A Preliminary Approach to the Use of Borehole Data, Including Television Surveys, for Characterizing Secondary Porosity of Carbonate Rocks in the Floridan Aquifer System

By Paul S. Safko, HSA Environmental, Inc., Tampa, Florida, and John J. Hickey

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MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
Suite 3015
227 North Bronough Street
Tallahassee, Florida 32301

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
gallon (gal)	0.003785	cubic meter
gallon per minute (gal/min)	0.00006309	cubic meter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

$$°F = 1.8 \times °C + 32$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

An approach that used borehole data for characterizing secondary porosity of carbonate rocks was applied to the Floridan aquifer system at four test sites in southeast Florida. The borehole data included television surveys, driller's comments, and caliper, flowmeter, and temperature logs. The goal underlying application of the approach was to identify secondary porosity features that were spatially interconnected beyond the immediate vicinity of a borehole. Such secondary porosity features would be related principally to geologic processes rather than being related principally to drilling activities and the mechanical properties of rocks.

The approach at each of the test sites consisted of first interpreting the borehole television survey to develop a log of apparent secondary porosity. The term "apparent secondary porosity" was used because secondary porosity features seen in video images could be the result of either geologic processes or drilling activities. Three types of secondary porosity were visually observable in the video images: vug porosity, cavern porosity, and fracture porosity. The next step consisted of an intercomparison of the apparent secondary porosity, driller's comments, and caliper, flowmeter, and temperature logs for the purpose of identifying correlations among the different logs. The driller's comments provided information about bit drops during drilling and about depth intervals with unstable and collapsing borehole walls. The caliper log provided information about borehole diameter and its variation with depth. Flowmeter and temperature logs were run during withdrawal and injection tests and provided information about where flow entered or exited a borehole.

The last step in the approach was the characterization of true effective secondary porosity or the characterization of macroporosity features that are spatially interconnected beyond the immediate vicinity of the borehole and thus related to geologic processes. Spatially interconnected secondary porosity beyond the immediate vicinity of a borehole was interpreted from the presence of entry or exit flow intervals in a borehole. Application of the approach to four test sites in southeast Florida led to two principal interpretations. One was that the true effective secondary porosity of dolomites within the lower part of the Floridan aquifer system at the sites was fracture porosity. The other was that cavern porosity observed in video images of those dolomites was caused largely by drilling-induced collapse of fractured borehole walls. These dolomites traditionally have been called the "boulder zone" in southeast Florida.

INTRODUCTION

Permeable intervals in the carbonate strata underlying Florida are commonly identified from flowmeter and temperature logs run in boreholes during pumping and injection tests. These logs show permeable intervals to be discrete zones with measurable flow between the borehole and adjacent rocks. Confining and semiconfining units are correspondingly hypothesized to coincide with intervals that show no measurable flow between the borehole and adjacent rocks.

The use of only flowmeter and temperature logs for the identification of confining and semiconfining units may introduce significant errors in hydrogeologic descriptions of the Floridan aquifer system. Errors may occur when permeable intervals are connected by vertical pathways that are adjacent to but not intercepted by a borehole. For example, Hickey (1982) reported such an error for a hypothesized dolomite confining unit that had been identified by using flowmeter and temperature logs. Upon injection testing, it was determined that the so-called confining unit was actually part of a permeable zone that included apparently separate permeable intervals near the top and bottom of the dolomite bed. If information had been available prior to the tests about the type of secondary porosity in the dolomite, which upon subsequent study was found to be fracture porosity, that error probably would have been avoided.

This report presents a preliminary approach for characterizing secondary porosity in the Floridan aquifer system through the interpretation of borehole television surveys, driller's comments, and caliper, flowmeter, and temperature logs. All of the secondary porosity features seen

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in a television survey are referred to as "apparent secondary porosity." The concept of "apparent porosity" is used to indicate that the secondary porosity features viewed in a television survey of a drilled borehole may be related either to drilling activities or to geologic processes. When secondary porosity features seen in a borehole television survey are interpreted to be spatially distributed and interconnected beyond the immediate vicinity of a borehole, those features are considered to be related to geologic processes and are called true effective secondary porosity. All of the borehole data used in this report that characterize true effective porosity are commonly acquired during ground-water investigations (Keys, 1990). What is new and different in this report is the interpretive logic of the approach that makes use of these commonly acquired borehole data for characterizing the true effective secondary porosity of carbonate rocks. Applications of the approach at four southeast Florida test sites are shown and discussed. The test sites were selected along the southeastern coast of Florida because cavern porosity had been previously reported for dolomites in the deeper part of the Floridan aquifer system along that coast (Chen, 1965; Kohout, 1967; Vernon, 1970; Puri and Winston, 1974).

HYDROGEOLOGIC SETTING

The Floridan aquifer system underlies all of peninsular Florida and consists of a sequence of carbonate rocks ranging from Paleocene to early Miocene in age. The top of the Floridan aquifer system is at the contact between the carbonate sequence and overlying clastic sediments. These overlying clastic sediments may be part of the surficial aquifer system, the intermediate aquifer system, or the intermediate confining unit (Southeastern Geological Society, 1986). The base of the Floridan aquifer system is the contact between the carbonate sequence and the underlying Paleocene evaporite beds.

The Floridan aquifer system may be confined, semiconfined, or unconfined depending upon the presence or absence of either the intermediate aquifer system or the intermediate confining unit. Several low permeability zones, known as middle confining units (Miller, 1986), separate the aquifer system into the Upper and Lower Floridan aquifer. Even though the aquifer system is a major source of freshwater, permeable zones at depth in the southern part and along the coastal margins of peninsular Florida contain saline ground water and are used for the injection of liquid waste in a number of places.

The Floridan aquifer system in the southeast Florida study area is about 2,500 ft thick and is composed, at least in part, of the following stratigraphic units (Miller, 1986): Cedar Keys Formation (Paleocene), Oldsmar Formation (early Eocene), Avon Park Formation (middle Eocene), Ocala Limestone (late Eocene), Suwannee Limestone (Oligocene), Tampa Limestone (early Miocene), and Hawthorn Formation (middle Miocene). Both the Suwannee and Tampa Limestones may be locally absent. Limestone predominates near the top and dolomite predominates near the bottom of the Floridan aquifer system.

Dolomites that have high transmissivity are present near the bottom of the Floridan aquifer system in southeast Florida. These rocks are known as the "boulder zone" and have been characterized by previous investigators (Chen, 1965; Kohout, 1967; Vernon, 1970; Puri and Winston, 1974) as possessing mainly cavernous secondary porosity. Reports about drilling characteristics associated with "boulders" and the interpretation of geophysical logs have been mainly used to identify cavernous porosity (Vernon, 1970, fig. 6; Puri and Winston, 1974, p. 34). As a result of using such data and because "cavernous porosity" is often used as a synonym for "high transmissivity," the literature has to be carefully read before assigning a literal meaning to any particular author's use of the term "cavernous porosity." Because the permeable dolomites near the bottom of the Floridan aquifer system contain saline ground water in southeast Florida, they are used for the subsurface injection of liquid wastes.

Overlying the Floridan aquifer system in the study area is the middle Miocene Hawthorn Formation that regionally is either the intermediate aquifer or the intermediate confining unit depending on the presence or absence of significant water-yielding zones. This formation varies in thickness from 100 to 400 ft over the study area and is composed of a mixture of phosphatic sand, shell, clay, and carbonate. Sand and shells of Pliocene to Holocene age, generally less than 200 ft in thickness, overlie the Hawthorn Formation and constitute the surficial aquifer system in the study area.

DESCRIPTION OF SITES

Site 1

Site 1 (fig. 1) is at the South Beaches wastewater treatment plant owned by Brevard County, Fla. It is just south of Melbourne Beach on a barrier island that is bordered by the Indian River to the west and the Atlantic Ocean to the east. The island is part of a chain of islands composed of relict beach ridges and dunes that are separated from the mainland by the Atlantic coastal lagoons (White, 1970). Land-surface altitudes in the vicinity of site 1 are generally less than 15 ft above sea level.

Drilling of the test hole for an injection well at the South Beaches wastewater treatment plant began in May 1984, and construction of the well was completed in January 1985. The test hole was drilled to a depth of 2,916 ft below land surface, and the lowermost 835 ft of the completed injection well was left uncased as a receiving interval for injectant. The injection zone

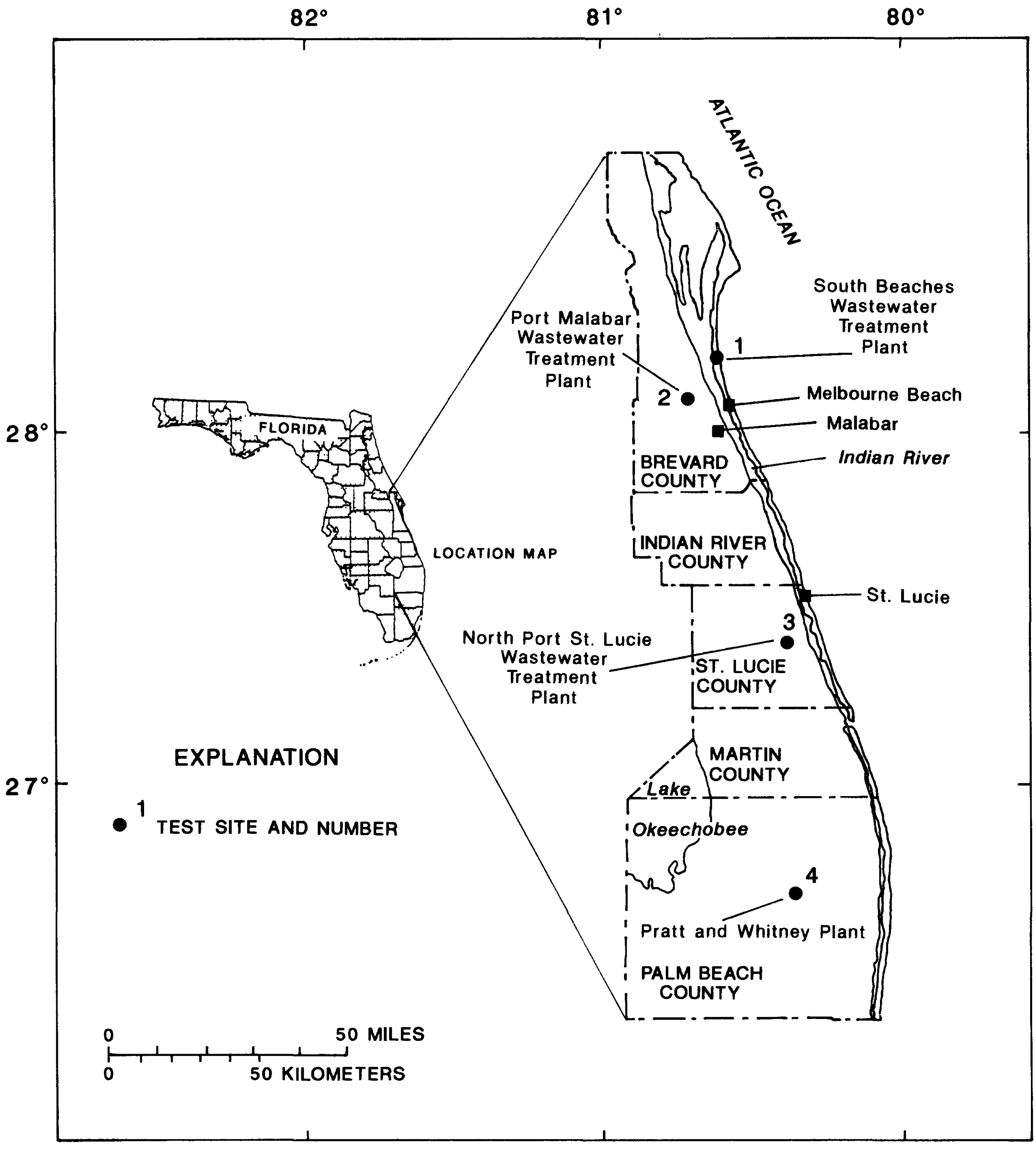

Figure 1. Map showing location of injection well test sites.

was described by Dames and Moore, Inc. (1985), as the "highly recrystallized dolomite encountered from 2,081 to 2,760 ft below land surface."

A borehole television survey was run when the test hole was open from 274 to 2,218 ft below land surface. Another television survey was run after the test hole was deepened to 2,916 ft. This later survey, unfortunately, was not available for this study. In addition to the television survey from 274 to 2,218 ft, other available borehole data included stratigraphic, lithologic, driller's comments, and caliper, flowmeter, and temperature logs (fig. 2). A chronology of drilling events and data-collection activities at site 1 is in appendix A.

Site 2

Site 2 (fig. 1) is at the Port Malabar wastewater treatment plant owned by the General Development Utilities Corporation[1] in Brevard County, Fla. It is within the Eastern Valley physiographic province adjacent to the Atlantic coastal ridges (White, 1970). Site 2 is approximately 3 mi south-southwest of site 1.

Drilling of the test hole for an injection well at the Port Malabar wastewater treatment plant began in July 1986, and construction of the injection well was completed in February 1987. The test hole was drilled to a depth of 3,009 ft below land surface, and the lowermost 959 ft of the completed injection well was left uncased as a receiving interval for injectant. The injection zone was described by CH2M Hill, Inc. (1987a), as the "permeable, cavernous dolomite occurring between approximately 2,100 and 2,300 ft."

A borehole television survey was run in the open borehole interval of the injection well from 2,050 to 3,009 ft below land surface. In addition to the television survey, other available borehole data included stratigraphic, lithologic, driller's comments, and caliper, flowmeter, and temperature logs (fig. 3). A chronology of drilling events and data-collection activities at site 2 is in appendix A.

Site 3

Site 3 (fig. 1) is in St. Lucie County, Fla., at the North Port St. Lucie wastewater treatment plant owned by the General Development Utilities Corporation. It is within the Eastern Valley physiographic province adjacent to the Atlantic coastal ridges (White, 1970). Site 3 is within the city of St. Lucie and is approximately 60 mi south-southeast of site 2.

Drilling of the test hole for an injection well at the North Port St. Lucie wastewater treatment plant began in April 1987, and construction of the injection well was completed in September 1987. The test hole was drilled to a depth of 3,324 ft below land surface, and the lowermost 574 ft of the completed injection well was left uncased as a receiving interval for injectant. The injection zone was described by CH2M Hill, Inc. (1987b), as the "highly permeable, cavernous dolomite occurring between approximately 2,900 and 3,200 ft."

A borehole television survey was run when the test hole was open from 1,950 to 3,324 ft below land surface. In addition to the television survey, other available borehole data included stratigraphic, lithologic, driller's comments, and caliper, flowmeter, and temperature logs (fig. 4). A chronology of drilling events and data-collection activities at site 3 is in appendix A.

[1]The use of firm names is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Site 4

Site 4 (fig. 1) is in Palm Beach County, Fla., at the Pratt and Whitney plant owned by United Technologies Corporation. Site 4 is approximately 50 mi south of site 3.

Drilling of the test hole for an injection well at the Pratt and Whitney plant began in September 1984, and construction of the injection well was completed in April 1985. The test hole was drilled to a depth of 3,310 ft below land surface, and the lowermost 582 ft of the completed injection well was left uncased as a receiving interval for injectant. The injection zone was described by CH2M Hill, Inc. (1985), as the "highly fractured and cavernous dolomite occurring from 2,900 ft to the total depth of the well."

A borehole television survey was run when the test hole was open from 1,865 to 3,310 ft below land surface. In addition to the borehole television survey, other available borehole data for the same depth interval included stratigraphic, lithologic, driller's comments, and caliper logs (fig. 5). Flowmeter and temperature logs were available only from 1,865 to 2,396 ft. A chronology of drilling events and data-collection activities at site 4 is in appendix A.

BOREHOLE TELEVISION SURVEYS

A borehole television survey is performed by lowering a specially designed, water-tight camera into a well for the purpose of inspecting the cased and uncased sections of the well. A closed-circuit video tape system is used to enable the operator to view current conditions as the camera is lowered into the subsurface. Simultaneously, the survey is recorded on video tape as a permanent record for later review. An on-screen digital display identifies the depth of the camera at all times.

Borehole television surveys at the four injection well sites studied were run by Deep Venture Diving Service. A number of surveys were run on each well in order to inspect casing integrity at various stages of construction and to view potential injection intervals in the open hole. A generalized schematic diagram of the camera system used is presented in figure 6. Actual dimensions of the particular system varied slightly depending on the hole diameter and whether black and white or color video images were produced.

