Types of Secondary Porosity of Carbonate Rocks in Injection and Test Wells in Southern Peninsular Florida

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CONVERSION FACTORS, ADDITIONAL ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.40	millimeter
foot (ft)	0.3048	meter
foot per minute (ft/min)	0.3048	meter per minute
mile (mi)	1.609	kilometer
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:

$$°C = (°F-32)/1.8$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD 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.

Additional Abbreviations

mg/L = milligrams per liter

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ABSTRACT

The types of secondary porosity present in carbonate injection intervals and in the overlying carbonate rocks were determined at 11 injection well sites and 3 test well sites in southern peninsular Florida. The hydrogeologic system consists of a thick sequence of carbonate rocks overlain by clastic deposits. Principal hydrogeologic units are the surficial aquifer system, the intermediate aquifer system or the intermediate confining unit, the Floridan aquifer system, and the sub-Floridan confining unit.

The concept of apparent secondary porosity was used in this study because the secondary porosity features observed in a borehole television survey could have been caused by geologic processes as well as by drilling activities. The secondary porosity features identified in a television survey were evaluated using driller's comments and caliper, flowmeter, and temperature logs. Borehole intervals that produced or received detectable amounts of flow, as shown by flowmeter and temperature logs, provided evidence 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. Features associated with interconnected secondary porosity were identified as effective secondary porosity.

Fracture porosity was identified as the most common type of effective secondary porosity and was observed predominantly in dolomite and dolomitic limestone. Cavity porosity was the least common type of effective secondary porosity at the study sites. In fact, of the more than 17,500 feet of borehole studied, a total of only three cavities constituting effective secondary porosity were identified at only two sites. These cavities were detected in dolomite rocks. Most apparent cavities were caused by drilling-induced collapse of naturally fractured borehole walls. Also, fractures usually were observed above and below cavities. The majority of vugs observed in the television surveys did not constitute effective secondary porosity.

No effective secondary porosity was evident in the limestone or dolomitic limestone in the 300-foot interval immediately above the injection interval at six sites on the southeastern coast of Florida. Injection wells commonly are cased through the 300-foot interval. Fractures or cavities that contribute to effective secondary porosity may be present in this interval, but were not detectable with the methods used. Widely dispersed, interconnected fractures or cavities can be present beyond the rock column intersected by the borehole and can provide local pathways for vertical migration of injected wastewater or the displaced saltwater. In the interval between the top of the Floridan aquifer system and a point 300 feet above the top of the injection interval, fractured rocks having effective secondary porosity were observed at five of six sites along the southeastern coast.

Borehole characteristics usually are related to the drilling characteristics of the rock type. In limestone, borehole diameters are consistently larger than the bit diameter whereas in dolomite, borehole diameters are intermittently larger than the bit diameter. The large borehole diameters associated with dredging probably are caused by

the presence of intensively fractured dolomite which collapses during drilling.

INTRODUCTION

Large volumes of wastewater are disposed of through injection wells completed in permeable carbonate rocks underlying peninsular Florida. Since about 1970, cavity porosity has been assumed to be the principal type of secondary porosity in most of the carbonate injection intervals. The apparently dense dolomite above and within injection intervals has been assumed to contain no vertically interconnected secondary porosity and to comprise a confining unit that restricts vertical flow of injected wastewater. More recently, however, the validity of these secondary porosity assumptions has been questioned. Application of a recently developed approach that uses borehole television surveys and other borehole data to analyze secondary porosity produced a different interpretation of secondary porosity. The approach was applied at four injection well sites along the eastern coast of Florida (Safko and Hickey, 1992), and the accrued data were used to develop two important interpretations. One interpretation is that effective secondary porosity of the highly transmissive dolomites within the Floridan aquifer system at the sites is predominantly fracture porosity. Effective secondary porosity has features that are spatially distributed and interconnected beyond the immediate vicinity of a borehole and are related to geologic processes. The second interpretation is that cavity porosity in video images of those dolomites is commonly only apparent porosity caused by drilling-induced collapse of fractured borehole walls. These dolomites traditionally have been called the "boulder zone" in southeastern Florida (Safko and Hickey, 1992).

Characterizing the types of secondary porosity of carbonate injection intervals and of overlying carbonate rocks is important for improving the understanding of the hydrogeology of the Floridan aquifer system and for determining the potential for movement of injected wastewater in the subsurface. In 1990, the U.S. Geological Survey, in cooperation with the Florida Department of Environmental Protection (then the Department of Environmental Regulation), began a study to characterize the type of secondary porosity in carbonate injection intervals and in overlying carbonate rocks at additional sites in peninsular Florida. The descriptive terminology and methodology used in this report comes directly, with little modification, from Safko and Hickey (1992). A more detailed discussion of the descriptive terminology and methodology is presented in that report.

Purpose and Scope

The principal types of secondary porosity in carbonate injection intervals and in the overlying carbonate rocks at 11 subsurface injection sites and 3 test sites in southern peninsular Florida are described in this report. Secondary porosity is characterized as either vug porosity, fracture porosity, or cavity porosity and was determined by using borehole television surveys and other borehole data, including driller's records and caliper, flowmeter and temperature logs. Only visible porosity (macroporosity) is described.

The study area includes southern peninsular Florida south of Melbourne Beach on the eastern coast and Old Tampa Bay on the western coast (fig. 1). Sites were selected on the basis of geographic coverage and the availability of borehole television surveys. The report contains comprehensive borehole interpretations, records of wells, secondary porosity classifications, generalized hydrogeologic sections, and detailed descriptions of television surveys of boreholes. Most of the data were obtained from published reports prepared by consulting engineers.

Acknowledgements

The author gratefully acknowledges the assistance provided by personnel of the Florida Department of Environmental Protection. Special thanks are given to Cathy Conrardy, Rich Deuerling, Marian Fugitt, Joe Haberfeld, Peggy Highsmith, Joe May, Al Mueller, and Judy Richtar who provided valuable information and extensive hydrogeologic data.

Previous Investigations

Safko and Hickey (1992) developed a preliminary approach for using borehole data and television surveys to characterize secondary porosity of carbonate rocks in the Floridan aquifer system on the southeastern coast of Florida. The methodology developed in that report was applied in this study.

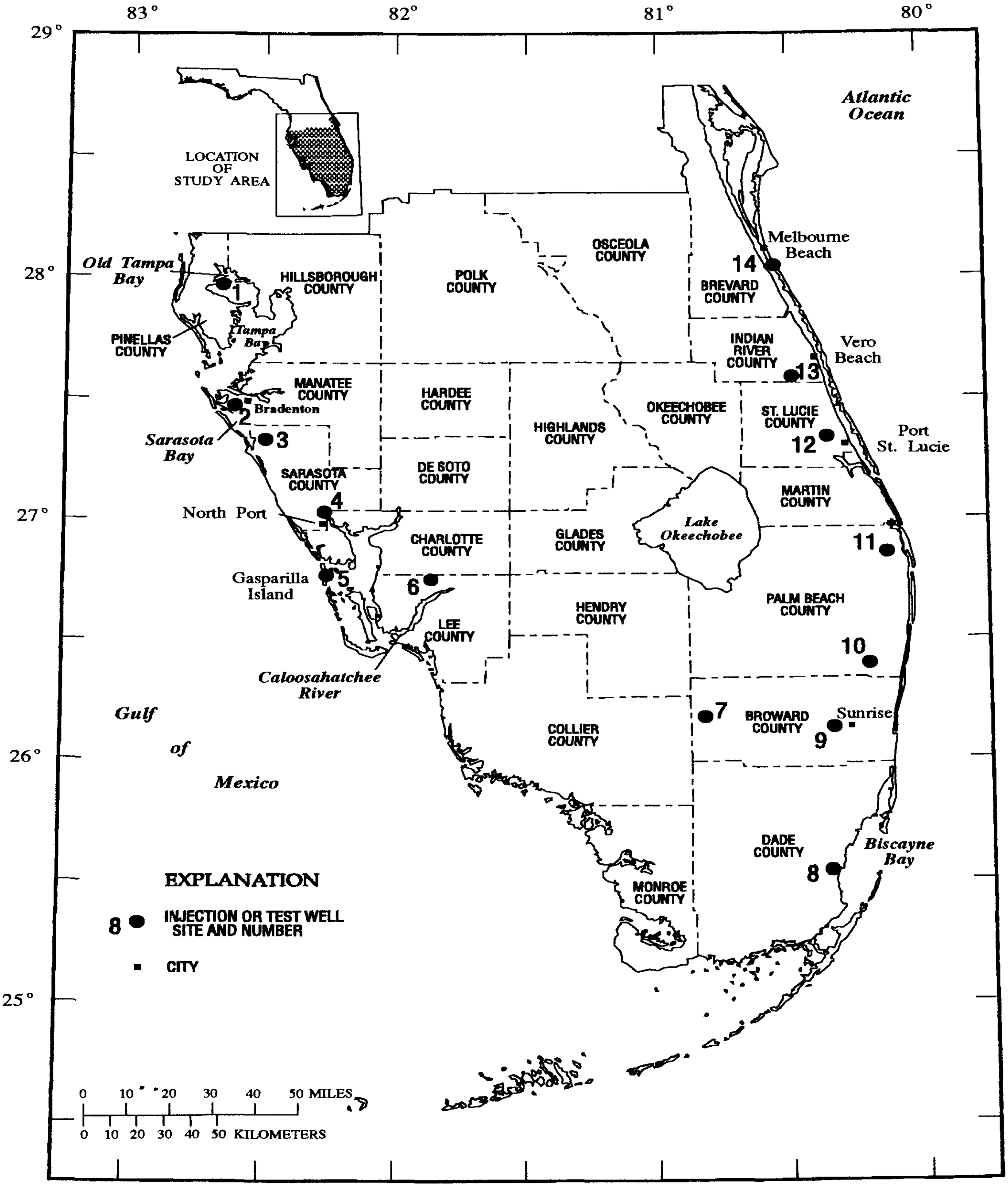


Figure 1. Locations of injection and test well sites.

Peninsular Florida has been described in numerous county, state, and regional hydrologic and geologic investigations. Parker and others (1955) described the water resources of southeastern Florida. Hickey (1982) reported on the hydrogeology and results of wastewater injection tests in Pinellas County. A description of the hydrogeologic framework of the study area was included by Miller (1986) in his regional description of the Floridan aquifer system. Meyer (1988) provided detailed hydrogeologic data on the Alligator Alley test well in Broward County. Tibbals (1990) presented detailed information on the Floridan aquifer system in east-central Florida that included parts of the study area for this report. Hutchinson (1992) assessed hydrogeologic conditions and provided information on wastewater injection in southwestern Sarasota and western Charlotte Counties.

Several engineering reports on test-injection wells contain descriptions of hydrogeologic conditions at the specific study sites used in this report. The engineering reports included those by CH2M Hill, Inc. (1977; 1979; 1984; 1985; 1986; 1987; 1988; 1989); Dames and Moore, Inc. (1985); Geraghty and Miller, Inc. (1986); Seaburn and Robertson, Inc. (1986); and Post, Buckley, Schuh, and Jernigan, Inc. (1988; 1989). The Southeastern Geological Society (1986) included southeastern Florida in its description of the hydrogeologic units of Florida. Deep Venture, Perry Florida, provided video tapes showing downhole images of boreholes at each study site.

HYDROGEOLOGIC SETTING

The hydrogeologic system in peninsular Florida consists of a thick sequence of carbonate rocks overlain by clastic deposits (fig. 2). Principal hydrogeologic units are the surficial aquifer system, the intermediate aquifer system or the intermediate confining unit, the Floridan aquifer system, and the sub-Floridan confining unit (Southeastern Geological Society, 1986).

The surficial aquifer system consists of Pliocene to Holocene age intermixed sand, clay, shell, and phosphate gravel with stringers of limestone and marl. The water table lies within the surficial aquifer system,

SYSTEM	SERIES	FORMATION	HYDROSTRATIGRAPHIC UNIT	USE OF ZONE
QUATERNARY	Holocene	Terrace deposits	Surficial aquifer system (includes Biscayne aquifer)	Source of domestic and municipal water supplies
	Pleistocene	Miami Oolite Key Largo Limestone Anastasia Formation Fort Thompson Formation Caloosahatchee Marl		
TERTIARY	Pliocene	Tamiami Formation	Intermediate aquifer sysytem or Intermediate confining unit	
	Miocene	Hawthorn Group		Source of reverse-osmosis feed and irrigation supplies
	Oligocene	Suwannee Limestone	Floridan aquifer system	
	Eocene	Ocala Limestone Avon Park Formation Oldsmar Formation		Injection zone for sewage and reverse-osmosis wastewater
	Paleocene	Cedar Keys Formation	Sub-Floridan confining unit	Unused except for one site injecting industrial wastewater
CRETACEOUS AND OLDER				

Figure 2. Hydrogeologic framework in southern Peninsular Florida. (Modified from Southeastern Geological Society, 1986; Swancar and Hutchinson, 1992; and Hutchinson, 1992.)

which in most places is unconfined, but beds of low permeability can cause semiconfined or locally confined conditions in the deeper parts of the aquifer system. The surficial aquifer system ranges in thickness from less than 10 ft in many areas to more than 300 ft.

The aquifer supplies water for irrigation, industrial, and municipal use where the surficial aquifer system is sufficiently thick and where other sources of ground water are limited. This is especially true in southeastern Florida where the highly permeable rocks of the surficial aquifer system constitute the Biscayne aquifer and are the principal source of water for several large municipalities (Parker and others, 1955).

Underlying the surficial aquifer system is the intermediate aquifer system or the intermediate confining unit. The intermediate aquifer system includes all rocks that lie between and collectively retard the exchange of water between the overlying surficial aquifer system and the underlying Floridan aquifer system. Generally, these rocks consist of fine-grained clastic deposits interlayered with carbonate strata of the Miocene and younger Series. In some areas, poor-yielding to nonyielding strata are present, and in those areas, the term "intermediate confining unit" is applied. In other areas, one or more low-to moderate-yielding aquifers could be interlayered with relatively impermeable confining beds and the term "intermediate aquifer system" is used to describe this situation. The aquifers within this system contain water under confined conditions (Southeastern Geological Society, 1986).

The top of the intermediate aquifer system or the intermediate confining unit coincides with the base of the surficial aquifer system. The thickness of the intermediate aquifer system or the intermediate confining unit ranges from less than 50 ft in the northwestern part of the study area to about 1,000 ft in northern Lee County (Miller, 1986).

The Floridan aquifer system underlies the intermediate aquifer system or the intermediate confining unit throughout the study area. The Floridan aquifer system consists of a sequence of carbonate rocks ranging from Paleocene to early Miocene in age. The top of the Floridan aquifer system is the contact between the carbonate sequence and overlying clastic sediments. These overlying clastic sediments could 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 underlying Paleocene evaporate beds.

The altitude of the top of the Floridan aquifer system ranges from near sea level in the northwestern part of the study area to about 1,100 ft below sea level in the southern part of the study area (fig. 3). The thickness of the Floridan aquifer system ranges from about 2,300 ft in northern Brevard County to more than 3,500 ft in southern Pinellas, western Manatee, and central Sarasota Counties (Miller, 1986).

The Floridan aquifer system may be confined, semiconfined, or unconfined depending upon the presence or absence of overlying material having low hydraulic conductivity. Several low permeability zones, known as middle confining units (Miller, 1986), separate the aquifer system into the Upper and Lower Floridan aquifers.

Dolomites that have high transmissivity and contain saline water are present in the Upper and Lower Floridan aquifers in southwestern Florida and in the Lower Floridan aquifer in southeastern Florida. These dolomites are used for the injection of liquid wastes in a number of places. In southeastern Florida, these highly transmissive rocks are known as the "boulder zone" because they possess drilling characteristics associated with "boulders" (Kohout, 1967). Traditionally, these dolomites have been assumed to have cavity porosity as the predominant porosity type. However, Safko and Hickey (1992) observed that, at four injection well sites in eastern Florida, fracture porosity, as opposed to cavity porosity, was the dominant type of secondary porosity in the "boulder zone." Within the study area, the altitude of the top of the "boulder zone" ranges from about 2,000 ft below sea level in northern Brevard County to about 3,300 ft below sea level in southwestern Monroe County (Miller, 1986). The "boulder zone" is not present in the western part of the study area according to Miller (1986).

The sub-Floridan confining unit underlies the Floridan aquifer system throughout the study area, as well as throughout peninsular Florida. The unit is primarily a sequence of anhydrite beds interlayered with low permeability carbonate rocks of Paleocene age and older Series. The presence of the unit limits the depth of active ground-water circulation. The top of the unit is marked by the sharp permeability contrast with the permeable carbonates of the Floridan aquifer system (Southeastern Geological Society, 1986).

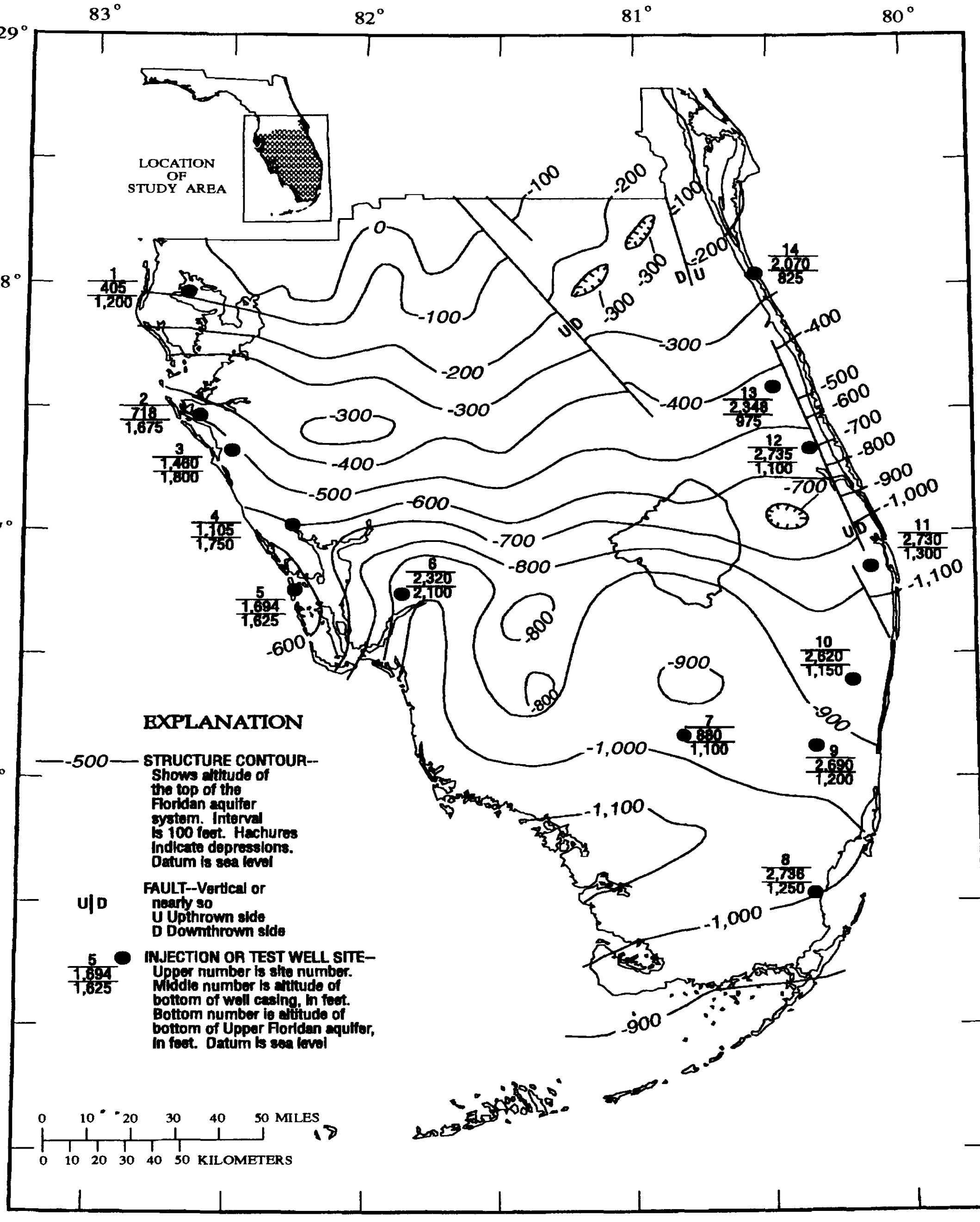


Figure 3. Altitude of the top of the Floridan aquifer system in southern peninsular Florida. (Adapted from Miller, 1986).

BOREHOLE TELEVISION SURVEYS

The borehole television camera systems utilize a "fast spreading" lens capable of producing a downhole image with a maximum horizontal (peripheral) field of view of approximately 3 ft and a maximum vertical field of view of approximately 2.5 ft, depending on water clarity and light conditions. Some distortion in the actual size and shape of borehole features is inherent in the images produced by the camera system. Theoretically, the images within the brightest part of the borehole wall are the least subject to distortion. Therefore, in this study, borehole features are described and measured as they were viewed in the most highly illuminated interval (Safko and Hickey, 1992). Borehole television surveys were conducted by Deep Venture.

Descriptive Terminology and Borehole Observations

The descriptive terminology and methodology used in this report comes almost directly, with little modification, from Safko and Hickey (1992). Secondary or postdepositional porosity was defined by Choquette and Pray (1970, p. 218) as any porosity in a rock created after final deposition. All secondary porosity features viewed 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 can be related either to drilling activities or to geologic processes. When visually observed secondary porosity features, or macroporosity, are interpreted to be spatially distributed and interconnected beyond the immediate vicinity of a borehole, these features are considered to be related to geologic processes and are called "effective secondary porosity" (Safko and Hickey, 1992).

The descriptive terminology used for both apparent and effective secondary porosity classifications are given in table 1. Three principal terms are utilized: vug porosity, cavity porosity, and fracture porosity. Photographs of borehole television images of the three porosity types are shown in figure 4. Vug porosity is used in this report to describe pores that are smaller than cavity porosity, but are large enough to be seen in a borehole television survey. 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 effective secondary porosity classifications

[>, greater than]

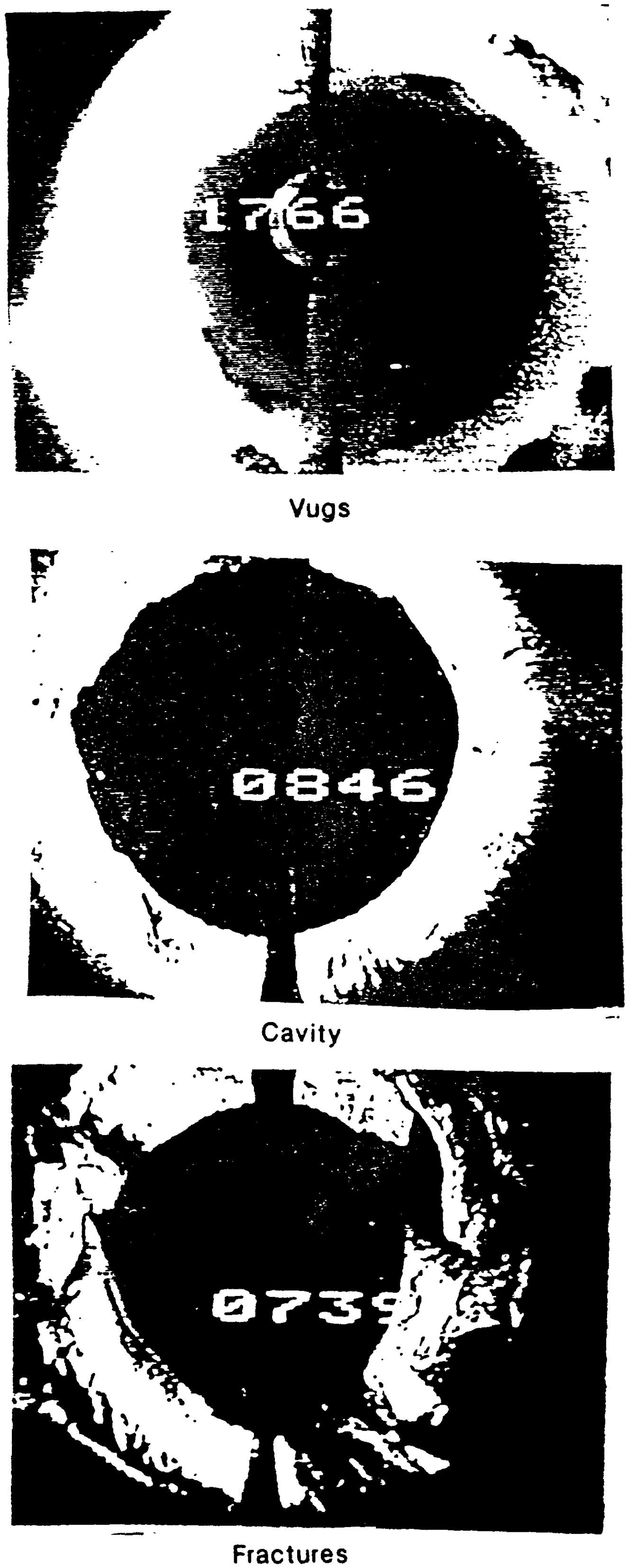
Classification	Size of largest dimension (feet)
Vug porosity	
Very small	0.01 - 0.05
Small	0.05 - 0.21
Medium	0.21 - 0.42
Large	0.42 - 0.84
Cavity porosity	
Small	0.84 - 2.00
Large	> 2.00
Fracture porosity	Fracture apertures generally were too small to be visually estimated.

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. Alternatively, because a drill bit breaks a rock into small chips, variations in rock mechanical properties, such as the size, shape, arrangement, and hardness of adjacent constituents, could result in a borehole wall with mechanically created, deep surface depressions. All porosity features related to drilling activities have a spatial distribution restricted to the immediate vicinity of a borehole, whereas porosity features related to geologic processes have a spatial distribution extending beyond the immediate vicinity of a borehole (Safko and Hickey, 1992).

Cavity porosity observed in a television survey of carbonate rocks appears as large voids in a borehole wall. The horizontal dimension of these voids usually is so large that the borehole wall completely disappears from view in a video image because the maximum horizontal field of view of the television cameras is about 3 ft. These large voids could have been caused by dissolution of the carbonate rocks. Alternatively, because a drill bit penetrates a rock by mechanically disrupting it, borehole diameters much larger than the bit diameter could be produced in rocks that have little cement between grains and in rocks that are intensively fractured or shattered. If wide enough, these mechanically disrupted intervals appear as voids in the borehole wall. As discussed in a following section of the text, many of the cavities observed in the television surveys studied for this report were in heavily fractured intervals that had unstable borehole walls.

Fracture porosity is used in this report to describe voids that occur along breaks in a unit of rock. Viewed in a television survey, fracture porosity appears as narrow, linear features separating blocks of nonfractured rock. The width of a typical fracture aperture viewed in a television survey generally is so small that it cannot be measured reliably. Vertical and oblique fracture directions appear predominant, even though determining fracture orientation is difficult when using television survey techniques.

Fracture porosity observed in a borehole can be related not only to stresses in rocks caused by tectonic deformation but also to stresses in rocks caused by



NUMBER INDICATES DEPTH OF BOREHOLE PHOTOGRAPH, IN FEET BELOW LAND SURFACE

Figure 4. Types of secondary porosity. (Photographs from video tapes made by Deep Venture, Perry, Fla.)

drilling activities. Because a drill bit rotates and exerts a downward force in order to penetrate a rock, the stresses related to the bit torque and downward force can fracture brittle crystalline rock that is typical of dolomite within the Floridan aquifer system. In addition to these drilling stresses, changes in the pre-existing stress field caused by the removal of rock from the borehole (Hubbert and Willis, 1972) is another factor that can cause fractures to develop immediately adjacent to the borehole (Safko and Hickey, 1992).

In addition to the porosity terms discussed above, a number of common generic textural terms are used to describe the overall shape and notable features of boreholes viewed in a television survey. Descriptive modifiers include among others, the terms round, irregular, rough, smooth, angular, and blocky. A combination of the porosity terms in table 1, along with relevant descriptive modifiers, is essential for describing the character of the secondary porosity visible in the television surveys.

Apparent Secondary Porosity Logs

Apparent secondary porosity logs were constructed for each well at the study sites on the basis of examination and interpretation of borehole television surveys. The logs are shown on the comprehensive borehole interpretation figures (figs. 5-18). Because of the scale of the figures and the large depth intervals, the porosity logs are generalized. The following three porosity types are represented on the logs: vug, cavity, and fracture. Distinctions between vug sizes could not be made at the given scale. Porosity symbols on the apparent and effective secondary porosity logs represent the predominant (not necessarily the only) porosity types observed at those depths. Porosity features are described more thoroughly in the television survey summaries in the appendix.

GEOLOGIC, DRILLING, AND BOREHOLE GEOPHYSICAL DATA

Geologic, drilling, and borehole geophysical data at each of the sites include 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 the comprehensive borehole interpretation diagrams (figs. 5-18). Stratigraphic and lithologic descriptions provide information about the relative age and types of rocks penetrated during drilling. The boreholes in the carbonate rocks were drilled using the air-reverse rotary technique. The drill rod is rigged as an air-lift pump in this drilling technique. The native formation water enters the drill rod through the drill bit and acts as the drilling fluid to entrain rock cuttings and bring them to the surface.

A log of driller's comments provided information about drilling events. Driller's comments included: (1) no reported problems, (2) bit drop, and (3) dredging. A bit drop occurs when a drill bit encounters cavity porosity that has a diameter greater than the bit diameter. A bit drop indicates that the encountered cavity porosity predates drilling of the borehole; therefore, the cavity porosity would be related to geologic processes. Alternatively, if a bit drop is not reported, then no cavity porosity was encountered during drilling (Safko and Hickey, 1992).

Dredging refers to the removal of rock fragments from a borehole before drilling can continue. Dredging is required as a consequence of 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 possibility, the driller lifts the drill bit from the bottom of the hole until native water circulation returns to levels observed before the borehole wall collapsed. Removal of the rock fragments at the bottom of the borehole (dredging) is necessary before drilling can continue (Safko and Hickey, 1992). Dredging was reported at many of the study sites, particularly during drilling through fractured dolomites in the lower part of the Floridan aquifer system.

Noteworthy events that can occur during drilling that are not shown in the comprehensive borehole interpretation diagrams include loss of circulation of drilling fluids, flow of water above land surface or casing, and interception of water-producing intervals that yield water only when the borehole is pumped. Commonly salt or mud is added to the well to stop the well from flowing. These incidents usually are noted in the discussion of effective secondary porosity characterization for each of the study sites.

