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Information Circular No. 86

HYDROGEOLOGIC CHARACTERISTICS OF THE SURFICIAL AQUIFER IN NORTHWEST HILLSBOROUGH COUNTY, FLORIDA

By
William C. Sinclair

Prepared by the
UNITED STATES GEOLOGICAL SURVEY
in cooperation with the
BUREAU OF GEOLOGY
DIVISION OF INTERIOR RESOURCES
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and
SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT

TALLAHASSEE, FLORIDA
1974

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Bureau of Geology
Tallahassee
February 12, 1974

Honorable Reubin O'D. Askew, *Chairman*
Department of Natural Resources
Tallahassee, Florida

Dear Governor Askew:

The Bureau of Geology of the Division of Interior Resources is publishing as its Information Circular No. 86 a report prepared by William C. Sinclair of the U. S. Geological Survey entitled, "Hydrogeologic Characteristics of the Surficial Aquifer in Northwest Hillsborough County, Florida".

Considerable information is available on the hydrogeologic properties of the Floridan aquifer of Northwest Hillsborough County, but little is known about these properties in the overlying surficial aquifer. This report provides a detailed evaluation of the storage of water in these surficial depositis and its movement into the Floridan aquifer.

Respectfully yours,

Charles W. Hendry, Jr., *Chief*
Bureau of Geology

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HYDROGEOLOGIC CHARACTERISTICS OF THE SURFICIAL AQUIFER IN NORTHWEST HILLSBOROUGH COUNTY, FLORIDA

By
William C. Sinclair

ABSTRACT

Fifty-nine holes were augered to the top of the limestone Floridan Aquifer. Lithologic and gamma logs of the holes were used in conjunction with laboratory analyses of samples to define the hydrogeology of the unconsolidated deposits of the surficial aquifer overlying the limestone. The surficial aquifer is comprised of an upper fine sand unit which averages about 15 feet thick and a lower sequence of sandy clay and clayey sand layers which average about 25 feet thick. Median grain size, specific yield, and vertical permeability of the surficial aquifer decrease downward. The coefficient of vertical permeability of the sand is about 100 gallons per day per square foot, but the coefficient of vertical permeability of the lower sand and clayey sand is much lower ranging from 0.01 to 0.1 gallon per day per square foot.

A confining layer of dense clay underlies the surficial aquifer separating it from the Floridan Aquifer below. The coefficient of vertical permeability of the clay is about 0.001 gallon per day per square foot. Although this clay is discontinuous, it averages 4 feet thick throughout the area and is apparently a weathering product of the underlying limestone. The limestone surface is irregular and its average depth is 45 feet below land surface.

The potentiometric surface in the surficial aquifer stands an average of 10 feet above that in the Floridan. Leakage from the surficial aquifer to the Floridan occurs through the confining layer as well as through perforations in the confining layer. Estimates of leakage to the Floridan Aquifer based on vertical permeability calculated at each test site varied widely from place to place. A regional estimate, based on the average coefficient of vertical permeability, is about 140,000 gallons per day per square mile.

INTRODUCTION

Heavy withdrawal of ground water from the Floridan Aquifer in northwest Hillsborough and northeast Pinellas Counties, Florida, has lowered the water table in the overlying surficial aquifer. The effects of the pumpage were anlayzed by Stewart (1968), and his analysis led the Southwest Florida Water Management District to request the U. S. Geological Survey to investigate the feasibility of artificially recharging the Floridan Aquifer in the area.

Considerable information is available on the hydraulic and hydrogeologic properties of the Floridan Aquifer in this area but little has been known about these properties in the overlying surficial aquifer. A principal aim of this investigation is to provide a detailed evaluation of the role of the surficial deposits in the storage of rain falling upon the land surface and its movement into the Floridan Aquifer.

The investigation began in December 1968. This report, the first from the investigation, documents the results of test drilling undertaken to define the hydrologic characteristics of the unconsolidated deposits. These deposits comprise both the sands of the surficial aquifer, which is the water-table aquifer in the area, and the clay confining bed that retards movement of water between this aquifer and the Floridan Aquifer below. The report is limited to description of the methods used and interpretation of data derived from the test drilling.

GEOGRAPHIC SETTING

Northwest Hillsborough County is a flat to slightly undulating sandy plain. Its altitude is about 50 feet in the eastern part of the area of investigation; the regional slope westward toward and into the Gulf of Mexico, is about 4 feet per mile.

The plain is perforated by sinkholes -- circular depressions typical of karst erosion -- that bottom as much as 15 to 20 feet below land surface. These small circular depressions, locally called cypress heads or cypress domes, are one of the most characteristic vegetative and geomorphic features of the gulf coastal lowlands. These features result from local subsidence of the land surface due to sapping of the surficial material into solution openings forming in the underlying limestone. Sinkholes are prevalent throughout the area in all stages of formation ranging from freshly collapsed pits a few feet in diameter to large lakes and swamps with irregular shorelines and bottoms -- composites of many coalescent sinkholes. The sinks permit local hydraulic connection between the surficial water-table aquifer and the Floridan Aquifer and are an important avenue of natural recharge to the Floridan Aquifer in this area.

Most of the natural surface drainage of the area is poorly developed. The myriad sinkhole swamps and lakes that dot the sandy plains fill when rainfall is heavy, then spill one into another as the water moves generally southwestward. Only a small part of the rainfall runs off and percolation to both aquifers is also slight. By far, the greatest part of rainfall in the area is lost by evaporation and transpiration.

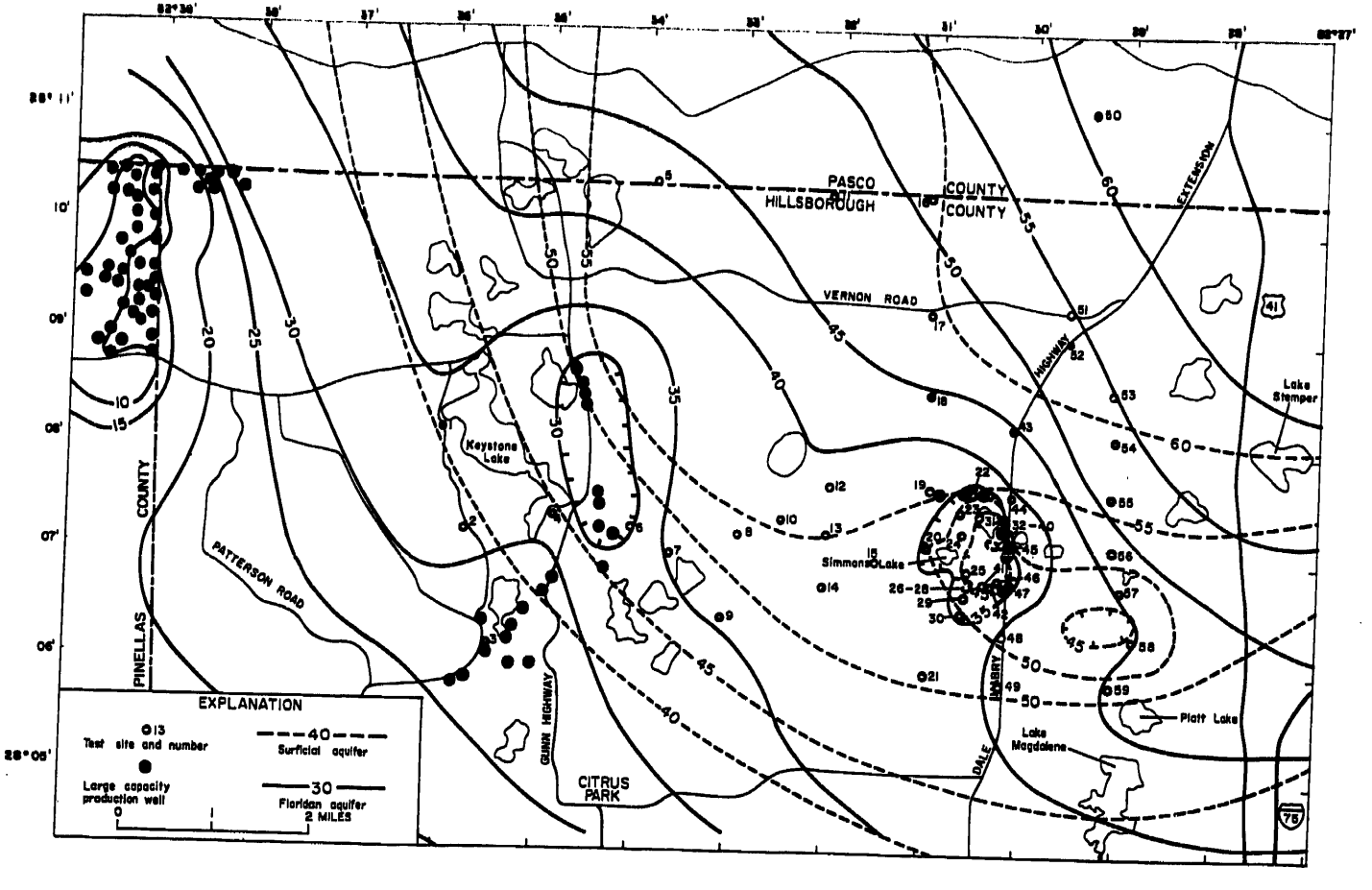
TEST DRILLING

Sites were selected for test drilling on the basis of many criteria. Broad geographical coverage seemed desirable to determine the variability of the surficial deposits within the area. Test holes were drilled one-half mile to 1 mile apart from east of the Section 21 well field to the Cosme well field, and at about 1-mile intervals both north and south of the Section 21 field (fig. 1). Within this geographical framework, sites were selected on different soils and landforms to determine whether soil and terrain might give some indication of the lithology of underlying deposits. Table 1 lists several geologic and hydrologic factors at each site, for comparison. The "Soil Survey, Hillsborough County" (Dept. Agriculture, 1968) was used as authority for the soil type (table 1) at the test sites.

Much of the test drilling was concentrated within the 1-square-mile area of the Section 21 well field where the effects of pumping from the Floridan Aquifer on water levels in lakes and in wells tapping the surficial aquifer are most severe. Test holes were augered in Starvation Lake (site 31) where a 12-foot decline in stage had exposed much of the bottom. A hole was also augered near Jackson Lake (site 23) just west of Starvation Lake. In Jackson Lake the stage did not seem to be fluctuating greatly. Test holes were augered in the center of a well-defined sinkhole marsh (site 40), and in a well-defined sinkhole swamp (sites 32-35). Several wells were also augered in a flatwoods area where incipient sinkholes are developing (sites 26-28) and in soil types not previously augered. In all, 59 wells were drilled and sampled using the power auger and one (site 60) was sampled at land surface by hand.

Where possible, wells were augered on Hillsborough County Road Department rights-of-way. The upper few feet there is generally artificial fill so the first sample was usually taken from 5 feet below land surface. The cooperation of the Hillsborough County Engineer's Office, the city of St. Petersburg Water Department, and the many private citizens who allowed access to their property is gratefully acknowledged.

Test sites where wells were drilled and sampled during this study are numbered in sequence. At each site a well was installed using 2-inch plastic casing with a screen set in the topmost part of the Floridan Aquifer. At most sites a shallow well was also installed with the screen set in the surficial aquifer just below the water table. Thus, measurements can be made of the potentiometric surface of each aquifer.


PASCO COUNTY
HILLSBOROUGH COUNTY
PINELLAS COUNTY
VERNON ROAD
PATTERSON ROAD
GUNN HIGHWAY
HIGGINS HIGHWAY
DALE EXTENSION
Keystone Lake
Simmons Lake
Lake Magdalene
Platt Lake
Lake Stemper
CITRUS PARK
EXPLANATION
Test site and number
Large capacity production well
Surficial aquifer
Floridan aquifer
0
2 MILES

SAMPLING METHODS

The test holes were augered with a truck-mounted power rig. The auger flights are 5 feet long, 8 inches in diameter, and are formed around a 3-inch diameter steel tube. A plug seals the bottom of the central tube during augering. This plug is held in place by 5-foot sections of steel rod. The steel rod is added to the string, along with additional auger flights, as the hole is deepened. When the auger bit reaches the desired sampling depth, the drill is stopped and the rods are pulled out. The sampler is then lowered through the auger and pushed or driven into the undisturbed material below the auger bit, cutting a cylindrical sample the diameter of the tube.

The sampler used is called a split spoon and is made of two half tubes that fit together to form a cylinder and are held together by a threaded coupling at the top and a threaded, case-hardened, cylindrical cutting shoe at the bottom. Three aluminum tubes 6 inches long and 1½ inches in diameter fit snugly into it. When the sample is retrieved, the split spoon is opened. The aluminum tubes are sealed at each end with plastic caps and labeled. The ends of the tubes are sealed in wax to prevent loss of moisture and disturbance of the sample before it reaches the laboratory.

Sampling unconsolidated material through a hollow-stem auger is superior to sampling by other methods because uncontaminated samples can be obtained at any desired depth in a relatively undisturbed condition. Most samples of clay and laminated clay and sand show the extent of disturbance by drag folds in the bedding planes at the cylinder walls. The clay is soft, and undisturbed samples were usually collected without difficulty. Because massive sand has little cohesion, undisturbed samples are nearly impossible to obtain from below the water table. The sand is homogeneous and the amount of disturbance is difficult to determine.

Samples were usually taken at 5-foot intervals. Test holes at sites 35, 37, 40, and 44 were sampled continuously from land surface to limestone. The lithologic logs of these test holes indicate that samples collected every 5 feet would prove adequate for the needs of this study when augmented by gamma logs.

LABORATORY ANALYSES

Sixty-nine samples from 25 of the test holes were analyzed by the Geological Survey's laboratory in Denver for certain physical and hydrologic parameters.