The borehole television camera systems used at the four injection well sites utilized a "fast spreading" lens capable of producing a downhole image with a maximum horizontal (peripheral) field of view of approximately 3 ft in diameter and a maximum vertical field of view of approximately 2.5 ft, depending on water clarity and light conditions. The camera was fixed in a vertically downward position and was not capable of a direct side view of the borehole wall. The camera was focused on the brightest part of the light halo created by the attached light source located approximately 2 ft from the camera lens. The depth indicator was set to record the depth at the most brightly illuminated point in the hole.

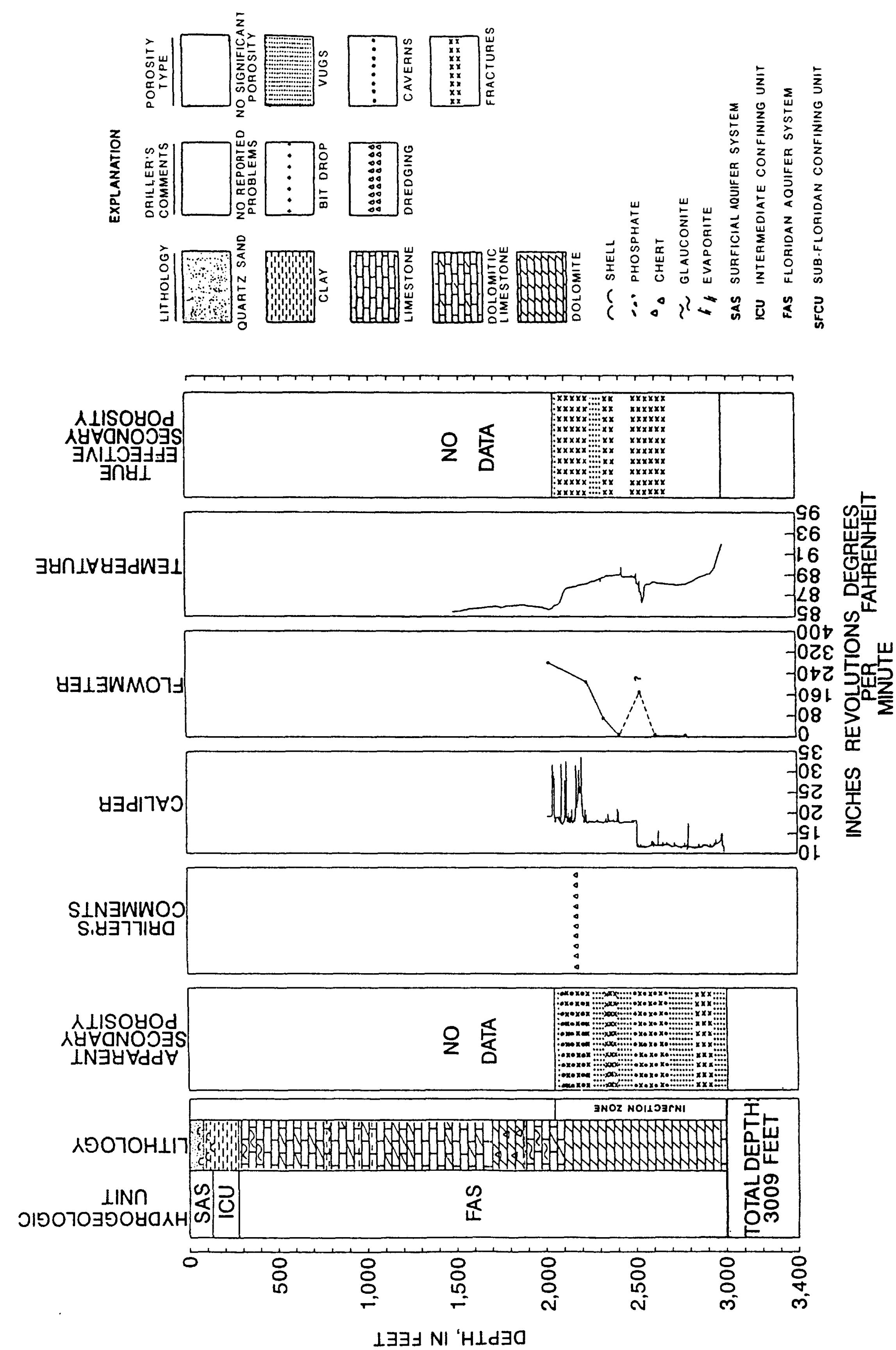

Figure 3. Site 2 comprehensive borehole interpretation.

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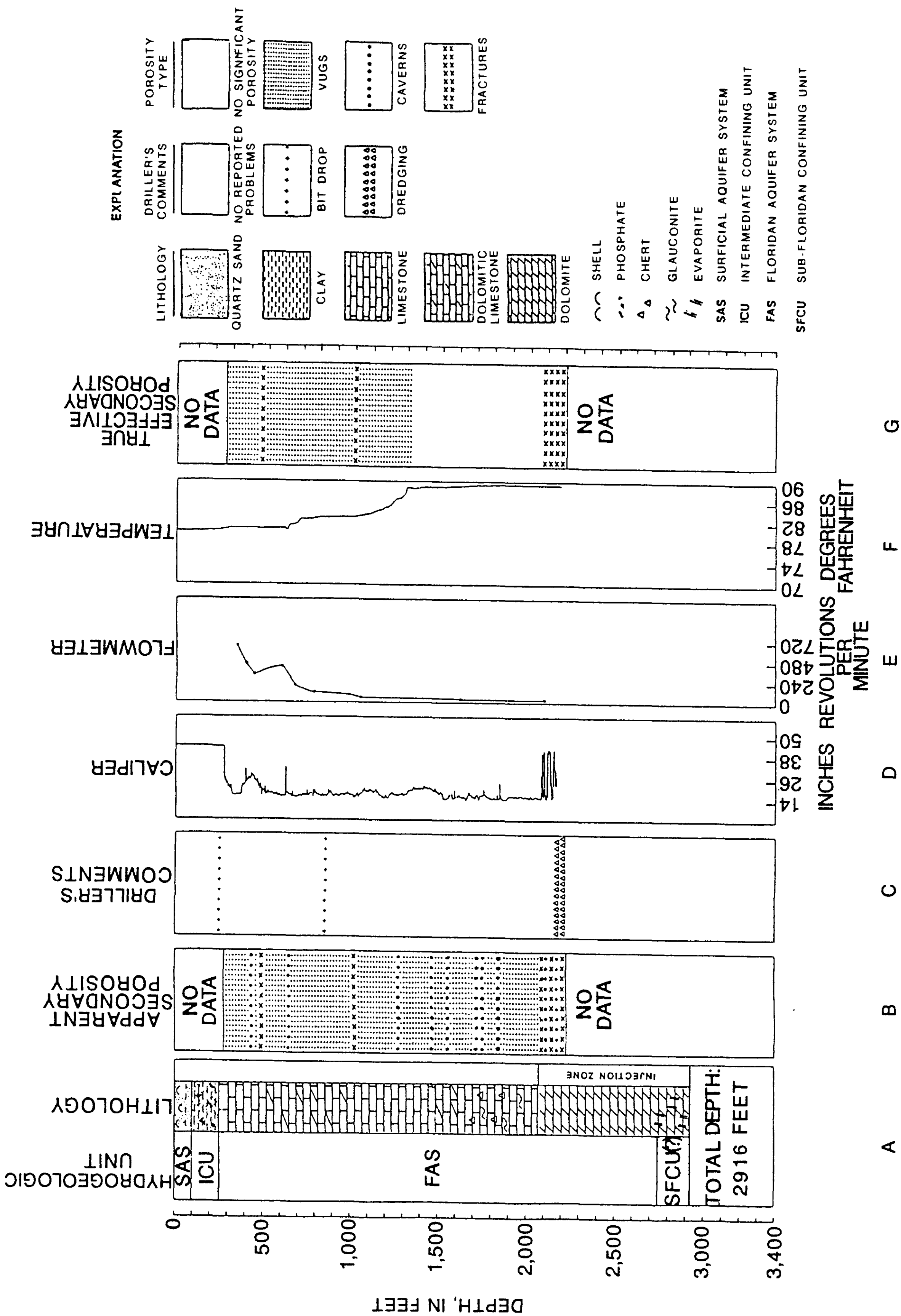

Figure 2. Site 1 comprehensive borehole interpretation.

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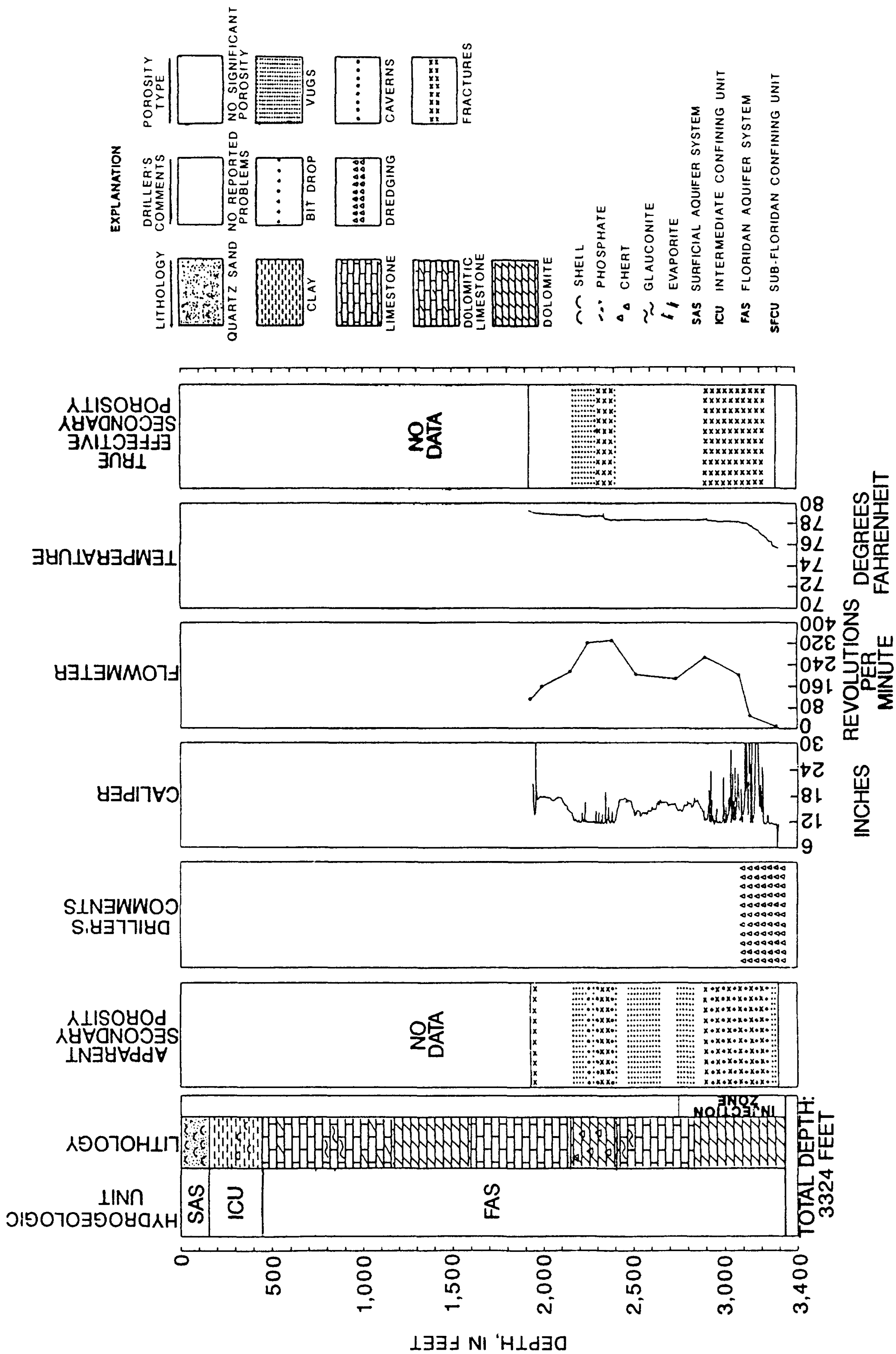

Figure 4. Site 3 comprehensive borehole interpretation.

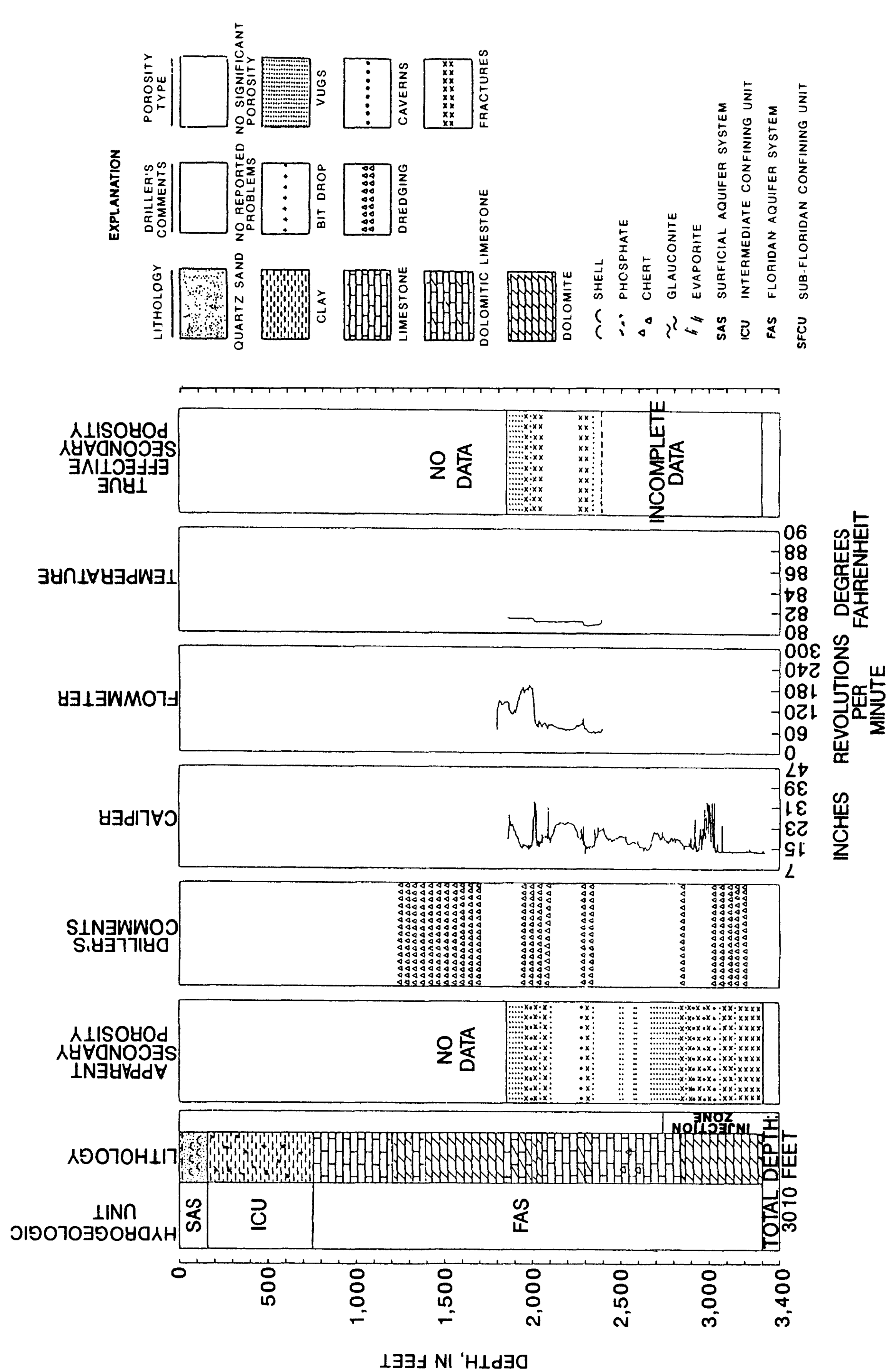

Figure 5. Site 4 comprehensive borehole interpretation.