Caliper logs provided information about the diameter of a borehole and its variation with depth. Caliper logs can be used to corroborate interpretations based on bit drop and dredging information because the borehole diameter commonly is larger than the drill bit diameter in depth intervals for which bit drop or dredging events were recorded.

Flowmeter logs provided information on the vertical movement of water in boreholes and information on depth intervals of inflow during pumping or natural flow and depth 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 are related to geologic processes. Stationary and continuous flowmeter measurements can be used to interpret borehole outflow or inflow. Stationary measurements are preferred because they are not influenced by flowmeter movement.

Temperature logs provided additional information on intervals of borehole outflow and inflow. In a theoretical borehole with no vertical flow either in the borehole or in the formation, water temperature increases 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 flow into or out of the borehole.

METHODOLOGY FOR CHARACTERIZATION OF EFFECTIVE SECONDARY POROSITY

Interpretation of effective secondary porosity in the carbonate rocks at each of the study sites was based upon an intercomparison between apparent secondary porosity features and the driller's comments and caliper, flowmeter, and temperature logs. The intercomparison procedures included the following steps (Safko and Hickey, 1992): (1) the borehole television survey was examined to identify "apparent" secondary porosity in intervals as being vug, fracture, or cavity porosities; (2) all of the other individual logs were compiled and the driller's comments log was compared with the apparent secondary porosity and caliper logs to determine whether 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 commonly is relatively large and usually is seen in the television survey and caliper log as such; (3) the depth intervals producing or receiving measurable amounts of flow were identified using the flowmeter and temperature logs; (4) as a final step, all of the confirmed observations and associations between the different data were used to interpret effective secondary porosity types.

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

In the following site interpretations, the assumption was made that when a depth interval with one type of porosity (vug or fracture) indicates flow into or out of the borehole in only a fraction of the interval, all of the secondary porosity in that depth interval was spatially interconnected and, thus, related to geologic processes. This assumption for characterizing depth intervals of effective porosity was based on information derived from a study of a fractured dolomite unit in west-central Florida (Hickey, 1982).

A limitation of the approach used in this report for characterizing effective secondary porosity is that it precludes 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 might be common in the Floridan aquifer system (Halley and Schmoker, 1983), but those intervals are not identified as being different from intervals with deep surface depressions related to drilling activities (Safko and Hickey, 1992).

CHARACTERIZATION OF EFFECTIVE SECONDARY POROSITY AT INDIVIDUAL SITES

By using the methodology described in the previous section, the principal types of secondary porosity in carbonate injection zones and the overlying rocks were determined for 11 subsurface injection sites and 3 test sites in the southern part of peninsular Florida (fig. 1). Well-construction data and other miscellaneous data are summarized for each site in table 2. Data for each site are summarized graphically in comprehensive borehole interpretation diagrams (figs. 5-18). Detailed descriptions of porosity features that were observed in the television survey are included in the appendix.

Hydrogeologic unit depths were estimated from lithologic logs at each site. In most cases, the data closely correlates with data reported by Miller (1986). However, for site 5 (Gasparilla Island), the hydrogeologic unit data correlate with data presented by Hutchinson (1992) and, for site 7 (Alligator Alley), the data correlate with data reported by Meyer (1988). In the discussions below, all depths are given in feet below sea level unless otherwise noted.

Site 1--Clearwater East Test Well, Pinellas County

Site 1 (fig. 1) is in Pinellas County at the Clearwater East Pollution Control Facility along the shore of Old Tampa Bay. The site is in section 16, township 29 south, range 16 east. Land surface is about 2 ft above sea level.

Test well A-1 was drilled at site 1 (fig. 5, table 2) to determine the feasibility of injecting secondary treated municipal sewage effluent. The site, however, was never used as an injection well site. Drilling of the test well began in February 1979 and was completed in April 1979. The well was drilled to a depth of 1,323 ft and cased to 405 ft. Data collected during drilling and testing of the test well were summarized by Seaburn and Robertson, Inc. (1986).

The test well at the Clearwater East site penetrated three principal aquifers. The uppermost unit, the surficial aquifer system, is about 15 ft thick and is composed mostly of quartz sand and shell fragments (fig. 5, col. A). Underlying the surficial aquifer system is a deposit of limestone and clay about 50 ft thick that constitutes the intermediate confining unit. The Floridan aquifer system underlies the intermediate confining unit and consists of carbonate rocks with little or no clastic sediments. The upper part of the Floridan aquifer system, penetrated by the test well from 63 to 618 ft, is mainly a limestone section. The lower part of the Floridan aquifer system, penetrated by the test well from 618 to 1,323 ft, is a sequence of dolomitic

Table 2. Records of injection and test wells used in this study in southern peninsular Florida

[Site number, site number as shown in fig. 1; Well number, identification number of well as stored in USGS files; IW, injection well; Depth, depth of well below sea level; Casing, depth of lowermost casing below sea level, in feet; Di., diameter of lowermost casing, in inches; Interval studied, in feet below sea level; Bottom temp., bottom hole temperature as measured by temperature logging probe, in degrees Fahrenheit; a, plugged back to land surface; p, well pumping; s, well static (not pumping, flowing, or injecting); f, well flowing; u, unknown status of well but possibly injecting]

Site number	Well number	Well name	County	Depth (feet)	Casing	Diameter	Interval studied	Altitude (feet)	Bottom temperature (°F)	Data source
1	275735082422501	Clearwater East Test Well A-1	Pinellas	1,323(a)	405	8	405-1,314	2	84.4 (p)	A
2	272709082373001	Manatee Co. SW Explor. Well	Manatee	1,676	718	8	718-1,676	20	89.0 (p)	B
3	271853082280901	Atlantic Utilities IW	Sarasota	1,882	1,460	12	470-1,882	17	98.0 (s)	C
4	270058082152501	North Port IW	Sarasota	3,190	1,105	14	550-3,190	10	111.4 (p)	D
5	264525082153501	Gasparilla Island IW	Lee	1,918	1,694	6	1,694-1,889	8	93.6 (s)	E
6	264358081525401	North Fort Myers IW	Lee	2,583	2,320	12	2,320-2,540	20	101.0 (s)	F
7	261016080492601	Alligator Alley Test Well	Broward	2,796	880	16	880-2,796	15	76.5 (f)	G
8	253033080200401	Miami Dade IW No. 5	Dade	3,190	2,736	20	1,784-3,190	5	63.5 (p)	H
9	260738080202501	Sunrise IW No. 1	Broward	3,190	2,690	24	1,780-3,182	10	57.0 (p)	I
10	262333080121201	Palm Beach Co. System 9 IW	Palm Beach	3,280	2,620	24	2,620-3,280	20	62.0 (s)	J
11	265118080075501	Seacoast Utilities IW	Palm Beach	3,300	2,730	24	2,000-3,300	20	65.3 (p)	K
12	272009080210301	North Port St. Lucie IW	St. Lucie	3,309	2,735	12	1,935-3,279	15	75.5 (p)	L
13	273505080285701	Hercules Inc. IW	Indian River	2,977	2,348	10	1,650-2,977	25	94.2 (u)	M
14	280230080325001	South Beaches IW	Brevard	2,906	2,070	20	264-2,195	10	---	N

A - Seaburn and Robertson, 1986
B - CH_2 M Hill, Inc., 1984
C - Post, Buckley, Smith, Schuh, and Jemigan, Inc., 1989
D - CH_2 M Hill, Inc., 1988
E - Geraghty and Miller, 1986
F - Post, Buckley, Smith, Schuh, and Jemigan, Inc., 1988
G - Meyer, 1988
H - CH2M Hill, Inc., 1977
I - CH2M Hill, Inc., 1985
J - CH2M Hill, Inc., 1986
K - CH2M Hill, Inc., 1989
L - CH2M Hill, Inc., 1987
M - CH2M Hill, Inc., 1979
N - Dames and Moore, 1985

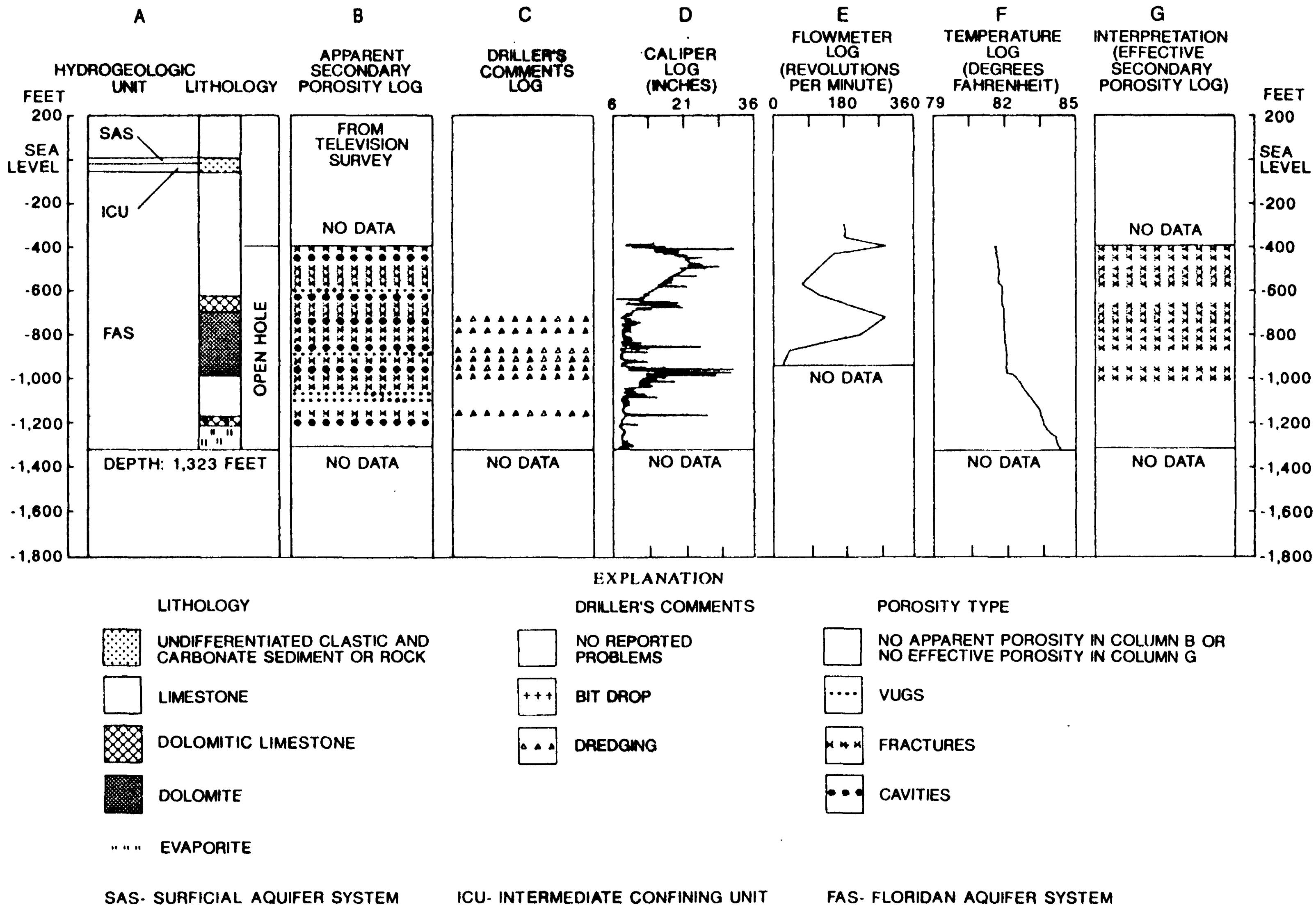


Figure 5. Comprehensive borehole interpretation at site 1--Clearwater East test well, Pinellas County.

limestone, dolomite, and limestone. Thin deposits of evaporite (gypsum or anhydrite) were observed between depths of 1,168 and 1,188 ft, 1,218 and 1,268 ft, and 1,318 to 1,323 ft (the bottom of the test well). The dissolved-solids concentration of water exceeded 10,000 mg/L at a depth of about 100 to 140 ft (Seaburn and Robertson Inc., 1986).

A borehole television survey was run on the open interval of the well from 405 to 1,317 ft. The date of the television survey was not confirmed but most likely was April 10, 1979. Visibility was good except from 1,016 to 1,043 ft and in several intervals below 1,191 ft. The apparent secondary porosity log (fig. 5, column B; appendix) shows that vug, fracture, and cavity porosity types often were observed in the borehole television survey. Vugs were observed predominantly from 590 to 653 ft; from 885 to 916 ft; and from 1,043 to 1,077 ft. Fractures and cavities were observed predominantly from 405 to 466 ft; from 500 to 515 ft; from 542 to 590 ft; from 653 to 885 ft; and from 916 to 1,043 ft. A combination of vugs, fractures, and cavities were observed from 1,077 to 1,167 ft. Secondary porosity was not observed below 1,167 ft, except for one large cavity at 1,208 ft. In most intervals where cavities were observed, fractures were observed immediately above and below the cavities. The camera stopped on a pile of boulders at a depth of 1,317 ft.

The daily drilling reports and the geolograph did not indicate the occurrence of a drill bit drop during drilling of the well. As shown in the driller's comments log (fig. 5, column C), dredging was reported from 720 to 735 ft; at 780 ft; from 871 to 907 ft; from 933 to 1,000 ft; and at 1,156 ft. The driller reported that circulation was lost at a depth of about 423 ft.

A caliper log was run on March 13, 1979, after the well had been drilled from 405 to 1,323 ft with a 7.87-in.-diameter drill bit (fig. 5, column D). Borehole diameters much larger than the bit diameter occurred consistently between 405 and 717 ft and between 947 and 1,043 ft, primarily in limestone and dolomitic limestone. Borehole diameters much larger than the bit diameter also occurred intermittently between 853 and 880 ft; at 925 ft; at 1,085 ft; and between 1,161 and 1,167 ft, mostly in dolomite. These intermittent wide areas generally are associated with the dredging reported in the driller's comments log and with the cavities observed in the television survey.

Flowmeter and temperature logs were run on March 13, 1979, when the well was open from 405 to 1,323 ft and being pumped at a rate of 725 gal/min (fig. 5, columns E and F). The flowmeter log, constructed from stationary measurements, was run only above 933 ft because of a partial blockage in the borehole below that depth. The flowmeter and temperature logs indicate that borehole inflow occurred from 423 to 447 ft; from 495 to 500 ft; from 559 to 575 ft; from 657 to 679 ft; from 720 to 870 ft; from 971 to 981 ft; and possibly from 1,256 to 1,260 ft.

Because no drill bit drops were reported, all reported cavities and those observed in the borehole television survey are interpreted to have been caused by mechanical disruption during drilling. Interpretation of the flowmeter and temperature logs in terms of borehole flow indicates the fracture secondary porosity between 405 and 466 ft; 500 and 515 ft; 542 and 590 ft; 653 and 885 ft; and 950 and 998 ft is spatially distributed and interconnected beyond the immediate vicinity of the borehole and, thus, is interpreted to be effective secondary porosity and related mainly to geologic processes. The above interpretations are shown in the effective secondary porosity log (fig. 5, column G). Possible borehole inflow was identified in the interval from 1,256 to 1,260 ft, but no secondary porosity is characterized. Porosity in this interval possibly may be composed of pores too small to be visible in the television survey.

Site 2--Manatee County Southwest Exploratory Well, Manatee County

Site 2 (fig. 1) is in Manatee County, in the southwest quarter of section 8, township 35 south, range 17 east, about 0.5 mi east of Sarasota Bay. An exploratory well was drilled at site 2 (fig. 6, table 2) to determine the feasibility of injecting secondary treated effluent at the Manatee County Utilities Department's Southwest Wastewater Treatment Plant near Bradenton. Later, a 1,690-ft-deep injection well, cased to 1,057 ft, was drilled approximately 2.7 mi northwest of the exploratory well. Data for the exploratory well were used in this report because of the availability of the television survey. Drilling of the exploratory well began in December 1983 and was completed in January 1984. The well was drilled to a depth of 1,676 ft and cased to 718 ft. Land surface is about 20 ft above sea level. Data collected during drilling and testing of the exploratory well are summarized in a report by CH2M Hill, Inc. (1984).

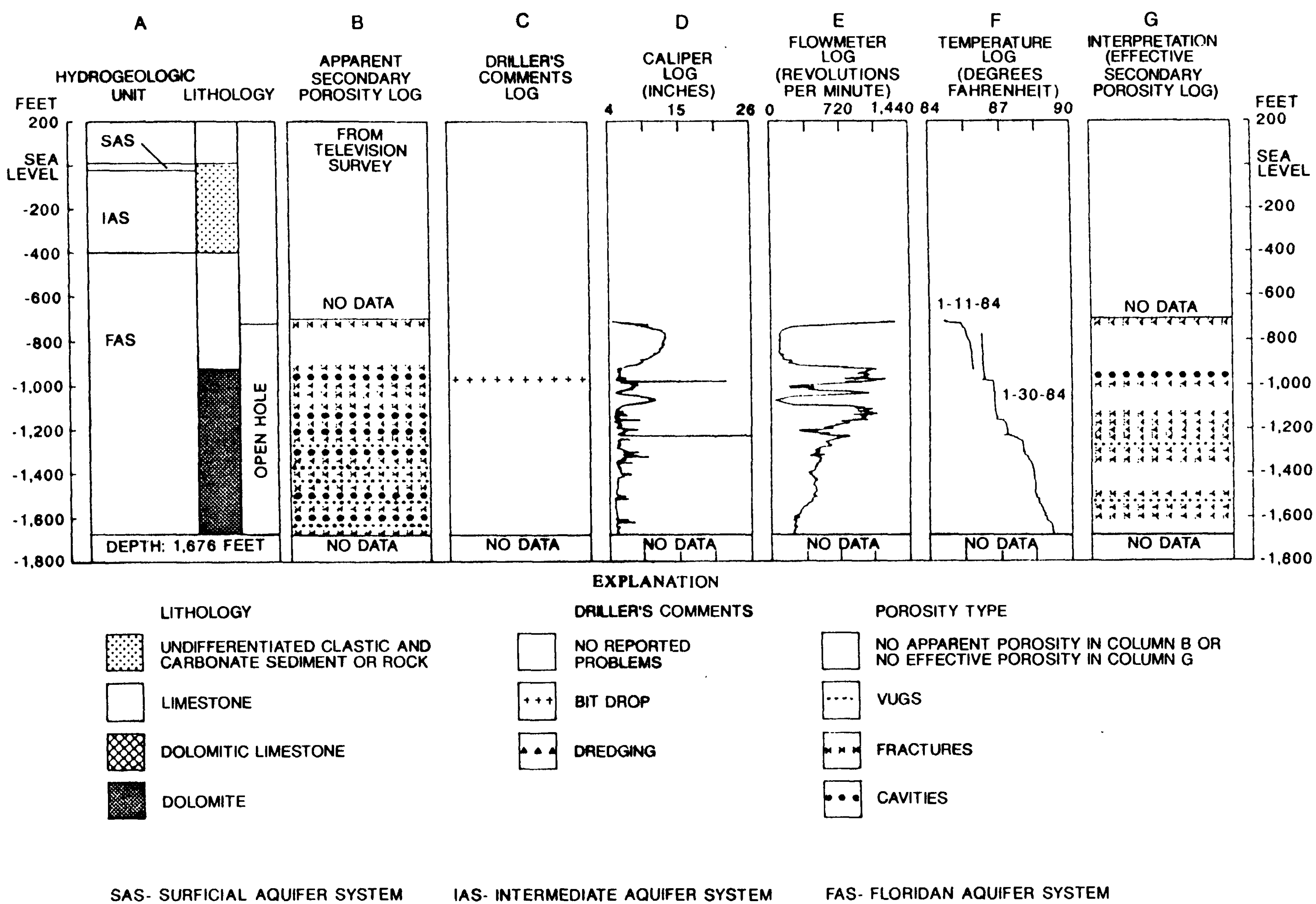


Figure 6. Comprehensive borehole interpretation at site 2--Manatee County Southwest exploratory well, Manatee County.

The exploratory well at the Manatee County site penetrated three principal aquifers. The uppermost unit, the surficial aquifer system, is about 45 ft thick and is composed mostly of sand (fig. 6, column A). Underlying the surficial aquifer system is a sequence of alternating sand, shell, clay, and limestone beds about 375 ft thick that constitutes the intermediate aquifer system.

The Floridan aquifer system underlies the intermediate aquifer system. The upper part of the Floridan aquifer system, penetrated by the test well from 400 to 933 ft, is predominantly limestone. The lower part of the Floridan aquifer system, penetrated by the exploratory well from 933 ft to the bottom of the borehole at 1,676 ft, is composed of dolomite. The dissolved-solids concentration of water exceeded 10,000 mg/L at a depth of 1,013 to 1,053 ft.

A borehole television survey was run on the open interval of the exploratory well from 718 to 1,676 ft. Visibility generally was good. The apparent secondary porosity log (fig. 6, column B; appendix) shows that vug, fracture, and cavity porosity types were identified in the borehole television survey. Vugs were present intermittently throughout the borehole, but were observed predominantly from 1,263 to 1,287 ft. Fractures were observed predominantly from 722 to 733 ft; from 926 to 959 ft; from 973 to 985 ft; from 1,029 to 1,040 ft; and from 1,096 to 1,103 ft. Large cavities were observed from 979 to 980 ft and from 1,226 to 1,231 ft. Numerous cavities and fractures were observed from 1,115 to 1,263 ft; from 1,287 to 1,353 ft; from 1,500 to 1,514 ft; and from 1,557 to 1,622 ft. Combinations of numerous vugs and fractures were observed from 1,353 to 1,500 ft; from 1,514 to 1,557 ft; and from 1,640 to 1,676 ft, the bottom of the borehole. In most intervals where cavities were observed, fractures also were observed immediately above and below the cavities. Most of the borehole was observed to be round and smooth except in areas where there were numerous fractures. In these areas, the borehole was irregular, rough, and angular.

The daily shift reports from CH2M Hill, Inc. (1984), do not indicate the occurrence of a drill bit drop. However, page 3-1 in the report states that "drilling became much more difficult after "dropping into a hole" at approximately 1,000 ft below the rotary table" (or 973 ft below sea level). Consequently, the driller's comments log (fig. 6, column C) indicates that a drill bit drop occurred at 973 ft. No dredging was reported in the daily shift reports; however, these reports did not contain much detail.

A caliper log was run on January 30, 1984, after the well was drilled from 718 to 1,676 ft with a 7.87-in.-diameter drill bit (fig. 6, column D). Borehole diameters much larger than the bit diameter occurred consistently between 727 and 908 ft and are associated with the limestone in this interval. Also, borehole diameters are consistently much larger than the bit diameter between 1,048 and 1,088 ft and are associated with dolomite in this interval. Many of the cavities observed in the television survey are associated with the intermittent large borehole diameters shown in the caliper log, especially in the lower section of the borehole below 1,129 ft where fractured dolomite occurs. Much of this interval, as discussed below, has fractures related to geologic processes.

A temperature log was run on January 11, 1984, when the well was open from 718 to 933 ft and being pumped at a rate of 55 gal/min (fig. 6, column F). Flowmeter and temperature logs were run on January 30, 1984, in conjunction with the caliper log when the well was open from 718 to 1,676 ft (fig. 6, columns E and F). The well was pumped at an unreported rate while being logged. The flowmeter and temperature logs indicate that borehole inflow occurred from 720 to 745 ft; from 969 to 983 ft; from 1,157 to 1,161 ft; from 1,228 to 1,252 ft; and from 1,513 to 1,625 ft. The well may not have been pumped at a large enough rate to interpret flow intervals accurately at the deeper depths.

The reported drill bit drop from 979 to 980 ft correlates closely to a large cavity observed in the borehole television survey at 979 ft. The caliper log shows a large increase in borehole diameter, and the temperature log shows borehole inflow near this depth. Interpretation of the flowmeter and temperature logs in terms of borehole flow indicates the fracture secondary porosity between 720 and 745 ft is effective secondary porosity. Interpretations also indicate the cavity secondary porosity between 979 and 980 ft and the vug and fracture secondary porosities between 958 and 992 ft; 1,129 and 1,353 ft; and 1,500 and 1,622 ft are effective secondary porosities. Conversely, because no other drill bit drops were reported, all other reported cavities and those observed in the borehole television survey are interpreted to have been caused by mechanical disruption during drilling. The above interpretations are shown in the effective secondary porosity log (fig. 6, column G).

Site 3--Atlantic Utilities Injection Well, Sarasota County

Site 3 (fig. 1) is in Sarasota County at the Atlantic Utilities Brentwood Wastewater Treatment Plant. The site is in the northwest quarter of section 35, township 36 south, range 20 east in the northwestern part of Sarasota County. Land surface is about 17 ft above sea level.

Drilling of the exploratory well at site 3 began in January 1986 and was completed in March 1986. The well, used as a monitor well, was drilled to a depth of 1,807 ft and then plugged from 1,220 to 1,410 ft. An injection well was drilled about 50 ft from the exploratory well. Drilling of the injection well at site 3 (fig. 7, table 2) began in July 1988 and was completed in November 1988. The injection well was drilled to a depth of 1,882 ft with the lowermost 422 ft left uncased as a receiving interval for treated municipal wastewater. All hydrogeologic data used for interpretations at this site were obtained from the injection well. Television borehole surveys were used from the exploratory well and the injection well. Data collected during drilling and testing of the exploratory and injection wells are summarized in a report by Post, Buckley, Schuh, and Jernigan, Inc. (1989).

The injection well at the Atlantic Utilities site penetrated three principal hydrogeologic units. The uppermost unit is a sand and shell deposit about 22 ft thick that constitutes the surficial aquifer system (fig. 7, column A). Underlying the surficial aquifer system is a sequence of alternating sand, clay, dolosilt, and limestone beds about 435 ft thick that constitutes the intermediate aquifer system.

The Floridan aquifer system underlies the intermediate aquifer system. The upper part of the Floridan aquifer system, penetrated by the injection well from about 440 to about 930 ft, is predominantly limestone. The lower part of the Floridan aquifer system, penetrated by the injection well from about 930 to 1,882 ft, is mainly a dolomite and dolomitic limestone section. Gypsum and anhydrite are present intermittently from about 1,780 ft to the bottom of the injection well at 1,882 ft. Some evaporite (gypsum) also was observed from about 1,300 to 1,370 ft. The dissolved-solids concentration of water exceeded 10,000 mg/L at a depth of about 1,300 ft.

A borehole television survey was not run on the open interval of the injection well prior to installation of the final casing. However, a television survey was run on the open interval of the nearby exploratory-monitor well from 180 to 1,460 ft on February 7, 1986. Also, a borehole television survey was run on the final open interval of the injection well from 1,460 to 1,882 ft on December 12, 1988. Visibility was fair throughout most of the borehole, but was poor from 517 to 925 ft.

The apparent secondary porosity log (fig. 7, column B; appendix) shows that vug, fracture, and cavity porosity types were identified in the borehole television survey. Vugs were present throughout the borehole, but were observed predominantly from 400 to 470 ft and from 1,855 to 1,882 ft. Vugs filled with what appears to be gypsum were observed from 1,788 to 1,847 ft. Fractures were observed predominantly from 481 to 515 ft; from 1,035 to 1,037 ft; from 1,206 to 1,215 ft; from 1,318 to 1,370 ft; from 1,460 to 1,591 ft; and from 1,604 to 1,753 ft. Cavities were observed intermittently from 196 to 289 ft; at 515, 1,050, and 1,060 ft; intermittently from 1,318 to 1,370 ft; and at 1,492, 1,552, 1,575, 1,590, 1,676, and 1,712 ft. In most intervals where cavities were observed, fractures also were observed immediately above and below the cavities. The borehole shape was mostly round and smooth, but was irregular and rough in areas where there were numerous fractures.

The driller's comments log (fig. 7, column C) indicates that dredging occurred in the dolomites from 1,280 to 1,310 ft. Post, Buckley, Schuh, and Jernigan, Inc. (1989), reported that circulation was lost while drilling at a depth of 413 ft.

A caliper log was run on September 9, 1988, after the well had been drilled from 470 to 1,416 ft with a 12.25-in.-diameter drill bit. A second caliper log was run on November 30, 1988, after the well had been drilled from 1,460 to 1,882 ft with a 12-in.-diameter bit. Both caliper logs are shown in figure 7, column D. Borehole diameters much larger than the bit diameter occurred in limestone between 530 and 700 ft; between 780 and 930 ft; and between 1,130 and 1,205 ft. Borehole diameters also are much larger in the interval between 1,274 and 1,290 ft. This interval contains dolomite, which, as discussed below, has fractures related to geologic processes, and also, as mentioned above, is in the interval in which dredging was reported.

Because the upper 1,460 ft of the borehole television survey was run on the nearby exploratory-monitor well and not on the injection well, this television survey is difficult to correlate with the caliper log of the injection well for the upper 1,460 ft of the borehole. However, the large cavity observed in the borehole television survey at 1,050 ft could be associated with the large borehole diameter shown in the caliper log run on September 9, 1988.

