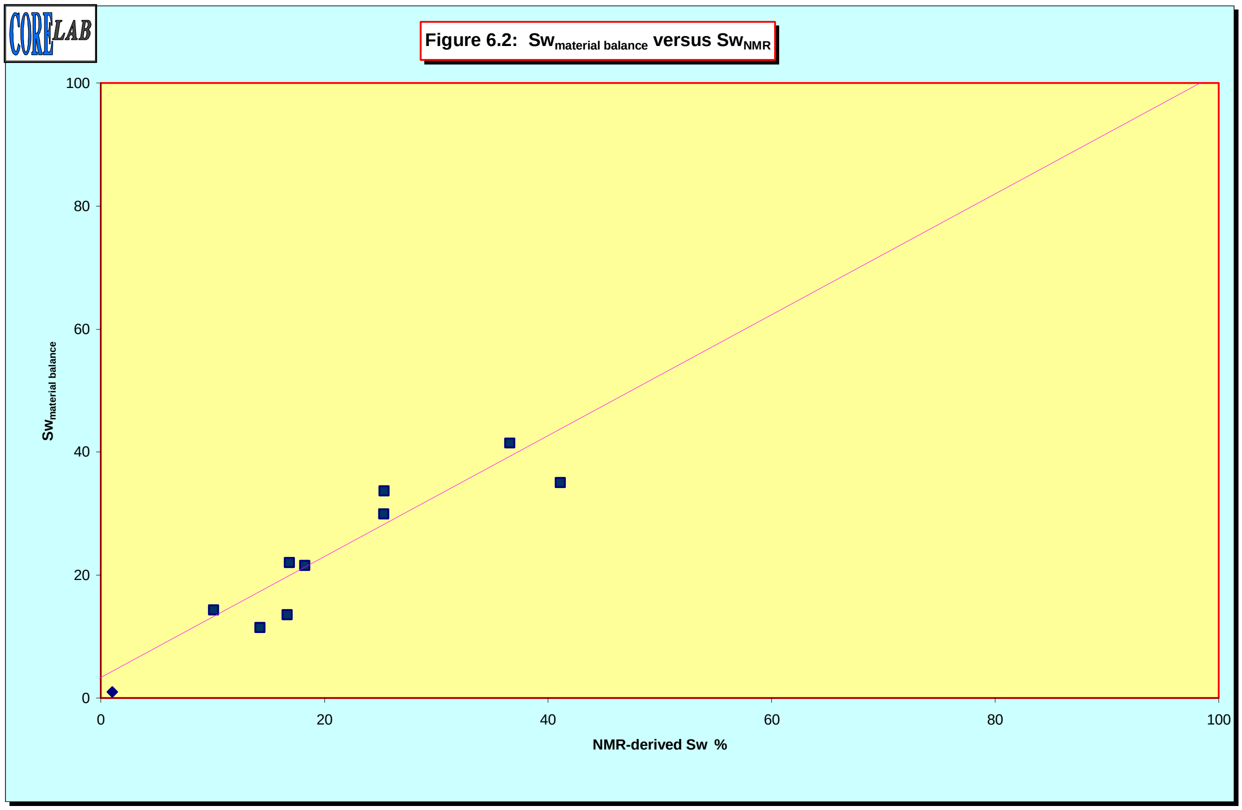


Figure 6.2: Sw material balance versus Sw NMR
CORELAB
Sw material balance
NMR-derived Sw %
0
20
40
60
80
100

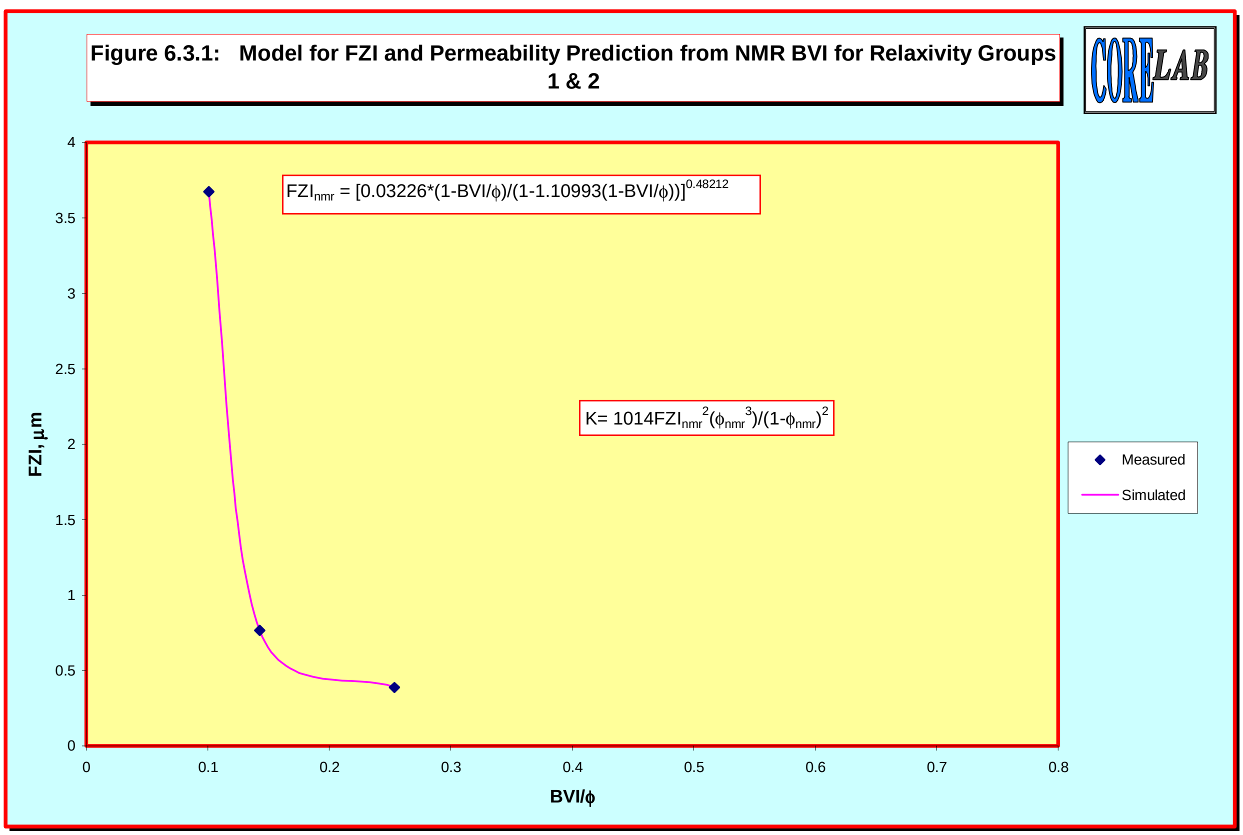


Figure 6.3.1: Model for FZI and Permeability Prediction from NMR BVI for Relaxivity Groups 1 & 2
CORELAB
FZInmr = [0.03226*(1-BVI/ϕ)/(1-1.10993(1-BVI/ϕ))]0.48212
K= 1014FZInmr2(ϕnmr3)/(1-ϕnmr)2
Measured
Simulated
FZI, µm
BVI/ϕ

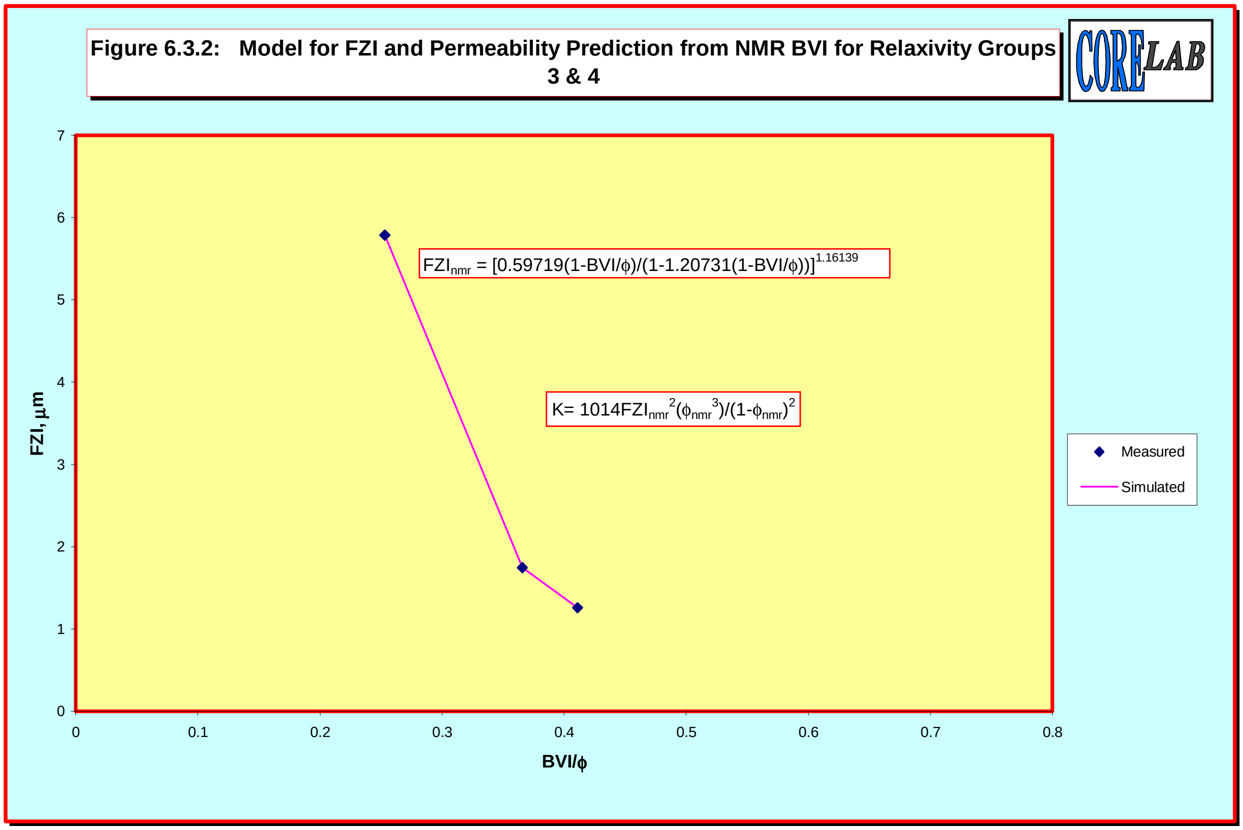


Figure 6.3.2: Model for FZI and Permeability Prediction from NMR BVI for Relaxivity Groups 3 & 4
CORELAB
FZInmr = [0.59719(1-BVI/ϕ)/(1-1.20731(1-BVI/ϕ))]1.16139
K= 1014FZInmr2(ϕnmr3)/(1-ϕnmr)2
Measured
Simulated
FZI, µm
BVI/ϕ
0
1
2
3
4
5
6
7
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

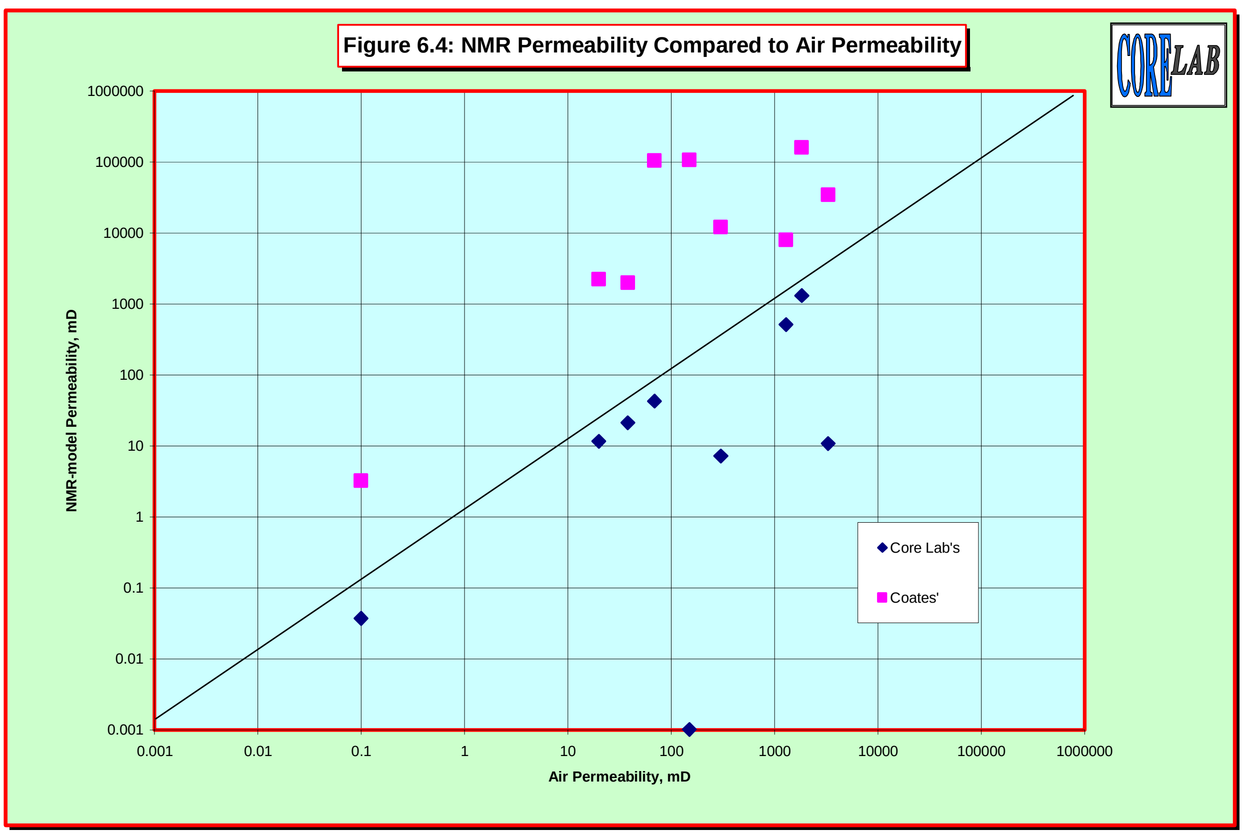


Figure 6.4: NMR Permeability Compared to Air Permeability
CORELAB
NMR-model Permeability, mD
Air Permeability, mD
1000000
100000
10000
1000
100
10
1
0.1
0.01
0.001
0.001
0.01
0.1
1
10
100
1000
10000
100000
1000000
Core Lab's
Coates'

Table 6.5 Magnetic Susceptibility

Sample ID	Sample Length (cm)	Sample Mass (gm)	R=Reading for tube plus sample	Ro=Empty tube Sample	Cbal= Balance Calibration	Mass Susceptibility Xg (csg/cm3)	Magnetism
3	2.50	0.2949	-67	-30	1.088	-3.412682E-07	Diamagnetic
7	2.40	0.3196	26	-30	1.088	4.575319E-07	Paramagnetic
10	2.70	0.4332	-70	-30	1.088	-2.712465E-07	Diamagnetic
12	2.40	0.2982	-50	-30	1.088	-1.751308E-07	Diamagnetic
16	2.50	0.3249	266	-30	1.088	2.478055E-06	Paramagnetic
20	2.50	0.3166	-53	-30	1.088	-1.975995E-07	Diamagnetic
21	2.30	0.2610	-59	-30	1.088	-2.780444E-07	Diamagnetic
29	2.30	0.2944	11	-30	1.088	3.485000E-07	Paramagnetic
33	2.40	0.4536	-28	-30	1.088	1.151323E-08	Paramagnetic

* A negative reading indicates a net diamagnetism.
* A positive reading indicates a net paramagnetism.

APPENDIX D

PETROLOGIC DATA

SOUTH FLORIDA WATER MANAGEMENT

BICY – TW – Well Cutting Descriptions

<u>FORAM-PELLET SUBFACIES</u>

820 to 825 feet

Echinoid-peloid-foram-pellet packstone fine to very coarse grained, poorly sorted, slightly dolomitic, slightly cemented, with poor to fair moldic and intraparticle porosity.

20% - Peloid-foram wackestone with poor intraparticle and moldic porosity.

10% - Dolomite very fine crystalline with some intercrystalline and microporosity.

825 to 830 feet

Skeletal-peloid-foram-pellet packstone slightly dolomitic slightly sandy.

10% - Grainstone, very fine to medium grained with fair very fine to medium moldic porosity and poor intraparticle porosity, slightly cemented with fine to coarse sparry calcite in vugs and molds, trace dolomite occlusion.

830 to 835 feet

30% - Sandy foram-pellet packstone, fine to medium grained, moderate sorted with fair very fine to medium size scattered molds.

40% - Sandy echinoid peloid-intraclast-pellet packstone, fine to very coarse-grained, very poorly sorted with fair moldic porosity with scattered occlusions, fine crystalline cement and overgrowth cement.

10% - dolomite, very fine to fine crystalline with fair intercrystalline porosity.

835 to 840 feet

40% - Slightly to very sandy gastropod-foram-pellet algal wackestone, very fine to very coarse grain, very poorly sorted.

10% - Slightly to well cemented, poor to fair moldic and intraparticle porosity. Trace good moldic porosity, trace glauconite cement.

40% - Slightly sandy to very sandy echinoid-skeletal-pellet packstone.

5% - Dolomite, very fine to fine crystalline with fair very fine to fine intercrystalline porosity, trace fine to course vugs occluded with dolomite.

840 to 845 feet

60% - Slightly sandy algal wackestone very fine to very coarse grained, very poorly sorted, trace moldic and intraparticle porosity, trace occluded moldic porosity.

20% - Slightly sandy echinoid-skeletal-foram pellet packstone, poor to fair moldic porosity.

10% - Dolomite, very fine to fine crystalline.

<u>INTERBEDDED FORAM-PELLET SUBFACIES-ALGAL SUBFACIES</u>

845 to 850 feet

60% - Slightly sandy skeletal-foram-pellet packstone, slightly-cemented, moderate to poorly sorted, very fine to medium grained, fair very fine to medium size moldic-vug porosity, trace intraparticle porosity.

10% - Dolomite, very fine to fine crystalline, fair intercrystalline porosity.

30% - Algal wackestone, fine to very coarse grained, very poorly sorted.

850 to 855 feet

70% - Slightly sandy skeletal-echinoid-foram-pellet packstone, very fine to fine grained moderate sorted, very slightly cemented.

30% - Algal wackestone, fine to very coarse grained, very poorly sorted, scattered patchy microporosity and vugs and some very fine to fine crystalline dolomite occlusions.

<5% - Dolomite, very fine to fine crystalline, fair intercrystalline to microporosity.

855 to 860 feet

60% - Slightly sandy coated grain-skeletal peloid-pellet packstone-wackestone, very fine to fine grained.

30% - Pellet algal wackestone.

5% - Dolomite, very fine to fine crystalline.

ALGAL SUBFACIES

860 to 865 feet

40% - Algal wackestone very fine to very coarse grained very poorly sorted, fair to poor scattered very fine fine size vugs and molds with 1% slightly cemented occluded vugs and molds, some scattered mega molds partly occluded and slightly dolomitic.

50% - Algal peloid-pellet-wackestone, very poorly sorted.

10% - Dolomite, very fine to fine crystalline with fair to poor intercrystalline porosity.

865 to 870 feet

Slightly sandy skeletal-echinoid-algal wackestone, very fine to very coarse grained, poor to fair very fine to medium size porosity.

20% - Sandy echinoid-skeletal-pellet packstone, poor to fair moldic and fair intercrystalline moldic porosity, slightly cemented, slightly dolomitic.

10% - Dolomite, fine to medium crystalline with fair moldic porosity.

FORAM-PELLET SUBFACIES

870 to 875 feet

Skeletal-bryozoan-encrusting foram skeletal pellet packstone, fine to very coarse grained, very poorly sorted, trace granular with poor moldic porosity.

50% - Dolomite, very fine to medium crystalline.

20% - Algal wackestone

INTERBEDDED ALGAL-COATED GRAIN SUBFACIES

875 to 880 feet

50% - Slightly sandy coated algal-echinoid-foram-coated grain packstone-wackestone with fair moldic porosity.

20% - Algal wackestone with poor moldic porosity development.

20% - Dolomite, very fine to medium crystalline with poor to fair intercrystalline porosity.

10% - Glauconite

880 to 885 feet

Slightly sandy skeletal-foram-pellet-packstone-wackestone, slightly dolomitic, slightly to well cemented. 30% pores occluded. Trace good moldic porosity, fine to coarse-grained, very poorly sorted.

30% - Slightly sandy algal wackestone, slightly dolomitic, fine to very coarse grained, trace granular.

10% - Dolomite, very fine to medium crystalline with fair intercrystalline porosity.

<u>COATED GRAIN SUBFACIES</u>

885 to 890 feet

Slightly sandy coated grain-foram-pellet packstone-wackestone very fine to very coarse gained, very poorly sorted, very slightly cemented with over growths, cement very fine to medium size porosity.

40% - Skeletal algal wackestone, slightly dolomitic.

10% - Dolomite with fair to poor intercrystalline porosity.

890 to 895 feet

Slightly sandy coated grain-foram-pellet-packstone, very fine to very coarse grained, very poorly sorted, fair to good vuggy moldic porosity with very fine to medium size porosity, very slightly cemented with overgrowth cement.

20% - Algal wackestone, slightly sandy.

5% - Dolomite, very fine to fine intercrystalline porosity.

895 to 900 feet

Slightly sandy-skeletal-algal-foram-pellet packstone-pellet packstone with some scattered coated grains, good moldic interparticle vuggy porosity, partly cemented in mega vugs with fine to coarse cement.

10% - Algal wackestone, very poorly sorted.

Trace dolomite, very fine to fine crystalline, with fair porosity.

<u>BRYOZON MOUND SUBFACIES</u>

900 to 905 feet

Bryozoan boundstone, slightly sandy, slightly dolomitic, very fine to granular grained, very poorly sorted, with fair to good moldic porosity. Algal-coated grain-pellet packstone, very poorly sorted, fair fine to coarse size moldic porosity.

<u>FORAM –PELLET SUBFACIES</u>

905 to 910 feet

Slightly sandy foram-pellet packstone to wackestone, medium to coarse grained 10% Good moldic porosity.

Bryozoan, very fine to coarse to pebble grained, very poorly sorted.

10% - Algal wackestone very coarse grained poor to fair moldic intraparticle porosity, good moldic porosity.

Trace dolomite, fine-medium crystalline with fair intercrystalline porosity.

COATED GRAIN SUBFACIES

910 to 915 feet

Slightly sandy slightly intraclastic-coated algal-pellet packstone, trace very porous moldic porosity, cemented with some dolomitic rim cement. Coated algal-foram-pellet packstone with good moldic-intraparticle porosity.

2% - Dolomite, very fair to fine crystalline with poor intercrystalline porosity.

FORAM-PELLET SUBFACIES

915 to 920 feet

Echinoid-coated grain-form-pellet packstone, very fine to coarse-grained, slightly dolomitic, fair to poor moldic porosity.

Low percentage of sandy algal wackestone with trace moldic porosity.
Trace dolomite.

COATED GRAIN SUBFACIES

920 to 925 feet

Foram coated grain-coated algal packstone, very fine to coarse grained, with good to very good moldic interparticle porosity. Trace excellent porosity.

10% - Algal wackestone, very fair to granular grained, very poorly sorted.

925 to 930 feet

60% slightly sandy peloid-coated grain-packstone-wackestone, trace grainstone, fine to coarse grained with good fine to coarse moldic porosity and interparticle porosity.

10% - Interclast-algal packstone, very poorly sorted, fine to very coarse grained.

10% - Algal wackestone, very fine to coarse grained, very fine crystalline, trace dolomitic, fair very fine to coarse size porosity, fair intercrystalline porosity.

930 to 935 feet

Slightly sandy peloid-foram-coated grained packstone, very fine to medium grained, fair to good very fine to medium size moldic and interparticle porosity.

10% - Pelecypod wackestone.

10% - Coated algal packstone**.**

935 to 940 feet

Sandy-peloid-pellet-coated grain packstone, fair to very good moldic interparticle porosity.
10% - Slightly cemented with equant calcite and dolomite. Traces of very dolomitic patches.

20% - Sandy algal wackestone, very fine to very coarse grained, very poorly sorted.

PELLET-FORAM SUBFACIES

940 to 945 feet

Slightly sandy peloid-pellet-foram packstone, moderate to well sorted, very fine to medium grained with some coarse-grained, very good vug, moldic, and interparticle porosity, slightly cemented.

945 to 950 feet

Slightly sandy-pellet-foram packstone, fine to medium grained, good fine to medium size moldic and interparticle porosity, traces dolomitic cement.

20% - Interclast-echinoid-coated algal wackestone, very fine to very coarse grained, very poorly sorted with poor moldic porosity of very fine to medium size.

10% - Gastropod wackestone, very fine to granular grained, very poorly sorted with a trace moldic porosity.

COATED GRAIN SUBFACIES

950 to 955 feet

Slightly to very sandy-foram-pellet-coated grain packstone, very fine to medium grained.

5% - Coarse-grained, moderate poorly sorted, good very fine to coarse size moldic porosity, fair interparticle porosity, trace cemented

955 to 960 feet

50% - Slightly sandy gastropod (10%)-peloid-foram-pellet coated grain packstone, very fine to medium grained, moderate sorted, fair moldic porosity.

30% - Slightly sandy echinoid-foram-pellet-bryozoan packstone-boundstone, very fine to granular grained, very poorly sorted.

20% - Bryozoan boundstone, granular to pebble grained.

10% - Re-crystallized wackestone with poor moldic porosity.

