Reese, R.S. and Wacker, M.A., 2007, A preliminary hydrogeologic framework for the surficial aquifer system in Palm Beach County, Florida

INTRODUCTION

The surficial aquifer system is the major source of freshwater for public water supply in Palm Beach County, Florida, yet many previous studies of the hydrogeology of this aquifer system have focused only on the eastern one-half to one-third of the county in the more densely populated coastal area (Land and others, 1973; Swayze and others, 1980; Swayze and Miller, 1984; Shine and others, 1989). Population growth in the county has resulted in the westward expansion of urbanized areas into agricultural areas and has created new demands on the water resources of the county. Additionally, interest in surface-water resources of central and western areas of the county has increased. In these areas, plans for additional surface-water storage reservoirs are being made under the Comprehensive Everglades Restoration Plan originally proposed by the U.S. Army Corps of Engineers and the South Florida Water Management District (1999), and stormwater treatment areas have been constructed by the South Florida Water Management District. Surface-water and ground-water interactions in the Everglades are thought to be important to water budgets, water quality, and ecology (Harvey and others, 2002).

Most of the previous hydrogeologic and ground-water flow simulation studies of the surficial aquifer system have not utilized a hydrostratigraphic framework, in which stratigraphic or sequence stratigraphic units, such as those proposed in Cunningham and others (2001), are delineated in this stratigraphically complex aquifer system. A thick zone of secondary permeability mapped by Swayze and Miller (1984) was not subdivided and was identified as only being within the Anastasia Formation of Pleistocene age. Miller (1987) published 11 geologic sections of the surficial aquifer system, but did not delineate any named stratigraphic units in these sections. This limited interpretation has resulted, in part, from the complex facies changes within rocks and sediments of the surficial aquifer system and the seemingly indistinct and repetitious nature of the most common lithologies, which include sand, shell, sandstone, and limestone.

Model construction and layer definition in a simulation of ground-water flow within the surficial aquifer system of Palm Beach County utilized only the boundaries of one or two major hydrogeologic zones, such as the Biscayne aquifer and surficial aquifer system; otherwise layers were defined by average elevations rather than geologic structure or stratigraphy (Shine and others, 1989). Additionally, each major permeable zone layer in the model was assumed to have constant hydraulic conductivity with no allowance for the possibility of discrete (thin) flow zones within the zone.

The key to understanding the spatial distribution and hydraulic connectivity of permeable zones in the surficial aquifer system beneath Palm Beach County is the development of a stratigraphic framework based on a consistent method of county-wide correlation. Variability in hydraulic properties in the system needs to be linked to the stratigraphic units delineated in this framework, and proper delineation of the hydrostratigraphic framework should provide a better understanding and simulation of the ground-water flow system. In 2004, the U.S. Geological Survey, in cooperation with the South Florida Water Management District, initiated an investigation to develop a hydrostratigraphic framework for the surficial aquifer system in Palm Beach County.

Purpose and Scope

The purpose of this report is to present the results of a preliminary study that delineates the hydrostratigraphic framework of the surficial aquifer system in Palm Beach County through the selection and county-wide correlation of stratigraphically significant geophysical log markers. This approach is applied to 105 wells selected in Palm Beach County and adjacent parts of neighboring counties (fig. 1 and table 1). Most of the selected wells penetrated to the base of the aquifer system and have both lithologic and geophysical log data that are used to correlate the geophysical markers and determine their relation to significant stratigraphic boundaries at a county-wide scale.

This report is a progress report for the investigation and specifically focuses on testing the correlation of each geophysical marker at a county-wide scale and determining their relation to previously defined important stratigraphic and hydrogeologic units. Further data collection and analyses are planned, and the linkage of hydraulic data to hydrostratigraphic units will be addressed.

Description of Study Area

The study area includes all of Palm Beach County and adjacent parts of Martin, Glades, Hendry, and Broward Counties (fig. 1), and is divided into three main physiographic provinces, which from east to west, are the Atlantic Coastal Ridge, the Sandy Flatlands, and the Everglades (fig. 2). The western boundary of the Atlantic Coastal Ridge province roughly parallels the coast and extends inland from 1 to 3 miles. The water-conservation areas (fig. 1), stormwater-treatment areas, and planned additional surface-water storage reservoirs are in the Everglades province. Most of the Everglades province north of the water-conservation areas encompasses the Everglades Agricultural Area.

