Potential for Ground-Water Development in Central Volusia County, Florida

By JOEL O. KIMREY

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 90-4010

Prepared in cooperation with
VOLUSIA COUNTY

Tallahassee, Florida
1990

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METRIC CONVERSION FACTORS

For use of readers who prefer to use metric units (International System), conversion factors for inch-pound units used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.00035	centimeters per second (cm/s)
square mile (mi^2)	2.56	square kilometer (km^2)
gallon per minute (gal/min)	0.06308	liter per second (L/s)
pound per cubic foot (lb/ft^3)	62.43	gram per cubic centimeter (g/cm^3)

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 both the United States and Canada, formerly called Sea Level Datum of 1929.

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By Joel O. Kimrey

Abstract

The Upper Floridan aquifer is the source of all public water supplies in Volusia County, east-central Florida. All freshwater in the Upper Floridan in Volusia County is derived from recharge within the county, and most discharge from the aquifer occurs at, or contiguous to, county boundaries. Freshwater in the Upper Floridan occurs to a maximum depth of about 1,450 feet under a potentiometric-surface high in the wetlands of central Volusia County. Brackish water occurs in the discharge areas that virtually surround the county.

The surficial aquifer, which consists of sandy, shelly, and clayey material, overlies the Upper Floridan throughout the county. The vertical permeability of the surficial aquifer and its hydraulic connection to the Upper Floridan in central Volusia County are such that together the two aquifers compose a system that is full and rejecting water from the surficial aquifer to surface runoff and evapotranspiration in the wetlands environment of the Talbot Terrace.

Some recharge to the Upper Floridan aquifer occurs everywhere in Volusia County where there is a downward head gradient between the water table in the surficial aquifer and the potentiometric surface of the Upper Floridan aquifer. The higher-rate recharge areas under present conditions are the ridges, particularly the De Land Ridge and Rima Ridge that, respectively, border the central Volusia County area to the west and east. However, the two-aquifer system in central Volusia County constitutes a potential recharge area that would function as a high-rate recharge area if water were withdrawn from the Upper Floridan for use, thereby lowering the potentiometric surface and inducing some of the water now being rejected from the surficial aquifer to leak downward into the Upper Floridan. By decreasing the rejected recharge by the amount of capture, more ground water would be available for use.

The potential recharge area is underlain by a large reserve of freshwater in an area that is presently little stressed by withdrawals. Large additional water supplies could be developed from well fields that are properly designed and managed to optimize capture of additional recharge water in central Volusia County. Development of water from the area, however, could result in adverse effects on both the aquifers and the surface environment unless it is planned and implemented from a firm base of scientific understanding.

INTRODUCTION

Volusia County, in east-central Florida, is an area of about 1,200 mi^2 (square miles) that is bordered by the St. Johns River on the west and southwest, and by the Atlantic Ocean on the east (fig. 1). Ground water from the Upper Floridan aquifer of the Floridan aquifer system is the sole source of public water supplies. The thickest zone of fresh ground water is in the central part of the county, in the generally swampy area between De Land Ridge and Rima Ridge. The Upper Floridan aquifer contains brackish ground water in the St. Johns River Valley, along the Atlantic coast, and to the north in Flagler County.

Intensive ground-water development was first concentrated in the coastal areas where most of the population still resides in the cities of Daytona Beach, Ormond Beach, and New Smyrna Beach, and adjacent areas. By the 1950's, saltwater encroachment and growing water needs in the beach areas had resulted in the expansion of the original well fields to the west toward central Volusia County. More recently, increased water demands in De Land, De Bary, Deltona, and adjacent areas, which are contiguous to areas of brackish ground water in the St. Johns River Valley, has created additional interest in the potential of central Volusia County to supply future potable water needs.

In 1971, a report published by the Florida Bureau of Geology (Knochenmus and Beard, 1971) concluded that the undeveloped aquifers in the central part of the county were full and rejecting recharge through runoff and evapotranspiration. Thus, if the potentiometric surface in central Volusia County were lowered by withdrawing water from the Upper Floridan aquifer for use, the rejected recharge would be decreased by the capture of water that would be induced to leak downward into the Upper Floridan. This would increase the amount of ground water available for use.

Subsequently, U.S. Geological Survey, in cooperation with the Volusia County Council undertook an additional investigation to (1) better define the understanding of central Volusia County as a potential recharge area, and (2) to determine if certain parts of the area had better recharge potential than others. Accordingly, a test-drilling program was planned and conducted in which continuous core samples, borehole

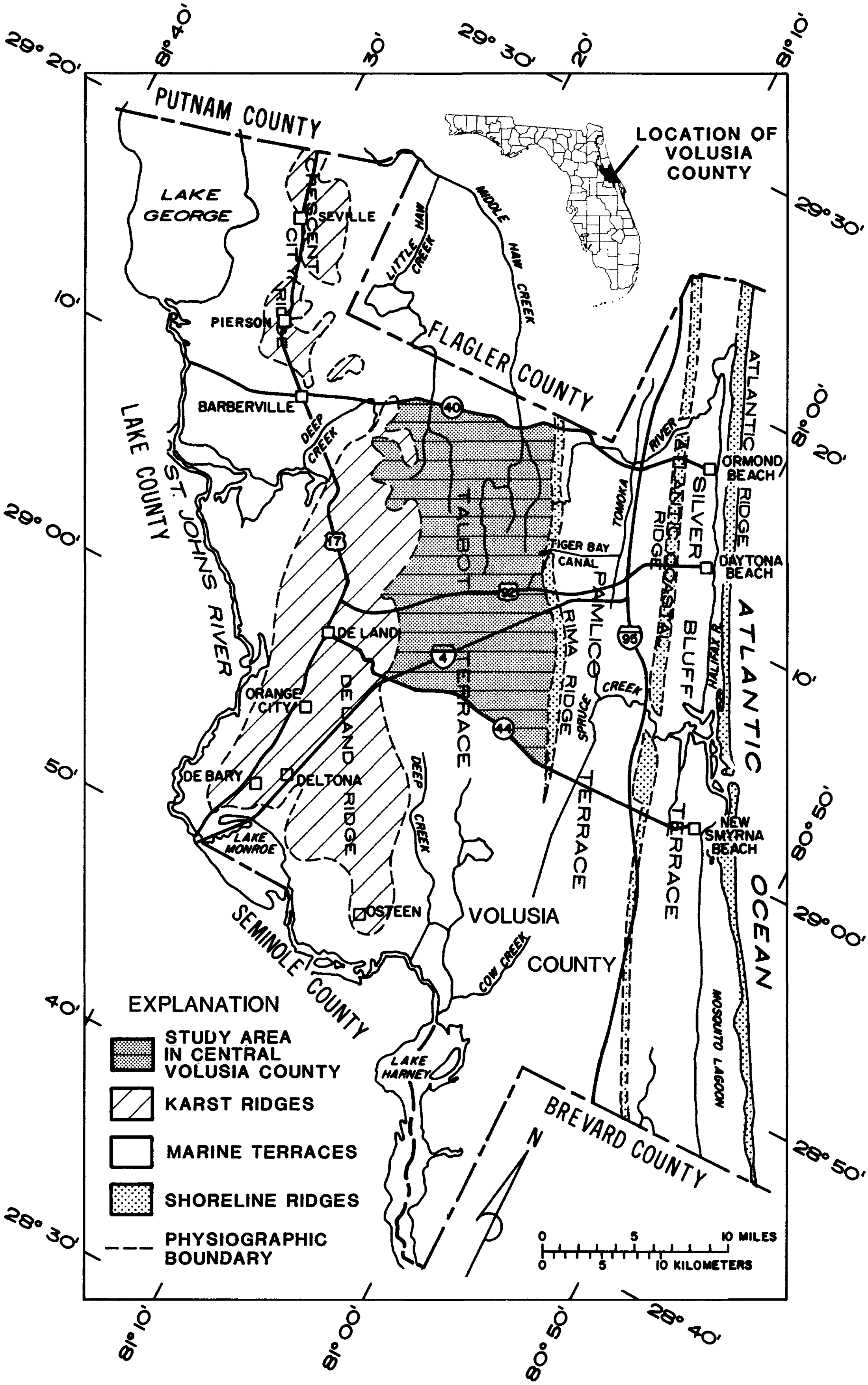

Figure 1. Location of study area and geographic and physiographic features in Volusia County.

geophysical logs, and related data were obtained at 14 sites. Most field work for the investigation was done from March through June of 1973.

The purpose of this report is to formally describe the potential recharge area in central Volusia County, discuss the hydrogeologic factors that need to be considered in development of water supplies from the area, and publish the lithologic logs and related data from the 1973 test-drilling program. For simplicity, this report was written from the time perspective of about 1974-75. No report was scheduled when the field work was done in 1973. More recent work has substantiated and strengthened the 1974-75 vintage interpretations that resulted from this work. Thus, the importance of documenting this early work has increased in the intervening years.

The 1973 investigation had the advantage of published results of two previous water-resources investigations and more than 20 years of data collection by the U.S. Geological Survey in cooperation with Volusia County and the Florida Geological Survey. Interpretive results of the previous investigations were published by the Florida Geological Survey (Wyrick, 1960) and by the Florida Bureau of Geology (Knochenmus, 1968; and Knochenmus and Beard, 1971).

Appreciation is expressed to Thomas C. Kelly, Volusia County Manager, for arranging for the support of this investigation by numerous county offices and departments. Special thanks are due Chester Hunter, Volusia County Public Works Department, for his services in liaison and guidance during field activities in sometimes difficult terrain. In preparing this report, acknowledgment is due James B. Holly, at that time with the U.S. Geological Survey, for his lithologic descriptions of the core materials.

HYDROLOGIC SETTING

Central Volusia County, as used in this report, is generally the part of the Talbot Terrace area bounded on the north by State Road 40, and on the south by State Road 44 (fig. 1). The area is a marine terrace with land-surface altitudes ranging from about 30 to 45 feet above sea level. Swamps and cypress heads occupy the lower areas and isolated small depressions; piney woods occur on the slightly higher land surfaces. The Talbot Terrace is bounded on the west by the De Land Ridge, and on the east by the Rima Ridge.

Surface drainage in central Volusia County is poorly developed. The area is flat and receives about 52 inches of rainfall annually. Natural water courses are not defined over most of the center of the area. North of an ill-defined divide, Middle Haw Creek and Little Haw Creek drain the area; Deep Creek drains the area to the south of this divide.

Volusia County is underlain by unconsolidated sediments of Pleistocene to Miocene age, which are in turn underlain by consolidated limestones and dolomites of Eocene age. Structurally, the county is an uplifted fault block bounded by a north-south trending fault on the west and an east-west trending fault on the south (see Wyrick, 1960, fig. 4 and Knochenmus and Beard, 1971, fig. 15). Most of the county, including the central area, lies on the uplifted part.