FORAM-PELLET SUBFACIES

960 to 965 feet

50% - Sandy-peloid-foram packstone, fine to medium grained, moderate well sorted with good to very good interparticle porosity, fair fine to medium size moldic porosity, trace intraparticle porosity.

50% - Sandy peloid-foram-pellet- packstone, fine to coarse grained, poorly sorted, poor to good moldic interparticle porosity.

10% - Algal-foram pellet packstone-wackestone.

COATED GRAIN SUBFACIES

965 to 970 feet

Slightly sandy-algal coated grained-foram-pellet packstone, fine to very coarse grained moderate to poor sorted. 10% slightly to well cemented with equant spar cement, very fine to very coarse size porosity. 10% fair to good interparticle porosity, and fair to good moldic intraparticle porosity.

10% - Well cemented grainstone with poor moldic and intraparticle porosity.

10% - Sandy algal-bryozoan wackestone with poor moldic intraparticle porosity.

970 to 975feet

40% - Sandy-coated algal-red algal encrusted-foram-pellet-coated grain packstone, very fine to coarse-grained, poorly sorted. 1% very good moldic interparticle porosity.

30% - Echinoid-coated algal packstone, encrusting red algal-green algal.

20% - Algal wackestone, fine to granular grained, very poorly sorted, with trace moldic porosity.

10% - Pellet-foram grainstone, fine-medium grained well sorted, fair moldic porosity.

Trace red algal boundstone.

<u>FORAM-PELLET SUBFACIES</u>

975 to 980 feet

Sandy to very sandy echinoid-coated algal-peloid-coated grain-foram pellet packstone, very fine to medium grained angular sand, fair to poor moldic intraparticle porosity. Trace interparticle porosity slightly cemented with overgrowth cement. Trace dolomite rim cement trace mold occluding cement.

<u>COATED GRAIN SUBFACIES</u>

980 to 985 feet

Slightly intraclastic, slightly to very sandy coated algal-foram-pellet coated grain packstone with trace grainstone fine to very coarse grained, very poorly sorted, good very fine to coarse size moldic porosity with trace.

10% - Sandy pellet algal wackestone with trace moldic porosity, very slightly cemented occluded algal fronds.

985 to 990 feet

Sandy coated grain algal-foram-pellet-peloid packstone, fine to coarse grained, moderate to poorly sorted, very good fine to coarse size interparticle porosity, trace moldic porosity.

20% - Sandy pelecypod-foram-pellet-packstone-wackestone, very fine to fine grained sand, very fine to granular grained, fair vug moldic porosity fair intraparticle porosity, poorly cemented rim cement, trace overgrowth cement, trace equant spar cement in moldic occlusions.

990 to 995 feet

Sandy peloid-coated grain packstone, fine to coarse grained, poorly sorted, fine to coarse size interparticle porosity, fair-poor moldic intraparticle porosity.

5% - Poorly cemented rim cement increase in very fine to medium angular and trace sandstone medium grained, nonporous.

995 to 1,000 feet

Slightly to very sandy-coated grain packstone-grainstone, fine to very coarse grained, poor to very poorly sorted, good to very good, fine to coarse interparticle porosity fair moldic porosity. Trace rim cement on coated grains.

20% - Sandstone, medium grained, moderately sorted, angular to subangular red and green in color

Trace coated algal wackestone.

Trace encrusting algae.

1,000 to 1,005 feet

Slightly to very sandy echinoid, coated grain-peloid-foram-pellet packstone very fine to medium grained moderate well sorted, very fine to medium size porosity, fair to good vuggy interparticle porosity. Fair moldic porosity, poor intraparticle porosity.

10% - Sandstone, fine to medium grained, moderate well sorted, poor moldic porosity.

1,005 to 1,010 feet

Sandy echinoid-peloid-foram-pellet-coated grain packstone, moderate to poorly sorted, fine to granular grained, fair to good moldic interparticle porosity, poor intraparticle porosity, and scattered vugs, trace very porous, trace shelter porosity, trace glauconite, some collapsed grains.

Trace sandy skeletal wackestone.

FORAM-PELLET SUBFACIES

1,010 to 1,015 feet

Slightly to very sandy coated grain (10%) peloid-foram-pellet packstone-trace grainstone, well sorted to very poorly sorted, fine to coarse-grained.

Trace sandy-foram wackestone.

Trace sandstone, medium grained, very poorly sorted, fine to coarse grained, angular.

Trace dolomitic.

KEY TO CORE DESCRIPTIONS SPREADSHEET

ROCK TYPE

B	BOUNDSTONE
COQ	COQUINA
G	GRAINSTONE
M	MUDSTONE
P	PACKSTONE
R	RUDSTONE
SS	SANDSTONE
W	WACKESTONE

GRAIN SIZE

B	BOULDER
C	COARSE
COB	COBBLE
F	FINE
G	GRANULE
M	MEDIUM
P	PEBBLE
TR	TRACE
V	VERY

POROSITY VISUAL DOMINANT, POROSITY VISUAL OTHER

F	FAIR
G	GOOD
P	POOR
SCAT	SCATTERED
TR	TRACE
VG	VERY GOOD
VP	VERY POOR

POROSITY DOMINANT, POROSITY OTHER

BP	BETWEEN PARTICLES
F	FRACTURE
FE	FENESTRAL
I	INTERCRYSTALLINE
LV	LARGE VUG
MICOR	MICROSCOPIC
MO	MOLDIC
SH	SHELTER
V	VUG
WP	WITHIN PARTICLES

PORE SIZE DOMINANT, PORE SIZE OTHER

C	COARSE
CM	CENTIMETER
F	FINE
G	GRANULE
LMO	LARGE MOLDIC
LV	LARGE VUG
M	MEDIUM
MICRO	MICROSCOPIC
MM	MILLIMETER
MO	MOLDIC
P	PEBBLE
TR	TRACE
VC	VERY COARSE
VF	VERY FINE

CEMENT

A	ABUNDANT
I	ISOPACHOUS
OG	OVERGROWTH
PART	PARTIALLY
R	RIM
REXL	RECRYSTALLIZATION
SL	SLIGHT
TR	TRACE
W	WELL

LAMINATIONS

INCL	INCLINED
MOD	MODERATE
SL	SLIGHT
T	THIN
VT	VERY THIN

SORTING

M	MEDIUM
MW	MODERATELY WELL
P	POOR
VP	VERY POOR
W	WELL

GLAUCONITE

SL	SLIGHT
TR	TRACE

SAND

S	SOME
SL	SLIGHT
TR	TRACE
V	VERY
VSL	VERY SLIGHT

DOLOMITE

A	ABUNDANT
SL	SLIGHT
TR	TRACE

Collier Consulting, Inc.
741 West College St.
Stephenville, Texas 76401
Office: (254) 968-8721 Fax (254) 968-8725
www.collierconsulting.com

CORRELATION OF BICY–TW CUTTINGS AND BICY–PW CORES

Seven transgressive markers are present in the SFWMD BICY-TW cuttings; five can be correlated with the SFWMD BICY-PW cores. The BICY-PW and the BICY-TW can be correlated on the basis of lithofacies type, fauna content, and facies. One of the best transgressive lithofacies markers is a transgressive lithofacies overlying a regressive mound complex in both wells. The transgressions are identified mainly on the basis of the deeper water fauna, fauna diversity, and foram assemblages. The following correlations of the transgressive markers were made:

BICY-TW			**BICY-PW**
1.	820-825'		No core
2.	840-845'		850-854.2'
3.	870-875'		Core gap
4.	895-900'		899.2-900.5'
-	900-905'	regressive sequence	900.5-901'
5.	915-920'		921.5-922.2'
6.	940-945'		941.1-941.1'
7.	975-980'		970-976.4'

The upper transgressive lithofacies at 825 to 830' in the BICY-TW consists of an echinoid-foram-pellet packstone to foram wackestone. It does not correlate with the BICY-PW core because no core exists for this interval.

The transgressive facies at 840-845' in BICY-TW consists of a sandy echinoid-skeletal-pellet packstone, which correlates with the foram intraclastic-molluscan wackestone at 850-854.2' in the BICY-PW. An assemblage of red algae, echinoids, and deeper water forams indicates a transgression in the BICY-TW. This unit also has a high gamma ray reading.

The transgressive lithofacies at 870-875' in the BICY-TW consists of skeletal-bryozoa-foram-pellet packstone. It correlations with a core gap at 862.4-879' in the BICY-PW.

A transgressive lithofacies at 895-900' in the BICY-TW consists of a foram-pellet packstone to skeletal-algal-foram-pellet packstone. It correlates with a transgressive pellet-foram packstone at 899.2-900.5' in the BICY-PW.

The previously described transgression overlies a major regressive sequence present in both wells. This regressive lithofacies in the BICY-TW consists of an algal-bryozoan boundstone, while in the BICY-PW the lithofacies consists of a coral boundstone. Both lithofacies indicate shallow mound complexes throughout the area of the two wells.

A slight transgression occurred at 915-920' in the BICY-TW. It consists of an echinoid-coated grain-foram-pellet packstone to echinoid-foram-pellet packstone. This lithofacies correlates to a pelecypod wackestone to pellet-foram packstone in the BICY-PW at 921.5-922.2'.

A transgressive lithofacies at 940-945' in the BICY-TW consists of a slightly sandy peloid-pellet-foram packstone. It correlates with a pelecypod coquina-grainstone at 941.1-941.4' in the BICY-PW well. The BIC-TW lithofacies at 940-945' contains an abundant and diverse foram assemblage consisting of deeper water forams.

The transgressive lithofacies at 975-980' in the BICY-TW consists of an echinoid-coated algal-peloid-foram-pellet packstone. It correlates to a very sandy pellet-intraclast packstone to very sandy intraclastic-pelecypod coquina at 980-981.6' in the BICY-PW well. The lithofacies in the BICY-TW also contains a diverse and abundant assemblage of forams.

The transgressive lithofacies at 1010-1015' starts the top of the next overlying transgression. This lithofacies in the BICY-TW consists of coated grain-peloid-foram pellet packstone-sandy foram wackestone. This lithofacies represents the beginning of a transgression and is characterized by echinoids and the beginning of a foram fauna change. The lithofacies in the BICY-TW does not correlate to the BICY-PW because it is below the BICY-PW core interval.

Generally, the BICY-TW is more shoreward of the BICY-PW. The BICY-TW contains much more sand throughout, more dolomite, and a more shoreward sequence of lithofacies. Coated grains and peloids are a more common allochem. Also there are much fewer molluscan fragments and coquinas observed in the BICY-TW than in the BICY-PW. The BICY-TW foram assemblage is a more shallow assemblage, except in the transgressive lithofacies.

October 10, 2001

Ron Shaw
Hughbert Collier

Core No.	Sample No.	Depth (ft.bls)	Horizontal Permeability (Kair-md)	Porosity Helium (%)	Grain Density (g/cm^3)	Description
			Sidewall Cores			
1	1	790.0	19.80	25.5	2.71	Limstone, pin point porosity
	2	790.0	36.50			
	3	790.0	15.20			
	4	790.0	16.40			
	5	790.0	26.90			
		Average:	**23.0**			
		Stand. Dev:	**8.83**			
2	1	1350.0	112.00	40.1	2.71	Limstone, pin point porosity
	2	1350.0	232.00			
	3	1350.0	221.00			
	4	1350.0	117.00			
	5	1350.0	113.00			
		Average:	**159.0**			
		Stand. Dev:	**61.77**			
3	1	1425.0	50.60	36.3	2.71	Limstone, pin point porosity
	2	1425.0	70.90			
	3	1425.0	59.80			
	4	1425.0	53.60			
	5	1425.0	78.30			
		Average:	**62.6**			
		Stand. Dev:	**11.71**			
4	1	1500.0	25.50		2.71	Limstone, pin point porosity
	2	1500.0	29.10			
	3	1500.0	30.20			
	4	1500.0	24.50			
	5	1500.0	24.30			
		Average:	**26.7**			
		Stand. Dev:	**2.74**			

Table D.1 Summary of Petrophysical Analyses – Sidewall Cores.

Core No.	Sample No.	Depth (ft.bls)	Horizontal Permeability (Kair-md)	Vertical Permeability (Kair-md)	Porosity Helium (%)	Grain Density (g/cm^3)	Description
Full - Diameter Core Measurements							
1	1	850.2	7.17	0.2	24.4	2.72	Lim, foss, vug
	2	850.5	3.39	0.0	24.5	2.72	Lim, foss, vug
	3	851.5	0.63	0.2	18.8	2.73	Lim, foss, vug
	4	853.0	0.98	0.4	19.7	2.73	Lim, foss, vug
	5	853.9	0.88		27.9	2.75	Lim, foss, chlk, pp
	6	854.3	0.01		6.5	2.85	Dol, foss, sl vug
	7	855.4	0.03		9.7	2.84	Dol, foss, sl vug
		Average:	**1.9**	**0.2**	**18.8**	**2.8**	
		Stand. Dev:	**2.60**	**0.14**	**7.97**	**0.06**	
2	1	859.3	5.59	1.1	10.5	2.85	Dol, foss, tr vug
	2	860.1	0.01		7.9	2.83	Dol, foss, lmy vug
	3	861.3	0.03		5.8	2.84	Dol, foss, tr vug
	4	862.5	38.30		13.2	2.84	Dol, foss, sl vug
		Average:	**11.0**		**9.4**	**2.8**	
		Stand. Dev:	**18.40**		**3.21**	**0.01**	
3	1	879.9	164.00		32.0	2.70	Lim, foss, pp
	2	880.3	3415.00		36.3	2.71	Lim, foss, pp
		Average:	**1789.5**		**34.2**	**2.7**	
4	1	899.1	712.00		27.4	2.71	Lim,foss, tr slt, sl vug
	2	900.1	492.00		34.4	2.71	Lim,foss, pp
	3	901.1	11069.00		38.4	2.71	Lim, pp, sl vug
		Average:	**4091.0**		**33.4**	**2.7**	
		Stand. Dev:	**6044.13**		**5.57**	**0.00**	
5	1	919.3	76.70		36.4	2.70	Lim, foss, pp
	2	919.8	562.00		45.3	2.70	Lim, foss, pp
	3	920.8	1660.00	294.0	37.2	2.72	Lim, foss, pp
	4	921.5	4569.00		32.6	2.71	Lim, foss, pp
	5	922.2	1.18		22.1	2.72	Lim, chlky, rk frag
		Average:	**1373.8**		**34.7**	**2.7**	
		Stand. Dev:	**1905.05**		**8.44**	**0.01**	
6	1	940.5	0.81		21.8	2.71	Lim, chlky, rk frag
7	1	970.6	81.40		31.5	2.71	Lim, foss, pp
	2	971.7	170.00		34.3	2.70	Lim, foss, slt, pp
	3	972.1	3238.00		34.8	2.70	Lim, foss, slt, pp
	4	973.8	581.00		32.6	2.70	Lim, foss, slt, pp
	5	975.7	1.45		24.1	2.67	Lim, slt
		Average:	**814.4**		**31.5**	**2.7**	
		Stand. Dev:	**1373.11**		**4.32**	**0.02**	

Table D.2 Summary of Petrologic Analyses – Full Diameter Cores.

Core No.	Sample No.	Depth (ft.bls)	Horizontal Permeability (Kair-md)	Vertical Permeability (Kair-md)	Porosity Helium (%)	Grain Density (g/cm^3)	Description
Full - Diameter Core Measurements							
8	1	980.9	17.80		26.6	2.68	Lim, slt, pp
	2	981.6	4033.00		29.4	2.70	Lim, foss, slt, pp
	3	982.1	1724.00		24.6	2.71	Lim, foss, slt, pp
	4	983.1	7562.00		28.8	2.71	Lim, foss, slt, pp
		Average:	**3334.2**		**27.4**	**2.7**	
		Stand. Dev:	**3263.63**		**2.19**	**0.01**	
9	1	984.1	5720.00		26.0	2.71	Lim, foss, slt, pp
	2	984.5	3695.00		31.3	2.71	Lim, foss, slt, pp
	3	985.6	91.80		23.9	2.68	Lim, v/slty - sndy
	4	986.5	9.19		24.3	2.67	Lim, v/slty - sndy
	5	987.2	1.37		29.8	2.70	Lim, v/slty - sndy
	6	987.7	2.02		27.7	2.68	Lim, v/slty - sndy
		Average:	**1586.6**		**27.2**	**2.7**	
		Stand. Dev:	**2501.07**		**2.99**	**0.02**	
10	1	990.1	48.60		30.0	2.70	Lim, foss, slt, vug
	2	991.2	11.20		18.0	2.67	Sd, lt gry-tn, frg, lmy
		Average:	**29.9**		**24.0**	**2.7**	

ft. bls = feet below land surface
md = millidarcy
% = percent
g/cm^3 = grams per cubic centimeter
Lim = Limestone
vug = vug (gy)
foss = fossils
pp = pin point porosity
sl vug = slightly vuggy
Stand. Dev = Standard Deviation

Table D.2 Summary of Petrologic Analyses – Full Diameter Cores (cont'd).

CORE DEPTH	ROCK TYPE	GRAIN SIZE	POROSITY VISUAL DOMINANT	POROSITY DOMINANT	POROSITY VISUAL OTHER	POROSITY OTHER	PORE SIZES DOMINANT	PORE SIZES OTHER	CEMENT	LAMINATIONS	SORTING	GLAUCONITE	SAND	DOLOMITE
Suwannee														
850.0 - 854.2	W	F-P	F	MO	TR	V	M-VC	1-4MM MO	I R		VP			TR-SL
854.2 - 855.6	P	F-P	F	MO	P	I	M-VC	1-2 CM		SL	P			A
859.0 - 862.4	P	M-P	F	FE	P	TR V-MO	VF-F	.5-1.5 CM			W			A
879.0 - 882.2	P	F-VC-P	VG	MO-BP	F	F-BP	VF-F	1-2 MM			P			
899.0 - 899.2	COQ	F-VC	G	WP	F	MO-BP-WP	C	.25-1CM			M-VP		SL	
899.2 - 900.5	P	VF-M	F	WP-BP	TR	MO-V	VF-F	1-3 MM	TR R		M		TR	
900.5 - 901.0	B	B	P	WP	TR	V	VF-F	1-3 MM						
901.0 - 901.8	COQ-G	F-VC	F-VG	BP-MO	TR	V	VF-VC	1-10 MM	A R		VP		10%	
919.0 - 920.5	W-P	VF-P	G	BP-MICRO	P	MO	VF-F	1-10 MM			P			
920.5 - 921.5	G	F-C	VG	MO-BP	TR	V	M-P	1-10 MM	A R		VP			
921.5 - 922.2	W	VF-C	F	BP-MO	F	BP	F-M	1-6 MM	A R		VP			
922.2 - 923.0	W-P	VF-P	F	BP IN CLASTS	TR-F	MO-BP	VF-F		A R		VP			
940.0 - 941.1	P	VF-P	VG	MICRO	TR	MO	.1-.2, 1-4 MM	F - 2 CM			VP-M			
941.1 - 941.4	G-COQ	VF-P	VG	MO	G	MO	F-C	1 MM-2 CM	A R		VP-M			
970.0 - 976.4	P-G	M-P	VG	BP	F	MO-BP	VF-M	.5-7 CM			VP	5-20%		
980.0 - 981.6	P	F-P	V P	BP-MO-MICRO	TR	WP	VF-M	.5-7 MM			VP	40-50%		
981.6 - 983.8	COQ	M-VC	VG	BP-MO	F	WP-F	F-C	.5-3 MM MO-V	A R		M-VP	20%		
984.0 - 985.3	COQ	M-VC	VG	BP-MO	F	WP-F	F-C	.5-3 MM MO-V	A R		M-VP	20%		
985.3 - 987.4	P	F-P	F	MO-WP	TR	BP-V	F-M	1-3 MM		SL	MW-P	30-50%		
987.4 - 988.2	M-W	VF-P	F	MO	TR	MO-WP	F-M	2 MM-7 CM MO		SL	P-VP	5-20%		
990.0 - 991.6	COQ-SS/M	VF-C	VP-G	MO-V	TR	WP-F	VC-P	1 MM-1 CM			P-VP	50-80%		

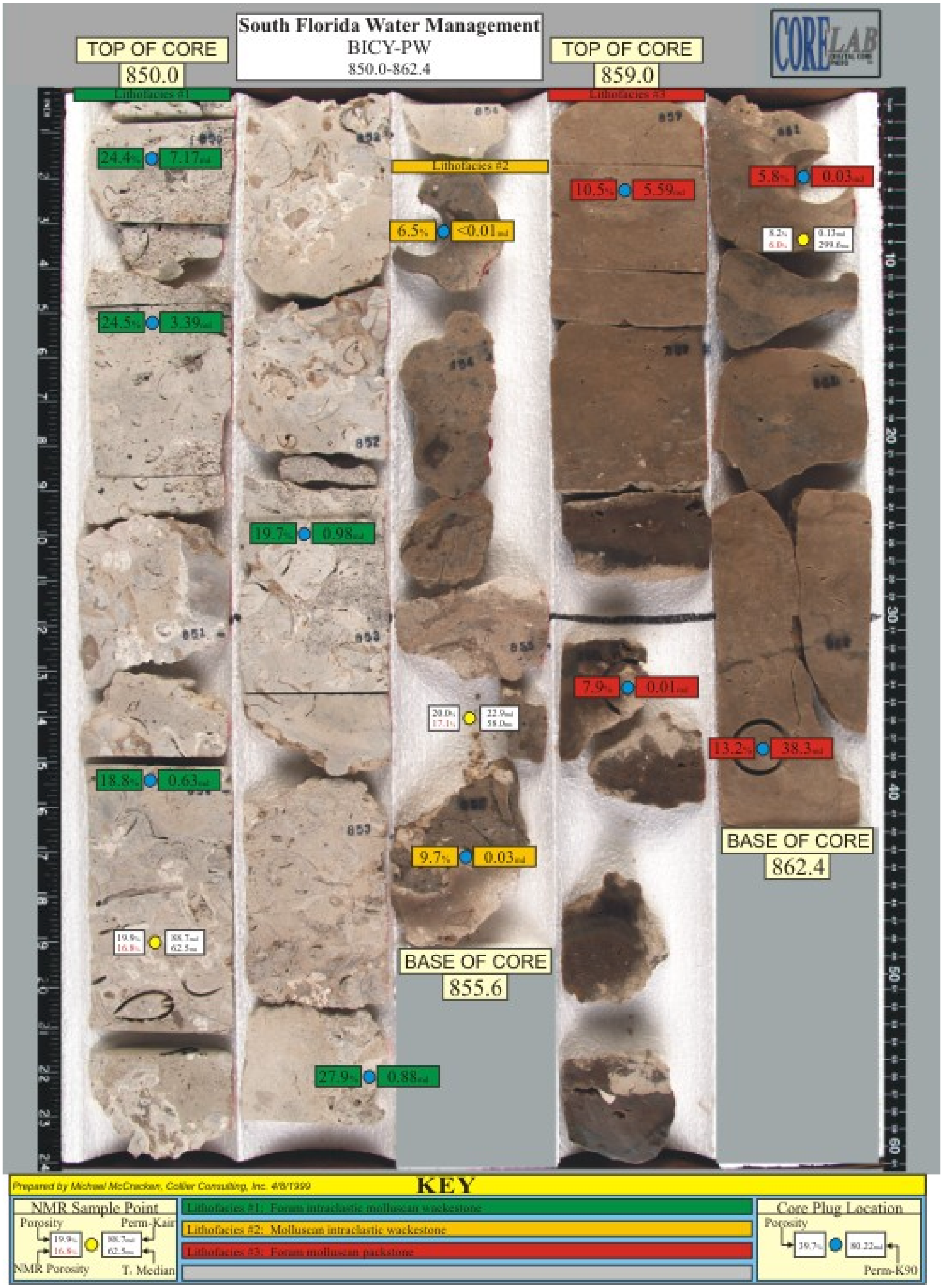
Table D.3 Petrologic Summary of Core Sections.

CORE DEPTH	LITHOFACIES	DEPOSITIONAL ENVIRONMENTS	Depth of Measurement (ft.bls)	Horizontal Permeability (Kair-md)	Porosity Helium (%)
850.0 - 854.2	FORAM-INTRACLASTIC-MOLLUSCAN WACKESTONE	BRYOZOAN MOUND FLANK	850.2	7.17	24.4
			850.5	3.39	24.5
			851.5	0.63	18.8
			853.0	0.98	19.7
			853.9	0.88	27.9
			Mean	**2.61**	**23.06**
854.2 - 855.6	MOLLUSCAN INTRACLASTIC WACKESTONE	INTERTIDAL	854.3	0.01	6.5
			855.4	0.03	9.7
			Mean	**0.02**	**8.10**
859.0 - 862.4	FORAM MOLLUSCAN PACKSTONE	SUPRATIDAL	859.3	5.59	10.5
			860.1	0.01	7.9
			861.3	0.03	5.8
			862.5	38.30	13.2
			Mean	**10.98**	**9.35**
879.0 - 882.2	FORAM PELECYPOD PACKSTONE	SHALLOW RESTRICTIVE LAGOON	879.9	164.00	32.0
			880.3	3415.00	36.3
			Mean	**1789.50**	**34.15**
899.0 - 899.2	GASTROPOD-PELECYPOD COQUINA	MOLLUSCAN SHOAL	899.1	712.00	27.4
899.2 - 900.5	PELLET-FORAM PACKSTONE	SHALLOW RESTRICTIVE LAGOON	900.1	492.00	34.4
900.5 - 901.0	CORAL BOUNDSTONE	CORAL MOUND	901.1	11069.00	38.4
919.0 - 920.5	GASTROPOD-PELECYPOD WACKSTONE-PACKSTONE	TIDAL FLAT	919.3	76.70	36.4
			919.8	562.00	45.3
			Mean	**319.35**	**40.85**
920.5 - 921.5	GASTROPOD-COATED GRAINS GRAINSTONE	SHALLOW RESTRICTIVE LAGOON	920.8	1660.00	37.2
921.5 - 922.2	PELECYPOD WACKESTONE-PELLET FORAM PACKSTONE	DEEP RESTRICTIVE LAGOON	921.5	4569.00	32.6
922.2 - 923.0	CHALKY INTRACLASTIC WACKSTONE-PACKSTONE	MOUND	922.2	1.18	22.1
940 - 941.1	CHALKY COATED GRAINS INTRACLASTIC PACKSTONE	SHALLOW RESTRICTIVE LAGOON-SHOAL FLANK	940.5	0.81	21.8

Table D.4 Summary of Petrologic Analyses by Collier Consulting.