Methods of Investigation

Through comparison of borehole natural gamma-ray (GR) geophysical logs to lithostratigraphic boundaries determined in cores from continuously drilled core (test coreholes), correlation markers were selected that approximately correspond to important lithostratigraphic unit boundaries. These GR markers were then correlated to all the other wells selected in the study area primarily using GR log signatures and, secondarily, lithologic descriptions.

To establish a framework for the entire aquifer system, most of the wells chosen for this study penetrated at least to the base of the surficial aquifer system, which ranges in depth in the county from about 140 to 360 feet below NGVD of 1929 (National Geodetic Vertical Datum of 1929) (Miller, 1987). Additionally, several previously drilled deeply penetrating test wells, in which no geophysical logs were originally run, were logged with a full suite of logs, including flowmeters to add to the coverage of wells with geophysical logs.

Correlation of GR logs in this study was carried out on an expanded vertical scale of 1 inch = 20 feet using working copies plotted with geophysical log software. Two other columns were added to these plots, including one showing lithologic symbols and one giving an abbreviated lithologic description. The entire stratigraphic section was correlated, not just the markers. Use of GR geophysical logs for correlation in the surficial aquifer system was found to be useful in this study; however, some characteristics of this aquifer system, particularly in the upper part, can make correlation difficult or subjective. These characteristics are: (1) generally low GR activity because of the low content of radioactive minerals, such as clay, phosphate and dolomite; (2) shifting environments of deposition due to multiple sea-level fluctuations creating multiple subaerial exposure surfaces and frequent facies changes (Perkins, 1977); and (3) GR peaks (a marked relative increase in GR activity over a short depth interval) may be located at "secondary depositional crusts" caused by precipitation of radioactive minerals at a paleo ground-water interface (Krupa, 1999). These depositional crusts, however, may also be present at subaerial exposure surfaces. In the lower part of the surficial aquifer system, clay and phosphatic sand and carbonate can be common and are associated with increased GR activity; most of these sediments were deposited in a marine environment without frequent or prolonged episodes of subaerial exposure.

Lithologic descriptions were compiled from previous studies and well construction reports. The formats, details, and quality of sample descriptions varied considerably, along with the sample collection method and sample quality. Different investigators describing samples tend to use different nomenclatures; therefore, some confusion can result in comparisons between wells. For example, "sandy limestone" described in one study can be the same as "calcareous sandstone" in another study. Well PB-1761 in southeastern Palm Beach County (fig. 1) was continuously cored as part of a previous study but was described in this study.

Three common sample collection methods used in previous studies, listed in order of increasing sample quality, include rock cuttings from mud rotary drilling, standard penetration test (SPT) samples, and continuously drilled core. The SPT method employs a split-barrel sampler, which in theory, collects in-situ formation samples in 1.5- to 2-foot intervals. Sample collection by the SPT method was done in the Central Everglades Restoration Project test wells (fig. 1). Wells with continuously drilled core include HE-1110 and HE-1116 in Hendry County and PB-1703, PB-1704, and PB-1761 in southern Palm Beach County (fig. 1). Data from 19 wells drilled to the Floridan aquifer system, which is deeper than the surficial aquifer system, were used in this study, because they provided data on deeper parts of the surficial aquifer system or were located in areas without shallow well control (fig. 1). The quality of the data from these deeper wells, however, is generally not as good because of the method of sample collection (mud rotary cuttings), larger hole diameter, longer sample intervals (10 feet), and less detailed lithologic description of the surficial aquifer system.

Previous Studies

Test-well drilling and hydrogeologic studies were conducted by the U.S. Geological Survey and South Florida Water Management District in Palm Beach County during the 1970s and 1980s. Data collected and inventoried during this period include lithologic and geophysical logs from 110 test wells (Schneider, 1976; Swayze and others, 1980). In eastern Palm Beach County, Swayze and Miller (1984) mapped the extent of a zone of high secondary permeability in the surficial aquifer system that represents the northern extension of the Biscayne aquifer. Miller (1987) mapped the base of the surficial aquifer system for the entire county and compiled 11 lithologic sections. Causaras (1985) determined stratigraphic units in the surficial aquifer system in Broward County adjacent to and south of Palm Beach County (fig. 1). Fish (1988) divided the aquifer system in Broward County into the Biscayne aquifer and an underlying or adjacent new and informally named "gray limestone" aquifer. Shine and others (1989) completed a ground-water resource assessment of the surficial aquifer system in eastern Palm Beach County, including ground-water flow models and detailed mapping of the Biscayne aquifer and a related production zone. Harvey and others (2002) conducted a more recent hydrogeologic study of the surficial aquifer system in or adjacent to the water-conservation areas in southeastern Palm Beach County, including test-well drilling, borehole geophysical logging, and hydraulic conductivity testing.