The Pleistocene to Miocene sediments consist of largely unconsolidated beds of shell, sand, and clay. Basal shellbeds and limestones tend to be more consolidated than the overlying materials. In central Volusia County, these sediments range in thickness from about 60 to 90 feet and dip generally to the east. They were referred to as the clastic aquifer by Knochenmus and Beard (1971). More recent practice tends to favor the terms surficial aquifer, or surficial aquifer system, as a standardized reference for such deposits. The present report thus uses "surficial aquifer" to apply to these deposits in central Volusia County. The surficial aquifer is underlain by Eocene limestones and dolomites which comprise the Upper Floridan aquifer.

Volusia County is unique, among Florida counties, in that the recharge of all its freshwater in the Upper Floridan aquifer occurs within the county boundaries. Practically all discharge of this local recharge also occurs within the county or in areas that are contiguous to the county boundaries. The Upper Floridan contains brackish water in downgradient parts of the discharge areas, so the thick section of freshwater in Volusia County is virtually surrounded by brackish-to-saline ground water. The potentiometric surface of the Upper Floridan aquifer for May 1973, which was during the period of test drilling for this investigation, is shown in figure 2. The 35-foot contour on this map defines the potentiometric-surface high that is centered in the western part of the central Volusia County area and underlain by about 1,450 feet of freshwater. Ground water moves generally away in all directions from the potentiometric-surface high to areas or points of discharge. To the east, natural discharge occurs into the ocean. To the southwest and west, discharge occurs in the Lake Harney area and to the St. Johns River Valley, including discrete points of discharge at the several large springs in the valley. To the north of the potentiometric-surface high, ground water moves toward brackish zones of the Upper Floridan aquifer in Flagler County. Discharge to well fields in May 1973 was sufficient to show as potentiometric surface depressions at Daytona Beach, New Smyrna Beach, De Land, and Pierson.

Some recharge to the Upper Floridan aquifer occurs everywhere in the county where the water table (in the surficial aquifer) is higher than the potentiometric surface of the Upper Floridan aquifer. The amount of recharge that occurs in any area is a direct function of (1) the head difference between the two aquifers, and (2) the vertical permeability of the surficial aquifer through which water must pass to recharge the Upper Floridan.

The general relations between the water table and the potentiometric surface of the Upper Floridan and the general direction of water movement are shown in figure 3, which is

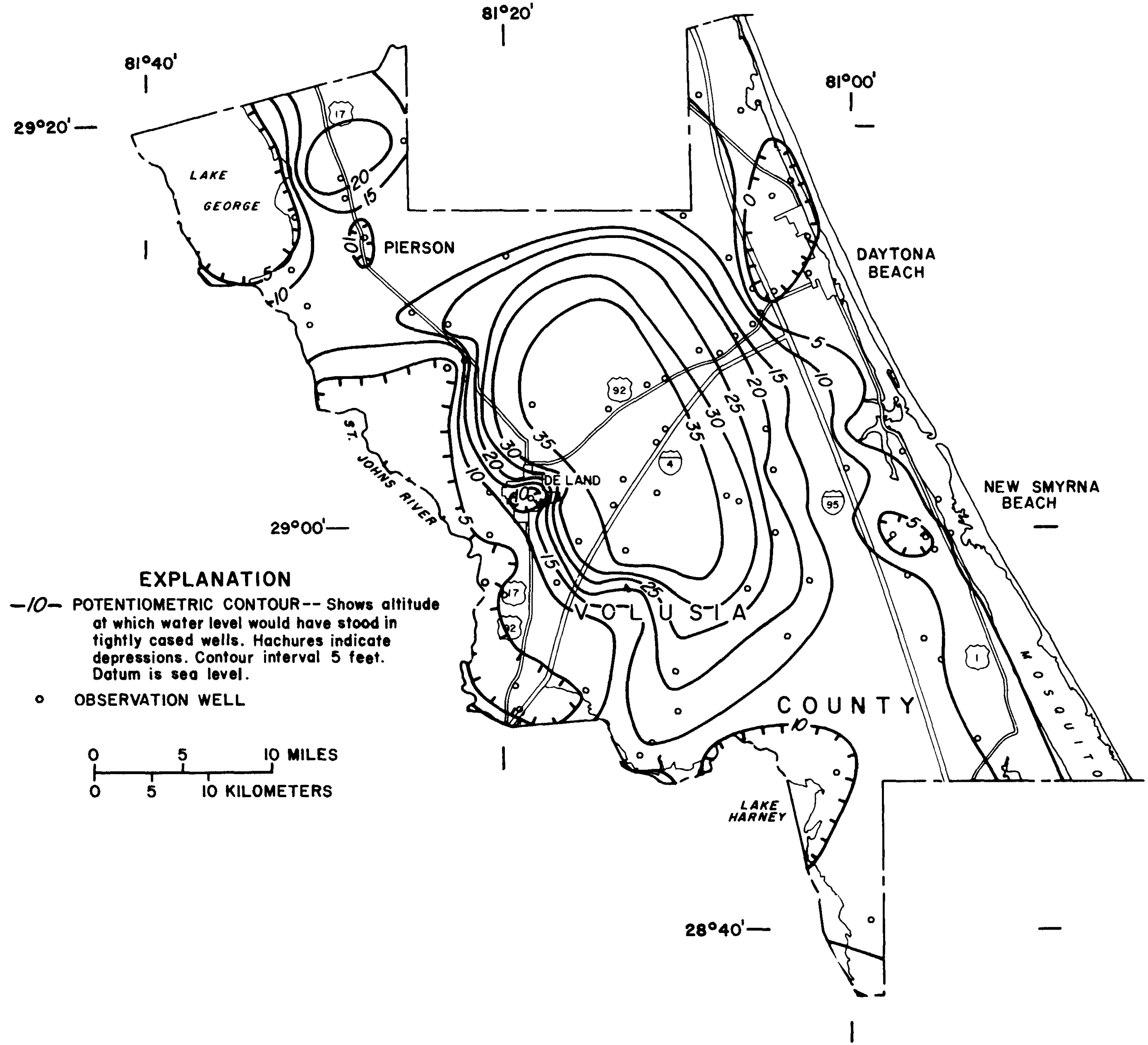

Figure 2. Potentiometric surface in the Upper Floridan aquifer, May 1973.

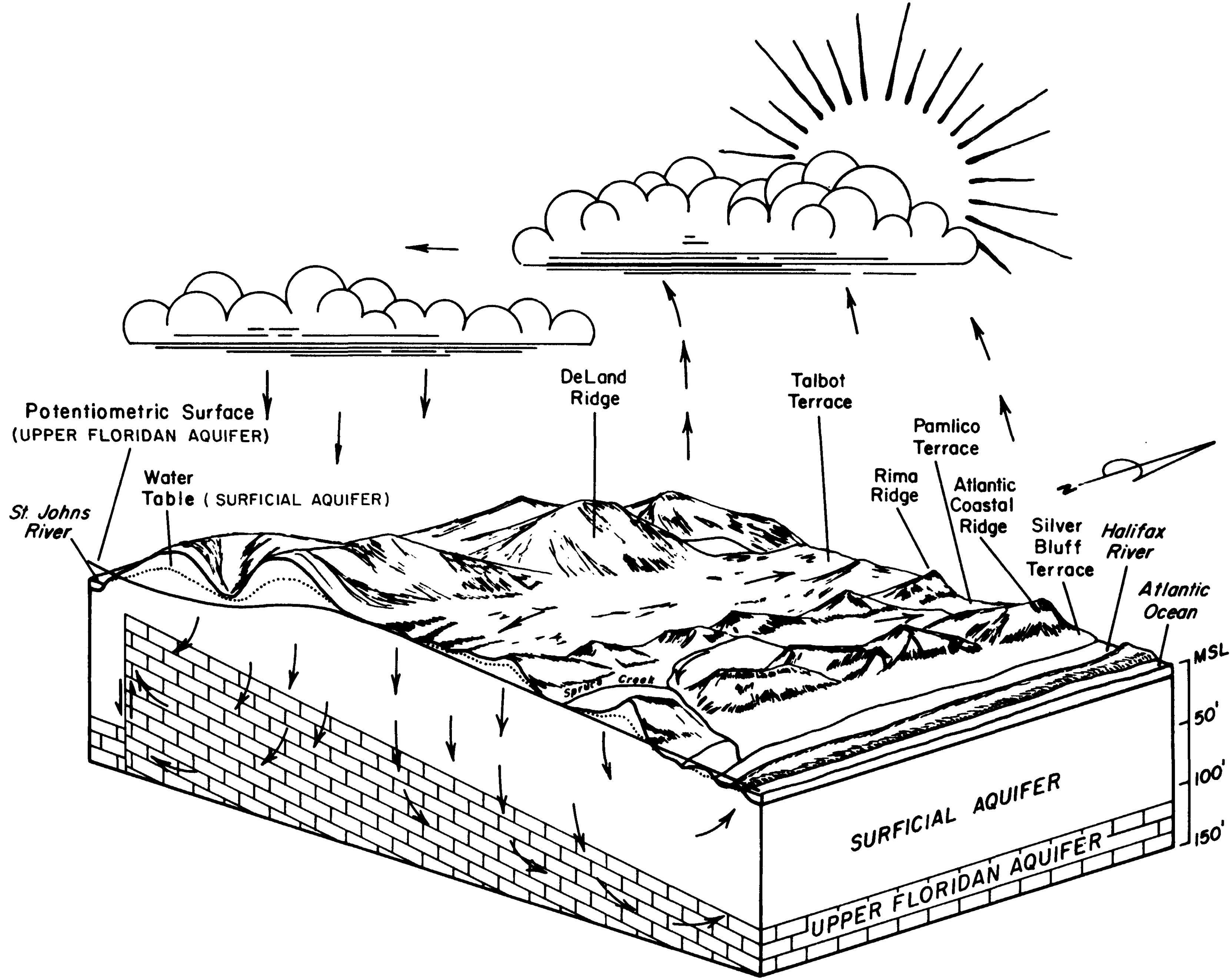

Figure 3. Block diagram of part of Volusia County showing generalized view of hydrogeologic systems. (Adapted from Knochenmus and Beard, 1971.)

adapted from Knochenmus and Beard (1971). In central Volusia County, the water table and potentiometric surface are both near land surface and near the same altitude most of the time, so little recharge, or discharge, could occur regardless of the vertical permeability of the surficial aquifer. Under the bordering ridges, the water table is from 10 to 20 feet higher than the potentiometric surface, so vigorous recharge can occur under existing conditions if there is high vertical permeability in the surficial aquifer and hydraulic connection between the two aquifers.