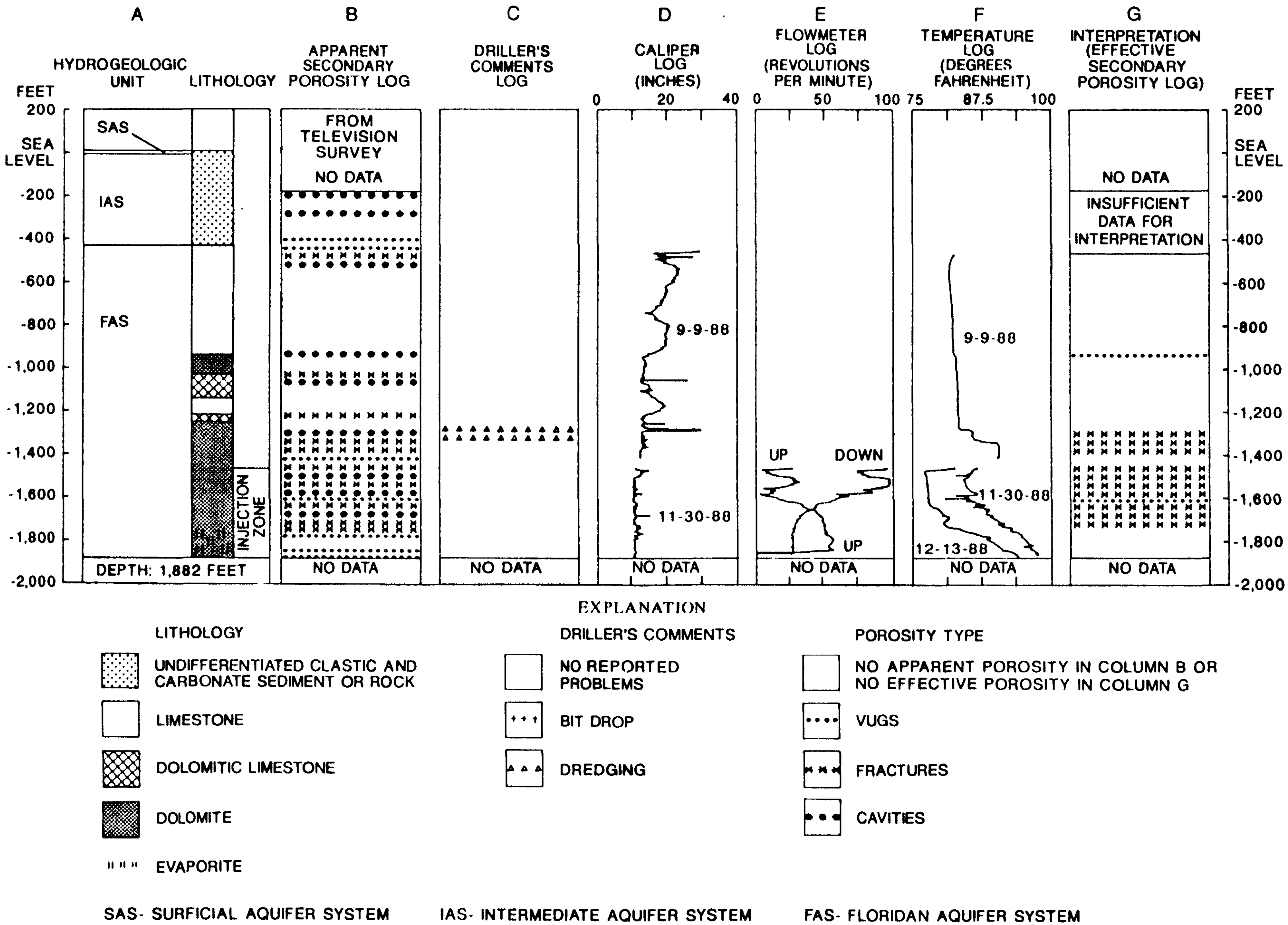


Figure 7. Comprehensive borehole interpretation at site 3--Atlantic Utilities injection well, Sarasota County.

Similarly, the cavities observed at 1,492, 1,575, and 1,676 ft in the borehole television survey of the injection well on December 12, 1988, are associated with the relatively larger borehole diameters shown in the caliper log run on the injection well on November 30, 1988. The large borehole diameters from 1,274 to 1,290 ft are associated with the dolomite dredging reported to have occurred within that interval.

Continuous flowmeter logs were run on November 30, 1988, when the well was open from 1,460 to 1,882 ft and being pumped at 500 gal/min (fig. 7, column E). A log was run while the meter was moving down at 27 ft/min and another log was run while the meter was moving up at 57 ft/min. The flowmeter log shows that most of the borehole inflow occurred from 1,460 to 1,655 ft. A temperature log was run on September 9, 1988, when the well was open from 470 to 1,416 ft and when no withdrawal or injection occurred in the well (fig. 7, column F). The log shows that some internal flow occurred in the intervals from 925 to 942 ft and from 1,284 to 1,350 ft.

Two temperature logs were run when the well was open from 1,460 to 1,882 ft (fig. 7, column F). One was run on November 30, 1988, 1 day after the well had been developed at 790 gal/min for 5 hours. The other log was run on December 13, 1988, 2 days after injecting 2 Mgal/d of 75 °F pond water for 24 hours. The temperature log run after the injection test showed cooler water in the borehole from 1,460 (bottom of the casing) to 1,655 ft, indicating that this interval of the borehole had received the cooler injection water during the test. Thus, this interval can be interpreted as a flow interval.

Because no drill bit drops were reported or shown in the geolograph record, all reported cavities and those observed in the borehole television surveys are interpreted to have been caused by mechanical disruption during drilling. Interpretation of the flowmeter and temperature logs in terms of borehole flow indicates that the vug and fracture secondary porosities between 925 and 942 ft; between 1,284 and 1,380 ft; and between 1,460 and 1,720 ft are effective secondary porosities. The above interpretations are shown in the effective secondary porosity log (fig. 7, column G).

Site 4--North Port Injectin Well, Sarasota County

Site 4 (fig. 1) is in Sarasota County, 2.5 mi south of the North Port Wastewater Treatment Plant. The site is in the northwestern corner of section 12, township 40 south, and range 20 east. Land surface elevation is about 10 ft above sea level.

Drilling of the injection well at site 4 (fig. 8, table 2) began in January 1987 and was completed in August 1987. The injection well was drilled to a depth of 3,190 ft with the lowermost 2,085 ft left uncased as a receiving interval for secondary treated municipal wastewater. Data collected during drilling and testing of the injection well are summarized in a report by CH2M Hill, Inc. (1988).

The injection well at the North Port site penetrated three principal hydrogeologic units. The uppermost unit is a sand and shell deposit about 75 ft thick that constitutes the surficial aquifer system (fig. 8, column A). Underlying the surficial aquifer system is a sequence of alternating sand, shell, clay, sandstone, and limestone beds about 485 ft thick that constitutes the intermediate aquifer system.

The Floridan aquifer system underlies the intermediate aquifer system. The upper part of the Floridan aquifer system, penetrated by the injection well from 550 to 1,060 ft, is primarily limestone. The lower part of the Floridan aquifer system, penetrated by the injection well from 1,060 to 3,190 ft, is primarily dolomite and dolomitic limestone. Evaporite, primarily in the form of gypsum nodules, is present intermittently from about 1,880 ft to the bottom of the section penetrated by the injection well at 3,190 ft. The dissolved-solids concentration of water exceeded 10,000 mg/L at a depth of about 540 to 590 feet.

A borehole television survey was run on the open interval of the injection well from 550 to 3,090 ft. Visibility was good. A television survey was not available for the bottom 100 ft of the borehole. The apparent secondary porosity log (fig. 8, column B; appendix) shows that vug, fracture, and cavity porosity types were identified in the borehole television survey. Vugs were present throughout the borehole, but were observed predominantly from 550 to 820 ft; from 1,545 to 1,950 ft; and from 2,617 to 3,090 ft; which was the last interval of the television survey. Vugs filled with gypsum were observed as discontinuous, concentric bands in the borehole wall below 1,880 ft. Above 1,880 ft, open vugs oriented in similar concentric bands were observed. Dissolution of the gypsum may have caused these open vugs. Fractures were observed predominantly from 665 to 670 ft; from 774 to 790 ft; at 965 ft; from 1,120 to 1,545 ft; and from 1,790 to 1,823 ft. Fractures also were observed from 2,983 to 3,001 ft

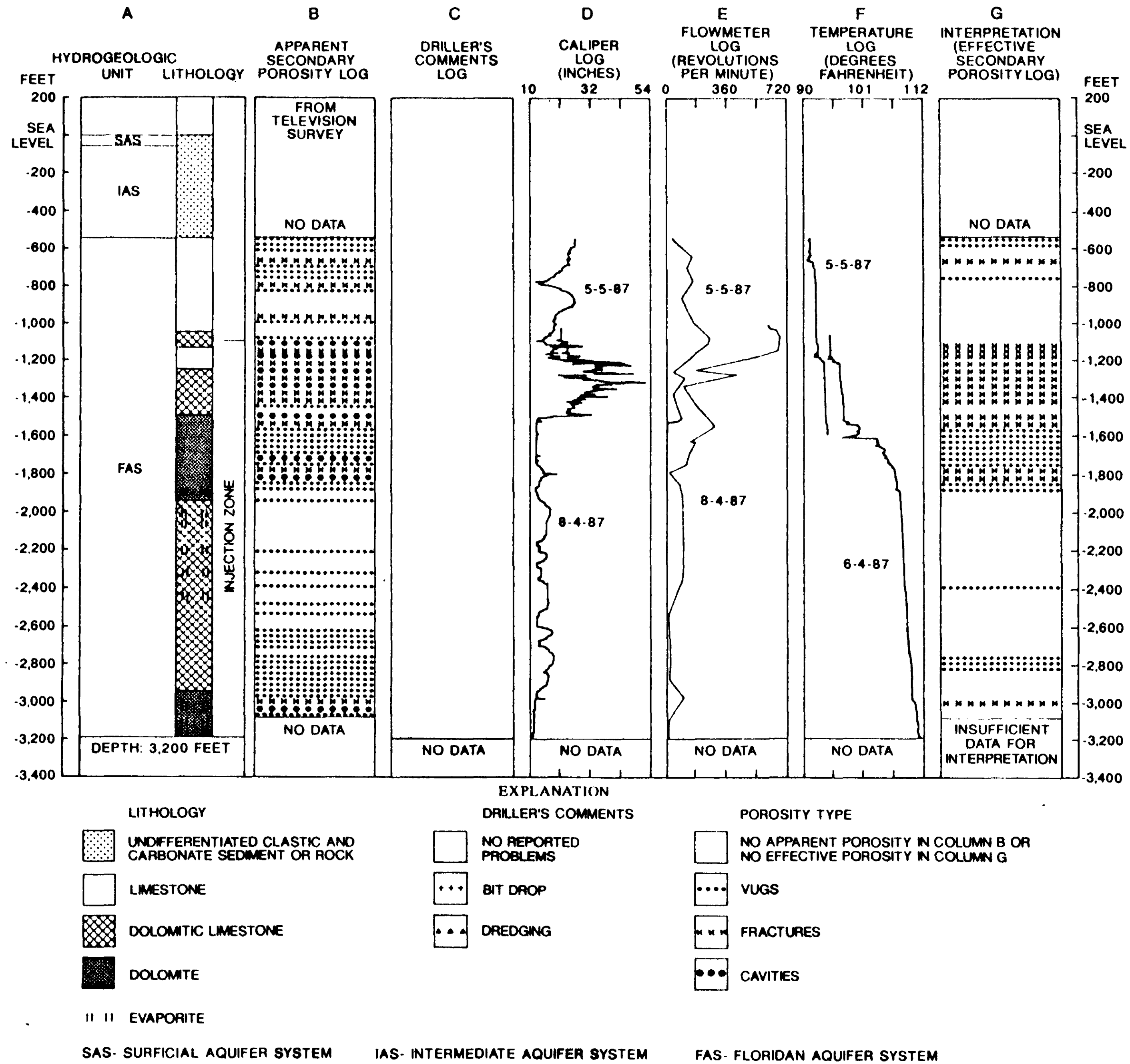


Figure 8. Comprehensive borehole interpretation at site 4--North Port injection well, Sarasota County.

and to a lesser extent from 3,001 ft to 3,090 ft. Numerous cavities were observed from 1,120 to 1,545 ft. Cavities also were observed at 1,712, 1,736, 1,805, 1,860, and 3,000 ft. At 1,512 ft, a boulder was partially blocking the borehole. In most intervals where cavities were observed, fractures also were observed immediately above and below the cavities. Most of the borehole was observed to be round and smooth except in areas where there were numerous fractures. In these areas, the borehole was irregular, rough, and angular.

The driller's comments log (fig. 8, column C) shows that neither dredging nor drill bit drops were reported during drilling of the injection well. However, CH2M Hill, Inc. (1988), reported that the borehole was obstructed by a large boulder at 1,512 ft and by very hard dolomite from 1,718 to 1,722 ft. CH2M Hill, Inc. also reported that the well started flowing at a depth of 570 ft. At 1,160 ft, this artesian flow was greater than 2,000 gal/min.

A caliper log was run on May 5, 1987, after the well had been drilled from 550 to 1,590 ft with a 12-in.-diameter drill bit. A second caliper log was run on June 4, 1987, after the well had been drilled from 1,090 to 1,500 ft with a 17.25-in.-diameter bit and from 1,500 to 3,190 ft with a 12.25-in.-diameter bit. Both caliper logs are shown in figure 8, column D. The May 5 caliper log is shown to only 1,232 ft in order to avoid overlapping the June 4 caliper log. The change in borehole diameter as a result of a change in bit diameter is evident in the caliper logs. Borehole diameters much larger than the bit diameter occurred between 1,205 and 1,490 ft. The cavities observed in the television survey in this same interval are associated with the large borehole diameters shown in the caliper log. This interval contains alternating sequences of limestone and dolomite that have fractures related to geologic processes, as discussed below, and are above the interval in which bridging was reported, as mentioned above. The association between fractured dolomite and rock fragments and borehole blockage (as observed in the television survey) suggests drilling-induced collapse of intensely fractured or shattered dolomite as a probable cause of the relatively large borehole diameters.

Flowmeter and temperature logs were run in conjunction with the caliper logs (fig. 8, columns E and F). Flowmeter logs were constructed from stationary measurements taken when the well was flowing at a rate of 1,350 gal/min (May 5, 1987) and when the well was pumped at a rate of 5,000 gal/min (June 4, 1987). The flowmeter and temperature logs show that borehole inflow occurred at 570 ft; from 655 to 670 ft; from 750 to 775 ft; from 1,170 to 1,220 ft; from 1,360 to 1,380 ft; from 1,510 to 1,880 ft; from 2,370 to 2,410 ft; from 2,740 to 2,790 ft; from 2,980 to 2,995 ft; and from 3,140 to 3,190 ft.

Because no drill bit drops were reported, all reported cavities and those observed in the borehole television survey are interpreted to have been caused by mechanical disruption during drilling. Interpretation of the flowmeter and temperature logs in terms of borehole flow indicates that the vug and fracture secondary porosities between 550 and 590 ft; between 655 and 670 ft; between 750 and 775 ft; between 1,120 and 1,442 ft; between 1,490 and 1,882 ft; between 2,370 and 2,410 ft; between 2,740 and 2,825 ft; and between 2,980 and 3,001 ft are effective secondary porosities (fig. 8, column G). Because no television survey was available for the bottom 100 ft of the borehole, the secondary porosity of the flow interval between 3,140 and 3,190 ft could not be characterized.

Site 5--Gasparilla Island Injection Well, Lee County

Site 5 (fig. 1) is on Gasparilla Island in Lee County at the wastewater treatment plant owned by the Gasparilla Island Water Association, Inc. The site is in the northeastern corner of section 14, township 43 south, range 20 east. Land surface is about 8 ft above sea level.

Drilling of the injection well at site 5 (fig. 9, table 2) began in November 1984 and was completed in January 1985. The injection well was drilled to a depth of 1,918 ft with the lowermost 224 ft left uncased as a receiving interval for secondary treated municipal wastewater. Data collected during drilling and testing of the injection well are summarized in a report by Geraghty and Miller, Inc. (1986).

The injection well at the Gasparilla Island site penetrated three principal hydrogeologic units. The uppermost unit is a sand and shell deposit about 60 ft thick that constitutes the surficial aquifer system (fig. 9, column A). Underlying the surficial aquifer system is a sequence of alternating sand, shell, clay, and limestone beds about 680 ft thick that constitutes the intermediate aquifer system.

The Floridan aquifer system underlies the intermediate aquifer system. The upper part of the Floridan aquifer system, penetrated by the injection well from about 732 to about 1,300 ft, is primarily limestone.

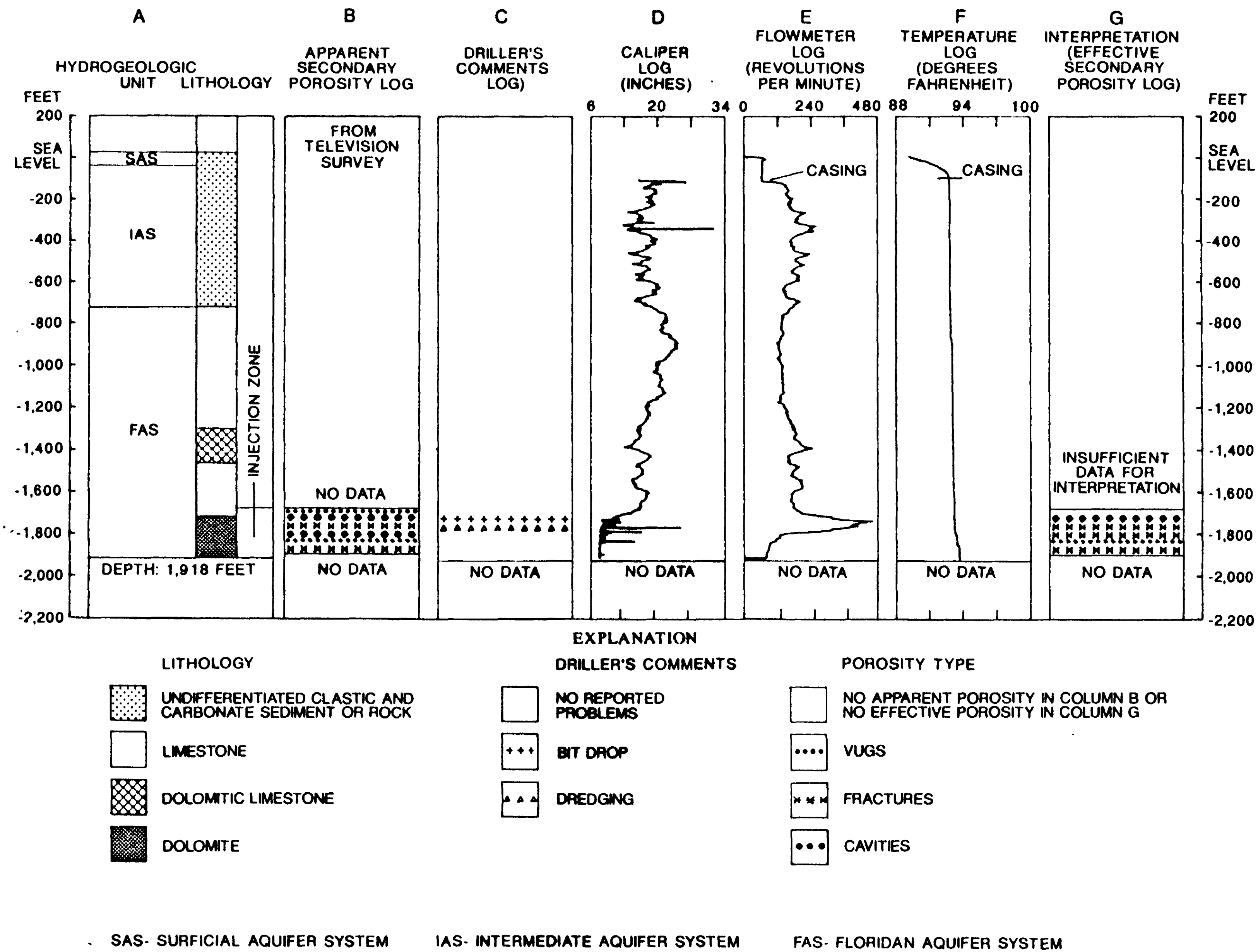


Figure 9. Comprehensive borehole interpretation at site 5--Gasparilla Island injection well, Lee County.

The lower part of the Floridan aquifer system, penetrated by the injection well from about 1,300 to 1,918 ft, is primarily dolomite, limestone, and dolomitic limestone. Nodules that resembled evaporite (gypsum) were observed in the borehole television survey from 1,736 to 1,848 ft, as discussed below. However, gypsum was not reported in the lithologic log. The dissolved-solids concentration of water exceeded 10,000 mg/L at a depth less than 200 feet.

The borehole television survey that was run on the open interval of the injection well in August 1986 was not used in this study because of the poor visibility in the borehole. Instead, a borehole television survey that was run in August 1990, several years after the well had been injected with wastewater, was used to identify secondary porosity features of the borehole. The observed open interval was from the bottom of the casing at 1,694 ft to the bottom of the borehole, which was (in 1990) at 1,889 ft. Visibility was good.

The apparent secondary porosity log (fig. 9, column B; appendix) shows that vug, fracture, and cavity porosity types were identified in the borehole television survey. Vugs were present throughout the borehole, but were observed primarily from 1,694 to 1,726 ft and from 1,826 to 1,871 ft. Vugs filled with what appeared to be gypsum were observed at 1,736 ft; from 1,756 to 1,770 ft; and from 1,823 to 1,848 ft. Fractures were observed predominantly from 1,726 to 1,756 ft; from 1,770 to 1,826 ft; and from 1,871 ft to the bottom of the television survey at 1,889 ft. Cavities were observed at 1,735, 1,742, 1,774, 1,795, 1801, and 1,840 ft. In most intervals where cavities were observed, fractures also were observed immediately above and below the cavities. The borehole shape varied from round to irregular and most of the borehole was rough.

The driller's comments log (fig. 9, column C) shows that a drill bit drop of 8 in. was reported at 1,739 ft during drilling of the injection well. The log also shows that dredging occurred in the fractured dolomites from 1,744 to 1,751 ft. Geraghty and Miller, Inc. (1986), reported that circulation was lost while drilling at depths from 82 to 121 ft; from 149 to 165 ft; from 268 to 274 ft; and at 442 ft.

A caliper log was run on December 20, 1984, after the well had been drilled from 113 to 1,918 ft with a 7.87-in.-diameter drill bit (fig. 9,column D). Borehole diameters much larger than the bit diameter occurred primarily above 1,735 ft in the limestone and dolomitic limestone. Also, the cavities observed in the television survey at 1,735, 1,742, 1,774, 1,795, and 1,840 ft are associated with the large borehole diameters shown in the caliper log. The interval that includes the observed cavities (1,735 to 1,840 ft) contains dolomite, which, as discussed below, has fractures, vugs, and two small cavities related to geologic processes, and also includes the interval in which dredging was reported.

Continuous flowmeter and temperature logs were run in conjunction with the caliper log when no concurrent withdrawal or injection occurred in the well (fig. 9, columns E and F). The reason the logs were run under static conditions was not discussed by Geraghty and Miller, Inc. (1986). The flowmeter and temperature logs show evidence of internal flow in the borehole, with most of the inflow occurring between 1,730 ft and the original bottom of the borehole (1,918 ft) and outflow occurring somewhere near the bottom of the casing at 113 ft. This outflow might be occurring in the interval between 113 and 121 ft where circulation was lost during drilling. The temperature log also shows inflow occurring at about 880 ft.

The reported drill bit drop of 8 in. at 1,739 ft correlates closely to small cavities observed in the borehole television survey at 1,735 and 1,742 ft. The caliper log shows a slight increase in borehole diameter, and the flowmeter log shows borehole inflow near these depths. Interpretation of the flowmeter and temperature logs in terms of borehole flow indicates that the cavity secondary porosity at 1,735 and 1,742 ft and the vug and fracture secondary porosities between 1,726 and 1,889 ft (bottom of the borehole) are effective secondary porosities. Conversely, because no other drill bit drops were reported, all other reported cavities and those observed in the borehole television survey are interpreted to have been caused by mechanical disruption during drilling. The above interpretations are shown in the effective secondary porosity log (fig. 9, column G). Because a television survey was not available for the bottom 29 ft of the borehole as originally drilled, the secondary porosity of the flow interval between 1,889 and 1,918 ft could not be characterized.

Site 6--North Fort Myers Injection Well, Lee County

Site 6 (fig. 1) is at the North Fort Myers wastewater treatment plant owned by North Fort Myers Utility, Inc., in Lee County. The site is in the southeastern quarter of section 14, township 43 south, range 24 east. Land-surface is about 20 ft above sea level.

Drilling of the injection well at site 6 (fig. 10, table 2) began in May 1987 and was completed in December 1987. The well was drilled to a depth of 2,583 ft and the lowermost 263 ft was left uncased as a receiving interval for treated municipal wastewater. Data collected during drilling and testing of the injection well are summarized in a report by Post, Buckley, Schuh, and Jernigan, Inc. (1988).

The injection well at the North Fort Myers site penetrated three principal hydrogeologic units. The uppermost unit is a sand and shell deposit about 10 ft thick that constitutes the surficial aquifer system (fig. 10, column A). Underlying the surficial aquifer system is a sequence of alternating sand, clay, sandstone, and limestone beds about 910 ft thick that constitutes the intermediate aquifer system.

The Floridan aquifer system underlies the intermediate aquifer system. The upper part of the Floridan aquifer system, penetrated by the injection well from about 900 to 1,730 ft, is mostly limestone. The lower part of the Floridan aquifer system, penetrated by the injection well from 1,730 to 2,583 ft, is mainly dolomite and dolomitic limestone with thin sequences of limestone. The dissolved-solids concentration of water exceeded 10,000 mg/L at about 1,530 ft.

A borehole television survey was run on December 2, 1987, on the open interval of the injection well from 1,560 to 2,583 ft. Visibility was good except for the bottom 43 ft where visibility was poor. The apparent secondary porosity log (fig. 10, column B; appendix) shows that vug, fracture, and cavity porosity types were identified in the borehole television survey. Vugs were present throughout most of the borehole, and concentric-shaped vugs were observed from 1,774 to 2,517 ft. Fractures were observed throughout the borehole, but were observed predominantly from 1,730 to 1,900 ft and from 2,110 to 2,525 ft. Cavities were observed at 1,650, 1,660, 1,724, 1,740, 1,893, 2,114, 2,120, 2,172, 2,360, 2,404, and 2,513 ft. In most intervals where cavities were observed, fractures also were observed immediately above and below the cavities. Most of the borehole was round and smooth except in areas where there were numerous fractures. In these areas, the borehole was irregular, rough, and angular.

The driller's comments log (fig. 10, column C) shows that dredging occurred from 2,241 to 2,404 ft. The daily drilling reports and the geolograph did not indicate the occurrence of drill bit drops during drilling of the well. Post, Buckley, Schuh, and Jernigan, Inc. (1988), reported that, during drilling at depths of 1,720, 1,760, and 2,165 ft, salt (granular sodium chloride) was used to stop artesian flow in the well.

A caliper log was run on September 22, 1987, after the well had been drilled from 1,560 to 2,330 ft with a 12.25-in.-diameter drill bit. A second caliper log was run on December 1, 1987, after the well had been drilled from 2,320 to 2,583 ft with an 11-in.-diameter bit. Both caliper logs are shown in figure 10, column D. The change in borehole diameter resulting from the change in bit diameter is evident in the caliper logs. Borehole diameters much larger than the bit diameter occurred between 1,560 and 1,720 ft in limestone and at 2,110, 2,120, and 2,404 ft in dolomite. This latter depth (2,404 ft) is in an interval with reported dredging and, as discussed below, is in an interval of effective fracture secondary porosity.

The association between fractured dolomite and dredging indicates borehole wall collapse of intensely fractured or shattered dolomite as a possible cause of the relatively large borehole diameter shown in the caliper log at 2,404 ft. Also, the large borehole diameters at 2,110 and 2,120 ft could have been caused by the collapse of fractured dolomite, but there are insufficient data to designate these fractures as effective fracture secondary porosity in figure 10, column G. The cavities observed in the television survey at 2,114, 2,120, and 2,404 ft are associated with the large borehole diameters shown in the caliper logs at or near these depths.

Continuous flowmeter logs were run up and down the well on September 22, 1987, when the well was open from 1,560 to 2,330 ft and on December 3, 1987, when the well was open from 2,320 to 2,583 ft (fig. 10, column E). These logs were run during periods when no withdrawal or injection occurred in the well. The flowmeter logs do not show evidence of internal flow in the borehole, even though salt was used to stop artesian flow in the well while drilling at depths of 1,720, 1,760, and 2,165 ft, which indicates there could have been some internal flow (Post, Buckley, Schuh, and Jernigan, Inc., 1988).

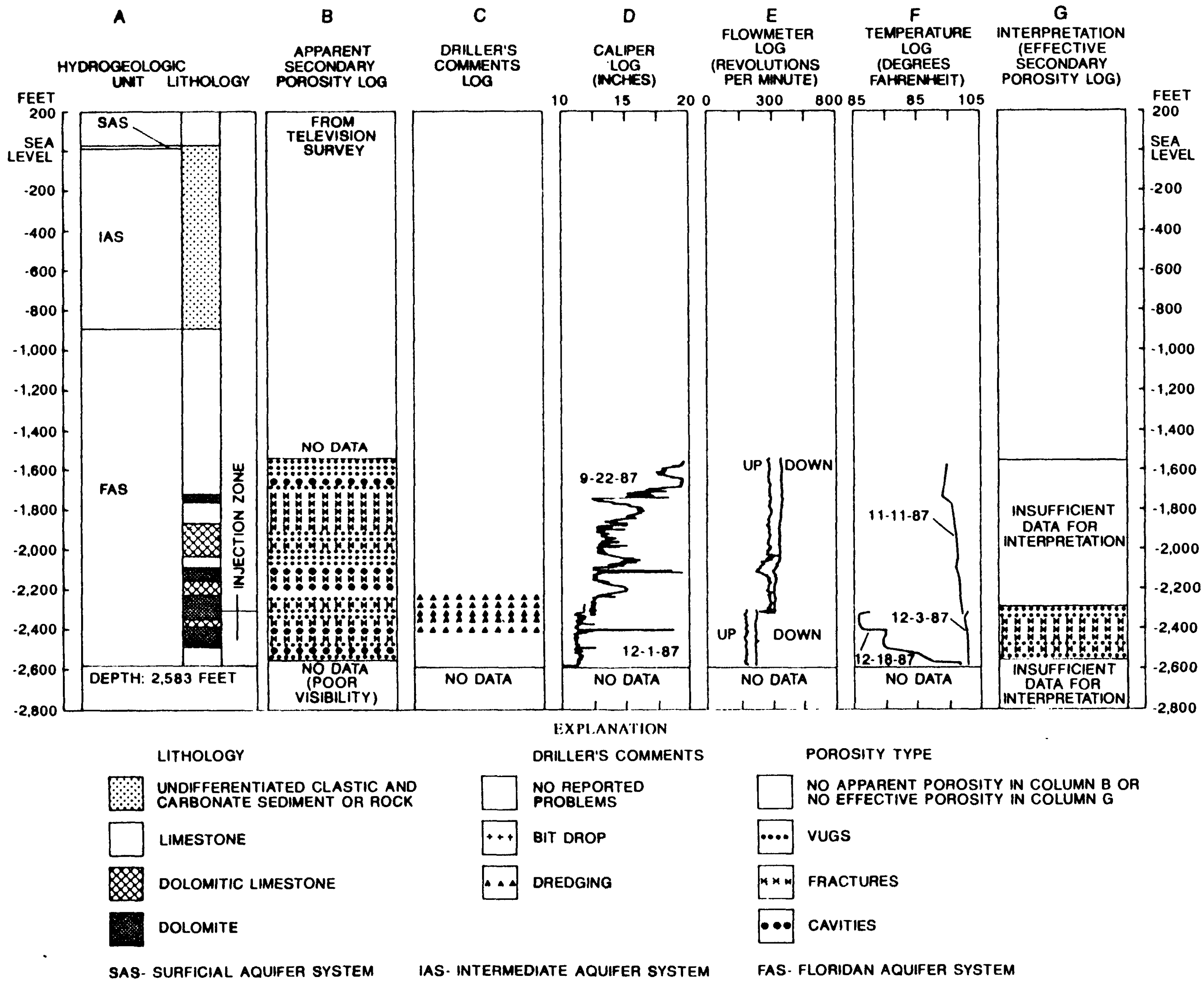


Figure 10. Comprehensive borehole interpretation at site 6--North Fort Myers injection well, Lee County.