PARTICLE–SIZE ANALYSES

In unconsolidated, granular material, the hydraulic conductivity is largely a function of the size and shape of the component grains and their degree of sorting. The median diameter is the particle size that is larger than 50 percent of the sample and smaller than the other 50 percent. The median diameter of the samples tested ranged from 0.002 mm (millimeter) for dense clay to 0.22 mm for sand and mixtures of sand and clay (table 2). The average of all the median diameters was 0.14 mm, and for the samples without an appreciable silt and clay fraction, 0.17 mm. These sizes are in the fine sand range (0.125 to 0.25 mm) of the Wentworth classification (Twenhofel and Tyler, 1941, p. 46-48, and Wentworth, 1922). Sand particles of medium size (0.25 to 0.5 mm) rarely constituted more than 2 or 3 percent of the samples except for sample 23-35[1/] which contained 16.8 percent. That fraction within the coarse sand size (0.5 to 1.0 mm) was less than 1 percent of any sample.

The sorting coefficient listed in table 2 is a measure of the degree of sorting in a sample. It is sometimes called the geometrical quartile deviation (Trask, 1932, p. 70-72). It is represented by the expression $(Q_3/Q_1)^{1/2}$ in which Q_3 is the particle diameter that is larger than 75 percent of the sample, and Q_1 is the particle diameter that is larger than 25 percent of the sample. A sorting coefficient less than 2.5 (Krumbein and Pettijohn, 1938, p. 232) indicates a well sorted material. Most of the sorting coefficients listed in table 2 are less than 2.5, indicating that most of the samples are well sorted.

HYDRAULIC CONDUCTIVITY

Hydraulic conductivity is the capacity of a material to transmit water. Hydraulic conductivity is reported in table 2 as the rate of flow, in cubic feet per day, through a cross-sectional area of 1 square foot, under a hydraulic gradient of 1 foot per foot, at the prevailing kinematic viscosity in units of feet per day. This terminology is suggested for use in reports of the Geological Survey by Lohman, and others, (1972). The coefficient of permeability is also reported in Meinzer Units, the former standard of the Geological Survey -- gallons per day per square foot, under a hydraulic gradient of 1 foot per foot at a temperature of 60° F.

Hydraulic conductivity of 36 samples was determined in the laboratory using either constant-head or variable-head permeameters. The conductivity of

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1/ Sample numbers are a composite of the site number and sample depth. For example, sample 23-35 is from a test well at site 23 and from a depth of 35 feet.

one clay sample was determined by a consolidation test. Because most of the tests were made on undisturbed material in the collection tube, the data cited in table 2 represent vertical permeability.

SPECIFIC YIELD

The specific yield of a material was defined by Meinzer (1923, p. 28) as "the ratio of (1) the volume of water which, after being saturated, it will yield by gravity to (2) its own volume". In applying laboratory results to field problems specific yield is commonly taken as a measure of the capacity of a water-table aquifer to store water.

The specific yields listed in table 2 were determined as the centrifuge-moisture equivalent. This equivalent is the moisture content of a sample after it has been saturated with water and then subjected for 1 hour to a force 1,000 times that of gravity. Such specific yields represent extreme degrees of dewatering and are higher than specific yields of the same materials under field conditions.

Specific yields decrease with increasing silt and clay content. Average specific yield for the sand sample is 34.6 percent for clayey sand, 28.9 percent; and for sandy clay, 19.1 percent. The specific yields of 11 samples of laminated sand and clay range from 22.4 to 37.4 percent. This variation reflects a wide range in clay content and degree of sorting within this unit. Specific yields determined for three samples of clay average 10.4 percent. The specific yield of another clay sample is 53.6 percent. This sample is a black, organic fluid clay found in solution openings in the upper part of the Floridan Aquifer.

CLAY – MINERAL IDENTIFICATION

Ten samples of clay were submitted to the laboratory for identification. The identifications, listed in table 3, show mixed-layered illite-montmorillonite, with illite generally predominant.

LITHOLOGY

The lithologic descriptions of the samples in table 4 were made at the test site. Observations were made of the properties that affect the hydrology of the sediments -- particle size, shape, sorting, clay content, and stratification. Color was also noted as an aid to interpretation of the environment of deposition; the degree of weathering; the presence of organic matter; and other pertinent factors significant to the geohydrology.

NATURAL – GAMMA LOGS

Natural gamma logs are useful in hydrologic studies as an aid in determining the type of materials penetrated by cased wells. The interpretation of gamma logs is qualitative because the instrument used for logging gamma radiation was not calibrated to a standard radiation source. Methods and results obtained in a given geohydrologic environment may not be applicable beyond that environment. The trace of gamma radiation obtained from logging of each test hole is shown in table 4. Extensive use of gamma logs was made in this study to extend interpretations of the geohydrologic properties of the surficial deposits obtained from studies of the samples.

All the logs were made with the probe traveling up the casing at 20 feet per minute. Pulse-averaging time was 8 seconds and full-scale deflection 100 counts per time constant. Thus, qualitative interpretation and correlation between each well logged was possible.

The natural radioactivity of material such as quartz sand and pure limestone is negligible. Most clay minerals are moderately radioactive. Thus, an increase in radioactivity may indicate an increase in the clay content of the material. This relationship is significant in a hydrologic study where the permeability of an aquifer may be controlled by clay content.

On the basis of samples collected at 5-foot intervals, the upper 15 to 20 feet of material in each well drilled was logged as sand or clayey sand. Minor fluctuations in the gamma traces indicate that in many of the test wells the material logged may have laminae of clayey material not noted in the samples.

The lithologic log for the test hole at site 35 is one of the more detailed in this report. The well was sampled continuously from land surface to limestone, and the gamma log agrees very closely with the lithologic log. This gamma log illustrates their usefulness in refining the lithologic logs for those wells sampled at 5-foot intervals. Where the gamma log was used to pick the boundary between units, the midpoint on the curve between minimum and maximum was taken as the contact.

Gamma radiation of the dense clay immediately overlying the limestone is very high. This clay is probably a weathering product of the underlying limestone and the very high gamma radiation may be due to enrichment of the clay with a concentration of secondary phosphate and uranium-rich minerals as described by Carr and Alverson (1959, p. 54, 67).

Phosphate and uranium analyses were not made during the current investigation but sample 37-36 (table 3) contains 2-3 percent of potash feldspar. Potassium-40 is a common source of high gamma radiation in feldspars and in clays formed by their decomposition.

At site 40, a thick section of peat and organically-rich clay was penetrated, and at site 21 about 20 feet of dense clay was countered. The gamma logs for both sites show that neither the peat nor the clays have appreciable radioactivity. No explanation is apparent for these anomalous logs but they indicate that the gamma log alone is not always a reliable indicator of lithology.

GEOHYDROLOGY

Laboratory analyses and field observations were used to determine the hydrologic characteristics of the material underlying the area of investigation. The material is divided into four major geohydrologic units: (1) limestone; (2) clay; (3) sand and clay; and (4) sand. The geohydrologic units are listed in table 4.

LIMESTONE

The Tampa Limestone is the consolidated bedrock immediately underlying the surficial deposits throughout the area studied, and is the upper unit of the Floridan Aquifer. The limestone is gray or light tan to white, usually sandy, fossiliferous in places and commonly contains clay lenses and cavities. The limestone is dense and hard; especially where sandy, but may be soft at places where badly weathered. Commonly, the upper surface of the limestone is case hardened by impregnation with silicon dioxide.

Cavities in the upper few feet of the limestone were penetrated by the auger at several sites. These cavities were commonly filled with a black clay. The black color indicates an organic origin; a sapropel, or gyttja, which may have flowed into the cavernous limestone through connection with swampy sinkholes. This clay is extremely soft and fluid as though it were not part of the aquifer structure. Sample 23-40 (table 2); which seems typical of this clay, had a specific yield of 53.6 percent, suggesting that it may have been intruded into its present position under artesian pressure.

Permeameter tests, made on two samples of limestone indicated coefficients of permeability of 0.1 and 15 gpd per ft^2. The actual range in permeability of the limestone is much greater because of variations in lithology, the degree of weathering, and because most movement of water through limestone is principally along enlarged bedding planes and joints. Tests of wells

in the Tampa Limestone indicate that the coefficient of permeability of the limestone in the test area is about 1,000 gpd per ft^2.

CLAY

A dense, plastic clay overlies the Tampa Limestone throughout the area and is often interbedded with thin layers of limestone in the upper part of the Floridan Aquifer. The clay is generally green or greenish-gray, is streaked or mottled with gray and black, and contains sand. The sand fraction in the 6 samples analyzed averaged 44 percent, and ranged from 22 percent to 64 percent.

The clay may be calcareous in places, particularly near the limestone contact. Clay, as described above, was penetrated in 47 of the 59 test holes. Where present, it is as much as 20 feet thick and averages about 4 feet.

The laboratory analyses of the clay minerals are similar to those obtained by Carr and Alverson (1959, p. 32) for clay minerals in west-central Florida. Carr and Alverson also show (1959, p. 52-53, fig. 14) with sand-clay ratios of the clay and unweathered limestone that the clay is a residuum of the underlying Tampa Limestone. They postulate 5 to 10 feet of original limestone for each foot of residual clay.

Other evidence that indicates the clay is a weathered residuum of the Tampa Limestone is (1) the presence of distorted and crenulated bedding planes in the clay resulting from slumping and collapse of underlying material; (2) the occurrence of fresh chert; and (3) the clay's high gamma radiation.

Carr and Alverson (1959) attribute the high gamma radiation to uranium-rich minerals concentrated by dissolution of the Tampa Limestone and possibly by leaching of these minerals from the younger Hawthorn and Bone Valley Formations. Although the Hawthorn and Bone Valley Formations were not identified in the test drilling, they probably once overlay the Tampa Limestone in this area as they do the Tampa Limestone in much of west-central Florida.

Samples collected at any depth expand somewhat when the overburden load is removed. The result is that the porosity and permeability, as determined in the laboratory, generally seem to be higher than expected for the material in place. This is particularly true of samples of plastic clay. Consolidation tests, although time consuming and expensive, yield values of permeability which more closely represent natural conditions because this test permits adjustment for the overburden load. Clay sample 17-65, selected as typical by comparing several

differential thermal analyses, was subjected to a consolidation test and the coefficient of vertical permeability, adjusted for an overburden load of 60 psi (pounds per square inch), was about 0.001 gpd per ft^2.

Permeability will vary within the clay because of differences in the sand content, the degree of compaction and the structure as well as many other factors. However, these variations are minor. Therefore, the coefficient of permeability obtained from the consolidation test, 0.001 gpd per ft^2, is considered representative of the vertical permeability of the clay layer in the area.

SAND AND CLAY

A sequence of sand and clay layers lies unconformably on the eroded surface of the weathered clay residuum or the limestone where the clay is absent. The mottles and crenulations which are common in the dense clay are absent in the laminated sand and clay. Stratification in this unit is apparently undisturbed, indicating that deposition occurred after that period of weathering of the Tampa Limestone represented by the dense clay.

The hydrologic characteristics of this unit vary greatly with the clay content of the material and with the degree of stratification. Vertical and lateral changes in composition are abrupt within the section.

Material comprising the sand and clay unit has been subdivided, for better definition of hydrologic properties, into three geohydrologic subunits: sandy clay, clayey sand, and sand and clay laminae.

SANDY CLAY

The term sandy clay is used to define material in which clay fills the interstices between sand grains. The proportion of clay is not high enough to give the material a plastic cohesiveness characteristic of the underlying residual clay. In four samples of this unit tested by the laboratory, the silt-clay fraction ranged from 24.3 to 42.9 percent. The coefficients of vertical permeability of these samples ranged from 0.0013 to 0.16 gpd per ft^2. For this study, a value of 0.01 gpd per ft^2 was taken as a reasonable average coefficient of vertical permeability of the material logged as sandy clay.

CLAYEY SAND

Clayey sand is the term used to describe that part of the laminated sequence which is chiefly sand but contains sufficient clay to have a significant

effect on its permeability. The clay appears to be evenly dispersed throughout the material. Silt and clay content of 10 samples of the clayey sand ranged from 8.2 to 25.4 percent and averaged 14.6 percent. The coefficient of vertical permeability of 6 samples whose clay content ranged from 12.2 to 20.0 percent ranged from 0.021 to 9.8 gpd per ft^2. A value of 1 gpd per ft^2 is a reasonable average for the clayey sand throughout the area.

SAND AND CLAY LAMINAE

The term sand and clay laminae is used to define material that is predominantly sand or clayey sand but is banded with distinct layers of sandy clay or clay. Individual layers of clay are as much as 1 centimeter thick. The silt and clay content of the six samples for which the coefficient of vertical permeability was also determined ranged from 10.7 to 19.4 percent. The vertical coefficient of permeability of these samples ranged from 0.0069 to 0.49 gpd per ft^2, and 0.01 gpd per ft^2 is a reasonable average.

The silt and clay content of the sand and clay laminae at site 60 is somewhat less than at other sites and ranges from 7.0 to 9.1 percent. Coefficients of horizontal permeability of the samples from site 60 ranged from 8.3 to 29 gpd per ft^2; with one anomalous value of 120 gpd per ft^2. Even excluding the anomalous value, the average for the horizontal permeabilities is more than 16 times greater than that of the average vertical permeability of the other sand and clay subunits.

The low vertical permeability of the subunit is caused by stratification. Although silt and clay comprise a small fraction of the total sample, their concentration in horizontal layers greatly retards vertical movement of water through the unit. The thin layers of dense clay have more effect on the vertical permeability than would a larger amount of clay evenly dispersed through the sand.