During both previous countywide investigations, efforts had been directed to defining principal recharge areas in Volusia County. Wyrick (1960) concluded that the principal recharge area was along the eastern side of the De Land Ridge. Knochenmus and Beard (1971) concurred with Wyrick, but then they also investigated the potential for recharge in the area between the De Land Ridge and Rima Ridge, that is, the Talbot Terrace area of central Volusia County. By conventional test drilling, hydrograph correlation, and analysis of surface-water runoff distribution, they concluded that a good hydraulic connection existed between the two aquifers in central Volusia County. Thus, there would be potential for the area to function as a recharge area if a downward head difference were imposed by withdrawal of water from the Upper Floridan aquifer. Pertinent quotations from the Knochenmus and Beard (1971) analysis of the area are repeated below:

"Under present hydrologic conditions, the most productive recharge areas are the eastern part of the Talbot Terrace and the ridges. There is a relatively good hydraulic connection between the clastic deposits and Floridan aquifer under most of the Talbot Terrace, with a greater head between the two hydrogeologic units in the eastern part of the terrace than in the western part, resulting in a better recharge area in the former. The western part of the terrace has good recharge potential, provided a sufficient head differential were maintained, either by lowering the piezometric surface or by raising the water table." (p. 13) and, "In the central part of the county the clastic aquifer is full and rejecting recharge through runoff and evapotranspiration. If the piezometric surface were lowered in this area by withdrawing water from the Floridan aquifer for use, this rejected recharge would be decreased by the capture of water. This would increase the amount of water available for use." (p. 1).

In summation, the previous investigators concluded that the ridges function as high-rate recharge areas because their topographic relief allows a relatively high downward head difference, or gradient, between the water table and the potentiometric surface. In central Volusia County the hydraulic connection between the aquifers and the availability of surplus water would constitute a potential recharge area. However, under present conditions, central Volusia County is not a high-rate recharge area. It is water logged much of the time by small head differences between the aquifers. Furthermore, the water table and the potentiometric surface of the Upper Floridan are at, or near, land surface most of the time, resulting in the perennially swampy condition over much of the area (Knochenmus, 1968).

METHODS OF INVESTIGATION

Test drilling for this investigation was done during May 1973. The primary question addressed by the test-drilling program was the permeability distribution, both lateral and vertical, for the surficial aquifer. Knochenmus and Beard (1971) had postulated that this aquifer had generally good permeability, and thus a good hydraulic connection to the Upper Floridan aquifer, throughout central Volusia County. Their hypothesis was based on some test-drilling data, but largely on indirect methods such as hydrograph correlation and distribution of surface-water runoff.

The approach taken for the present investigation was to directly examine permeability distribution for central Volusia County by drilling a series of 14 core holes (fig. 4). The drilling sites were chosen, as permitted by access, to cover an area of about 135 mi^2 between the De Land Ridge and Rima Ridge and bounded by State Road 40 on the north and State Road 44 on the south. The parts of central Volusia County that are north of State Road 40 and south of State Road 44 were not explored by test drilling because of the absence of access roads into the swampy terrain.

The 14 core holes were drilled by continuous coring from land surface to the top of the Upper Floridan aquifer. The 6-inch diameter cores were examined in the field for lithology and visual estimates of permeability. Then, parts of some cores were selected for laboratory permeability tests and the remainder of the core samples were stored for later, more detailed lithologic description in the laboratory. Single-point electric logs and natural gamma-ray logs were obtained from the test holes, where possible, to supplement the visual permeability estimates and to provide data for intervals where core samples were not recovered. No casing was installed in the core holes, so some of the open holes collapsed before the borehole geophysical logs could be obtained. Additional natural gamma-ray logs were obtained for several existing cased wells for correlation purposes in the general area of investigation. The laboratory lithologic descriptions for the 14 core holes are included in the appendix of this report. A complete set of the core samples is on file with the Florida Geological Survey, Tallahassee, Fla.

The core samples chosen for laboratory permeability determinations were largely those from zones of lower permeability. Cores from clayey zones tend to be less distorted than those from more permeable materials, and these cores can be transported with minimum additional disturbance to a soils laboratory where representative parts may be selected and prepared for the permeability tests. The laboratory permeabilities determined in this manner for clay core samples, however, may be lower than the *in situ* permeabilities of the sample materials, because of compaction related to the coring process.

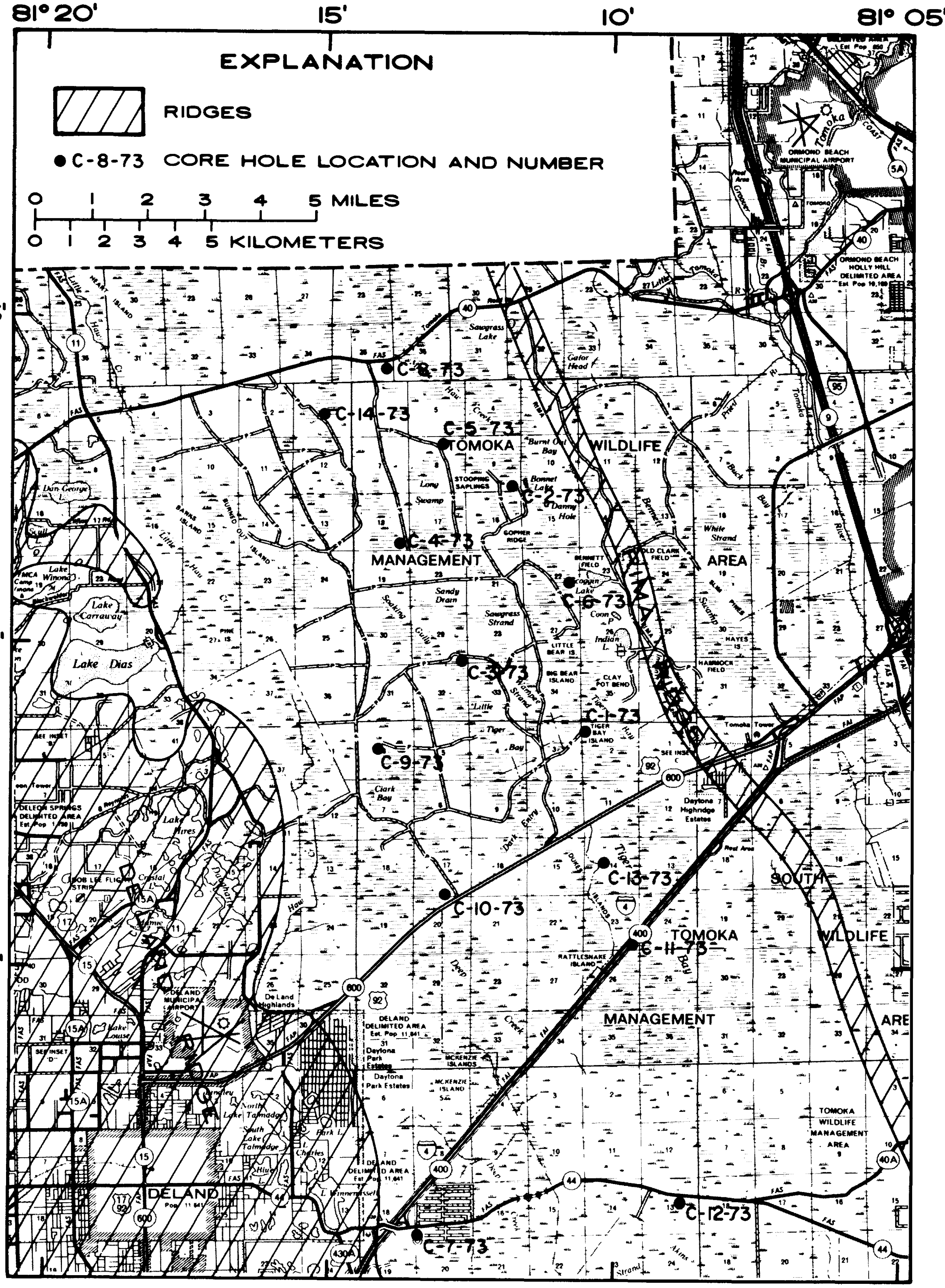

Figure 4. Location of test-drilling sites and ridges in central Volusia County.

ANALYSIS OF DATA

Examination of core samples in the field indicated generally good vertical permeability for the surficial aquifer throughout the area of investigation. The distribution of the less-permeable zones (the sandy to silty clays, and silty to clayey sands) that were penetrated by core drilling are shown in figure 5. Criteria used in preparation of the fence diagram were to (a) extend the low-permeability zones to adjacent core holes if their lithology appeared to repeat at the same horizon, and to (b) show the less permeable zones pinching out between core holes in which they did not appear to repeat. These sandy to silty clays and silty to clayey sands are the materials that retard vertical ground-water movement, either upward or downward, depending on the direction of the ground-water gradient. Other materials penetrated by coring were much more permeable, so the distribution and permeability of the finer-grained materials are the key to an analysis of the area's potential as a high-rate recharge area.

The zones of finer-grained materials are, with few exceptions, relatively thin. They are also limited in areal extent and occur at different horizons in the surficial aquifer. The thickest zone of finer-grained material penetrated was about 15 feet of olive-green silt to clayey silt in the lower part of core hole 14. Total thickness of this material was not determined because drilling was stopped in this olive-green, fine-grained material that did not occur in any of the other core holes. The material of lowest permeability penetrated, on the basis of visual examination, was in core hole 1, where about 14 feet of blue-to-gray silty clay occurs near the contact between the surficial and Upper Floridan aquifers. This clayey bed was penetrated at only one other site (core hole 3) where it was about 8-feet thick.

The lower-permeability materials, sandy to silty clays, also occurred in core holes 7, 8, 10, 11, and 12. With the possible exception of core holes 7 and 10, these clay beds could not be correlated between core holes. Their thickness ranged from 6 inches in core hole 8, to about 7 feet in core hole 7.

Silty to clayey sand, a slightly more permeable material than the clays described above, was penetrated in nine core holes (2, 3, 4, 6, 7, 8, 9, 13, and 14). This material was also largely discontinuous between core holes and occurred at different horizons in the surficial aquifer.

Table 1 presents values for laboratory coefficients of permeability for a total of 11 core samples that were collected from 9 different core holes. (The U.S. Geological Survey now uses the term "hydraulic conductivity" instead of "coefficient of permeability." The latter term, however, is used herein to avoid confusion, because the laboratory data were reported as coefficients of permeability.) The core samples were selected during test drilling from zones that (a) appeared to have low permeability, and (b) yielded core samples in relatively undisturbed condition. The laboratory permeability determinations were conducted by Florida Testing Laboratories, Inc.,[1] Clearwater, Fla., under contract to Volusia County. The method used for permeability determinations was as follows (Florida Testing Laboratories, Inc., written commun., 1973):

"The falling head permeability test was used to obtain a measure of the approximate vertical coefficient of permeability. The samples were allowed to consolidate under an estimated overburden pressure prior to permeation. This was accomplished in a fixed ring consolidometer adapted for utilization as a permeameter. A submerged density of 55 pcf (pounds per cubic foot) was assumed in the estimation of overburden pressure."

The laboratory permeability values range from about 2.7×10^{-8} to 1.2×10^{-4} cm/s (centimeters per second), or 7.6×10^{-5} to 3.4×10^{-1} ft/d (feet per day). As previously discussed, these values may be considered to be conservative values for vertical coefficients of permeability; however, the user is cautioned that permeabilities of selected samples may be greatly different from that of the natural *in situ* materials. The intent of presenting these values herein is to indicate the probable magnitude and range of values for vertical coefficients of permeability in the less permeable materials in central Volusia County.