A temperature log, run on November 11, 1987, after the well had been reamed with a 24-in.-diameter bit (fig. 10, column F), indicates that some internal flow could have been occurring in the borehole between 1,710 and 2,110 ft. However, because the log was run during a period when no withdrawal or injection occurred in the well, data are insufficient to interpret this interval as a flow interval.

Two temperature logs were run when the well was open from 2,320 to 2,583 ft. One log was run on December 3, 1987, 2 weeks before injection of 4 Mgal/d of 62-°F lake water for 16 hours, and the other log was run on December 18, 16 hours after the injection ended (fig. 10, column F). The temperature log run after the injection test showed cooler water in the borehole from 2,320 (bottom of the casing) to about 2,525 ft, indicating that most of the open interval of the borehole had received the cooler injection water during the test and that this interval can be interpreted as a flow interval.

Because no drill bit drops were reported or shown in the geolograph record, all reported cavities and those observed in the borehole television survey are interpreted to have been caused by mechanical disruption during drilling. Interpretation of the flowmeter and temperature logs in terms of borehole flow indicates that the vug and fracture secondary porosities between 2,320 and 2,525 ft in the dolomite and dolomitic limestone are effective secondary porosities (fig. 10, column G).

Insufficient data (lack of pumping, flowing, or injecting flowmeter and temperature logs) for the interval above 2,320 ft do not allow an interpretation of the effective secondary porosity types above that depth. Likewise, poor visibility in the bottom 43 ft of the borehole television survey limits an interpretation below 2,540 ft.

Site 7--Alligator Alley Test Well, Broward County

Site 7 (fig. 1) is in west-central Broward County, about 5 mi east of the Broward-Collier County line. The test well was drilled at site 7 (fig. 11, table 2) as part of the Florida Regional Aquifer System Analysis (RASA) project. Data are summarized in a report by Meyer (1988). Land surface is about 15 ft above sea level. Drilling of the well began in September 1980 and was completed in November 1980. The well was drilled to a depth of 2,796 ft and was cased to 880 ft.

The hydrogeology was described in detail by Meyer (1988). The well penetrated three principal aquifers. The uppermost unit, the surficial aquifer system, is about 180 ft thick, of which the upper 60 ft is composed of unconsolidated shelly, quartz sand, and the lower 120 ft is composed of sandy, shelly limestone (fig. 11, column A). Underlying the surficial aquifer system is a sequence of alternating sand, shell, clay, and limestone beds about 590 ft thick that constitutes the intermediate aquifer system.

The Floridan aquifer system underlies the intermediate aquifer system. The upper part of the Floridan aquifer system, penetrated by the test well from 755 to 1,555 ft, is primarily limestone. The lower part of the Floridan aquifer system, penetrated by the test well from 1,555 to 2,796 ft, is composed of alternating beds of limestone, dolomitic limestone, and dolomite. The depth at which the dissolved-solids concentration of water exceeded 10,000 mg/L was estimated to be below 1,415 ft by Meyer (1988, p.25) and at about 2,170 ft by Ron Reese (U.S. Geological Survey, written commun., 1992).

A borehole television survey was run on the open interval of the test well from 880 to 2,792 ft. Visibility generally was good. The apparent secondary porosity log (fig. 11, column B; appendix) shows that vug, fracture, and cavity porosity types were identified in the borehole television survey. Vugs were present intermittently throughout the borehole, but were observed predominantly from 958 to 969 ft; from 1,551 to 1,565 ft; from 1,653 to 1,661 ft; and from 2,087 to 2,107 ft. Fractures were observed predominantly from 1,091 to 1,100 ft; from 2,117 to 2,125 ft; from 2,145 to 2,150 ft; and from 2,195 to 2,205 ft. Numerous cavities and fractures were observed from 952 to 958 ft; from 1,602 to 1,609 ft; from 2,244 to 2,252 ft; from 2,430 to 2,556 ft; and from 2,599 to 2,701 ft. At 2,407 ft, the borehole was blocked by a boulder. The television survey was interrupted while the boulder was removed. In most intervals where cavities were observed, fractures also were observed immediately above and below the cavities. Most of the borehole was round and smooth except in areas where there were numerous fractures. In these areas, the borehole was irregular, rough, and angular.

The driller's comments log (fig. 11, column C) shows that dredging was reported from 880 to 1,000 ft and at 2,055 ft during drilling of the test well. No drill bit drops were reported. The well was flowing at 880 ft, and mud and salt were used to stop the flow from 880 ft to at least 2,375 ft.

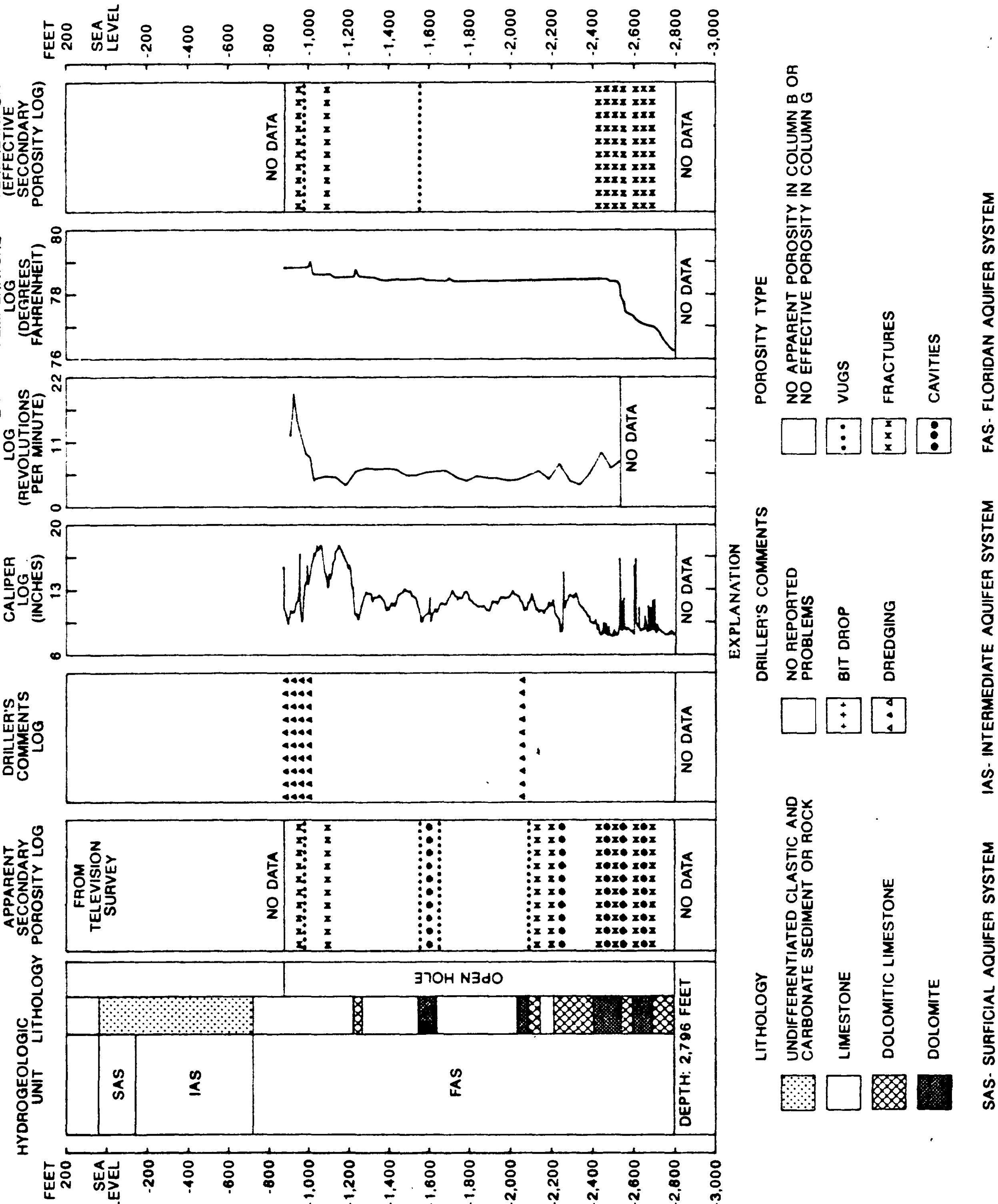


Figure 11. Comprehensive borehole interpretation at site 7--Alligator Alley test well, Broward County.

A caliper log was run on November 18, 1980, after the well had been drilled from 880 to 2,796 ft with an 8-in.-diameter drill bit (fig. 11, column D). Borehole diameters much larger than the bit diameter occur consistently between 990 and 1,220 ft and are associated with the limestone in this interval. Other intermittent wide areas were observed at about 2,240 ft; from 2,530 to 2,550 ft; from 2,600 to 2,630 ft; and from 2,670 to 2,700 ft and are associated with dolomite and dolomitic limestone. Many of the cavities observed in the television survey are associated with the large borehole diameters shown in the caliper log, especially in the lower section of the borehole below 2,400 ft where alternating sequences of dolomitic limestone and dolomite occur. This sequence, as discussed below, has fractures related to geologic processes and is below the interval in which a boulder was blocking the borehole. The association between fractured dolomite and rock fragments blocking the borehole (as observed in the television survey) indicates collapse of intensely fractured or shattered dolomite during drilling as a probable cause of the relatively large borehole diameters.

A flowmeter log (fig. 11, column E) was run on January 14, 1981, when the well was open from 880 to 2,796 ft. The flowmeter tool was able to reach a depth of only 2,693 ft because soft clay and drill cuttings had reportedly filled into the borehole. The flowmeter log was constructed from stationary measurements taken when the well was flowing at an unreported rate (probably about 1,000 gal/min). A temperature log (fig. 11, column F) was run on July 16, 1983, when the well was open from 880 to 2,796 ft and flowing at about 1,000 gal/min. The flowmeter and temperature logs show that borehole inflow occurred from 880 to 1,020 ft; from 1,090 to 1,130 ft; from 1,560 to 1,580 ft, and from 2,450 to about 2,700 ft and possibly to the bottom of the borehole at 2,796 ft.

Because no drill bit drops were reported, all reported cavities and those observed in the borehole television survey are interpreted to have been caused by mechanical disruption during drilling. Interpretation of the flowmeter and temperature logs in terms of borehole flow indicates the vug and fracture secondary porosities between 952 and 969 ft; 1,091 and 1,100 ft; 1,550 and 1,565 ft; 2,430 and 2,550 ft; and 2,599 and 2,701 ft are effective secondary porosities (fig. 11, column G). Borehole inflow was identified in the interval 880 to 952 ft, but no secondary porosity is characterized. Porosity in this interval could be too small to be visible in the television survey.

Site 8--Miami-Dade Injection Well Number 5, Dade County

Site 8 (fig. 1) is in Dade County at the South District Regional Wastewater Treatment Plant owned by the Miami-Dade Water and Sewer Authority Department. The site is in the northeastern corner of section 21, township 56 south, range 40 east, about 1 mi west of Biscayne Bay. Land surface is less than 5 ft above sea level.

Drilling of injection well I-5 at site 8 (fig. 12, table 2) began in July 1977 and was completed in October 1977. The well was drilled to a depth of 3,190 ft with the lowermost 454 ft left uncased as a receiving interval for secondary treated municipal wastewater. The injection well was first named deep test well no. 1, but later was named injection well I-5. Data collected during drilling and testing of the injection well are summarized in a report by CH2M Hill, Inc. (1977).

The injection well at the Miami-Dade site penetrated three principal hydrogeologic units. The uppermost unit is a limestone deposit about 105 ft thick that constitutes the surficial aquifer system, also called the Biscayne aquifer (fig. 12, column A). Underlying the surficial aquifer system is a sequence of alternating sand, shell, gravel, clay, siltstone, and limestone beds about 810 ft thick that constitutes the intermediate aquifer system.

The Floridan aquifer system underlies the intermediate aquifer system. The upper part of the Floridan aquifer system, penetrated by the injection well from 910 to 2,140 ft, is primarily limestone. The lower part of the Floridan aquifer system, penetrated by the injection well from 2,140 to 3,190 ft, is primarily dolomite and dolomitic limestone. The dissolved-solids concentration of water exceeded 10,000 mg/L at a depth less than 1,750 ft.

A borehole television survey was run on the open interval of the injection well from 1,784 to 3,190 ft. Visibility ranged from good to poor. The apparent secondary porosity log (fig. 12, column B; appendix) shows that vug, fracture, and cavity porosity types were identified in the borehole television survey. Vugs were present throughout the borehole, but were observed predominantly from 2,465 to 2,600 ft; from 2,765 to 2,800 ft; and from 3,050 to 3,100 ft. Fractures were observed predominantly from 2,460 to 2,465 ft; from 2,600 to 2,625 ft; and from 2,692 to 2,700 ft.

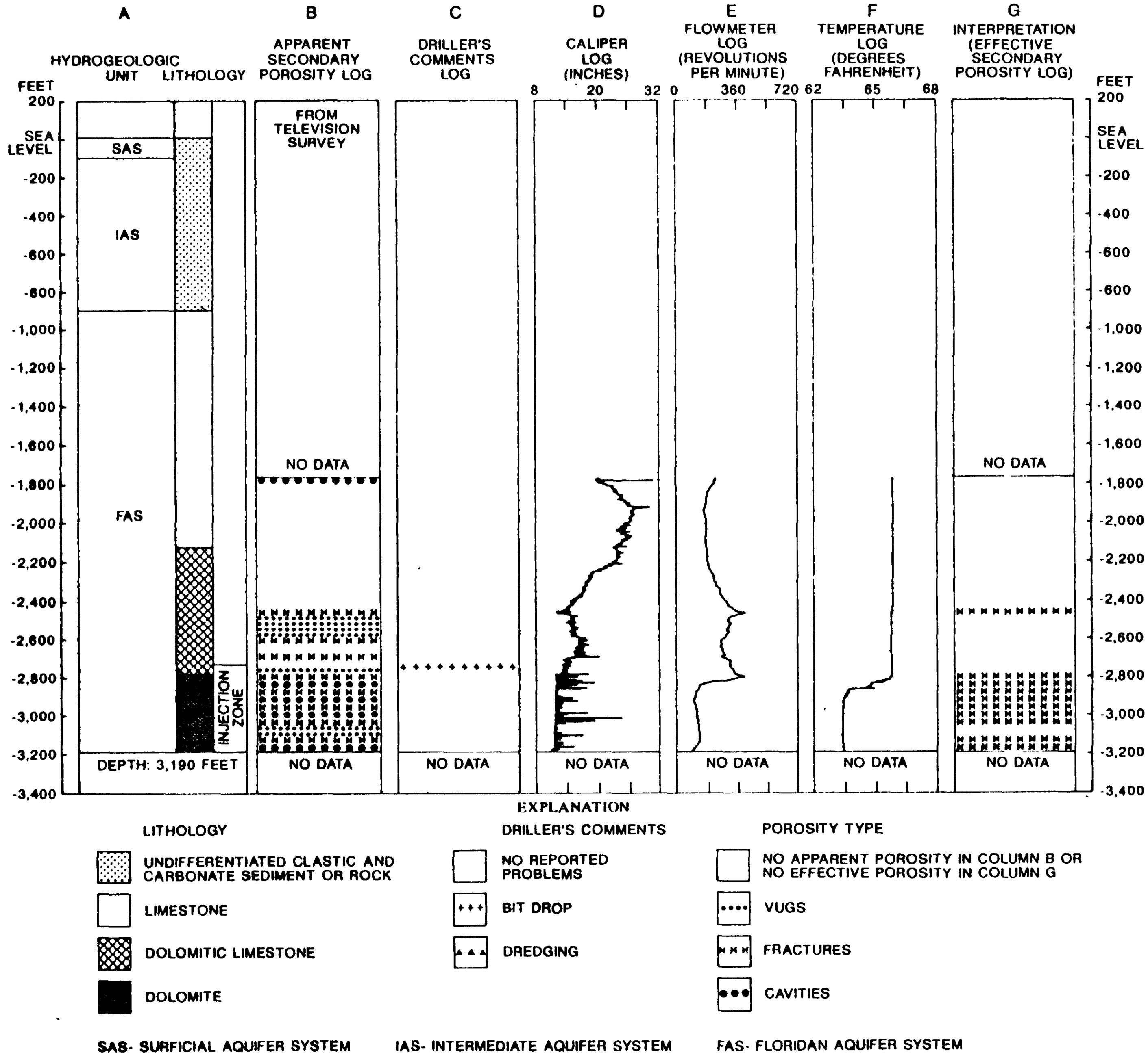


Figure 12. Comprehensive borehole interpretation at site 8--Miami-Dade injection well number 5, Dade County.

Numerous fractures and cavities were observed from 1,786 to 1,788 ft; from 2,800 to 3,050 ft; and from 3,100 to 3,180 ft. In most intervals where cavities were observed, fractures also were observed immediately above and below the cavities. Most of the borehole was round and smooth, except in areas where there were numerous fractures. In these areas, the borehole was irregular, rough, and angular.

The driller's comments log (fig. 12, column C) shows that a 2-ft drill bit drop was reported at 2,747 ft during drilling of the injection well. CH2M Hill, Inc. (1977), reported that the well started flowing at a depth of 1,023 ft. At 2,066 ft, the artesian flow was greater than 2,600 gal/min, and, at 2,749 ft, the flow was about 1,500 gal/min.

A caliper log was run on September 21, 1977, after the well had been drilled from 1,784 to 2,246 ft with a 17.5-in.-diameter drill bit and from 2,246 to 3,190 ft with a 12.25-in.-diameter bit (fig. 12, column D). The change in borehole diameter as a result of a change in bit diameter is evident in the caliper log. Although the size of the borehole approximates the size of the bit diameter for most of the interval between 2,790 ft and the borehole bottom at 3,190 ft, borehole diameters much larger than the bit diameter also are common in this interval. The cavities observed in the television survey in this same interval are associated with the large borehole diameters shown in the caliper log. This interval contains dolomite, which, as discussed below, has fractures related to geologic processes.

Flowmeter and temperature logs were run in conjunction with the caliper log on September 21, 1977, when the well was open from 1,784 to 3,190 ft and are shown in figure 12, columns E and F. The well was pumped at a rate of 800 gal/min while the logs were run. Flowmeter logs were constructed from continuous measurements recorded when the flowmeter was being lowered down the borehole. The temperature and flowmeter logs show that borehole inflow occurred within the intervals from 2,460 to 2,462 ft; from 2,794 to 2,918 ft; from 3,008 to 3,012 ft; and from 3,142 to 3,180 ft.

The reported 2-ft drill bit drop at 2,747 ft was not associated with any borehole inflow. Also, no cavity was observed at that depth in the borehole television survey. Consequently, neither apparent nor effective cavity secondary porosity is interpreted to exist at that depth. Because no other drill bit drops were reported, all reported cavities and those observed in the borehole television survey are interpreted to have been caused by mechanical disruption during drilling. Interpretation of the flowmeter and temperature logs in terms of borehole flow indicates the fracture secondary porosity between 2,460 and 2,465 ft; between 2,794 and 3,050 ft; and between 3,142 and 3,180 ft is effective secondary porosity (fig. 12, column G).

Site 9--Sunrise Injection Well Number 1, Broward County

Site 9 (fig. 1) is in Broward County at the city of Sunrise Wastewater Treatment Plant no. 3. The site is in the northwest quarter of the northeast quarter of section 3, township 50 south, range 40 east. Land surface is about 10 ft above sea level.

Two injection wells were drilled at this site. This report summarizes and interprets data collected at injection well no. 1 (fig. 13, table 2). Drilling of injection well no. 1 began in February 1984 and was completed in January 1985. The well was drilled to a depth of 3,190 ft, with the lowermost 500 ft left uncased as a receiving interval for secondary treated municipal wastewater. Data collected during drilling and testing of the injection well were summarized by CH2M Hill, Inc. (1985).

The injection well at the Sunrise site penetrated three principal hydrogeologic units. The uppermost unit is a sand, shell, and limestone deposit about 210 ft thick that constitutes the surficial aquifer system (fig. 13, column A). This unit also is referred to as the Biscayne aquifer. Underlying the surficial aquifer system is a sequence of alternating sand, clay, siltstone, and limestone beds about 820 ft thick that constitutes the intermediate aquifer system.

The Floridan aquifer system underlies the intermediate aquifer system. The upper part of the Floridan aquifer system, penetrated by the injection well from 1,020 to 2,280 ft, is primarily limestone. The lower part of the Floridan aquifer system, penetrated by the injection well from 2,280 to 3,190 ft, is composed of alternating beds of limestone, dolomitic limestone, and dolomite. Dolomite and dolomite with chert occur below 2,880 ft. The dissolved-solids concentration of water exceeded 10,000 mg/L at a depth greater than 1,640 ft.

A borehole television survey was run on the open interval of the test well from 1,780 to 3,182 ft. Visibility was generally good. The apparent

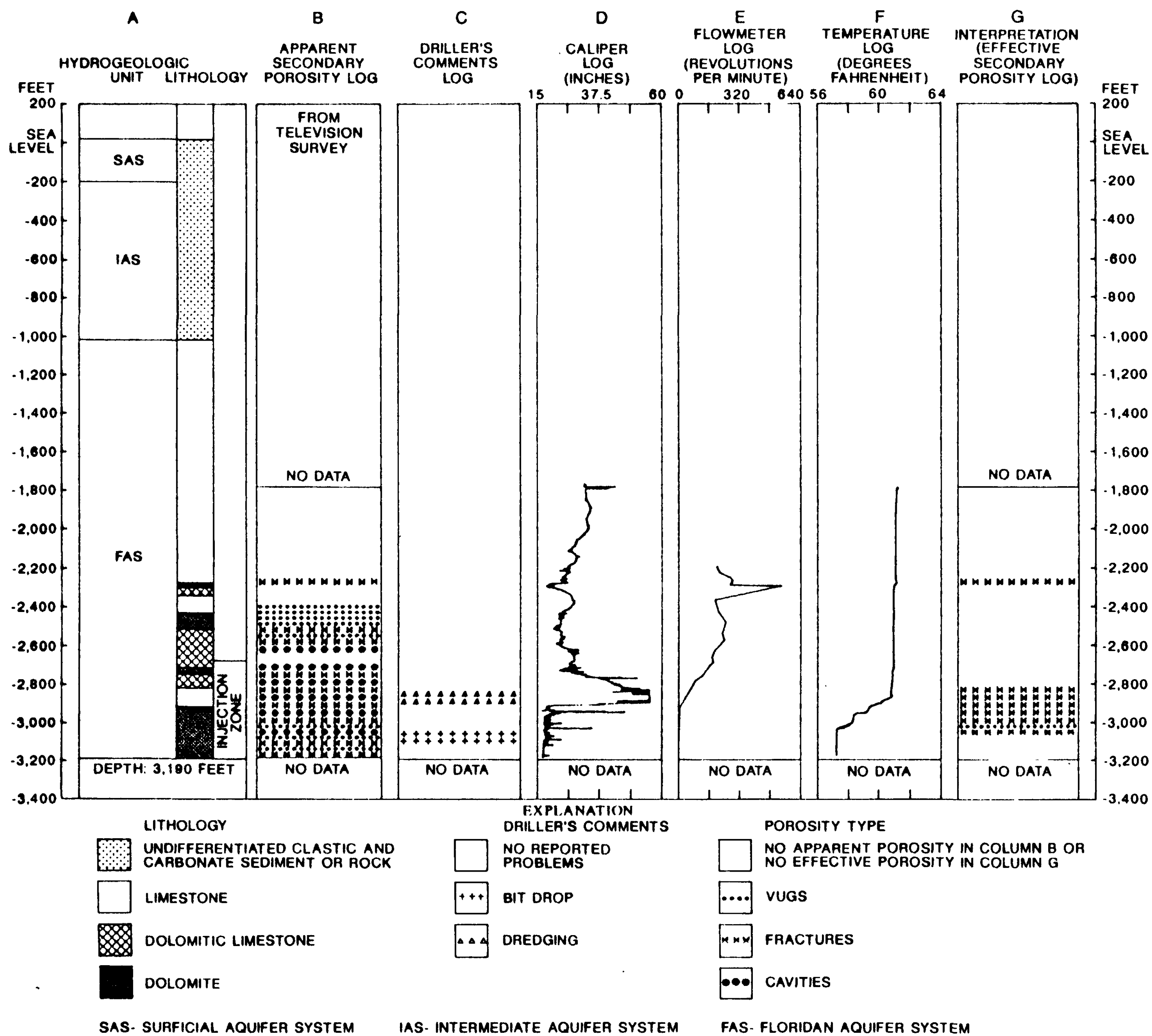


Figure 13. Comprehensive borehole interpretation at site 9--Sunrise injection well number 1, Broward County.

porosity log (fig. 13, column B; appendix) shows that vug, fracture, and cavity porosity types often were observed in the borehole television survey. Vugs were observed predominantly from 2,410 to 2,510 ft. Fractures were observed predominantly from 2,271 to 2,301 ft. Vugs and fractures were observed predominantly from 2,510 to 2,587 ft and from 3,140 to 3,182 ft. Fractures and cavities were observed predominantly from 2,587 to 2,642 ft and from 2,708 to 2,965 ft. Vugs, fractures, and cavities were observed predominantly from 2,965 to 3,140 ft. In most intervals where cavities were observed, fractures also were observed immediately above and below the cavities.

The driller's comments log (fig. 13, column C) shows that dredging was reported from 2,851 to 2,906 ft during drilling of the injection well. CH2M Hill, Inc. (1985) commented in their daily drilling shift reports that salt was used to stop the flow from the well from 1,109 to 1,820 ft and at 2,251 ft.

A caliper log was run on November 3, 1984, after the well had been drilled from 1,780 to 3,190 ft with a 17.5-in.-diameter drill bit (fig. 13, column D). Borehole diameters much larger than the bit diameter occurred consistently between 1,780 and 2,280 ft; 2,300 and 2,440 ft; 2,640 and 2,740 ft; and 2,770 and 2,880 ft and are associated with the limestone and dolomitic limestone in these intervals. The wide borehole diameters shown in figure 13, column D from about 2,820 to 2,880 ft are associated with the reported dredging near that interval.

Other intermittent large diameter areas are observed from 2,948 to 2,956 ft and at 3,010, 3,034, 3,078, 3,098, 3,128 and 3,182 ft and are associated with dolomite. Many of the cavities observed in the television survey are associated with the large borehole diameters shown in the caliper log, especially in the lower section of the borehole below 2,880 ft where dolomite occurs.

Flowmeter and temperature logs (fig. 13, columns E and F) were run on November 11, 1984, when the well was open from 1,780 to 3,190 ft and was pumped at a rate of 4,000 gal/min. The flowmeter log was constructed from stationary measurements. The flowmeter and temperature logs show that a relatively small amount of borehole inflow occurred from 2,275 to 2,295 ft, and that a relatively large amount of inflow occurred from 2,860 to 3,040 ft.

Because no drill bit drops were reported, all reported cavities and those observed in the borehole television survey are interpreted to have been caused by mechanical disruption during drilling. Interpretation of the flowmeter and temperature logs in terms of borehole flow indicates the fracture secondary porosity between 2,271 and 2,301 ft and between 2,850 and 2,965 ft and the vug and fracture secondary porosities between 2,965 and 3,040 ft are effective secondary porosities (fig. 13, column G).

Site 10--Palm Beach County System 9 Injection Well, Palm Beach County

Site 10 (fig. 1) is in southeastern Palm Beach County at the north wastewater treatment plant of Palm Beach County Water Utilities Department System No. 9. The site is in the northwest corner of section 7, township 47 south, range 42 east. Land surface is about 20 ft above sea level.

Drilling of the injection well at site 10 (fig. 14, table 2) began in March 1985 and was completed in October 1985. The injection well was drilled to a depth of 3,280 ft with the lowermost 660 ft left uncased as a receiving interval for treated municipal wastewater. Data collected during drilling and testing of the injection well are summarized in a report by CH2M Hill, Inc. (1986).

The injection well at the Palm Beach County no. 9 site penetrated three principal hydrogeologic units. The uppermost unit is a calcareous sandstone and sandy limestone deposit about 210 ft thick that constitutes the surficial aquifer system (fig. 14, column A). Underlying the surficial aquifer system is a sequence of alternating clay, sandstone, shell, and limestone beds about 760 ft thick that constitutes the intermediate aquifer system.

The Floridan aquifer system underlies the intermediate aquifer system. The upper part of the Floridan aquifer system, penetrated by the injection well from 950 to 1,490 ft, is primarily limestone. The lower part of the Floridan aquifer system, penetrated by the injection well from 1,490 to 3,280 ft, is primarily dolomite and dolomitic limestone. The dissolved-solids concentration of water exceeded 10,000 mg/L at a depth of about 1,700 ft.