SAND

The uppermost deposit underlying the study area is a clean well-sorted, fine to very fine quartz sand. The sand has no apparent bedding and is noncohesive except for a zone of cementation which occurs at places near the surface. The sand ranges from 0 to 35 feet in thickness and averages about 16 feet. It is absent at only one site. The sand is commonly white to light tan or buff colored near the surface where it often contains a mixture of organic matter and silt.

The clay content of the massive sand unit seems to increase gradually with depth. This clay may have been reworked by wave action on the underlying laminated sand and clay unit thus obscuring the contact. It is also possible that the sand may be a near-shore facies of the underlying unit.

The lithologic descriptions of the sand in table 4 were verified by laboratory analyses. Particle-size analyses of 19 samples show that the silt and clay fraction ranges from 0.2 to 6.8 percent. All the samples are within the fine sand classification of Wentworth (median diameter 0.125 to 0.25 mm). The average of the median grain size for all samples was 0.17 mm. The coefficient of vertical permeability of five samples ranged from 2.7 where the silt clay content was 4.7 percent to 98 gpd per ft^2 where the silt clay content was 0.9 percent. An aquifer test made in the surficial aquifer indicates that the horizontal coefficient of permeability of this sand is about 100 gpd/ft^2. That value is considered a reasonable average for the unit.

HYDROLOGIC SYSTEM

In northwest Hillsborough County surficial sand of relatively high permeability and large storage capacity is underlain by layers of sand and clay of less permeability and storage capacity. Underlying these units is a relatively impermeable clay which overlies the permeable limestone of the Floridan Aquifer and is the most important factor in retarding the downward movement of water from the surficial aquifer to the Floridan Aquifer.

A common method of calculating the composite coefficient of vertical permeability of a section is by the equation (modified from DeWiest, 1965, p. 231):

$$Pv = \frac{M}{m_1/p_1 + m_2/p_2 + \cdots m_n/p_n}$$

where Pv is the composite coefficient of vertical permeability for all confining layers,
M is the total thickness of all confining layers,
m is the thickness of each confining layer,
p is the coefficient of permeability of the confining layers as described in the preceding sections.

For example, well 23 in table 4 is shown to penetrate 4 feet of clay, 8 feet of sandy clay, 16 feet of sand and clay laminae, and 11 feet of sand. The clay and sandy clay are considered to be confining layers because of their low coefficients of permeability; 0.001 and 0.01 gpd per ft^2. Although the vertical

permeability of the sand and clay laminae is also low, this subunit is considered a part of the aquifer along with the 11 feet of sand, because of the high horizontal permeability. Substituting the values from the log of well 23 into the equation: :

$$Pv = \frac{4 + 8}{4/0.001 + 8/0.01}$$

$$= \frac{12}{4800}$$

$$= 0.0025 \text{ gpd per ft}^2$$

The clay, with a coefficient of permeability of 0.001 gpd per ft^2, is the dominant factor in the equation controlling the composite vertical permeability of the surficial deposits.

The values of composite coefficients of vertical permeability divided by the confining layer thickness are listed in table 1 where they are called leakage factors. These range from 0.3×10^{-4} to 33.0×10^{-4} and average 4.9×10^{-4} gpd/ft^3.

Estimates of leakage from the surficial aquifer through the confining bed to the Floridan Aquifer may be made by multiplying the leakage factor by the difference in head in the two aquifers. For example: assuming a head difference of 10 feet and using the average factor given above, than 10 ft x .00049 gpd/ft^3 = .0049 gpd/ft^2. Leakage over 1 square mile, under these conditions would be about 140,000 gallons per day.

Inter-aquifer leakage is commonly estimated from aquifer test data. Cherry and others (1970, p. 60) report a leakage factor of 1.5×10^{-3} on the basis of a long-term aquifer test on a well in the Section 21 well field. This leakage factor is an order of magnitude larger than 4.9×10^{-4} -- the average of the values calculated from the well logs throughout the area. Data collected from the test drilling are biased by the location of the test sites (relatively few were drilled in sinkholes, swamps, and lake bottoms) just as aquifer-test data are biased by the location of the pumped well. In the absence of an infinite number of test sites or aquifer tests, the true value of regional leakage can only be approached by judicious interpretation of the available data.

Variations in the composite vertical permeability are large within short distances because of the variations in the thickness of the dense clay layer. Variations in clay thickness may result from local variations in the rate of dissolution of the underlying limestone which, in turn, may be due to local

variations in limestone lithology. Variations in the topography of the limestone surface just before the onset of karst erosion represented by the clay may also affect the thickness of the clay layer. The clay may have been subject to subaerial erosion prior to the deposition of the sand and clay unit and to removal by subsidence into active sinkholes.

Study of the logs in table 4 indicates that at least three generations of sinkholes exist; relict, established, and incipient. Sinkholes apparently developed in the surface of the Tampa Limestone before deposition of the sand and clay unit. Sites 17 and 44, for example, are flatwood areas with no surface indication of sinkhole development. The logs of the wells drilled at sites 17 and 44 (table 4) indicate a swampy environment at depth. These deposits are overlain by the sand and clay and the sand. The limestone surface in these wells was found 35 and 20 feet lower than the limestone surface encountered at the nearest adjacent test sites. The sinkholes penetrated by these wells are relict.

Well 40 was drilled within a circular marsh -- an established sinkhole of at least 50-years duration, judging from the size of the cypress trees. Well 40 penetrated more than 60 feet of black clay and peat and had not reached limestone at 107 feet below land surface. Nearby wells penetrate limestone at 45 feet on the average.

The appearance of incipient sinkholes, some only a few feet in diameter, attest to the stoping of surficial sediments into newly developing solution cavities in the limestone. Many of the incipient sinks have developed surface expression since the beginning of this study in 1968.

Although natural recharge occurs more rapidly through perforations in the confining layer than where the clay is intact, sinkholes occupy a small percentage of the total area and leakage through the clay confining layer, although slower, probably constitutes the major part of natural recharge to the Floridan Aquifer in the area.

Variations in thickness of clay and in depth to the limestone surface are so great over such short distances that very close spacing of test holes would be necessary to delineate any pattern. No relations were discovered among surface terrain, vegetation or soil type and the types of materials penetrated in test wells which might aid in predicting the nature of these materials from surface expressions in places where there are no test wells. Circular depressions, swamps, and lakes are presumed to represent sinkholes which perforate the clay layer and permit hydraulic connection between the aquifers. Many of these features may be underlain by plugged sinkholes and, conversely, active sinks may exist that have not yet developed any surface expression.

The contours on the potentiometric surfaces of the surficial aquifer and the upper part of the Floridan Aquifer (fig. 1) show the difference in water level between the two. The potentiometric surface of the surficial aquifer is rarely more than 10 feet below land surface and is commonly less than 5 feet. Contours on the potentiometric surface of the surficial aquifer generally reflect the configuration of the land topography. The contours slope gently from an altitude of about 60 feet in the northeastern part of the area southwestward toward Tampa Bay and the gulf.

The potentiometric surface in the upper part of the Floridan Aquifer in this area stands 5 to 10 feet lower than that of the surficial aquifer (the water table) under natural conditions. The artesian head is a function of the altitude of the water table, the resistance to vertical movement of water from the surficial aquifer through the confining layer to the Floridan Aquifer, and the resistance to horizontal movement of water through the Floridan Aquifer.

Near the Section 21 well field where data are sufficient to define both potentiometric surfaces in detail, a depression in the water table overlies the cone of depression in the Floridan Aquifer. The latter depression is due to pumpage from the Floridan Aquifer and the former to leakage induced by the increased head difference between the two aquifers.

The minor depression in the water table southeast of the well field may be due to the absence of the confining layer in this area and a consequent high rate of leakage to the Floridan Aquifer. The logs of test wells in this area show that the limestone is at a shallow depth and is overlain directly by the surficial aquifer.

Just east of the well field, Lakes Charles, Saddleback, and Round are artificially maintained at stages between 50 and 55 feet by pumpage from the Floridan Aquifer. Seepage from the lakes maintains the potentiometric surface of the surficial aquifer at a relatively high level in this area even though considerable leakage to the Floridan Aquifer is also taking place. The effects of this leakage on the potentiometric surface of the Floridan Aquifer are not obvious because of the relatively high permeability of the limestone.

SUMMARY

Northwest Hillsborough County is underlain by a surficial sand (water-table) aquifer that has a large capacity to store water. The sand becomes less permeable with depth and grades downward through a sequence of sand and clay layers. Although the sand and clay is an important part of the surficial aquifer, the vertical permeability of the lower unit is low because of the

horizontal laminae of clayey sand and sandy clay. A dense, plastic clay underlies the sand and clay unit throughout most of the area. The clay, a weathering product of the underlying limestone, forms a confining layer because of its extremely low permeability and is the most important factor in retarding the downward movement of water from the surficial to the Floridan Aquifer.

Lithologic logs based on auger samples taken at 5-foot intervals in combination with natural-gamma logs adequately defined the components of the surficial aquifer system and the confining bed.

Laboratory tests of the size, sorting, permeability and storage capacity of samples of sediments of the surficial aquifer and confining bed were useful in estimating field values for the various geohydrologic units. The values of vertical coefficient of permeability thus calculated vary widely but are useful in making regional estimates of infiltration capacity or in calculating the rate of recharge to the Floridan Aquifer from the overlying surficial aquifer.

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Table 1. Relationship of soil, terrain, geology and hydrology at 59 test sites
(gpd per ft³: gallons per day per square foot per foot)

Test site number[a]	Soil type	Terrain	Altitude (feet) Land surface	Altitude (feet) Top of limestone[b]	Clay thickness (feet)	Leakage factor gpd per ft³x10⁻⁴	Altitude of potentiometric surface (feet) Floridan Aquifer	Altitude of potentiometric surface (feet) Surficial aquifer	Date of measurement
1	Leon	flat, lakeshore	44.4	-19	14	0.7	33.32	41.39	12-12-71
2	Blanton	upland, interlake	47.9	-20	0	33.	40.40	----	----
3	Leon	flat, interlake	47.7	-19	2	2.9	27.14	39.58	11-05-71
4	Blanton	slope, lakeshore	48.3	- 2	5	2.0	----	35.10	----
5	Leon	extensive flatland	64.4	29	4.5	2.2	59.36	59.99	05-18-71
6	Leon	flat, interlake	50.6	- 4	0	10.0	----	49.23	11-05-69
7	Leon	flat, interlake	52.5	- 1	8	1.3	35.46	44.21	05-18-71
8	Ona	flat, interlake	51.4	6	3	3.3	--	49.95	11-05-69
9	Ona	flat, interlake	50.1	-10	10	0.9	35.53	47.30	11-05-69
10	Leon	flat, interlake	56.1	- 6	6	1.4	37.73	51.33	05-18-71
11	Leon	low drainageway	57	17	0	5.0	49.5	54.0	05-16-70
12	Leon	flat, interlake	56.3	5	6	1.7	34.4	----	05-16-70
13	Leon	flat, interlake	58.3	8	5	1.7	52.02	53.00	05-27-71
14	Leon	flat, interlake	57.7	- 2	7	1.2	31.66	52.91	05-16-70
15	Ona	flat, interlake	54.5	9	5	1.5	36.87	51.4	05-16-70
16	Leon	extensive flatland	60	19	2	5.0	50.7	55.7	05-16-70
17	Leon	extensive flatland	61.3	-19	11	0.3	52.06	58.60	05-18-71
18	Ona	extensive flatland	58.6	16	0	11.0	49.78	56.75	09-05-69
19	Leon	flat, interlake	56.9	5	7	1.4	27.43	----	05-16-70
20	Leon	flat, interlake	56.9	19	3	3.3	28.76	50.74	05-16-70

[a] Test sites shown on figure 1.
[b] Negative numeral is distance in feet below sea level.

Table 1. Relationship of soil, terrain, geology and hydrology at 59 test sites (cont.)
(gpd per ft³; gallons per day per square foot per foot)

Test site number	Soil type	Terrain	Altitude (feet) Land surface	Altitude (feet) Top of limestone[b]	Clay thickness (feet)	Leakage factor gpd per ft³x10⁻⁴	Altitude of potentiometric surface (feet) Floridan Aquifer	Altitude of potentiometric surface (feet) Surficial aquifer	Date of measurement
21	Ona	extensive flatland	53	- 3	20	0.5	43.28	----	05-27-71
22	Leon	flat, interlake	56.4	11	5	2.0	20.16	50.62	05-16-70
23	Leon	flat, interlake	55.2	14	4	2.1	27.99	50.28	05-16-70
24	Leon	flat, interlake	56.2	14	2	5.0	28.96	49.62	05-16-70
25	Rutledge	flat, lakeshore	53.0	8	3	3.3	38.59	48.54	05-16-70
26	Ona	flat, incipient sinks	56.1	8	14	0.7	33.09	46.94	05-16-70
27	Ona	flat, incipient sinks	56.3	8	4	2.5	33.62	47.26	05-16-70
28	Ona	flat, incipient sinks	58.3	19	1	10.0	43.90	48.30	05-16-70
29	Leon	flat, incipient sinks	59.0	20	3	3.3	47.99	51.17	05-16-70
30	Ona	flat, incipient sinks	59.4	7	1	10.0	29.23	50.25	05-16-70
31	Lake bottom	shallow between deeps	50.4	3	5	2.0	25.87	44.18	05-27-71
32	Ona	flat, interlake	56.0	16	4	2.5	25.58	45.23	05-16-70
33	Ona	flat, interlake	56.0	20	5	2.0	25.39	44.92	05-16-70
34	Ona	flat, interlake	56.0	6	5	2.0	25.19	44.58	05-16-70
35	Ona	flat, interlake	55.1	13	5	2.0	26.00	43.97	05-16-70
36	Swamp	sinkhole swamp	52.5	10	4.5	1.8	26.02	43.63	05-16-70
37	Ona	flat, interlake	56	?	7+	1.4	----	----	----
38	Ona	flat, interlake	55.1	-10	17	0.5	25.60	44.21	05-16-70
39	Ona	flat, interlake	55.8	13	0	13	25.49	44.37	05-16-70
40	Swamp	sinkhole marsh	53.1	below -54	-	-	----	44.24	05-16-70