In summation, examination of the continuous core samples from the 14 core holes indicates that vertical permeability is generally high in the surficial aquifer in central Volusia County. The aquifer contains several low-permeability zones that would, locally, function as a barrier to vertical movement of ground water; however, these zones of clay and sandy clay are laterally discontinuous and many of the low permeability zones are relatively thin. As a result, the low-permeability zones do not constitute an areally extensive confining unit. Also, examination of the core samples and geophysical logs did not indicate any lack of hydraulic connection at the contact between the surficial aquifer and the Upper Floridan aquifer.

RESPONSE OF THE TWO-AQUIFER SYSTEM TO HYDRAULIC STRESS

The surficial aquifer and the Upper Floridan aquifer in central Volusia County thus constitute an interconnected two-aquifer system which tends to respond, in gross fashion, to hydraulic stresses as a single aquifer. The water table in the surficial aquifer and the potentiometric surface in the Upper Floridan aquifer tend to be at about the same altitude and at, or near, the land surface most of the time. However, because the water table and the potentiometric surface are separate pressure surfaces, they may respond in different measure, or degree, to hydrologic stresses, as discussed below.

1The use of firm names in this report is for identification purposes only, and does not constitute endorsement by the U.S. Geological Survey.

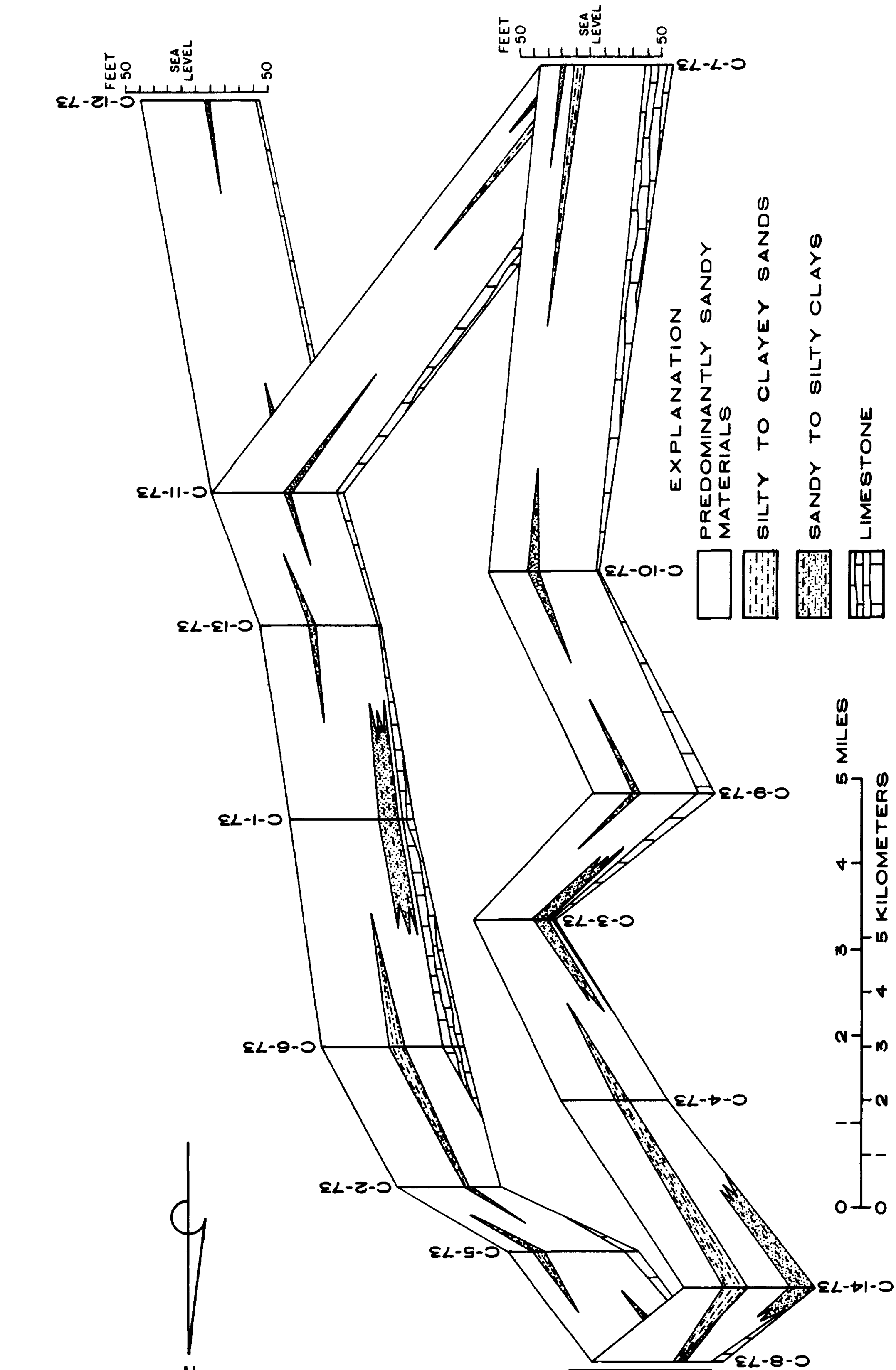

Figure 5. Fence diagram showing generalized distribution of less permeable zones in the surficial aquifer, central Volusia County.

Table 1. Laboratory permeabilities for selected core samples
[cm/s, centimeters per second; ft/d, feet per day]

Core hole No. and depth	Description of core sample	Average vertical coefficient of permeability (cm/s)	Average vertical coefficient of permeability (ft/d)
C-3-73 (44/49)	Bluish-gray plastic clay, with traces of brown-gray fine sand inclusions.	8.4×10^{-5}	2.4×10^{-1}
C-7-73 (32/33)	Bluish-gray sandy clay with traces of shell fragments.	1.2×10^{-4}	3.4×10^{-1}
C-7-73 (20/29)	Gray plastic clay with traces of shell fragments.	3.8×10^{-8}	1.1×10^{-4}
C-8-73 (62/63)	Bluish-gray plastic clay.	9.2×10^{-7}	2.6×10^{-3}
C-8-73 (69/70)	Light gray slightly clayey fine sand with fine shell fragments.	1.3×10^{-5}	3.6×10^{-2}
C-9-73 (64/65)	Light gray slightly clayey fine sand with traces of shell fragments.	7.9×10^{-6}	2.2×10^{-2}
C-10-73 (31/33)	Bluish-gray plastic clay with large limestone inclusions.	2.9×10^{-6}	8.1×10^{-3}
C-11-73 (52/53)	Bluish-gray clay with small horizontal sand lenses, (brittle as received).	3.7×10^{-6}	1.0×10^{-2}
C-12-73 (46/47)	Bluish-gray sandy clay with traces of shell fragments.	2.7×10^{-8}	7.6×10^{-5}
C-13-73 (36/37)	Greenish-gray clay (slightly brittle as received).	2.8×10^{-7}	7.8×10^{-4}
C-14-73 (80/81)	Greenish-gray clay (brittle as received).	3.6×10^{-6}	1.0×10^{-2}

The water table in the surficial aquifer responds directly, and almost immediately, to local rainfall. Available storage, however, is very limited in this aquifer because the water table is at or near land surface most of the time, as reflected by the generally swampy conditions that prevail in central Volusia County. If the water table in the surficial aquifer is below land surface when it rains, the water table tends to rise rapidly until it reaches land surface; any additional water then becomes overland, or surface, runoff. When the water table is higher than the altitude of the potentiometric surface, a downward hydraulic gradient exists, and water from the surficial aquifer percolates downward to recharge the Upper Floridan aquifer. At times when the potentiometric surface is higher than the water table, the surficial aquifer may receive some recharge from slow upward percolation of water from the Upper Floridan aquifer. So, the surficial aquifer is recharged by direct rainfall and by some upward movement of water from the Upper Floridan aquifer; it is discharged by downward movement of water to the Upper Floridan aquifer and by rejection of water to the wetlands environment.

The potentiometric surface of the Upper Floridan aquifer tends to respond more to longer term seasonal or annual rainfall trends than to individual rainfall events. Thus, the potentiometric surface tends to fall below the areal water table during periods of prolonged deficient rainfall, and it rises above land surface in low-lying areas over part of central Volusia County during periods of wetter than average conditions (Knochenmus, 1968). The Upper Floridan is recharged by downward percolation of ground water from the surficial aquifer; it is discharged by distant well fields and natural discharge areas and, to some degree, by upward movement of water to the surficial aquifer.

Although these two aquifers may be visualized as composing an interrelated hydrologic system, their potential roles in regard to water supply are quite different. The Upper Floridan, because of its generally high transmissivity, is the prime, direct source of water for high-yielding wells, not only in Volusia County but throughout much of central Florida. The surficial aquifer, though having high permeability in terms of upward or downward percolation of ground water, does not have the transmissivity necessary for development of large well yields. Thus, in terms of water supply, the Upper Floridan aquifer is important as the direct source of water for higher yielding wells; and the surficial aquifer is important as the medium through which recharge is transmitted to the Upper Floridan.

The position and altitude of the potentiometric-surface high in central Volusia County is probably due, in part, to slow outflow of ground water because of locally low transmissivity in the Upper Floridan aquifer. The few data available for transmissivity in central Volusia County, (mainly from specific-capacity tests) tend to indicate that transmissivity of the Upper Floridan is lower in central Volusia than in other areas of the county. A similar conclusion was reached in the investigation of the large potentiometric-surface high for the Upper Floridan aquifer in the Green Swamp area of west-central Florida (Pride and others, 1966); and the central Volusia County area, though smaller, appears to be hydrogeologically similar to the Green Swamp area. Another factor that may contribute to slow drainage from the Upper Floridan in central Volusia County is the large volume of water that is recharged to the aquifer along the ridges on both sides of the waterlogged potential recharge area. The water recharged under the Rima Ridge and De Land Ridge and moving downgradient, respectively east and west, would tend to have a backwater type of hydraulic effect to further retard outflow from the Upper Floridan aquifer and accentuate the potentiometric-surface high in central Volusia County. A combination of hydrogeologic and topographic features thus results in the waterlogged conditions that prevail in the potential recharge area in central Volusia County.

SIGNIFICANCE OF THE POTENTIAL RECHARGE AREA

Recharge and discharge for an aquifer system under natural conditions are virtually equal on a long-term basis; the system is in dynamic equilibrium and seasonal, or annual, differences in recharge and discharge are reflected in changes of storage within the aquifer system. Equilibrium conditions are disturbed when wells are constructed and put into use in an area, because pumping of wells creates a gradient toward the wells, or center of pumpage, in order to withdraw water from an aquifer. This alteration of the natural gradient then results in (a) a decrease in natural discharge of an aquifer by decreasing the gradient toward areas of natural discharge, and (b) an increase in recharge to an aquifer by increasing the vertical gradient between the water table and the potentiometric surface.