Mapping of the gray limestone aquifer was conducted by Reese and Cunningham (2000). This aquifer was found to extend from Broward, Collier, and Hendry Counties into southwestern Palm Beach County. Depositional sequences within and beneath the surficial aquifer system were mapped in southern Florida including Palm Beach County by Cunningham and others (2001). Some generalized sequence stratigraphic data in the upper part of the Biscayne aquifer of the surficial aquifer system of southeastern Florida are included in Cunningham and others (2004).

The Pleistocene deposits of southeastern Florida, including Palm Beach County, have been subdivided into five units or stratigraphic cycles, which are from oldest to youngest referred to as Q1, Q2, Q3, Q4, and Q5 (Perkins, 1977). These units are predominantly marine in origin but are separated by subaerial exposure surfaces. In another proposed nomenclature for the southern Florida stratigraphy all the Pleistocene-aged formations are grouped and referred to as the "Okeechobee Formation" (Scott, 1992).

HYDROSTRATIGRAPHIC FRAMEWORK AND SELECTION AND CORRELATION OF GEOPHYSICAL LOG MARKERS

This section describes the hydrostratigraphic framework of the surficial aquifer system in Palm Beach County through the selection, correlation, and mapping of GR geophysical log markers that have hydrostratigraphic significance. The first part of this section discusses the relation of different markers to lithostratigraphic unit boundaries. The second part discusses their relation to hydrostratigraphic units.

Correspondence of Geophysical Log Correlation Markers to Lithostratigraphic Units

The lithostratigraphic units used in this report to describe the surficial aquifer system (fig. 3) are similar to those used in many previous studies, including Schroeder and others (1954), Causaras (1985), Shine and others (1989), Harvey and others (2002). The description of some of these units in this study, however, differs from some previous studies. Some exceptions, in ascending stratigraphic order, are as follows:

- The upper part of the Peace River Formation can include a thick unit predominantly composed of quartz sand, referred to as the "unnamed formation" by Reese and Cunningham (2000), which may have been included with the Tamiami Formation in previous studies (Causaras, 1985; Schroeder and others, 1954);
- The Tamiami Formation is divided into an upper Pinecrest Sand Member, which can be composed primarily of sandy limestone in parts of Palm Beach County (regardless of its name), and a lower Ochopee Limestone Member (Reese and Cunningham, 2000);
- The Caloosahatchee Formation may not be present in most of eastern Palm Beach County and was not identified in southwestern Palm Beach County (Reese and Cunningham, 2000), and the extent of this unit in the rest of the county is uncertain; and
- The Fort Thompson Formation is probably equivalent to the Lake Okeelanta beds tentatively identified in southwestern Palm Beach County (Reese and Cunningham, 2000). The Fort Thompson Formation is present in south-central Palm Beach County, but grades laterally to the east into the Anastasia Formation (Causaras, 1985).

The Ochopee Limestone Member of the Tamiami Formation in many places is distinctive lithologically. This member has been described as containing pelecypod lime rudstone and floatstone, is commonly gray in color ranging to dark gray or even black, and can contain abundant skeletal moldic porosity (Reese and Cunningham, 2000). Based on lithologic descriptions from previous studies in eastern Palm Beach County, the interval interpreted to be the Ochopee Limestone Member in this study commonly has several thin hard layers of limestone or sandstone near its upper boundary. The top and base of the Ochopee Limestone have been identified as regional-scale depositional sequence boundaries by Cunningham and others (2001). Siliciclastic sediment and rock, such as clay, silt, clayey sand, silty sand, or sandstone is usually present below the base of the Ochopee Limestone.

The contact between the Tamiami Formation and the overlying formation is placed shallower in the stratigraphic section in this study than in most previous studies. The Pinecrest Sand Member of the Tamiami Formation was included in the Anastasia Formation by Swayze and Miller (1984). The characteristics used to define the top of the Tamiami Formation are its color, which can be light to medium gray and shades of olive gray, its high quartz sand-grain content with variable grain size (very fine to very coarse), and its locally high (greater than 1 or 2 percent) phosphate and heavy mineral grain content. Some other previous studies appear to have included the Pinecrest Sand Member in the Caloosahatchee Formation (Schroeder and others, 1954; Land and others, 1973).