A borehole television survey was run on the open interval of the injection well from 2,620 to 3,280 ft. Visibility was good for most of the interval, but was poor from 2,700 to 2,720 ft and from 2,886 to 3,036 ft. The apparent secondary porosity log (fig. 14, column B; appendix) shows that vug, fracture, and cavity

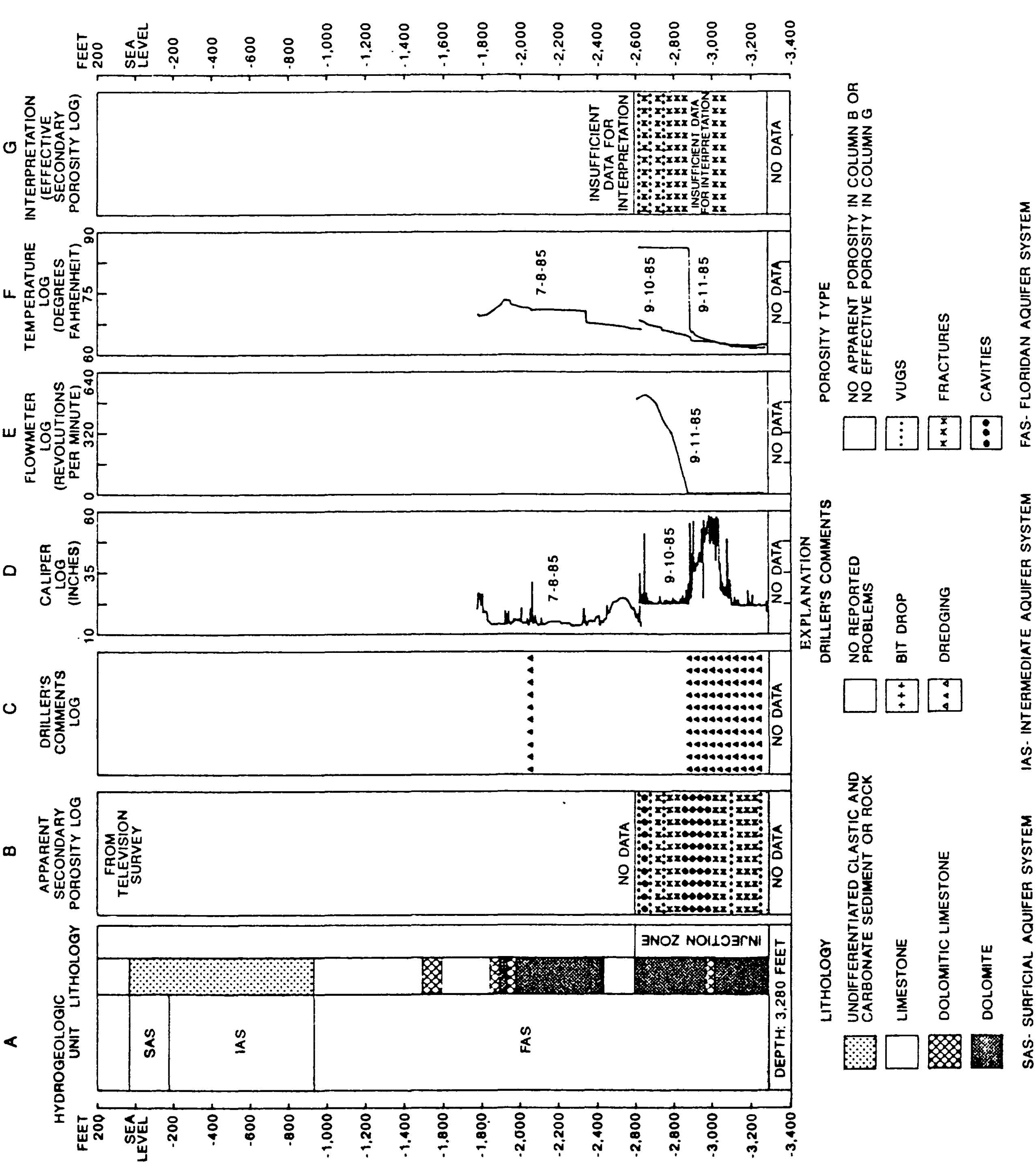


Figure 14. Comprehensive borehole interpretation at site 10--Palm Beach County system 9 injection well, Palm Beach County.

porosity types were identified in the borehole television survey. Vugs were present throughout the borehole, but were observed predominantly from 2,620 to 2,650 ft; from 2,660 to 2,700 ft; from 2,735 to 2,765 ft; from 3,100 to 3,123 ft; and from 3,239 to 3,277 ft. Fractures were observed predominantly from 2,650 to 2,660 ft; from 2,720 to 2,735 ft; from 2,765 to 2,883 ft; from 3,036 to 3,100 ft; from 3,123 to 3,185 ft; and from 3,224 to 3,239 ft. The borehole wall was not visible from 2,700 to 2,720 ft and from 2,883 to 3,036 ft and thus these intervals are described as having cavity apparent secondary porosity. Cavities also were observed at 2,648, 2,848, 2,865, 2,876, 3,076, 3,113, 3,135, 3,189, 3,193, and 3,207 ft. In most intervals where cavities were observed, fractures also were observed immediately above and below the cavities. Most of the borehole was round and smooth, except in areas where there were numerous fractures. In those areas, the borehole was irregular and rough.

The driller's comments log (fig. 14, column C) shows that dredging occurred from 2,030 to 2,085 ft while reaming through dolomite and from 2,880 to 3,245 ft while drilling through fractured dolomite and dolomitic limestone. CH2M Hill, Inc. (1986) reported that the borehole was "blocked by a piece of rock" at 2,910 ft. CH2M Hill, Inc., also reported that circulation was lost while drilling at a depth of 1,995 ft and that salt was used to stop artesian flow in the well at depths from 1,870 to 3,196 ft.

A caliper log was run on July 8, 1985, after the well had been drilled from 1,780 to 3,280 ft with a 17.5-in.-diameter drill bit. The upper 850 ft of that log is shown in figure 14, column D. A second caliper log was run on September 10, 1985, after the well had been drilled from 2,620 to 3,280 ft with a 22.5-in.-diameter bit (fig. 14, column D). The change in borehole diameter as a result of a change in bit diameter is evident in the caliper logs. Borehole diameters consistently much larger than the bit diameter occurred in limestone between 2,450 and 2,590 ft. Borehole diameters consistently much larger than the bit diameter also occurred between 2,880 and 3,100 ft. This section of the borehole contains dolomite and dolomitic limestone and is within the interval in which dredging was reported. Also, the cavities observed in the borehole television survey at 2,648, 2,848, 2,865, and 2,876 ft; from 2,883 to 3,036 ft; and at 3,076, 3,113, 3,135, 3,189, and 3,207 ft are associated with the large borehole diameters shown in the caliper log run on September 10, 1985. The large borehole diameters from 2,006 to 2,010 ft and from 2,050 to 2,066 ft shown in the caliper log run on July 8, 1985, are associated with the dolomite dredging reported within that interval.

A temperature log was run on September 10, 1985, when the well was open from 2,620 to 3,280 ft and when no withdrawal or injection was occurring (fig. 14, column F). This log shows the temperature of water in the borehole decreases with depth. Another temperature log was run on September 11, 1985, while 87-°F surface water was injected in the well at a rate of 4,500 gal/min for about 2 hours. A flowmeter log was constructed from stationary measurements made concurrently with the temperature log on September 11, 1985 (fig. 14, column E). The flowmeter and temperature logs show that a flow interval exists between 2,620 and 3,090 ft.

A temperature log also was run on July 8, 1985, concurrently with the caliper log and is shown in figure 14, column F. This log was run when no withdrawal or injection was occurring and indicates that some internal flow may have been occurring in the borehole between 1,800 and 2,070 ft; at 2,340 ft; and between 2,560 and 2,565 ft. However, the evidence is insufficient to designate these intervals as definite flow intervals.

Because no drill bit drops were reported, all reported cavities and those observed in the borehole television survey are interpreted to have been caused by mechanical disruption during drilling. Interpretation of the flowmeter and temperature logs in terms of borehole flow indicates the vug and fracture secondary porosities between 2,620 and 2,883 ft and between 3,036 and 3,090 ft are effective secondary porosities (fig. 14, column G).

As discussed above, the borehole wall was not visible from 2,883 to 3,036 ft, and, by definition, this interval is described as having apparent cavity secondary porosity. Also, as discussed above, the flowmeter and temperature logs show that borehole flow exists within this interval. However, because no drill bit drops were reported between 2,883 and 3,036 ft, there are insufficient data to interpret the effective porosity type as cavity secondary porosity. However, because the dolomite rocks above and below this interval are characterized as having fracture effective secondary porosity, it is likely that the dolomite rocks in the interval 2,883 to 3,036 ft are fractured and can be characterized as also having effective secondary porosity (shown as "insufficient data for interpretation" in fig. 14, column G). Likewise, insufficient data above 2,620 ft do not allow for an interpretation of the effective secondary porosity above that depth.

Site 11--Seacoast Utilities Injection Well, Palm Beach County

Site 11 (fig. 1) is in northeastern Palm Beach County at the Seacoast Utilities Authority PGA Wastewater Treatment Plant. The site is in the southeast quarter of section 34, township 41 south, range 42 east. Land surface is about 20 ft above sea level.

Drilling of the injection well at site 11 (fig. 15, table 2) began in May 1988 and was completed in September 1988. The injection well was drilled to a depth of 3,300 ft with the lowermost 570 ft left uncased as a receiving interval for secondary treated municipal wastewater. Data collected during drilling and testing of the injection well are summarized in a report by CH2M Hill, Inc. (1989).

The injection well at the Seacoast Utilities site penetrated three principal hydrogeologic units. The uppermost unit is a sand and shell deposit with stringers of limestone about 320 ft thick that constitutes the surficial aquifer system (fig. 15, col. A). Underlying the surficial aquifer system is a thick deposit of clay with limestone stringers about 580 ft thick that constitutes the intermediate aquifer system.

The Floridan aquifer system underlies the intermediate aquifer system. The upper part of the Floridan aquifer system, penetrated by the injection well from 880 to 1,750 ft, is primarily limestone. The lower part of the Floridan aquifer system, penetrated by the injection well from 1,750 to 3,300 ft, is a sequence of alternating limestone, dolomitic limestone, and dolomite deposits. The dissolved-solids concentration of water exceeded 10,000 mg/L at a depth of about 1,920 ft.

A borehole television survey was run on the open interval of the injection well from 2,000 to 3,300 ft. Visibility was good for most of the interval, but was poor from 2,250 to 2,415 ft and from 2,490 to 2,532 ft. The apparent secondary porosity log (fig. 15, column B; appendix) shows that vug, fracture, and cavity porosity types were observed often in the borehole television survey. Vugs were present throughout the borehole, but were observed predominantly from 2,000 to 2,080 ft; from 2,645 to 2,730 ft; and from 2,775 to 2,990 ft. Fractures were observed predominantly from 2,570 to 2,592 ft. Cavities were observed at 2,427, 2,487, and 2,532 ft; fractures and cavities were observed from 3,029 to 3,180 ft; and fractures, vugs, and cavities were observed from 3,180 to 3,300 ft. In most intervals where cavities were observed, fractures also were observed immediately above and below the cavities.

The driller's comments log (fig. 15, column C) shows that dredging was reported at 1,000 and 1,860 ft; from 1,895 to 1,955 ft; at 2,201, 2,515, 2,725, and 3,024 ft; from 3,046 to 3,050 ft; at 3,101 ft; and from 3,156 to 3,205 ft during drilling of the injection well. CH2M Hill, Inc. (1989), reported a boulder fell in the borehole at 1,903 ft. Salt was not used to prevent flow, but the well was reported in the driller's log to "come alive" at 910 and 1,500 ft. "Come alive" most likely means that water was flowing from the well at these depths.

A caliper log was run on August 20, 1988, after the well had been drilled from 2,000 to 3,300 ft with a 12.25-in.-diameter drill bit (fig. 15, column D). Borehole diameters much larger than the bit diameter occurred consistently between 2,160 and 2,340 ft and between 2,780 and 2,950 ft and are associated with the limestone rocks in these intervals.

Other intermittent, large diameter areas were observed at 2,428, 2,532, and 3,044 ft; from 3,062 to 3,218 ft; and at 3,273 ft and are associated with dolomite and dolomitic limestone. Many of the cavities observed in the television survey, as well as the dredging in the drilling reports, are associated with the large borehole diameters shown in the caliper log, especially in the lower section of the borehole below 3,000 ft where fractured dolomite occurs. The association between fractured dolomite, dredging, and a reported boulder falling in the borehole indicates collapse of intensely fractured or shattered dolomite during drilling as a probable cause of the relatively large borehole diameters.

Flowmeter and temperature logs (fig. 15, columns E and F) were run on August 21, 1988, when the well was open from 2,000 to 3,300 ft. The well was being pumped at a rate of 1,050 gal/min during the flowmeter logging and at a rate of 550 gal/min during the temperature logging. The flowmeter log was constructed from stationary measurements. The flowmeter and temperature logs show that all significant borehole inflow occurred from 3,036 to 3,266 ft.

Because no drill bit drops were reported, all reported cavities and those observed in the borehole television survey are interpreted to have been caused by mechanical disruption during drilling. Interpretation of the flowmeter and temperature logs in terms of borehole flow indicates the fracture secondary porosity between 3,029 and 3,180 ft and the fracture and vug secondary porosities between 3,180 and 3,300 ft are effective secondary porosities (fig. 15, column G).

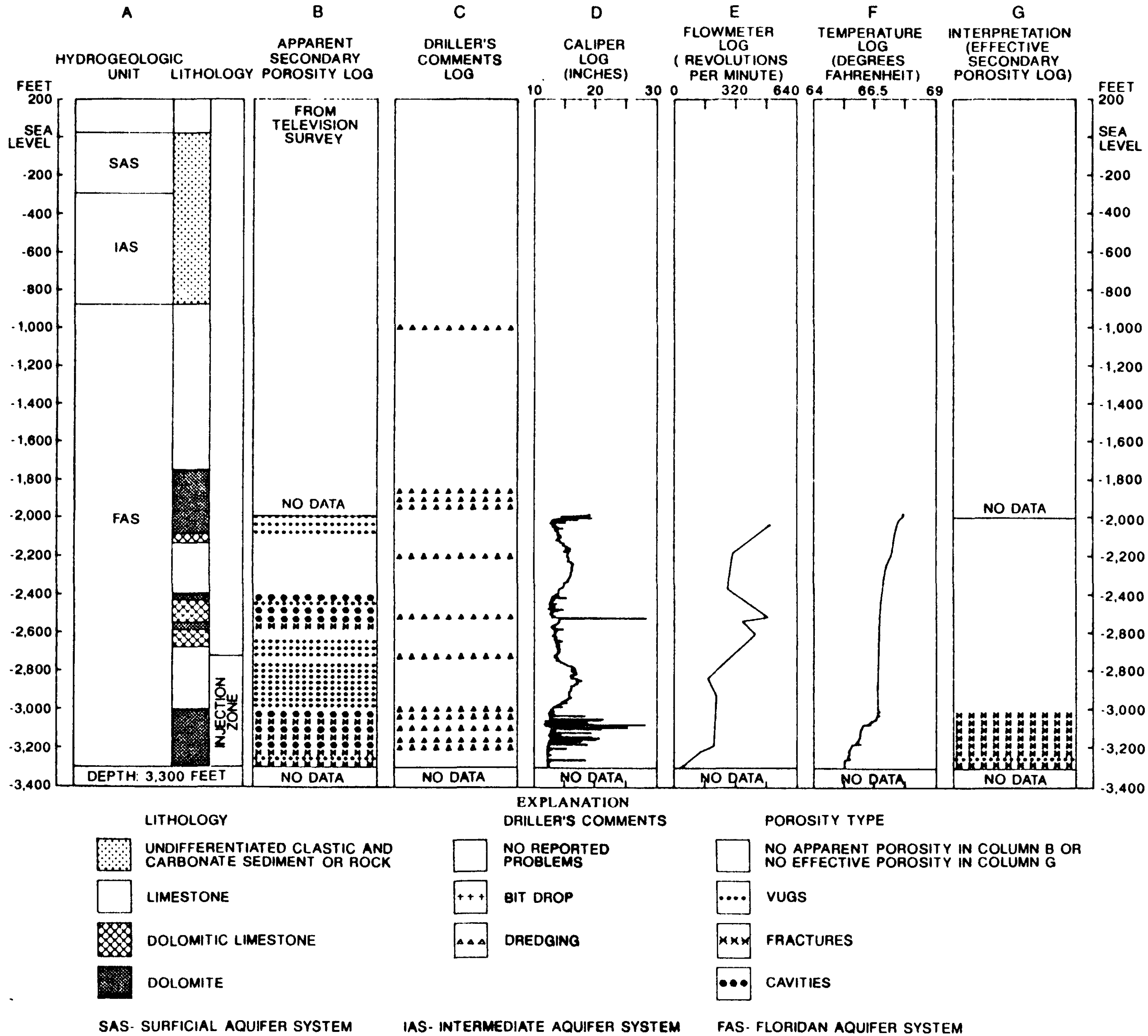


Figure 15. Comprehensive borehole interpretation at site 11--Seacoast Utilities injection well, Palm Beach County.

Site 12--North Port St. Lucie Injection Well, St. Lucie County

Site 12 (fig. 1) is in St. Lucie County at the General Development Utilities North Port St. Lucie Wastewater Treatment Plant, Port St. Lucie. The site is in the northeast quarter of section 20, township 36 south, range 40 east. Land surface is about 15 ft above sea level.

Drilling of the injection well at site 12 (fig. 16, table 2) began in April 1987 and was completed in August 1987. The injection well was drilled to a depth of 3,309 ft with the lowermost 574 ft left uncased as a receiving interval for secondary treated municipal wastewater. Data collected during drilling and testing of the injection well are summarized in a report by CH2M Hill, Inc. (1987).

The injection well at the North Port St. Lucie site penetrated three principal hydrogeologic units. The uppermost unit is a sand and shell deposit about 120 ft thick that constitutes the surficial aquifer system (fig. 16, column A). Underlying the surficial aquifer system is a thick deposit of sand with phosphate and shells about 490 ft thick that constitutes the intermediate aquifer system.

The Floridan aquifer system underlies the intermediate aquifer system. The upper part of the Floridan aquifer system, penetrated by the injection well from 595 to 895 ft, is primarily limestone. The lower part of the Floridan aquifer system, penetrated by the injection well from 895 to 3,309 ft, is a sequence of alternating limestone, dolomitic limestone, and dolomite deposits. The dissolved-solids concentration of water exceeded 10,000 mg/L at a depth of approximately 1,700 ft.

A borehole television survey was run on the open interval of the injection well from 1,935 to 3,279 ft. At 3,279 ft, the borehole was blocked by what appeared to be a boulder. Visibility was good for most of the interval, but was poor from 1,935 to 2,145 ft and from 2,355 to 2,670 ft. The apparent secondary porosity log (fig. 16, column B; appendix) shows that vug, fracture, and cavity porosity types were identified in the borehole television survey. Vugs were observed predominantly from 2,145 to 2,333 ft; from 2,355 to 2,670 ft; and from 2,705 to 2,815 ft. Fractures were observed predominantly from 2,334 to 2,355 ft and from 3,200 to 3,279 ft. Cavities and fractures were observed predominantly from 2,875 to 3,200 ft. In most intervals where cavities were observed, fractures also were observed immediately above and below the cavities.

The driller's comments log (fig. 16, column C) shows that dredging was reported from 3,025 to 3,220 ft during drilling of the injection well. Bentonite was added to the well to prevent flow. The driller reported a rock blocking the borehole at 3,279 ft.

A caliper log was run on June 25, 1987, after the well had been drilled from 1,935 to 3,309 ft with a 12.25-in.-diameter drill bit (fig. 16, column D). The caliper log reached a total depth of 3,295 ft. Borehole diameters much larger than the bit diameter occurred consistently between 1,935 and 2,145 ft; 2,400 and 2,475 ft; and 2,615 and 2,845 ft and are associated with the limestone rocks in these intervals. Also, intermittent wide borehole diameters were observed at 1,945 ft; between 2,200 and 2,370 ft; and between 2,893 and 3,197 ft. Many of the cavities observed in the television survey, as well as the dredging in the drilling records, are associated with the intermittent large borehole diameters shown in the caliper log and also are associated with fractured dolomite rocks (fig. 16, columns A-C).

Flowmeter and temperature logs were run on June 25, 1987, when the well was open from 1,935 to 3,309 ft (fig. 16, columns E and F). However, a rock fragment near the bottom of the borehole prevented either logging tool from reaching the bottom. The flowmeter log was constructed from stationary measurements made while the well was pumped at a rate of 1,040 gal/min, and the temperature log was run while the well was pumped at a rate of 850 gal/min. The flowmeter and temperature logs show that borehole inflow occurred from 2,300 to 2,350 ft, from 2,880 to 2,945 ft, and from 3,027 to 3,285 ft.

Because no drill bit drops were reported, all reported cavities and those observed in the borehole television survey are interpreted to have been caused by mechanical disruption during drilling. Interpretation of the flowmeter and temperature logs in terms of borehole flow, indicates the vug and fracture secondary porosities between 2,285 and 2,355 ft and the fracture secondary porosity between 2,875 and 3,279 ft are effective secondary porosity (fig. 16, column G). Because a rock fragment blocked the borehole and prevented full penetration of the television camera, flowmeter tool, and temperature tool, secondary porosity interpretations could not be made below a depth of 3,279 ft.

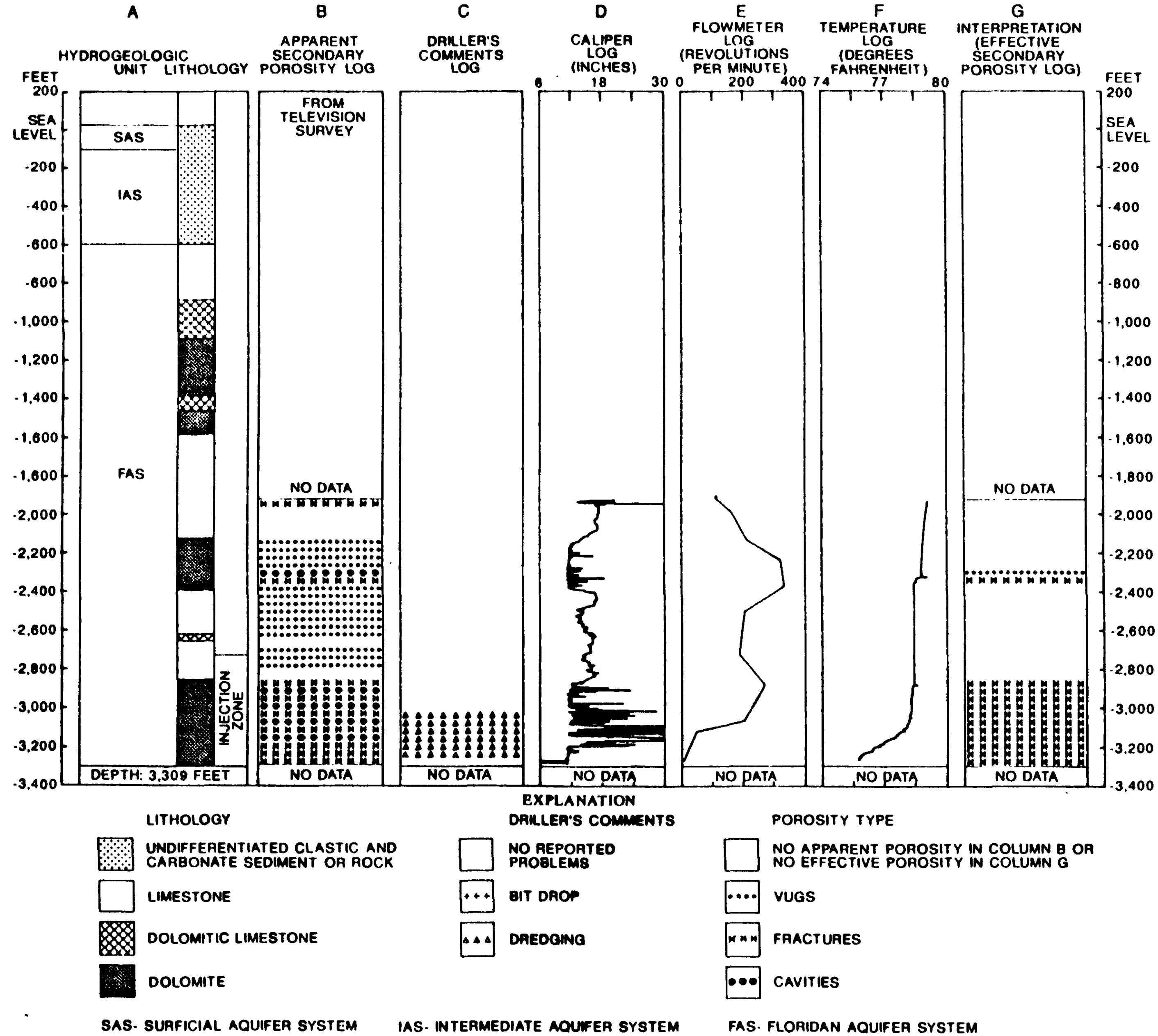


Figure 16. Comprehensive borehole interpretation at site 12--North Port St. Lucie injection well, St. Lucie County.

Site 13--Hercules, Inc., Injection Well, Indian River County

Site 13 (fig. 1) is in Indian River County at the Hercules, Inc., plant. The site is in the southwestern corner of section 25, township 33 south, range 38 east, about 4 mi southwest of Vero Beach. Land surface is about 25 ft above sea level.

Drilling of the injection well at site 13 (fig. 17, table 2) started in July 1978 and was completed in November 1978. The injection well was drilled to a depth of 2,977 ft with the lowermost 629 ft left uncased as a receiving interval for pectin processing water. Data collected during drilling and testing of the injection well are summarized in a report by CH2M Hill, Inc. (1979).

The injection well at the Hercules site penetrated three principal hydrogeologic units. The uppermost unit is a sand and shell deposit about 95 ft thick that constitutes the surficial aquifer system (fig. 17, column A). Underlying the surficial aquifer system is a sequence of alternating sand, shell, clay, chert, and limestone beds about 360 ft thick that constitutes the intermediate aquifer system.

The Floridan aquifer system underlies the intermediate aquifer system at about 430 ft. Dolomitic limestone occurs in the upper 400 ft of the Floridan aquifer system and is underlain by alternating sequences of dolomite, limestone, and dolomitic limestone. Chert occurs with dolomite from 1,960 to 2,090 ft. The dissolved-solids concentration of water exceeded 10,000 mg/L at a depth between 1,634 and 1,670 ft.

A borehole television survey was run on the open interval of the injection well from 1,650 to 2,977 ft. Visibility was good. The apparent secondary porosity log (fig. 17, column B; appendix) shows that vug, fracture, and cavity porosity types were identified in the borehole television survey. Vugs were present throughout the borehole, but were observed predominantly from 1,670 to 1,800 ft; from 2,170 to 2,215 ft; from 2,273 to 2,380 ft; from 2,593 to 2,733 ft; and from 2,950 to 2,977 ft. Although no gypsum was reported in the lithologic log, apparent gypsum nodules and vugs filled with gypsum were observed from 2,931 to 2,945 ft. Dark, discontinuous, concentric bands in the borehole wall were observed from 2,093 to 2,120 ft; from 2,396 to 2,410 ft; at 2,440, 2,466, 2,715, 2,780, and 2,838 ft; from 2,880 to 2,887 ft; and at 2,920 ft. Fractures were observed predominantly from 1,875 to 2,070 ft. Cavities were observed from 2,008 to 2,020 ft. A mixture of fractures and cavities was observed from 2,380 to 2,593 ft, and a mixture of vugs, fractures, and cavities was observed from 2,733 to 2,907 ft. In most intervals where cavities were observed, fractures also were observed immediately above and below the cavities. Most of the borehole was round to pitted to smooth, except in areas where there were numerous fractures. In those areas, the borehole was irregular, rough, and angular.

The driller's comments log (fig. 17, column C) shows that no drill bit drops were reported during drilling of the injection well. CH2M Hill, Inc. (1979), reported that the well was flowing at a rate of 46 gal/min at a depth of 435 ft; 430 gal/min at 820 ft; 1,500 gal/min at 1,090 ft; and 6,600 gal/min at 1,687 ft. Salt was added to the well to control the flow at 1,687 ft.

A caliper log was run on August 17, 1978, after the well had been drilled from 435 to 1,672 ft with a 12-in.-diameter drill bit. A second caliper log was run on October 3, 1978, after the well had been drilled from 1,650 to 1,780 ft with an 18-in.-diameter bit and from 1,780 to 2,977 ft with a 12.25-in.-diameter bit. Both caliper logs are shown in figure 17, column D. Borehole diameters consistently much larger than the bit diameter occurred between 435 and 775 ft; 1,780 and 1,900 ft; and 2,125 and 2,380 ft in limestone and dolomitic limestone. Borehole diameters much larger than the bit diameter also occurred intermittently throughout the borehole (fig. 17, column D). These large diameter areas were observed primarily in the fractured dolomites. The cavities observed in the television survey also are associated with the large borehole diameters shown in the caliper logs.

Flowmeter logs were run in conjunction with the caliper logs and are shown in figure 17, column E. Flowmeter logs were constructed from stationary measurements taken when the well was flowing at a rate of 2,500 gal/min (August 17, 1978) and when the well was receiving injection water at a rate of about 1,000 gal/min (October 3, 1978). The August 17 temperature log was run concurrently with the caliper and flowmeter logs and is shown in figure 17, column F. The well casing was cemented on September 30, and the temperature log run on October 3 showed the effects of the cement hardening. Consequently, that log was not used for interpretation of flow intervals. Instead, a temperature log run on September 21, 1978, is shown in figure 17, column F. The status of the well on September 21 when the temperature log was run is uncertain. The flowmeter and temperature logs show

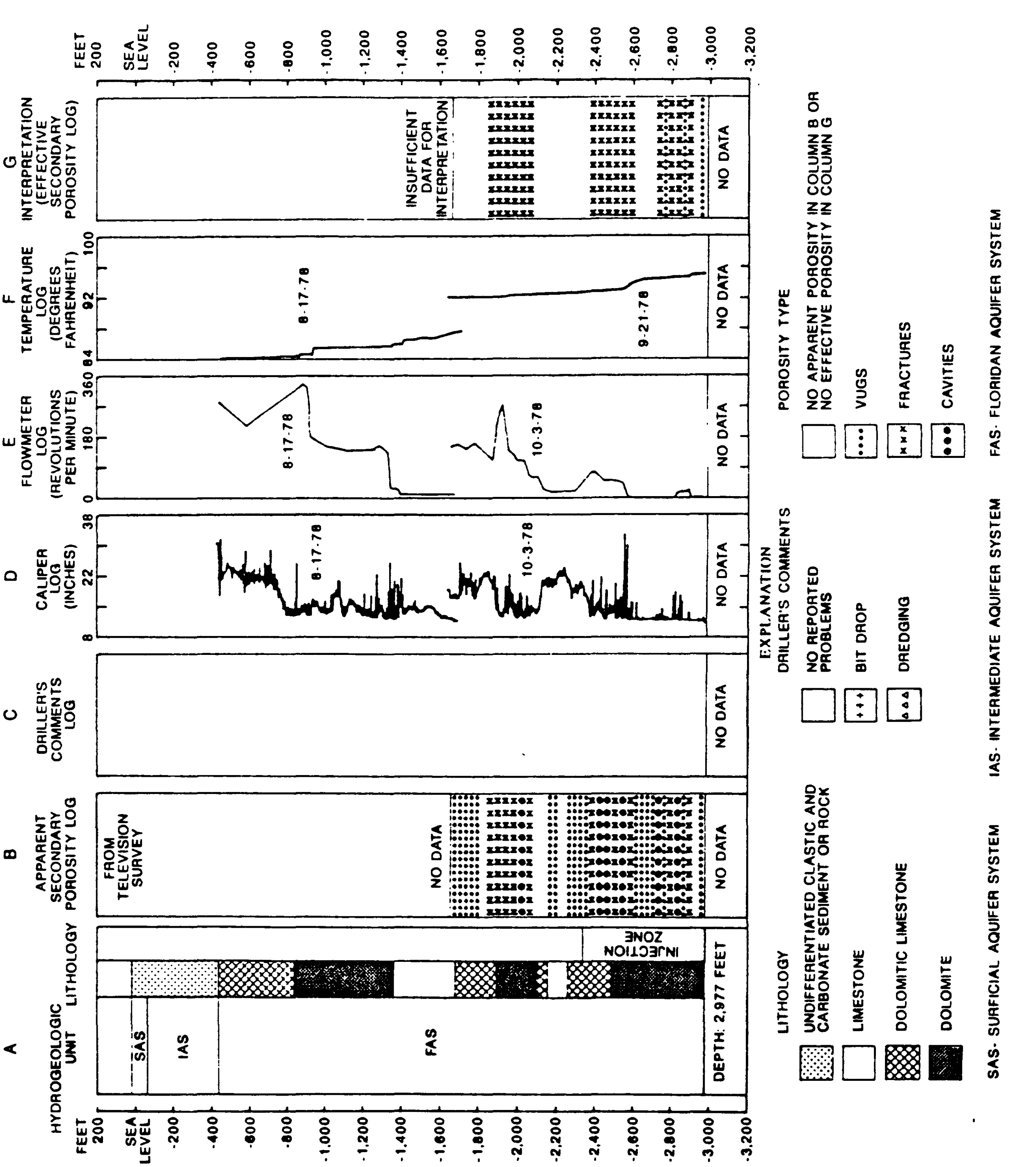


Figure 17. Comprehensive borehole interpretation at site 13--Hercules, Inc., injection well, Indian River County.

that borehole inflow occurred from 852 to 853 ft; from 912 to 927 ft; from 1,225 to 1,400 ft; from 1,900 to 2,000 ft; from 2,040 to 2,070 ft; from 2,380 to 2,455 ft; from 2,540 to 2,590 ft; and from 2,827 to 2,830 ft. Internal flow occurred near the bottom of the borehole with water entering the borehole at about 2,955 ft and exiting at about 2,905 ft. The direction of this internal flow was determined from continuous flowmeter measurements made as the flowmeter moved up the borehole (not shown in fig. 17).