Table 1. Relationship of soil, terrain, geology and hydrology at 59 test sites (cont.)
(gpd per ft^3: gallons per day per square foot per foot)

Test site number	Soil type	Terrain	Altitude (feet) Land surface	Altitude (feet) Top of limestone[b/]	Clay thickness (feet)	Leakage factor gpd per $ft^3 x10^{-4}$	Altitude of potentiometric surface (feet) Floridan Aquifer	Altitude of potentiometric surface (feet) Surficial aquifer	Date of measurement
41	Leon	flat, incipient sinks	59.0	15	0	14.0	29.14	47.53	05-16-70
42	Blanton	upland, interlake	51.9	30	0	20	47.84	47.89	05-16-70
43	Ona	extensive flatland	60	-15	3	1.5	41.1	57.6	05-16-70
44	Leon	flat, interlake	59.8	- 9	7	1.2	34.90	----	05-16-70
45	Leon	flat, interlake	57.1	9	4	2.5	24.23	48.87	05-16-70
46	Blanton	upland, interlake	58.5	27	4	2.5	29.88	43.72	05-27-70
47	Leon	flat, interlake	55.8	15	9	1.1	13.30	46.74	05-16-70
48	Leon	extensive flatland	60	25	1	10	53.4	52.4	05-16-70
49	Leon	extensive flatland	60.7	18	3	2.3	52.19	58.26	11-04-69
50	-	flat, lakeshore	68.0	13	5	1.4	60.60	63.18	05-16-70
51	Leon	flat, interlake	64.4	9	5	2.0	52.25	60.55	05-27-70
52	Leon	extensive flatland	66.8	20	3	2.8	55.00	61.73	05-18-71
53	Leon	flat, interlake	64.5	22	2	4.0	52.21	61.26	05-16-70
54	Leon	flat, interlake	66.0	16	3	3.3	51.15	61.31	05-16-70
55	Blanton	flat, interlake	61.8	22	3	3.3	52.25	57.25	05-16-70
56	Leon	flat, interlake	59.3	14	7	1.4	47.46	51.78	05-16-70
57	Leon	flat, interlake	55.6	25	4	2.5	46.72	47.97	05-16-70
58	Blanton	upland, interlake	56	11	0	33.0	40.2	49.5	05-16-70
59	Leon	flat, interlake	56	21	0	20.0	47.4	50.5	05-16-70

Table 2. Results of laboratory analyses of 66 samples of sedimentary deposits from test wells at 24 sites

Hydraulic conductivity: ft day^{-1} cubic feet per day per square foot. Coefficient of permeability gpd/ft^2, gallons per day per square foot.

Test site number	Sample depth[a/] (ft)	Lithology	Hydraulic conductivity (ft day^{-1})	Permeability (gpd/ft^2)	Specific yield (percent)	Median diameter (mm)	Sorting coefficient
2	5	Sand	---	---	---	0.19	1.3
4	5	do	---	---	---	.19	1.3
5	5	do	0.36	2.7	35.7	.18	1.3
6	5	do	---	---	36.5	.18	1.3
8	4.5	Clayey sand	---	---	40.7	.18	1.4
10	55.5	Clay	---	---	16.4	---	---
11	5	Sandy clay	---	---	30.3	.16	1.4
	29.5	do	.0002	.0015	11.8	.13	3.6
13	5	Sand	---	---	36.0	.16	1.3
16	20	Clayey sand	---	---	---	.12	1.4
	40	Clay	.0004	.0030	---	.11	8.9
17	5	Sand	---	---	31.8	.15	1.2
	30	Sandy clay	.0043	.032	21.8	.15	5.4
	40	Sand & clay	.0009	.0067	---	.09	1.4
	65	Clay	.0002	.0015	---	.074	13.
	74.5	do	.0005	.0037	---	.045	9.6
20	5	Sand	---	---	35.6	.17	1.3
23	10	Sand	1.1	8.2	33.7	---	---
	15	Clayey sand	.0056	.042	---	0.13	1.5
	20	do	.0394	.29	21.9	.17	1.3
	25	Sand and clay	.0039	.029	22.4	.098	1.4
	30	do	.0013	.097	---	.20	1.5
	35	Sand	.66	4.9	---	.19	1.3
	40	Clay	---	---	53.6	---	---
	44.5	Limestone	.013	.097	---	---	---

(See footnotes at end of table.)

Table 2. Results of laboratory analyses of 66 samples of sedimentary deposits from test wells at 24 sites (cont'd.)

Hydraulic conductivity: ft day^{-1}, cubic feet per day per square foot. Permeability: gpd/ft^2 gallons per day per square foot

Test site number	Sample depth (ft)	Lithology	Hydraulic conductivity (ft day^{-1})	Permeability (gpd/ft^2)	Specific yield (percent)	Median diameter (mm)	Sorting coefficient
26	38	Clay	.0003	.0024	---	.088	1.6
	45	do	.0016	.012	---	.002	7.7
31	5	Sand	---	---	27.1	.22	1.2
	10	do	---	---	40.3	.19	1.1
	15	Clayey sand	---	---	41.7	.17	1.4
	25	Sand and clay	---	---	37.4	.21	1.4
	29.5	Sandy clay	.021	.16	22.9	.095	2.8
	35	Clayey sand	---	---	36.4	0.088	1.3
	40	Sand and clay	---	---	---	.22	1.4
	44.5	Clay	---	---	6.1	.023	7.9
37	[b]10.6	Clayey sand	0.11	0.82	27.3	.13	1.4
	[b]18.4	Sand and clay	---	---	35.4	.17	1.4
	[b]20	do	---	---	34.1	.15	1.4
	[b]24.5	do	---	---	35.9	.092	1.2
	[b]30	Clayey sand	1.3	9.8	15.4	.092	1.2
	[b]33.3	Sandy clay	.0098	.073	19.8	.18	2.0
45	5	Sand	13	98	37.6	.15	1.3
	10	do	1.7	12	33.6	.14	1.2
	15	Clayey sand	.46	3.4	---	.110	1.5
	20	Sand and clay	.066	.49	---	.13	1.4
	25	do	.052	.39	---	.14	1.4
	30	Clayey sand	.0028	.021	20.2	.13	1.4

Table 2. Results of laboratory analyses of 66 samples of sedimentary deposits from test wells at 24 sites (cont'd.)

Hydraulic conductivity: ft day^{-1}, cubic feet per day per square foot. Permeability: gpd/ft^2 gallons per day per square foot

Test site number	Sample depth	Lithology	Hydraulic conductivity (ft day^{-1})	Permeability (gpd/ft^2)	Specific yield (percent)	Median diameter (mm)	Sorting coefficient
45	35.5	Clayey sand	---	---	25.8	0.18	1.4
	40	Sand	---	---	28.6	.17	1.3
	45	Clay	0.0028	0.021	---	.12	14
	47.5	Limestone	2.1	16	---	---	---
	20	Sand and clay	---	---	---	.094	1.4
50	54	Clay	.0007	.0052	8.7	---	---
51	5	Sand	---	---	30.2	.15	1.2
	50	Sand and clay	.0052	.039	---	.17	1.4
55	5	Sand	---	---	35.4	.16	1.3
56	5	do	---	---	35.6	.16	1.3
57	5	do	---	---	38.8	.14	1.2
58	5	do	---	---	36.1	.16	1.3
59	5	do	---	---	---	.16	1.3
[d]60-1	[b]0	Sand and clay	1.1	8.2	26.2	0.13	1.4
60-2	[b]0	do	2.3	17	27.4	.14	1.4
60-3	[c].25	do	16.	120	26.0	.16	1.4
60-4	[b]0	do	2.1	16	26.7	.13	1.4
60-5	[c].25	do	1.6	12	26.8	.14	1.6
60-6	[b].5	do	3.9	29	28.4	.13	1.4

[a]Sample depth is feet below land surface to top of 6-inch sample.
[b]Vertical samples in slotted tube for determination of horizontal permeability.
[c]Horizontal samples in plain tube for comparison with vertical samples in slotted tube.
[d]Site 60 is not an auger hole. Samples are from the bottom of an excavation about 10 feet below land surface.

Table 3. Clay-mineral identification for selected samples

Test site	Sample depth (feet)	Description
		Differential Thermal Analysis
5	35	Illite. Mixed-layered clay (illite and montmorillonite) small amount; quartz, small amount; organic material, small amount; $CaCO_3$, none.
17	65	Illite, Mixed-layer clay (illite and montmorillonite) small amount; quartz, large amount; organic material, moderate amount; $CaCO_3$ none.
23	40	Illite, small amount; organic material, large amount; $CaCO_3$, very large amount, 75 percent.
26	38	Mainly mixed-layered clays, composed of illite and montmorillonite. Illite predominant.
26	45	Mainly mixed-layered clays composed of illite and montmorillonite. Illite predominant.
31	44.5	Illite. Mixed-layered clay (illite and montmorillonite), small amount; quartz, small amount; organic material, small amount; $CaCO_3$, none.
50	20	Illite. Quartz, small amount; organic, large amount; $CaCO_3$, none.
50	54	Illite. Mixed-layered clay (illite and montmorillonite), small amount; quartz, fair amount; organic material, fair amount; $CaCO_3$, none.

Table 3. Clay-mineral identification of selected samples (cont.)

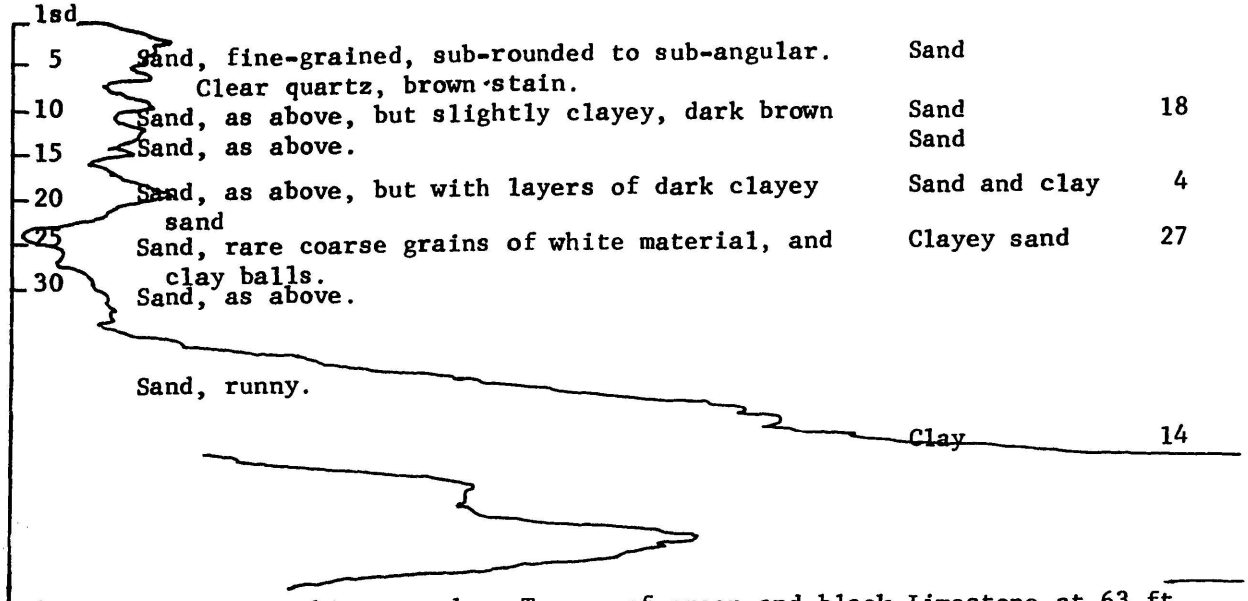
Test site	Sample depth (feet)	Description
		X-ray Diffraction
37	36	Sample contains about 35 percent quartz, 2-3 percent feldspar, and the remainder clay minerals. The clay mineral is montmorillonite with a small amount of illite mixed layering. The basal spacing is indicative of Ca-montmorillonite.
46	30	Sample contains about 30 percent quartz and the remainder clay minerals. Clay minerals consist primarily of a random-mixed-layer illite-montmorillonite in which the montmorillonite layers are the most abundant. The peaks are poorly defined, but d spacings greater than 15° indicate the presence of some regular mixed layering. On heating to 300°C, the clay mineral collapses to 10.4°, which indicates some interlayering.

TABLE 4

Logs showing lithology, gamma radiation, and generalized geohydrology of surficial deposits at sites tested in northwest Hillsborough County

(Trace of line on log represents gamma radiation. Radiation increases to right. For location see figure 1 a/ Sediment analysis available, see table 2. b/ Clay-mineral identification available, see table 3.)

Site 1



Site 2

Sample depth (feet)		Geohydrologic unit	Thickness (feet)
lsd			
5	[a] Sand, very fine-grained, well rounded clear quartz.		
10	Sand, as above but slightly silty with black rootlets.	Sand	17
15	Sand, as at 5 ft.		
17	Sand, as above but with broken layers of dense black-brown clay.		
20		Sand and clay	13
25	Sand, with layers of clay, as above.		
30	Sand, as at 5 ft but runny; clayey.		
35	Sand, as above	Clayey sand	30
45	Sand, very fine to medium-grained, with brown clay.		
55	Sand, light brown, clayey.		
60	Sand and clay layers, light brown.	Sand and clay	5
65	Clay, sandy, with limestone chips.	Sandy clay	3
68	Limestone.	Limestone at 68 ft.	