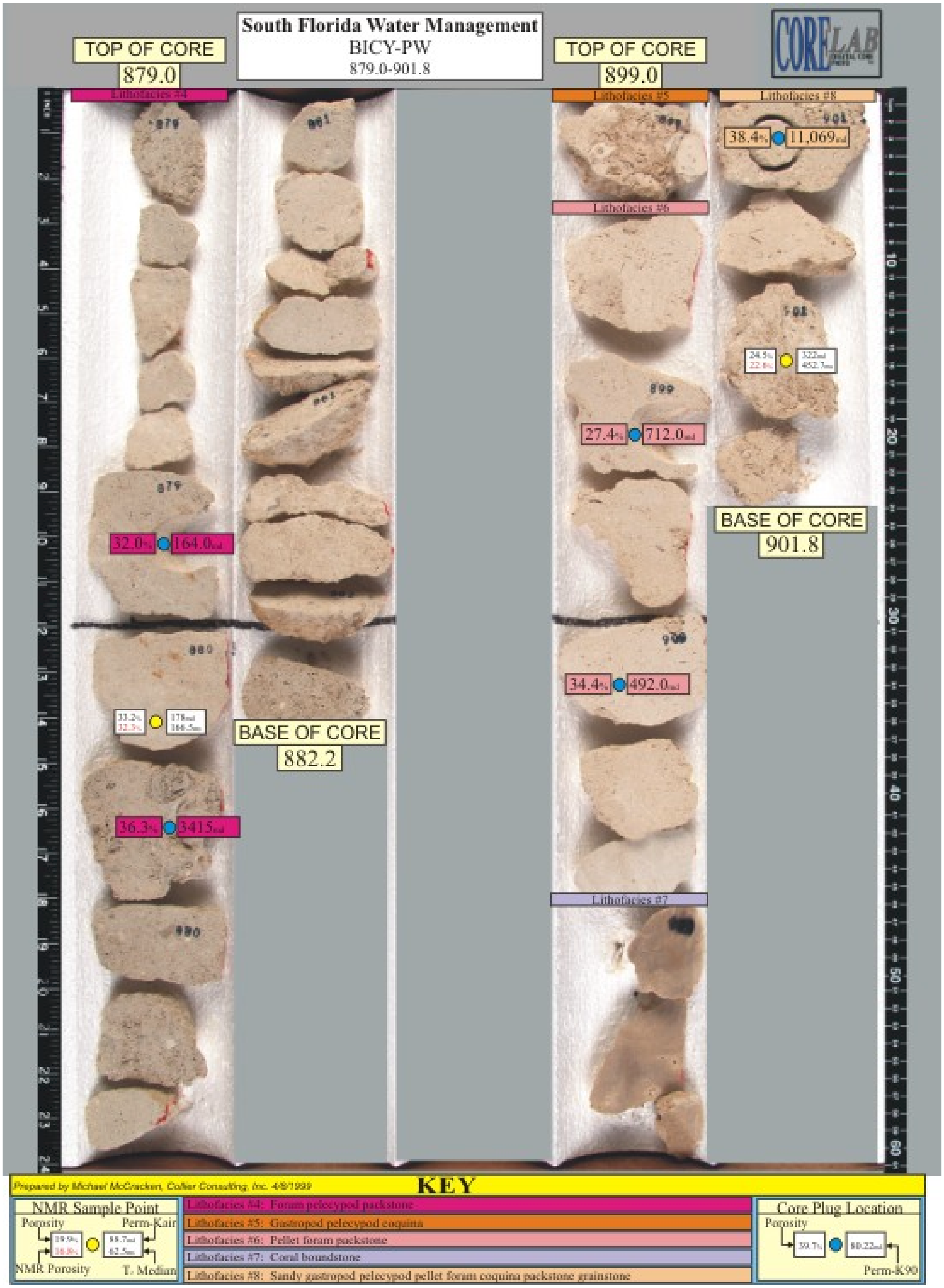
CORE DEPTH	LITHOFACIES	DEPOSITIONAL ENVIRONMENTS	Depth of Measurement (ft.bls)	Horizontal Permeability (Kair-md)	Porosity Helium (%)
941.1 -941.4	PELECYPOD COQUINA GRAINSTONE	MOLLUSCAN SHOAL			
970- 976.4	CHALKY FORAM PELOID-PELLET PACK.-GRAINSTONE		970.6	81.40	31.5
	TO		971.7	170.00	34.3
	SANDY INTRACLASTIC FORAM PELLET PACKSTONE	SHALLOW RESTRICTIVE LAGOON	972.1	3238.00	34.8
			973.8	581.00	32.6
			975.7	1.45	24.1
			Mean	**814.37**	**31.46**
980 - 981.6	VERY SANDY PELLET-INTRACLAST PACKSTONE	SHALLOW RESTRICTIVE LAGOON	980.9	17.80	26.6
981.6 - 983.8	VERY SANDY SLIGHTLY INTRACLASTIC PELECYPOD COQUINA	MOLLUSCAN SHOAL	981.6	4033.00	29.4
			982.1	1724.00	24.6
			983.1	7562.00	28.8
			Mean	**3334.20**	**27.35**
984 - 985.3	SANDY, SLIGHTLY INTRACLASTIC PELECYPOD COQUINA	MOLLUSCAN SHOAL	984.1	5720.00	26.0
			984.5	3695.00	31.3
			Mean	**4707.50**	**28.65**
985.3 - 987.4	SANDY, CHALKY FORAM PELLET PACKSTONE	SHALLOW RESTRICTIVE LAGOON	985.6	91.80	23.9
			986.5	9.19	24.3
			Mean	**50.50**	**24.10**
987.4 - 988.2	CHALKY,SANDY INTRACLASTIC MUDSTONE-WACKESTONE	INTERTIDAL	987.2	1.37	29.8
			987.7	2.02	27.7
			Mean	**1.70**	**28.75**
990 - 991.6	INTERBEDDED CHALKY SANDY COQUINA w/ SANDY, CHALKY SANDSTONE	INTERTIDAL	990.1	48.60	30.0
			991.2	11.20	18.0
			Mean	**29.90**	**24.00**

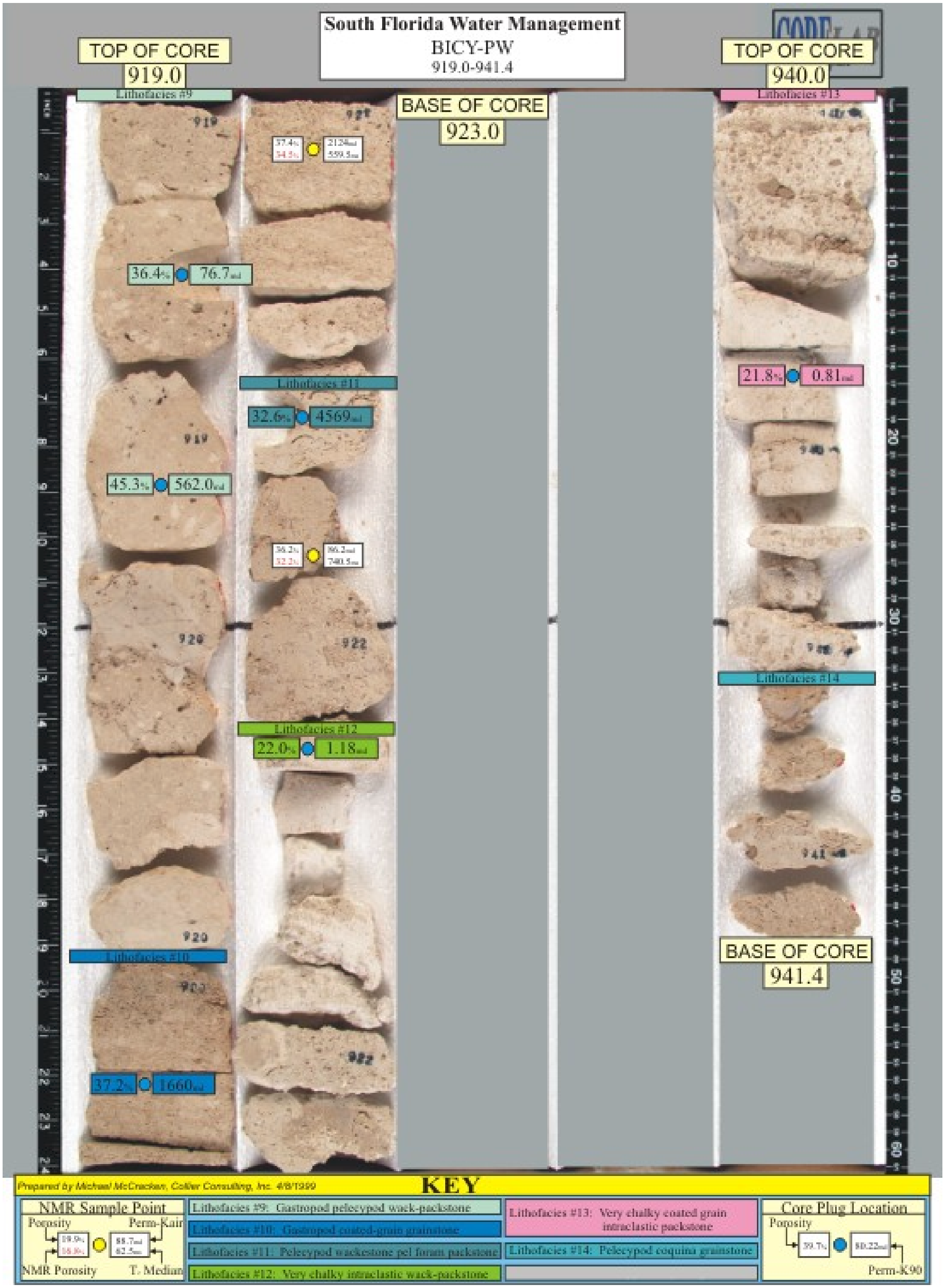
Table D.4 Summary of Petrologic Analyses by Collier Consulting (cont'd).

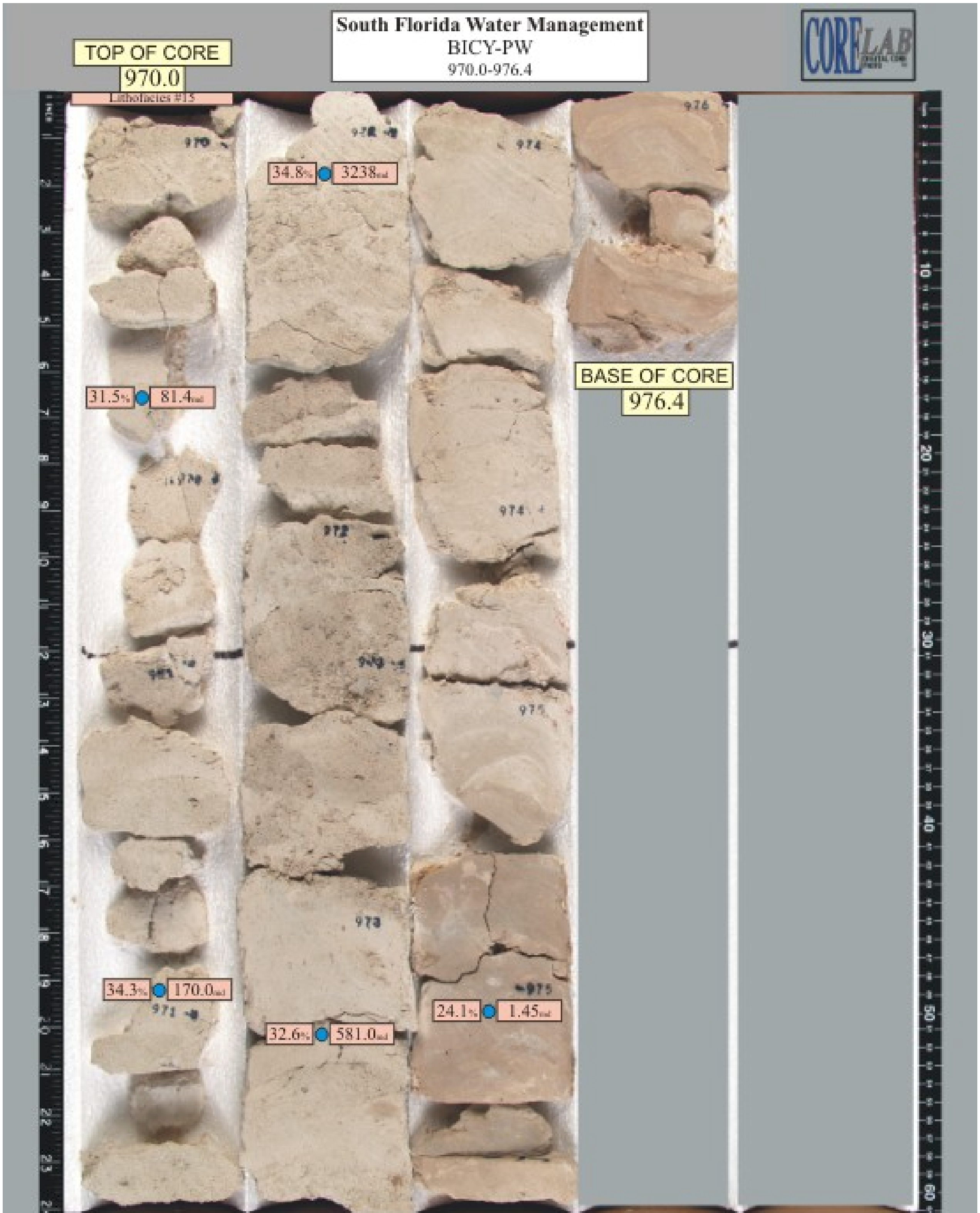


South Florida Water Management
BICY-PW
850.0-862.4
TOP OF CORE
850.0
TOP OF CORE
859.0
CORELAB
Lithofacies #1
Lithofacies #2
Lithofacies #3
24.4% 7.17md
24.5% 3.39md
18.8% 0.63md
19.7% 0.98md
27.9% 0.88md
6.5% <0.01md
9.7% 0.03md
10.5% 5.59md
7.9% 0.01md
5.8% 0.03md
13.2% 38.3md
BASE OF CORE
855.6
BASE OF CORE
862.4

Prepared by Michael McCracken, Collier Consulting, Inc. 4/8/1999
KEY
NMR Sample Point
Porosity
Perm-Kair
NMR Porosity
T2 Median
Lithofacies #1: Foram intraclastic molluscan wackestone
Lithofacies #2: Molluscan intraclastic wackestone
Lithofacies #3: Foram molluscan packstone
Core Plug Location
Porosity
Perm-K90


South Florida Water Management
BICY-PW
879.0-901.8
TOP OF CORE
879.0
Lithofacies #4
32.0%
164.0md
36.3%
3415md
BASE OF CORE
882.2
TOP OF CORE
899.0
Lithofacies #5
Lithofacies #6
27.4%
712.0md
34.4%
492.0md
Lithofacies #7
Lithofacies #8
38.4%
11,069md
BASE OF CORE
901.8
Prepared by Michael McCracken, Collier Consulting, Inc. 4/8/1999
KEY
NMR Sample Point
Porosity
Perm-Kair
NMR Porosity
T. Median
Lithofacies #4: Foram pelecypod packstone
Lithofacies #5: Gastropod pelecypod coquina
Lithofacies #6: Pellet foram packstone
Lithofacies #7: Coral boundstone
Lithofacies #8: Sandy gastropod pelecypod pellet foram coquina packstone grainstone
Core Plug Location
Porosity
Perm-K90


South Florida Water Management
BICY-PW
919.0-941.4
TOP OF CORE
919.0
BASE OF CORE
923.0
TOP OF CORE
940.0
BASE OF CORE
941.4
Lithofacies #9
36.4%
76.7md
45.3%
562.0md
Lithofacies #10
37.2%
1660md
Lithofacies #11
32.6%
4569md
Lithofacies #12
22.0%
1.18md
Lithofacies #13
21.8%
0.81md
Lithofacies #14
Prepared by Michael McCracken, Collier Consulting, Inc. 4/8/1999
KEY
NMR Sample Point
Porosity
Perm-Kair
NMR Porosity
T. Median
Lithofacies #9: Gastropod pelecypod wack-packstone
Lithofacies #10: Gastropod coated-grain grainstone
Lithofacies #11: Pelecypod wackestone pel foram packstone
Lithofacies #12: Very chalky intraclastic wack-packstone
Lithofacies #13: Very chalky coated grain intraclastic packstone
Lithofacies #14: Pelecypod coquina grainstone
Core Plug Location
Porosity
Perm-K90

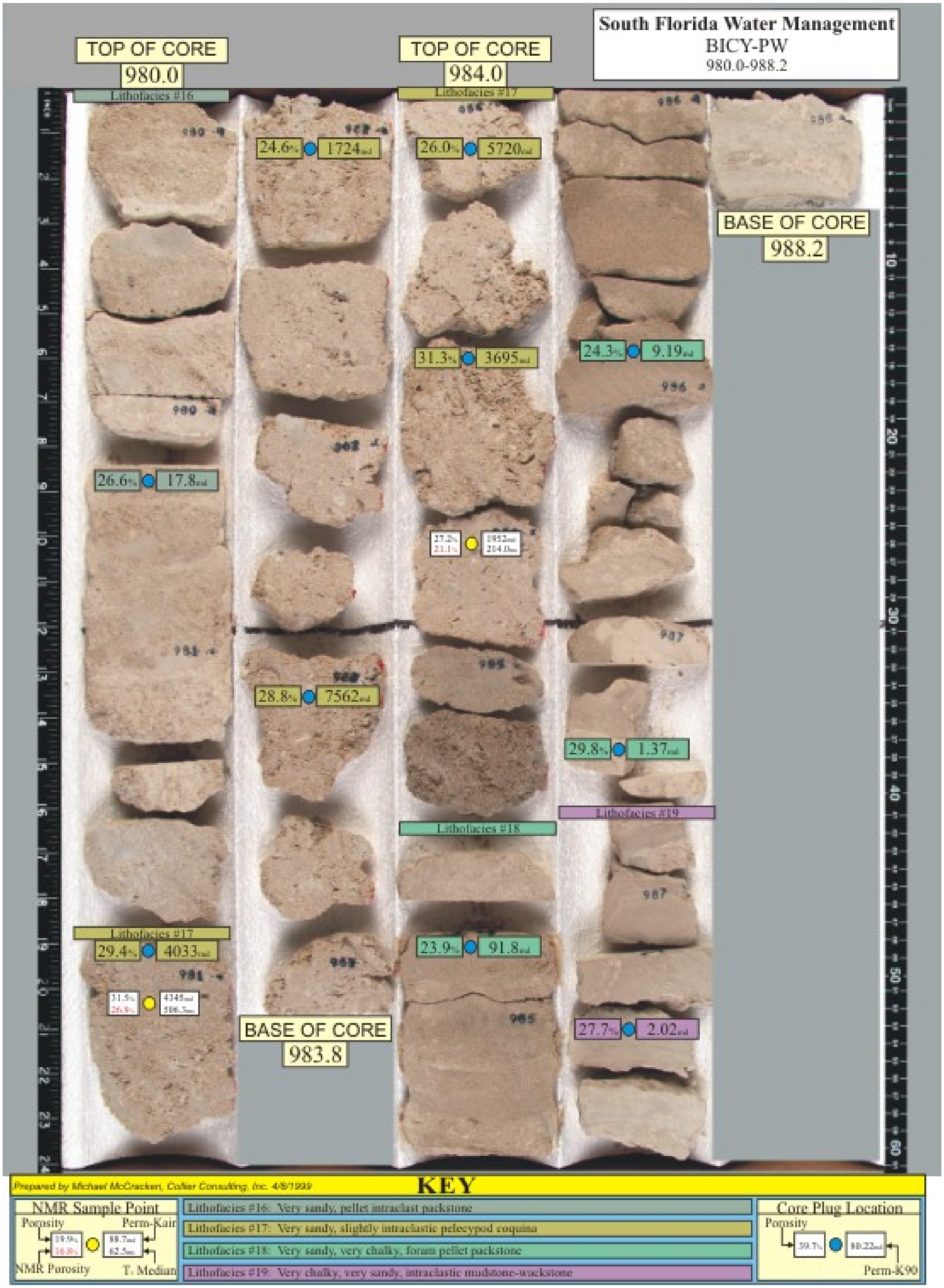


KEY

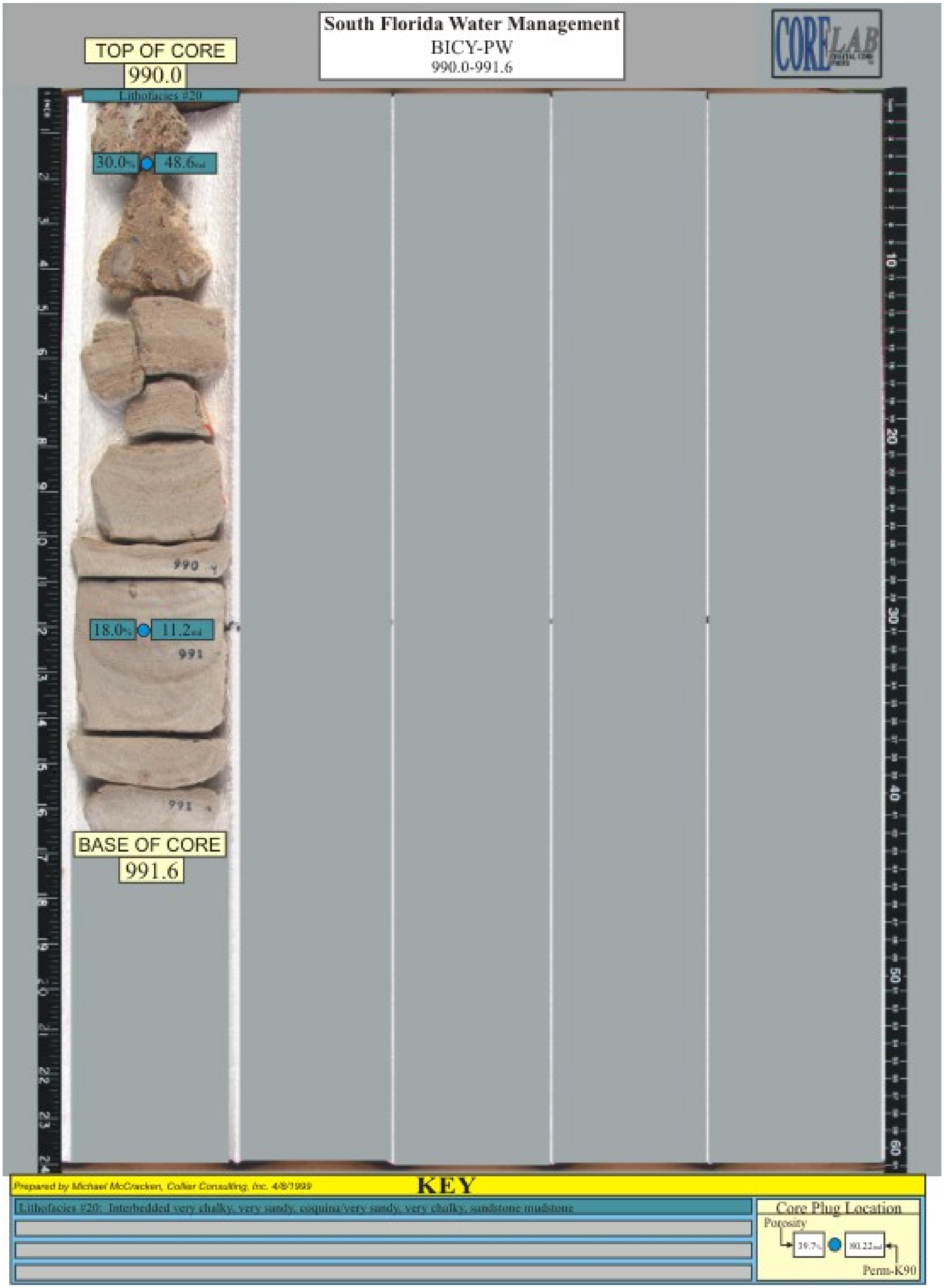
Prepared by Michael McCracken, Collier Consulting, Inc. 4/8/1999

Lithofacies #15: Very chalky foram peloid pellet pack grainstone very sandy intraclastic foram pellet packstone