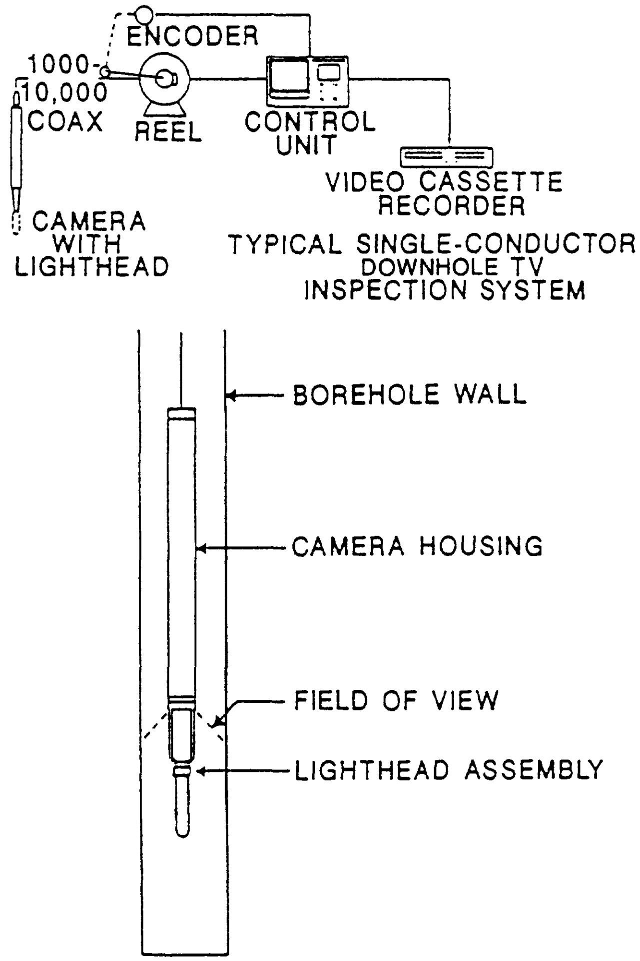

Figure 6. Borehole television equipment schematic.

Some degree of distortion in the actual size and shape of borehole features was inherent in the images produced by the camera system. Theoretically, the images within the brightest part of the borehole wall were the least subject to distortion. Therefore, in this study, borehole features were described and measured as they were encountered by the most highly illuminated interval within the field of view as the camera moved slowly downward. Approximate measurements of features were made possible through comparison to the known diameter of the light housing that was visible in all of the video images. The black and white camera system had a light housing diameter of 0.21 ft (2.5 in.), and the color camera system had a light housing diameter of 0.17 ft (2.0 in.). The size of the smallest feature that the principal author thought he could discriminate as a separate entity in a video image was about 0.01 ft.

The sharpness and clarity of a video image of the borehole wall are directly related to the transparency of the water in the borehole at the time of a television survey. Drilling mud placed at the top of the water column (called a "mud wafer") was used instead of salt to maintain water levels below land surface during test hole drilling at three of the subsurface injection sites, which required that the water in the borehole be completely flushed prior to the borehole survey. With the exception of one of the borehole videos at site 2, the transparency of borehole water at the time of each television survey used in this report was such that the borehole wall was clearly visible.

Descriptive Terminology and Borehole Observations

The descriptive terminology used in this report was modified from Choquette and Pray (1970) for the purpose of characterizing the secondary porosity features seen in a borehole television survey. Secondary or post-depositional porosity was defined by Choquette and Pray (1970, p. 218) as any porosity in a rock created after final deposition. Because the secondary porosity features seen in the borehole television surveys could have been created either by drilling activities or geologic processes, or some combination, all of the visually observed features or macroporosity are called apparent secondary porosity. The identification in this report of true effective secondary porosity, or those porosity features caused by geologic processes at each site, is based upon comparisons between the apparent secondary porosity features and driller's comments and caliper, flowmeter, and temperature logs at a site. The data and assumptions used for interpreting true effective secondary porosity are discussed later in the sections titled "Geologic, Drilling, and Geophysical Borehole Data" and "Characterization of True Effective Secondary Porosity."

The descriptive terminology used for both apparent and true secondary porosity features are given in table 1. Three principal terms are utilized: they are vug porosity, cavern porosity, and fracture porosity. Vug porosity is used in this report to describe pores that are smaller than cavern porosity and are large enough to be seen in a borehole television survey. Because a television camera has to be positioned some distance from a borehole wall, it generally cannot be determined whether or not an observed pore in a video image conforms to the position, shape, or boundaries of a fabric element of the host rock. As a result, the term vug porosity applies not only to nonfabric selective porosity but also to fabric selective porosity, such as moldic porosity. This concept of vug porosity differs from the concept proposed by Choquette and Pray (1970) who restricted the term to nonfabric selective porosity. Table 1 lists three size categories for vug porosity: small, medium, and large. These correspond, respectively, to the common grain-size classifications of pebble, small cobble, and large cobble. The lower size limit for vug porosity in table 1 was set at 0.01 ft to correspond with the smallest feature estimated to be clearly distinguishable in a borehole television survey.

Table 1. Apparent and true secondary porosity classifications

[>, greater than]

Classification	Size of largest dimension (feet)
Vug porosity	
Small	0.01 – 0.21
Medium	0.21– 0.42
Large	0.42–0.84
Cavern porosity	
Small	0.84–2.00
Large	>2.00
Fracture porosity	Fracture apertures generally were too small to be visually estimated.

Vug porosity observed in a television survey of carbonate rocks appears as deep surface depressions in a borehole wall. These surface depressions could be related to dissolution of the carbonate rocks. Also, because a drill bit breaks a rock into small chips, any variation in the mechanical properties of a rock, such as the size, shape, arrangement, and hardness of adjacent parts or constituents could result in a borehole wall with mechanically created, deep surface depressions. All porosity features related to drilling activities would have a spatial distribution restricted to the immediate vicinity of a borehole, whereas porosity features related to geologic processes would have a spatial distribution extending beyond the immediate vicinity of a borehole.

Cavern porosity observed in a television survey of carbonate rocks appears as large voids in a borehole wall. The horizontal dimension of these voids was commonly large enough so that the borehole wall completely disappeared from view in a video image. These large voids could be related to dissolution of the carbonate rocks. Also, because a drill bit penetrates a rock by mechanically disrupting it, rock intervals that have little cement between grains and rock intervals that are intensively fractured or shattered could result in intervals with mechanically created borehole diameters much larger than the bit diameter. These mechanically disrupted intervals, if wide enough, would appear as voids in the borehole wall because of the television camera's maximum horizontal field of view of about 3 ft. As discussed in a following section of the text, many of the caverns seen in the television surveys studied for this report were located in extensively fractured intervals that had unstable borehole walls.

Fracture porosity is used in this report to describe voids that occur along breaks in a rock. No size qualifiers were used for fracture porosity. When viewed in a television survey, fracture porosity appeared as narrow, linear features separating blocks of unfractured rock. The width of a typical fracture aperture viewed in a television survey was generally so small that it could not be reliably measured. Also, and even though it was difficult to directly determine from a television survey, vertical and oblique fracture directions appeared to predominate.

Fracture porosity observed in a borehole may be related not only to stresses in rocks caused by tectonic deformation but also to stresses in rocks caused by drilling activities. Because a drill bit rotates and exerts a downward force in order to penetrate a rock, the stresses related to a bit's torque and downward force could cause a brittle crystalline rock, such as many of the dolomites within the Floridan aquifer system, to fracture. In addition to these drilling stresses, changes in the preexisting stress field caused by the removal of rock from the borehole (Hubbert and Willis, 1972) is another factor that could cause fractures to develop immediately adjacent to the borehole.

In addition to the porosity terms discussed above, a number of common generic textural terms were used to describe the overall shape and notable features of boreholes seen in a television survey. Descriptive modifiers included the terms round, irregular, rough, smooth, angular, and blocky, among others. A combination of the porosity terms in table 1, along with relevant descriptive modifiers, was essential for describing the character of the macroporosity visible in the television surveys. Descriptions of secondary porosity seen in boreholes at each study site are listed in appendix B.

Examination of Borehole Television Surveys

The most representative borehole television survey at each of the four study sites was selected for examination. When more than one survey was available for a site, the one that included the longest and deepest interval of borehole was used. The video cassettes containing the surveys were replayed on a standard home video cassette recorder (VCR). Extensive use of the "pause" and "slow motion" features of the VCR was essential in evaluating the borehole features. Size determinations of the porosity features were accomplished through actual physical measurement of the images as they were in the highly illuminated part of the borehole. As mentioned previously, determination of the scale of the video images was made possible through comparative measurements of the known diameter of the light housing that was visible in all of the images.

Each video was reviewed a number of times to produce a detailed survey summary. The first review was intended to provide a preliminary overview of the porosity types and features visible at the surveyed depths. The second review was more thorough and involved the identification and description of major porosity intervals and the overall shape and character of the borehole within those intervals. A major porosity interval was loosely defined as a depth interval in which all the rocks exhibit similar porosity characteristics or a specific range of porosity features. Once the major porosity intervals were identified and described, the third and final video examination was performed. During this review, the notable features within each of the major intervals were identified and described. Notable features included significant porosity features that were not described specifically in the general porosity interval description. In general, vugs were too numerous to describe individually; however, any unusually shaped or uncommon features were noted. Most caverns and fractures were individually described and measured unless they were found in such densities that individual description was not practical.

The television survey summaries generated for each of the four well sites are presented in appendix B. The general descriptions of the major porosity intervals found at each well site were used to generate the apparent secondary porosity logs. The detailed descriptions of notable features provides a comprehensive data base that is useful for analyzing significant porosity features at particular depths of interest.

Apparent Secondary Porosity Logs

Apparent secondary porosity logs, based upon examination and interpretation of borehole television surveys at the four sites studied for this report, are shown in column B of figures 2 through 5. Due to the scale of the figures and the large depth intervals covered, the porosity logs are generalized. The following three porosity types are represented on the logs: vugs, caverns, and fractures. Distinctions between small, medium, and large vugs could not be made at the given scale. It is important to note that porosity symbols found on the apparent secondary porosity logs represent the predominant (not necessarily the only) porosity types found at those depths. For a more thorough examination of porosity features, one must refer to the television survey summaries.

The apparent secondary porosity log for the South Beaches (fig. 2, col. B) shows the variety of porosity types within the surveyed depths of 290 to 2,205 ft. Vug porosity seems to predominate throughout most of the upper limestone parts of the borehole. Zones of little or no visible apparent secondary porosity were observed from approximately 1,464 to 1,485 ft and 1,705 to 1,756 ft. Cavern porosity was observed near the approximate depths of 437, 650, 1,276, 1,560, 1,756, and 1,843 ft. Fracturelike features were noted at depths of about 488 and 1,028 ft. Fracture and cavern porosity were observed from about 2,080 ft to the total surveyed depth of 2,205 ft.

The apparent secondary porosity log for the Port Malabar site (fig. 3, col. B) shows the porosity types within the surveyed depths of 2,062 to 3,000 ft. Vug porosities were observed from approximately 2,062 to 2,092 ft; 2,400 to 2,500 ft; 2,705 to 2,845 ft; and 2,928 to 3,000 ft. Fracture and cavern porosities were observed from approximately 2,094 to 2,399 ft; 2,502 to 2,704 ft; and 2,846 to 2,928 ft. As with the South Beaches site, cavern porosity was identified in association with fracture porosity.

The apparent secondary porosity log for the North Port St. Lucie site (fig. 4, col. B) shows the porosity types within the surveyed depths of 1,951 to 3,294 ft. Several zones of little or no visible apparent secondary porosity were observed from depths of approximately 1,952 to 2,160 ft; 2,415 to 2,464 ft; 2,655 to 2,736 ft; and 2,839 to 2,890 ft. Vug porosity was observed from about 2,161 to 2,255 ft; 2,257 to 2,303 ft; 2,386 to 2,414 ft; 2,465 to 2,654 ft; 2,737 to 2,838 ft; and 3,245 to 3,294 ft. Cavern porosity was observed near depths of 2,256, 2,304, and 2,385 ft. Fracture porosity was noted at roughly 1,951 ft and from 2,304 to 2,385 ft. Fracture and cavern porosities were observed from about 2,891 to 3,244 ft.

The apparent secondary porosity log for the Pratt and Whitney site (fig. 5, col. B) shows the porosity types within the surveyed depths of 1,866 to 3,317 ft. Several intervals of little or no visible apparent secondary porosity were observed in the upper part of the borehole from approximately 2,125 to 2,270 ft; 2,315 to 2,335 ft; 2,357 to 2,481 ft; 2,530 to 2,565 ft; and 2,605 to 2,670 ft. Fracture porosity was observed from about 1,947 to 1,985 ft; 2,000 to 2,040 ft; and 2,055 to 2,090 ft. Vug porosity predominated throughout the remainder of the upper part of the surveyed interval. Fracture and cavern porosities were observed from about 2,271 to 2,314 ft; 2,850 to 2,865 ft; 2,880 to 2,910 ft; 2,920 to 3,040 ft; 3,080 to 3,145 ft; and 3,157 to 3,300 ft. Several narrow intervals of vug porosity were present near the bottom of the borehole.

GEOLOGIC, DRILLING, AND GEOPHYSICAL BOREHOLE DATA

Geologic, drilling, and geophysical borehole data at each of the four injection sites included stratigraphic and lithologic descriptions, driller's comments, and caliper, flowmeter, and temperature logs. These data are shown, respectively, in columns A, C, D, E, and F in figures 2 through 5. Stratigraphic and lithologic descriptions provide information about the relative age and types of rocks penetrated during drilling. The boreholes in the carbonate rocks at each of the four sites were drilled using the air-reverse rotary technique. In this drilling technique, the drill rod is rigged as an air-lift pump and native formation water enters the drill rod through the drill bit to act as the drilling fluid that entrains rock cuttings bringing them to the surface.

A log of driller's comments provides information about events encountered during drilling. Driller's comments shown in figures 2 through 5 are: (1) no reported problems, (2) bit drop, and (3) dredging. A bit drop happens when a drill bit encounters cavern porosity that has a diameter greater than the bit diameter. A bit drop implies that the encountered cavern porosity predates drilling of the borehole, and, thus, the cavern porosity would be related to geologic processes. Alternatively, if a bit drop is not reported, then no cavern porosity was encountered during drilling.

Dredging refers to the removal of rock fragments from a borehole before drilling can continue. Dredging results from the collapse of unstable, intensively fractured borehole walls. When a borehole wall collapses, the drill bit is buried and the supply of native water to the drill rod is reduced, leading to the possibility of lost circulation and plugging of the drill rod with cuttings. To avoid this circumstance, the driller has to lift the drill bit from the bottom of the hole until native water circulation returns to what it was before the borehole wall collapsed. Removal of the rock fragments now at the bottom of the borehole is necessary before drilling can continue, and, as mentioned above, this is known as dredging. Dredging was reported at each of the four study sites, particularly during drilling through fractured dolomites in the lower part of the Floridan aquifer system.

A caliper log provides information about the diameter of a borehole and its variation with depth. It can be used to confirm bit drops and dredging because, at those depths, the borehole diameter should be relatively large.

A flowmeter log provides information about the vertical movement of water in boreholes and information about intervals of inflow during pumping and intervals of outflow during injection. Rock intervals that exhibit borehole outflow or inflow must have spatially interconnected or effective porosity that extends beyond the immediate vicinity of a borehole. Thus, the porosity in those intervals would be related to geologic processes. Stationary and continuous flowmeter measurements were used at the four study sites to interpret borehole outflow or inflow. Stationary measurements were used at three of the four sites and are preferred because they are not influenced by flowmeter movement.

A temperature log provides additional information about intervals of borehole outflow and inflow. In a theoretical borehole with no vertical flow either in the borehole or in the formation, water temperature would increase at a constant rate with increasing depth due to the geothermal gradient. Deviations from this linear temperature trend during pumping or injection can be interpreted as an indication of borehole outflow or inflow.

A limitation of the approach proposed in this report for characterizing true effective secondary porosity is that it precludes the identification of noninterconnected or isolated secondary porosity related to geologic processes. For example, zones of moldic porosity that have no intervals of borehole outflow or inflow may be common in the Floridan aquifer system (Halley and Schmoker, 1983), but those intervals would not be identified as being any different from intervals with deep surface depressions related to drilling activities.

CHARACTERIZATION OF TRUE EFFECTIVE SECONDARY POROSITY

Interpretation of true effective secondary porosity in the carbonate rocks at each of the four study sites, as mentioned above, was based upon an intercomparison between apparent secondary porosity features and the driller's comments, and caliper, flowmeter, and temperature logs at a site. The intercomparison procedures generally included the following steps.

After the borehole television survey was interpreted in terms of identifying depth intervals with "apparent" vug, cavern, and fracture porosity and after compiling all of the other individual logs, then the driller's comments log was compared with the apparent secondary porosity and caliper logs for the purpose of determining whether or not reported bit drops and dredging were consistent with those logs. At the depth of either a reported bit drop or dredging, the diameter of a borehole should be relatively large and should be seen in the television survey and caliper log as such. After this step, the depth intervals producing or accepting measurable amounts of flow were identified using the flowmeter and temperature logs. As a final step, all of the confirmed observations and associations between the different data were used to interpret true effective secondary porosity beginning with the characterization of cavern porosity.