Four GR geophysical log correlation markers that approximately correspond to important lithostratigraphic unit boundaries were selected for the study (fig. 3), and are referred to as the H, O, T, and F markers from deepest to shallowest because they approximate the top of the Hawthorn Group, Ochopee Limestone Member, Tamiami Formation, and Fort Thompson Formation, respectively. Each of these markers and its relation to lithostratigraphic units are discussed in this section.

The test coreholes used for the origin of these GR markers are HE-1110 in southeastern Hendry County and PB-1703, PB-1704, and PB-1761 in southern Palm Beach County (fig. 1); these coreholes are shown together with the markers on hydrostratigraphic sections A-A' (fig. 4), which extends west to east across southern Palm Beach County (figs. 1 and 4). The markers are also shown on hydrostratigraphic section B-B', which extends from south to north along the Atlantic coast (figs. 1 and 5). Interpreted lithostratigraphic and hydrogeologic boundaries are also shown in figures 4 and 5 using columns along the side of each well, and the sources for these interpretations, which are predominantly previous studies, are given in table 2. Information giving the lithologic sampling method used and source of the lithologic description for each well is also given in table 2. For some of these wells most of the lithostratigraphic boundaries were not identified in previous studies or well construction reports and could not be identified in this study.

Marker H approximately corresponds to the stratigraphic boundary at the base of the Ochopee Limestone Member of the Tamiami Formation and the top of the Peace River Formation of the Hawthorn Group (fig. 3) and was placed at this boundary in the test coreholes (fig. 4); it generally coincides with an increase in GR activity with depth at the base of the Ochopee Limestone, which usually has low GR activity.

Marker O was placed at a GR peak located approximately at or just below the top of the Ochopee Limestone Member. This peak (or group of several peaks) and its characteristic pattern was found to be laterally persistent in some parts of the study area. Good examples of GR logs displaying the characteristic pattern of this peak are wells PB-1704 and PB-1765 (fig. 4) and PB-1784 and PB-1693 (fig. 5). In test corehole PB-1704, this peak is 14 ft below the top of the Ochopee Limestone Member and is associated with a blackened limestone crust, laminated calcrete, and two subaerial exposure surfaces (Reese and Cunningham, 2000). In four other test coreholes to the west and south of the study area in southern Florida, the top of the Ochopee Limestone Member was found to be marked by blackened crust or an exposure surface or zone (Cunningham and others, 2001).

The lithologic nature of the Ochopee Limestone Member defined by markers H and O is indicated to change across Palm Beach County (figs. 4 and 5). The lithology generally grades from greater sand and sandstone (siliclastic) content in western Palm Beach County to greater limestone content in eastern Palm Beach County (fig. 4); however, siliclastic content in central Palm Beach County along the coast can be high (fig. 5).

Marker T is located at or near the top of the Tamiami Formation (fig. 3). In test corehole PB-1761 (fig. 4; located at same site as PB-1765), marker T coincides with a laminated calcrete layer that is interpreted to mark the upper contact of the Tamiami Formation. Placement of the top of the Pinecrest Sand Member of the Tamiami Formation in this well at the depth of the calcrete layer (60 feet below land surface), or as much as 10 feet deeper, is supported by paleontologic study of mollusk (G.L. Wingard, U.S. Geological Survey, written commun., 2006) The calcrete is indicative of subaerial exposure. Perkins (1977) indicates that a subaerial exposure surface, referred to as a discontinuity surface, is present at the base of Pleistocene-aged rocks, and Pleistocene-aged rocks could bound the top of the Tamiami Formation (Cunningham and others, 2001). Marker T typically coincides with a GR peak or group of peaks, and in some cases a characteristic GR log pattern (for example, wells PB-1704 in fig. 4 and PB-600 in fig. 5), but this peak is not as distinctive or correlative as the one for marker O. Similar to the Ochopee Limestone Member, the siliciclastic content of the Pinecrest Sand Member as defined by markers T and O generally is indicated to increase from eastern to western Palm Beach County, at least in the southern part of the county (fig. 4).