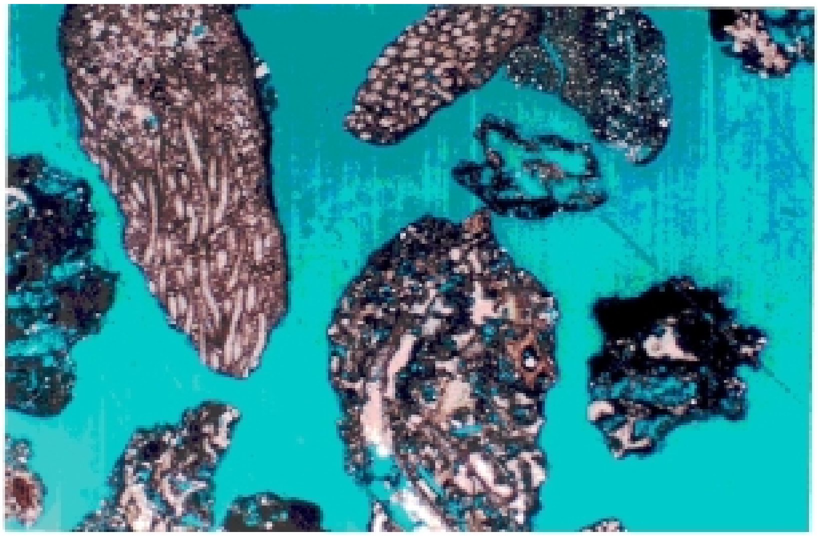
Core Plug Location: Porosity 39.7% ● 80.22md Perm-K90



South Florida Water Management
BICY-PW
980.0-988.2
TOP OF CORE
980.0
Lithofacies #16
26.6%
17.8md
Lithofacies #17
29.4%
4033md
24.6%
1724md
28.8%
7562md
BASE OF CORE
983.8
TOP OF CORE
984.0
Lithofacies #17
26.0%
5720md
31.3%
3695md
Lithofacies #18
23.9%
91.8md
24.3%
9.19md
29.8%
1.37md
Lithofacies #19
27.7%
2.02md
BASE OF CORE
988.2
Prepared by Michael McCracken, Collier Consulting, Inc. 4/8/1999
KEY
NMR Sample Point
Porosity
Perm-Kair
NMR Porosity
T. Median
Lithofacies #16: Very sandy, pellet intraclast packstone
Lithofacies #17: Very sandy, slightly intraclastic pelecypod coquina
Lithofacies #18: Very sandy, very chalky, foram pellet packstone
Lithofacies #19: Very chalky, very sandy, intraclastic mudstone-wackestone
Core Plug Location
Porosity
Perm-K90


South Florida Water Management
BICY-PW
990.0-991.6
TOP OF CORE
990.0
Lithofacies #20
30.0%
48.6md
18.0%
11.2md
BASE OF CORE
991.6
Prepared by Michael McCracken, Collier Consulting, Inc. 4/8/1999
KEY
Lithofacies #20: Interbedded very chalky, very sandy, coquina/very sandy, very chalky, sandstone mudstone
Core Plug Location
Porosity
39.7%
80.22md
Perm-K90

APPENDIX E
PETROLOGIC DATA – PHOTOMICROGRAPHS

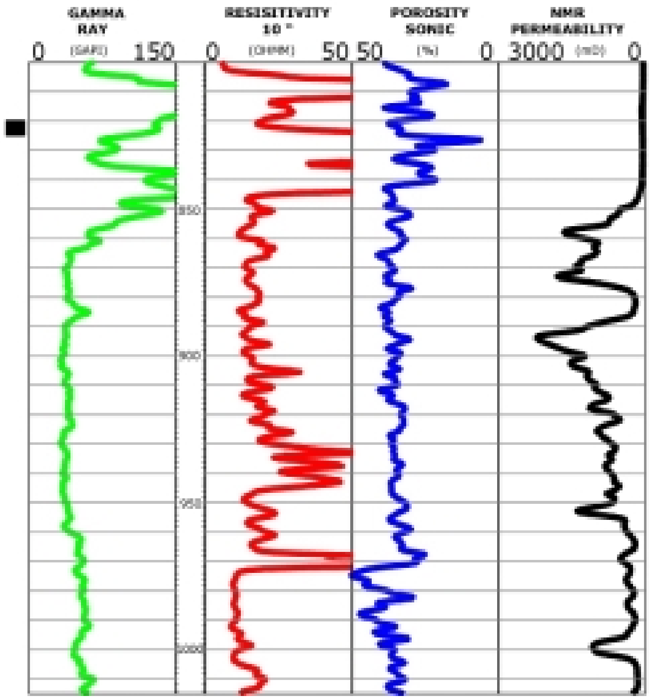


WELL: BICY-TW
DEPTH: 820-825
MAGNIFICATION: 20X

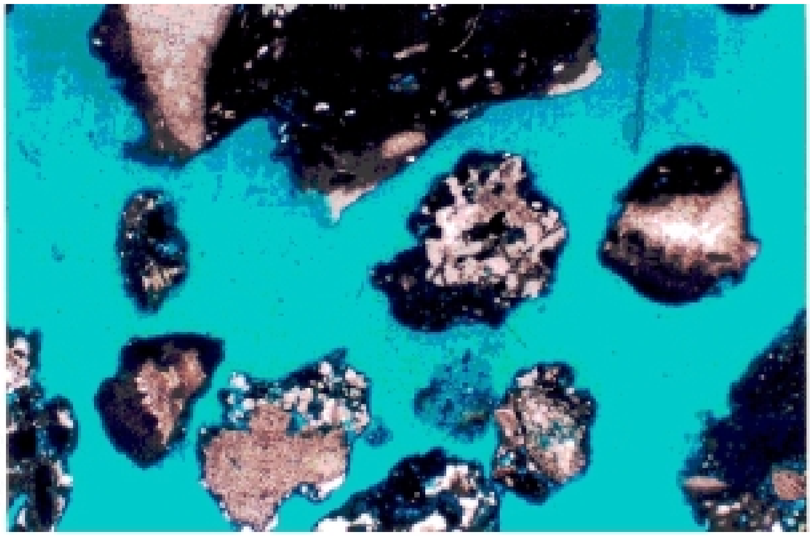
FORAM-PELLET SUBFACIES: Echinoid-peloid-foram-pellet packstone, fine-very coarse grained, poorly sorted, slightly dolomitic, slightly cemented, with poor to fair moldic and intraparticle porosity.

20% peloid-foram wackestone with poor intraparticle and moldic porosity.

10% dolomite very fine crystalline with some intercrystalline and microporosity.



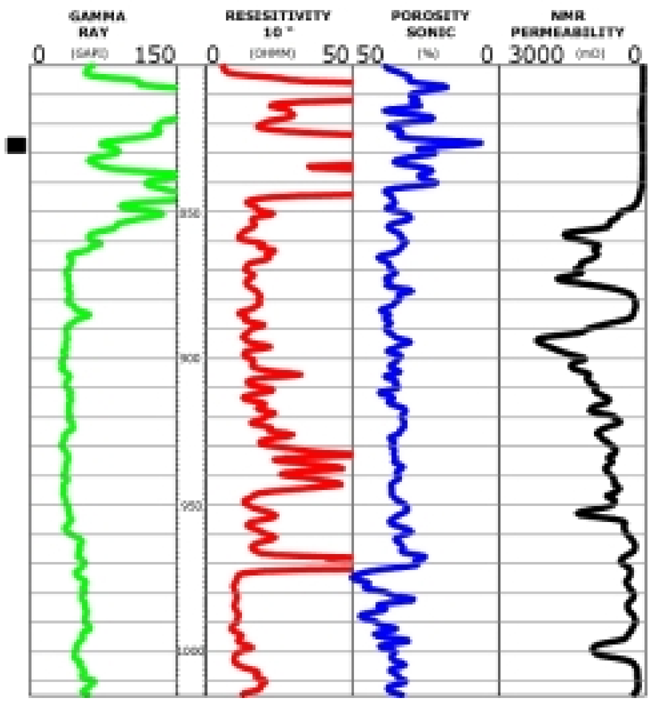
No Core Available



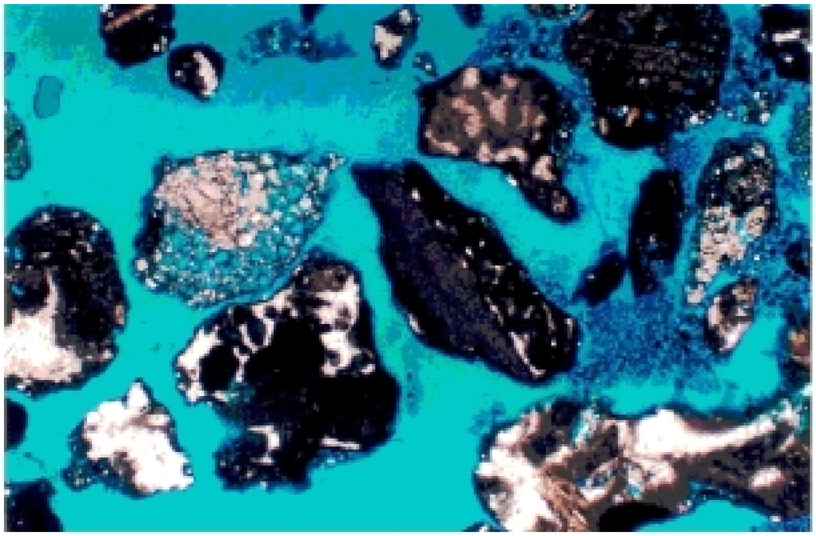
WELL: BICY-TW
DEPTH: 825-830
MAGNIFICATION: 20x

FORAM-PELLET SUBFACIES: Skeletal-peloid-foram-pellet packstone slightly dolomitic slightly sandy.

10% grainstone, very fine to medium grained with fair very fine to medium moldic porosity and poor intraparticle porosity, slightly cemented with fine to coarse sparry calcite in vugs and molds, trace dolomite occlusion.



No Core Available

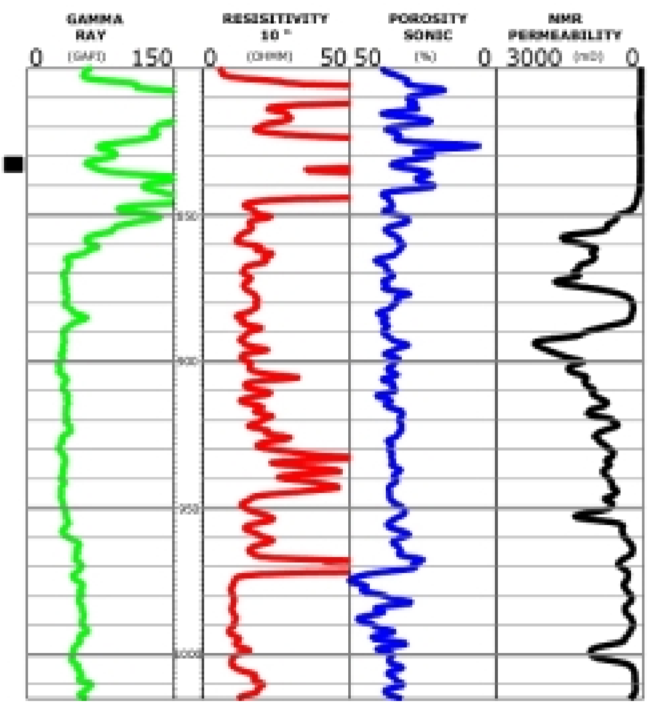


WELL: BICY-TW
DEPTH: 830-835
MAGINIFICATION: 20X

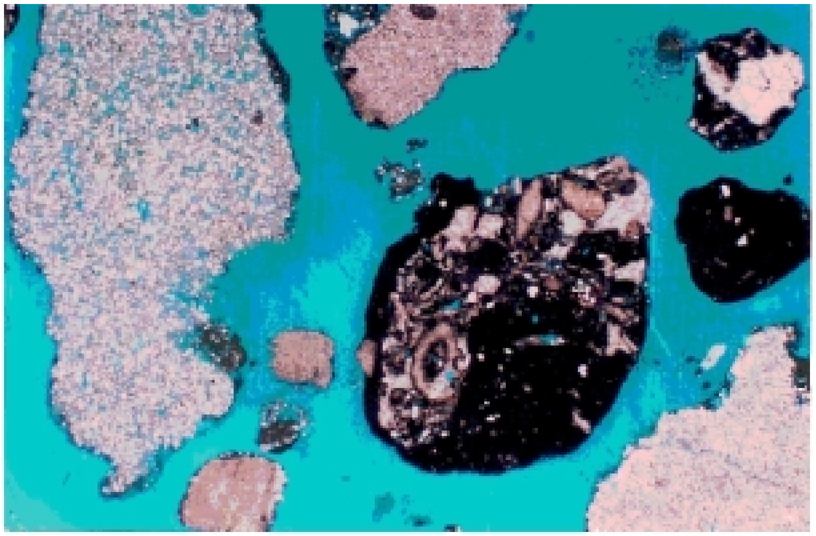
FORAM-PELLET SUBFACIES: 30% slightly sandy foram-pellet packstone, fine to medium grained, moderate sorted with fair very fine to medium size scattered molds.

40% slightly sandy echinoid peloid-intraclast-pellet packstone, fine to very coarse grained, very poorly sorted with fair moldic porosity with scattered occlusions, fine crystalline cement and overgrowth cement.

10% dolomite, very fine to fine crystalline with fair intercrystalline porosity.



No Core Available



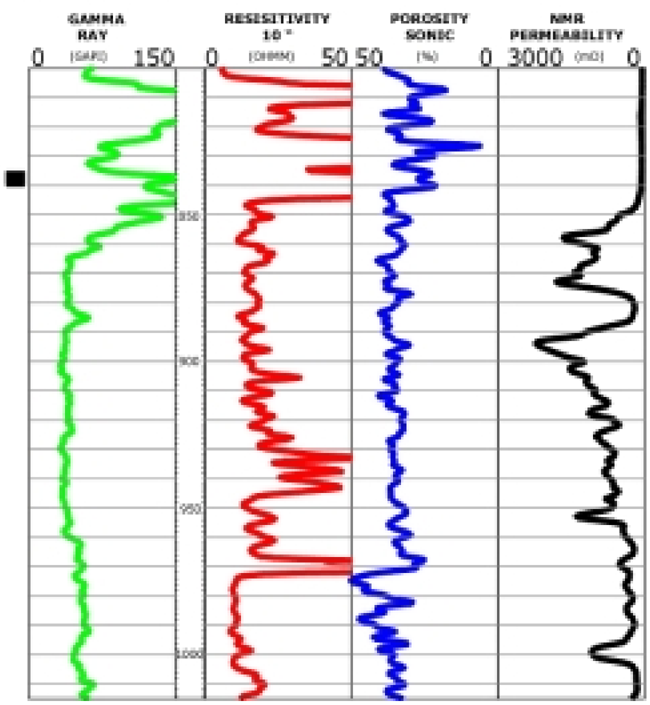
WELL: BICY-TW
DEPTH: 835-840
MAGNIFICATION: 20X

FORAM-PELLET SUBFACIES: 40% slightly to very sandy gastropod-foram-pellet algal wackestone, very fine to very coarse grain, very poorly sorted.

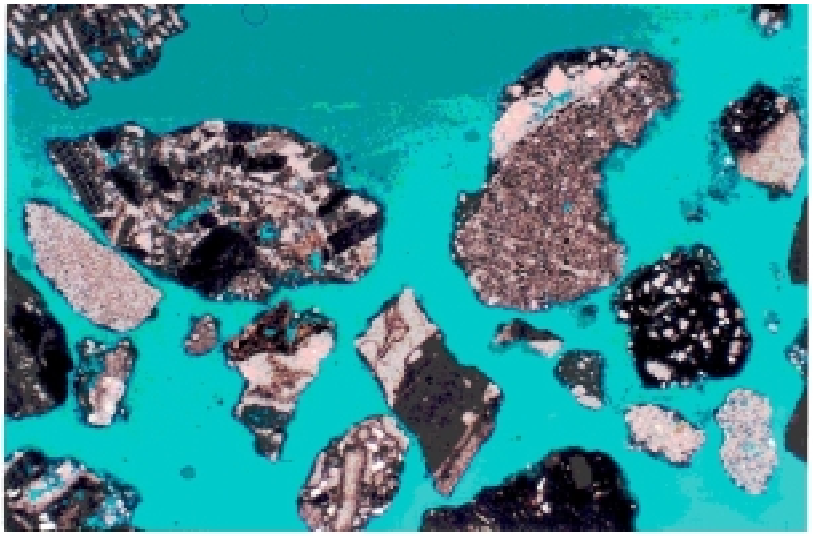
10% slightly to well cemented, poor to fair moldic and intraparticle porosity. Trace good moldic porosity, trace glauconite.

40% slightly sandy to very sandy echinoid-skeletal-pellet packstone.

5% Dolomite, very fine to fine crystalline with fair very fine to fine intercrystalline porosity, trace fine to course vugs occluded with dolomite.



No Core Available

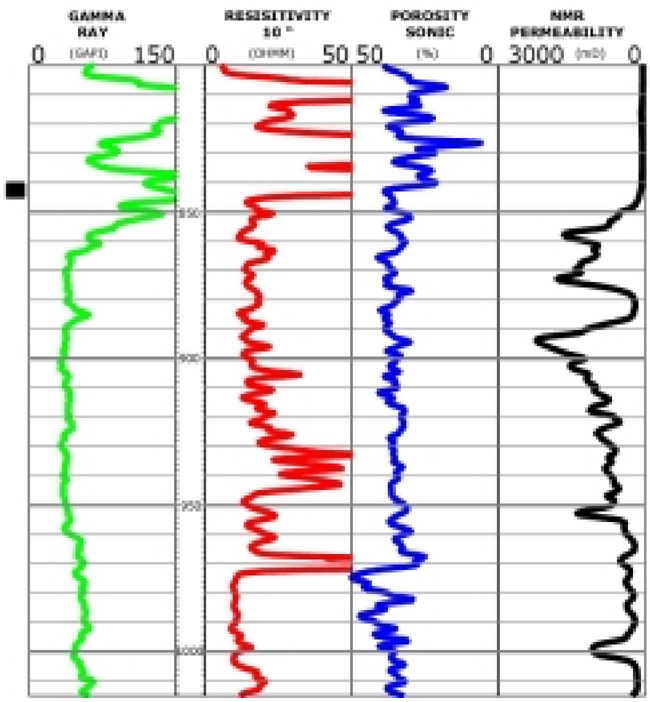


WELL: BICY-TW
DEPTH: 840-845
MAGNIFICATION: 20X

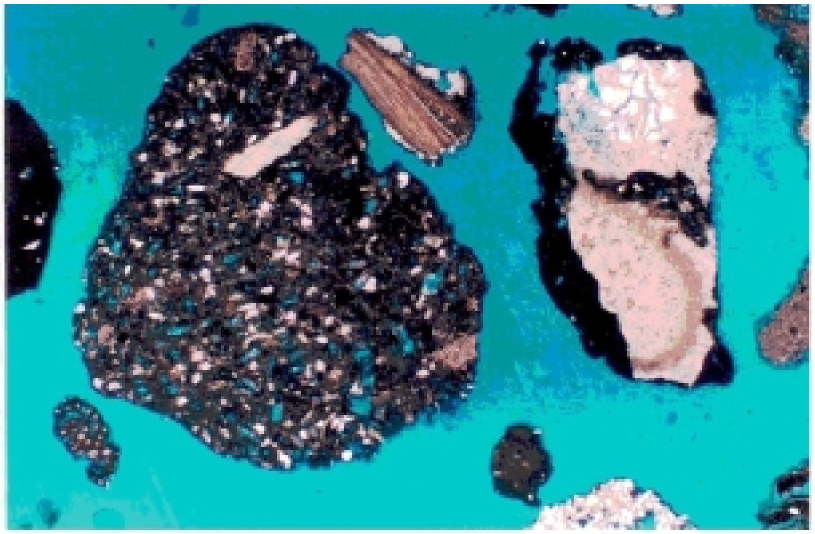
FORAM-PELLET SUBFACIES: 60% slightly sandy algal wackestone, very fine to very coarse grained, very poorly sorted, trace moldic and intraparticle porosity, trace occluded moldic porosity.

20% slightly sandy echinoid-skeletal-foram pellet packstone, poor to fair moldic porosity.

10% dolomite, very fine to fine crystalline.



No Core Available

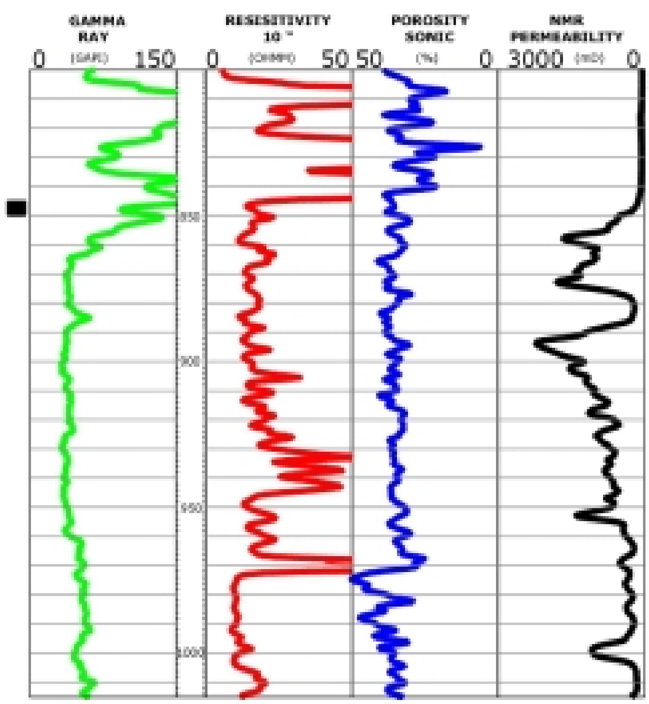


WELL: BICY-TW
DEPTH: 845-850
MAGNIFICATION: 20X

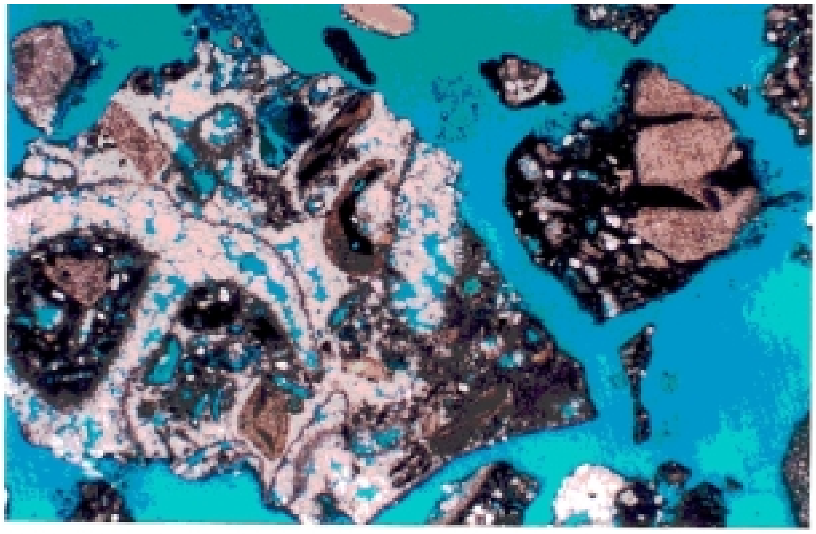
INTERBEDDED FORAM-PELLET AND ALGAL SUBFACIES: 60% Slightly sandy skeletal-foram-pellet packstone, slightly cemented, moderate to poorly sorted, very fine to medium grained, fair very fine to medium size moldic-vug porosity, trace intraparticle porosity.

10% Dolomite, very fine to fine crystalline, fair intercrystalline porosity.

30% Algal wackestone, fine to very coarse grained, very poorly sorted.