Site 3

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
1sd			
4	Sand, fine-grained, rounded to subrounded. Clear quartz stained dark brown by slight silt content.	Sand	15
5	Sand, as above but white.		
10	Sand, as above but with some clay.		
15	Sandy, clayey.		
20	Sand, clayey, as above but with streaks of light tan clay.	Clayey sand	15
25	Sand, clayey, massive, runny.		
30	Sand, runny as above. Slightly more clay.	Sand	5
40	Sand, clayey as above.	Clayey sand	5
45	Sand and clay and shell	Sand	10
50	Clay, light green, sandy.		
55	Sand, slightly clayey, with clay balls.	Sandy clay	15
60	Clay, light green, sandy.		
65	Clay, light green with layers of dense black clay.	Clay	2
67	Limestone, gray, sandy, hard.	Limestone at 67 ft.	

Site 4

Sample depth (feet)		Geohydrologic unit	Thickness (feet)
lsd			
5	[a] Sand, very fine-grained, well-rounded clear quartz. Slightly clayey.		
10	Sand, as above, but black from organic material.	Sand	20
15	Sand, as at 5 ft. but dark brown.		
20	Sand, as above, but with streaks of clay.	Sand and clay	5
25	Sand, brown, clayey.		
30	Sand, brown, clayey.	Clayey sand	10
35	Sand, as above, with clay streaks and chips of charcoal to 5 mm.		
40	Sand and clay, light brown with streaks of black clay.	Sand and clay	10
45 48	Clay and sandy clay laminae. Dark brown with pieces of white chalky chert.	Clay	5
50	Clay, green, plastic. Weathered limestone at 50 ft.	Limestone at 50 ft.	
54	Limestone.		

Site 5

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
1s			
5	a/ Sand, very fine-grained, sub-angular clear quartz with dark brown stain. Very slightly clayey.		
10	Sand, as above but with black stain.	Sand	20
15	Sand, as above.		
20	Sand, as above but with more clay.		
25	Sand, clayey as above.		
30	Sand, clayey as above.	Clayey sand	11
35	b/ Clay, pure, slick, greenish-tan	Clay	4.5
	Limestone at 35.5'.		
40	Limestone, white, sandy.	Limestone at 35.5 ft.	

Site 6

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickenss (feet)
lsd			
5	[a] Sand, brown, fine-grained, slightly silty, organic.		
10	Sand, as above.	Sand	20
15	Sand, as above with rootlets.		
20	Sand, tan, clayey.		
		Clayey sand	12
25	Sand, clayey as above.		
30	Sand, clayey as above.		
33	Sand, with clay streaks.	Sand and clay	13
38	Sand, as above with more clay.		
40	Sand and clay, as above.		
45	Clay, sandy. Dark gray-black drusy chert.	Sandy clay	10
50	Clay, dark gray with yellow streaks, sandy.		
55	Limestone, sandy. Weathered light gray and cream. Fine drusy pyrite in small vugs.	Limestone at 55 ft.	

Site 7

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
1ad			
8	Sand, dark brown, very fine-grained, silty.	Sand	15
10	Sand, as above but darker brown.		
15	Sand and clay laminae, light brown.		
20	Sand and clay, as above but more clay.	Sand	16
25	Sand and clay, as above.		
30	Sand and clay, as above.		
32	Sand, very fine-grained, well rounded, clear quartz.	Sand	4
35	Sand, as above.		
40	Sand and clay laminae, light gray.	Sand and clay	10
43	Sand and clay, as above.		
45	Sand and clay. Clay is dense plastic, black and green.		
47	Clay, plastic, shades of green with streaks of white sand. Contortions in laminae may be due to collapse.	Clay	8
53	Limestone, white, with brown chert.	Limestone at 53 ft.	

Site 8

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
1sd			
5	a/ Sand, gray, very fine-grained, slightly clayey.		
10	Sand, as above.	Sand	17
15	Sand, tan, very fine-grained, clayey.		
20	Sand, clayey.		
25			
26	Sand, grayish-brown, more clayey.	Clayey sand	25
30	Sand, clayey, as above.		
35	Sand, slightly clayey, light tan.		
40	Sand, very fine-grained, light tan.		
42	Clay, blue, plastic.	Clay	3
45	Limestone, hard, weathered, white with nodules of gray.	Limestone at 45 ft.	

Site 9

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lad			
5	Sand, very fine-grained, rounded to sub-rounded clear quartz.	Sand	28
10	Sand, light brown, fine-grained to silty, poorly sorted, slightly clayey. Occasional dark grains.		
20	Sand and clay, layers, clean white sand, brown clay.		
30	Sand, clayey	Clayey sand	2
		Sandy clay	5
35	Clay, sandy, tough, grayish brown.		
40	Sand, white, fine-grained to silty. Poorly sorted, sub-rounded to sub-angular.	Sand	5
		Sandy clay	10
59	Clay, black.	Clay	10
60	Limestone, sandy, white.	Limestone at 60 ft.	

Site 10

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	Sand, very fine-grained, brown.		
10	Sand, as above, dark brown	Sand	15
15	Sand, as above.		
17	Sand and clay, dark brown. Clay nodules and thin layers of dense dark clay.	Sand and clay	10
20			
22	Sand and clay, as above.		
25	Sand, clayey, light brown.	Sandy clay	3
	Clay, sandy.	Sand and clay	5
30	Sand, very fine-grained. Occasional clay balls.		
35	Sand, very fine-grained, tan.	Sand	7
40	Sand, clayey, very runny.	Clayey sand	6
45	Sand, less clay, very runny.	Sandy clay	10
50	Clay, variegated yellow-gray, sandy.		
55	a/ Clay, gray with stringers of green, plastic, chips of limestone at base.	Clay	6
60	Clay, as above but with more coarse pieces of limestone.		
62	Limestone, gray.	Limestone at 62 ft.	

Site 11

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	a/ Sand, clayey, grayish-tan, tough, with rootlets and chips of marl.	Sandy clay	8
10	Sand, very fine-grained, rounded to sub-rounded, some clay, light tan, occasional dark grains.		
15	Sand, as above but with slightly more clay, gray.		
20	Sand, very fine-grained, sub-rounded clear quartz. Very slightly clayey.	Clayey sand	20
25	Sand, as above but with more gray clay.		
30	a/ Clay, light green, sandy, tough plastic.	Sandy clay	12
35	Sand, light gray, very fine-grained, rounded to sub-rounded, slightly clayey.		
40			
44	Limestone, white, sandy, crumbly.	Limestone at 40 ft.	

Site 12

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	Sand, light gray, clayey.	Clayey sand	6
10	Sand, very fine-grained, rounded to sub-rounded, clear quartz, slightly clayey.	Sand	14
15	Sand, as above but no clay.		
20	Sand and clay laminae.		
25	Sand and clay, as above but with more clay.	Sand and clay	6
30	Clay, greenish-brown, sandy.		
35	Sand, light brown, clayey.	Clayey sand	19
40	Sand, clayey, runny.		
45	Sand, clayey.		
47	Clay, green, sandy.	Clay	6
55	Limestone, gray, sandy, with dark layers of sand and siliceous cement.	Limestone at 51 ft.	

Site 13

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
1sd			
5	a/ Sand, brown, very fine-grained.	Sand	16
10	Sand, as above but darker brown, with organic silt.		
12	Sand, as above.		
15	Sand, as at 5 ft but slightly silty.		
17	Clay, black.	Clay	2
20	Sand, light brown, very fine-grained, slightly silty.	Sand	7
30	Clay, light gray, sandy.	Sandy clay	7
33	Sand, gray, clay laminae.	Sand and clay	2
36	Sand, light brown, very fine-grained, silty.	Sand	3
40	Sand, runny.	Clayey sand	10
45	Clay, very soft. Tools dropped three feet without resistence.	Clay	3
50	Limestone, white, soft, dense.	Limestone at 50 ft.	
59	Limestone, white, medium hard, amorphous.		

Site 14

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	Sand, very fine-grained, sub-rounded to sub-angular clear quartz, brown. Slightly clayey.		
10	Sand, as above but with black stain from silt.		
15	Sand, as above.	Sand	16
20	Sand, as above but clayey, with streaks of clean white sand.	Clayey sand	5
25	Sand, white, very fine-grained, rounded clear quartz.	Sand	6
30	Sand and ~~clay~~, laminae light brown.	Sand and clay	5
35	Clay, sandy.	Sandy clay	5
40	Sand, very fine-grained, sub-rounded, runny.	Sand	10
47	Clay, gray, soupy, ~~with sand~~, shells to 1 mm and chert, grayish-white, to 3 cm.	Clay	7
55	Clay, sandy, soupy as above.	~~Sandy~~ clay	6
60	Limestone, gray, sandy, hard.	Limestone at 60 ft.	

Site 15

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
1sd			
5	Sand, dark brown, very fine-grained, with some organic material.		
10	Sand, chocolate brown, as above.	Sand	17
15	Sand, as above but with less organic material.		
20	Sand, white, clayey.		
25	Clay, light gray, sandy (very fine-grained).	Sandy clay	15
27			
30	Clay, white-gray, sandy (very fine-grained).	Clayey sand	5
35	Sand, white, very fine-grained, clayey.	Sandy clay	3
40			
42	Clay, very soft; sampler dropped from 40 to 42'.	Clay	5
45	Limestone, light gray, very hard.	Limestone at 45 ft.	

Site 16

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
1sd			
5	Sand, light brown, very fine-grained sub-rounded clear quartz, slightly clayey.		
10	Sand, as above but dark brown.	Sand	17
15	Sand, as above but with mottles of slightly clayier sand.		
20	a/ Sand, as above but with streaks of sandy clay.	Sand and clay	5
25	Sand, tan, very fine-grained. Sub-rounded, clear quartz, slightly clayey.		
30	Sand, light brown, clayey.	Clayey sand	17
35	Sand, clayey as above.		
40	a/ Clay, brown and gray layers, plastic with some sand and chert.	Clay	5
45	Limestone, white-gray, dense with some sand, crystals of calcite.	Limestone at 44 ft.	
47	Limestone.		

Site 17

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	a/ Sand, very fine-grained, sub-rounded to rounded, clear quartz, with slight black silt.		
10	Sand, as above, but with slight brown silt.		
15	Sand, as above, runny.	Sand	15
20	Sand, as at 5 ft but with slightly more clay and layers of gray sandy clay.		
25	Sand, light tan, very fine-grained, sub-rounded, runny, with some clay.		
30	a/ Clay, brown, sandy (very fine-grained, sub-rounded).	Clayey sand	25
35	Sand, light tan, very fine-grained, sub-rounded, runny with some clay.		
40	a/ Sand, as above, with layers of sandy gray clay.	Clay	3
45	Clay, black, plastic, with layers of black sandy clay.	Sand and clay	20
50	Clay, black, with drusy pyrite and black fibrous material. Sandy.		
55	Clay, dark gray, sandy, with layers of pure black clay.	Sandy clay	4
60	Sand, gray, very fine-grained, sub-rounded, slightly clayey. Very soft; sampler sank to 62'.	Clay	4
65	b/ Clay, green, plastic, some sand.	Sandy clay	5
75	a/ Clay, green and black layers and mottles. Plastic, sandy.	Clay	4
80	Limestone, white-gray, dense, hard.	Limestone at 80 ft.	

Site 18

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	Sand, light brown, very fine-grained, sub-angular to sub-rounded, and dark brown clay.		
10	Sand, very fine-grained, sub-rounded, with black silt.	Sand	18
15	Sand, white, very fine and occasional medium-grained. Sub-rounded to rounded.		
20	Sand, as above, but with greenish-brown clay.		
25	Clay, greenish-brown, sandy.	Clayey sand	10
		Sandy clay	5
30	Sand, white, very fine-grained. Sub-rounded, clear quartz with gray clay.	Clayey sand	5
35	Clay, gray, with layers of sand, as above.	Sandy clay	4
40	Sand, gray, clayey.		
45	Limestone, white and light tan, sandy, dense, hard.	Limestone at 42 ft.	

Site 19

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	Sand, brown, very fine-grained, sub-angular to sub-rounded.		
10	Sand, as above.	Sand	20
15	Sand, white. Fine-grained, slight clay.		
20	Sand, as above but with more clay.		
25	Clay, brown, and white clayey sand. Alternate layers.		
30	Clay, gray, with streaks of white sand.	Sand and clay	15
35	Sand and clay laminae, gray.		
40	Sand, light gray, fine-grained, some clay.	Clayey sand	10
45	Sand, as above but with layers of gray clay.		
50	Clay, green and gray streaks and mottles, plastic, some sand.	Clay	7
55	Limestone, gray, sandy, with sandy green clay. Soft.	Limestone at 52 ft	
58			

Site 20

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
1sd			
5	a/ Sand, tan, very fine-grained. Occasional mottlings of chocolate brown clay.		
10			
15		Sand	17
20	Sand, tan, very fine-grained, with brown clay.	Clayey sand	18
25			
30	Sand, as above, but with slightly less clay.		
35	Sand, tan, very fine-grained, with some clay.		
40	Limestone, light gray, dense, with scattered sand.	Clay Limestone at 38 ft.	3
45	Clay, greenish-gray, very soft, fluid, sandy.		
50	Limestone.		
54			

Site 21

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	Sand, tan, very fine-grained, sub-rounded to rounded.		
10	Sand, as above, but with slight gray clay.	Sand	17
15	Sand, white, very fine-grained, sub-rounded to rounded.		
20	Sand, as above, but with some gray clay.		
25		Clayey sand	19
30	Sand, as above, and grayish-tan clay layers.		
35	Sand, light gray, fine to very fine-grained, slightly clayey.	Clay	3
40	Clay, light green, crumbly, with some sand and fine pyrite.		
45	Clay, as above, but with mottles of black clay.	Clay (?)	17
50	Clay, as above. Very hard, dry, breaks into blocks.		
55	Clay, as above, but not hard.	Limestone at 56 ft.	
60	Limestone.		