The source of water withdrawn from an aquifer by wells is from (1) a decrease in storage in the aquifer, (2) a reduction of the previous discharge from the aquifer, (3) an increase in the recharge to the aquifer, or (4) a combination of these changes (Theis, 1940, p. 277). The decrease in discharge from the aquifer plus the increase in recharge is termed "capture" (Lohman, 1972, p. 3). Thus, when water is withdrawn from an aquifer, the head in the aquifer will continue to decline until, or unless, the rate of withdrawal is equaled by the capture. If the rate of sustained withdrawal continues to exceed the capture, heads in the aquifer will continue to decline and a condition of mining of ground water occurs, which constitutes a depletion of the resource. If, however, sustained withdrawals are balanced by capture of water, a condition of dynamic equilibrium again occurs in the aquifer system. Capture is, thus, a most important factor in development of ground-water supplies; sustained yield is, in effect, limited by capture and cannot exceed it (Bredehoeft and others, 1982).

The two-aquifer system in central Volusia County, presently unstressed, is in dynamic equilibrium and water is being rejected to the wetlands environment because the system is full most of the time. However, results of the test-drilling program indicate that central Volusia County would function as a high-rate recharge area if large supplies of ground water were developed from the Upper Floridan aquifer in the area. This would result because development of water from well fields in the Upper Floridan in central Volusia County would lower the potentiometric surface, thus allowing greater downward leakage, or capture, of water that is presently rejected from the surficial aquifer to the wetlands environment. Capture of water in this manner would increase the amount of water available for use if ground water were withdrawn on a sufficiently large and sustained basis. If the use made of such withdrawals were consumptive, at least so far as central Volusia County is concerned, the greatest capture of water from the water table and wetlands environment would result.

FACTORS TO BE CONSIDERED IN DEVELOPMENT OF GROUND-WATER SUPPLIES

The potential high-rate recharge area of central Volusia County is underlain by a large reserve of fresh ground water that is presently little stressed. Because of its location, however, it would appear only a matter of time until water supplies are developed from the area to supply population centers in both the east and west-southwest parts of the county. There are advantages to development of water supplies from central Volusia County; but adverse effects on both the aquifers and the surface environment could result if development of water supplies is not systematically planned and accomplished from a firm base of scientific understanding of the hydrogeology in the area. Several factors that have relevance to any future large-scale development of water supplies from central Volusia County are discussed below.

A major advantage of developing well fields in central Volusia County is that water supplies would be withdrawn from a part of the Upper Floridan aquifer that is both laterally and vertically remote from the occurrence of brackish or saline ground water. Brackish water in the Upper Floridan virtually surrounds Volusia County, but the potential high-rate recharge area is at, or near, the center of freshwater occurrence. Also, the thickest known zone of freshwater in Volusia County was determined to be about 1,450 feet, in a test well drilled under the potentiometric-surface high in the western part of central Volusia County (Knochenmus and Beard, 1971).

Achieving capture of water in central Volusia County is, from a hydrogeologic perspective, quite simple in that it only requires the construction and pumping of wells to lower the potentiometric surface of the Upper Floridan aquifer and thus increase downward leakage of recharge water. This has the advantageous effect of minimizing the fraction of the well yield that is derived from storage within the aquifer. It should be possible to design and operate well fields in such a manner that almost all of their yield will come from capture, which would minimize drawdowns in the Upper Floridan. Optimal design and operation of well fields, however, will require additional knowledge of the two-aquifer system.

Net capture of water from the total aquifer system by inducing downward leakage at any site in central Volusia County would be maximized if the ground water is withdrawn for consumptive use, that is, not simply discharged to the adjacent wetlands environment where it could be returned to the cone of depression. Withdrawal of water for public supplies considering present distribution of population would amount to consumptive removal of the water from central Volusia County, thus maximizing capture of recharge water from the wetlands environment. This process, although advantageous to development of water supplies, needs to also be considered in terms of potential effects of the capture process on the wetlands environment, which would be the major source of captured recharge water. Sustained development of ground-water supplies would result in less water being available to the surface environment, because a significant part of ground water withdrawn in central Volusia County would come from downward leakage from surface, or near-surface sources. The ultimate effects on the wetlands environment are speculative, based on available data; but it appears logical that sustained long-term withdrawals would permanently decrease wetness by significantly changing the water-budget components in the area. Again, the effect on the wetlands is a subject for which additional scientific understanding of the potential high-rate recharge area is needed. It is a factor to be considered in the planning and design of withdrawals, but it should be possible to strike a tenable balance between water for public supplies and maintenance of wetlands environment.

Development of ground water in central Volusia County will also need to consider the effects of surface drainage on capture. Central Volusia County, under 1973 conditions, is largely a wetlands area. The present drainage system, still largely natural, is sluggish and does not have a great effect in relieving the waterlogged conditions, which may be considered as the source of water to pumping wells through the capture process. However, removal of significant water from the wetlands environment by improved surface drainage would subtract from water available for capture by wells, and thus detract from the potential ground-water yield of the central Volusia County area. Therefore, an attempt to impose severe surface-drainage improvements on central Volusia County could negate part of its function as a potential high-rate recharge area. Also, parts of central Volusia County could not be effectively drained by surface channels because of the relation of the potentiometric surface to land surface (Knochenmus, 1968). Effective drainage of these parts could only be achieved by lowering the potentiometric surface, which could be accomplished most effectively by pumping from wells in the Upper Floridan aquifer.

Other factors that need to be considered in regard to development of water supplies in central Volusia County are (1) yields of wells from the Upper Floridan aquifer, and (2) the probability of some changes in water quality after sustained withdrawals. The few available data indicate that the Upper Floridan has lower transmissivity in central Volusia than in some other areas of Volusia County or central Florida. As an example, wells in central Volusia County might be expected to yield a few hundred gallons per minute for a given drawdown, as compared to a higher yield for the equivalent drawdown in areas that have higher transmissivity. This is a relative factor; wells in central Volusia County are expected to be productive, though not as productive as wells in other areas. Expected well yields, however, are an important factor in well-field design and water-use planning and a better understanding of transmissivity distribution for the Upper Floridan in central Volusia County is a need that can be addressed in future investigations.

The second factor mentioned above relates to some probable changes that may occur in quality of water pumped from the aquifer under conditions of large, sustained withdrawals. Present quality of water in the Upper Floridan is slightly more mineralized in central Volusia County than in the adjacent ridge areas (Knochenmus and Beard, 1971, figs. 17, 19; and unpublished data in U.S. Geological Survey files). This is considered to result from the waterlogged condition, that is, from increased residence time as a result of slower outflow of ground water from the Upper Floridan in central Volusia County. The waterlogged condition would be diminished if large-scale, sustained supplies of ground water are developed from central Volusia County. Downward leakage of the captured recharge water with lower dissolved mineral content could eventually result in less mineralized water in the Upper Floridan. As a result, well fields might, at some point in time, produce softer, less mineralized water than they would initially produce from the Upper Floridan. A major change in quality of water would not be expected from this process, but it would be desirable to monitor the water quality if well fields are put into production in central Volusia County.

Another possible cause of changes, with time, in quality of water withdrawn from central Volusia would be the downward inducement of pollutants from the surface environment. Any soluble conservative pollutant that might occur over the area of capture in the hydrogeologic environment of central Volusia County could eventually be induced into the Upper Floridan aquifer. At present, the wetlands environment is virtually in pristine condition in regard to water quality and occurrence of pollutants. Land-use planning could assure that the area remains free of materials that could pollute water supplies in the future.

SUMMARY AND CONCLUSIONS

Volusia County is virtually a self-contained entity in regard to occurrence and movement of fresh ground water in the Upper Floridan aquifer. All of the freshwater in this aquifer is derived from recharge within the county, and discharge from the aquifer occurs within or contiguous to county boundaries. The Upper Floridan aquifer is the source of all public water supplies in the county. The surficial aquifer, composed of sands, shell, and clayey materials, overlies the Upper Floridan throughout Volusia County, and functions as the medium through which the more productive Upper Floridan aquifer is recharged and discharged.

Freshwater in the Upper Floridan occurs to a maximum depth of about 1,450 feet in association with a potentiometric-surface high that coincides with the Talbot Terrace in the central part of the county, which is largely a wetlands area. The aquifer contains brackish to saline water in discharge areas to the east along the Atlantic coast, to the west and southwest in the St. Johns River Valley, and to the north in Flagler County.

Ground-water withdrawals in the past were first located near the population centers that are in or near discharge areas and, thus, most likely to encounter problems with saltwater encroachment. Growing needs for water in recent years have focused more attention on the wetlands area of central Volusia County as the major source for future water needs.

The results of previous countywide investigations (Wyrick, 1960; and Knochenmus and Beard, 1971) concur that the present high-rate recharge areas for the Upper Floridan aquifer are the ridge areas, particularly the De Land Ridge and Rima Ridge that border the central Volusia wetlands to the west and east, respectively. Knochenmus and Beard (1971) further concluded that the undeveloped aquifers in the central part of the county were full and rejecting water to surface runoff and evapotranspiration on the Talbot Terrace wetlands. Thus, if the potentiometric surface in this area were lowered by withdrawal of water for use, some of the rejected recharge would be induced downward or captured to become leakage into the Upper Floridan aquifer. This would decrease the rejected recharge by the amount of such capture, thus making more ground water available for use.

During the investigation reported here, 14 core holes were drilled on the Talbot Terrace wetlands between State Road 40 on the north and State Road 44 on the south, which composes the area referred to in this report as central Volusia County. Analysis of the data indicates that vertical permeability in the surficial aquifer is generally high throughout central Volusia County, and that the surficial and Upper Floridan aquifers constitute an interconnected two-aquifer system which tends to respond, in gross fashion, to hydraulic stresses as a single unit. Thus, central Volusia County is considered to be a potential high-rate recharge area from which large water supplies could be developed from wells in the Upper Floridan aquifer by capture of water that is now rejected from the surficial aquifer.

The potential high-rate recharge area is underlain by a large reserve of fresh ground water in an area that is currently little stressed by withdrawals. The area contains the thickest zone of freshwater in Volusia County, and is laterally remote from areas underlain by brackish ground water. The threat of saltwater encroachment to coastal well fields and the growing needs for additional water continue to increase interest in the water resource in central Volusia County, so it seems virtually certain that the water resources of the area will eventually be utilized.

Large supplies can be developed from well fields in central Volusia County that are properly designed and managed to optimize capture of water. Development of water supplies needs to be systematically planned and implemented from a firm base of scientific understanding; otherwise, adverse effects on both the aquifers and the surface environment could result. Several factors, or considerations, that are relevant to optimizing the development and management of ground water in central Volusia County are:

(a) Exportation of withdrawals from central Volusia County is necessary to maximize the net capture for any given amount of withdrawal.

(b) Well fields need to be designed and operated so that most of their yield will come from capture. This will minimize drawdown in the Upper Floridan aquifer.

(c) Sustained development of ground water may result in less water being available to the surface wetlands environment. However, with proper understanding and planning, it may be possible, to maintain an acceptable balance between water for public water supply and maintenance of the wetlands environment.