No Core Available

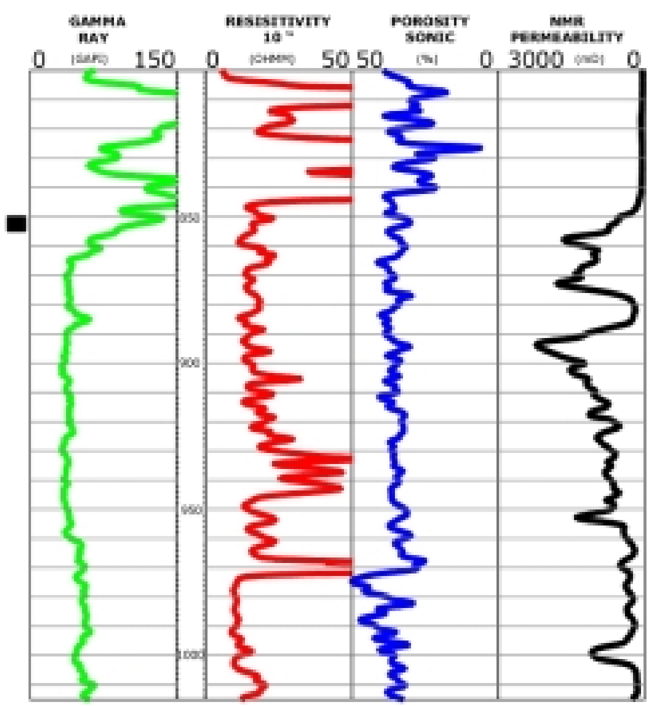


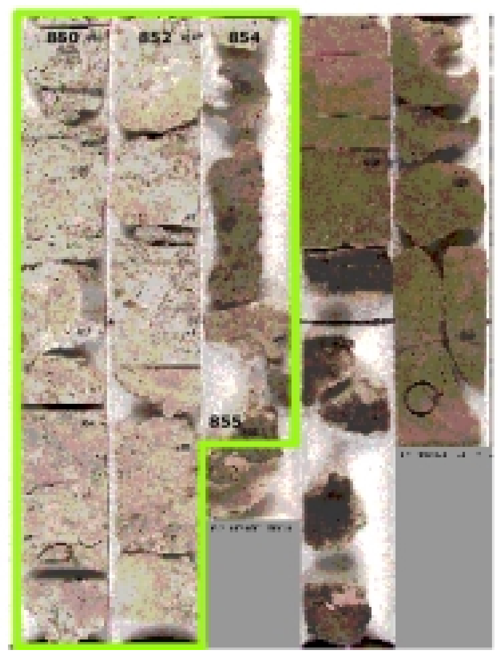
WELL: BICY-TW
DEPTH: 850-855
MAGNIFICATION: 20X

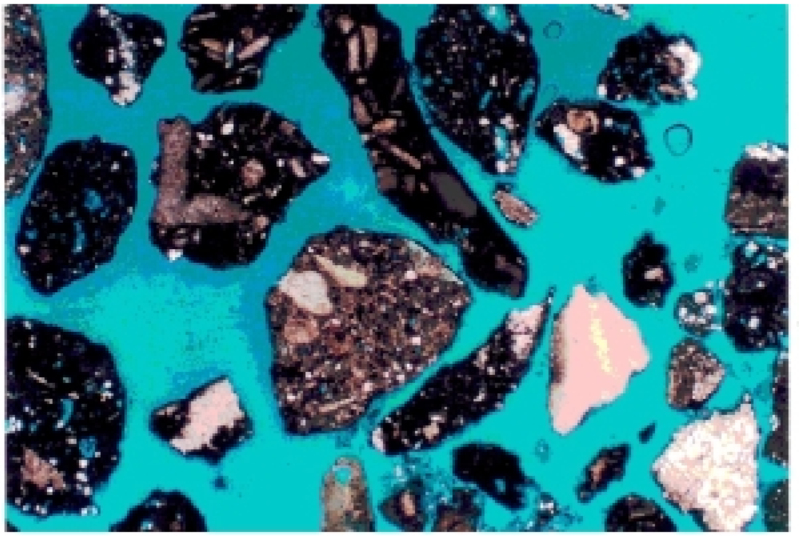
INTERBEDDED FORAM-PELLET AND ALGAL SUBFACIES: 70% slightly sandy skeletal-echinoid-foram-pellet packstone, very fine to fine grained moderate sorted, very slightly cemented.

30% Algal wackestone, fine to very coarse grained, very poorly sorted, scattered patchy microporosity and vugs and some very fine to fine crystalline dolomite occlusions.

<5% Dolomite, very fine to fine crystalline, fair intercrystalline to microporosity.







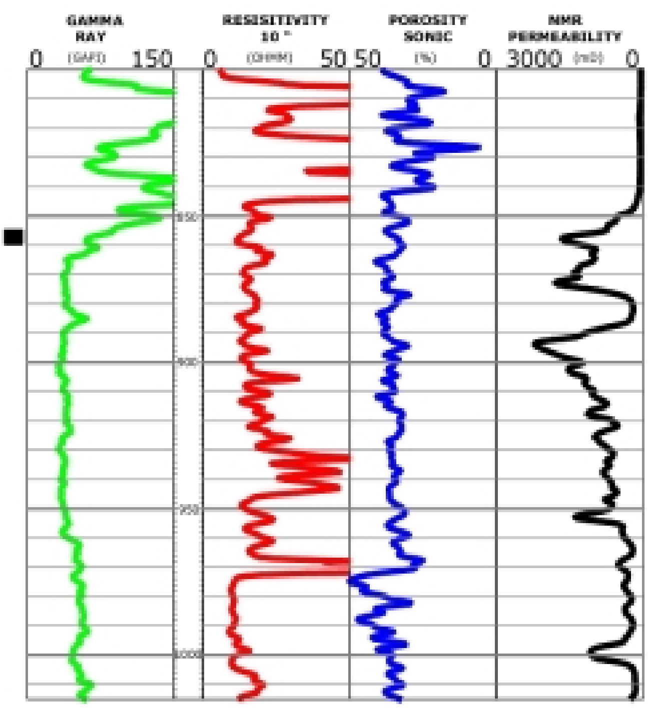
WELL: BICY-TW
DEPTH: 855-860
MAGNIFICATION: 20X

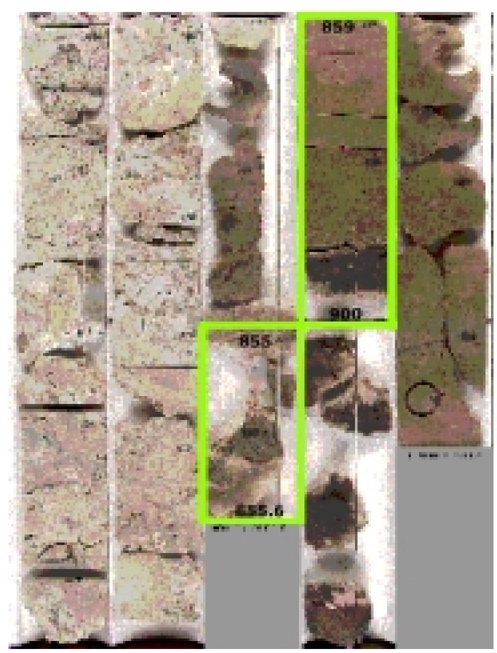
INTERBEDDED FORAM-PELLET AND ALGAL SUBFACIES:

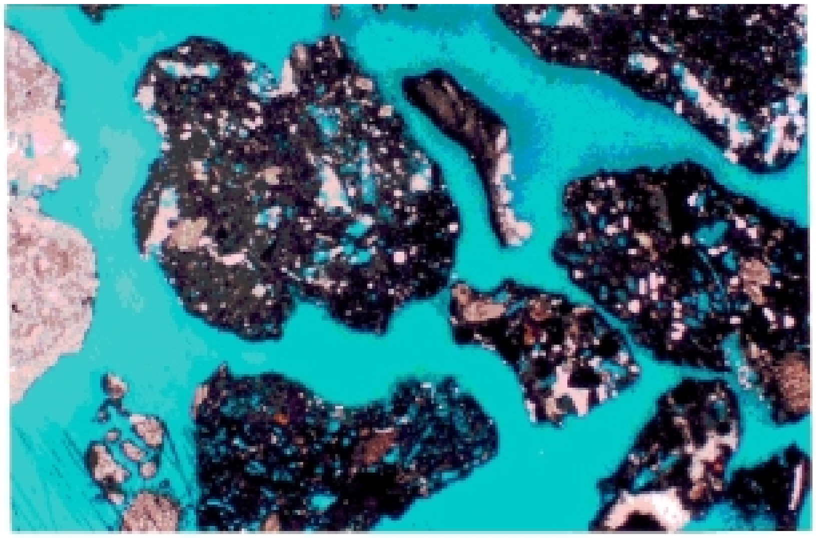
60% slightly sandy coated grain-skeletal peloid-pellet packstone-wackestone, very fine to fine grained.

30% Pellet algal wackestone.

5% Dolomite, very fine to fine crystalline.





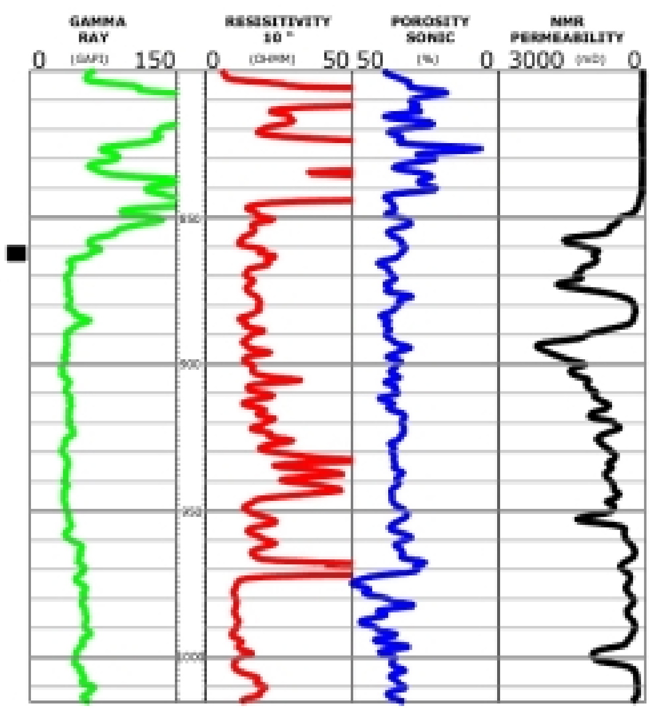


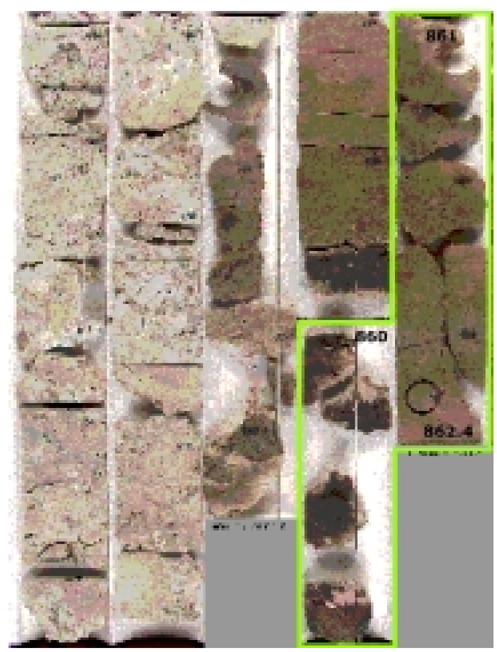
WELL: BICY-TW
DEPTH: 860-865
MAGNIFICATION: 20X

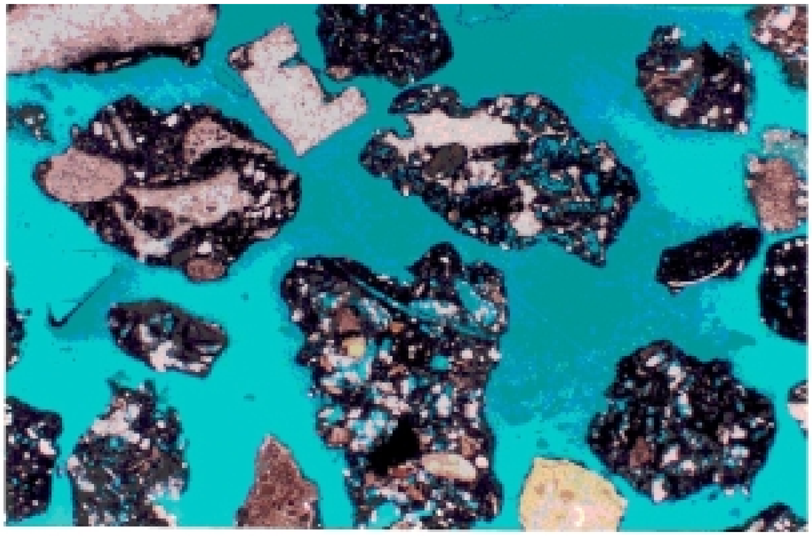
ALGAL SUBFACIES: 40% Algal wackestone, very fine to very coarse grained, very poorly sorted, fair to poor scattered very fine to fine size vugs and molds with 1% slightly cemented occluded vugs and molds, some scattered mega molds partly occluded and slightly dolomitic.

50% Algal peloid-pellet-wackestone, very poorly sorted.

10% Dolomite, very fine to fine crystalline with fair to poor intercrystalline porosity.





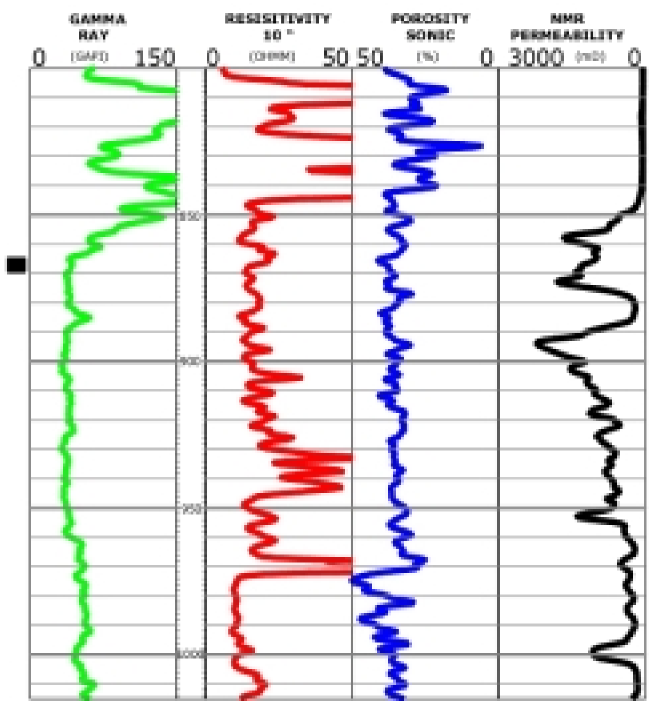


WELL: BICY-TW
DEPTH: 865-870
MAGNIFICATION: 20X

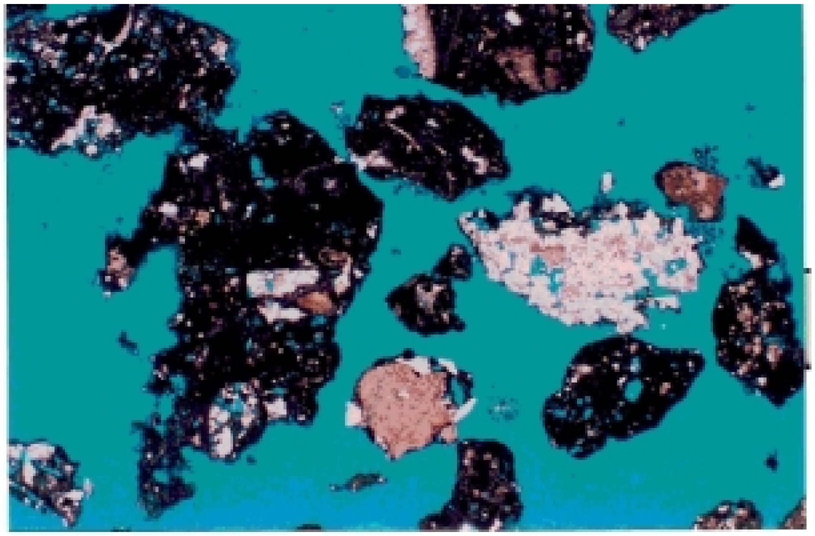
ALGAL SUBFACIES: Slightly sandy skeletal-echinoid-algal wackestone, very fine to very coarse grained, poor to fair very fine to medium size porosity.

20% Sandy echinoid-skeletal-pellet packstone, poor to fair moldic and fair intercrystalline moldic porosity, slightly cemented, slightly dolomitic.

10% Dolomite, fine to medium crystalline with fair moldic porosity.



No Core Available

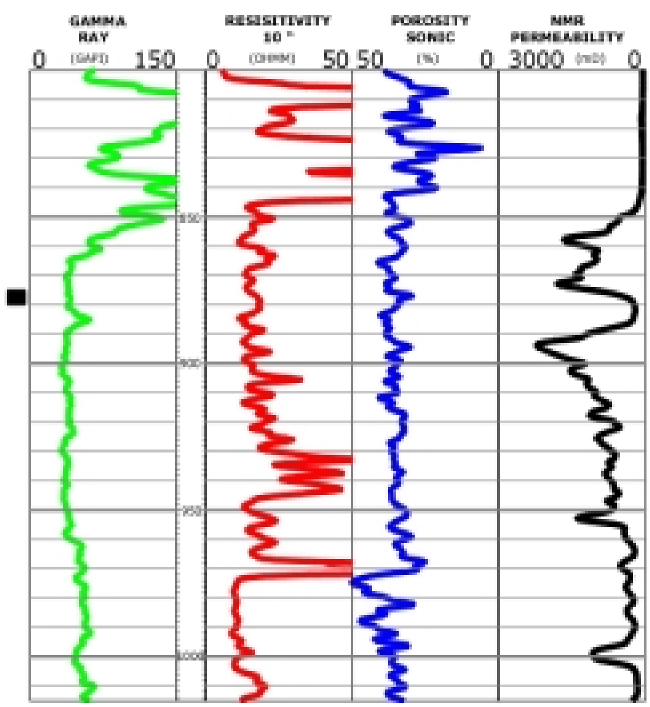


WELL: BICY-TW
DEPTH: 875-880
MAGNIFICATION: 20X

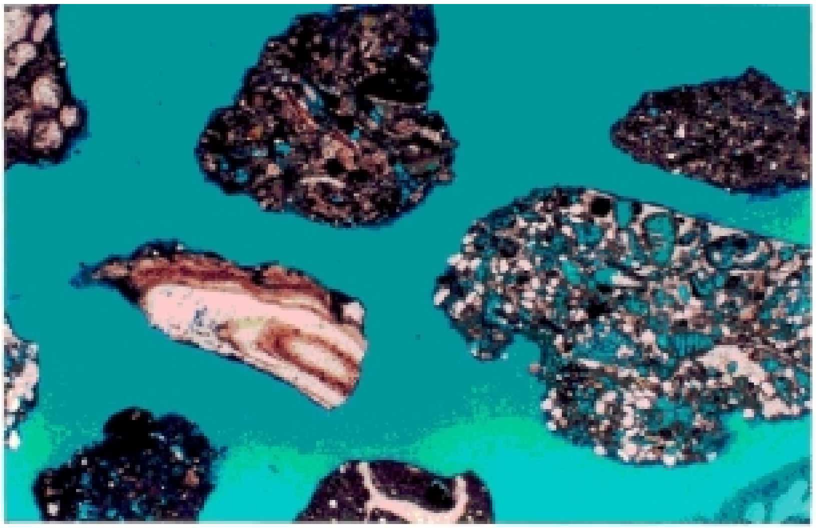
FORAM-PELLET SUBFACIES: 50% slightly sandy coated algal-echinoid-foram-coated grain packstone-wackestone with fair moldic porosity.

20% Algal wackestone with poor moldic porosity.

20% Dolomite, very fine to medium crystalline with poor to fair intercrystalline porosity.



No Core Available



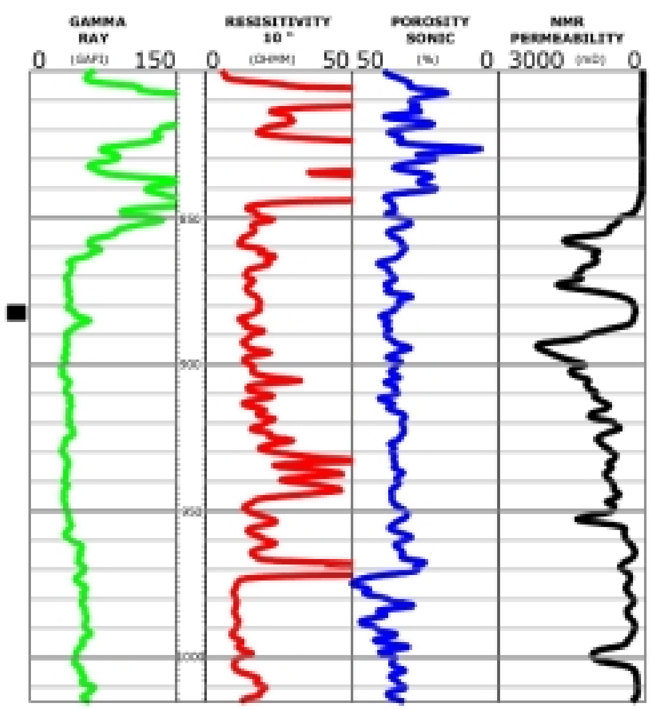
WELL: BICY-TW
DEPTH: 880-885
MAGNIFICATION: 20X

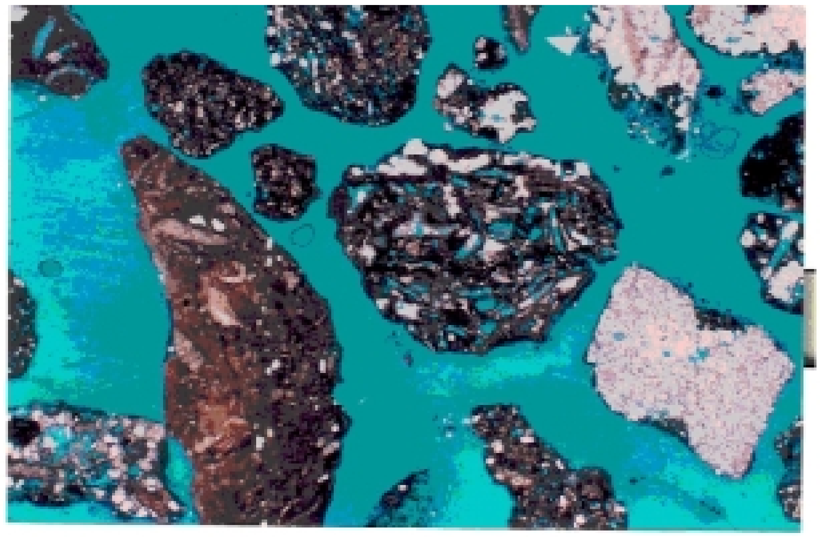
FORAM-PELLET SUBFACIES: Slightly sandy skeletal-foram-pellet-packstone-wackestone, slightly dolomitic, slightly to well cemented.

30% pores occluded. Trace good moldic porosity, fine to coarse grained, very poorly sorted.

30% slightly sandy algal wackestone, slightly dolomitic, fine to very coarse grained, trace granular.

10% Dolomite, very fine to medium crystalline with fair intercrystalline porosity.



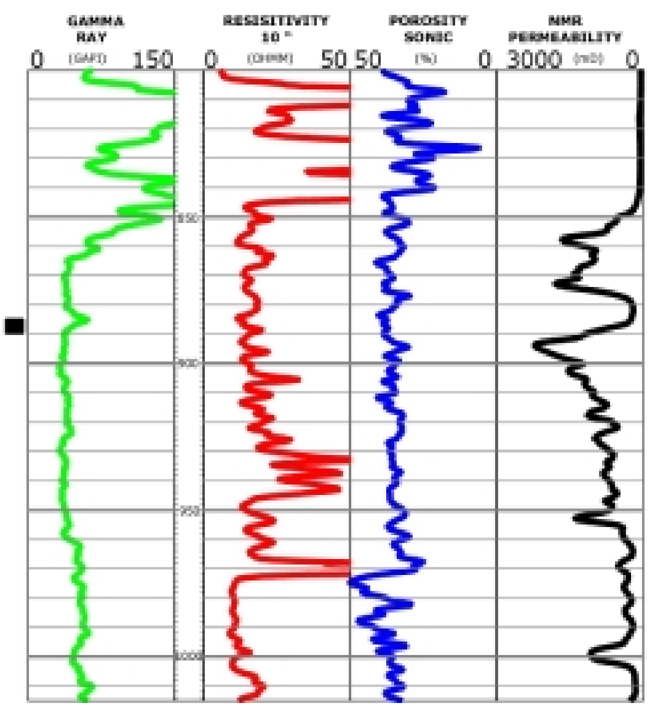


WELL: BICY-TW
DEPTH: 885-890
MAGNIFICATION: 20X

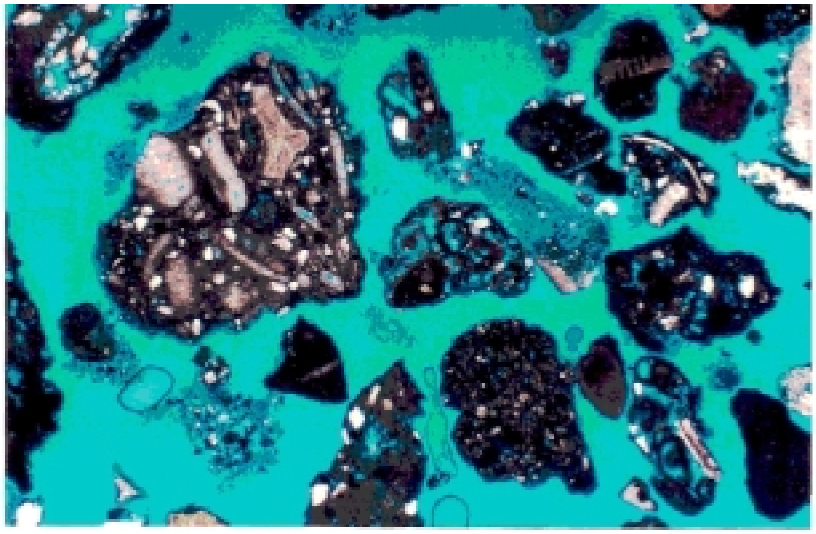
COATED GRAIN SUBFACIES: Slightly sandy coated grain-foram-pellet packstone-wackestone, very fine to very coarse gained, very poorly sorted, very slightly cemented with overgrowths, cement very fine to medium size porosity.

40% skeletal algal wackestone, slightly dolomitic.

10% dolomite with fair to poor intercrystalline porosity.