Before visually observed cavern porosity in a television survey was considered to be spatially interconnected beyond the immediate vicinity of a borehole and thus to be true effective porosity, both a bit drop and flow exiting or entering the borehole had to occur at the depth of the cavern porosity. If a bit drop was not reported, then "cavern porosity" was interpreted to be related to the drilling process and the mechanical properties of the rocks. Additionally, if dredging was reported for the interval and fractures were observed at both the top and bottom of "cavern porosity" in the television survey, then the visually observed "cavern porosity" was interpreted to be an excavation of local extent that was probably related to the collapse of an extensively fractured borehole wall during drilling.

In the following test site interpretations, it is assumed that, when a depth interval with the same type of vug or fracture porosity shows borehole outflow or inflow in only a fraction of the interval, all of the secondary porosity in that depth interval is spatially interconnected and, thus, related to geologic processes. This assumption for characterizing depth intervals of effective porosity is based upon a fractured dolomite unit in west-central Florida (Hickey, 1982).

Site 1

The driller's comments log (fig. 2, col. C) indicates that dredging and drill bit drops occurred (Dames and Moore, Inc., 1985) at site 1. Dredging was reported between about 2,080 and 2,205 ft below land surface during drilling through a dolomite within the Oldsmar Formation of early Eocene age. In addition, two drill bit drops were reported, one at 255 ft below land surface and the other at 858 ft. The bit drop at 255 ft was in the Hawthorn Formation of middle Miocene age. It occurred above the top of the Floridan aquifer system and could not be confirmed because of the lack of other borehole data. The bit drop at 858 ft was in a limestone within the Avon Park Formation of middle Eocene age. This bit drop was within the Floridan aquifer system, but could not be confirmed because no cavern porosity and no large borehole diameters at or near that depth were shown in either the borehole television survey or the caliper log (fig. 2, cols. B and C). Because no borehole inflow occurred at or near 858 ft, it is probable that no cavern was ever present, and the reported bit drop probably was caused by a mechanical problem that resulted from the bit hanging up and then dropping. Whatever the actual cause, the reported bit drop at 858 ft appears to have been caused by something other than by the presence of cavern porosity.

The caliper log (fig. 2, col. D) was run, as was the borehole television survey and the flowmeter and temperature logs, after the borehole had been drilled with a 14.75-in. diameter bit from 290 to 2,205 ft below land surface. Borehole diameters that are much larger than the bit diameter are shown in the caliper log to lie between 2,080 and 2,205 ft. This interval of relatively large borehole diameters contains a dolomite, which was later shown to have fractures related to geologic processes, and included the depths at which dredging was reported. The association between fractured dolomite and dredging points toward borehole wall collapse of intensively fractured or shattered dolomite as a probable cause of the relatively large borehole diameters.

Stationary flowmeter measurements taken during artesian flow in the borehole were used to construct the flowmeter log (fig. 2, col. E). This log indicates that most of the borehole inflow occurred between about 400 and 1,100 ft below land surface. The flowmeter log also indicates that a small quantity of inflow occurred below about 2,100 ft. The temperature log (fig. 2, col. F), run in conjunction with the flowmeter measurements, indicates inflow, not only within the same intervals as the flowmeter log, but also between about 300 and 600 ft and between about 1,100 and 1,320 ft.

The apparent secondary porosity log (fig. 2, col. B) indicates that vug, cavern, and fracture porosities were identified in the borehole television survey. Because there were no confirmed drill bit drops in the Floridan aquifer system, in spite of the fact that the vertical and horizontal dimensions of some borehole intervals as shown in the caliper log are much larger than the bit diameter, all of the caverns in the apparent secondary porosity log are interpreted to be related to drilling activities and the mechanical properties of the rocks. Also, because dredging was reported at various depths during drilling through dolomites between 2,080 and 2,205 ft below land surface and fractures were observed at the top and bottom of the cavern porosities shown in the apparent secondary porosity log in the vicinity of the dredging depths, the apparent cavern porosities at and near the dredging depths in the dolomites are interpreted to be excavations of local extent that are probably related to collapse of extensively fractured borehole walls during drilling.

As a result of interpreting the flowmeter and temperature logs in terms of intervals of borehole inflow, the vug and fracture porosities between 300 and 1,320 ft and the fracture porosity in the dolomites between 2,080 and 2,205 ft are interpreted to be spatially distributed and interconnected beyond the immediate vicinity of the borehole and, thus, are interpreted to be true effective secondary porosity and related mainly to geologic processes. Conversely, because borehole inflow is not indicated between 1,320 and 2,080 ft, the vug porosity observed in the television survey is interpreted not to be distributed spatially and interconnected beyond the immediate vicinity of the borehole and, thus, to be related, at least in part, to drilling activities and the mechanical properties of the rocks. The above interpretations are shown in the true effective secondary porosity log (fig. 2, col. G).

Site 2

The driller's comments log (fig. 3, col. C) indicates that dredging occurred at site 2. Dredging was reported in the driller's daily record (Alsay, Inc., written commun., 1986) at 2,183 ft below land surface. Dredging occurred during drilling through a dolomite within the Oldsmar Formation of early Eocene age. Both the driller's and consultant's daily records report no drill bit drops. This was confirmed by the drilling company (Jim Kern, Alsay, Inc., oral commun., 1989). Even though the consultant and driller do not mention drill bit drops, both state in their respective daily reports that caverns were encountered during drilling. The consultant states that cavities were found at 2,120 ft below land surface, small cavities were found between 2,183 and 2,273 ft, and an "opening" was found between 2,403 and 2,409 ft. The driller states that caverns were found at 2,120 ft and between 2,409 and 2,413 ft. The driller interpreted the presence of caverns between 2,409 and 2,413 ft (this latter number appears in the consultant's report as 2,403) from a change in the color of water removed from the borehole during drilling. The driller reported a "water color change to black" at 2,409 ft and a "change back to brown" at 2,413 ft.

The cavern reported by the consultant and the driller (2,403-2,413 ft) was not confirmed because no cavern porosity and no relatively large borehole diameters were seen in either the borehole television survey or the caliper log at or near the reported depth interval. In addition, a question was raised about the actual presence of the other reported cavities because of the need to acidize the borehole for the purpose of improving its ability to accept injectant. If caverns related to geologic processes were encountered and were open to the borehole, particularly in a borehole drilled with the air-reverse rotary technique, it would be unlikely that acidization would be needed to improve the capability of a well for accepting injectant. Because no bit drops were reported and because of the above question about the actual presence of caverns and the need to acidize the borehole, all of the caverns reported between 2,120 and 2,273 ft are considered to be unsupported interpretations. As such, the reported caverns are not shown in the apparent secondary porosity log in figure 3.

The caliper log (fig. 3, col. D) was run, as were the borehole television survey and the flowmeter and temperature logs, after the borehole had been drilled from 2,050 ft (base of casing) to 2,530 ft below land surface with an 18-in. diameter bit and from 2,530 to 3,009 ft with a 12.5-in. diameter bit. The change in borehole diameter resulting from the change in bit diameter is evident in the caliper log (fig. 3, col. C). The largest borehole diameters shown in the caliper log lie between 2,050 and 2,240 ft. This interval contains a dolomite, which was later shown to have fractures related to geologic processes, and included the depth at which dredging was reported. The association between fractured dolomite and dredging points toward borehole wall collapse of intensively fractured or shattered dolomite as a probable cause of the relatively large diameters.

The flowmeter log (fig. 3, col. E) was constructed from measurements made when injecting at a rate of about 2,000 gal/min after the well had been acidized. One flowmeter measurement in the log at about 2,500 ft below land surface is questionable because it was larger than measurements at and near that depth in an accompanying continuous flowmeter log. The flowmeter log shows that most borehole outflow during injection occurred between about 2,050 and 2,400 ft with little, if any, borehole outflow between 2,400 and 3,009 ft.

The temperature log (fig. 3, col. F) was run in the borehole before acidization and 8 days after injecting at a rate between 3,500 and 4,000 gal/min for 12.5 hours. Because of this, the temperature log is not readily interpreted. However, the relatively lower temperatures between 2,500 and 2,600 ft might indicate that this interval had accepted some water during injection prior to acidization.

The apparent secondary porosity log (fig. 3, col. B) indicates that vug, cavern, and fracture porosities were identified in the borehole television survey. Because there were no reported and confirmed drill bit drops, in spite of the fact that the vertical and horizontal dimensions of some borehole intervals as shown in the caliper log are much larger than the bit diameter, all of the caverns in the apparent secondary porosity log are interpreted to be related to drilling activities and the mechanical properties of the rocks. Also, because dredging was reported during drilling through dolomites at 2,183 ft below land surface and fractures were observed at the top and bottom of the cavern porosities shown in the apparent secondary porosity log near that depth, the apparent cavern porosities in the dolomites are interpreted to be excavations of local extent that are probably related to collapse of extensively fractured borehole walls during drilling.

As a result of interpreting the flowmeter and temperature logs in terms of intervals of borehole outflow, the vug and fracture porosities between 2,062 and 2,400 ft and between 2,500 and 2,700 ft are interpreted to be spatially distributed and interconnected beyond the immediate vicinity of the borehole and, thus, are interpreted to be true effective secondary porosity and related mainly to geologic processes. Conversely, because borehole outflow was not indicated between 2,400 and 2,500 ft and between 2,700 and 3,009 ft, the vug and occasional fracture porosities between those depths are interpreted not to be spatially interconnected beyond the immediate vicinity of the borehole and, thus, to be related, at least in part, to drilling activities and the mechanical properties of rocks. The above interpretations are shown in the true effective secondary porosity log (fig. 3, col. G).

Site 3

The driller's comments log (fig. 4, col. C) indicates that dredging occurred at site 3. Dredging was reported (CH2M Hill, Inc., 1987b) between about 3,100 and 3,350 ft below land surface during drilling through a dolomite within the Oldsmar Formation of early Eocene age. No drill bit drops were reported at site 3 during drilling.

The caliper log (fig. 4, col. D) was run, as were the borehole television survey and the flowmeter and temperature logs, after the borehole had been drilled from about 1,950 ft (base of the intermediate casing) to 3,324 ft with a 12.25-in. diameter bit. The caliper and other logs, including the television survey, did not reach the bottom of the drilled hole because a rock fragment (probably dolomite) blocked the borehole at about 3,290 ft after being dislodged from the borehole wall. The largest borehole diameters shown in the caliper log lie between about 2,900 and 3,200 ft. This interval contains a dolomite, which was later shown to have fractures related to geologic processes, and included the interval within which dredging was reported. The association between fractured dolomite and dredging, including the rock fragment blocking the borehole, points toward borehole wall collapse of intensively fractured or shattered dolomite as a probable cause of the relatively large diameters.

The flowmeter log (fig. 4, col. E) was constructed from measurements made when the borehole was pumped at a rate of 1,040 gal/min. The flowmeter log shows that most borehole inflow occurred within two intervals, one between 2,200 and 2,400 ft and the other between 2,900 and 3,200 ft.

The temperature log (fig. 4, col. F) was run when the borehole was pumped at a rate of 850 gal/min. This log indicates borehole inflow from the same two intervals as shown by the flowmeter log. An interesting feature of the temperature log is that the temperatures near the bottom of the log decrease with depth. This is an example of the reverse thermal gradient found associated with the so-called "boulder zone" (Kohout, 1967) in the Floridan aquifer system in southeast Florida. The temperature at the bottom of the borehole was about 75.5 °F and was the lowest bottom hole temperature encountered at the four study sites.

The apparent secondary porosity log (fig. 4, col. B) indicates that vug, cavern, and fracture porosities were identified in the borehole television survey. Because there were no reported drill bit drops, in spite of the fact that the vertical and horizontal dimensions of some borehole intervals, as shown in the caliper log, are much larger than the bit diameter, all of the caverns in the apparent secondary porosity log are interpreted to be related mainly to drilling activities and the mechanical properties of the rocks. Also, because dredging was reported at various depths during drilling through dolomites between about 3,100 and 3,350 ft below land surface and fractures were observed at the top and bottom of cavern porosities shown in the apparent secondary porosity log in the vicinity of the dredging depths, the cavern porosities at and near the dredging depths in the dolomites are interpreted to be excavations of local extent that are probably related to collapse of extensively fractured borehole walls during drilling.

As a result of interpreting the flowmeter and temperature logs in terms of intervals of borehole inflow, the vug and fracture porosities between 2,160 and 2,415 ft and between about 2,890 and 3,240 ft are interpreted to be spatially interconnected beyond the immediate vicinity of the borehole and, thus, to be true effective secondary porosity related mainly to geologic processes. Conversely, because borehole outflow was not indicated between 1,950 and 2,160 ft, between 2,415 and 2,890 ft, and between 3,240 and 3,290 ft, the occasional vug and fracture porosities between those depths are interpreted not to be interconnected spatially beyond the immediate vicinity of the borehole and to be related, at least in part, to drilling activities and the mechanical properties of rocks. The fractures near 1,950 ft may have been caused by stresses related to installation of the intermediate casing. The above interpretations are shown in the true effective secondary porosity log (fig. 4, col. G).

Site 4

The driller's comments log (fig. 5, col. C) indicates that dredging occurred at site 4. Dredging was reported (CH2M Hill, Inc., 1985) within several intervals between about 1,200 and 3,250 ft below land surface during drilling through dolomites and dolomitic limestones within the Avon Park Formation of middle Eocene age and the Oldsmar Formation of early Eocene age. No drill bit drops were reported at site 4 during drilling.

The caliper log (fig. 5, col. D) was run, as was the borehole television survey, after the borehole had been drilled from 1,865 (base of the intermediate casing) to 3,310 ft below land surface with a 12.25-in. diameter bit. The largest borehole diameters shown in the caliper log lie between about 1,980 and 2,080 ft, between about 2,280 and 2,350 ft, and between about 2,900 and 3,050 ft. The two uppermost intervals contain dolomitic limestone and dolomite, and the lowermost interval contains only dolomite. All three intervals were shown to have fractures related to geologic processes and included depths at which dredging was reported. The association between fractured dolomite and dredging points toward borehole wall collapse of intensively fractured or shattered dolomitic intervals as a probable cause of the relatively large diameters.

The flowmeter log (fig. 5, col. E) and temperature log (fig. 5, col. F) were run when the borehole was open between 1,865 and 2,396 ft and the borehole was pumped at 475 gal/min. The flowmeter log is a continuous log because stationary measurements were not available. Both the flowmeter and temperature logs indicate that borehole inflow occurred between about 1,990 and 2,020 ft and between about 2,280 and 2,300 ft. These intervals contain dolomitic limestone and dolomite, respectively.

The apparent secondary porosity log (fig. 5, col. B) indicates that vug, cavern, and fracture porosities were identified in the borehole television survey. Because there were no reported drill bit drops, in spite of the fact that the vertical and horizontal dimensions of some borehole intervals, as shown in the caliper log, are much larger than the bit diameter, all of the caverns in the apparent secondary porosity log are interpreted to be related to drilling activities and the mechanical properties of rocks. Also, because dredging was reported at various depths during drilling through dolomitic limestones and dolomites between 1,865 and 3,050 ft below land surface and fractures were observed at the top and bottom of cavern porosities shown in the apparent secondary porosity log in the vicinity of the dredging depths, the apparent cavern porosities at and near the dredging depths in the dolomitic limestones and dolomites are interpreted to be excavations of local extent that are probably related to collapse of extensively fractured borehole walls during drilling.

As a result of interpreting the flowmeter and temperature logs in terms of intervals of borehole inflow, only the interval between 1,865 and 2,400 ft can be evaluated for true effective secondary porosity. Within that interval, the vug and fracture porosities between 1,865 and 2,125 ft and the vug and fracture porosity between 2,270 and 2,350 ft are interpreted to be interconnected spatially beyond the immediate vicinity of the borehole and, thus, to be true effective secondary porosity related mainly to geologic processes.

The above interpretations are shown in the true effective secondary porosity log (fig. 5, col. G).

DISCUSSION AND CONCLUSIONS

Borehole television surveys, in conjunction with driller's comments and caliper, flowmeter, and temperature logs, provide a source of data for characterizing the observable secondary porosity or macroporosity of the Floridan aquifer system. One benefit of a television survey is that secondary porosity features can be observed directly. Another important related benefit is that fracture porosity not previously discernible in other borehole data, except cores, can be identified.

Borehole television surveys have limitations and need to be interpreted cautiously when characterizing secondary porosity features in the carbonate rocks of the Floridan aquifer system. One limitation of a television survey is that it records only those features that are large enough to be visible in video images. Also, there is some degree of distortion in the size and shape of features seen in the images produced by the camera systems. Another limitation is that the television cameras commonly are fixed in a vertically downward position and are not capable of recording a side view of a borehole wall. The principal limitation of a television survey is that the apparent secondary porosity features observed may represent only local porosity features caused by drilling or due to the mechanics of the rock and not true secondary porosity features.