Based on some previous studies or well construction reports, the top of the Tamiami Formation was placed much deeper in the section than the T marker, but in others this contact was found to be close to the depth of the marker. In some areas, the lithology of the Pinecrest Sand Member may be similar to or gradational to the lithology of overlying units, making its upper contact difficult to define. The top of the Tamiami Formation was placed near the O marker in wells PB-1775 and PB-1195 in well construction reports (figs. 4 and 5, table 2), perhaps because of the distinctive lithology of the Ochopee Limestone Member as previously described. In a previous study of several other wells in eastern Palm Beach County the depth to the top of the Tamiami Formation is within 10 feet of the T marker (Johnson, 1988). These wells are PB-652A (fig. 5, table 2), PB-665, and PB-667 (data source of Schneider (1976) in fig. 1).

Marker F was originally chosen to be near the top of the Lake Okeelanta beds (probable Fort Thompson Formation equivalent) in test corehole PB-1704 (fig. 4). Marker F typically coincides with a GR peak, group of peaks, or zone of relative increase in GR activity (for example, wells PB-1105 in fig. 4 and PB-1082 in fig. 5), but this marker is not as correlative as the deeper markers. In some wells in the eastern part of Palm Beach County, marker F is located near the top of limestone or sandstone units and base of a quartz sand unit (for example, wells PB-1775 and G-2916 in fig. 4 and PB-675 in fig. 5). Additionally, in four wells, this marker is near the top of the Fort Thompson Formation determined in previous studies; these wells are PB-1775 (fig. 4, table 2), PB-1144 (fig. 5, table 2), and PB-665 and PB-667 (fig. 1; Johnson, 1988). Although it does serve to divide the stratigraphic section between the surface and the T marker, the stratigraphic significance of marker F is uncertain. Generally, thick intervals of sand are present in the upper part of the interval between the surface and T marker in eastern Palm Beach County that are not present in western Palm Beach County (figs. 4 and 5).

Figure 1. Study area and all wells used in the study.

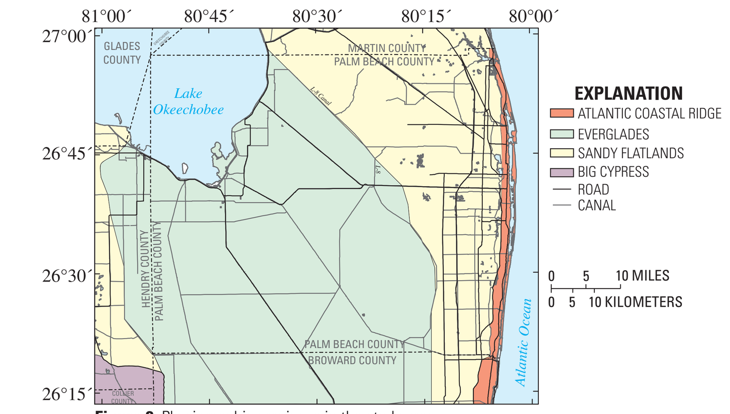

Figure 2. Physiographic provinces in the study area.

Series	Lithostratigraphic units		Approximate thickness (feet)	Lithology	Correlation Marker	Hydrogeologic unit (WEST – EAST)
HOLOCENE		LAKE FLIRT MARL, UNDIFFERENTIATED SOIL AND SAND	0 - 5	Marl, peat, organic soil, quartz sand		SURFICIAL AQUIFER SYSTEM: WATER TABLE AQUIFER
PLEISTOCENE		PAMLICO SAND	0 - 80	Quartz sand with some shell beds, sandstone and limestone		
		MIAMI LIMESTONE	0 - 12	Oolitic limestone, quartz sand and sandstone	F	BISCAYNE AQUIFER
		FORT THOMPSON FORMATION / LAKE OKEELANTA BEDS (?)	0 - 50	Marine limestone and minor gastropod-rich freshwater limestone, quartz sandstone and sandy limestone		
		ANASTASIA FORMATION	0 - 140	Coquina, shell, quartz sand and sandy limestone		
		CALOOSAHATCHEE FORMATION	0 - 50?	Sandy to shelly marl, clay, silt and quartz sand	T	SEMICONFINING UNIT
PLIOCENE	TAMIAMI FORMATION	PINECREST SAND MEMBER	20 - 100	Quartz sand, pelecypod-rich quartz sandstone and sandy limestone, shell, terrigenous mudstone, local abundant phosphate grains	O	
		OCHOPEE LIMESTONE MEMBER	40 - 130	Pelecypod lime rudstone and floatstone, pelecypod-rich quartz sand and sandstone, moldic quartz sandstone	H	GRAY LIMESTONE AQUIFER; SEMICONFINING UNIT
MIOCENE	UPPER HAWTHORN GROUP	UNNAMED FORMATION; PEACE RIVER FORMATION	300 - 500	Quartz sand, sandstone, clay-rich quartz sand, silt, marl, terrigenous mudstone or clay, diatomaceous mudstone, local abundant phosphate grains		INTERMEDIATE CONFINING UNIT

Figure 3. Lithostratigraphic units recognized in the study area, their generalized geology, and relation with hydrogeologic units. Modified from Reese and Cunningham (2000) and Cunningham and others (2001).