Because no drill bit drops were reported, all reported cavities and those observed in the borehole television survey are interpreted to have been caused by mechanical disruption during drilling. Interpretation of the flowmeter and temperature logs in terms of borehole flow indicates the vug and fracture secondary porosities between 1,875 and 2,070 ft; 2,380 and 2,593 ft; 2,733 and 2,907 ft; and 2,950 and 2,955 ft are effective secondary porosities (fig. 17, column G). Because no television survey was available for the upper 1,650 ft of the borehole, the secondary porosity of the flow intervals between 852 and 853 ft; 912 and 927 ft; and 1,225 and 1,400 ft could not be characterized.

Site 14–South Beaches Injection Well, Brevard County

Site 14 (fig. 1) is at the South Beaches Wastewater Treatment Plant owned by Brevard County and is on a barrier island about 1.5 mi south of Melbourne Beach and about 0.25 mi west of the Atlantic Ocean. Land surface is about 10 ft above sea level.

Drilling of the injection well at site 14 (fig. 18, table 2) began in May 1984 and was completed in January 1985. The injection well was drilled to a depth of 2,906 ft with the lowermost 836 ft left uncased as a receiving interval for treated municipal wastewater. Data collected during drilling and testing of the injection well are summarized in a report by Dames and Moore, Inc. (1985).

The injection well at the South Beaches site penetrated three principal hydrogeologic units. The uppermost unit is a sand, shell, sandstone, and sandy limestone deposit about 120 ft thick that constitutes the surficial aquifer system (fig. 18, column A). Underlying the surficial aquifer system is a sequence of sand and calcareous clay about 130 ft thick that constitutes the intermediate confining unit.

The Floridan aquifer system underlies the intermediate confining unit. The top of the Floridan aquifer system is at 240 ft. The upper part of the Floridan aquifer system is primarily limestone and is about 290 ft thick. Underlying this limestone deposit is a 1,540-ft-thick sequence of alternating dolomite, limestone, and dolomitic limestone deposits. A thick deposit of dolomite begins at 2,070 ft (top of the "boulder zone") and continues to 2,770 ft. Underlying this deposit is a dolomite and evaporite (gypsum) deposit that extends to the bottom of the injection well at 2,906 ft. The dissolved-solids concentration of water exceeded 10,000 mg/L at a depth of about 1,190 ft.

A borehole television survey was run on the open interval of the injection well from 264 to 2,195 ft. Visibility was good. The apparent secondary porosity log (fig. 18, column B; appendix) shows that vug, fracture, and cavity porosity types were identified in the borehole television survey. Vugs were observed from 264 to 2,070 ft. Fractures were observed predominantly from 474 to 481 ft and from 1,009 to 1,023 ft, and fractures with cavities were observed from 2,070 to 2,195 ft. Cavities were observed predominantly at 406, 459, 480, 618, 660, 768, 1,261, 1,270, 1,516, 1,582, 1,746, 1,818, 1,823, 1,834, and 1,840 ft. A second borehole television survey was run after the well had been deepened to 2,906 ft, but this survey was not available for this study. Consequently, the interpretation is limited to the upper 2,195 ft of the injection well.

The driller's comments log (fig. 18, column C) shows that dredging occurred from 2,070 to 2,195 ft while drilling through fractured dolomite. In addition, two drill bit drops were reported, at 245 and 848 ft. The bit drop at 245 ft could not be confirmed because of the lack of other borehole data. The bit drop at 848 ft was in a dolomitic limestone in the Floridan aquifer system. However, the bit drop could not be confirmed because cavity porosity and large borehole diameters at or near that depth were not observed in the television survey or in the caliper log (fig. 18, columns B and D). The well started flowing at a depth of 288 ft. At 1,281 and 2,150 ft, the artesian flow was about 2,000 gal/min.

A caliper log was run on August 6, 1984, after the well had been drilled from 264 to 2,195 ft with a 14.75-in.-diameter drill bit (fig. 18, column D). Borehole diameters much larger than the bit diameter occurred consistently between 278 and 320 ft and between 370 and 485 ft and are associated with the limestone rocks in these intervals. Borehole diameters much larger than the bit diameter occurred in limestone

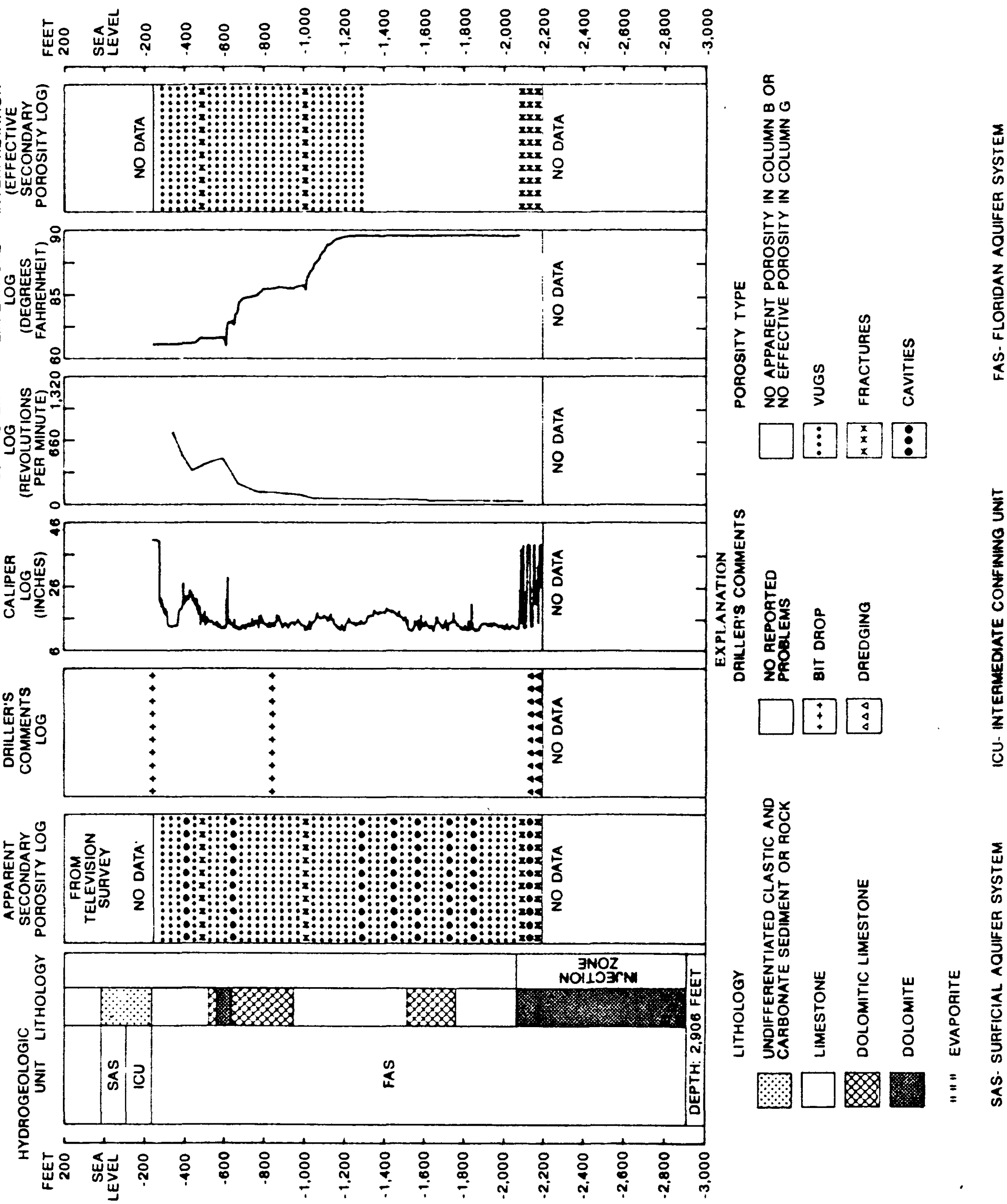


Figure 18. Comprehensive borehole interpretation at site 14--South Beaches injection well, Brevard County.

and chert from 1,842 to 1,846 ft; in dolomite from 618 to 628 ft; and intermittently in dolomite from 2,078 to 2,195 ft. The large borehole diameters between 2,078 and 2,195 ft are associated with the dredging reported in that interval. Many of the cavities observed in the television survey are associated with the large borehole diameters shown in the caliper log, especially in the section of the borehole below 2,078 ft.

Flowmeter and temperature logs (fig. 18, columns E and F) were run on August 6, 1984, when the well was open from 264 to 2,195 ft. However, the logs were run to a depth of only 2,095 ft. The well was flowing at an unreported rate, probably about 3,000 gal/min. The flowmeter log was constructed from stationary measurements. The flowmeter and temperature logs show that most of the borehole inflow occurred between 290 and 1,250 ft and that a small amount of inflow occurred below 2,090 ft.

Because reported drill bit drops could not be confirmed, all reported cavities and those observed in the borehole television survey are interpreted to have been caused by mechanical disruption during drilling. Interpretation of the flowmeter and temperature logs in terms of borehole flow indicates the vug and fracture secondary porosities between 290 and 1,270 ft and the fracture secondary porosity between 2,070 and 2,195 ft are effective secondary porosities (fig. 18, column G).

REGIONAL INTERPRETATIONS AND DISCUSSION

Interpretation of the data for the 14 study sites (fig. 19) led to several observations and associations that seem to apply on a regional scale. Hydrogeologic units and the distribution and relation of effective secondary porosity of rock types within and overlying the injection interval are shown in hydrogeologic sections *A-A′*, *B-B′*, and *C-C′* (figs. 20-22). Locations of the sections are shown in figure 19. The top of the Floridan aquifer system shown in the generalized sections was estimated from data for the 14 individual study sites. Except for sites 5 and 7, discrepancies between the interpretations made in this report (figs. 20-22) and in that by Miller (1986, plate 26) (figure 3 in this report) are minor.

Vugs constituting effective secondary porosity commonly were not observed in limestone except at site 14, where they were present from 290 to 1,270 ft in rocks penetrated by the borehole. Data for this upper interval were not available at most of the other sites. Most vugs with effective secondary porosity were present in dolomite and dolomitic limestone throughout the study area. The majority of vugs observed in the borehole television surveys (apparent vugs) did not constitute effective secondary porosity. This was especially true for the very small and small vugs.

Fracture porosity was the most common type of effective secondary porosity observed at the study sites. Fracture porosity was observed predominantly in dolomite and dolomitic limestone, and fracture porosity in dolomite rocks was the most abundant effective secondary porosity within the injection interval at the 11 injection well sites (figs. 20-22). Fractures, either apparent or effective, usually were present above and below cavities whether apparent or effective. The size of the porosity symbols in relation to scale of figures 5 through 18 was too large to show this fracture-cavity relation accurately in all cases.

Cavity porosity was the least common type of effective secondary porosity at the study sites. In fact, of the more than 17,500 ft of borehole studied, only three cavities constituting effective secondary porosity were identified and that at only two sites. At site 2, a cavity constituting effective secondary porosity was observed from 979 to 980 ft (fig. 20). At site 5, cavities constituting effective secondary porosity were observed at 1,735 and 1,742 ft (fig. 20). All the above mentioned cavities were in dolomite rocks. Most of the cavities observed in the borehole television surveys are interpreted as being caused by drilling-induced collapse of fractured borehole walls.

Data were analyzed for rocks overlying the injection interval at six sites (sites 8, 9, and 11-14) on the southeastern coast of Florida using the described methodology. Effective secondary porosity was not discernible in the limestone or dolomitic limestone that occupies the 300-ft interval immediately above the injection interval at these six sites. This does not mean that fractures or cavities that contribute to effective secondary porosity do not occur in the interval, but only that they were not detectable with the methods used. Widely dispersed, interconnected fractures or cavities could occur beyond the rock column intersected by the borehole and could provide localized pathways for vertical migration of injected wastewater or the displaced saltwater. In the interval between the top of the Floridan aquifer system and a point 300 ft above the top of the injection interval, fractured rocks with effective secondary porosity were observed at five of the six

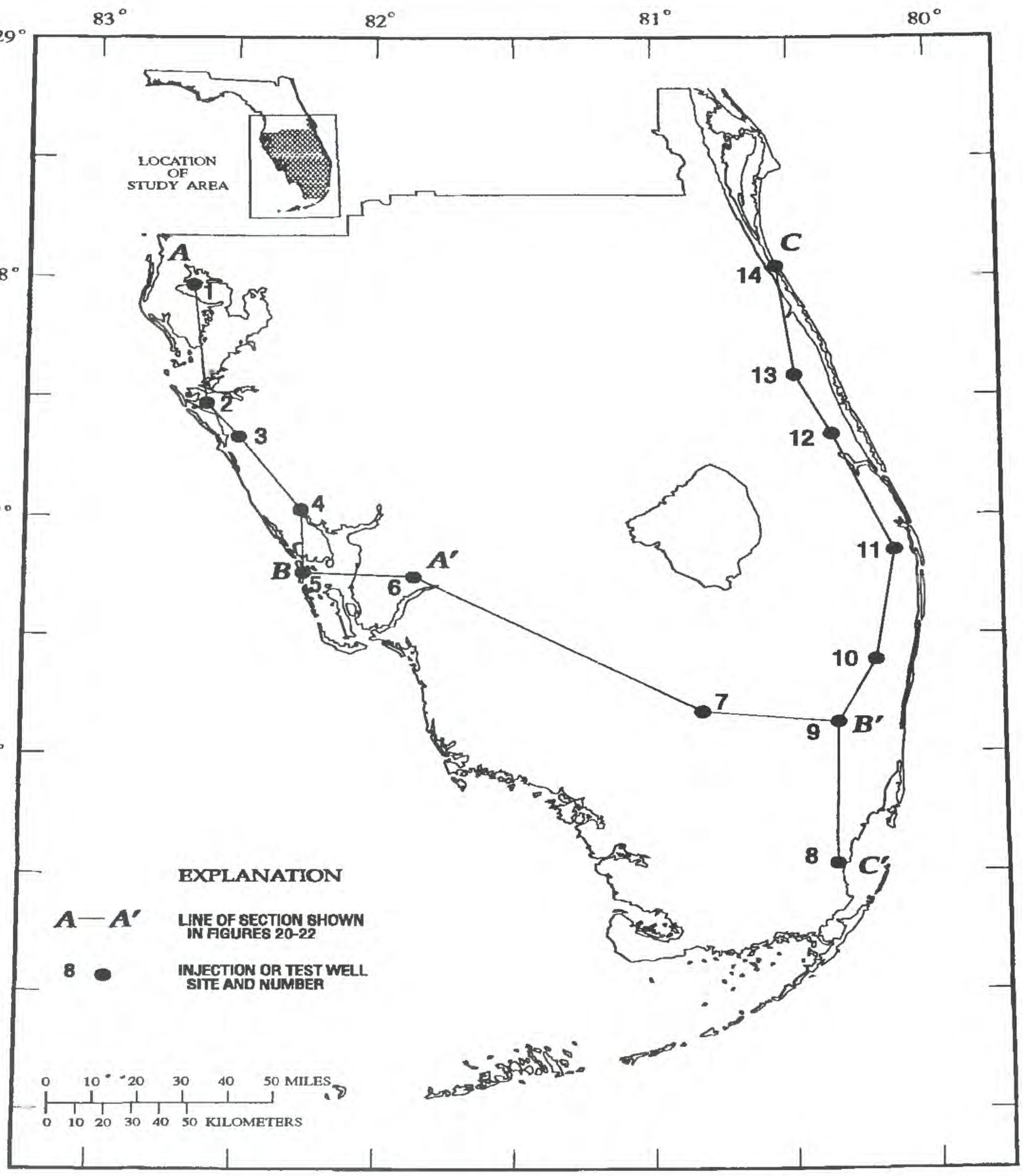


Figure 19. Locations of generalized hydrogeologic sections.

sites. However, no fractures with effective secondary porosity were observed at site 11.

Data were analyzed for rocks overlying the injection interval at two sites (sites 3 and 4) on the southwestern coast of Florida (fig. 20, section *A-A′*). Fractures constituting effective secondary porosity occurred in dolomite rocks that lie within 80 ft of the top of the injection interval at site 3. Vugs constituting effective secondary porosity occurred in limestone rocks more than 430 ft above the top of the injection interval at site 4. At site 2, fractures constituting effective secondary porosity occurred in dolomite rocks at a depth of 992 ft, only 65 ft above the top of the injection interval of a nearby injection well. As discussed in the methodology section, a limitation of the approach used in this report for characterizing effective secondary porosity was that the approach precludes identification of noninterconnected or isolated secondary porosity related to geologic processes. The method also ignores small-scale porosity which can be an important fraction of total porosity and can contribute significantly to fluid flow.

Borehole shape, as shown in the caliper logs, usually was related to the drilling characteristics of the rock type. Borehole diameters consistently much larger than the drill bit diameters were associated with

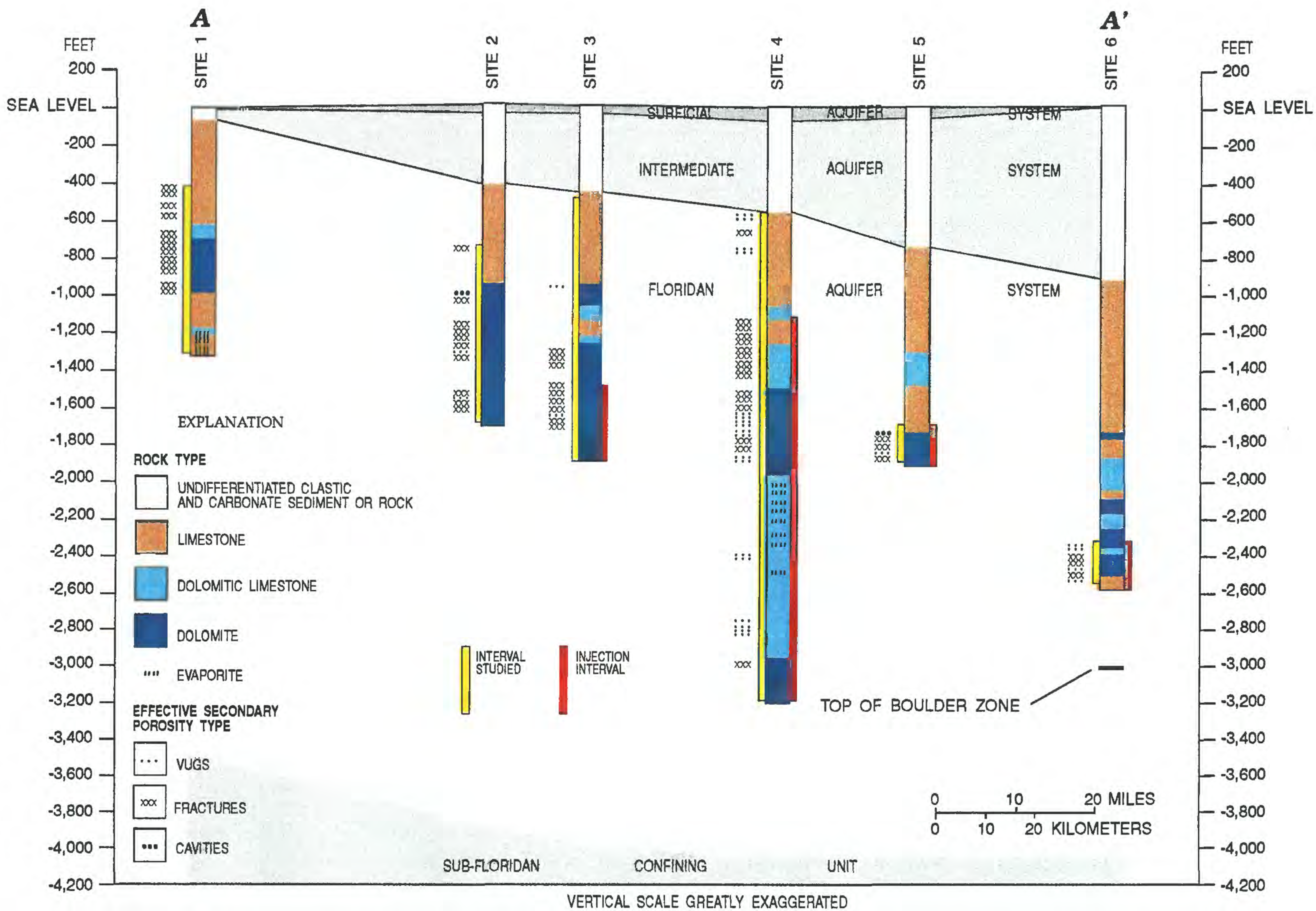


Figure 20. Generalized hydrogeologic section A-A′ showing distribution and relation of effective secondary porosity features to rock type. (Line of section is shown in figure 19.)

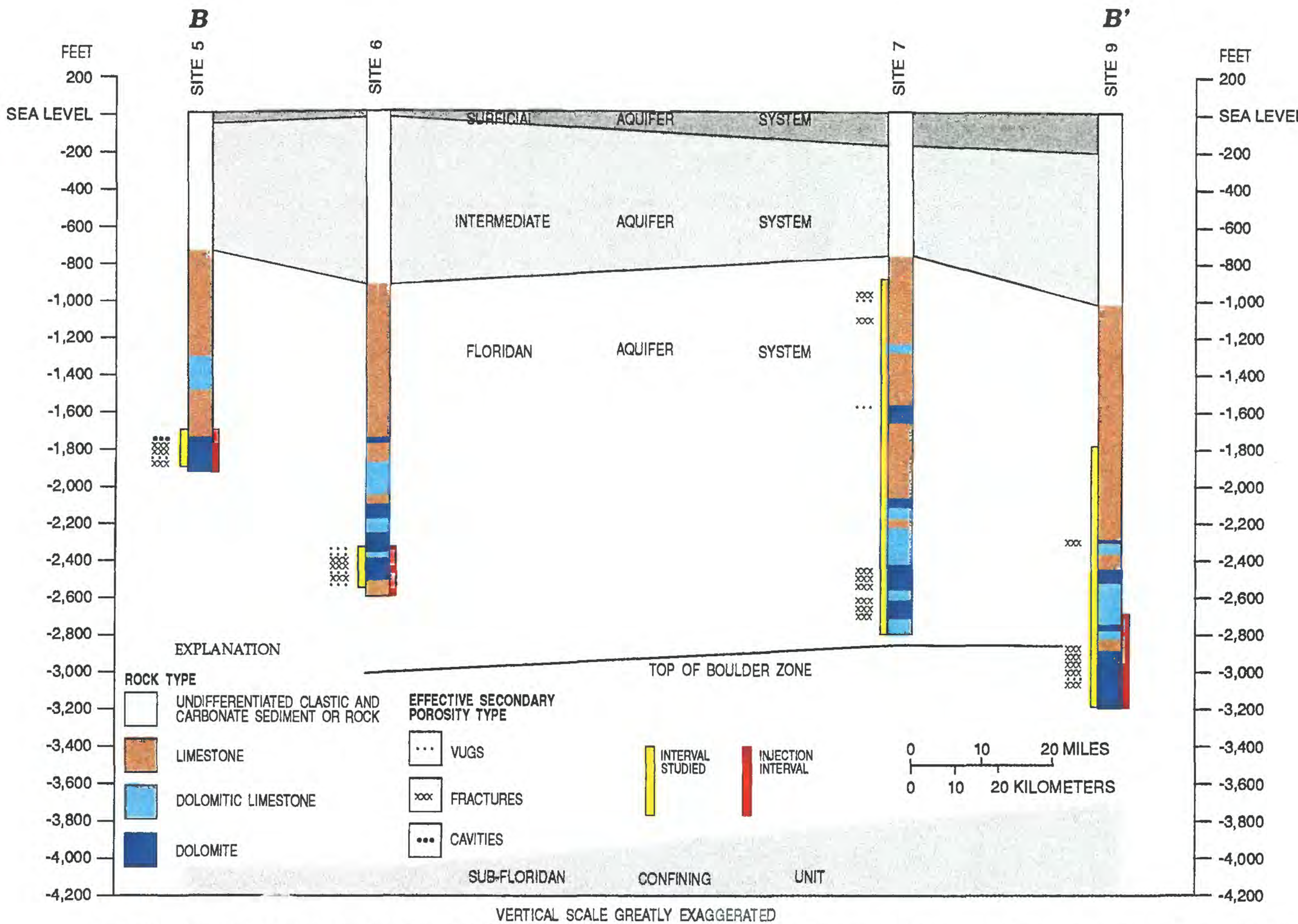


Figure 21. Generalized hydrogeologic section *B-B'* showing distribution and relation of effective secondary porosity features to rock type. (Line of section is shown in figure 19.)

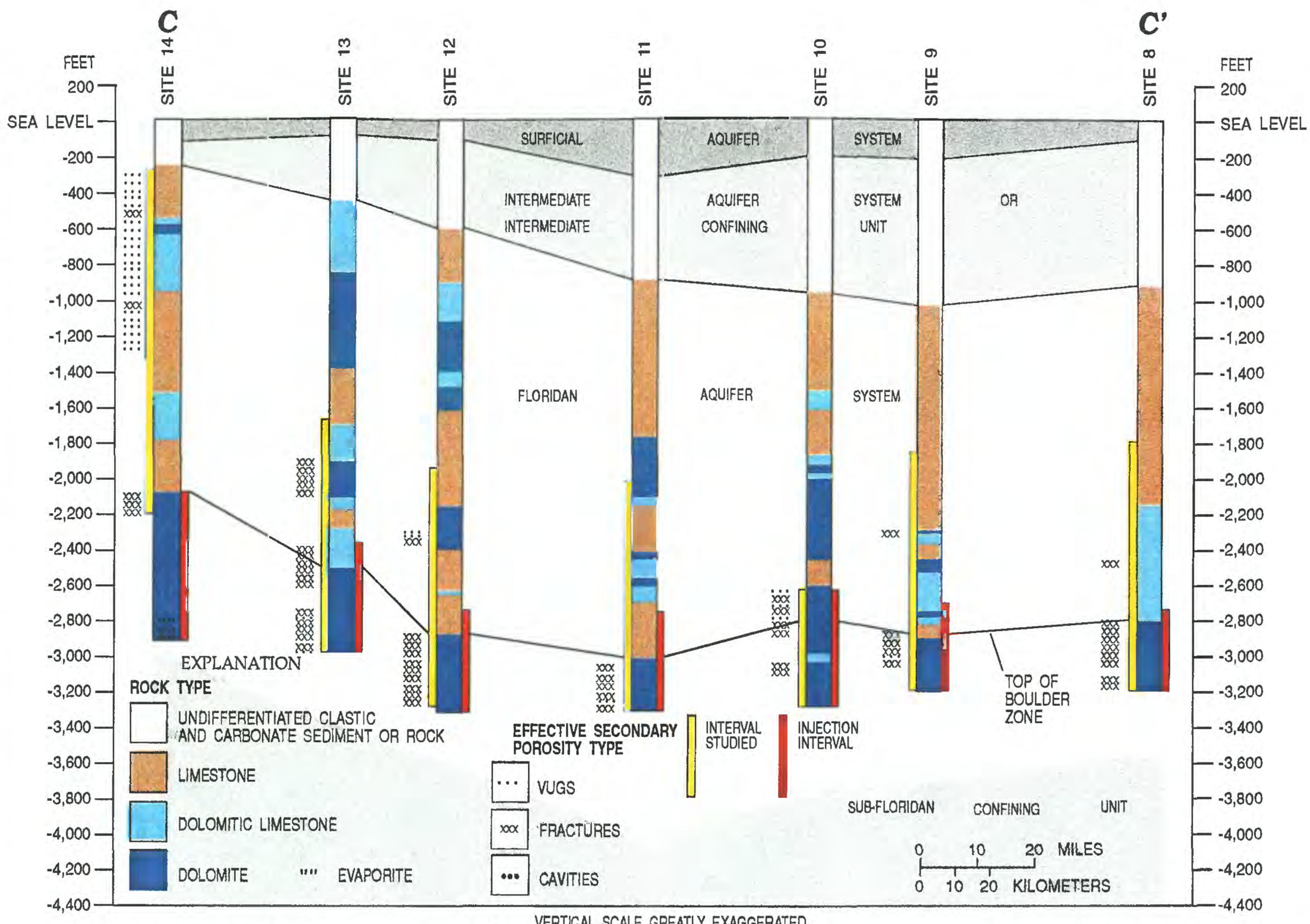


Figure 22. Generalized hydrogeologic section *C-C'* showing distribution and relation of effective secondary porosity features to rock type. (Line of section is shown in figure 19.)

limestone. Borehole diameters only intermittently much larger that the drill bit diameters (shown as spikes on the caliper logs) were associated with dolomite. Intervals where dredging was reported usually contained fractured dolomite rocks and had borehole diameters much larger than the drill bit diameters. The association between fractured dolomite and dredging indicated the collapse of intensively fractured or shattered dolomite in the borehole wall as a probable cause of the relatively large diameters (Safko and Hickey, 1992).