Site 22

Sample depth (feet	Increased radiation →	Geohydrologic unit	Thickness (feet)
1sd			
5	Sand, light brown, very fine-grained, sub-rounded to rounded, clear quartz.	Sand	5
10	Sand, as above, but with some clay; gray with brownish mottlings of higher clay content.		
15	Sand, as above, but with less clay.	Clayey sand	15
20	Sand and clay laminae, brownish-gray.		
25			
30	Sand and clay, as above but runny.	Sand and clay	20
35			
40	Clay, greenish-gray, layers of varying sand content.	Clay	5
45	Limestone, gray, sandy, with layers of sandy green clay.	Limestone at 45 ft.	
48			

Site 23

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	Wood.		
10	a/ Sand, ~~white, very~~ fine to fine-grained, sub-rounded.	Sand	11
15	a/ Sand, as above, ~~but with~~ layers of clay.		
20	a/ Sand, as above, ~~clayey,~~ runny.	Sand and clay	18
25	a/ Sand and clay laminae.		
30	a/ Sand, white, very fine-grained ~~clear quartz with streaks~~ of gray clay.	Sandy clay	8
35	a/ ~~Sand, light tan, fine-grained,~~ sub-rounded, slightly clayey.	Clay	4
40	a/ b/ Clay, black, very soft, ~~plastic~~, some chert. Limestone, very soft.	~~Limestone at 41 ft.~~	
45	a/ Limestone, light gray, crumbly, some sand.		

Site 24

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
1sd			
5	Sand, very fine-grained, well-rounded, well sorted clear quartz.	Sand	5
10	Sand, as above, but with clay layers.		
15		Sand and clay	15
20	Sand, clayey, with streaks of clean sand.		
25	Sand, light gray, clayey.		
30	Sand, as above, but slightly more clayey.	Clayey sand	20
35			
40	Clay, brown and green laminae, with layers of sandy clay.	Clay	2
45	Limestone, gray, sandy. Gastropod 1 cm across.	Limestone at 42 ft.	
50	Limestone, gray, sandy, with chips of green clay.		
53	Dark gray sandy clay at 50' with shards of chert.		

Site 25

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
1	Sand, dark brown, fine-grained, silty, roots.		
5	Sand, fine-grained, sub-rounded clear quartz. Slightly silty.	Sand	16
6			
8	Sand, as above, but black.		
10	Sand, as above. Hardpan from 6.5' to 12'.		
12	Sand, as above, but more indurated.		
15	Sand, white, fine to very fine-grained, sub-rounded clear quartz.		
20	Sand, brown, clayey.	Clayey sand	9
25	Sand, light brown, fine to very fine-grained, sub-rounded clear quartz. Runny.	Sand	5
30	Sand, clayey.	Clayey sand	5
35	Sand, tan, fine-grained, sub-rounded clear quartz.	Sand	7
44	Clay, green, dense.	Clay	3
45	Limestone, sandy, weathered.	Limestone at 45 ft.	
49			

Site 26

Sample depth (feet)		Geohydrologic unit	Thickness (feet)
1sd	Sand, fine-grained, sub-rounded clear quartz slightly silty (black) with many rootlets and humus.	Sand	10
1			
5	Sand, as above but more silt (brown). No humus.		
10	Sand, as above but with chips of brown, clayey, indurated sand.		
15	Sand, as at 1 ft. but with layers and mottles of brown clayey sand.	Sand and clay	15
20	Sand and clay laminae.		
25	Sand, fine to very fine-grained, sub-rounded clear quartz with matrix of brown clay.	Clayey sand	9
33	Clay, sandy, grades downward into dense green clay at 34'.		
38 a/ b/	Clay, greenish-gray, dense. With streaks of sand.	Clay	14
45 a/ b/	Clay, as above.		
48	Limestone, hard.	Limestone at 48 ft.	
51			

Site 27

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
10	Sand, clayey.	Clayey sand	20
15	Sand, brown, clayey.		
20	Sand, fine to very fine-grained, sub-rounded clear quartz. With layers of clayey sand.		
25	Sand, clayey as above, clay content increases downward.	Sand and clay	24
38	Clay.		
45	Clay, greenish tan, dense, sandy, with chert fragments.	Clay	4
48	Limestone, hard.	Limestone at 48 ft.	
53			

Site 28

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	Sand, light brown, very fine-grained, rounded, slightly clayey.		
10	Sand, as above but with layers of dark brown.	Sand	12
15	Sand, as at 5 ft but with layers of blocky, chocolate brown clay and stringers of clean white sand.		
20	Clay, sandy, tough.		
25	Sand and clay laminae, light gray.	Sand and clay	26
30	Sand, white, very fine-grained, rounded, with laminae of light tan. Sand,		
35	Sand, tan, very fine-grained, and layers of grayish-brown sandy clay.	Clay	1
40	Clay, alternate brown (tough) and black (fluid), sandy.	Limestone at 39 ft.	
43	Limestone, gray with green mottles, sandy, hard.		

Site 29

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	Sand, very fine to fine-grained, sub-rounded clear quartz and tan clay.	Sand	16
10	Sand, white, very fine to fine-grained, sub-rounded clear quartz.		
15			
17	Sand, as above but with greenish clay.	Clayey sand	3
20	Sand, as at 10'.		
25	Sand, as above but with greenish clay.		
30	Sand and clay laminae.	Sand and clay	17
35	Sand, and gray clay.	Clay	3
39	Limestone, light gray, sandy, very hard.	Limestone at 39 ft.	

Site 30

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
4	Sand, brown, fine to very fine-grained, rounded clear quartz.	Sand	4
5	Sand, as above, but clayey.	Clayey sand	10
10	Sand, clayey as above but indurated.		
15	Sand and clay laminae, light and dark brown, very hard layers.		
20			
25		Sand and clay	37
30			
35	Sand and clay, alternate layers of clean sand and sandy clay, 5 to 10 mm thick.		
40	Clay, sandy, soft, with fragments of bluish-white chert to 2 cm.		
52	Limestone, sandy, very hard.	Clay	1
54	Limestone.	Limestone at 52 ft.	

Site 31

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	a/ Sand, very fine-grained, sub-angular to sub-rounded clear quartz.	Sand	15
10	a/ Sand, as above, but slightly clayey, runny.		
15	a/ Sand, as above, but more clayey.		
20	Sand, clayey as above, very runny.		
25	a/ Sand and clay, brown.	Sand and clay	27
30	a/ Clay, light brown, sandy, tough.		
35	a/ Sand, clayey.		
40	a/ Sand and clay laminae.		
45	a/b/ Clay, green, plastic, sandy and black clay, soft plastic with chert chips.	Clay	5
50	Limestone, soft, sandy, with mollusc shell.	Limestone at 47 ft.	
59	Limestone.		

Site 32

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	Sand, light tan, very fine-grained, occasional medium-grained. Well rounded clear quartz, slightly clayey.		
10	Sand, as above, but brown.	Sand	15
15	Sand, as at 5' but with streaks of brown sandy clay.		
20			
25	Clay, tan, sandy layers.	Sand and clay	21
30	Sand, clayey as at 15'		
35	Clay, tough, plastic, sandy, with streaks of sand.		
39	Clay, green, plastic, grades downward into limestone.	Clay	4
40	Limestone, light gray, hard. Fissure filled with calcite.	Limestone at 40 ft.	
48	Limestone, soft, slightly sandy, clay streaks.		

Site 33

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	Sand, tan, very fine-grained, well-rounded, clear quartz. Slightly silty.	Sand	10
10	Sand, dark brown, clayey.		
15	Sand, as at 5' but with streaks of dark brown clay.		
20	Clay, dark brownish-gray, dense, plastic.	Sand and clay	21
25	Sand, some clay.		
30	Sand, very fine to medium grained, rounded, some clay.		
35	Sand, clayey, runny.	Clay	5
38	Limestone, light gray to buff, very thin-bedded, occasional sand grains.	Limestone at 36 ft.	
41	Cavity (?), half foot of very soft drilling.		
48	Limestone.		

Site 34

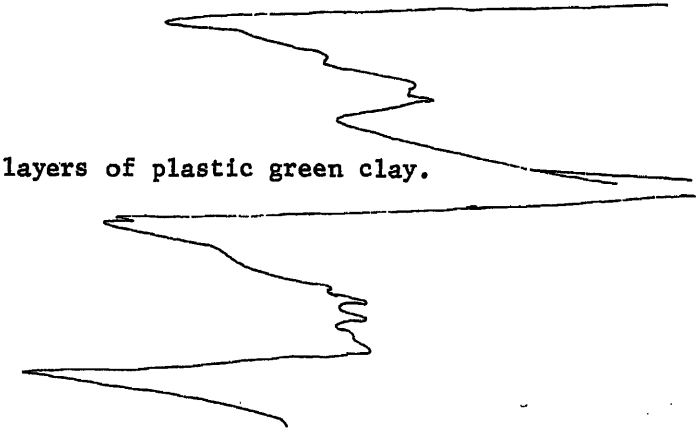
Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd 1	Sand, tan, very fine to fine-grained.		
5		Sand	20
10	Sand, as above, but slightly clayey.		
15	Sand, as above, but with very fine-grained clay balls, dark brown.		
20	Sand, as above, but with more clay balls.	Sand and clay	15
23 25	Sand and clay laminae.		
30	Sand, very fine-grained, slightly clayey.		
35	Clay, greenish-gray, plastic, with layers of soft non-calcareous white material. Grades downward into sandy clay with chert plates.	Clay	5
40	Clay, dark gray, plastic, silty.		
50	Clay, green, plastic, slightly sandy.	Limestone at 50 ft.	
50.5	Limestone, light gray, sandy.		
55	Limestone, as above.		
62	Limestone.		

Site 35

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lad			
1	Sand, tan, very fine-grained, well-rounded clear quartz.		
2.5	Slightly silty.		
6	Sand, as above, but with organic mottles.		
7.5	Sand, light brown with streaks of iron-stained cemented grains. Very fine-grained, well-rounded, slightly silty.	Sand	19
9			
10.5	Sand, as above, but with no streaks.		
11	Sand, as above, but with clay mottles.		
13	Sand, as above, but with streaks of organic material.		
14.5	Sand, very fine-grained, with thin clay streaks.		
15	Sand, as above.		
17	Sand, very fine-grained, clayey, runny.		
23	Clay, gray, sandy, plastic.		
24	Sand, clayey; streaks of varying clay content.		
26	Sand, clayey, massive.	Clayey sand	18
29.5	Sand, clayey, more clay than above.		
31.5	Sand, clayey, with layers of sandy clay.		
32	Sand, very fine-grained, slightly clayey, soupy.		
37	Clay, green-gray with occasional play of pyrite colors.		
38	Sandy, plastic, vugs of drusy, white kaolinite (?)		
40	Clay, alternate streaks of green and brown, plastic, slick, some sand.		
	Clay, softer than above, slightly more sand.	Clay	5

Site 35 continued

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
40	Clay, dark gray, much chert in plates and angular pieces to 2 cm. Black with gray rime.	Limestone at 42 ft.	
42	Limestone, light gray, very hard.		
53	Limestone, soft, with layers of plastic green clay.		
69	Limestone with clay streaks; hard and soft layers.		



Site 36

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	Organic soil; swamp.		
		Clayey sand	13
13	Sand, brown, very fine-grained.	Sand	11
24	Clay, sandy, massive, gray.	Sandy clay	10
26	Clay, more sandy than above.		
34	Sand, clayey.	Clayey sand	4
38	Clay, dark gray, slick, gritty with grains and plates of chert.	Clay	4.5
42.5	Limestone, light gray, very hard.		
		Limestone at 42.5 ft.	
48	Clay.		
55	Limestone.		
67	Limestone.		

Site 37

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
1.5	Sand, very fine to fine-grained, sub-angular clear quartz. Slight black silt.		
5			
6.5	Sand, as above, but with slight pinkish tinge.	Sand	11
9.6	a/ Sand, as above, but with very slight clay.		
10.6	Sand, clayey.		
11.1	Sand, clayey with mottles of clean sand.	Clayey sand	1
12	Sand, very fine to fine-grained, sub-angular, with laminae of sandy clay and clayey sand.		
20		Sand and clay	13
22	Sand and clay, as above but with more clay.		
25.5	a/ Sand, clayey, very runny.	Clayey sand	9
30	a/ Sand, clayey.		
33.3	a/ Clay, sandy.		
33.8	Clay, brown, sandy.	Clay	7+
34	Clay, green, plastic.		
36.5	b/ Clay.		

Site 38

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
1sd			
5	Sand. very fine-grained. well rounded clear quartz.		
10	Sand, as above, but with black silt; indurated.		
15	Sand, as above, but slightly less indurated.	Sand	35
20	Sand, dark brown, slightly indurated, silty.		
25			
30	Sand, very fine-grained, occasional medium-grained, slightly clayey, runny.		
35	Sand, runny.		
40	Sand, gray, clayey.	Sandy clay	13
45	Clay, gray, sandy.		
50	Clay, black, plastic, sandy.		
55	Clay, black, plastic, with chert grains and pieces to 1 cm. Streaks of sandy clay.	Clay	17
60	Clay, greenish-black, plastic, sandy, very soft.		
		Limestone at 65 ft.	
74	Limestone.		