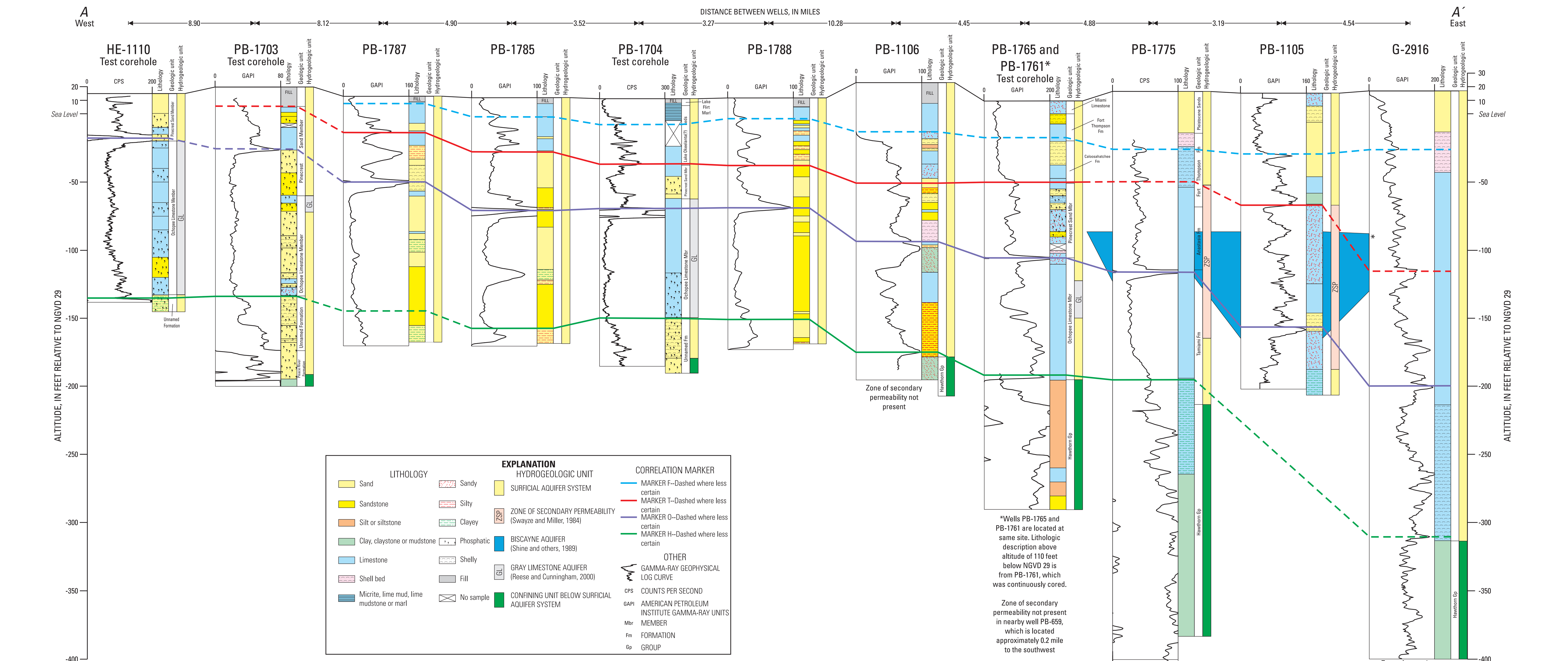

Figure 4. Hydrostratigraphic section *A-A´*.

Gray limestone aquifer projected from nearby well PB-1428, which is located approximately 0.24 miles to the southwest (Fish, 1988)

Zone of secondary permeability projected from nearby well PB-1100 (approximately 0.2 mile to southwest)

Zone of secondary permeability not determined in this well or area
* Position of Biscayne aquifer in this well is projected

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