No Core Available

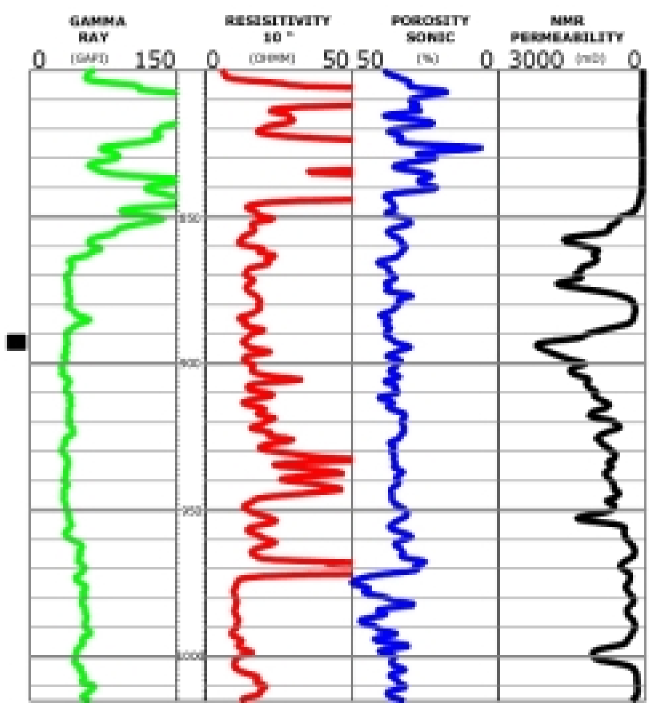


WELL: BICY-TW
DEPTH: 890-895
MAGNIFICATION: 20X

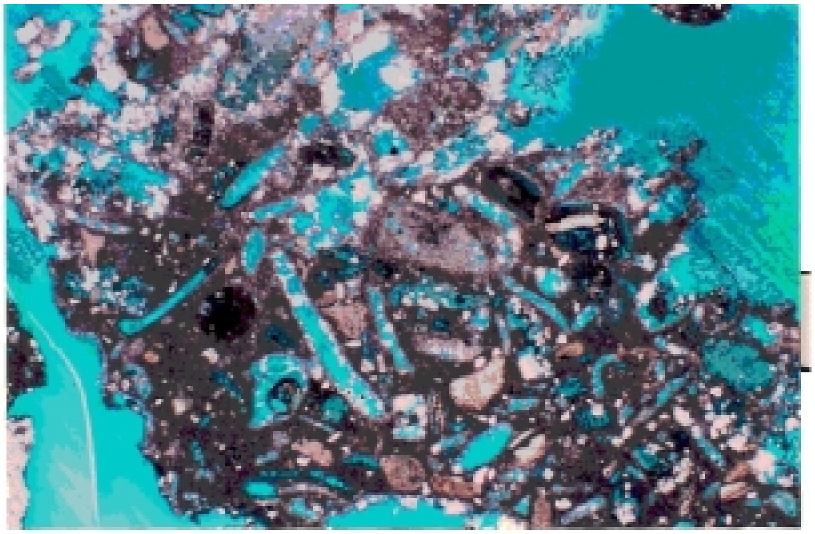
COATED GRAIN SUBFACIES: Slightly sandy coated grain-foram-pellet-packstone, very fine to very coarse grained, very poorly sorted, fair to good vuggy moldic porosity with very fine to medium size porosity, very slightly cemented with overgrowth cement.

20% algal wackestone, slightly sandy.

5% dolomite, very fine to fine intercrystalline porosity.



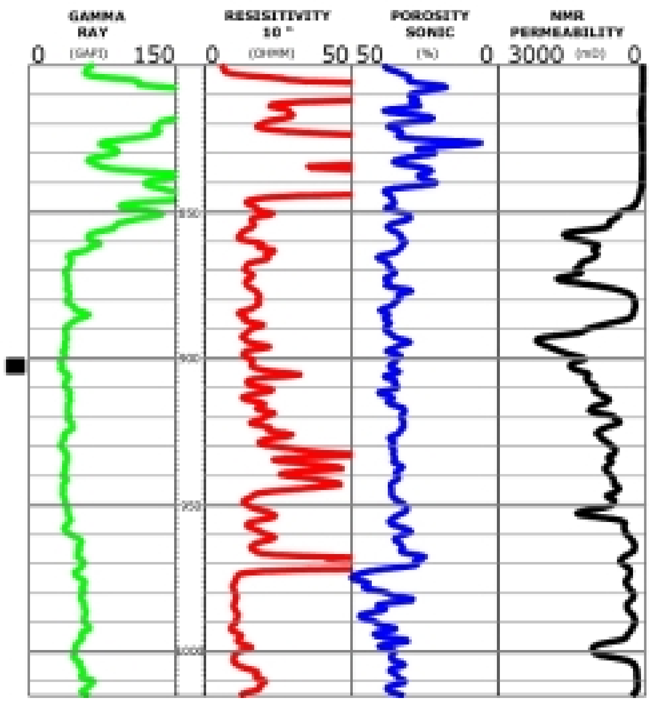
No Core Available

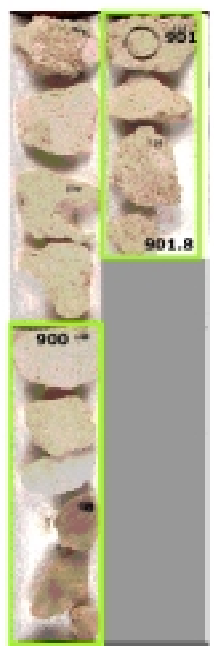


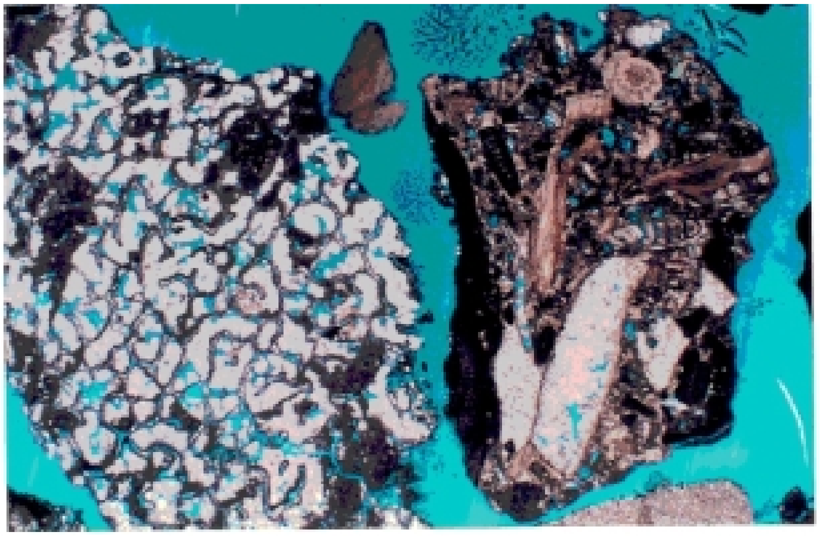
WELL: BICY-TW
DEPTH: 900-905
MAGNIFICATION: 20X

BRYOZON MOUND SUBFACIES: Bryozoan boundstone, slightly sandy, slightly dolomitic, very fine to granular grained, very poorly sorted, with fair to good moldic porosity.

Algal-coated grain-pellet packstone, very poorly sorted, fair fine to coarse size moldic porosity.







WELL: BICY-TW
DEPTH: 905-910
MAGNIFICATION: 20X

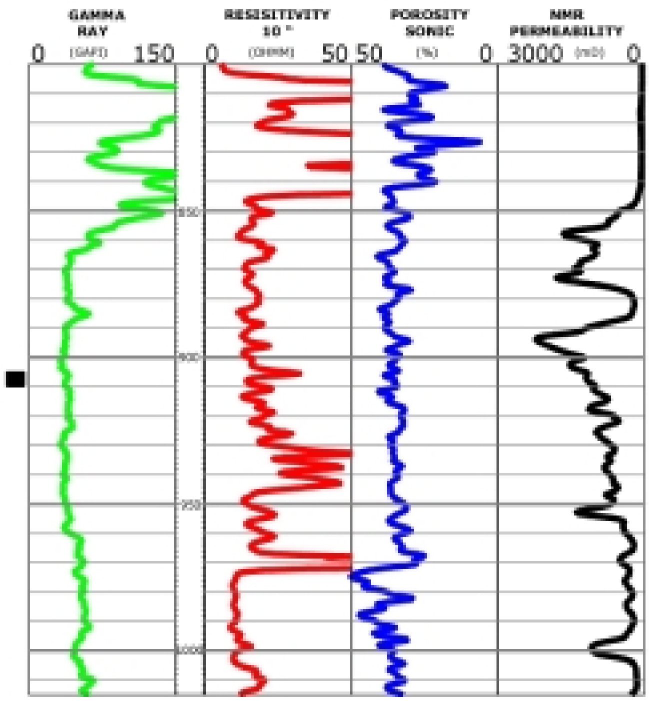
FORAM-PELLET SUBFACIES: Slightly sandy foram-pellet packstone to wackestone, medium to coarse grained.

10% good moldic porosity.

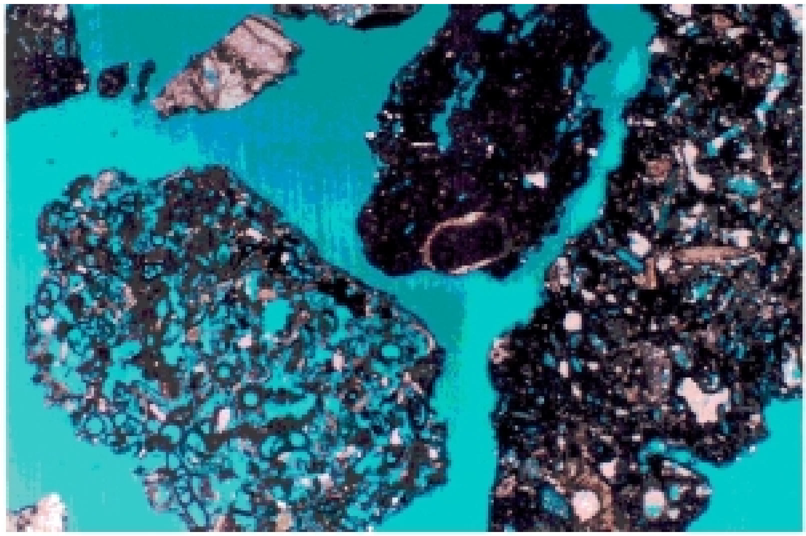
Bryozoan, very fine to coarse to pebble grained, very poorly sorted.

10% algal wackestone, very coarse grained poor, to fair moldic intraparticle porosity. 1% good moldic porosity.

Trace dolomite, fine-medium crystalline with fair intercrystalline porosity.



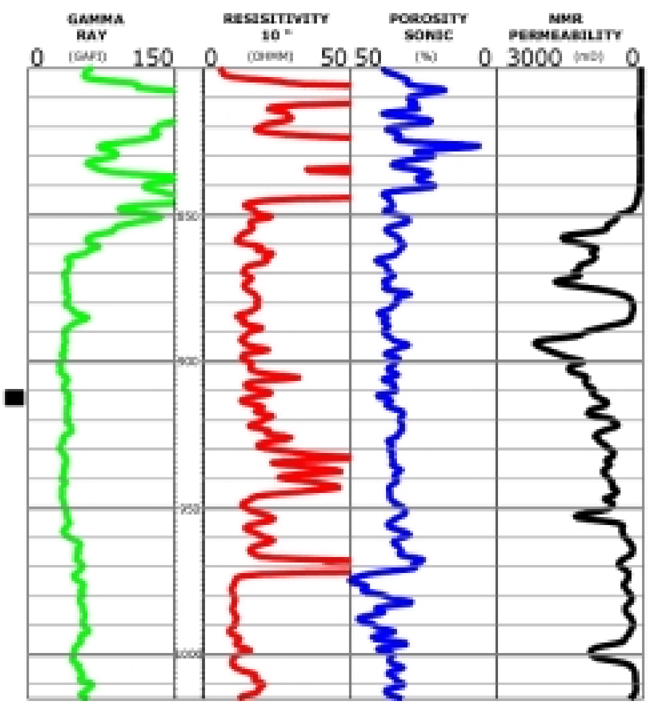
No Core Available



WELL: BICY-TW
DEPTH: 910-915
MAGNIFICATION: 20X

COATED GRAIN SUBFACIES: Slightly sandy slightly intraclastic-coated algal-pellet packstone, trace very porous moldic porosity, cemented with some dolomitic rim cement. Coated algal-foram-pellet packstone with good moldic-intraparticle porosity.

2% dolomite, very fair to fine crystalline with poor intercrystalline porosity.



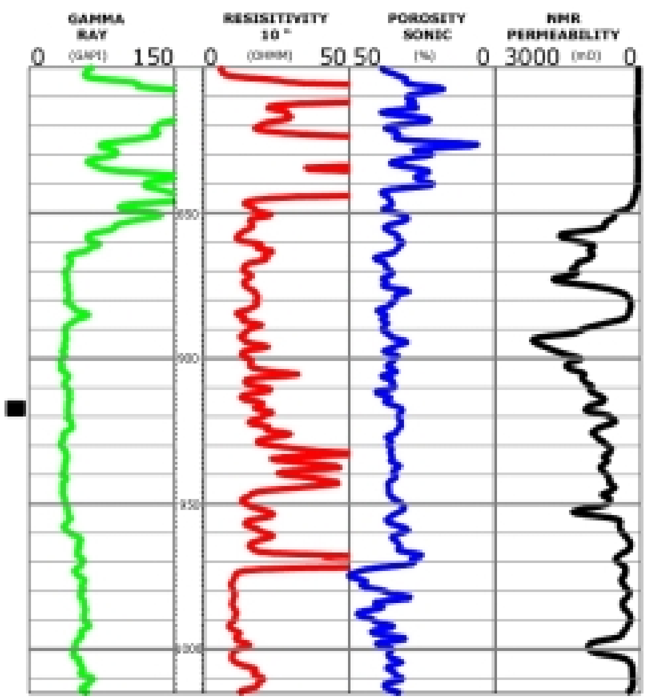
No Core Available

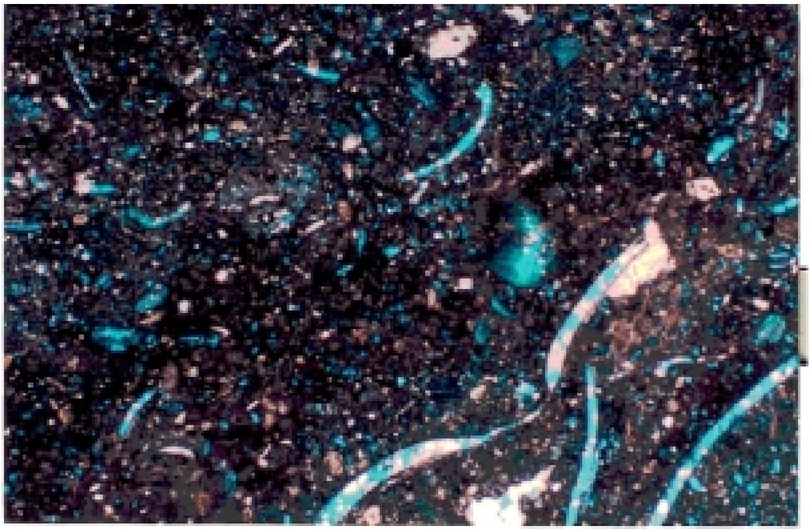
WELL: BICY-TW
DEPTH: 915-920
MAGNIFICATION: 20X

FORAM-PELLET SUBFACIES: Very slightly sandy echinoid-coated grain-form-pellet packstone, very fine to coarse grained, slightly dolomitic, fair to poor moldic porosity.

Very slightly sandy algal wackestone with trace moldic porosity.

Trace dolomite.

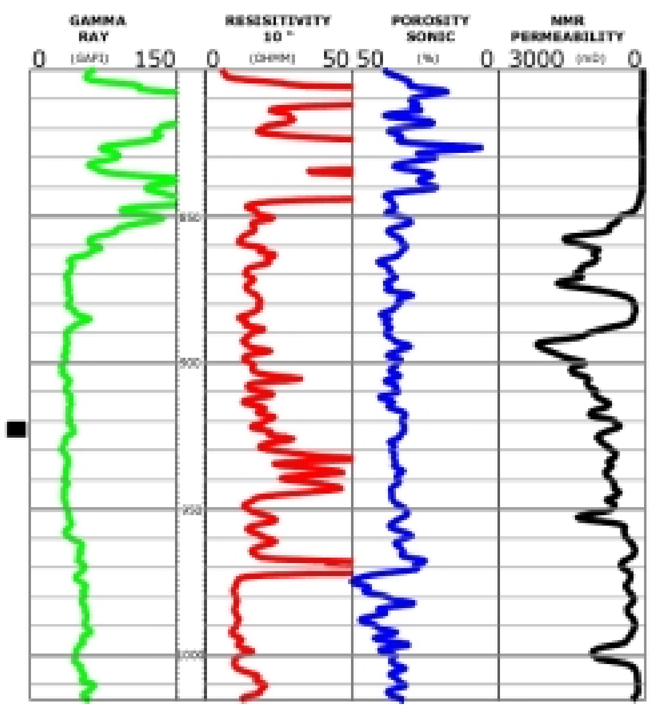


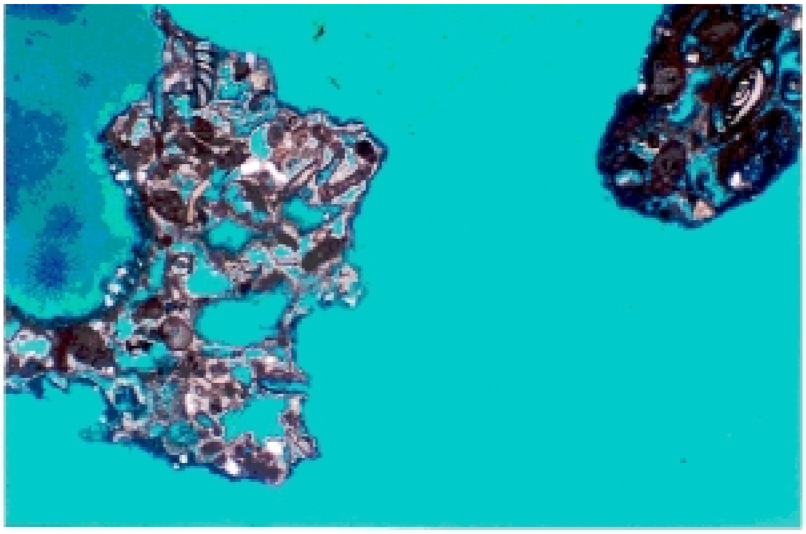


WELL: BICY-TW
DEPTH: 920-925
MAGNIFICATION: 20X

COATED GRAIN SUBFACIES: Foram coated grain-coated algal packstone, very fine to coarse grained with good to very good moldic interparticle porosity. Trace excellent porosity.

10% algal wackestone, very fair to granular grained, very poorly sorted.



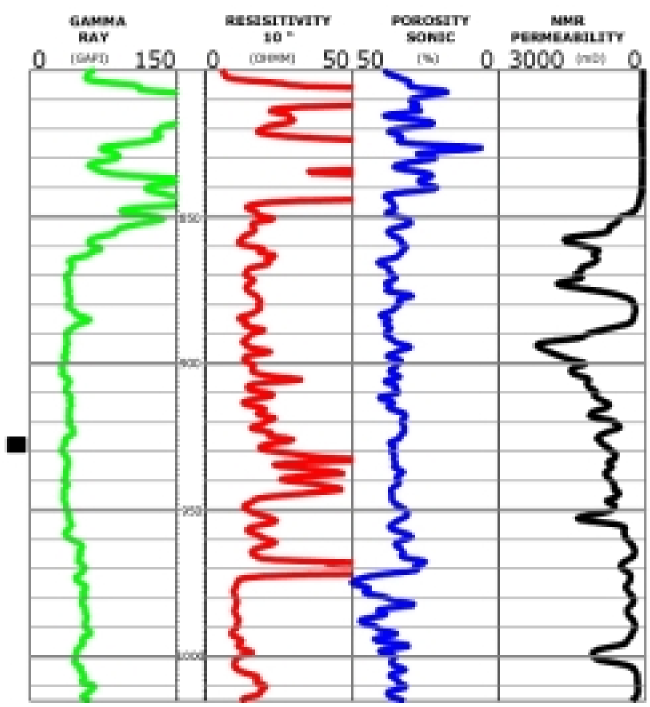


WELL: BICY-TW
DEPTH: 925-930
MAGNIFICATION: 20X

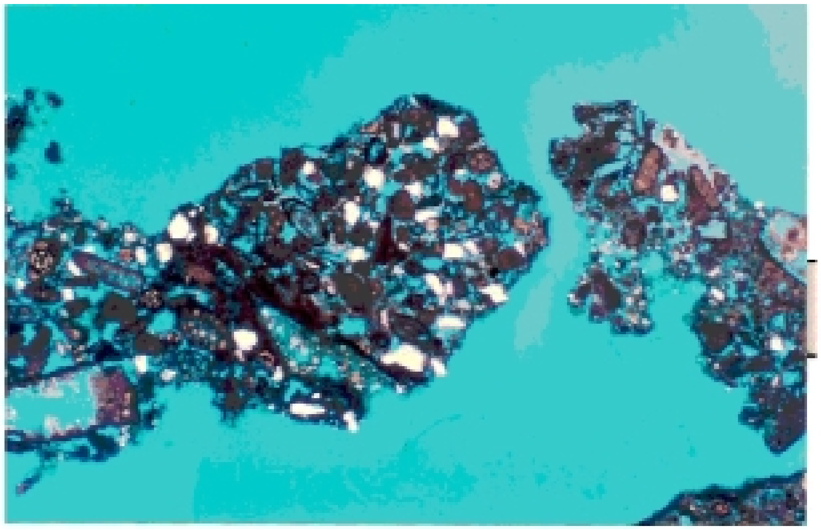
COATED GRAIN SUBFACIES: 60% slightly sandy peloid-coated grain-packstone-wackestone, trace grainstone, fine to coarse grained with good fine to coarse moldic porosity and interparticle porosity.

10% interclast-algal packstone, very poorly sorted, fine to very coarse grained.

10% algal wackestone, very fine to coarse grained, very fine crystalline, trace dolomitic, fair very fine to coarse size porosity, fair intercrystalline porosity.



No Core Available

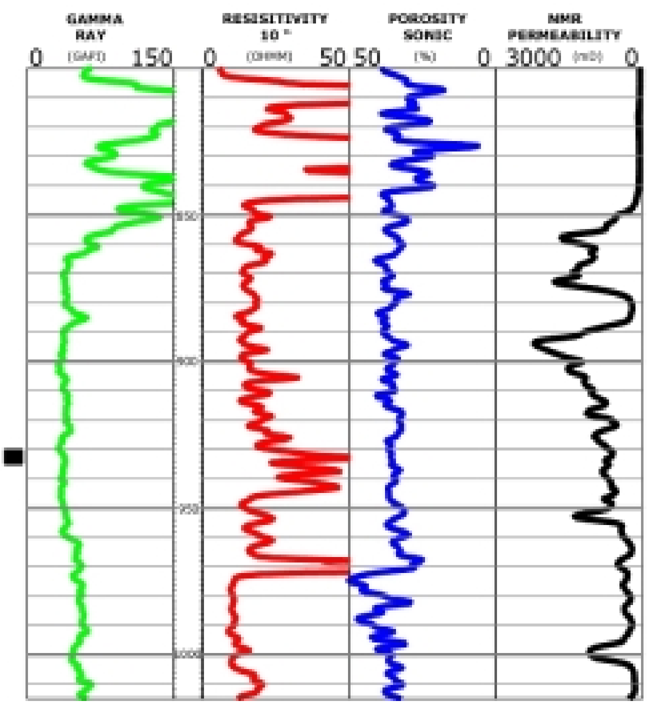


WELL: BICY-TW
DEPTH: 930-935
MAGNIFICATION: 20X

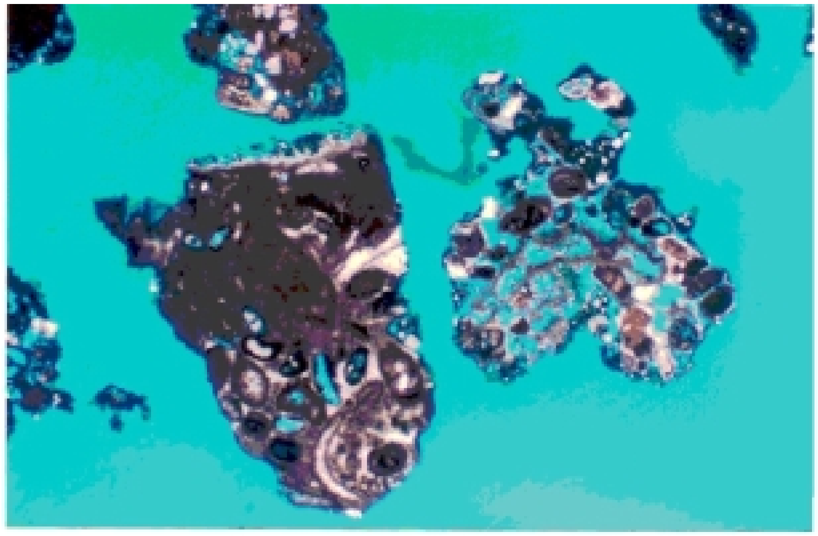
COATED GRAIN SUBFACIES: Slightly sandy peloid-foram-coated grained packstone, very fine to medium grained, fair to good very fine to medium size moldic and interparticle porosity.

10% pelecypod wackestone.

10% Coated algal packstone.