(d) The effects of surface drainage on capture need to be considered. Removal of significant additional water from central Volusia County by improved surface drainage will decrease the amount of water available for capture by well fields. Surface drainage would not be effective for areas where the potentiometric surface of the Upper Floridan aquifer is above land surface.

(e) Transmissivities of the Upper Floridan aquifer generally are lower in central Volusia than in other areas of the county. Also, some changes in quality of ground water with time of withdrawal may occur as less mineralized water from the surficial aquifer and the surface environment is induced to the Upper Floridan aquifer by the capture process.

(f) The quality of water in the aquifers would be susceptible to surface contamination unless the surface environment were maintained free of pollutants, which could easily be induced to water supplies in this hydrogeologic setting.

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APPENDIX
Laboratory lithologic descriptions for core holes, well nos. VOL C-1 73 through VOL C-14 73

page 17 follows

Well No.: VOL C-1 73
Date: May 7, 1973
Depth: 87.4

VOL C-1 73

Depth, feet below land surface	Description
0.5-3.0	Sand; brown; very fine to fine, poorly sorted, rounded to subangular quartz grains; no microfossils.
3.0-5.5	Sand; light brown; very fine to fine, poorly sorted, rounded to angular quartz grains; no microfossils.
5.5-8.0	No sample.
8.0-8.7	Slightly silty sand; light brown; fine to medium, poorly sorted, rounded to angular quartz grains; no microfossils.
8.7-13.4	Lost core - split spoon sample number 1 (8.7-10.2). Slightly silty sand; light brown; very fine to fine, poorly sorted, rounded to angular, frosted quartz grains; no microfossils.
13.4-16.0	Lost core - split spoon sample number 2 (14.0-16.0). Slightly silty sand; light brown; same as 8.7-13.4.
16.0-21.0	Lost core - split spoon sample number 3 (19.0-21.0). Slightly silty sand; light brown; same as 13.4-16.0.
21.0-29.0	Lost core - split spoon sample number 4 (24.0-26.0). Slightly silty sand; light gray; very fine to coarse, poorly sorted, rounded to angular, frosted quartz grains; no microfossils.
29.0-36.0	Lost core - split spoon sample number 5 (29.0-31.0). Slightly silty sand; light gray; same as 21.0-29.0, but finer (very fine to medium).
36.0-42.0	Lost core - split spoon sample number 6 (36.0-38.0). Slightly silty sand; light gray; same as 29.0-36.0, but finer (very fine to fine) with small amount of mica.
42.0-49.4	Shelly, silty sand; green-gray; fine to coarse, poorly sorted, rounded to angular, frosted quartz grains; medium to coarse, angular to rounded shell; abundant large shell fragments and complete shells; some small slightly clayey zones; foraminifera abundant; ostracoda rare.
49.4-62.0	Shelly, silty sand; green-gray; very fine to fine, poorly sorted, angular to subrounded quartz grains, some frosted; fine to medium angular to rounded shell; foraminifera abundant; ostracoda common; small bed of green-gray; silty clay at 51.0-51.4.
62.0-76.0	Clayey silt and silty clay, carbonate rich; gray; foraminifera and ostracoda common; sponge spicules common.
76.0-77.0	Slightly silty, shelly sand, carbonate rich; gray; fine to medium, poorly sorted, rounded to subrounded, frosted quartz grains; fine to medium, rounded shell, foraminifera rare, no ostracoda.
77.0-79.2	Sandy limestone; white; fine grained.
79.2-87.4	Limestone; cream-white; granular; composed almost entirely of foraminifera.

Well No.: VOL C-2 73
Date: May 8, 1973
Depth: 73.4

VOL C-2 73

Depth, feet below land surface	Description
0.5-4.5	Slightly silty sand; light gray; very fine to medium, poorly sorted, rounded to subangular quartz grains (some frosted); no microfossils.
4.5-7.7	Silty sand; light yellow-brown; very fine to medium, poorly sorted, rounded to subrounded frosted quartz grains; no microfossils.
7.7-13.9	Silty sand; dark brown; very fine, poorly sorted, subrounded to angular quartz grains; no microfossils; 12.9-13.9 containing medium, well rounded, frosted grains.
13.9-16.9	Silty sand to slightly silty sand; light gray-brown; very fine to fine, poorly sorted, rounded to angular quartz grains; no microfossils.
16.9-21.0	Lost core - split spoon sample number 1 (19.0-21.0). Sand; light brown, fine to medium, poorly sorted, rounded to subrounded frosted quartz grains; no microfossils.
21.0-25.2	Silty sand to sandy silt; light gray; very fine, poorly sorted, rounded to subrounded quartz grains; no microfossils.
25.2-26.0	Sand; white; very fine to fine, poorly sorted, rounded to subangular frosted quartz grains; no microfossils.
26.0-28.8	Slightly silty sand; brown; very fine to medium, poorly sorted rounded to angular quartz grains (some frosted); no microfossils.
28.8-36.7	Lost core - split spoon sample number 2 (33.0-35.0). Slightly silty sand; brown; same as 26.0-28.8.
36.7-45.0	Lost core - split spoon sample number 3 (41.0-43.0). Slightly silty sand; brown; same as 28.8-36.7.
45.0-48.8	Silty sand to clayey silty sand; light gray; very fine, poorly sorted, subangular to angular; no microfossils.
48.8-55.9	Lost core - split spoon sample number 4 (51.0-53.0). Silty sand, carbonate rich; light gray; very fine to fine, poorly sorted, rounded to angular quartz grains; partially indurated.
55.9-58.0	Lost core - split spoon sample number 5 (56.0-58.0). Silty sand, carbonate rich; light gray; same as 48.8-55.9.
58.0-73.4	Sand, carbonate rich; light gray; very fine to fine, poorly sorted, rounded to subangular quartz grains (some frosted); foraminifera and ostracoda common.

Well No.: VOL C-3 73
Date: May 9, 1973
Depth: 57.7

VOL C-3 73

Depth, feet below land surface	Description
0.5-1.5	Sand; gray; very fine to medium, poorly sorted, rounded to angular frosted quartz grains; no microfossils.
1.5-3.5	Silty sand; dark brown; very fine to medium, poorly sorted, rounded to angular frosted quartz grains; dark brown iron stain; no microfossils.
3.5-8.4	Lost core - split spoon sample number 1 (6.0-8.0). Sand; light gray-brown; very fine to fine, poorly sorted, subrounded to angular quartz grains (some frosted); no microfossils.
8.4-13.4	Slightly silty sand; dark brown; fine, moderately well sorted, subrounded to angular quartz grains (some frosted); brown iron stain; no microfossils.
13.4-16.7	Sand and silty sand; light brown; very fine to fine, poorly sorted, angular to subangular frosted quartz grains; no microfossils.
16.7-21.3	Sand to slightly silty and slightly clayey sand; light to dark brown; very fine to fine, poorly sorted, angular to subangular, frosted quartz grains; no microfossils.
21.3-27.4	Slightly silty sand; light gray; very fine to fine, poorly sorted, angular to subangular, quartz grains; few larger frosted grains; no microfossils.
27.4-33.7	Sand; gray; very fine, poorly sorted, angular to subangular quartz grains; slightly micaceous; no microfossils.
33.7-38.8	No sample.
38.8-43.9	Slightly silty, shelly sand, carbonate rich; light gray; very fine, poorly sorted angular quartz sand; fine to medium rounded to angular shell; few large shell fragments, slightly micaceous, abundant foraminifera; no ostracoda.
43.9-52.0	Silty to silty and sandy clay; gray; slightly micaceous, occasional dolomite rhomb; ostracoda rare; foraminifera common.
52.0-57.7	Silty, shelly sand, carbonate rich; light gray; very fine to fine, poorly sorted, rounded to angular quartz grains; very fine to coarse, rounded to angular shell, large shell fragments and complete shells common; echinoid spines and plates; ostracoda and foraminifera rare.

Well No.: VOL C-4 73
Date: May 9, 1973
Depth: 73.7

VOL C-4 73

Depth, feet below land surface	Description
1.0-4.4	Silty sand; brown to white; very fine to fine, poorly sorted, rounded to subangular frosted quartz grains; no microfossils.
4.4-5.5	Slightly clayey and silty sand; red-brown; fine, poorly sorted, rounded to subrounded, frosted quartz grains; no microfossils.
5.5-10.1	Slightly clayey and silty sand; light gray; fine grading downward to very fine, poorly sorted, rounded to subrounded, frosted quartz grains; no microfossils.
10.1-12.3	Slightly silty and clayey sand; brown; fine, poorly sorted, rounded to subangular, frosted quartz grains; no microfossils.
12.3-15.7	Lost core - split spoon sample number 1 (13.0-15.0). Slightly silty sand; dark brown; very fine to fine, poorly sorted, rounded to subangular, frosted quartz grains; no microfossils.
15.7-18.5	No sample.
18.5-22.9	Lost core - split spoon sample number 2 (20.0-22.0). Slightly silty sand; brown; same as 12.3-15.7 except for lighter color.
22.9-28.7	Sand; light brown; fine, poorly sorted, rounded to subangular frosted quartz grains; no microfossils.
28.7-37.2	Lost core - split spoon sample number 3 (31.0-33.0). Sand; light brown; very fine to fine, poorly sorted, rounded to angular quartz grains; no microfossils.
37.2-45.0	Silty sand and sandy silt, carbonate rich; light gray to brown; very fine, poorly sorted, rounded to angular quartz grains; no microfossils.
45.0-46.3	Lost core - split spoon sample number 4 (45.0-45.8). Shelly, slightly silty sand, carbonate rich; light gray; very fine, poorly sorted, rounded to angular quartz grains; shell fragments common; no microfossils.
46.3-53.4	Lost core - split spoon sample number 5 (51.0-53.0). Shelly, slightly silty sand, carbonate rich; light gray; same as 45.0-46.3; small complete shells common.
53.4-54.4	No sample.
54.4-55.6	Silty shelly sand, carbonate rich; light gray; very fine to fine, poorly sorted, rounded to subangular quartz grains; large shell fragments to small complete shells common; no microfossils.
55.6-66.5	Lost core - split spoon sample number 6 (64.5-66.5). Silty, shelly sand, carbonate rich; light gray; same as 54.4-55.6.
66.5-73.7	Silty, shelly sand, carbonate rich; light gray; very fine to fine, poorly sorted, angular to subangular quartz grains, fine to medium, subangular to rounded shell; large shell fragments common; foraminifera and ostracoda common; some areas are partially indurated.
date?	*Lagena hexagona* var. *scalariformis*

Well No.: VOL C-4 73
Date: May 9, 1973
Depth: 73.7

VOL C-4 73—Continued

Depth, feet below land surface	Description
66.5-73.7	*Hemicythere sculpturata* GB 38
	Jugosocythereis bicarinata GB 38
	Caudites chipolensis ? GB 36
	Paracytheridea shoalriverensis GB 36