The intensively fractured dolomite rocks observed in the borehole television surveys generally were described as "blocky" (appendix). Intensively fractured dolomites often were associated with water-producing intervals. Cavities also were observed as associated with these fractured rocks in the television surveys. However, because no drill bit drops were reported in most of the blocky intervals, the cavities were designated as apparent porosity, and the effective secondary porosity type was designated as fracture porosity. In southeastern Florida, these blocky dolomite intervals usually correlate with the top of the "boulder zone," are in the Lower Floridan aquifer, and are a significant part of the injection interval (fig. 22).

In southwestern Florida, the blocky, fractured dolomite rocks comprising the injection interval have drilling and hydrogeologic characteristics similar to those of rocks in the "boulder zone" in southeastern Florida (figs. 20 and 22). However, the rocks in southwestern Florida occur in the Upper Floridan aquifer and are not considered part of the "boulder zone" according to Miller (1986), which raises a question about the usefulness of the "boulder zone" concept.

Although the study did not focus on water quality, several observations are worth noting. The interface where the dissolved-solids concentration of water exceeded 10,000 mg/L was in the Floridan aquifer system at all sites except site 5. At site 5 on Gasparilla sland, the 10,000-mg/L interface was in the intermediate aquifer system, less than 200 ft below sea level.

Water temperature increased with depth at sites 1 through 6 on the southwestern coast of Florida and at sites 13 and 14 on the southeastern coast. Water temperature decreased with depth at sites 7 through 12. Water at sites 7 through 12 had a reversal in the geothermal gradient that may be attributed to the cooling effect of the deep bottom water offshore in the Atlantic Ocean (Kohout, 1967).

Information gained from this study can be used for additional purposes. For example, examination of borehole television surveys indicates that the likelihood of having fractures or cavities constituting effective secondary porosity in limestone is minimal. This information could be important in the selection of injection interval depths.

Data available for applying the methods used in this study were limited. For example, borehole television surveys of the rocks overlying the injection interval were available for less than half of the injection wells in southern peninsular Florida. Another limitation was the lack of flowmeter and temperature logs that were run under pumping or injecting conditions. This was especially true for the rocks overlying the injection interval. These logs are essential for determining borehole flow intervals, which are needed to determine if the apparent secondary porosity also is effective secondary porosity. Future applications of the methods used in this study would be improved if the flowmeter and temperature logs are run one after another within the same depth intervals during borehole pumping or injecting and if borehole television surveys also are conducted.

SUMMARY

A recently developed procedural method was used to characterize the types of secondary porosity in carbonate injection intervals and overlying carbonate rocks at 11 injection well sites and 3 test well sites in southern peninsular Florida.

In southern peninsular Florida, the hydrogeologic system consists of a thick sequence of carbonate rocks overlain by clastic deposits. Principal hydrogeologic units are the surficial aquifer system, the intermediate aquifer system or the intermediate confining unit, the Floridan aquifer system, and the sub-Floridan confining unit. The surficial aquifer system consists of Pliocene to Holocene age intermixed sand, clay, shell, and phosphate gravel with stringers of limestone and marl and ranges in thickness from less than 10 ft to more that 300 ft.

The intermediate aquifer system or the intermediate confining unit underlies the surficial aquifer system and includes clastic deposits and rocks that lie between and collectively retard the exchange of water between the overlying surficial aquifer system and the underlying Floridan aquifer system. The intermediate aquifer system ranges in thickness from less than 50 ft to about 1,000 ft.

The Floridan aquifer system underlies the intermediate aquifer system or the intermediate confining unit and consists of a sequence of carbonate rocks ranging from Paleocene to early Miocene in age. The altitude of the top of the Floridan aquifer system ranges from near sea level to about 1,100 ft below sea level. Several low permeability zones separate the aquifer system into the Upper and Lower Floridan aquifers. Dolomites that have high transmissivity and contain saline water are present in the Upper and the Lower Floridan aquifers in southwestern Florida and in the Lower Floridan aquifer in southeastern Florida. In a number of places, these dolomites are used for the injection of liquid wastes. In southeastern Florida, the dolomites form the "boulder zone."

The sub-Floridan confining unit underlies the Floridan aquifer system. The unit is primarily a sequence of evaporite (anhydrite) beds interlayered with low permeability carbonate rocks of Paleocene age and older Series. The presence of this unit limits the depth of active ground-water circulation on mainland Florida.

The concept of apparent secondary porosity was used in this study because the secondary porosity features observed in a borehole television survey could have been caused by geologic processes as well as by drilling activities. The secondary porosity features identified in a television survey were evaluated using driller's comments and caliper, flowmeter, and temperature logs. Borehole intervals that produced or received detectable amounts of flow, as shown by flowmeter and temperature logs, provided evidence 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. Porosity features in these intervals were then identified as effective secondary porosity. Identification of noninterconnected or isolated secondary porosity related to geologic processes was not possible in this study.

This study confirmed the conclusions of earlier investigators that (1) effective secondary porosity of the highly transmissive dolomites within the Floridan aquifer system was predominantly fracture porosity and (2) cavity porosity in video images of those dolomites was usually apparent porosity caused by drilling-induced collapse of fractured borehole walls. In addition, this study concluded that the majority of vugs observed in the borehole television surveys did not constitute effective secondary porosity. This was especially true for the very small and small vugs observed in dolomite and also for most vugs observed in limestone.

Fracture porosity, the most common type of effective secondary porosity, was present predominantly in dolomite and dolomitic limestone. Fractures, either apparent or effective, usually were present above and below cavities, whether apparent or effective. Cavity porosity, the least common type of effective secondary porosity, was present in only three cavities at two sites. The three cavities constituting effective secondary porosity were detected in dolomite rocks.

Effective secondary porosity was not discernible in the limestone or dolomitic limestone in the 300-ft interval immediately above the injection interval at six sites on the southeastern coast of Florida. Fractures or cavities that contribute to effective secondary porosity may be present in this interval, but were not detectable with the methods used. Widely dispersed, interconnected fractures or cavities could exist beyond the rock column intersected by the borehole and could provide local pathways for vertical migration of injected wastewater or the displaced saltwater. Insufficient data were available to make a generalized conclusion about the porosity of rocks immediately overlying the injection interval on the southwestern coast of Florida.

Borehole characteristics usually are related to the drilling characteristics of the rock type. In limestone, borehole diameters are consistently larger than the bit diameters, whereas in dolomite, the borehole diameters are intermittently larger than the bit diameter. The large borehole diameters associated with dredging probably are caused by the collapse of intensively fractured dolomite.

The term "blocky" was used to describe the intensively fractured dolomite rocks associated with water-producing intervals that were usually a significant part of the injection interval. Cavities often were associated with these fractured rocks in the television surveys. However, because drill bit drops rarely were reported, the cavities were designated as having apparent secondary porosity, and the effective secondary porosity type was most often designated as fracture porosity.

The interface where the dissolved-solids concentration of water exceeded 10,000 mg/L was in the Floridan aquifer system at all sites except site 5. At site 5 on Gasparilla Island, the 10,000 mg/l interface was in the intermediate aquifer system. Water temperature increased with depth in the Floridan aquifer system at sites 1 through 6 and sites 13 and 14. Water temperature decreased with depth at sites 7 through 12, possibly because of the cooling effect of deep bottom water offshore in the Atlantic Ocean.

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Appendix

Logs of Television Surveys of Boreholes at Sites 1-14

Site 1--Clearwater East Test Well, Pinellas County, Florida

Depth, in feet below sea level	Description of borehole and notable features
405	Out of casing.
405 to 466	Fractures and cavities; large cavity at 415 ft; blocky, irregular, rough borehole.
466 to 500	Not much apparent secondary porosity; occasional small vug and fracture; round, smooth borehole.
500 to 515	Fractures, wide, high angle; somewhat blocky, irregular, rough borehole.
515 to 542	No apparent secondary porosity; round, smooth to pitted borehole.
542 to 543	Cavity with fractures; irregular, rough borehole.
543 to 553	No apparent secondary porosity; similar to interval 515 to 542 ft; round, smooth borehole.
553 to 585	Fractures, high angles; occasional medium vug; round, smooth to rough borehole.
585 to 590	Cavity, large, with fractures; blocky, irregular borehole.
590 to 623	Vugs, small to large, round to angular; round, smooth to rough borehole.
623 to 633	Cavities, small, with fractures; somewhat blocky, irregular, rough borehole.
633 to 653	Vugs, small to large, most are angular, with some fractures; round borehole.
653 to 683	Fractures and cavities, many of each; blocky, irregular rough borehole.
683 to 688	No apparent secondary porosity; round, smooth borehole.
688 to 694	Cavities, small; fractures, high angle; somewhat blocky, irregular borehole.
694 to 713	Not much apparent secondary porosity; occasional small to large vug; wide, concentric darker band at 696 ft; round, smooth to pitted borehole.
713 to 742	Fractures, wide, high angle; looks like drilling tool scraping marks on borehole wall; round to irregular borehole.
742 to 773	Fractures and cavities; blocky, round to irregular, rough borehole.
773 to 842	Fractures, high angle; a few small to large vugs or small cavities; not as blocky as above; round to irregular, rough borehole.
842 to 885	Fractures and cavities; large cavities at 846, 848, 850, 852, 855, 858, 861, 866, 882, and 884 ft; particles moving downward; blocky, irregular, smooth to rough borehole.
885 to 916	Vugs, very small to medium; occasional narrow fracture; not much apparent secondary porosity; round, smooth to rough borehole.
916 to 932	Fractures and cavities; small cavities at 920, 923, and 927 ft; particles moving downward; round to irregular borehole.

Site 1.--Clearwater East Test Well, Pinellas County, Florida--Continued

Depth, in feet below sea level	Description of borehole and notable features
932 to 950	Vugs, very small to small; occasional fracture; not much apparent secondary porosity; round, pitted to rough borehole.
950 to 998	Fractures and cavities; large cavities at 955, 958, 960, 969, 972, and 986 ft; particles moving downward; blocky, irregular, rough borehole.
998 to 1,043	Fractures in the form of jagged or angular parts of borehole, especially near small cavities at 1,011, 1,016, and 1,029 ft; also very small to large vugs, round to angular; becoming murky at 1,016 ft; doesn't appear to have much secondary porosity; round to irregular, smooth to rough borehole.
1,043 to 1,077	Vugs, very small to large, mostly round, but several of the large ones are angular, also a few discontinuous, concentric vugs; small cavities at 1,046 and 1,060 ft with larger cavity at 1,072 ft; not as murky as above; particles moving downward; round, smooth to pitted borehole.
1,077 to 1,085	Cavities, large; also fractures; boulder at 1,080 ft; particles moving downward; round to irregular, smooth to rough borehole.
1,085 to 1,128	Combination of very small to large, round vugs; fractures and small cavities; also several concentric, dark bands; round to irregular, smooth to rough borehole.
1,128 to 1,130	Concentric, light-colored bands, may be gypsum; round, smooth borehole.
1,130 to 1,142	No apparent secondary porosity; round mostly smooth borehole.
1,142 to 1,144	Fractures, criss-cross pattern, appear to be filled with darker material; also discontinuous, concentric vug; round, smooth borehole.
1,144 to 1,155	No apparent secondary porosity; occasional very small vug; round, smooth borehole.
1,155 to 1,160	Not much apparent secondary porosity; fractures at 1,155 and 1,157 ft; some very small to small vugs; round, pitted borehole.
1,160 to 1,167	Cavities and fractures; boulders setting on ledge; blocky, irregular, and rough borehole.
1,167 to 1,191	No apparent secondary porosity; looks tight; lighter colored material; round, smooth borehole.
1,191 to 1,208	No apparent secondary porosity; possible lithologic contact at 1,191 ft; becoming murky (decreased visibility); particles moving downward; lighter material in criss-cross pattern with darker lines, possibly gypsum; round, very smooth borehole.
1,208 to 1,209	Cavity.
1,209 to 1,273	No apparent secondary porosity; occasional small to large vug, some are discontinuous, concentric, some apparently filled with gypsum; still murky; lighter colored material; round, very smooth borehole.

Site 1.--Clearwater East Test Well, Pinellas County, Florida--Continued

Depth, in feet below sea level	Description of borehole and notable features
1,273 to 1,317	No apparent secondary porosity; visibility decreasing; particles still moving downward; more apparent gypsum-filled small to medium vugs; very small, round, dark spots (vugs?) below 1,280 ft; round, smooth borehole.
1,317	End of television survey.

Site 2--Manatee County Southwest Exploratory Well, Manatee County, Florida

Depth, in feet below sea level	Description of borehole and notable features
718	Out of casing.
718 to 722	No apparent secondary porosity; round, smooth borehole.
722 to 733	Fractures, wide, vertical; cavity at 722 and 729 ft; blocky, round to irregular, rough borehole.
733 to 919	Occasional very small to small vug; little or no apparent secondary porosity; poor visibility, especially murky from 791 to 796 ft; round, smooth borehole.
919 to 923	Same as above, but not as smooth.
923 to 926	Vugs, very small to small; discontinuous, concentric vug and downward flow at 925 ft; round, smooth borehole.
926 to 933	Fractures, narrow to wide, vertical; round, smooth to pitted borehole.
933 to 940	Not much apparent secondary porosity; round, pitted borehole.
940 to 959	Fractures, narrow to wide, vertical; downward flow observed; does not look like it produces much water; few small vugs 958 to 959 ft; round, smooth borehole.
959 to 973	Vugs, small, with narrow fractures; round, smooth to rough borehole.
973 to 979	Fractures, with many very small to small vugs; round to irregular, smooth borehole.
979 to 980	Cavity.
980 to 985	Fractures, wide; blocky, irregular, rough borehole.
985 to 990	Vugs, very small to small, numerous; murky at 989 ft; round borehole.
990 to 992	Fractures; small cavity at 991 ft; irregular, rough borehole.
992 to 1,026	No apparent secondary porosity; occasional very small to small vug; isolated high angle, short, wide fractures or angular vugs at 1,011 and 1,015 ft; round, smooth borehole.
1,026 to 1,027	Dark concentric bands; round, smooth borehole.
1,027 to 1,029	Vugs, small; round, smooth borehole.
1,029 to 1,040	Fractures, wide and linear, various angles, with small vugs; round, smooth borehole.
1,040 to 1,096	No apparent secondary porosity; murky; possible vugs at 1,091 ft; round, smooth borehole.
1,096 to 1,103	Fractures, all angles; still murky; round, smooth to rough borehole.
1,103 to 1,115	Vugs, very small to small; dark concentric band at 1,110 ft; round, smooth borehole.
1,115 to 1,129	Fractures, narrow to wide, some high angle, look like dark streaks with small vugs and concentric dark bands 1,119 to 1,121 ft; small cavities at 1,116 and 1,122 ft; round borehole.
1,129 to 1,263	Fractures, wide; cavities at 1,135, 1,152, 1,157, 1,167, 1,199, 1,201, and 1,216 ft; and large cavity at 1,226 to 1,231 ft; cavities also at 1,245, 1,252, and 1,257 ft, with occasional small angular vug; downward flow observed at 1,135 and 1,226 ft; blocky, round to irregular and smooth to rough borehole.

Site 2--Manatee County Southwest Exploratory Well, Manatee County, Florida--Continued

Depth, in feet below sea level	Description of borehole and notable features
1,263 to 1,287	Vugs, small to medium, numerous; occasional narrow, dark concentric band; small cavity or large vug at 1,280 ft; round, smooth borehole.
1,287 to 1,353	Fractures and cavities; particles falling down well; blocky, round to irregular, smooth to rough borehole.
1,353 to 1,500	Fractures and vugs, fractures are at various angles, some high angle; vugs are very small to large; interval seems tighter than that above; mostly round, smooth to rough borehole.
1,500 to 1,514	Intermittent fractures and cavities; blocky, round to irregular borehole.
1,514 to 1,557	Vugs and fractures; similar to interval 1,353 to 1,500 ft.
1,557 to 1,622	Intermittent fractures and cavities; somewhat blocky in places, but mostly round to irregular, smooth to rough borehole.
1,622 to 1,640	Vugs, very small to small; round, smooth borehole.
1,640 to 1,676	Fractures and vugs, vugs are very small to large; borehole is mostly round and smooth except at 1,657 ft where it is irregular and blocky.
1,676	End of television survey.

Site 3--Atlantic Utilities Exploratory and Injection Wells, Sarasota County, Florida

Depth, in feet below sea level	Description of borehole and notable features
	Exploratory Well
180 to 196	Poor visibility.
196 to 198	Cavity.
208 to 209	Cavity.
209 to 286	Poor visibility; occasional very small to small vug; not much apparent secondary porosity; round borehole.
286 to 287	Cavity.
289 to 291	Cavity.
291 to 357	Not much apparent secondary porosity; occasional very small to small vug with discontinuous, concentric vug at 336 ft; possible small fracture at 345 ft; round, smooth borehole.
357 to 400	Not much apparent secondary porosity; occasional very small vug; dark-colored blotches on round, smooth to pitted borehole.
400 to 481	Vugs, very small to small; possible fracture at 400 ft; poor visibility (difficult to see with light reflection); dark colored blotches on round, pitted borehole.
481 to 515	Fractures, with small angular vugs; large vug or small cavity at 490 ft; irregular, rough borehole.
515 to 517	Cavity.
517 to 936	Poor lighting, probably not much apparent secondary porosity; a few small vugs at 690 to 692 ft; medium to large vugs and vertical dark streaks at 762 to 764 ft; more dark streaks at 777 ft; becoming more murky at 816 ft and then better visibility at 925 ft; round, smooth borehole.
936 to 937	Cavity, small; round, smooth borehole.
937 to 957	Vugs, medium; round, pitted borehole.
957 to 1,028	Not much apparent secondary porosity; occasional vug, some discontinuous, concentric vugs.
1,028 to 1,029	Possible small vertical fractures.
1,029 to 1,035	Vugs, small; round borehole.
1,035 to 1,037	Fractures, wide; medium vugs.
1,037 to 1,044	No apparent secondary porosity.
1,044 to 1,049	Fractures; round borehole.
1,050 to 1,051	Cavity.
1,054 to 1,057	Vugs, large, discontinuous, concentric; round borehole.
1,060 to 1,061	Cavity.
1,061 to 1,096	No apparent secondary porosity.
1,096 to 1,099	Fractures; medium discontinuous, concentric vug; round borehole.
1,099 to 1,103	Vugs, very small to small; round borehole.
1,103 to 1,167	No apparent secondary porosity.
1,167 to 1,168	Fracture, 1 to 2 in. wide; round borehole.
1,168 to 1,206	No apparent secondary porosity.
1,206 to 1,215	Fractures; angular, blocky borehole.
1,215 to 1,220	No apparent secondary porosity.

Site 3--Atlantic Utilities Exploratory and Injection Wells, Sarasota County, Florida--Continued

Depth, in feet below sea level	Description of borehole and notable features
1,220 to 1,228	Vugs, large, discontinuous, concentric; round borehole.
1,228 to 1,231	Fracture, vertical; round borehole.
1,231 to 1,242	No apparent secondary porosity.
1,242 to 1,262	Poor visibility; possible fractures; rough borehole.
1,262 to 1,282	Poor visibility; dark blotches; occasional small vug.
1,282 to 1,299	Poor visibility.
1,299	Possible cavity.
1,303	Possible cavity.
1,305	Sudden appearance of flow or turbidity.
1,305 to 1,318	Occasional small vug.
1,318 to 1,338	Cavities, small to large; fractures; occasional vug, round to irregular borehole.
1,338 to 1,370	Cavities, small to medium; wide fractures; some vugs; round to irregular, blocky borehole.
1,370 to 1,460	Fractures and large vugs or small cavities alternating with intervals containing no apparent secondary porosity; round to irregular borehole.
	Injection Well
1,460 to 1,572	Alternating sequences of fractures (some vertical and some showing as narrow, linear, dark streaks) and areas with little or no apparent secondary porosity; occasional discontinuous, concentric vug; wide spots or cavities at 1,492 and 1,552 ft; round to irregular, smooth to rough borehole.
1,572 to 1,575	Fractures, wide; blocky, irregular, rough borehole.
1,575 to 1,576	Cavity
1,576 to 1,590	Fractures, with some large, discontinuous, concentric vugs; round borehole.
1,590 to 1,591	Cavity.
1,591 to 1,604	Vugs, small to medium, with narrow fractures; round borehole.
1,604 to 1,649	Fractures, mostly narrow, with very small to large vugs, some discontinuous, concentric vugs; round to irregular borehole.
1,649 to 1,655	Vugs, small to large; flow is downward; round, smooth borehole.
1,655 to 1,676	Fractures.
1,676 to 1,678	Cavity.
1,678 to 1,780	Alternating sequences of narrow fractures and very small to small vugs; possible small cavity or large vug at 1,712 ft; possibly gypsum in fracture at 1,750 ft; round, smooth to rough borehole.
1,780 to 1,847	Not much apparent secondary porosity; possibly gypsum nodules in discontinuous, concentric vugs; downward flow observed at 1,809 and 1,829 ft; flow appeared to increase at 1,829 ft; round, smooth borehole.
1,847 to 1,855	Murky, no visibility.

Site 3--Atlantic Utilities Exploratory and Injection Wells, Sarasota County, Florida--Continued

Depth, in feet below sea level	Description of borehole and notable features
1,855 to 1,880	Vugs, discontinuous, concentric, not filled with gypsum; downward flow 1,859 and 1,865 ft; round, smooth borehole.
1,880 to 1,902	Vugs, few, discontinuous, concentric, some possibly filled with gypsum, but most not; not much apparent secondary porosity, but, at 1,901 ft, flow appears to be downward; round, smooth borehole.
1,902	End of television survey.

Site 4--North Port Injection Well, Sarasota County, Florida

Depth, in feet below sea level	Description of borehole and notable features
550 to 590	Vugs, very small to small; large vug or small cavity at 590 ft; round, smooth to rough borehole.
590 to 600	No apparent secondary porosity; round, smooth borehole.
600 to 602	Vugs, small to medium; round, smooth borehole.
602 to 613	No apparent secondary porosity; round, smooth borehole.
613 to 620	Vugs, very small to small; round, smooth to rough borehole.
620 to 655	No apparent secondary porosity; round, smooth borehole.
655 to 665	Vugs, very small; round borehole.
665 to 670	Fractures; round, rough borehole.
670 to 718	Vugs, very small, few; round, smooth borehole.
718 to 728	No apparent secondary porosity; round, smooth borehole.
728 to 762	Vugs, very small to medium; round, smooth borehole.
762 to 774	Vugs, small; a few small fractures; round, rough borehole.
774 to 779	Fractures; small cavity; irregular, rough borehole.
779 to 790	Vugs, small to large; fractures; round, smooth borehole.
790 to 820	Vugs, very small to small; dark concentric bands at 797 ft; dark blotches on round, smooth to rough borehole.
820 to 965	No apparent secondary porosity; round, smooth borehole.
965 to 966	Fractures, small, high angle; round, smooth borehole.
966 to 989	No apparent secondary porosity; round, very smooth borehole.
989 to 990	Vug, one large concentric shape; round, very smooth borehole.
990 to 1,080	No apparent secondary porosity; one small vug; round, very smooth borehole.
1,080 to 1,120	Vugs, very small to small; dark blotches on round, smooth borehole.
1,120 to 1,130	Cavities (1,120, 1,121, 1,128, and 1,130 ft), with fractures and small vugs; irregular, smooth borehole.
1,130 to 1,140	Fractures, with small vugs; poor visibility (lighting); irregular, smooth borehole;
1,140 to 1,163	Vugs, small to large; round, smooth borehole.
1,163 to 1,170	Fractures; irregular, smooth borehole.
1,170 to 1,176	Vugs, very small to small; round, smooth borehole.
1,176 to 1,188	Cavities (1,180-1,182 and 1,185-1,186 ft), with fractures and small vugs; blocky, irregular, rough borehole.
1,188 to 1,190	Vugs, medium, concentric; round, smooth borehole.
1,190 to 1,206	No apparent secondary porosity.
1,206 to 1,212	Fractures; irregular borehole.
1,212 to 1,215	Cavity; irregular borehole.
1,215 to 1,222	Fractures; irregular borehole.
1,222 to 1,260	Cavities, with many fractures; few small vugs; ledge at 1,258 ft; irregular, rough borehole.
1,260 to 1,270	Vugs, very small; round, smooth borehole.
1,270 to 1,280	Cavities, with fractures.
1,280 to 1,295	Fractures, with very small to small vugs; irregular, smooth borehole.
1,295 to 1,320	Fractures, with small cavities; blocky, irregular borehole.

Site 4--North Port Injection Well, Sarasota County, Florida--Continued

Depth, in feet below sea level	Description of borehole and notable features
1,320 to 1,327	Cavity, large.
1,327 to 1,402	Fractures, smaller, not as many as above, with very small vugs; irregular borehole.
1,402 to 1,403	Cavity, small.
1,403 to 1,420	Fractures; rough borehole.
1,420 to 1,427	No apparent secondary porosity; round, smooth borehole.
1,427 to 1,428	Cavity.
1,428 to 1,442	Fractures, with very small vugs; blocky, irregular, rough borehole.
1,442 to 1,462	Vugs, very small to small, with some fractures; round, smooth, borehole.
1,462 to 1,490	No apparent secondary porosity; round, smooth borehole.
1,490 to 1,496	Cavity (1,495-1,496 ft), with fractures; irregular, rough borehole.
1,496 to 1,501	Fractures; blocky, irregular, rough borehole.
1,501 to 1,502	Cavity.
1,502 to 1,545	Fractures, high angle, with many cavities; boulder blocking camera access at 1,512 ft; camera removed to knock boulder free; blocky, round, rough borehole.
1,545 to 1,598	Vugs, small to medium, angular to round; round, smooth borehole.
1,598 to 1,600	Fractures; possible small cavity or large vug; irregular, rough borehole.
1,600 to 1,790	Vugs, small to medium, angular and concentric, with a few high angle fractures; small cavity at 1,712 and 1,736 ft; round, smooth to rough borehole.
1,790 to 1,805	Fractures, with small to medium vugs; round, smooth to rough borehole.
1,805 to 1,810	Cavity, with fractures; irregular borehole.
1,810 to 1,823	Fractures, with small vugs; round, rough borehole.
1,823 to 1,860	Vugs, very small to small; round, smooth to rough borehole.
1,860 to 1,861	Cavity, small.
1,861 to 1,882	Vugs, very small to medium, occasional discontinuous concentric vug; round, smooth to rough borehole.
1,882 to 1,925	No apparent secondary porosity; concentric beds of vugs apparently filled with gypsum at depths of 1,882, 1,887, 1,889, 1,896, 1,912, 1,915, and 1,920 ft; round, very smooth borehole.
1,925 to 1,950	Vugs, small, rounded, some filled with gypsum; round, very smooth borehole.
1,950 to 2,170	No apparent secondary porosity; occasional small vug, some filled with gypsum; some small dark blotches; several concentric bands of gypsum; round, smooth borehole.
2,170 to 2,190	No apparent secondary porosity; much gypsum; small vugs, most filled with gypsum; tiny fractures at 2,178 ft; less smooth to rough borehole.
2,190 to 2,210	No apparent secondary porosity.
2,210 to 2,223	Vugs, very small to small, with much gypsum; round, rough borehole.

Site 4--North Port Injection Well, Sarasota County, Florida--Continued

Depth, in feet below sea level	Description of borehole and notable features
2,223 to 2,245	No apparent secondary porosity; occasional small vug.
2,245 to 2,255	Vugs, very small to small, some filled with gypsum; round, smooth borehole.
2,255 to 2,280	No apparent secondary porosity; occasional small vug and gypsum; round, smooth borehole.
2,280 to 2,305	No apparent secondary porosity; gypsum; small fractures at 2,293 ft; round, smooth borehole.
2,305 to 2,330	Vugs, very small to small; gypsum; round, smooth borehole.
2,330 to 2,380	No apparent secondary porosity; gypsum; occasional small vug; round, smooth borehole.
2,380 to 2,400	Vugs, very small to small, few; round, smooth borehole.
2,400 to 2,423	No apparent secondary porosity; round, smooth borehole.
2,423 to 2,430	Vugs, very small to small; round, rough borehole.
2,430 to 2,460	No apparent secondary porosity; round, smooth borehole.
2,460 to 2,495	Vugs, very small to small; round, smooth borehole.
2,495 to 2,520	No apparent secondary porosity; round, smooth borehole.
2,520 to 2,530	Vugs, very small to small; round, smooth borehole.
2,530 to 2,617	No apparent secondary porosity; upward flow observed at 2,534 ft; some gypsum; occasional vug; round, smooth borehole.
2,617 to 2,624	Vugs, very small; round, rough borehole.
2,624 to 2,637	No apparent secondary porosity; concentric dark bands; round, smooth borehole.
2,637 to 2,685	Vugs, very small; round, smooth borehole.
2,685 to 2,716	Vugs, very small to small; gypsum at 2,716 ft; round, smooth borehole.
2,716 to 2,745	No apparent secondary porosity; round, smooth borehole.
2,745 to 2,825	Vugs, very small to small, one medium vug at 2,825 ft; round, smooth borehole.
2,825 to 2,840	No apparent secondary porosity; round, very smooth borehole.
2,840 to 2,983	Vugs, very small to occasional small; round, smooth borehole.
2,983 to 3,000	Fractures, high angle; small vugs; round borehole.
3,000 to 3,001	Cavity, small.
3,001 to 3,090	Vugs, small to large, with fractures; gypsum at 3,010, 3,020, 3,035, and 3,065 ft and other depths, gypsum-filled vugs and fractures; round to irregular, smooth to rough borehole.
3,090	End of television survey.