Site 39

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
1sd			
5	Sand, light gray, very fine-grained, well rounded.		
10	Sand, as above, but light brown.		
15	Sand, as at 5 ft., but yellow-brown.	Sand	20
20	Sand, as at 5 ft., but with chunks of gray sandy clay.		
25	Sand, as above, but with sand balls cemented by black, hard cement.	Clayey sand	15
30	Sand, as at 5 ft. runny.		
35	Sand, medium-grained clear quartz and gray sandy clay.	Sandy clay	8
40	Clay, sandy, dense.		
45	Limestone, grayish-white, dense, sandy.	Limestone at 43 ft.	
51	Limestone.		

Site 40

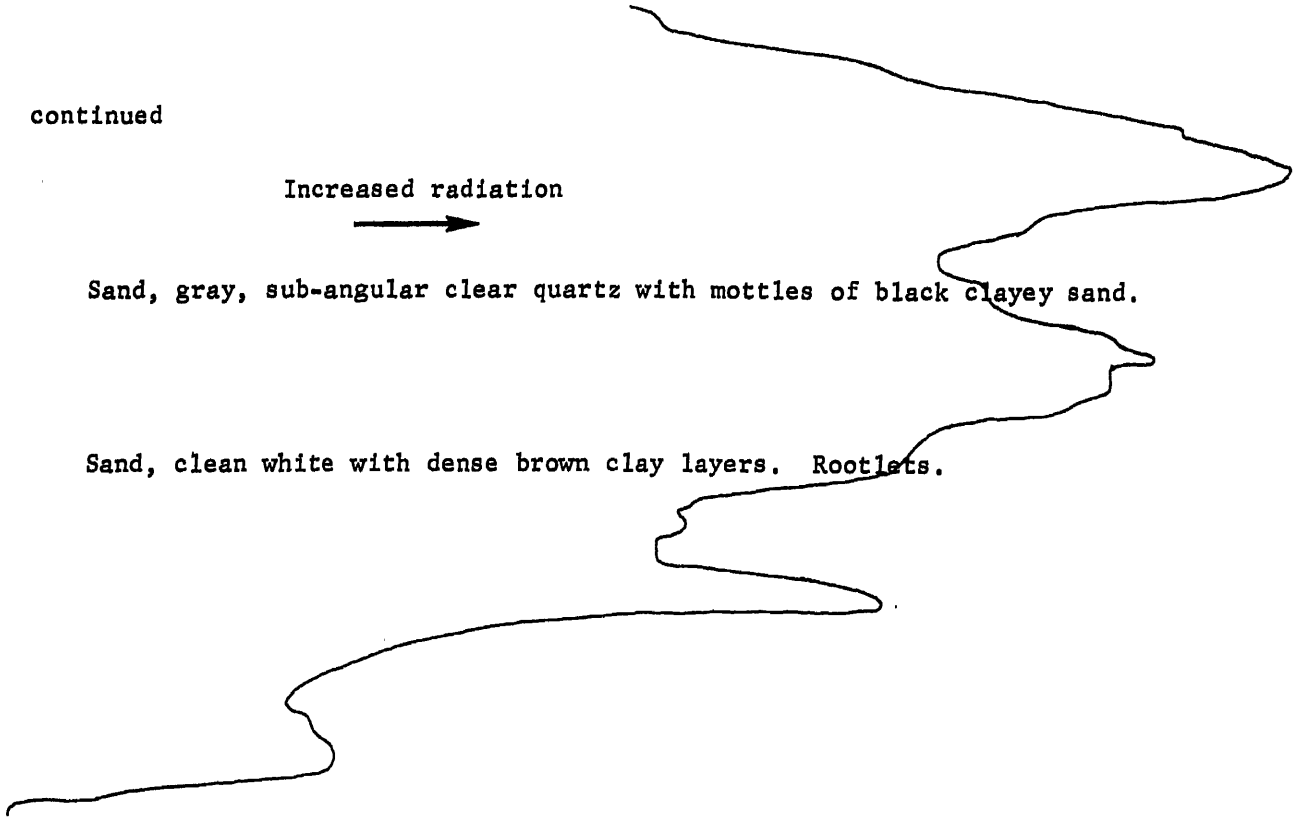
Sample depth (feet)	Increased radiation →
lsd	
1	Sand, gray, fine-grained to slightly silty, well-rounded clear quartz;
1.5	rootlets.
2	Sand, as above, but brown.
2.5	Sand, as above, but with less silt.
3	Sand, brown, very fine-grained to slight silt.
4	Sand, as above, but with occasional medium-grain.
4.5	Sand, as above, but with chips of black cemented sand.
5	Sand, as at 4'.
5.5	Sand, light tan, very fine to fine-grained.
6	Sand, as above, but clean whitish-tan.
7	Sand, as above, but with well-cemented black streaks.
8.5	Sand, white, fine-grained to slight silt, sub-angular clear quartz.
9	Sand, as above, but with streaks of black, silty sand.
9.5	Sand, as at 8.5 ft.
10	Sand, as at 8.5 ft. but with clay mottles.
11.5	Sand, as above, but more clayey.
12	Sand, as at 8.5', but gray.

Site 40 continued

Sample depth (feet)	Increased radiation →
13.5	Sand, clayey with layers of black and brown clayey sand.
14	Sand, fine-grained to slight silt, sub-angular clear quartz.
15	Sand, as above, but gray.
16	Sand, clayey with mottles of black clayey sand.
17.5	Sand, dark gray, clayey.
18.5	Sand, clayey.
19	Sand and clayey sand laminae.
20	Sand, black, clayey.

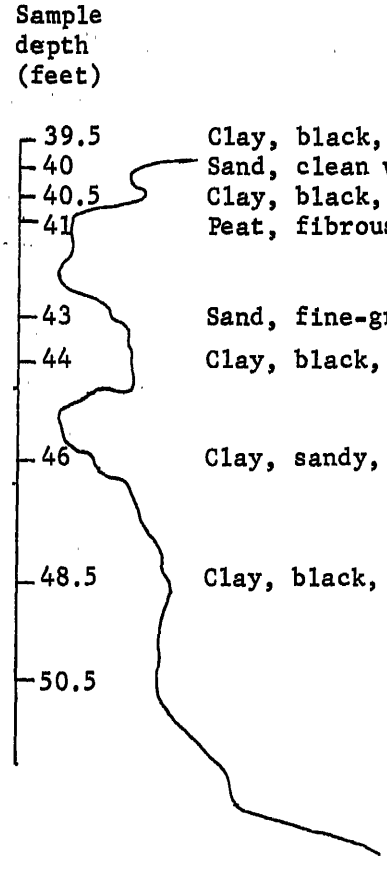
Site 40 continued

Sample depth (feet)	Increased radiation →
29.5	Sand, gray, sub-angular clear quartz with mottles of black clayey sand.
33	Sand, clean white with dense brown clay layers. Rootlets.

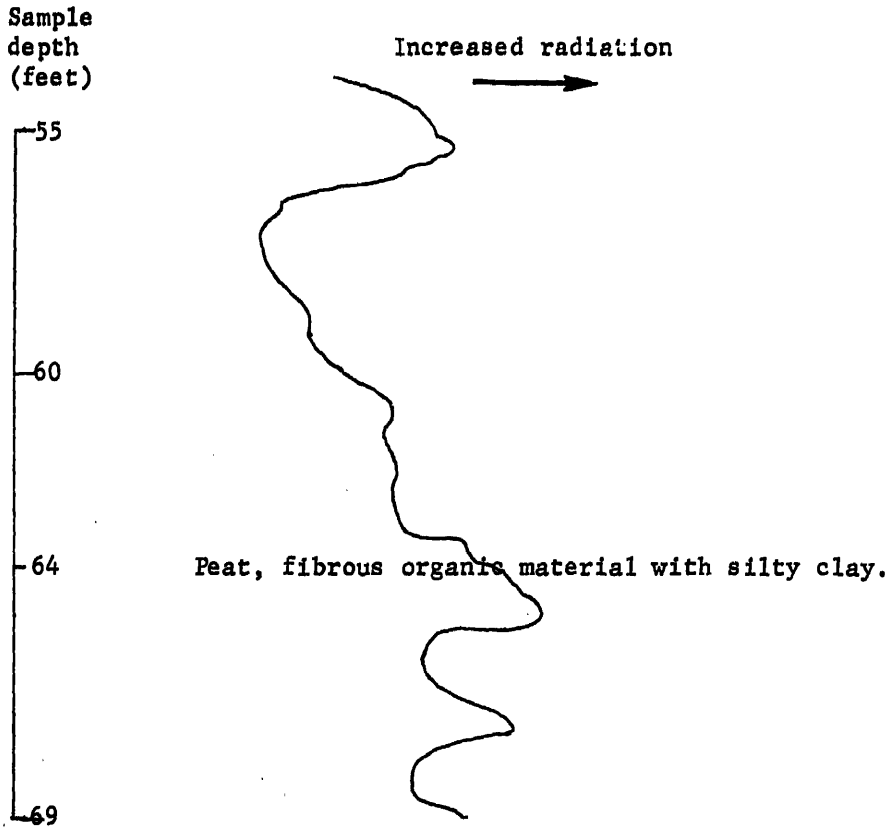


Site 40 continued

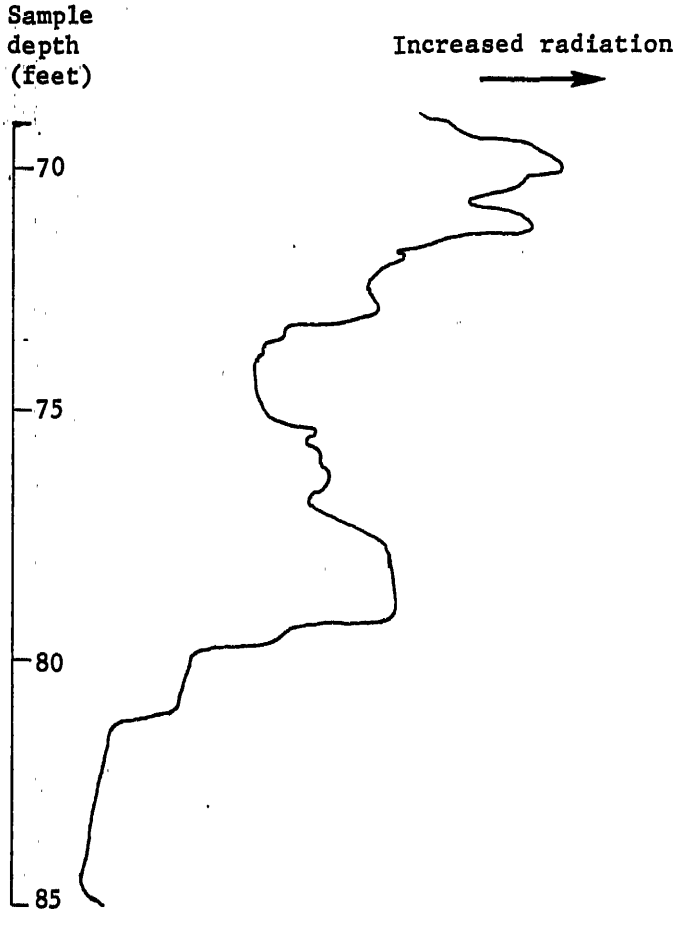
Sample depth (feet)	
39.5	Clay, black, plastic, sandy, with bits of organic material (Charcoal?)
40	Sand, clean white quartz, and black, plastic, sandy clay in layers.
40.5	Clay, black, blocky, plastic, with occasional clean sand grain.
41	Peat, fibrous brown roots and organic material.
43	Sand, fine-grained to slightly clayey, sub-angular clear quartz, and black clay.
44	Clay, black, and fibrous organic material.
46	Clay, sandy, organic.
48.5	Clay, black, blocky, organic material.
50.5	



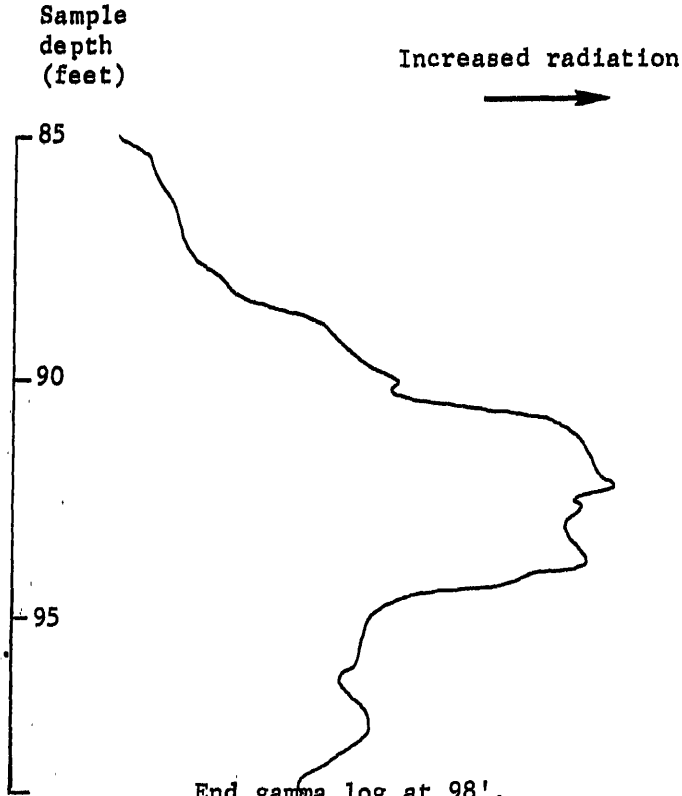
Site 40 continued



Site 40 continued



Site 40 continued



End gamma log at 98'.