Well No.: VOL C-5 73
Date: May 10, 1973
Depth: 91.0

VOL C-5 73

Depth, feet below land surface	Description
0.5-2.5	Sand; white to brown; very fine to medium, poorly sorted, rounded to subangular, frosted quartz grains; no microfossils.
2.5-5.5	Silty sand; light yellow to gray; very fine to medium, poorly sorted, rounded to subangular frosted quartz grains; no microfossils.
5.5-15.3	Slightly clayey silty sand; light yellow to gray; very fine to medium, poorly sorted, rounded to subangular frosted quartz grains; no microfossils.
15.3-23.3	Slightly clayey to clayey sand; green-gray to light gray; very fine, poorly sorted, subrounded to angular; no microfossils.
23.3-28.5	Sand; light gray; same as 15.3-23.3, but with less clay.
28.5-34.1	Lost core - split spoon sample number 1 (31.0-33.0). Sand; light gray; very fine to medium, poorly sorted, rounded to subangular frosted quartz grains; no microfossils.
34.1-36.0	Silty sand, carbonate rich; light gray; very fine, poorly sorted, rounded to angular quartz grains; no microfossils.
36.0-45.3	Slightly silty, shelly sand, carbonate rich; light gray; very fine to fine, poorly sorted, rounded to angular quartz grains (some frosted); very fine to medium, rounded to angular shell, shell fragments common; foraminifera abundant; no ostracoda.
45.3-53.1	No sample.
53.1-57.9	Shelly sand, carbonate rich; light gray; same as 36.0-45.3.
57.9-63.3	Lost core - split spoon sample number 2 (60.0-62.0). Shelly sand, carbonate rich; light gray; same as 53.1-57.9 with more shell fragments.
63.3-71.6	Slightly silty, shelly sand, carbonate rich; light gray; fine to medium, poorly sorted, rounded to angular quartz grains (some frosted); fine to coarse, rounded to angular shell; large shell fragments and complete shells common; foraminifera rare; no ostracoda.
71.6-80.6	No sample.
80.6-91.0	Limestone; cream-white; granular.

Well No.: VOL C-6 73
Date: May 10, 1973
Depth: 99.5

VOL C-6 73

Depth, feet below land surface	Description
0.5-5.0	Lost core - split spoon sample number 1 (3.0-5.0). Sand; white to brown; very fine to medium, poorly sorted, rounded to subangular frosted quartz grains; no microfossils.
5.0-6.0	Sand; white to brown; very fine to coarse, poorly sorted, rounded to subrounded frosted quartz grains; no microfossils.
6.0-10.0	Silty sand; dark brown; very fine to coarse; poorly sorted, rounded to subrounded, frosted quartz grains; brown iron stain; no microfossils.
10.0-11.2	Sand to silty sand; light brown; very fine to coarse, poorly sorted, rounded to subrounded, frosted quartz grains; no microfossils.
11.2-15.8	Lost core - split spoon sample number 2 (11.0-13.0). Sand; light brown; fine to medium, poorly sorted, rounded to subangular frosted quartz grains; no microfossils.
15.8-22.5	Lost core - split spoon sample number 3 (20.0-22.0). Sand; gray-brown; fine to medium, poorly sorted, rounded to angular quartz grains (some frosted); no microfossils.
22.5-25.6	Lost core - split spoon sample number 4 (22.0-24.0). Sand; brown; fine to medium, poorly sorted, rounded to subangular frosted quartz grains; no microfossils.
25.6-33.3	Lost core - split spoon sample number 5 (31.0-33.0). Sand; white to light brown; very fine to fine, poorly sorted, angular to subangular quartz grains; no microfossils.
33.3-46.3	Lost core - split spoon sample number 6 (44.0-46.0). Sand; white to brown; same as 25.6-33.3.
46.3-59.3	Slightly silty sand, silty sand, and clayey silty sand; light gray; very fine, poorly sorted, angular quartz grains; mica flakes common; foraminifera common; ostracoda rare.
59.3-79.3	Silty sand, carbonate rich; light gray; very fine to fine, poorly sorted, rounded to angular quartz grains (some frosted); occasional large shell fragments; foraminifera common; ostracoda rare.
79.3-84.4	Silty shell and sand, carbonate rich; light gray; very fine to fine, poorly sorted, rounded to angular quartz grains; very fine to medium, rounded to angular shell; large shell fragments common; foraminifera common; ostracoda rare.
84.4-99.5	Limestone; gray to white.

Well No.: VOL C-7 73
Date: May 11, 1973
Depth: 92.0

VOL C-7 73

Depth, feet below land surface	Description
0.5-3.0	Sand; light gray; very fine to fine, poorly sorted, angular to subrounded quartz grains; no microfossils.
3.0-13.4	Slightly clayey, silty to slightly silty sand; light gray; very fine to fine, poorly sorted, rounded to angular quartz grains (some frosted); no microfossils.
13.4-17.6	Limey, silty sand and limey sand; light gray; very fine to medium, poorly sorted, rounded to subangular quartz grains; shell fragments abundant to rare; no microfossils.
17.6-19.6	Clayey silt to silty clay; green-gray; small complete shells common; no microfossils.
19.6-26.4	Sand; light green-gray; very fine, poorly sorted angular to subrounded quartz grains; foraminifera and ostracoda common.
26.4-32.1	Silt and sandy clayey silt; light green-gray; some layers with abundant shell fragments; foraminifera and ostracoda common.
32.1-33.1	Silty sand and clay; brown; very fine to fine, poorly sorted, rounded to subangular quartz grains (some frosted); no microfossils.
33.1-36.3	Slightly silty sand and shell, carbonate rich; light gray; very fine to medium, poorly sorted, rounded to subangular quartz grains (some frosted); fine to coarse, angular to rounded shell; large shell fragments abundant; foraminifera common; ostracoda rare.
36.3-43.7	Lost core - split spoon sample number 1 (41.0-43.0). Slightly silty sand and shell, carbonate rich; light gray; same as 33.1-36.3, but with larger shell fragments.
43.7-47.0	Slightly silty sand and shell, carbonate rich; light gray; same as 36.3-43.7.
47.0-53.7	Silty sand, carbonate rich; light gray; fine to medium, poorly sorted, rounded to subangular quartz grains (some frosted); occasional shell fragments; no microfossils.
53.7-58.1	Lost core - split spoon sample number 2 (55.0-57.0). Silty sand, carbonate rich; light gray; same as 47.0-53.7.
58.1-69.1	Silty sand, carbonate rich; light gray; very fine to fine, poorly sorted, rounded to subangular quartz grains (some frosted); shell fragments common; foraminifera common; ostracoda rare.
69.1-73.9	Silty sand, carbonate rich; light gray; fine to medium, poorly sorted, rounded to subrounded frosted quartz grains; shell fragments common; foraminifera common; ostracoda rare.
73.9-92.0	Limestone; white to cream.

Well No.: VOL C-8 73
Date: May 14, 1973
Depth: 92

VOL C-8 73

Depth, feet below land surface	Description
0.5-4.7	Silty sand; brown; very fine to fine, poorly sorted, rounded to angular quartz grains; no microfossils.
4.7-10.0	Lost core - split spoon sample number 1 (8.0-10.0). Slightly silty sand; light gray; very fine to fine, poorly sorted, rounded to angular quartz grains (some frosted); no microfossils.
10.0-18.9	Lost core - split spoon sample number 2 (15.0-17.0). Slightly silty sand; light gray; same as 4.7-10.0.
18.9-25.8	Lost core - split spoon sample number 3 (23.0-25.0). Slightly silty sand; light gray; same as 10.0-18.9.
25.8-33.1	Lost core - split spoon sample number 4 (30.0-32.0). Slightly silty sand; light gray; same as 18.9-25.8.
33.1-39.1	Silty to slightly silty sand and some slightly clayey sand; light gray; very fine to medium, poorly sorted, rounded to angular quartz grains (some frosted); no microfossils.
39.1-58.9	Sand, with thin beds of silty sand and clayey, silty sand; light gray to white; very fine to fine, poorly sorted, rounded to angular quartz grains (some frosted); no microfossils.
58.9-60.0	Sand to silty sand, carbonate rich, with thin beds of clayey silt; light gray; fine, poorly sorted, angular quartz grains; foraminifera common; no ostracoda.
60.0-62.5	Sand to silty sand, carbonate rich, with thin beds of silty clay; light gray; fine, poorly sorted, angular quartz grains; foraminifera common; no ostracoda; 0.5-foot bed of silty clay at 62 feet.
62.5-69.7	Sand to silty sand, carbonate rich; light gray; very fine to fine, poorly sorted rounded to angular quartz grains (some frosted); no microfossils.
69.7-75.1	Lost core - split spoon sample number 5 (74.0-75.1). Slightly silty, shelly sand, carbonate rich; light gray; very fine to fine, poorly sorted, rounded to angular quartz grains (some frosted); fine to medium, angular to rounded shell, large shell fragments common; no microfossils; partially indurated.
75.1-82.0	No sample (same as 69.7-75.1).
82.0-92.0	Limestone; white; granular.

Well No.: VOL C-9 73
Date: May 15, 1973
Depth: 84.5

VOL C-9 73

Depth, feet below land surface	Description
0.5-5.2	Slightly silty sand; gray to brown; very fine to fine, poorly sorted, angular to subrounded quartz grains; no microfossils.
5.2-7.9	Lost core - split spoon sample number 1 (5.0-7.0). Slightly silty sand; brown; same as 0.5-5.2.
7.9-13.3	Lost core - split spoon sample number 2 (10.0-12.0). Slightly silty sand; brown; same as 5.2-7.9.
13.3-20.7	Slightly silty sand; brown; same as 7.9-13.3.
20.7-23.3	Sand and slightly silty sand; white to light brown; very fine to fine, poorly sorted, angular quartz grains; no microfossils; small quartz crystals present.
23.3-29.1	Lost core - split spoon sample number 3 (27.0-29.0). Slightly silty sand; brown; fine to very fine, poorly sorted, angular to subrounded; no microfossils.
29.1-31.0	Silty sand to sandy silt; light gray-brown; very fine, poorly sorted, angular to subangular quartz grains; no microfossils.
31.0-33.0	Clayey, sandy, silt; gray; no microfossils.
33.0-34.1	Sand; white; fine, moderately well sorted, rounded to angular quartz grains (some frosted); no microfossils.
34.1-50.1	Shelly sand to silty shelly sand, carbonate rich; light gray; very fine to medium, poorly sorted, rounded to subrounded, frosted quartz grains; fine to medium, angular to rounded shell; large shell fragments common; no microfossils.
50.1-60.0	Shelly, slightly silty sand, carbonate rich; light gray; very fine to fine, poorly sorted, subrounded to angular quartz grains; fine, angular to rounded shell; large shell fragments common; foraminifera rare; no ostracoda.
60.0-66.1	Shelly, slightly silty sand, carbonate rich; light gray; same as 50.1-60.0, but with greater shell content.
66.1-74.1	Lost core - split spoon sample number 4 (73.0-74.1). Limestone; white granular.
74.1-84.5	Limestone; white granular.