The concept of apparent secondary porosity was used in this study because the macroporosity features seen in a borehole television survey could have been caused not only by geologic processes but also by drilling activities. To identify secondary porosity caused by geologic processes, the secondary porosity features viewed in a television survey were evaluated using driller's comments and caliper, flowmeter, and temperature logs. Borehole intervals that produced or accepted measurable amounts of flow, as shown by flowmeter and temperature logs, were used as an indication that the secondary porosity of the interval was spatially distributed and interconnected beyond the immediate vicinity of a borehole and, thus, was related to geologic processes. These features were then identified as true effective secondary porosity. Identification of noninterconnected or isolated secondary porosity related to geologic processes is not possible with the method proposed and used in this study.

The approach developed in this report was applied to four test sites in southeast Florida. This application resulted in a common interpretation that the secondary porosity of the dolomites in the lower part of the Floridan aquifer system at all of the sites was mainly fracture porosity rather than cavern porosity. Another conclusion was that the cavern porosity observed in video images of those dolomites was probably caused mainly by drilling-induced collapse of intensively fractured borehole walls. These dolomites have traditionally been called the "boulder zone" in southeast Florida and, at the study sites, these dolomites were chosen by consulting firms as the injection zone. The importance of fracture porosity, as opposed to cavern porosity, in the "boulder zone" is an interpretation that differs from the interpretation of a number of previous investigators and, as such, is an example of the potential usefulness of the approach developed in this report.

This study has shown that borehole television surveys in conjunction with driller's comments and caliper, flowmeter, and temperature logs can be used to characterize the secondary porosity or macroporosity of carbonate rocks caused by geologic processes. For any future applications of the approach, it is important that the flowmeter and temperature logs are run one after the other within the same depth interval during borehole pumping or injection.

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APPENDIX A

APPENDIX A

CHRONOLOGY OF DRILLING AND DATA-COLLECTION ACTIVITIES AT SITES 1, 2, 3, AND 4

(Excluding water-quality testing)

Site 1: South Beaches Injection Well
Summary of Drilling and Testing Events

<u>May 15-21, 1984</u>

- Drilling pad preparation.
- Drilling 14.75-in diameter pilot hole to a depth of 292 ft using mud rotary method.

<u>May 21, 1984</u>

- Geophysical logging: Spontaneous potential
  Resistivity
  Gamma ray
  Caliper

<u>May 22-June 9, 1984</u>

- Reaming pilot hole to 46-in. diameter to a depth of 286 ft using mud rotary method.

<u>June 9-21, 1984</u>

- Setting 40-in. casing to a depth of 274.5 ft.
- Drill rig maintenance.
- Constructing discharge line to the Indian River.

<u>June 21-August 4, 1984</u>

- Drilling 14.75-in. diameter pilot hole to a depth of 2,218 ft using reverse air method with formation water as drilling fluid.
- Coring runs (11 total ran from July 4 to July 30).

<u>August 5-6, 1984</u>

- Ran color television survey.

August 6-8, 1984

- Geophysical logging: Gamma ray
  Caliper
  Long and short normal resistivity
  Fluid resistivity
  Spinner
  Temperature

August 8-17, 1984

- Packer testing.

August 17-21, 1984

- Maintenance and preparations for reaming.

August 21-September 23, 1984

- Reaming 38-in. diameter hole from 287 to 1,710 ft using reverse air method with formation water as drilling fluid.

- Correcting turbidity problems with discharge to river.

September 23-25, 1984

- Ran caliper log.

- Ran black and white television survey.

September 25-October 13, 1984

- Setting 32-in. casing to a depth of 1,697 ft.

- Ran temperature logs inside casing.

October 13-24, 1984

- Redrilling collapsed 14.75-in. diameter pilot hole to a depth of 2,080 ft using reverse air method with formation water as drilling fluid.

October 24, 1984

- Ran Volan-Schlumberger log.

October 25-November 6, 1984

- Reaming 30-in. diameter hole to 2,083 ft using reverse air method with formation water as drilling fluid.

November 6-28, 1984

- Setting 20-in. casing to 2,080 ft.
- Grouting and casing testing.

November 28-December 23, 1984

- Reaming 18-in. diameter hole to 2,218 ft using reverse air method with formation water as drilling fluid.
- Encountered numerous "caving" problems.
- Modified drill bit to prevent plugging of the bit and lost circulation (December 6).

December 24-26, 1984

- Shut down for holidays.

December 27, 1984-January 16, 1985

- Resumed drilling with 18-in. diameter bit to a total and final depth of 2,916 ft.
- Hole no longer caving.

January 16-20, 1985

- Developed well.
- Ran pump out tests.
- Geophysical logging: Temperature
Caliper
Flowmeter
- Ran color television survey.

January 20, 1985

- Consultants offsite.

Site 2: General Development Utilities Corporation Port Malabar Injection Well Summary of Drilling and Testing Events

<u>May 12-August 13, 1986</u>

- Drill pad preparation.
- Installing surface casings.
- General maintenance and drill rig set up.

<u>August 14-15, 1986</u>

- Drilling 12.25-in. diameter pilot hole to a depth of 452 ft using mud rotary method.

<u>August 15-16, 1986</u>

- Geophysical logging: Single point electric
Spontaneous potential
Gamma ray
Caliper

<u>August 16-24, 1986</u>

- Reaming pilot hole to 50-in. diameter to a depth of 400 ft using mud rotary method.

<u>August 24-26, 1986</u>

- Setting 38-in. O.D. casing to a depth of 400 ft.

<u>August 27-29, 1986</u>

- Drilling 12.25-in. diameter pilot hole to a depth of 640 ft using mud rotary method.

<u>August 30-September 24, 1986</u>

- Installed mud wafer.
- Drilling 12.25-in. diameter pilot hole to a depth of 1,660 ft using reverse air method.
- Sections of hole redrilled several times to straighten.
- Drill rig maintenance.
- Coring runs (eight total) from selected depths in the interval from 931 to 1,670 ft.

September 24-25, 1986

- Geophysical logging: Borehole compensated sonic
  Dual induction
  Gamma ray
  Caliper
  Long and short normal resistivity and spontaneous potential
  Temperature
  Fluid resistivity

September 26-October 24, 1986

- Reaming pilot hole to 36-in. diameter to a depth of 1,605 ft using reverse air method.

- Drill rig maintenance.

- Pond liner installations.

October 25-31, 1986

- Setting 30-in. casing to a depth of 1,600 ft.

October 31 to November 14, 1986

- Drilling 12.25-in. diameter pilot hole to a depth of 2,501 ft using reverse air method.

- Coring runs (seven total) from selected depths in the interval from 1,912 to 2,017 ft.

November 15, 1986

- Geophysical logging: Gamma ray
  Caliper
  Long and short normal resistivity and spontaneous potential
  Temperature
  Fluid resistivity
  Dual induction
  Borehole compensated sonic

November 16-21, 1986

- Ran pumping test.

- Ran packer tests (four total) in the depth interval 1,897 to 2,049 ft.

November 21-26, 1986

- Reaming pilot hole to 28-in. diameter to a depth of 2,063 ft using reverse air method.

November 27-30, 1986

- Drilling operations suspended for Thanksgiving Holiday.

- Awaiting supplies.

December 1-4, 1986

- Installed gravel up to 2,059 ft to plug open hole and capped with cement to facilitate setting of casing.

- Drill rig maintenance.

- Ran caliper log (December 4).

December 5-11, 1986

- Setting 20-in. casing to a depth of 2,050 ft.

- Ran temperature log and pressure test (December 8) inside casing.

December 12-16, 1986

- Reaming pilot hole to 18-in. diameter to a depth of approximately 2,530 ft using reverse air method.

December 16-17, 1986

- Geophysical logging: Cement bond log
  Acoustic velocity
  Caliper
  Temperature

December 18-23, 1986

- General maintenance.

- Ran pumping test filling the lined pond.

- Ran 12-hour injection test.

December 24-26, 1986

- Drilling operations suspended for Christmas Holiday.

NOTE: Injection test results indicated that the well's capacity was 3 Mgal/d less than designed and at considerably higher pressures. A well improvement program that included deepening and acidization was approved by Florida Department of Environmental Regulation, which led to the following additional work:

January 7-8, 1987

- Ran 12-hour injection test.
- Ran color television survey (unavailable).

January 9-14, 1987

- Killing well with salt.
- Drilling 12.25-in. diameter pilot hole to a depth of 3,000 ft using open circulation reverse air by discharging to the pond and pumping back into the injection well.

January 15, 1987

- Geophysical logging: Caliper
  Temperature
  Gamma ray
  Long and short normal resistivity and spontaneous potential

January 16-17, 1987

- Installed 4.5-in. acid line to 2,118-ft depth, pumped in 18,000 gal of 32-percent inhibited HCl, and intermittently surged.

January 18, 1987

- Injection test.
- Geophysical logging: Fluid velocity
- Black and white television survey

January 19 to mid-February 1987

- General maintenance and cleanup.
- Consultants offsite (January 28).
- Wellhead construction.

Site 3: General Development Utilities Corporation North Port St. Lucie Injection Well Summary of Drilling and Testing Events

<u>Mid-April to May 1, 1987</u>

- Drill pad preparation.

- General maintenance and drill rig set up.

- Drilling 60-in. diameter hole to a depth of 40 ft using mud rotary method and setting 40 ft of 54-in. casing.

<u>May 2, 1987</u>

- Drilling 12.25-in. diameter pilot hole to a depth of 201 ft using mud rotary method.

- Geophysical logging: Caliper
Gamma ray
Single point electric and sp

<u>May 3-5, 1987</u>

- Reaming pilot hole to 48-in. diameter to a depth of 200 ft using mud rotary method.

- Setting 42-in. casing to a depth of 195 ft.

<u>May 6-8, 1987</u>

- Drilling 12.25-in. diameter pilot hole to a depth of 894 ft using mud rotary method.

- Geophysical logging: Caliper
Gamma ray
Long and short normal electric and sp

<u>May 9-14, 1987</u>

- Reaming pilot hole to 40-in. diameter to a depth of 854 ft using mud rotary method.

- Setting 32-in. casing to a depth of 850 ft.

May 15-22, 1987

- Setting up for reverse air drilling on remainder of hole.
- General maintenance.
- Installed mud wafer.
- Drilling 12.25-in. diameter pilot hole to a depth of 2,005 ft using reverse air method.

May 23, 1987

- Geophysical logging: Caliper
  Gamma ray
  Long and short normal resistivity and spontaneous potential
  Temperature
  Fluid resistivity
  Dual induction

May 24 to June 12, 1987

- General maintenance.
- Reaming pilot hole to 31-in. diameter to a depth of 1,950 ft using reverse air method.
- Setting 22-in. casing to a depth of 1,950 ft.

June 13-23, 1987

- Drilling 12.25-in. diameter pilot hole to a depth of 3,324 ft using reverse air method.
- Coring runs (seven total) from selected depths in the interval from 2,100 to 2,635 ft.

June 24-25, 1987

- Geophysical logging: Caliper
  Gamma ray
  Long and short normal resistivity and spontaneous potential
  Temperature
  Fluid resistivity
  Fluid velocity

June 26, 1987

- Ran color television survey.

- Made bridge plugs out of 4" x 4" boards and palmettos from 2,875 to 2,805 ft.

June 27 to July 17, 1987

- Reaming pilot hole to 21-in. diameter to a depth of 2,765 ft using reverse air method.

- Setting 12-in. casing to a depth of 2,750 ft.

- Plugged hole bottom with sand and cement.

- Ran temperature logs, pressure test, wave train display, and cement bond log inside 12-in. casing.

July 18-28, 1987

- Drilling out plug and cleaning out hole to a total depth of 3,324 ft.

- Ran pumping test filling the lined pond.

- Ran 16-hour injection test.

July 29-30, 1987

- Ran black and white television survey.

July 31 to August 4, 1987

- General maintenance and site cleanup.

August 5, 1987

- Geophysical logging: Caliper
  Temperature

August 18, 1987

- Consultants' work on injection well assumed to be completed. No further daily logs.

Site 4: United Technologies-Pratt and Whitney Injection Well
Summary of Drilling and Testing Events

September 8 to October 8, 1984

- Drill pad preparation.

- Installing surface casings.

- Drilling 14.75-in. diameter pilot hole to a depth of 180 ft using mud rotary method.

October 9, 1984

- Geophysical logging: Caliper
  Gamma ray
  Long and short normal resistivity and spontaneous potential

October 9-12, 1984

- Reaming pilot hole to 46-in. diameter to a depth of 165 ft using mud rotary method.

- Setting 40-in. casing to a depth of 165 ft.

October 13-15, 1984

- Drilling 12.25-in. diameter pilot hole to a depth of 1,032 ft using mud rotary method.

October 15, 1984

- Geophysical logging: Caliper
  Gamma ray
  Long and short normal resistivity and spontaneous potential
  Temperature

October 16-24, 1984

- Reaming pilot hole to 38-in. diameter to a depth of 970 ft using mud rotary method.

- Setting 30-in. casing to a depth of 970 ft.

October 25 to November 1, 1984

- Drilling 12.25-in. diameter pilot hole to a depth of 1,870 ft using reverse air method.

November 2, 1984

- Geophysical logging: Caliper
  Gamma ray
  Long and short normal resistivity and spontaneous potential
  Fluid resistivity
  Temperature

November 3 to December 28, 1984

- Reaming pilot hole to 28-in. diameter to a depth of 1,865 ft using reverse air method.

- Repairs, bit retrieval, and milling.

- Shut down for holidays (December 22-26).

December 29, 1984 to January 18, 1985

- Setting 20-in. casing to a depth of 1,865 ft.

- Ran temperature log.

- Milling with 18-in. diameter bit.

January 18-23, 1985

- Drilling 12.25-in. diameter pilot hole to a depth of 2,400 ft using reverse air method.

- Coring runs (three total) from selected depths in the interval from 1,893 to 2,400 ft.

January 24, 1985

- Ran 4-hour pump test.

- Geophysical logging: Caliper
  Temperature
  Fluid resistivity
  Flowmeter

January 25 to February 1, 1985

- Drilling 12.25-in. diameter pilot hole to a depth of 3,310 ft using reverse air method.

February 2-6, 1985

- Geophysical logging: Caliper
  Gamma ray
  Long and short normal resistivity and spontaneous potential
  Temperature
  Fluid resistivity
  Acoustic velocity

- Color television survey

February 7 to March 22, 1985

- Constructing bridge plug at 2,735-ft depth.

- Maintenance and bit retrieval.

- Reaming pilot hole to 18-in. diameter to a depth of 2,735 ft using reverse air method.

- Setting 10-in. casing to a depth of 2,728 ft.

- Ran temperature log inside of casing (March 16).

- Ran casing pressure test.

March 23-29, 1985

- Drilling out plug.

- Ran cement bond log (March 27).

- Developing well and constructing well head.

March 30, 1985

- Ran black and white television survey.

March 31 to April 3, 1985

- Ran 12-hour step injection test.

- Site cleanup and demobilization.

APPENDIX B

APPENDIX B

BOREHOLE TELEVISION SURVEY SUMMARIES

Site 1: South SITE 1: SOUTH BEACHES INJECTION WELL
Color Television Survey

August 6, 1984, depth logged: 0 to 2,205 ft.

42-in. diameter casing from 0 to 274 ft.

46-in diameter open hole from 275 to 289 ft.
(Wall not clearly visible in videos).

14.75-in. diameter pilot hole from 290 to 2,205 ft.

Summary of Apparent Secondary Porosity Intervals

Interval A — Depth 290 to 398 ft

General borehole shape: Round.

General borehole wall description: Consistently pitted with small uniform vugs. Occasional medium vugs also found.

Depth (ft)	Notable Features
296-300	Zone containing several semicircular medium vugs.
306	Circular medium vug.
319-321	Zone containing several medium vugs, which are pitted with small vugs.
336	Circular medium vug.
351	Horizontally elongated and shallow medium vug.
379.5	Vertically elongated medium vug.

Interval B — Depth 399 to 521 ft

General borehole shape: Round to semi-irregular.

General borehole wall description: Consistently pitted with small and occasional medium vugs. Narrow intervals of large vugs and/or small caverns are common.

Depth (ft)	Notable Features
405-408	Zone containing series of medium and large vugs.
411.5	Vertically elongated medium vug.
416-417	Circular widening of hole (small cavern?).
423-425	As above.
469-470	Circular full-hole small cavern.
479-492	Excessively pitted zone with small and medium vugs.
484-486	Pair of linear vertical features (fractures?) approximately 1-in. wide on opposite sides of wall.
488-491	Pair of linear vertical features (fractures?) approximately 1-in. wide.
500-501	Circular full-hole small cavern.