107 Sand, black, silty, with organic material.

Site 41

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd	Sand, fine to very fine-grained, well rounded clear quartz with slight black silt.	Sand	5
5	Sand, clayey.		
10	Sand, with brown resinous clay matrix.	Clayey sand	10
15	Sand, as above and layers of indurated clayey sand.		
20	Sand, gray, clayey, and layers of tough sandy clay.		
25	Sand, gray, clayey.		
30	Sand, as above with clayey sand streaks.	Sand and clay	22
35	Clay, sandy, and layers of clayey sand.		
40	Clay, green, dense, sandy, very soft.	Sandy clay	7
44	Limestone, weathered.	Limestone at 44 ft.	
46	Limestone, hard.		
49	Limestone.		

Site 42

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
1sd	Sand, dark brown stain, fine-grained sub-rounded to sub-angular clear quartz.	Sand	3
4	Sand, as above, but clayey.	Clayey sand	1
10	Sand, ~~as at 2'~~, but clean white.	Sand	13
15	Sand, runny.		
20	Sand, with gray clay and streaks of dark gray ~~sandy clay.~~	~~Sand and clay~~	5
23	Limestone, weathered, mottled with green clay.	~~Limestone~~ at 22 ft.	
25	Limestone, very hard, siliceous layers banded with weathered, soft layers of white limestone. One well-rounded pebble of gray, pitted phosphate.		
29			

Site 43

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	Sand, very fine-grained, sub-rounded clear quartz.		
10	Sand, as above, but with slight brown clay.	Sand	15
15	Sand, fine-grained to silt, poorly sorted, rounded to sub-rounded, with layers of brown clayey sand.		
20	Sand, as above, but with less clay.		
25	Clay, grayish-green, sandy, tough.	Sand and clay	19
30	Sand, clayey.		
35	Clay.	Clay	3
40	Clay, green, sandy, tough, with white chert.		
45			
47	Clay, as above, but with no chert.	Sandy clay	38
55	Clay, sandy, and with light green clay layers.		
65	Clay, as above, but with white chert.		
75	Limestone, grayish-white, sandy.	Limestone at 75 ft.	

Site 44

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
1	Sand, gray, very fine-grained, rounded to sub-rounded clear quartz with slight black silt.		
3	Sand, light yellowish-brown.	Sand	9
4.5	Sand, dark brown, very fine-grained, rounded to sub-rounded clear quartz slightly clayey.		
6	Sand, as above, but more clayey.		
7.5	Sand, as at 5 ft. but with very slight clay.		
9	Sand, light brown, very fine-grained, round to sub-rounded clear quartz with some clay.		
10.5	Sand, more clayey than above. Rootlets.		
12	Sand, clean white, and layers of light brown, sandy clay.	Clayey sand	11
13.5	Sand, light tan, as at 9' but with less clay.		
15	Sand, clayey, runny.		
16.5	Sand, clayey.		
18.5	Sand, clayey, with layers of sandy clay.		
20	Sand and clay laminae.		
23	Sand, white, very fine-grained, round to sub-rounded clear quartz slightly clayey.		
24.5	Sand and clay laminae, as at 20'		
25.5	Clay, greenish-gray sandy.	Sand and clay	13
27	Sand, white, with yellow-brown streaks, slightly clayey.		
28.5	Sand, light brown, with some clay and layers of clayey sand.		
30	Sand, as above but with more clay.		

Site 44 continued

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
30			
32	Sand, white, very fine-grained, slightly clayey.		
33.5	Clay, dark gray, dense, some sand.		
35	Clay, black, slightly sandy.		
		Clay	7
39.5	Clay, dark gray.		
41	Sand, white, very fine-grained, round to sub-rounded, slightly clayey, with layers of dark-gray clay.	Sand and clay	5
44	Sand, white, and black clay in layers.		
45.5	Clay, black, sandy.		
47	Clay, black, dense, with streaks of clean white snad and yellow-brown rootlets.		
48.5	Clay, black, with more white sand and black woody material, and rare plates of chert.		
		Sandy clay	10
55.5	Clay, black, and sand in laminations.		

Site 44 continued

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
55.5			
57	Sand and clay laminae with rootlets.		
58.5	Sand and clay laminae, more sand.		
60	Clay, black, dense, and shells.		
62.5	Sand and clay and shell fragments.	Sand and clay	14
64	Sand and clay laminae, more clay.		
65.5	Sand and clay laminae, gray, few shells.		
67	Sand and clay and broken shell, gray.		
69	Limestone, gray, hard, sandy.	Limestone at 69 ft.	

Site 45

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	a/ Sand, light brown, very fine-grained, rounded clear quartz.	Sand	12
10	a/ Sand, as above, but with slight black silt.		
15	a/ Sand and clay laminae, black and brown, partly indurated.	Sand and clay	18
20	a/ Sand, very fine-grained to slightly clayey, layers and mottles of chocolate-brown clay.		
25	a/ Clay and layers of clean white sand.		
30	a/ Sand, clayey.		
35	a/ Sand, clayey as above, runny.	Clayey sand	14
40			
45	a/ Clay, laminations of green and black plastic clay with very fine sand.	Clay	4
48	a/ Limestone, mottled gray and white, hard.	Limestone at 48 ft.	
52			

Site 46

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
~~1ad~~			
5	Sand, light brown, very fine to fine-grained, sub-angular clear quartz, with slight silt in streaks.	Sand	10
10	Sand, as above, but white with occasional streaks, light brown silt.		
15	Sand, as at 5 ft. but with light grayish-brown clay.		
20	Sand, as above but with less clay.	Clayey sand	17
25	Sand, very fine to fine-grained, sub-angular to sub-rounded clear quartz, slightly clayey.	Clay	4
30	b/ Clay, greenish-tan, plastic, sandy.	Limestone at 31 ft.	
35	Limestone, white, sandy, with layers of green plastic clay alternating to 45'.		
40	Limey clay, greenish-tan mottled plastic clay with layers and mottles of gray limestone.		
45	Limestone and clay layers.		

Site 47

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	Sand, tan, very fine-grained to silt, rounded to sub-rounded clear quartz.		
10	Sand, light brown, slight clay.		
15	Sand, as above, but with streaks of white sand.	Sand	30
20	Sand, light brown, very fine-grained to silt, rounded to sub-angular, slight clay.		
25	Sand, as above, but with very slight clay.		
30	Sand, as above, but very clayey.	Sandy clay	2
35	Clay, greenish-brown, sandy, with small pieces of white chert.	Clay	9
40	Clay, greenish-brown, very pure, slimy.	Limestone at 41 ft.	
41	Limestone, very hard, cherty.		
44			

Site 48

Sample depth (feet)		Geohydrologic unit	Thickness (feet)
lsd			
5	Sand, fine-grained to slight clay, sub-rounded to sub-angular clear quartz.	Sand	20
10			
15	Sand, clean white, as above but without clay.		
20	Sand, as at 5 ft. but with brownish-gray clay.		
25			
30	Sand, with gray clay.	Clayey sand	14
34	Clay, green, plastic, sandy.	Clay	1
35	Limestone, creamy white, sand, soft greenish-black clay streaks.	Limestone at 35 ft.	
39			

Core of contact shows:
Clay, 10 - 20% sand at 34.5 ft.
Clay, 10 - 20% sand with limestone streaks.
Sandy limestone or calcareous sand.
Limestone, 10 - 20% sand with streaks of black clay at 35.0 ft.

Site 49

Sample depth (feet)		Geohydrologic unit	Thickness (feet)
lsd			
5	Sand, light tan, very fine-grained to slight clay, sub-rounded clear quartz.	Sand	15
10	Sand, as above, but whitish.		
15	Sand, as above, but with brown clay, runny.		
20	Sand and clay layers, brown, very runny.	Sand and clay	20
25			
30			
35	Sand, tan, very fine-grained to slight clay, sub-rounded clear quartz.	Clayey sand	5
40	Clay, greenish-tan, plastic, sandy.	Clay	3
45	Limestone, hard, dense, sandy.	Limestone at 43 ft.	
49			

Site 50

Sample depth (feet)		Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd				
5		Sand, light tan, very fine-grained, well-sorted, sub-rounded.	Sand	12
10		Sand, as above, but with dark stain.		
15		Sand, brown stain, clayey.		
20	a/b/	Sand and clay. Streaks of brown sandy clay and white sand.	Sand and clay	8
25		Sand, light brown, clayey, runny.	Clayey sand	10
30		Sand, slight clay, poor sample.		
35		Clay, greenish-tan, sandy, tough.	Sandy clay	20
40		Sand, clayey.		
55	b/	Clay, greenish-gray, plastic, sandy, with chips of limestone at 55.5'.	Clay	5
60		Limestone, cream, cheesy-soft, with soft gray clay, sandy, with occasional chert chips.	Limestone at 55 ft.	

Site 51

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	a/ Sand, very fine-grained, rounded, well-sorted clear quartz.	Sand	10
10	Sand, as above, and gray clay laminae.		
15			
21	Sand and clay, as above becomes dense black clay at 21'.	Sand and clay	15
25	Clay, gray, dense, becomes white sand at 25'.		
30	Sand, very fine-grained, well-sorted, rounded, clear quartz.	Sand	10
35	Sand, as above, and gray clay laminae.		
40	Sand, as at 30', and clay.		
42	Sand, as above, but with more clay.	Sand and clay	15
45	Sand and clay laminae.		
50	a/ Sand and clay laminae, as above; streaks of clean sand and green or gray clay.	Clay	5
55	Limestone.	Limestone at 55 ft.	
63	Limestone.		

Site 52

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	Sand, very fine-grained, rounded, clear quartz, slightly clayey.	Sand	5
10	Sand, as above, with more gray clay.		
15			
20	Sand, clayey.	Clayey sand	27
25			
30			
32	Sand, as above, but more clay.		
35			
37	Sand, clayey, as above, but with slightly less clay.		
40	Sand and clay, laminae.	Sand and clay	6
45	Clay, greenish, with gray-black mottles, sandy.	Sandy clay	6
50	Clay, black, sticky, very soft.	Clay	3
52	Limestone, light gray, sandy.	Limestone at 47 ft.	

Site 53

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	Sand, light tan, very fine to fine-grained, rounded clear quartz.	Sand	5
10	Sand, as above, and light gray clay.		
15		Clayey sand	20
20			
22	Sand, clayey, brownish-gray.		
25	Sand, clayey, as above, but with lenses of clean white sand.	Sandy clay	5
30	Clay, light gray, with sand and sandy streaks.		
35	Sand, with light greenish-tan clay.	Clayey sand	10
40	Clay, greenish-gray, plastic, sandy, and with streaks of sandy clay.	Clay	2
41.5			
45	Limestone, whitish-gray, hard, sandy.	Limestone at 41.5 ft.	

Site 54

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	Sand, light gray, very fine to fine-grained, slightly clayey.		
10	Sand, as above, but stained dark brown.		
15	Sand, as at 5', mottled tan and gray.	Sand	35
20			
25	Sand, as above, but even tan; no mottling.		
30	Sand, as above, but with even less clay.		
35	Sand, clayey, runny.		
40	Sand, as above, but with less clay. Runny sand.	Clayey sand	12
		Clay	3
50	Limestone, gray, sandy.	Limestone at 50-ft.	
60	Limestone.		

Site 55

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	a/ Sand, light tan, very fine-grained, well-rounded, very slight clay.		
10	Sand, as above, but with more clay, stained dark brown.	Sand	25
15	Sand, brown, very fine-grained, slight clay, runny.		
20			
25			
30	Sand, as above, but with streaks of gray clay.	Sand and clay	12
35	Sand, light tan, clayey.		
40	Limestone, variegated gray and brown. Harder brown part is granular, crepe-rubber texture; argillaceous.	Clay Limestone at 40 ft.	3
45	Limestone, gray.		

Site 56

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
1sd			
5	a/ Sand, white, fine-grained, well-sorted, rounded.	Sand	10
10	Sand, as above, but stained black and slightly clayey.		
15			
20	Sand, as at 5 ft. but tan.		
25	Sand, light gray, clayey.	Clayey sand	28
30	Sand, gray, clayey.		
35	Sand, light tan, slightly less clay than above.		
40	Clay, green and black mottled, slightly sandy and with sand layers.	Clay	7
45	Clay, as above, with chips of gray limestone.	Limestone at 45 ft.	
49	Limestone.		

Site 57

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	a/ Sand, dark brown, very fine-grained, well-rounded with streaks of white clay.		
10		Sand	10
15			
20	Sand, as above, runny.	Clayey sand	17
25	Sand, light gray, clayey.		
30	Clay, green-brown-black banded, dense, with layers of clean sand.	Clay	4
32	Limestone, grayish-tan, hard, slightly sandy.	Limestone at 31 ft.	

Site 58

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
lsd			
5	a/ Sand, very fine-grained, rounded, clear quartz.	Sand	8
10	Sand, as above, but stained dark brown, clayey.		
15	Sand, as above, but with less clay.		
20	Sand, light tan, very fine-grained, well-rounded, clean with streaks of chocolate brown clay.	Sand and clay	27
25	Sand, as above, but with no clay.		
30	Sand, as above but with chocolate brown clay balls.		
35	Sand, light gray, clayey.	Sandy clay	3
40	Sand, as above, but with streaks and layers of dark gray clay; chip of white chert.	Sand and clay	7
45	Limestone, grayish-brown, sandy, hard.	Limestone at 45 ft.	
49	Limestone.		

Site 59

Sample depth (feet)	Increased radiation →	Geohydrologic unit	Thickness (feet)
1sd			
5	a/ Sand, light tan with brown mottles, very fine-grained, with organic material.		
10	Sand, light gray, very fine-grained, well rounded, clayey.	Sand	5
15	Sand, as above, but with mottles of reddish brown.	Sand and clay	20
18	Sand, as above, but with no clay.		
20			
25	Sand, light brown, very fine to fine-grained, with slight clay in streaks.	Clayey sand	5
30		Sandy clay	5
35	Limestone, gray with green mottles, sandy, clayey.	Limestone at 35 ft.	
39	Limestone.		