Site 5--Gasparilla Island Injection Well, Lee County, FLorida

Depth, in feet below sea level	Description of borehole and notable features
1,694 to 1,722	Vugs, very small to small; small fractures; apparent downward flow; round, smooth borehole.
1,722 to 1,726	Vugs, very small to small, angular; small fractures; round, rough borehole.
1,726 to 1,732	Fractures, small; very small to medium vugs; round, smooth borehole.
1,732 to 1,736	Vugs, small, some appear to be filled with gypsum; fractures, small; small cavity at 1,735 ft; round to irregular, rough borehole.
1,736 to 1,756	Fractures, high angle; small cavity at 1,742 ft; small to medium vugs; blocky, irregular, rough borehole.
1,756 to 1,770	Vugs, very small to medium; fractures, less blocky; possible small gypsum nodules; round, smooth to rough borehole.
1,770 to 1,774	Fractures; pebble-sized rocks at 1,772 ft; upward flow; irregular borehole.
1,774 to 1,776	Cavity, large; borehole walls out of view.
1,776 to 1,780	Fractures; small to medium vugs, some discontinuous, concentric-shaped; round, rough borehole.
1,780 to 1,781	Vug, large, concentric; round, rough borehole.
1,781 to 1,788	Fractures, large, high angle; very small to medium vugs; round to irregular, smooth to rough borehole.
1,788 to 1,792	Vugs, small to medium; small fractures; round borehole.
1,792 to 1,795	Fractures; small to medium vugs; irregular, rough borehole.
1,795 to 1,796	Cavity; blocky, irregular, rough borehole.
1,796 to 1,801	Fractures, angular; very small to small vugs; blocky, irregular, rough borehole.
1,801 to 1,802	Cavity.
1,802 to 1,806	Vugs, very small to small; few small fractures; irregular, rough borehole.
1,806 to 1,807	Fractures; very small to large vugs; irregular, rough borehole.
1,807 to 1,816	Vugs, very small to medium, angular; fractures; irregular, rough borehole with pieces broken off.
1,816 to 1,824	Vugs, very small to small, elongated shape; criss-crossing patterns; fractures; lighting-reflection change; small gypsum nodules at 1,823 ft; round, smooth borehole.
1,824	Much upward flow.
1,824 to 1,826	Fractures immediately below flow area; irregular borehole.
1,826 to 1,840	Vugs, very small to small; some elongated, angular, larger ones filled with gypsum.
1,840 to 1,841	Cavity, borehole walls out of view.
1,841 to 1,862	Vugs, very small to large; dark blotches on round to irregular, rough borehole.
1,862 to 1,871	Vugs, very small to small, angular vugs or small fractures at 1,865 ft; less vugs with depth; possible fracture at 1,871 ft; round, rough borehole.
1,871 to 1,889	Fractures; very small to small vugs; blocky; round to irregular, rough borehole.
1,889	End of television survey.

Site 6--North Fort Myers Injection Well, Lee County, Florida

Depth, in feet below sea level	Description of borehole and notable features
1,560	Out of casing.
1,560 to 1,650	Vugs, very small to small, angular; dark blotches on round, smooth borehole.
1,650 to 1,660	Cavities small, with very small vugs; round, smooth borehole.
1,660 to 1,724	Vugs, very small to small, rounded; with a few fractures; blotches on round, smooth borehole.
1,724 to 1,740	Cavities, small, with vertical fractures; irregular, rough borehole.
1,740 to 1,760	Fractures, vertical, with a few small vugs; dark blotches on round, smooth borehole.
1,760 to 1,893	Fractures, vertical, with very small to small, rounded vugs; dark blotches on round, smooth borehole.
1,893 to 1,894	Cavity, small.
1,894 to 1,909	Fractures, with small vugs; round, rough, blocky borehole.
1,909 to 1,940	Occasional very small to small vug; concentric dark bands; dark blotches on round, smooth borehole.
1,940 to 1,973	Vugs, very small to medium, rounded, with a few vertical fractures; dark blotches on round, smooth borehole. borehole.
1,973 to 1,990	Fractures, vertical, with small vugs; small cavity at 1,986 ft; looks like upward flow may be distorting shape of borehole; dark blotches on irregular, rough borehole.
1,990 to 2,090	Vugs, very small to small; dark blotches on round to irregular, smooth to rough borehole.
2,090 to 2,130	Fractures, with cavities at 2,114 and 2,120 ft, with very small vugs; blocky, round to irregular, smooth to rough borehole.
2,130 to 2,160	Vugs, very small to small, with small cavities at 2,135 ft; dark blotches on round, smooth borehole.
2,160 to 2,170	Fractures, with very small vugs; round to irregular, smooth borehole.
2,172 to 2,173	Cavity, small.
2,173 to 2,210	Vugs, very small to small; dark blotches on round, smooth borehole.
2,210 to 2,250	No apparent secondary porosity; dark blotches on one-half of round, smooth borehole.
2,250 to 2,280	Vugs, very small to small, with small fractures; round, smooth borehole.
2,280 to 2,310	Vugs, small to large, more numerous, rounded, with fractures.
2,310 to 2,385	Vugs, small, rounded, with fractures; small cavity at 2,360 ft; mostly round, smooth borehole.
2,385 to 2,413	Fractures, with some small to medium vugs; large cavity from 2,404 to 2,406 ft; round to irregular, smooth borehole.
2,413 to 2,450	Vugs, small, many, with many fractures; smooth borehole.
2,450 to 2,475	Fractures, with small vugs; round, smooth borehole.

Site 6--North Fort Myers Injection Well,
Lee County, Florida--Continued

Depth, in feet below sea level	Description of borehole and notable features
2,475 to 2,513	Vugs, small, with fractures; possible small cavity at 2,508 ft; concentric dark bands; mostly round and smooth borehole.
2,513 to 2,514	Cavity, large.
2,514 to 2,525	Fractures; concentric dark bands, dark particles (lignite?) flecking off sides; round, rough to smooth borehole.
2,525 to 2,555	No apparent secondary porosity; poor visibility.
2,555 to 2,570	Vugs, small; poor visibility; round, smooth borehole.
2,570 to 2,583	Poor visibility.
2,583	End of television survey.

Site 7--Alligator Alley Test Well, Broward County, Florida

Depth, in feet below sea level	Description of borehole and notable features
880	Out of 16-in. casing; last 2 ft look like they are at an angle to the rest.
880 to 952	Not much apparent secondary porosity; occasional very small to small vug; maybe algae growth on round borehole.
952 to 958	Fractures and cavities; angular; blocky, irregular, rough borehole.
958 to 969	Vugs, very small to small, round to angular; dark blotches or possible vugs; round, smooth borehole.
969 to 1,091	No apparent secondary porosity; strong upward flow blurs image; poor visibility.
1,091 to 1,100	Fractures, some high angular; blocky, irregular, rough borehole.
1,100 to 1,108	Vugs, very small to medium; round, smooth borehole.
1,108 to 1,551	No apparent secondary porosity; intermittent dark blotches on borehole wall, some are linear on one side as if caused by tool scraping; occasional concentric dark bands and small to medium vugs.
1,551 to 1,565	Vugs, very small to small, few; round, smooth borehole.
1,565 to 1,602	Not much apparent secondary porosity; occasional vug and concentric dark band and round dark blotches; round, mostly smooth borehole.
1,602 to 1,609	Small cavity or large vug, with fractures; irregular, rough borehole.
1,609 to 1,616	Vugs, very small to medium, circular and discontinuous concentric; round, smooth borehole.
1,616 to 1,653	No apparent secondary porosity; round, smooth borehole
1,653 to 1,661	Vugs, large, discontinuous concentric; round, smooth borehole.
1,661 to 2,087	No apparent secondary porosity; occasional small to medium vugs and dark concentric band; looks like gypsum-filled vugs at 1,675, 1,680 and 1,739 ft; round, smooth borehole, but rough at 2,072 and 2,073 ft.
2,087 to 2,107	Vugs, very small to medium; few narrow linear fractures at 2,100 ft; round, but not as smooth borehole.
2,107 to 2,117	Not much secondary porosity; round, smooth borehole.
2,117 to 2,125	Fractures, narrow and short, various angles; light colored (looks like gypsum), round, rough borehole.
2,125 to 2,145	Not much secondary porosity; occasional very small to small vug and concentric dark band; round, smooth borehole.
2,145 to 2,150	Fractures, narrow and short; doesn't look like a water-producing interval; round, smooth borehole.
2,150 to 2,195	Not much secondary porosity; many dark concentric bands; narrow fracture at 2,162 ft; round, smooth borehole.
2,195 to 2,205	Fractures, narrow and small; flow observed at 2,201 ft and blurred image; angular, irregular, smooth to rough borehole.
2,205 to 2,244	Not much secondary porosity; occasional vug and concentric dark band; something flapping at the borehole wall at 2,229 ft showing upward flow; round, smooth borehole.

Site 7--Alligator Alley Test Well, Broward County, Florida--Continued

Depth, in feet below sea level	Description of borehole and notable features
2,244 to 2,252	Fractures, small, narrow and high angle; also cavity from 2,245 to 2,246 ft; round to irregular, smooth to rough borehole.
2,252 to 2,430	Not much secondary porosity; occasional very small to small vug with numerous concentric dark bands; looks like gypsum-filled vug at 2,315 ft; upward flow; round, smooth borehole.
Special Note:	Boulder blocking borehole at 2,407 ft and camera unable to pass; new television survey made after boulder was drilled out. In the new television survey, a cavity was viewed at 2,420 ft and the depth counter was reset to read 2,430 ft; (actually 2,435 and 2,445 ft below land surface, which is 15 ft above sea level). Consequently, it is uncertain if the depths above 2,430 ft are accurate or should have been adjusted.
2,430 to 2,556	Fractures and cavities, intermittent in irregular, rough borehole; with concentric dark bands in round, smooth borehole; flow is upward at 2,430 ft and weaker or downward at 2,537 ft; not sure if well is flowing at surface; cavities at 2,430, 2,443, 2,457, 2,476, 2,505, 2,527, 2,530, and 2,536 ft.
2,556 to 2,599	No apparent secondary porosity; looks like gypsum nodules; round, smooth borehole; flow is possibly zero or downward at 2,580 ft because small particles are observed falling downward.
2,599 to 2,701	Fractures and cavities; fractures are large and numerous; round to irregular, smooth to rough borehole.
2,701 to 2,792	Not much apparent secondary porosity; becoming more murky; particles observed falling down borehole; round, pitted to rough borehole.
2,792	End of television survey.

Site 8--Miami-Dade Injection Well Number 5, Dade County, Florida

Depth, in feet below sea level	Description of borehole and notable features
1,784	End of casing.
1,786 to 1,788	Large cavity, with fractures; blocky; irregular, rough borehole.
1,788 to 1,980	No apparent secondary porosity; occasional small vug or dark blotch; thin dark concentric band at 1,789, 1,843, 1,852, and 1,907 ft; round, smooth borehole.
1,980 to 2,000	Poor visibility, bad lighting, murky.
2,000	Camera orientation changes, better visibility.
2,000 to 2,130	No apparent secondary porosity; occasional wide, dark concentric band; round, smooth borehole.
2,130	Vug, large, discontinuous, concentric; possible lithologic contact.
2,130 to 2,210	No apparent secondary porosity; thin, dark concentric band at 2,171 ft, becoming murky at 2,165 ft; round, smooth borehole.
2,210	Vug, large, discontinuous, concentric, possible lithologic contact.
2,215	Borehole appears to widen, might be large vug or small cavity; smooth borehole.
2,216 to 2,292	No apparent secondary porosity; round, smooth borehole.
2,292 to 2,460	No apparent secondary porosity; intermittent, wide concentric bands that are darker, rougher, and shinier than the rest of the round, smooth borehole; concentric bands becoming wider with depth.
2,460 to 2,465	Fractures, blocky; irregular, rough borehole.
2,465 to 2,515	Vugs, intermittent, discontinuous, concentric, with dark concentric bands; intermittent in round, smooth borehole.
2,515 to 2,520	Vugs and fractures; darker; possible lithologic contact; round, rough borehole.
2,520 to 2,584	Vugs, small to large, some discontinuous, concentric, with intermittent, wide concentric bands that are darker, rougher, and shinier; round, smooth to rough borehole.
2,584 to 2,586	Fractures, narrow, high angle; round, smooth borehole.
2,586 to 2,600	Same as from 2,520 to 2,584 ft.
2,600 to 2,625	Fractures, narrow, high angle; round, smooth borehole.
2,625 to 2,692	No apparent secondary porosity; occasional small to medium vug; round to irregular, smooth to rough borehole; poor visibility.
2,692 to 2,700	Fractures, small, narrow, also somewhat blocky, different from fractures above; irregular borehole.
2,700 to 2,765	Not much apparent secondary porosity; occasional small to large vugs, some discontinuous, concentric vugs; round, smooth borehole.
2,765 to 2,800	Vugs, small to large, intermittent, discontinuous, concentric; large vug or small cavity at 2,795 ft; round, smooth borehole.
2,800 to 3,050	Fracture, wide, with many cavities; occasional small to large vugs; flow appears to be upward at about 3,020 ft, flow had appeared downward at all depths above; round to irregular, blocky, mostly rough borehole.

Site 8--Miami-Dade Injection Well Number 5, Dade County, Florida--Continued

Depth, in feet below sea level	Description of borehole and notable features
3,050 to 3,068	Vugs, small to medium, vugs could actually be rocks of darker color; round, smooth borehole.
3,068 to 3,074	Fractures, narrower, some high angle; some vugs; large vug or small cavity at 3,070 ft, irregular, not as blocky borehole.
3,074 to 3,096	Vugs, small to medium; round, smooth borehole.
3,096 to 3,097	Small cavity or large vug.
3,097 to 3,102	Vugs, small to medium; round, smooth borehole.
3,102 to 3,103	Small cavity or large vug.
3,103 to 3,108	No apparent secondary porosity; round, smooth borehole.
3,108 to 3,109	Cavity, large; fractures; somewhat blocky, irregular, rough borehole.
3,109 to 3,127	Vugs, small to large with large vugs at 3,113, 3,115, 3,120, and 3,124 ft.
3,127 to 3,128	Cavity and fractures; no strong upward flow as particles are falling downward.
3,128 to 3,147	Vugs, small to large, one discontinuous, concentric; also high angle, narrow fractures; round, smooth borehole.
3,147 to 3,148	Cavity, small to large vugs, angular; could be fractured; irregular, rough borehole.
3,148 to 3,152	No apparent secondary porosity; round, smooth borehole.
3,152 to 3,153	Cavity, small.
3,153 to 3,168	Not much apparent secondary porosity; occasional vug; round, smooth borehole.
3,168 to 3,180	Fractures and small cavities; also medium vugs; somewhat blocky, round to irregular, smooth to rough borehole.
3,180 to 3,190	Occasional vug; particles falling downward; round, smooth borehole.
3,190	End of television survey.

Site 9--Sunrise Injection Well Number 1, Broward County, Florida

Depth, in feet below sea level	Description of borehole and notable features
1,780	Bottom of casing.
1,780 to 2,010	No apparent secondary porosity; concentric, dark bands at 1,838, 1,880, 1,908, and 1,930 ft; dark blotch at 1,970 ft; round, very smooth borehole.
2,010 to 2,110	Same as above but not as smooth, borehole more pitted; possible small vug at 2,025 ft; concentric band or formation contact at 2,067 ft.
2,110 to 2,180	Still no apparent secondary porosity, although very small dark spots could be interpreted as vugs.
2,180 to 2,190	Poor visibility, murky; impossible to see borehole wall.
2,190 to 2,205	Still murky, but borehole wall is barely visible; no apparent secondary porosity; round, smooth borehole.
2,205 to 2,225	Too murky to see borehole wall.
2,225 to 2,262	Borehole wall barely visible; possible small vug at 2,228 ft. Hard to determine what is there, definitely not fractures or cavities; consistent texture, probably round, smooth to pitted borehole; no apparent secondary porosity.
2,262 to 2,271	Darker borehole wall; very poor visibility.
2,271 to 2,301	Intermittent layers of fractures and small cavities or large vugs in a mostly round, smooth borehole. Vertical fracture at 2,296 ft.
2,301 to 2,410	Occasional small vug; not much apparent secondary porosity; round, smooth borehole.
2,410 to 2,510	Vugs, small to large, numerous; some areas are wide like large vugs or washed out part of hole; round, mostly smooth borehole.
2,510 to 2,527	Vugs, small to large; fractures, small; round to irregular borehole.
2,527 to 2,543	No apparent secondary porosity; round, smooth borehole.
2,543 to 2,587	Vugs, small, and small narrow fractures; round to irregular borehole.
2,587 to 2,642	Fractures, small, with small cavities; occasional vug; round to irregular borehole.
2,642 to 2,671	No apparent secondary porosity; occasional very small vug; round, smooth borehole.
2,671 to 2,679	Vugs, small to medium, angular to round; round, borehole.
2,679 to 2,708	No apparent secondary porosity; round, smooth borehole.
2,708 to 2,850	Cavities and fractures; small cavities at 2,708, 2,718, 2,728, and 2,736 ft; larger cavities at 2,758, 2,762, 2,830, and 2,840 ft; round to irregular, mostly rough borehole.
2,850 to 2,872	Cavity, very large; no borehole wall visible.
2,872 to 2,965	Cavities and fractures; fractures are wide, some fractures are narrow and high angle; many more cavities and fractures than in the overlying sections; blocky, irregular borehole.
2,965 to 3,085	Cavities, small; vugs, small to large; and fractures, small with some high angle; large cavity at 3,020 ft; many discontinuous, concentric, dark bands or vugs; round to irregular borehole.

Site 9--Sunrise Injection Well Number 1, Broward County, Florida--Continued

Depth, in feet below sea level	Description of borehole and notable features
3,085 to 3,140	Vugs, more numerous, small to large; fractures and cavities also; round, smooth to rough borehole.
3,140 to 3,155	Fractures, narrow, criss-cross pattern, looks like fractures filled with darker material; round, smooth to rough borehole.
3,155 to 3,182	Vugs and fractures, some wide and high angle; round, smooth to rough borehole.
3,182	End of television survey.

Site 10--Palm Beach County System 9 Injection Well,
Palm Beach County, Florida

Depth, in feet below sea level	Description of borehole and notable features
2,620 to 2,639	Vugs, small to large, round and spherical; round, smooth borehole.
2,639 to 2,641	Fractures, with angular vugs; round, rough borehole.
2,641 to 2,648	Vugs, small; round, smooth borehole.
2,648 to 2,650	Cavity.
2,650 to 2,700	Vugs, very small to small, with some high-angle fractures; round, rough borehole.
2,700 to 2,720	Murky water, cannot identify borehole features; possible cavity.
2,720 to 2,725	Fractures, small, high-angle; irregular, smooth borehole.
2,725 to 2,735	Fractures, large; a few small vugs; blocky, irregular borehole.
2,735 to 2,755	Vugs, very small to medium, round and spherical; round, smooth borehole.
2,755 to 2,765	Vugs, very small to medium, with high-angle fractures; round, smooth borehole.
2,765 to 2,770	Fractures, with small to medium vugs; irregular, blocky, smooth to rough borehole.
2,770 to 2,775	Vugs, very small to medium, with fractures; round, rough borehole.
2,775 to 2,780	Fractures, high angle, with very small to small vugs; round, smooth borehole.
2,780 to 2,785	Vugs, very small to small; round, rough borehole.
2,785 to 2,789	Fractures, wide, with very small to small vugs; irregular, smooth borehole.
2,789 to 2,797	Vugs, very small to small; round, rough borehole.
2,797 to 2,848	Fractures, with very small to small vugs; round to irregular, smooth to rough, blocky borehole.
2,848 to 2,849	Cavity, small.
2,849 to 2,855	Fractures; round to irregular, smooth borehole.
2,856	Wire or stick lodged across borehole.
2,855 to 2,865	Fractures, same as above.
2,865 to 2,866	Cavity, small.
2,866 to 2,883	Fractures, wide, high angle; occasional vug; possible cavity at 2,876 ft; round to irregular, smooth, blocky borehole.
2,883 to 2,886	Cavity.
2,886 to 3,036	Murky water, poor visibility; possible cavities.
3,036 to 3,100	Fractures, with occasional medium to large vug, some angular; possible cavity at 3,076 ft; irregular, smooth to rough, wide borehole.
3,100 to 3,123	Vugs, numerous, small to large, round and spherical; large vug or small cavity at 3,113 ft; round, smooth, light-colored, shiny, narrower borehole.
3,123 to 3,136	Fractures; light-colored breccia, square and rectangular shape; possible cavity at 3,135 ft; round, smooth borehole.
3,136 to 3,154	Fractures; increased amounts of breccia; round borehole.
3,154 to 3,182	Fractures, small, high angle, and horizontal, narrow with occasional small to medium vug; very round, smooth borehole.

Site 10--Palm Beach County System 9 Injection Well, Palm Beach County, Florida--Continued

Depth, in feet below sea level	Description of borehole and notable features
3,182 to 3,185	Fractures; irregular, rough, blocky borehole.
3,185 to 3,187	Vug, large, discontinuous, concentric; round, smooth borehole.
3,187 to 3,189	No apparent secondary porosity.
3,189 to 3,190	Cavity, small.
3,190 to 3,193	Fractures; round, smooth to rough borehole.
3,193 to 3,194	Cavity, small.
3,194 to 3,199	No apparent secondary porosity.
3,199 to 3,200	Vug, large, discontinuous, concentric; round, smooth borehole.
3,200 to 3,201	Fracture, small.
3,201 to 3,207	Vugs; round, smooth borehole.
3,207 to 3,208	Cavity, small.
3,209 to 3,212	Fractures.
3,214 to 3,215	Vug, large.
3,219 to 3,223	Vugs, small to large, including discontinuous, concentric vug at 3,219 ft; round, smooth borehole.
3,223 to 3,239	Fractures; round, smooth borehole.
3,239 to 3,252	Vugs, small to large, discontinuous, concentric, with fractures; round smooth borehole.
3,252 to 3,254	Fractures; round, smooth borehole.
3,254 to 3,277	Vugs, small; round, smooth borehole.
3,277 to 3,280	Fractures; round, rough borehole.
3,280	End of television survey.

Site 11--Seacoast Utilities Injection Well,
Palm Beach County, Florida

Depth, in feet below sea level	Description of borehole and notable features
2,000	Out of casing.
2,000 to 2,080	Vugs, most very small to small, a few medium, elliptical to round; a few fractures also; round, smooth borehole.
2,080 to 2,250	No apparent secondary porosity; occasional small vug; round, smooth borehole.
2,250 to 2,415	Same as above, becoming more murky with depth; very difficult to see because of poor visibility.
2,415 to 2,427	Same as above; rougher borehole.
2,427 to 2,428	Cavity, small, with fractures; irregular, rough borehole.
2,428 to 2,445	No apparent secondary porosity; round, smooth to rough borehole.
2,445 to 2,465	Vugs, small to medium, round to angular and irregular; fractures, vertical and narrow; smooth to rough borehole.
2,465 to 2,487	No apparent secondary porosity; round, smooth to rough borehole.
2,487 to 2,490	Cavity, small, with rough edges or fractures; borehole wall visible; irregular, rough borehole.
2,490 to 2,532	Not much secondary porosity; occasional small vug and small fracture; poor visibility; round, smooth to rough borehole.
2,532 to 2,535	Cavity, large; borehole wall not visible.
2,535 to 2,555	Borehole wall visible briefly; camera hitting borehole wall creates zero visibility because of the sediments.
2,555 to 2,570	No apparent secondary porosity; round, smooth, borehole.
2,570 to 2,592	Fractures, vertical; vugs, small to medium, angular; round, smooth to rough borehole.
2,592 to 2,645	No apparent secondary porosity; occasional small vug; dark blotches, some are discontinuous and concentric; occasional small vug; round, smooth borehole.
2,645 to 2,730	Vugs, very small to medium, mostly small, more numerous than above, round to angular; also dark, discontinuous blotches as above; round, smooth to rough borehole.
2,730 to 2,775	No secondary porosity; an occasional very small vug; round, smooth borehole.
2,775 to 2,964	Vugs, very small, most may just be darker material in borehole; fractures or angular section of borehole from 2,775 to 2,777 ft; vertical fracture at 2,941 ft; round, smooth to pitted borehole.
2,964 to 2,990	Vugs, very small to small, more numerous; round, smooth to rough borehole.
2,990 to 3,010	No apparent secondary porosity; round, smooth, borehole.
3,010 to 3,029	Vugs, small to medium; small fractures at 3,019 ft; round, smooth borehole.
3,029 to 3,033	Fractures, blocky; cavity at 3,032 ft; irregular, smooth to rough borehole.
3,033 to 3,045	No apparent secondary porosity; round, smooth borehole.
3,045 to 3,180	Fractures and cavities; blocky; looks like visible flow at 3,083 ft; boulder at 3,164 ft; irregular, smooth to rough borehole.

Site 11--Seacoast Utilities Injection Well,
Palm Beach County, Florida--Continued

Depth, in feet below sea level	Description of borehole and notable features
3,180 to 3,200	Fractures, narrow, not blocky; vugs, small to medium, angular; round to irregular, smooth to rough borehole.
3,200 to 3,300	Fractures and vugs, similar to above but borehole is smoother; small cavities at 3,232, 3,241, 3,259, and 3,272 ft; mostly round, smooth to rough borehole.
3,300	End of television survey.

Site 12-- North Port St. Lucie Injection Well, St. Lucie County, Florida

Depth, in feet below sea level	Description of borehole and notable features
1,935	End of 22-in.-diameter casing.
1,935 to 1,936	Fractures; round, smooth borehole.
1,936 to 2,145	Poor visibility; no apparent secondary porosity; round, smooth borehole.
2,145 to 2,285	Vugs, small to medium, some discontinuous, concentric; round, smooth to pitted borehole.
2,285 to 2,333	Vugs, small to large; more numerous; round, smooth borehole.
2,333 to 2,334	Cavity, small.
2,334 to 2,355	Fractures, small, with small vugs; round to irregular borehole.
2,355 to 2,670	Vugs, very small to small; poor visibility; round, smooth borehole.
2,670 to 2,705	No apparent secondary porosity; round, smooth borehole.
2,705 to 2,815	Vugs, very small to small; round, smooth to pitted borehole.
2,815 to 2,875	No apparent secondary porosity; round pitted borehole.
2,875 to 3,200	Fractures, many high angle, with cavities; irregular, blocky, rough borehole.
3,200 to 3,279	Fractures, less numerous with depth; round to irregular, blocky, smooth to rough borehole, more smooth with depth.
3,279	Borehole blocked by what appears to be a boulder; end of television survey.

Site 13--Hercules, Inc., Injection Well, Indian River County, Florida

Depth, in feet below sea level	Description of borehole and notable features
Note: Freshwater being injected during television survey.	
1,650	Out of casing.
1,650 to 1,670	No apparent secondary porosity.
1,670 to 1,800	Vugs, very small to small, with a few fractures from 1,712 to 1,720 ft and from 1,784 to 1,786 ft; round, smooth to pitted borehole.
1,800 to 1,875	No apparent secondary porosity; occasional very small to medium vugs; round borehole.
1,875 to 2,070	Fractures, angular, some high angle, with few small to medium vugs; small cavities at 1,955 ft and from 2,008 to 2,020 ft; round to irregular and blocky, smooth to rough borehole.
2,070 to 2,170	Not much apparent secondary porosity; few medium to large vugs; one vug appeared to be filled with gypsum at 2,075 ft; dark areas at 2,086 and 2,089 ft; round, smooth to rough borehole.
2,170 to 2,215	Vugs, very small to small; round, smooth to pitted borehole.
2,215 to 2,273	Not much secondary porosity; occasional very small to small vug; poor lighting; round, smooth to pitted borehole.
2,273 to 2,380	Vugs, very small, may be dark areas and not actual vugs; hard to see with poor lighting.
2,380 to 2,390	Fractures and cavities with some vugs.
2,390 to 2,410	Vugs, very small to large with some angular and oriented vertically at 2,388 ft; discontinuous, concentric vug at 2,401 ft; thin, dark, circular rings or bands at 2,410 ft; round, smooth borehole.
2,410 to 2,426	No secondary porosity; small cavity at 2,422 ft; round, smooth borehole.
2,426 to 2,460	Fractures and cavities; discontinuous, concentric ring at 2,440 ft; round to irregular borehole.
2,460 to 2,500	Not much secondary porosity; occasional small to medium vug; round, smooth borehole.
2,500 to 2,593	Fractures and cavities, with small to large vugs; blocky, irregular borehole.
2,593 to 2,733	Vugs, very small to medium, some angular and elliptical (2,691-2,692 ft); round, smooth borehole.
2,733 to 2,907	Fractures, cavities, and vugs; high-angle fractures; numerous cavities; small to large vugs; flow appears upward at 2,844 ft; blocky, round to irregular borehole.
2,907 to 2,950	Not much secondary porosity; occasional vug; downward flow at 2,931 ft; possible gypsum nodules and gypsum-filled vugs from 2,937 to 2,945 ft; round borehole.
2,950 to 2,977	Vugs, small to medium; appears to be downward flow near bottom; round borehole.
2,977	End of television survey.

Site 14--South Beaches Injection Well, Brevard County, Florida

[Modified from Safko and Hickey, 1992]

Depth, in feet below sea level	Description of borehole and notable features
264	Out of casing
286 to 326	Vugs, medium, discontinuous, concentric; round borehole.
326 to 370	Vugs, medium, occasional; round borehole.
390 to 511	Vugs, small to medium; with small cavities; linear fractures from 474 to 476 ft; round to irregular borehole.
511 to 611	Vugs, small to large; round, smooth to pitted borehole.
611 to 820	Vugs, small to large, some discontinuous, concentric; with small cavities; picture out of focus indicating possible flow from 653 to 660 ft; round to irregular borehole.
820 to 1,169	Vugs, small to large; fractures at 1,009 and 1,094 ft; water apparently flowing from the fracture at 1,094 ft; picture out of focus indicating possible flow from 1,050 to 1,054 ft; round, smooth to pitted borehole.
1,169 to 1,271	Vugs, small to large, with small cavities; round, smooth to pitted borehole.
1,271 to 1,671	Vugs, small, not as numerous as above, some concentric; some intervals have no apparent secondary porosity; small cavities at 1,516 and 1,582 ft; round, smooth to pitted borehole.
1,671 to 1,800	Vugs, small to large; some intervals have no apparent secondary porosity; small cavities from 1,746 to 1,769 ft; round to irregular, smooth borehole.
1,800 to 1,817	Dark patches, generally smooth, but sometimes rough or angular, indicating possibly breaking away from host rock during drilling; medium vug with apparent water and sediment flowing from it; round to irregular, smooth to rough borehole.
1,817 to 1,842	Cavities, small; numerous dark patches; occasional vug; round to irregular borehole.
1,842 to 2,069	Vugs, small to medium, some in "honeycomb" pattern, some discontinuous, concentric; occasional dark band and occasional coring mark; round, smooth to pitted borehole.
2,070 to 2,195	Cavities and fractures; fractures are horizontal and vertical; blocky, irregular borehole.
2,195	End of television survey.