Well No.: VOL C-10 73
Date: May 15, 1973
Depth: 77.5

VOL C-10 73

Depth, feet below land surface	Description
0-2.0	Silty sand; light gray; very fine, poorly sorted, rounded to subangular frosted quartz grains; no microfossils.
2.0-10.4	Clayey sand and silty sand; yellow to light gray; very fine, poorly sorted, rounded to angular quartz grains (some frosted); no microfossils.
10.4-18.4	Slightly limey sand to slightly silty and slightly clayey sand; light gray to white; very fine, poorly sorted, rounded to angular; trace of mica; no microfossils.
18.4-28.8	Slightly sandy, clayey silt; gray to gray-green; trace of mica; abundant foraminifera; no ostracoda.
28.8-34.5	Clayey silt to silty clay; gray to gray-green; pyrite and dolomite rhombs; no ostracoda; foraminifera rare.
34.5-57.4	Slightly silty sand and shell, carbonate rich; light gray; very fine to fine, poorly sorted, rounded to subangular frosted quartz grains; very fine to coarse, rounded to angular shell; large shell fragments and complete shells common; echinoid spines; foraminifera fairly common; ostracoda rare.
57.4-63.2	Slightly silty sand and shell, carbonate rich; light gray; fine to medium, poorly sorted, rounded to subangular frosted quartz grains; fine to medium, rounded to angular shell, large shell fragments abundant; some layers predominately shell hash; echinoid spines; foraminifera abundant; ostracoda rare.
63.2-68.8	No sample.
68.8-71.3	Slightly silty sand and shell, carbonate rich; light green-gray; fine, poorly sorted, rounded to angular quartz sand; fine, rounded to angular shell; large shell fragments and complete shells abundant; foraminifera and ostracoda common.
71.3-74.4	No sample.
74.4-77.5	Limestone; white granular.

Well No.: VOL C-11 73
Date: May 16, 1973
Depth: 92.9

VOL C-11 73

Depth, feet below land surface	Description
0.5-4.9	No sample (road fill).
4.9-9.5	Slightly silty sand; dark brown to light gray; very fine to fine, poorly sorted, rounded to subangular frosted quartz grains; no microfossils.
9.5-12.5	Slightly clayey to slightly silty sand; brown; very fine to fine, poorly sorted, rounded to angular quartz grains (some frosted); no microfossils.
12.5-18.7	Sand grading to slightly clayey sand; light brown; very fine to fine, poorly sorted, rounded to angular quartz sand; no microfossils.
18.7-27.7	Lost core - split spoon sample number 1 (25.0-27.0). Sand; light brown; very fine, poorly sorted, rounded to angular quartz sand; slightly micaceous; no microfossils.
27.7-32.9	Lost core - split spoon sample number 2 (31.0-32.9). Slightly clayey sand; gray; fine, poorly sorted, angular to subrounded quartz grains; shell fragments common; no microfossils.
32.9-37.9	Silty sand; light gray; very fine, poorly sorted, angular to subangular quartz grains; shell fragments common; foraminifera rare; no ostracoda.
37.9-46.4	Slightly silty and clayey sand; green-gray; very fine, poorly sorted, angular to subangular quartz grains; slightly micaceous; occasional beds of shell fragments and whole shells; foraminifera abundant; ostracoda rare.
46.4-50.0	Sand; gray; fine, poorly sorted, rounded to subangular frosted quartz grains; foraminifera common; ostracoda rare.
50.0-55.4	Silty clay and slightly sandy to clayey silt with some thin beds of sand; green-gray; pyrite, dolomite rhombs; foraminifera common; ostracoda rare.
55.4-63.4	Slightly silty sand and shell, carbonate rich; light gray; very fine to fine, poorly sorted, angular to subrounded quartz grains; fine to coarse angular to rounded shell; large shell fragments and complete shells abundant; foraminifera and ostracoda common.
63.4-70.9	Slightly silty sand and shell, carbonate rich; light gray; very fine to medium, poorly sorted, rounded to angular quartz grains (some frosted); fine to very coarse, rounded to angular shell; large shell fragments and complete shells abundant; foraminifera and ostracoda fairly common.
70.9-79.4	Lost core - split spoon sample number 3 (77.0-79.0). Slightly silty sand and shell, carbonate rich; light gray; same as 63.4-70.9.
79.4-86.1	Slightly silty to silty sand, carbonate rich; light green-gray; very fine to fine, poorly sorted angular to subangular quartz sand; very fine to fine, rounded to angular shell; occasional complete shell or large fragments; foraminifera and ostracoda common.
86.1-92.9	Limestone; white granular.

Well No.: VOL C-12 73
Date: May 16, 1973
Depth: 82.3

VOL C-12 73

Depth, feet below land surface	Description
0.5-4.3	No sample (road fill).
4.3-10.0	Slightly silty to slightly clayey sand; light gray; very fine to fine, poorly sorted, rounded to angular quartz sand; no microfossils.
10.0-13.3	Slightly silty sand; light brown; very fine to fine, poorly sorted, rounded to subangular quartz grains (some frosted); no microfossils.
13.3-15.5	Lost core - split spoon sample number 1 (15.0-16.0). Slightly silty sand; light brown; same as 10.0-13.3.
15.5-23.4	Slightly silty sand; light brown; same as 13.3-15.5.
23.4-28.9	Slightly silty sand, carbonate rich; gray; very fine, poorly sorted, angular to subangular; few shell fragments; no microfossils.
28.9-33.2	No sample.
33.2-34.2	Clayey silt and sand; gray; no microfossils.
34.2-37.4	Sand to silty sand, carbonate rich; light gray to green-gray; very fine to fine, poorly sorted, angular to subrounded quartz grains; foraminifera abundant; ostracoda rare; some beds with shell fragments.
37.4-40.0	Silty sand, carbonate rich; light gray; fine, poorly sorted, rounded to angular quartz grains (some frosted); occasional shell fragments; no microfossils.
40.0-47.1	Silty to clayey sand; green-gray; very fine to fine, poorly sorted, angular quartz grains; occasional shell fragments; no microfossils.
47.1-47.6	Slightly silty clay; gray; occasional shell fragments; no microfossils.
47.6-66.0	Slightly silty, shelly sand, carbonate rich; light gray; very fine to medium, poorly sorted, rounded to angular quartz grains (some frosted); fine to coarse, rounded to angular shell; abundant large shell fragments and complete shells; foraminifera and ostracoda rare.
66.0-80.6	Silty sand and shell, carbonate rich; light gray; very fine to fine, poorly sorted, rounded to subangular quartz grains (some frosted); fine, angular to rounded shell and calcareous grains; abundant large shell fragments and complete shells; foraminifera and ostracoda rare.
80.6-82.3	Sandy limestone; beige; numerous casts of small pelecypods; heavily solution channeled; no microfossils.

Well No.: VOL C-13 73
Date: May 17, 1973
Depth: 85.2

VOL C-13 73

Depth, feet below land surface	Description
0-1.7	Silty sand; brown to white; very fine to fine, poorly sorted, angular to rounded frosted quartz grains; no microfossils.
1.7-2.5	Silty sand; dark brown; very fine to fine, poorly sorted, rounded to subangular frosted quartz grains; about 30 percent organic material; no microfossils.
2.5-9.5	Silty sand; brown to light gray; very fine to fine, poorly sorted, rounded to subangular frosted quartz grains; no microfossils.
9.5-17.0	Silty to slightly silty sand; light brown to gray-brown; very fine to medium, poorly sorted, rounded to angular quartz grains (some frosted); no microfossils.
17.0-18.5	Lost core - split spoon sample number 1 (17.0-18.0). Silty to slightly silty sand; gray-brown; same as 9.5-17.0.
18.5-21.5	Lost core - split spoon sample number 2 (21.0-22.0). Silty to slightly silty sand; gray-brown; same as 17.0-18.5 with slight trace of shell fragments.
21.5-33.7	Slightly silty sand, carbonate rich; light to dark gray; very fine, poorly sorted, angular to subrounded quartz grains; shell fragments and small, complete shells common; foraminifera common; no ostracoda.
33.7-38.2	Interbedded sand, silt, silty sand, and clayey sand and silt; light gray to green-gray; very fine, poorly sorted, angular to subangular quartz grains; some beds with abundant small, complete shells; foraminifera common; no ostracoda.
38.2-43.2	Sand; light gray; very fine to fine, poorly sorted, rounded to angular quartz grains (some frosted); no microfossils.
43.2-64.9	Slightly silty sand and shell, carbonate rich; light gray; very fine to fine, poorly sorted, rounded to angular quartz grains (some frosted); fine to coarse, rounded to angular shell and calcareous grains; abundant large shell fragments and small, complete shells; foraminifera and ostracoda rare; interval from 45 to 48 feet predominately shell fragments.
64.9-72.0	Slightly silty sand and shell, carbonate rich; light gray; same as above with less shell and more lime; foraminifera abundant; ostracoda common.
72.0-83.0	Silty, shelly sand, carbonate rich; light green-gray; very fine to fine, poorly sorted, angular to subangular quartz grains; very fine to fine, rounded to angular shell with larger fragments common; foraminifera and ostracoda rare.
83.0-85.2	Limestone; white; granular; composed largely of foraminifera; ostracoda common.

Well No.: VOL C-14 73
Date: May 17, 1973
Depth: 92.0

VOL C-14 73

Depth, feet below land surface	Description
0-2.0	Sand; white; fine, poorly sorted, rounded to subangular frosted quartz grains; no microfossils.
2.0-2.5	Sand; dark brown; fine, poorly sorted, rounded to subangular quartz grains; no microfossils.
2.5-16.6	Silty to slightly clayey sand; yellow to gray; very fine to fine, poorly sorted, rounded to subangular quartz grains (some frosted); no microfossils.
16.6-30.2	Sand; light gray to light yellow; very fine, poorly sorted, angular to subangular; slightly micaceous; no microfossils.
30.2-39.2	Interbedded silty sand, silt, clayey silt, and sandy, silty clay (all containing shell fragments); green-gray; very fine, poorly sorted, angular quartz grains; shell fragments and complete shells common; foraminifera common; no ostracoda.
39.2-45.7	No sample.
45.7-46.7	Interbedded silty sand, silt, clayey silt, and sandy silty clay; green-gray; same as 30.2-39.2.
46.7-56.7	Sand; white; fine, poorly sorted, angular to subrounded quartz grains (some frosted); shell fragments and small, complete shells common; no microfossils.
56.7-60.7	Lost core - split spoon sample number 2 (57.0-59.0). Slightly silty sand and shell, carbonate rich; light gray; fine to medium, poorly sorted, rounded to subrounded, frosted quartz grains; fine to coarse; rounded shell and calcareous grains; large shell fragments and small complete shells abundant; occasional phosphate nodules; no microfossils.
60.7-77.5	Slightly silty sand and shell, carbonate rich; light gray; same as 56.7-60.7.
77.5-81.2	Silt; olive green; containing phosphate nodules and thin layers of black sand.
81.2-92.0	Clayey silt; olive green; containing phosphate nodules and thin layers of black sand; becoming indurated at 91 feet.