Interval C   Depth 522 to 621 ft

General borehole shape: Round.

General borehole wall description: Intermittently pitted with small vugs. Some smooth nonpitted sections. Occasional intervals containing thin, horizontal bands of apparent secondary porosity.

Depth (ft)	Notable Features
547-553	Relatively smooth wall.
557-561	Interval containing several small horizontal vug bands (drilling marks?).
569-571	As above.
581-589	Intensely pitted with small and medium vugs.
590-591	Vertically elongated large vug.
592-606	Interval containing several small horizontal vug bands (drilling marks?).

Interval D Depth 622 to 830 ft

General borehole shape: Round to semi-irregular.

General borehole wall description: Marked by small and some medium vugs. Periodic intervals containing large vug(s) and/or small cavern(s).

Depth (ft)	Notable Features
622-630	Picture appears out of focus indicating possible flow and mixing of waters of unlike temperature and/or concentration.
628-629.5	Smooth-walled 1/2-hole small cavern.
633-635	Full-hole small cavern with pitted edges.
636-648	Intensely pitted with small and medium vugs.
663-670	Picture appears out of focus indicating possible flow and mixing of waters of unlike temperature and/or concentration.
669.5-670	Full-hole small cavern.
687-690	Picture appears out of focus indicating possible flow and mixing of waters of unlike temperature and/or concentration.
732	Dark, horizontal band approximately 1-in. thick.
755	Large, relatively smooth, circular, 1/4-hole vug.
760-765	Parallel vertical grooves approximately 1/2-in. wide (drilling marks?).
769-775	Deeply pitted with small and medium vugs.
778-780	Irregularly shaped vertical small cavern.
787-813	Deeply pitted with small, medium, and occasional large vugs.
817	Diagonal sharp-edged feature (fracture?).

Interval E   Depth 831 to 1,179 ft

General borehole shape: Round.

General borehole wall description: Smooth to lightly pitted with predominantly small vugs. Several apparent vertical fractures found in discrete intervals. Occasional medium vugs and other features as described below.

Depth (ft)	Notable Features
910-920	Half of hole smooth while other half is lightly pitted with small vugs.
935-940	Vertical striations (drilling marks?).
944-962	Fairly roughly pitted with small and medium vugs.
987-989	Horizontal banding associated with color change (lithologic change?).
1,015-1,033	Picture appears out of focus indicating possible flow and mixing of waters of unlike temperature and/or concentration.
1,019-1,022	Pair of vertical fracturelike grooves approximately 1 in. wide.
1,024-1,033	Fractures mentioned above continue. Widened at the top, narrow and sharp-edged toward the base. Notable water flowing from both sides of the openings.
1,035-1,036	Vertically elongated large vug. Possible continuation of overlying fracture.
1,037-1,061	Roughly pitted with mainly small vugs.
1,060-1,064	Picture appears out of focus indicating possible flow and mixing of waters of unlike temperature and/or concentration.
1,104.5-1,106	Angular vertical crack (fracture?) with apparent water flowing from it.
1,107-1,120	Smooth wall with periodic small and medium vugs.
1,121-1,121.5	Circular 1/4-hole large vug.

Interval F   Depth 1,180 to 1,281 ft

General borehole shape: Round.

General borehole wall description: Intermittent small and/or medium vugs on an otherwise smooth wall. Occasional intensely pitted zones.

Depth (ft)	Notable Features
1,183-1,188	Intensely pitted with mainly small and some medium vugs.
1,207-1,210	Narrow vertical striations (drilling marks?).
1,215-1,243	Consistently pitted with small and medium vugs.
1,264-1,280	Large, medium, and small irregularly shaped sinuous vugs.
1,271-1,272	Circular small cavern with angular small cobble-size rock on cavern floor.
1,280-1,281	Circular small cavern.

Interval G   Depth 1,282 to 1,681 ft

General borehole shape: Round.

General borehole wall description: Lightly pitted with small surficial vugs on otherwise smooth wall. Intervals of little or no apparent secondary porosity common. Occasional isolated intervals containing large vugs, medium vugs, and/or small caverns.

Depth (ft)	Notable Features
1,306	Horizontal band of small vugs.
1,328-1,329	Zone of several semicircular seemingly interconnected large vugs.
1,340-1,344	Smooth with no apparent secondary porosity.
1,354-1,464	Smooth with only occasional small vugs.
1,395-1,396	Small cavern (?) extending across the hole.
1,465-1,485	Smooth with no apparent secondary porosity.
1,486-1,525	Smooth with only occasional small vugs.
1,526-1,527	Full-hole and crumbly walled small cavern.

1,578-1,579	Band of small vugs.
1,592.5-1,594	Half-hole small cavern.
1,609-1,619	Coring mark.
1,611.5-1,612	Band of darker colored rock (lithology change?).
1,622-1,626	Smooth with only occasional small vugs.
1,638-1,655	As above.
1,656-1,660	Pitted with small vugs in "honeycomb" pattern.

Interval H Depth 1,682 to 1,863 ft

General borehole shape: Round to slightly angular.

General borehole wall description: Relatively smooth with periodic intervals of discrete vugs and small caverns. Other features include zones of banding and apparent lithology changes (dark patches).

Depth (ft)	Notable Features
1,682-1,691	Smooth wall sparsely pitted with small and medium vugs.
1,692-1,693	Numerous small vugs in "honeycomb" pattern.
1,705	As above.
1,706-1,724	Smooth with little apparent secondary porosity. Occasional dark patches and banding (lithology changes?).
1,725-1,730	Numerous small vugs in "honeycomb" pattern. Coring mark also present.
1,731-1,755	Smooth with little apparent secondary porosity. Some banding and intermittent coring marks.
1,756-1,779	Zone of sparse yet seemingly interconnected small caverns and large vugs spaced throughout a smooth background.
1,780-1,810	Relatively smooth with occasional small vugs and dark regions (lithology changes?).
1,811-1,827	Relatively smooth with numerous dark patches of rock (lithology changes?). Dark patches are generally smooth but sometimes rough and angular, indicating breaking away from host rock during drilling.

1,824.5	Medium vug with apparent water and sediment flowing from it.
1,828-1,863	Numerous dark patches, sometimes angular and broken in appearance. Occasional small caverns and vugs in host rock.
1,833.5-1,835.5	Vertically elongated small cavern.
1,841-1,842	Semicircular small cavern containing rounded, dark colored, small cobble sized rock.
1,844-1,847	Half-hole small cavern of unknown horizontal extent.
1,850.5-1,852	Shallow angular small cavern in light rock surrounded by dark rock (dark rock plucked away by drilling process?).

Interval I — Depth 1,864 to 2,079 ft

General borehole shape: Round.

General borehole wall description: Relatively smooth with periodic small and medium vugs. Occasional vuggier zones and other features as described below.

Depth (ft)	Notable Features
1,864-1,865	Thin, dark, horizontal vug bands on pale rock (lithology change).
1,874-1,878	Consistently pitted with small vugs, some in "honeycomb" pattern.
1,879-1,881	Series of widely spaced, horizontal vug bands approximately 1/2 in. wide (fracture related?).
1,882-1,916	Smooth with few vugs. Some light-colored, nonvuggy banding and coring marks.
1,920-1,962	Fairly consistently pitted with small and few medium vugs.
1,946-1,960	Coring marks.
1,955-1,956	Large semicircular vug.
1,986-2,000	Consistently pitted with small and infrequent medium vugs often in discrete zones.
2,011-2,022	As above with minor banding and coring marks.

2,023-2,043	Lightly pitted with small vugs. Thin banding with slightly darker appearance than background.
2,059-2,077	Granular texture with color change and lightly pitted with small vugs (lithology change?). Some coring marks and thin banding.
2,078-2,079	Deeply pitted with small and medium vugs.

Interval J — Depth 2,080 to 2,205 ft (survey end)

General borehole shape: Angular and irregular.

General borehole wall description: Wall fragmented showing both vertical and horizontal, sharp-edged, fracturelike cracks, crevices, and other features. Wall virtually composed of angular, blocky rock fragments ranging in size from pebbles to boulders. Vug, small cavern, and large cavern-sized openings common throughout the interval.

Depth (ft)	Notable Features
2,080-2,081	Quarter-hole small cavern surrounded by angular blocks.
2,081-2,083	Angular vertical crevice approximately 2 in. wide.
2,085-2,088	Angular 1/4-hole small cavern.
2,096-2,100	Irregularly shaped, full-hole small cavern of varying width with variously sized rock fragments at the base.
2,104-2,105	Relatively smooth and circular, 1/2-hole small cavern.
2,111-2,115	Full-hole small cavern with crumbly walls.
2,117-2,122	Wide, full-hole large cavern with blocky, irregular walls.
2,124	Rock fragment on left side of picture showing apparent fracture development.
2,124-2,134	Half-hole large cavern with angular walls.
2,135-2,140	Apparent vertical fracture approximately 1 to 3 in. wide extending across borehole.
2,149	Very angular wall at roof of opening.
2,150-2,156	Full-hole large cavern of unknown horizontal extent with boulders and other sized rubble at base. One particularly angular boulder.

2,159-2,163	Angular and pitted rock fragments.
2,175-2,176	Half-hole small cavern with linear fracturelike features on left.
2,177-2,187	Full-hole large cavern of unknown horizontal extent. Angular boulders and other rock fragments at the base.
2,188-2,192	Angular boulders forming roof of underlying cavern, or possibly a blockage of the preceding cavern caused by wall collapse and plugging.
2,193-2,205	Full-hole large cavern of varying width (widest width unknown). Large pile of rubble at base consisting of angular to rounded boulders and other sized rock fragments.

Site 2: General Development Utilities Corporation Port Malabar Injection Well Black and White Television Survey

January 18, 1987, depth logged: 0 to 3,000 ft

20-in. diameter casing from 0 to 2,050 ft

30-in. diameter open hole from 2,051 to 2,061 ft

18-in. diameter open hole from 2,062 to 2,515 ft

12.25-in. diameter open hole from 2,516 to 3,000 ft

Summary of Apparent Secondary Porosity Intervals

Interval A — Depth 2,062 to 2,085 ft

General borehole shape: Round.

General borehole wall description: Consistently pitted with small vugs with intervals of dark, irregular medium and large vugs. Horizontal vug bands also present.

Depth (ft)	Notable Features
2,063-2,064	Large and medium rough textured vugs.
2,066.5	Pair of large surficial vugs on opposite sides of wall.
2,067-2,068	Several surficial and vertically elongated medium vugs.
2,068-2,069	Band of large, horizontally elongated, apparently connected, sharp-edged vugs (small cavern?).
2,070-2,071	Thin, dark, horizontal vug bands on pitted wall.

Interval B — Depth 2,086 to 2,116 ft

General borehole shape: Round to irregular.

General borehole wall description: Alternating relatively smooth-walled sections and intervals roughly pitted with a variety of irregular vugs and/or caverns. fracturelike cracks noted especially on smooth-walled sections.

Depth (ft)	Notable Features
2,086-2,088	Roughly pitted with numerous small and medium vugs. Third hole horizontal small cavern also noted.
2,088	Pair of large angular vugs on opposite sides of wall.
2,089	Half-hole horizontal small cavern.
2,090-2,092	Series of irregularly shaped, angular medium and large vugs.
2,092-2,093	Half-hole, irregular, and angular small cavern.
2,095	Thin, horizontal vug band.
2,095-2,096.5	Three vertical cracks approximately 0.5 in. wide (solution enlarged fractures?).
2,097-2,101	Irregularly shaped and angular large cavern with parts of side wall pitted with small vugs.
2,102-2,108	Relatively smooth wall with occasional small and medium vugs, often in horizontal bands.
2,108.5-2,109.5	Horizontal band of deep small and medium vugs.
2,110.5-2,111.5	Large circular vug on smooth wall.
2,112-2,113	Horizontal band of small vugs.
2,114-2,116	Vertical crack approximately 0.75 in. wide, ending in a medium and a large vug.

Interval C   Depth 2,117 to 2,239 ft

General borehole shape: Round to irregular and angular.

General borehole wall description: Blocky, angular, cavernous sections alternating with relatively smooth yet fractured wall intervals.

Depth (ft)	Notable Features
2,118-2,131	Large cavernous region with blocky, angular walls of unknown horizontal extent in places. Parts of wall are pitted with small vugs.
2,132-2,146	Relatively smooth-textured wall, yet intensely fractured and blocky in places. Occasional medium and large vug-sized openings created by fracturing.
2,146.5-2,147.5	Angular, blocky, 1/2-hole small cavern with vertical fractures at base.
2,148,-2,152	Relatively smooth wall with occasional small cracks.
2,153-2,155	Half-hole small cavern on wall pitted with small and medium vugs.
2,156-2,159	Large, blocky, angular cavern of relatively narrow horizontal extent.
2,160-2,179	Relatively smooth wall with occasional vuggy intervals and small vertical cracks.
2,175.5	Dark, thin, horizontal vug band on smooth wall.
2,179-2,226	Rough, angular, blocky, cavernous section of unknown horizontal extent in places. Some surface textures rough and pitted. Extensive cracks noted throughout, especially at base.
2,227-2,237.5	Alternating smooth sections and sections deeply pitted with mainly small and medium vugs. Occasional angular, fracturelike cracks also noted.
2,237.5-2,239	Several vertical fractures leading into a rough, irregular, full-hole, small cavernous area.

Interval D — Depth 2,240 to 2,355 ft

General borehole shape: Round to semi-irregular.

General borehole wall description: Relatively smooth to lightly pitted wall with frequent intervals containing medium and large vugs. Extensive fractured intervals and periodic cavities also present.

Depth (ft)	Notable Features
2,246.5-2,247	Large 1/2-hole surficial vug.
2,249	Band of three circular medium vugs.
2,251.5-2,252	Three-quarter hole, horizontally elongated, large vug.
2,254-2,257	Wall pitted with small and medium vugs.
2,258-2,260	Series of thin, horizontal vug bands and a vertical fracturelike feature approximately 1 inch wide.
2,262.5	Thin, horizontal, dark band (vugs?).
2,267	Several sharp-edged, fracturelike features.
2,268.5-2,270.5	Series of horizontally elongated medium and large vugs.
2,271-2,271.5	Full-hole large cavern.
2,274-2,276	Deeply pitted with mainly small vugs.
2,278-2,283	Wall rough and broken creating small and medium vug-sized openings.
2,286-2,287	Vertical fracture approximately 0.5 in. wide.
2,293-2,295	Deeply pitted with small and some medium vugs.
2,295-2,297.5	Series of large, irregularly shaped, broken vugs with evidence of fracturing at base.
2,299-2,301	Series of nearly vertical fractures approximately 0.5 to 1.5 in. wide.
2,301-2,306	Pitted with irregular small and medium vugs.
2,306-2,307	Series of thin, horizontal vug bands.
2,307-2,309	Pair of vertical "hairline" cracks on opposite sides of wall.
2,311-2,313	Deeply pitted with small and some medium vugs.

2,314-2,315	Several vertical sharp-edged cracks approximately 0.5 to 1 in. wide.
2,322-2,327	Fairly deeply pitted with small and some medium vugs.
2,327-2,328.5	Pair of vertical fractures approximately 1 in. wide on opposite sides of wall.
2,330-2,332	Several parallel and nearly vertical fracturelike features approximately 1 in. wide.
2,333-2,335	Wall has broken brecciated appearance.
2,336	Thin, dark, horizontal vug band.
2,336-2,355	Series of vertical to nearly vertical, continuous sharp-edged fracture pairs ranging in size from approximately 0.5 to 2 in. wide.

Interval E Depth 2,356 to 2,409 ft

General borehole shape: Round to irregular and angular.

General borehole wall description: Alternating broken fractured cavernous intervals and relatively smooth-walled sections with occasional fractures.

Depth (ft)	Notable Features
2,356-2,370	Wall broken, crumbled, and cracked, yet still fairly intact. Wall consists of angular particles ranging in size from pebble to large cobble.
2,371-2,382	Relatively smooth wall with occasional minor vertical fractures.
2,382.5-2,399	Pair of linear vertical fractures approximately 1 in. wide leading into a widely fractured interval with small and medium vug-sized openings on an otherwise smooth wall.
2,400-2,403	Dark, roughly pitted wall.
2,404-2,409	Wall appears totally crumbled (brecciated appearance) with light-colored, angular particles of various sizes in a dark-colored matrix. Some medium and large vug-sized openings are created by the crumbling wall.

Interval F — Depth 2,410 to 2,631 ft

General borehole shape: Round to semi-irregular.