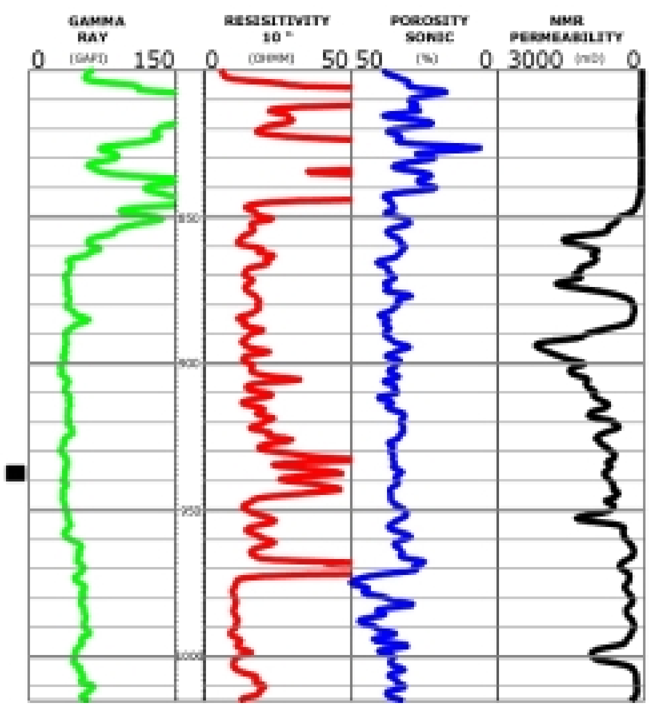
No Core Available



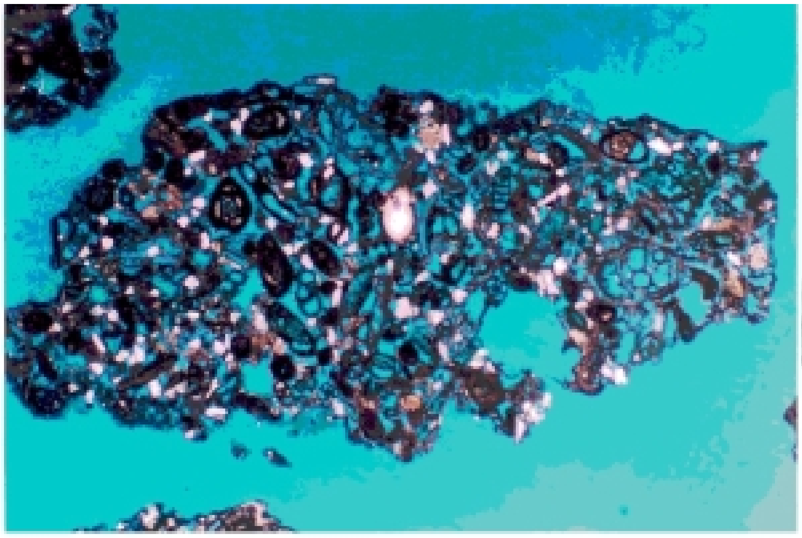
WELL: BICY-TW
DEPTH: 935-940
MAGNIFICATION: 20X

COATED GRAIN SUBFACIES: Slightly sandy-peloid-pellet-coated grain packstone, fair to very good moldic interparticle porosity. 10% slightly cemented with equant calcite and dolomite. Traces of very dolomitic patches.

20% sandy algal wackestone, very fine to very coarse grained, very poorly sorted.

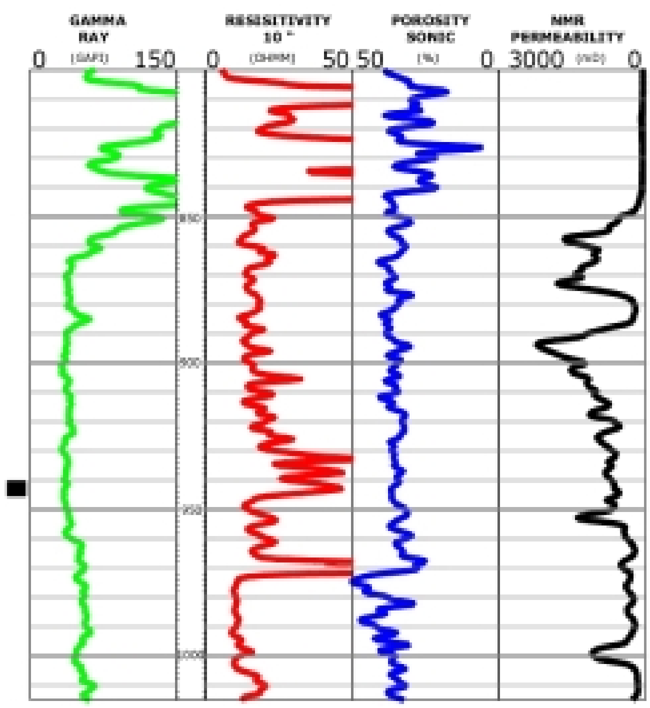


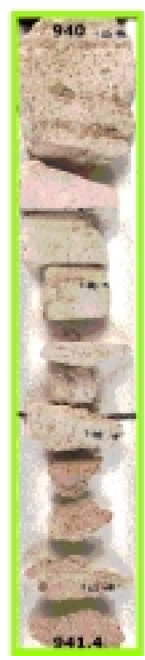
No Core Available

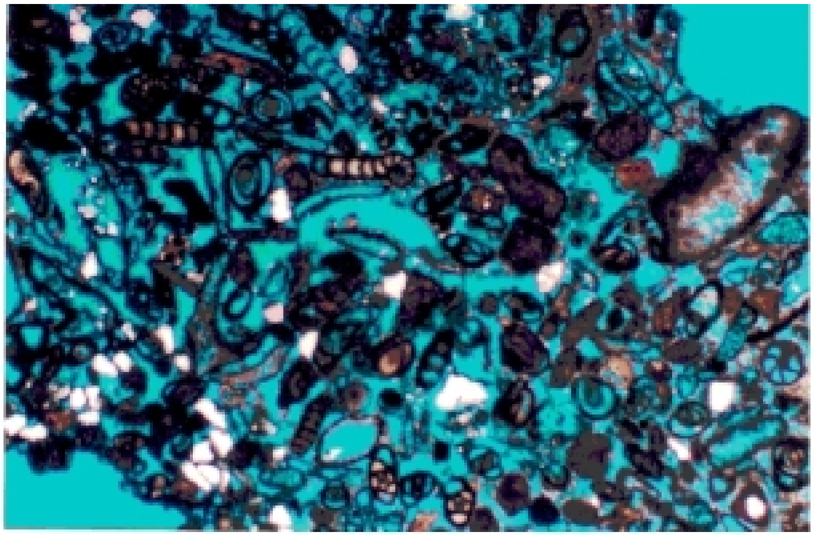


WELL: BICY-TW
DEPTH: 940-945
MAGNIFICATION: 20X

PELLET-FORAM SUBFACIES: Slightly sandy peloid-pellet-foram packstone, moderate to well sorted, very fine to medium grained with some coarse grained, very good vug, moldic, and interparticle porosity, slightly cemented.





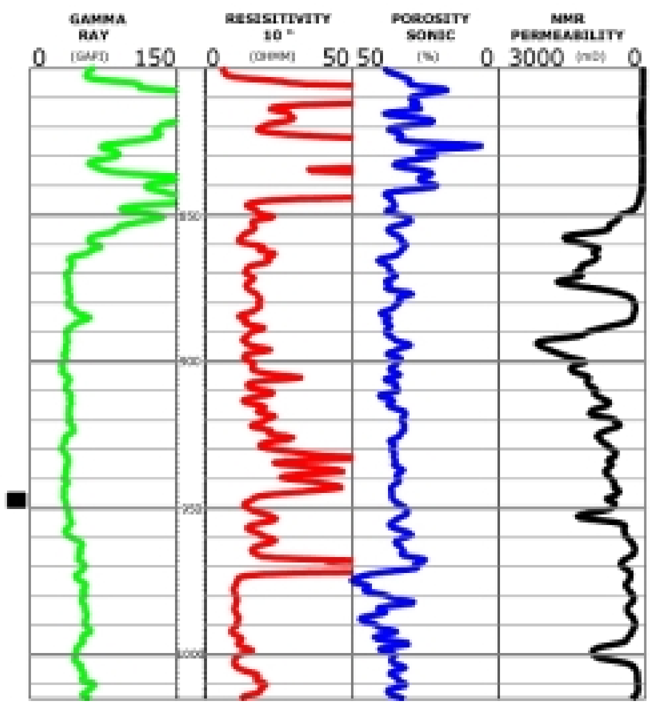


WELL: BICY-TW
DEPTH: 945-950
MAGNIFICATION: 20X

PELLET-FORAM SUBFACIES: Very slightly sandy-pellet-foram packstone, fine to medium grained, good fine to medium size moldic and interparticle porosity, traces dolomitic cement.

20%ilnterclast-echinoid-coated algal wackestone, very fine to very coarse grained, very poorly sorted with poor moldic porosity of very fine to medium size.

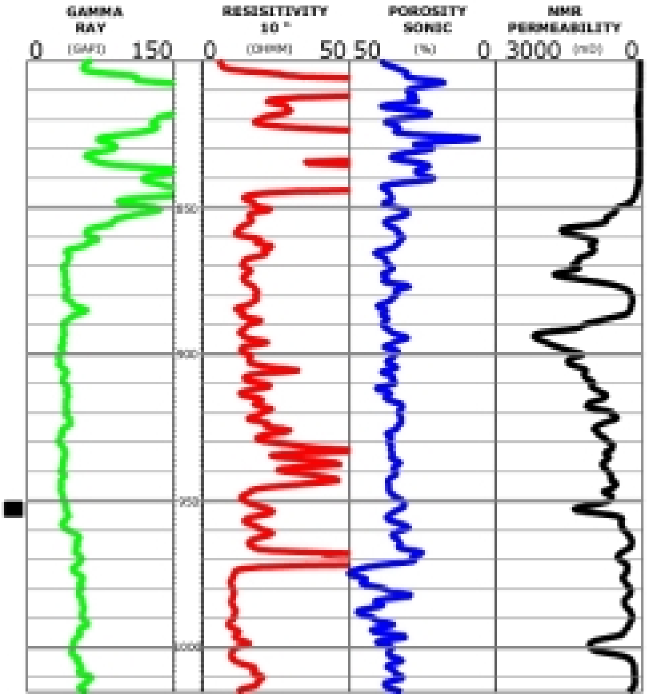
10% gastropod wackestone, very fine to granular grained, very poorly sorted with a traceof moldic porosity.



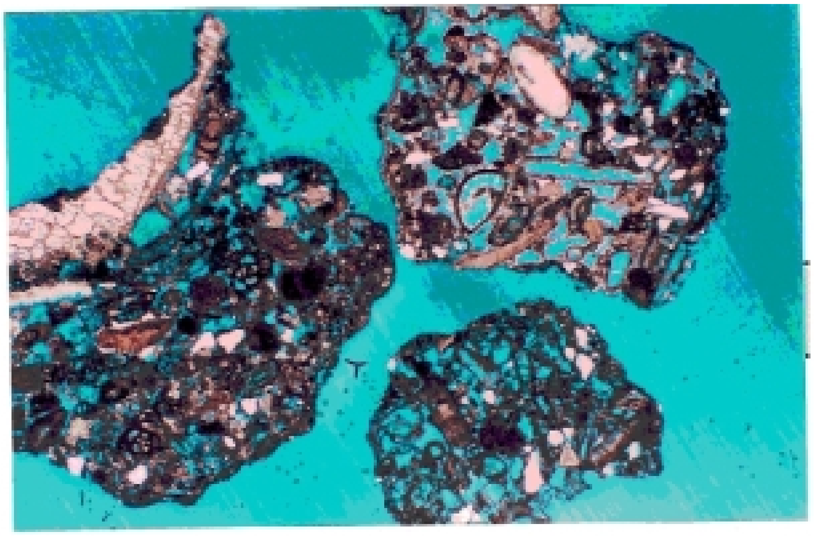
No Core Available

WELL: BICY-TW
DEPTH: 950-955
MAGNIFICATION: 20X

COATED GRAIN SUBFACIES: Slightly to very sandy-foram-pellet-coated grain packstone, very fine to medium grained. 5% coarse grained, moderate poorly sorted, good very fine to coarse size moldic porosity, fair interparticle porosity, trace cemented.



No Core Available



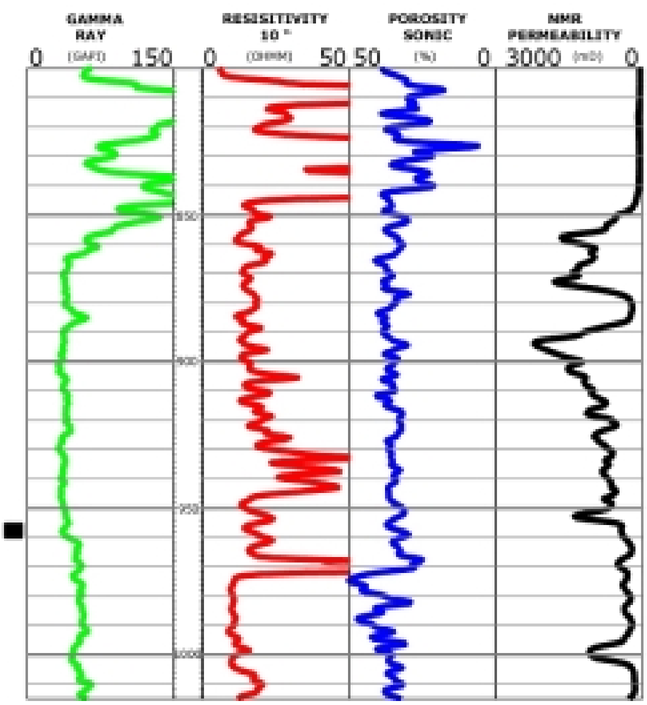
WELL: BICY-TW
DEPTH: 955-960
MAGNIFICATION: 20X

COATED GRAIN SUBFACIES: 50% slightly sandy gastropod (10%)-peloid-foram-pellet coated grain packstone, very fine to medium grained, moderate sorted, fair moldic porosity.

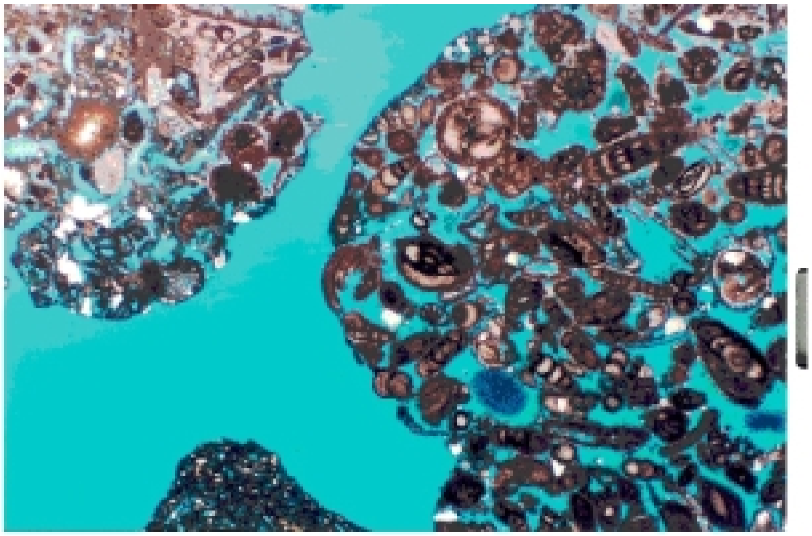
Slightly sandy echinoid-foram-pellet-bryozoan packstone-boundstone, very fine to granular grained, very poorly sorted.

20% bryozoan boundstone, granular to pebble grained.

10% slightly sandy recrystallized wackestone with poor moldic porosity.



No Core Available

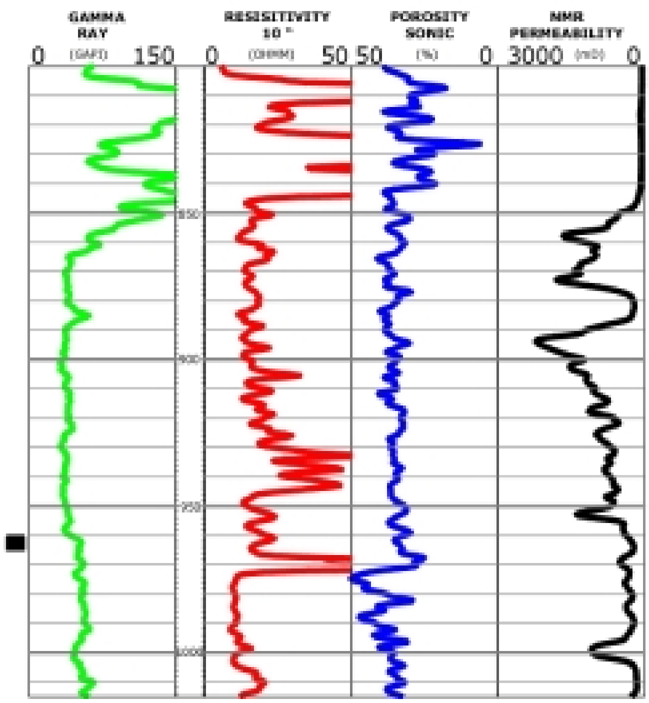


WELL: BICY-TW
DEPTH: 960-965
MAGNIFICATION: 20X

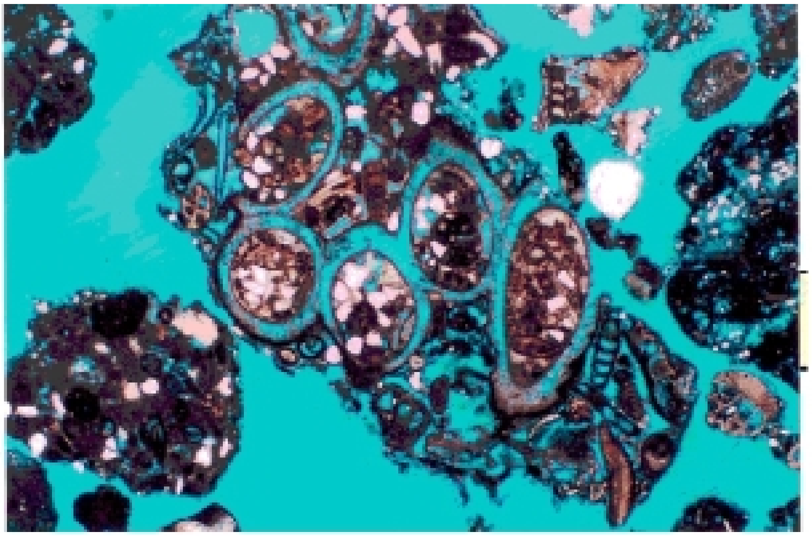
FORAM-PELLET SUBFACIES: 50% slightly sandy-peloid-foram packstone, fine to medium grained, moderate well sorted with good to very good interparticle porosity, fair fine to medium size moldic porosity, trace intraparticle porosity.

50% slightly sandy peloid-foram-pellet- packstone, fine to coarse grained, poorly sorted, poor to good moldic interparticle porosity.

10% algal-foram pellet packstone-wackestone.



No Core Available

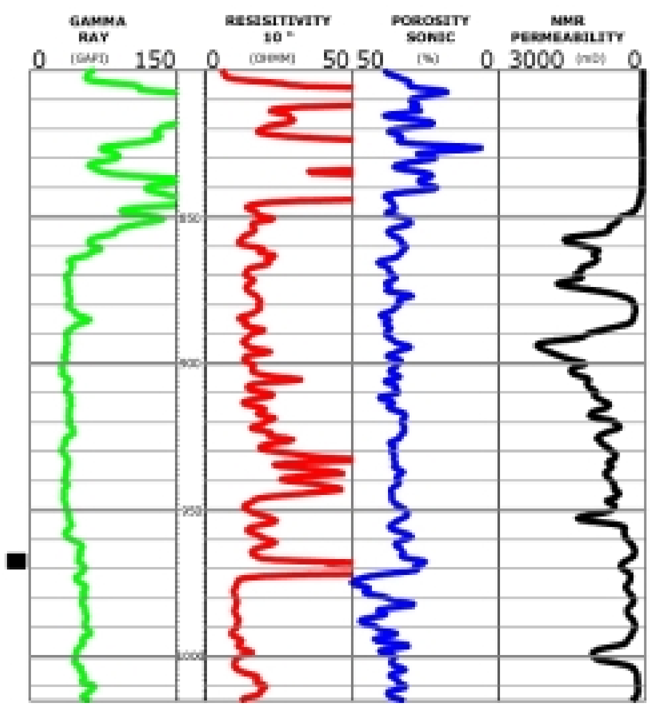


WELL: BICY-TW
DEPTH: 965-970
MAGNIFICATION: 20X

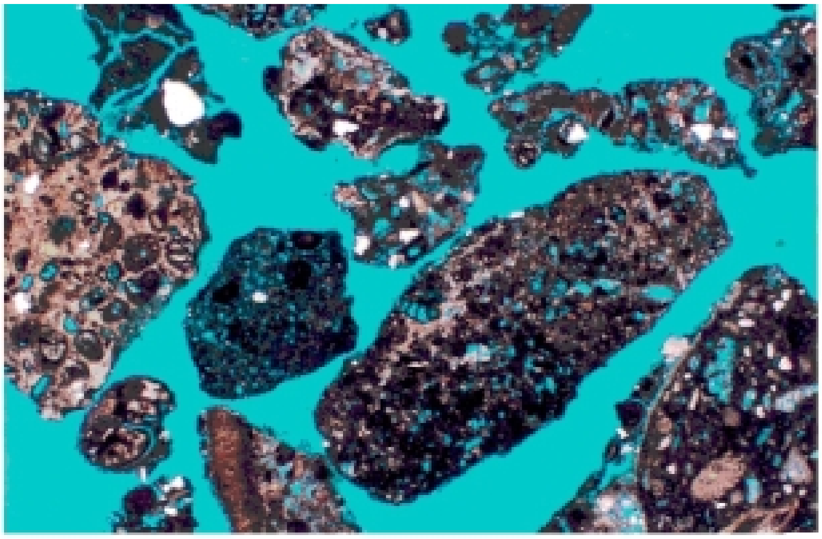
COATED GRAIN SUBFACIES: Slightly sandy-algal coated grained-foram-pellet packstone, fine to very coarse grained moderate to poor sorted. 10% slightly to well cemented with equant spar cement, very fine to very coarse size porosity. 10% fair to good interparticle porosity, and fair to good moldic intraparticle porosity.

10% well cemented grainstone with poor moldic and intraparticle porosity.

10% slightly sandy algal-bryozoan wackestone with poor moldic intraparticle porosity.



No Core Available



WELL: BICY-TW
DEPTH: 970-975
MAGNIFICATION: 20X

COATED GRAIN SUBFACIES: 40% sandy-coated algal-red algal encrusted-foram-pellet-coated grain packstone, very fine to coarse grained, poorly sorted.

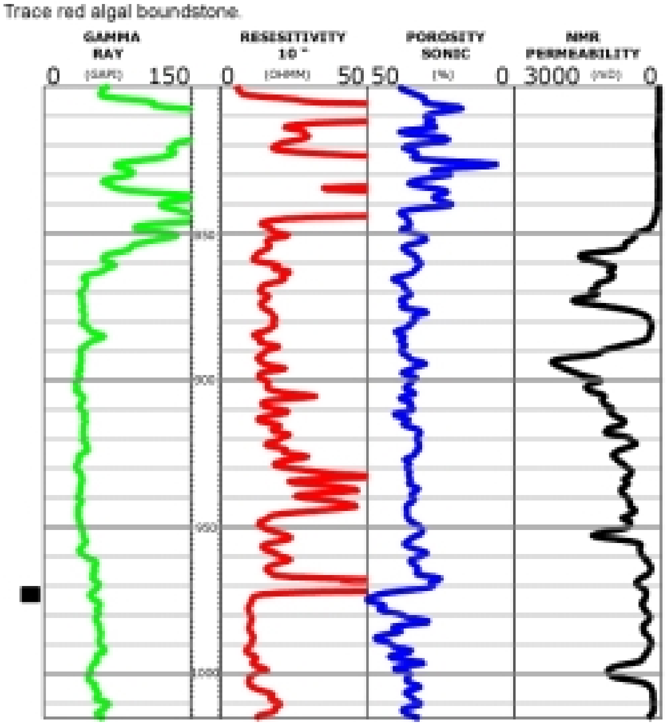
1% very good moldic interparticle porosity.

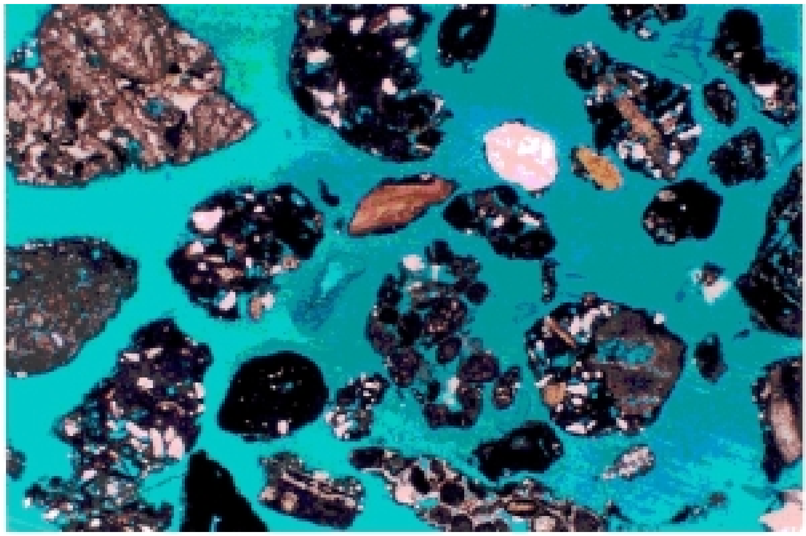
30% echinoid-coated algal packstone, encrusting red algal-green algal.