General borehole wall description: Relatively smooth to lightly pitted. Occasional fractures, large and medium vugs, and horizontal vug bands.

Depth (ft)	Notable Features
2,412-2,414	Thin series of horizontal vug bands.
2,415	Pair of large vugs.
2,416-2,419	Pitted with mainly small vugs.
2,419	Series of thin, horizontal vug bands.
2,419-2,430	Relatively smooth with some small surficial vugs.
2,432.5-2,436	Series of short, vertical fracturelike cracks. Picture appears out of focus indicating possible flow and mixing of waters of unlike temperature and/or concentration. Phenomenon ends in cavern at 2,436 ft.
2,436-2,436.5	Horizontally elongated, 3/4-hole small cavern.
2,443-2,446	Sharp-edged crack leading into a series of intensely pitted, thin, horizontal vug bands.
2,446-2,450	Intensely pitted with small and some medium vugs.
2,451-2,452	Series of small vertical cracks.
2,455-2,459	Vertical fracturelike crack on pitted wall.
2,460-2,464	Relatively smooth wall.
2,464.5-2,467	Interval of thin, horizontal vug bands.
2,472	Pair of thin, horizontal vug bands.
2,481-2,496	Deeply pitted with small and some medium vugs. Occasional horizontal vug bands.
2,499-2,507	Series of thin, widely spaced, horizontal vug bands on lightly pitted wall.
2,511-2,520	Picture appears out of focus indicating possible flow and mixing of waters of unlike temperature and/or concentration. Phenomenon ends in cavern at 2,520 ft.

2,515	Change in borehole diameter from 18 to 12.25 in.
2,515-2,519	Wall pitted with small and some medium vugs.
2,519.5-2,520.5	Rough, irregular, full-hole small cavern.
2,521-2,523	Rough and irregularly pitted and mainly small and medium vugs.
2,523.5-2,525	Two pairs of vertical fractures approximately 0.5 to 1 in. wide on irregular background.
2,527-2,531	Fairly intensely pitted with mainly small and some medium vugs.
2,533	High-angle fracturelike feature approximately 0.75 in. wide.
2,534-2,536.5	Picture appears out of focus indicating possible flow and mixing of waters of unlike temperature and/or concentration. Phenomenon ends in rough, irregular, full-hole small cavern at 2,536.5 ft.
2,537	Horizontal crack approximately 1 in. wide.
2,537.5-2,541	Intensely pitted with small and some medium vugs.
2,541-2,543	Picture appears out of focus indicating possible flow and mixing of waters of unlike temperature and/or concentration. Phenomenon ends in dark, fractured region of wall near 2,543 ft.
2,543.5-2,547	Picture appears out of focus indicating possible flow and mixing of waters of unlike temperature and/or concentration.
2,543.5-2,545	Small vertical cracks leading into rough, irregular, 3/4-hole small cavern.
2547	Irregular medium and large rough vugs.
2548.5-2,552	Pitted with irregular and surficial small and medium vugs.
2,554.5-2,555	Full-hole, rough-edged, small cavern.
2,559	Sharp-edged fracturelike feature.
2,561-2,563	Roughly pitted with mainly small and some medium vugs.
2,563	Quarter hole large vug.
2,566-2,572	Roughly pitted with mainly small and some medium vugs. Occasional large vugs and fracturelike features.

2,572-2,594	Relatively smooth wall with periodic small and medium vugs often occurring in horizontal bands. Occasional small, high-angle fractures.
2,595-2,599	Roughly pitted with small, medium, and large vug-sized openings and several vertical, sharp-edged features.
2,602-2,602.5	Rough, 1/2-hole small cavern with broken rock fragments at base.
2,603-2,612	Rough wall with small, medium, and some large vugs. Angular broken features common.
2,612.5	Roughly textured, full-hole small cavern.
2,613-2,626	Pitted with irregular small and medium vugs.
2,626.5-2,627.5	Series of nearly vertical sharp-edged features.

Interval G   Depth 2,632 to 2,809 ft

Note: Substantial suspended solids begin to appear in the water. Cloudiness increases with depth, and visibility decreases with depth until total darkness is encountered near the bottom of the hole.

General borehole shape: Round to irregular.

General borehole wall description: Generally pitted with rough-textured, small, medium, and some large vugs. Caverns and vertical sharp-edged, fracturelike features common.

Depth (ft)	Notable Features
2,632-2,633	Rough, angular, broken, full-hole small cavern.
2,634.5-2,635.5	Rough, angular, broken, 3/4-hole small cavern with evidence of fractures at base.
2,640	Thin, dark, horizontal vug band.
2,647-2,659	Pitted with small and some medium vugs, often in horizontal bands. Some fracturelike features also present.
2,659.5-2,660.5	Rough, irregular, full-hole small cavern.
2,661	Sharp-edged, fracturelike feature.
2,666-2,667	Several vertical fracturelike features approximately 0.75 in. wide.

2,672	Pair of irregularly shaped, rough-edged, medium vugs on opposite sides of wall.
2,674	Two dark, horizontal vug bands approximately 1 in. thick.
2,675	Several rough small and medium vugs.
2,678	Irregular, 1/2-hole, surficial large vug.
2,680-2,683	Interval of thick horizontal vug bands and assorted irregularly shaped small, medium, and large vugs.
2,685	Sharp-edged, 3/4-hole small cavern with vertical fracture extending downward from base.
2,687-2,688	Dark, horizontal vug bands.
2,689-2,692	Deeply pitted with small, medium, and occasional large vugs.
2,693-2,694	Small vertical fracturelike feature on pitted wall.
2,696.5-2,699	Deeply pitted with small and some medium vugs.
2,703-2,704.5	Broken, brecciated, dark-colored wall.
2,705	Circular medium vug.
2,705-2,706	Rough, broken wall.
2,706-2,708	Pitted with small and medium vugs.
2,712-2,721	Series of dark, thin (<1 in. thick), horizontal vug bands on relatively smooth wall.
2,723	Dark, horizontal vug band approximately 3 in. thick (small cavern?).
2,724-2,729	Irregularly pitted with deep small, medium, and occasional large vugs.
2,731-2,736	Series of thin, horizontal vug bands and several short fracturelike cracks.
2,741-2,773	Sparsely pitted with small and some medium vugs on otherwise smooth wall. Occasional thin, horizontal vug bands.
2,774-2,787	Fairly densely pitted with small and medium vugs and thin, dark, horizontal vug bands.
2,788-2,788.5	Rough, irregular, full-hole small cavern.
2,789	Dark, thin, horizontal vug band crossing through a small and medium vug.

2,791	Pair of thin, horizontal vug bands separated by vuggy, cracked rock.
2,793-2,799	Densely pitted with rough, irregular, small and medium vugs.
2,800-2,801	Rough, irregular, 1/2-hole small cavern with abrupt sharp-edged base.
2,802.5-2,804	Irregular, blocky, sharp-edged large cavern with vertical fractures at base.
2,805-2,809	Roughly pitted with small and some medium vugs.

Interval H — Depth 2,810 to 3,000 ft (survey end)

General borehole shape: Round.

General borehole wall description: Fairly consistently pitted with small and some medium vugs. Dark, horizontal layers and vug bands common. Occasional fracturelike features.

Depth (ft)	Notable Features
2,822-2,829	Hole appears to widen into dark bands that grade into an overall dark, granular wall (lithologic change?).
2,830-2,838	Fairly intensely pitted with irregular small and medium vugs.
2,841.5-2,845	As above.
2,849	Thin, horizontal vug band intersecting large, irregular vug. Short, vertical, sharp-edged feature extending down from vug and on opposite wall.
2,852-2,853	Numerous small, sharp-edged, fracturelike features.
2,854-2,855	Gradual horizontal small cavern.
2,859-2,860	Dark, horizontal vug band with vertical fracture extending downward.
2,860-2,871	Pitted with irregular small and medium vugs and dark-banded sections.
2,871	Vertical sharp-edged feature.
2,877-2,879	Numerous dark, horizontal vug bands and small, nearly vertical, sharp-edged features.
2,879-2,881	Deeply pitted with irregular small and medium vugs and horizontal vug bands.

2,882-2,882.5	Wide, vertical, sharp-edged, medium vugs (fracture related?).
2,887-2,887.5	As above.
2,913-2,915	Narrow, vertically elongated, sharp-edged vugs (fracture related?).
2,918-2,918.5	As above.
2,919-2,935	Deeply pitted with rough, irregular, small and medium vugs. Broken, sharp-edged wall appearance in places.
2,935-3,000	Increasing turbidity. Poor visibility. Wall appears to be fairly consistently pitted with small and medium vugs, occasional horizontal vug bands, and dark granular layers.

Site 3: General Development Utilities Corporation North Port St. Lucie Injection Well Color Television Survey

June 26, 1987, depth logged: 1,950 to 3,294 ft.

22-in. diameter casing from 0 to 1,950 ft.

12.25-in. diameter open hole from 1,951 to 3,324 ft.

Summary of Apparent Secondary Porosity Intervals

Interval A — Depth 1,951 to 1,962 ft

General borehole shape: Round to semi-irregular.

General borehole wall description: Fractures and sharp-edged openings present throughout interval. Wall relatively smooth to lightly pitted with small vugs.

Depth (ft)	Notable Features
1,951-1,956	Series of horizontal and vertical fractures separating wall into blocks.
1,957-1,959.5	As above.
1,960-1,961.5	Sharp-edged, small cavern (fracture related?).

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Interval B — Depth 1,963 to 2,161 ft

General borehole shape: Round.

General borehole wall description: Smooth with little or no visible apparent secondary porosity. Occasional small vugs.

Note: Borehole appears very wide; therefore, entire wall is not always clearly visible on video. Water is also fairly turbid.

Depth (ft)	Notable Features
1,963.5	Thin, horizontal vug band.
1,966.5-1,967	As above.
2,056-2,059	Lightly pitted with surficial small vugs.
2,104-2,106	As above.
2,123-2,127	As above.

Interval C — Depth 2,162 to 2,193 ft

General borehole shape: Round.

General borehole wall description: Lightly pitted with small and some medium vugs. Occasional more intensely pitted intervals.

Depth (ft)	Notable Features
2,169-2,169.5	Interval pitted with small vugs.
2,173-2,176	Sparsely pitted with small and occasional medium vugs.
2,183	Horizontal band of circular medium vugs.
2,184-2,186	Sparsely pitted with surficial circular medium vugs.

Interval D — Depth 2,194 to 2,278 ft

General borehole shape: Round to semi-irregular.

General borehole wall description: Intervals of mainly rough, small and some medium vugs on otherwise smooth wall. Periodic large vugs, caverns, and fracturelike features also present.

Depth (ft)	Notable Features
2,196-2,198	Relatively smooth with little or no visible apparent secondary porosity.
2,202	Circular medium vug.
2,210-2,211.5	Vertical, sharp-edged feature approximately 1 in. wide.
2,216-2,223	Roughly pitted with small and medium vugs.
2,227	Horizontal band of medium vugs.
2,228-2,232	Roughly pitted with small and medium vugs.
2,232	Large, smooth, circular vug.
2,233-2,235	Irregular, rough-edged, full-hole small cavern.
2,236-2,237	Series of irregularly shaped small and medium vugs.
2,242.5-2,244	Vertically elongated large vug.
2,245	Horizontal band of medium vugs.
2,255.5-2,260	Series of rough, irregular small and medium vugs.
2,262	Horizontally elongated, 1/2-hole, rough small cavern.
2,267-2,268	Vertically elongated and narrow large vug leading into pitted interval.
2,273	Narrow, rough, full-hole small cavern.
2,274-2,278	Roughly pitted with small and medium vugs.

Interval E Depth 2,279 to 2,406 ft

General borehole shape: Round to irregular.

General borehole wall description: Generally pitted with rough-textured, small, medium, and some large vugs. Caverns and vertical sharp-edged, fracturelike features common.

Depth (ft)	Notable Features
2,279-2,280	Vertically elongated large vug.
2,284.5-2,285	Vertically elongated medium vug leading into large rough vug.

2,285-2,295	Series of rough medium and large vugs on otherwise smooth wall.
2,295.5-2,296.5	Rough, irregular, full-hole small cavern.
2,311.5-2,312.5	Full-hole, cavern-sized, gradual opening.
2,313.5-2,314	Circular large vug.
2,319-2,321	Relatively smooth interval.
2,322-2,323	Series of circular medium vugs.
2,332-2,334	Irregularly shaped, full-hole small cavern with evidence of fracturing.
2,337-2,344	Series of intermittent medium and large circular vugs on otherwise smooth wall.
2,347-2,350.5	Roughly pitted, irregularly shaped, full-hole large cavern of unknown horizontal extent in places.
2,351-2,357	Roughly pitted with mainly small and medium vugs.
2,357-2,357.5	Narrow (<1 in.), vertical fracturelike crack.
2,357-2,359	Two vertically elongated, seemingly interconnected, large vugs.
2,360-2,361.5	Half-hole, roughly pitted small cavern.
2,363-2,367.5	Half-hole, roughly pitted, and irregularly shaped large cavern with vertical fractures at base.
2,368-2,369	Roughly pitted, 1/2-hole small cavern.
2,369.5-2,370	Circular large vug.
2,372-2,374	Vertically elongated series of large vugs.
2,379-2,391	Hole roughly pitted and irregularly shaped. Numerous small, medium, and large vugs, and small caverns.
2,391.5-2,392.5	Circular large vug.
2,396-2,396.5	Narrow, vertical, fracturelike crack.
2,398-2,402	Relatively smooth interval.

Interval F — Depth 2,407 to 2,767 ft

General borehole shape: Round.

General borehole wall description: Smooth with little or no visible apparent secondary porosity. Occasional small and some medium vugs found in discreet intervals.

Note: Borehole appears very wide; therefore, entire wall is not always clearly visible on video. Water is also fairly turbid.

Depth (ft)	Notable Features
2,408-2,413	Lightly pitted with small vugs.
2,450	Pair of irregularly shaped medium vugs on opposite sides of wall.
2,465	Irregularly shaped, surficial medium vug.
2,487-2,498	Lightly pitted with small vugs.
2,501.5	Thin, horizontal band of small vugs.
2,508-2,524	Lightly pitted with small vugs.
2,530-2,571	As above.
2,588-2,620	As above.
2,623-2,643	As above.
2,645-2,648	Pitted with small and medium vugs.
2,652.5-2,654.5	As above.
2,737-2,740	Lightly pitted with small vugs.
2,753-2,767	As above.

Interval G — Depth 2,768 to 2,889 ft

General borehole shape: Round to semi-irregular.

General borehole wall description: Lightly pitted with small and some medium vugs. Occasional nonpitted intervals, heavily pitted intervals, and large vugs.

Depth (ft)	Notable Features
2,782-2,795	Relatively smooth with little or no visible apparent secondary porosity.
2,799-2,800	Irregularly shaped large vug.
2,801-2,819	Relatively smooth with little or no visible apparent secondary porosity.
2,820-2,821	Irregularly shaped large vug.
2,821-2,822.5	Narrow (<1 in.), vertical, fracturelike crack.
2,837-2,838.5	Intensely pitted with small and medium vugs.
2,839-2,865	Relatively smooth with little or no visible apparent secondary porosity.
2,871.5-2,889	As above.

Interval H   Depth 2,890 to 3,009 ft

General borehole shape: Round to irregular and angular.

General borehole wall description: Alternating relatively smooth to lightly pitted sections and intervals roughly pitted with a variety of irregular vugs and/or caverns. Fractures and blocks common in both cavernous and smooth-walled sections.

Depth (ft)	Notable Features
2,891-2,895	Irregularly shaped, full hole, angular large cavern with parts of side wall pitted with small vugs. Distinct vertical fractures approximately 1 in. wide at base.
2,895-2,896.5	Fractures from above continue on otherwise smooth wall.
2,897.5-2,899	Angular, 1/2-hole, small cavern.
2,899.5-2,901	Lightly pitted with small and some medium vugs.
2,901.5-2,907	Relatively smooth with little or no visible apparent secondary porosity.
2,908-2,945	Fractured, blocky, roughly pitted interval with openings ranging from small vug to large cavern in size. Boulders present in some caverns. Distinct vertical fractures present throughout interval.