20% algal wackestone, fine to granular grained, very poorly sorted, with trace moldic porosity.

10% pellet-foram grainstone, fine-medium grained, well sorted, fair moldic porosity.

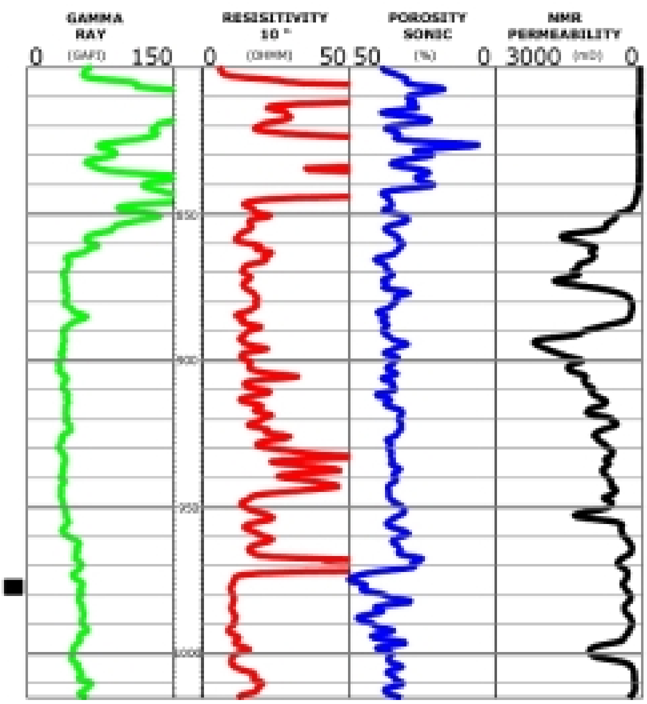
Trace red algal boundstone.

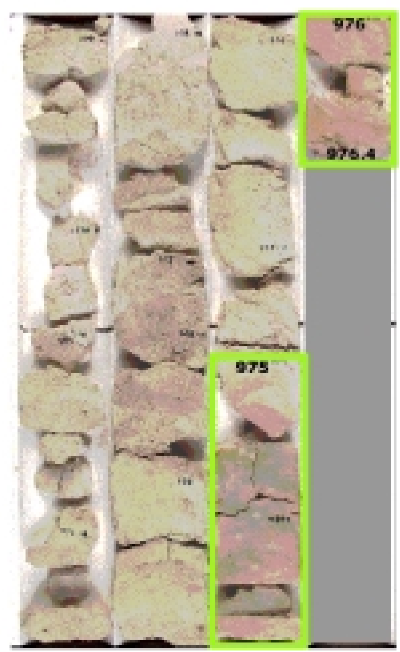


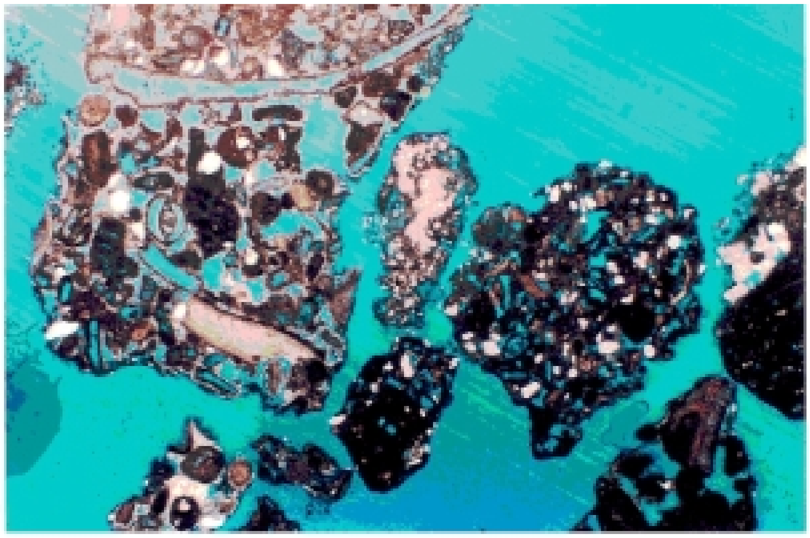


WELL: BICY-TW
DEPTH: 975-980
MAGNIFICATION: 20X

FORAM-PELLET SUBFACIES: Sandy to very sandy echinoid-coated algal-peloid-coated grain-foram pellet packstone, very fine to medium grained angular sand, fair to poor moldic intraparticle porosity. Trace interparticle porosity slightly cemented with overgrowth cement. Trace dolomite rim cement, trace mold occluding cement.



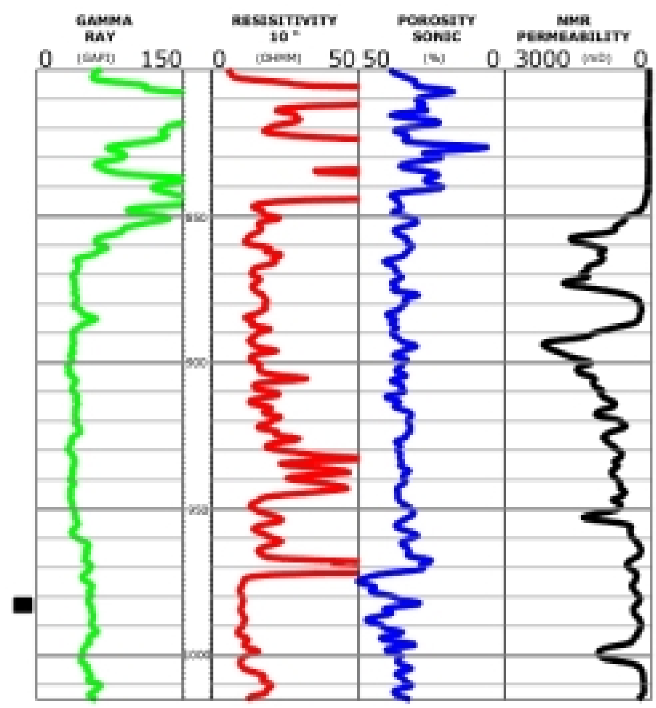


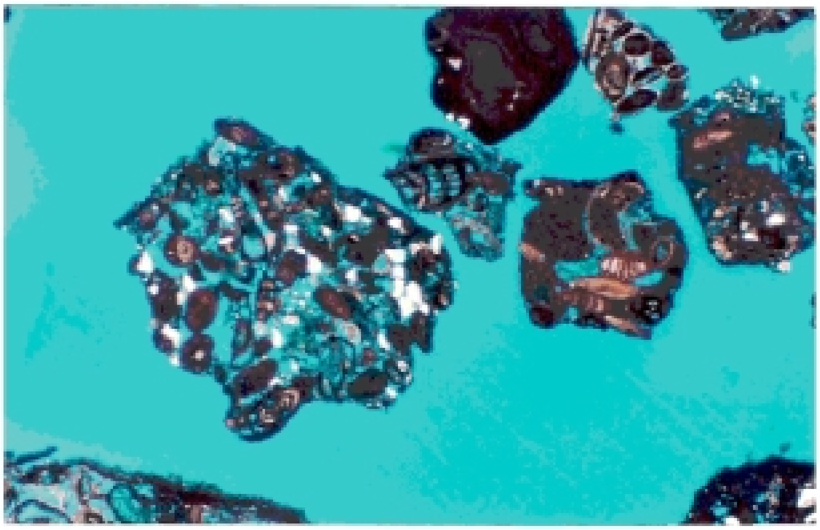


WELL: BICY-TW
DEPTH: 980-985
MAGNIFICATION: 20X

COATED GRAIN SUBFACIES: Slightly intraclastic, slightly to very sandy coated algal-foram-pellet coated grain packstone with trace grainstone, fine to very coarse grained, very poorly sorted, good very fine to coarse size moldic porosity.

10% sandy pellet algal wackestone with trace moldic porosity, very slightly cemented occluded algal fronds.

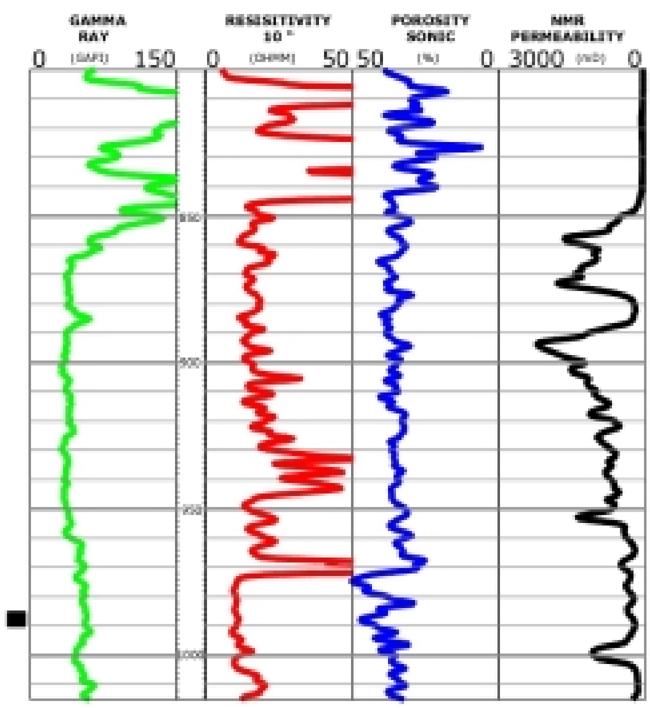


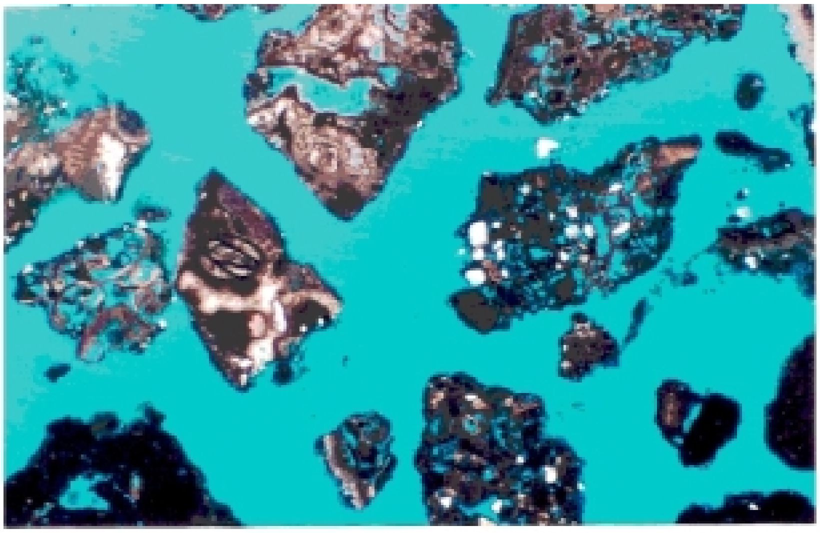


WELL: BICY-TW
DEPTH: 985-900
MAGNIFICATION: 20X

COATED GRAIN SUBFACIES: Sandy coated grain algal-foram-pellet-peloid packstone, fine to coarse grained, moderate to poorly sorted, very good fine to coarse size interparticle porosity, trace moldic porosity.

20% sandy pelecypod-foram-pellet-packstone-wackestone, very fine to fine grained sand, very fine to granular grained, fair vug moldic porosity, fair intraparticle porosity, poorly cemented rim cement, trace overgrowth cement, trace equant spar cement in moldic occlusions.

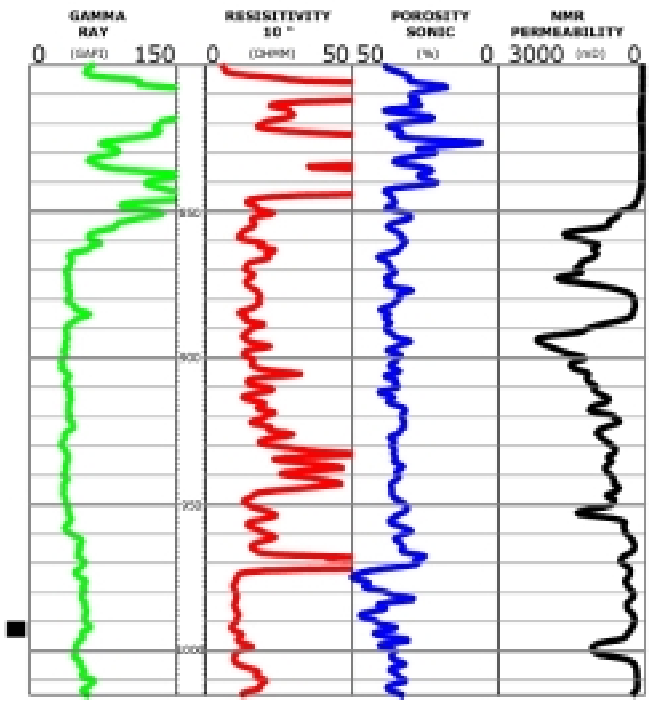


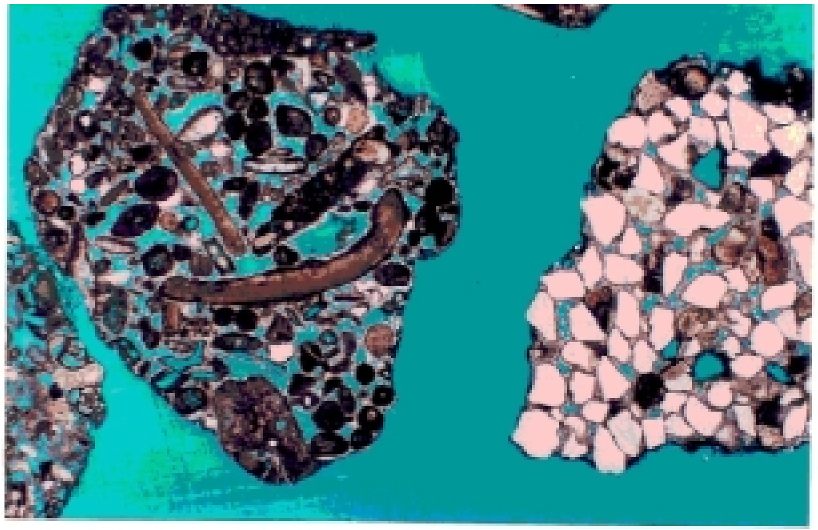


WELL: BICY-TW
DEPTH: 990-995
MAGNIFICATION: 20X

COATED GRAIN SUBFACIES: Sandy peloid-coated grain packstone, fine to coarse grained, poorly sorted, fine to coarse size interparticle porosity, fair-poor moldic intraparticle porosity.

5% poorly cemented rim cement, increase in very fine to medium angular and trace sandstone medium grained, nonporous.





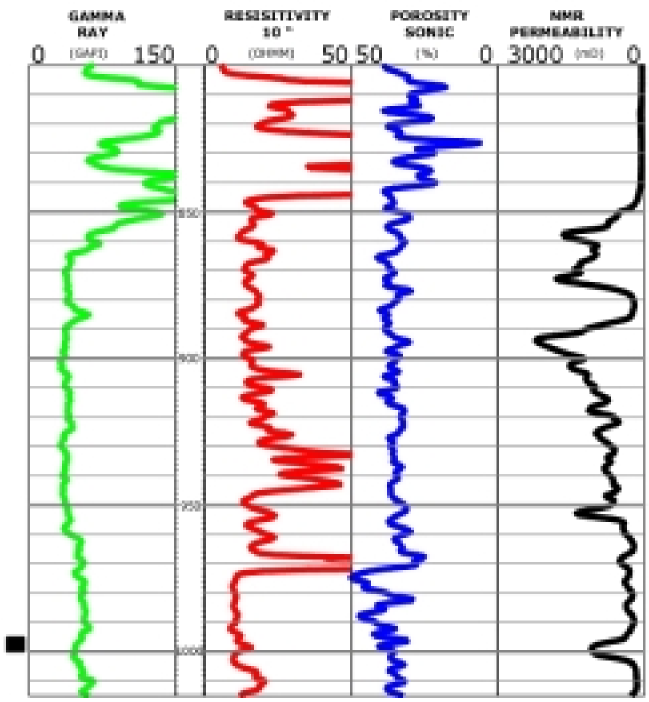
WELL: BICY-TW
DEPTH: 995-1000
MAGNIFICATION: 20X

COATED GRAIN SUBFACIES: Slightly to very sandy-coated grain packstone-grainstone, fine to very coarse grained, poor to very poorly sorted, good to very good, fine to coarse interparticle porosity fair moldic porosity. Trace rim cement on coated grains.

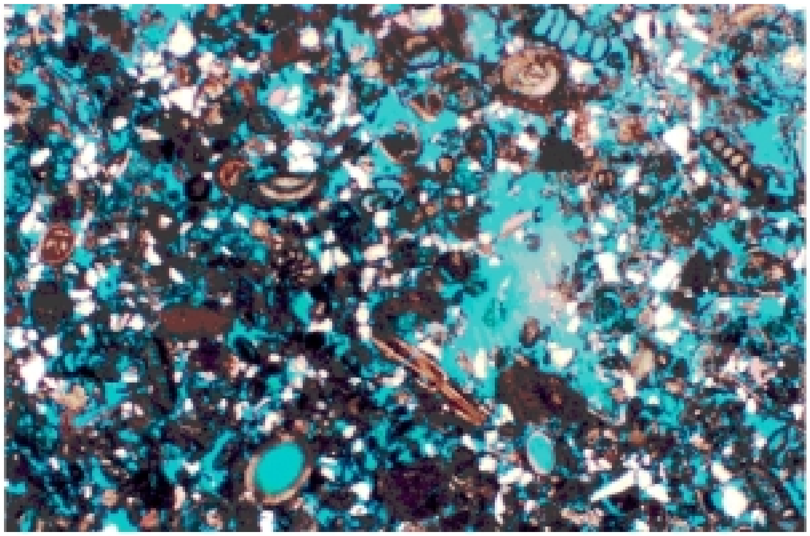
20% sandstone, medium grained, moderate sorted, angular to subangular.

Trace coated algal wackestone.

Trace encrusting algae.



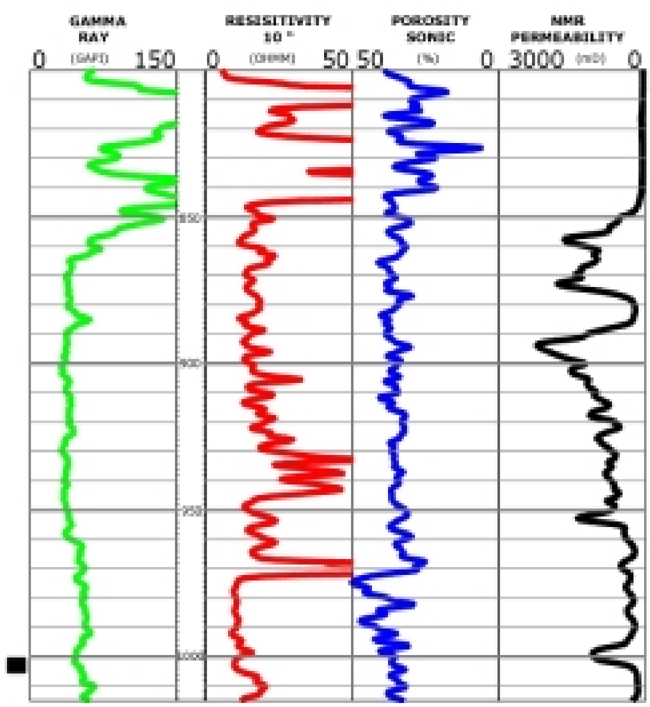
No Core Available



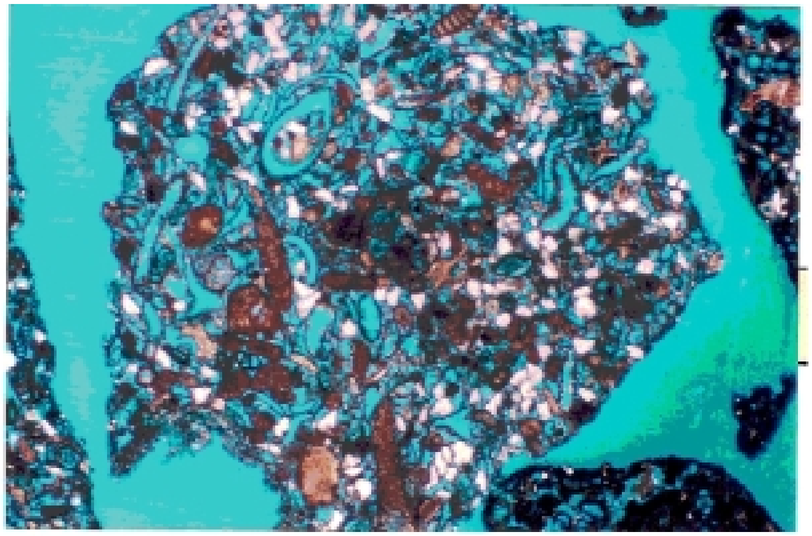
WELL: BICY-TW
DEPTH: 1000-1005
MAGNIFICATION: 20X

COATED GRAIN SUBFACIES: Slightly-very sandy echinoid, coated grain-peloid-foram-pellet packstone, very fine to medium grained moderate well sorted, very fine to medium size porosity, fair to good vuggy interparticle porosity. Fair moldic porosity, poor intraparticle porosity.

10% Sandstone, fine to medium grained, moderate well sorted, poor moldic porosity.

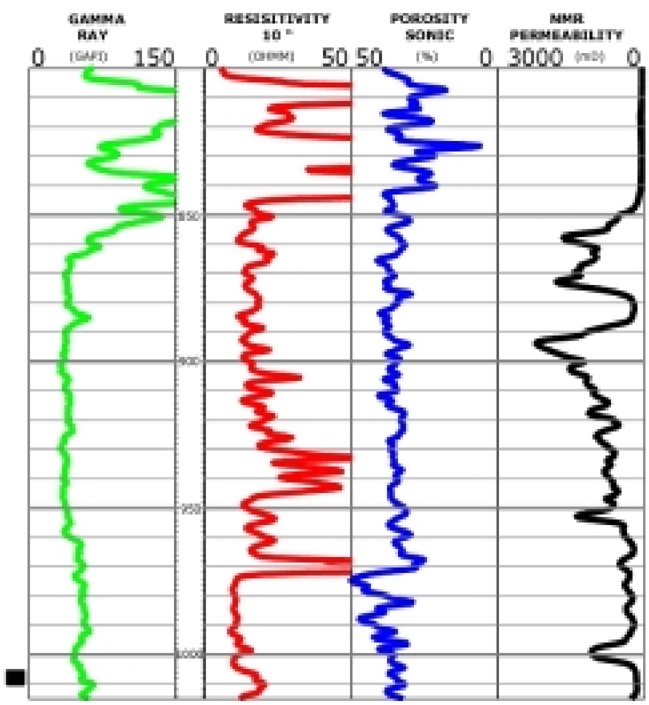


No Core Available



WELL: BICY-TW
DEPTH: 1005-1010
MAGNIIFCATION: 20X

COATED GRAIN SUBFACIES: Sandy echinoid-peloid-foram-pellet-coated grain packstone, moderate to poorly sorted, fine to granular grained, fair to good moldic interparticle porosity, poor intraparticle porosity, and scattered vugs, trace very porous, trace shelter porosity, trace glauconite, some collapsed grains.
Trace sandy skeletal wackestone.



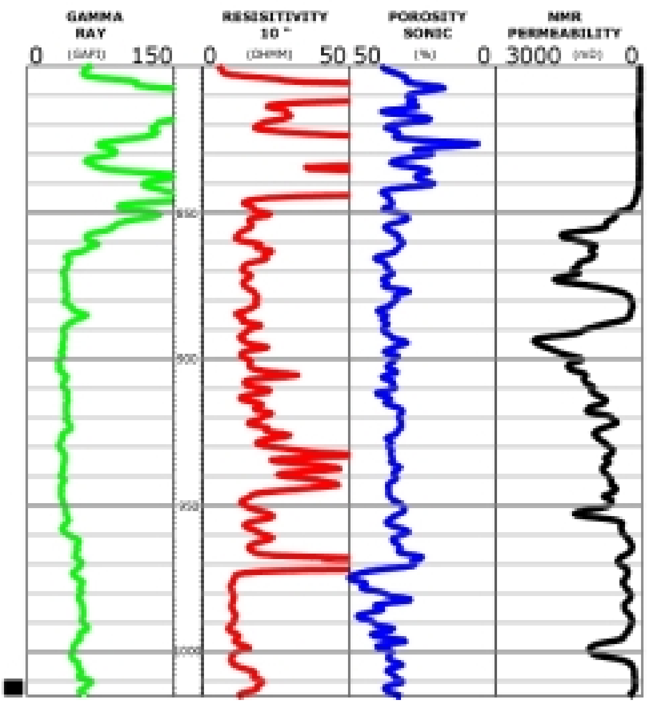
No Core Available

WELL: BICY-TW
DEPTH: 1010-1015
MAGNIFICATION: 20X

FORAM-PELLET SUBFACIES: Slightly to very sandy coated grain (10%) peloid-foram-pellet packstone-trace grainstone, well sorted to very poorly sorted, fine to coarse grained.

Trace sandy-foram wackestone.

Trace sandstone, medium grained, very poorly sorted, fine to coarse grained, angular. Trace dolomite.



No Core Available