2,945.5-2,948.5	Relatively smooth wall with two vertical-fracture pairs approximately 2 in. wide.
2,959-2,964	Fractured, blocky interval with openings ranging in size from small vug to small cavern.
2,966-2,969.5	Pair of vertically elongated, fracture-related large vugs leading into a full-hole, angular, small cavern.
2,970-2,979	Relatively smooth to lightly pitted with small and some medium vugs.
2,979.5-2,982.5	Pair of vertical fractures leading into interval pitted with small and medium vugs.
2,983	Half-hole, rough, small cavern.
2,985.5-2,987.5	Pair of vertical fractures approximately 1.5 in. wide.
2,988-2,990.5	Relatively smooth to lightly pitted with small vugs.
2,991-2,2992	Two pairs of vertical fractures approximately 2 in. wide.
2,994.5-3,003	Fractured, blocky, brecciated, angular, cavernous interval. Picture appears out of focus indicating possible flow and mixing of waters of unlike temperature and/or concentration.
3,003-3,009	Relatively smooth to lightly pitted with small vugs.

Interval I — Depth 3,010 to 3,216 ft

General borehole shape: Irregular and angular.

General borehole wall description: Wall generally fragmented showing extensive vertical and horizontal fracturing. Cavern walls pitted and blocky. Occasional nonfractured, yet pitted, intervals also present.

Depth (ft)	Notable Features
3,010-3,015.5	Irregularly shaped, pitted, fractured, blocky, large cavern.
3,017-3,022	Fractured, pitted section.
3,022.5-3,041	Series of irregularly shaped, heavily pitted, fractured, blocky caverns.
3,041.5-3,044.5	Deeply pitted with small, medium, and large vugs.
3,045-3,050.5	Fractured, blocky, pitted, large cavern of unknown horizontal extent.

3,051-3,057.5	Pitted, fractured, blocky interval with various vug-sized openings.
3,058-3,064.5	Large pitted cavern with angular fractured blocks at base.
3,065-3,068	Deeply pitted large cavern.
3,068.5-3,073	Pitted, blocky, fractured interval.
3,073.5-3,083	Irregularly shaped, pitted, angular, large cavern of unknown horizontal extent with blocks at base.
3,083.5-3,091.5	Intensely fractured, brecciated interval.
3,092-3,098	Fractured, blocky, lightly pitted, large cavern with extensive vertical-fracture development near base.
3,098.5-3,099	Large circular vug.
3,101-3,102	Two pairs of nearly vertical fractures approximately 1 in. wide.
3,102.5-3,103	Large, rough, circular vug.
3,104.5-3,105.5	Circular, rough, 1/2-hole, small cavern.
3,106-3,110	Fractured, blocky, angular interval.
3,110.5-3,128	Fractured, blocky, large cavern of unknown horizontal extent.
3,128.5-3,131.5	Large, blocky boulders.
3,132-3,145	Fractured, blocky, pitted, large cavern of unknown horizontal extent.
3,145.5-3,148	Pitted interval with some blocky boulders.
3,148.5-3,155	Fractured, blocky, pitted, large cavern of unknown horizontal extent.
3,155.5-3,163.5	Blocky and pitted with mainly small vugs. Vertical fractures near base of interval.
3,164-3,186	Fractured, blocky, pitted, full-hole cavern of unknown horizontal extent in places.
3,186-3,201.5	Fractured, blocky, pitted, 1/2-hole cavern of unknown horizontal extent in places.
3,202-3,216.5	Fractured, blocky, pitted, full-hole cavern of unknown horizontal extent in places.

3,206	Picture appears out of focus indicating possible flow and mixing of waters of unlike temperature and/or concentration.

Interval J — Depth 3,217 to 3,294 ft (survey end)

General borehole shape: Round to semi-irregular.

General borehole wall description: Generally pitted with small and some medium vugs. Occasional fractured, cavernous intervals.

Depth (ft)	Notable Features
3,217-3,233.5	Deeply pitted with small and medium vugs.
3,334-3,246	Blocky, angular, pitted, fractured, cavernous section.
3,246.5-3,294	Lightly pitted with small and occasional medium vugs.
3,247.5-3,250.5	As above with nearly vertical, pitted, fracturelike features.
3,260.5-3,262	As above.
3,268-3,269	As above.
3,294	Borehole blocked by what appears to be a boulder.

Site 4: United Technologies-Pratt and Whitney Injection Well Color Television Survey

February 5, 1985, depth logged: 1,865 to 3,317 ft.

20-in. diameter casing from 0 to 1,865 ft.

12.25-in. diameter pilot hole from 1,866 to 3,317 ft.

Summary of Apparent Secondary Porosity Intervals

Interval A — Depth 1,866 to 1,999 ft

General borehole shape: Round to semi-irregular.

General borehole wall description: Lightly pitted with small and some medium vugs. Occasional fracturelike features and intensely vuggy sections, especially near bottom of the interval. Water turbid and hole appears wide at top of interval.

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Depth (ft)	Notable Features
1,866-1,916.5	Borehole wide, entire wall not clearly visible. Wall appears to be lightly pitted with small vugs.
1,917-1,918	Series of narrow (<1 in.), vertically elongated medium vugs.
1,927-1,928	As above.
1,932-1,933	Series of nearly vertical, sharp-edged, fracturelike features.
1,935	As above.
1,942-1,944	Deeply pitted with small, medium, and large vugs.
1,946-1,948	As above with evidence of fracturing.
1,950-1,953.5	Vertical fracture approximately 1 in. wide.
1,962-1,965.5	Deeply pitted with small and some medium vugs.
1,971-1,975	Series of narrow, vertical fractures ending in a rough, 1/2-hole, large vug.
1,978-1,979	Two pairs of narrow, vertical fractures on pitted wall.
1,981-1,982	As above.
1,985-1,986	Series of narrow, vertical fractures ending in a deeply pitted interval.
1,989.5-1,991	Several narrow, vertical fractures.
1,991.5-1,994	Deeply pitted with small and medium vugs.
1,996.5	Narrow, horizontal vug band.

Interval B — Depth 2,000 to 2,027 ft

General borehole shape: Angular and irregular.

General borehole wall description: Series of fractured, pitted, cavernous intervals of large horizontal extent.

Depth (ft)	Notable Features
2,000-2,005	Large, pitted, blocky, full-hole cavern with extensive fracturing at base.
2,006-2,008	Small, full-hole, pitted cavern.
2,008.5-2,027	Large, blocky, pitted cavern of unknown horizontal extent with extensive fracturing at base.

Interval C — Depth 2,028 to 2,104 ft

General borehole shape: Round to semi-irregular.

General borehole wall description: Lightly pitted with small and occasional medium vugs. Periodic fractures found throughout the interval. Some large vugs, caverns, and smooth intervals also found.

Depth (ft)	Notable Features
2,032-2,034	Series of small, nearly vertical, fracturelike features on pitted wall.
2,036-2,040	As above with large angular vug at top of interval.
2,042.5-2,043	Pair of angular medium vugs.
2,051	Three medium and roughly circular vugs.
2,054-2,056	Rough, 1/2-hole, small cavern with vertical fractures at base.
2,057.5-2,058.5	Medium vug with vertical fracture extending from base.
2,061-2,085	Relatively smooth with little or no visible apparent secondary porosity.
2,088-2,090	Half-hole, rough, angular, fractured, small cavern.
2,090.5-2,093	Full-hole, rough, angular, fractured, large cavern.

Interval D — Depth 2,105 to 2,270 ft

General borehole shape: Round.

General borehole wall description: Relatively smooth with little or no visible apparent secondary porosity. Entire hole not always clearly visible due to turbidity and wideness of hole.

Depth (ft)	Notable Features
2,117.5-2,124	Lightly pitted with small vugs.
2,140.5-2,154	As above.
2,159-2,161	As above.

Interval E Depth 2,271 to 2,299 ft

General borehole shape: Angular and irregular

General borehole wall description: Series of angular, fractured, pitted, cavernous intervals.

Depth (ft)	Notable Features
2,271-2,273	Half-hole, rough, fractured, small cavern.
2,273.5-2,280	Full-hole, rough, blocky, large cavern ending in a series of distinct vertical fractures.
2,280.5-2,288	Blocky, fractured interval.
2,289-2,296	Full-hole, large cavern with boulders.
2,296.5-2,299	Blocky, fractured interval.

Interval F Depth 2,300 to 2,357 ft

General borehole shape: Round.

General borehole wall description: Circular, discrete, small and medium vugs on otherwise smooth wall. Occasional fractures and smooth intervals.

Depth (ft)	Notable Features
2,300-2,303.5	Several nearly vertical, narrow fractures along with circular vugs.
2,306-2,308	As above.
2,315-2,316	As above.
2,316-2,322	Relatively smooth with little or no visible apparent secondary porosity.
2,325-2,326	Several nearly vertical, narrow fractures along with circular vugs.

2,331-2,334	Relatively smooth with little or no visible apparent secondary porosity.
2,348-2,352	Several nearly vertical, narrow fractures along with circular vugs.
2,353-2,354.5	Half-hole, small cavern with evidence of fracturing at base.

Interval G — Depth 2,358 to 2,721 ft

General borehole shape: Round.

General borehole wall description: Relatively smooth to lightly pitted with small and infrequent medium vugs. Intervals with little or no visible apparent secondary porosity common. Occasional large vugs and dark patches (lithology changes?).

Depth (ft)	Notable Features
2,358-2,360.5	Relatively smooth with little or no visible apparent secondary porosity.
2,428	Circular medium vug.
2,437-2,448	Relatively smooth with little or no visible apparent secondary porosity.
2,456-2,462	As above.
2,466-2,481	As above.
2,521-2,530	Series of irregularly shaped medium and large vugs.
2,530.5-2,535.5	Relatively smooth with little or no visible apparent secondary porosity.
2,538-2,543	As above.
2,547-2,550	Coring mark.
2,553-2,556	Relatively smooth wall with series of dark, nearly circular patches (lithology change?). Patches appear to be "chipped."
2,556.5-2,563.5	Relatively smooth with little or no visible apparent secondary porosity.
2,564-2,565	Large circular vug.
2,573-2,576.5	Relatively smooth with little or no visible apparent secondary porosity.

2,581-2,583	As above.
2,584	Thin, horizontal band of medium vugs.
2,587.5	As above.
2,592-2,597	Fairly deeply pitted with small and some medium vugs.
2,597.5-2,601	Relatively smooth with little or no visible apparent secondary porosity.
2,602	Thin, horizontal band of medium vugs.
2,604-2,644	Relatively smooth wall with series of dark, nearly circular patches (lithology change?). Patches appear to be "chipped" out of wall.
2,644.5-2,670	Relatively smooth with little or no visible apparent secondary porosity.
2,703-2,709	As above.

Interval H Depth 2,722 to 2,881 ft

General borehole shape: Round.

General borehole wall description: Lightly pitted with surficial small and some medium vugs. Nonpitted intervals common. Occasional horizontal vug bands, large vugs, and small caverns.

Depth (ft)	Notable Features
2,722.5-2,723	Horizontal vug band.
2,725.5-2,728	Series of horizontal vug bands.
2,732.5-2,733	Small horizontal cavern.
2,748-2,750	Relatively smooth with little or no visible apparent secondary porosity.
2,760.5-2,764	As above.
2,764.5-2,767	Deeply pitted with small and medium vugs.
2,773-2,778	Relatively smooth with little or no visible apparent secondary porosity.
2,789-2,791	Series of thin (<1 in.), horizontal vug bands.
2,798.5-2,801	Relatively smooth with little or no visible apparent secondary porosity.

2,802-2,803	Series of thin, horizontal vug bands on smooth wall.
2,803.5-2,806	Relatively smooth with little or no visible apparent secondary porosity.
2,810-2,822	As above.
2,822.5-2,825	Deeply pitted with small vugs and one vertically elongated medium vug.
2,825.5-2,833.5	Relatively smooth with little or no visible apparent secondary porosity.
2,835-2,844	As above.
2,845	Circular medium vug on smooth wall.
2,846-2,854	Relatively smooth with occasional thin, horizontal vug bands.
2,854.5-2,858	Deeply pitted with angular small and medium vug-sized openings with evidence of vertical fracturing.
2,858.5-2,868	Relatively smooth with little or no visible apparent secondary porosity.
2,868.5	Circular, shallow medium vug.
2,869-2,875	Relatively smooth with occasional horizontal vug bands.
2,876-2,881	Pair of thin (<0.5 in.), vertical fractures ending in roughly pitted interval.

Interval I Depth 2,882 to 2,940 ft

General borehole shape: Round to semi-irregular and angular.

General borehole wall description: Pitted with rough small, medium, and large vugs. Occasional caverns and fracturelike features.

Depth (ft)	Notable Features
2,882-2,884	Full-hole small cavern.
2,884-2,885	Vertical, sharp-edged, fracturelike features on pitted wall.
2,892.5-2,893.5	Quarter-hole, rough, circular, large vug of unknown horizontal extent.
2,902-2,908	Series of nearly horizontal, sharp-edged, fracturelike features.

2,912-2,913.5	Roughly pitted, full-hole, small cavern.
2,914-2,920	Roughly pitted, slightly blocky, full-hole, large cavern of unknown horizontal extent.
2,920-2,924	Pair of vertical fractures approximately 1 in. wide.
2,924.5-2,931	Fractured, blocky, pitted interval.
2,931.5-2,940	Pitted with mainly small vugs with evidence of fracturing.

Interval J   Depth 2,941 to 3,028 ft

General borehole shape: Irregular and angular.

General borehole wall description: Series of pitted, broken, angular, cavernous intervals of unknown horizontal extent in places. Occasional non-cavernous, yet pitted and fractured, sections.

Depth (ft)	Notable Features
2,940-2,949.5	Blocky, pitted, fractured interval. Wall composed almost entirely of broken rock fragments.
2,950-2,952	Half-hole, roughly pitted, small cavern with fractures and rock fragments at base.
2,953-2,964	Roughly pitted with small, medium, and large irregular, "crumbly" vugs.
2,965-2,975	Half-hole, large, pitted, irregular cavern.
2,976-2,978	Half-hole, blocky, small cavern.
2,980-3,007	Full-hole, large, fractured, blocky cavern of unknown horizontal extent and containing numerous boulders.
3,008-3,019	As above with numerous fractures and boulders at base.
3,019.5-3,020.5	Fractured smooth wall.
3,021-3,028	Fractured, full-hole, large cavern.

Interval K Depth 3,029 to 3,317 ft (survey end)

General borehole shape: Round to semi-irregular and angular.

General borehole wall description: Relatively smooth to lightly pitted with mainly small and some medium vugs. Solution enlarged fractures and intensely fractured, small cavernous sections common throughout.

Depth (ft)	Notable Features
3,029-3,040	Relatively smooth wall with extensive vertical and horizontal apparently solution-enlarged fractures.
3,040.5-3,041.5	Roughly pitted, 1/4-hole, small cavern.
3,042-3,043.5	As above.
3,044-3,053	Relatively smooth to lightly pitted wall with evidence of solution-enlarged fractures.
3,053.5-3,064.5	Lightly pitted with small vugs.
3,065-3,068	Relatively smooth to lightly pitted wall with evidence of solution-enlarged fractures.
3,068.5-3,069.5	Blocky, full-hole, small cavern.
3,070-3,080	Relatively smooth wall with extensive vertical and horizontal apparently solution-enlarged fractures.
3,080.5-3,101	Relatively smooth to lightly pitted with occasional elongated, sharp-edged, vuggy features (fracture related?).
3,101.5-3,102.5	Two large, wide (approximately 2 in.), horizontal, sharp-edged, vuggy features (fracture related?).
3,103-3,109	Relatively smooth to lightly pitted with occasional elongated, sharp-edged, vuggy features (fracture related?).
3,110-3,114	Series of large, wide (approximately 2 in.), horizontal, sharp-edged, vuggy features (fracture related?).
3,114.5-3,144	Relatively smooth to lightly pitted with occasional elongated, sharp-edged, vuggy features (fracture related?).
3,145-3,156	Lightly pitted with small vugs.
3,157-3,159	Pair of narrow, vertical fractures.

3,160-3,205	Relatively smooth to lightly pitted with occasional elongated, sharp-edged, vuggy features (fracture related?).
3,206-3,217	Series of vuggy, apparently solution-enlarged fractures (vertical and horizontal) on an otherwise smooth wall.
3,217.5-3,222	Relatively smooth to lightly pitted with occasional elongated, sharp-edged, vuggy features (fracture related?).
3,222.5-3,237	Series of vuggy, apparently solution-enlarged fractures (vertical and horizontal) on an otherwise smooth wall.
3,237-3,243	Relatively smooth to lightly pitted with occasional elongated, sharp-edged, vuggy features (fracture related?).
3,244-3,251	Series of vuggy, apparently solution-enlarged fractures (vertical and horizontal) on an otherwise smooth wall.
3,252-3,300	Relatively smooth to lightly pitted with occasional elongated, sharp-edged, vuggy features (fracture related?).
3301	Pair of rough, circular, medium vugs.
3,302-3,317	Lightly pitted with small and occasional medium vugs.

*U.S. Government Printing Office: 1992 — 631-117/60002