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LITHOSTRATIGRAPHIC AND HYDROSTRATIGRAPHIC CROSS SECTIONS THROUGH PINELLAS AND HILLSBOROUGH COUNTIES, SOUTHWEST FLORIDA

By

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LITHOSTRATIGRAPHIC AND HYDROSTRATIGRAPHIC CROSS SECTIONS THROUGH PINELLAS AND HILLSBOROUGH COUNTIES

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INTRODUCTION

A cooperative program exists between the Southwest Florida Water Management District (SWFWMD) and the Florida Geological Survey (FGS) to construct geologic and hydrogeologic cross sections throughout the 16 county SWFWMD region. The purpose of the program was to delineate the extent of lithostratigraphic and hydrostratigraphic units within the region to aid in the management and protection of ground-water resources. In order to systematically accomplish these goals, the project was subdivided into three phases, each with separate study areas: Phase I included the southwest region of the District, from Pinellas and Hillsborough to Charlotte Counties; Phase II included the northwest part of the District, from Levy and Marion to Pasco Counties; and Phase III included the southeastern portion of the District, encompassing all areas not covered in Phases I and II. Regional lithostratigraphy of Eocene through Miocene formations, gamma-ray log characteristics of these formations and aquifer-system delineation within each study area were the primary focuses of the cross sections. Most of the data used to construct the cross sections were taken from wells drilled as part of the SWFWMD Regional Observation and Monitor-Well Program (ROMP; Gomberg, 1975). In areas where ROMP data were not available, borehole data from the FGS and the United States Geological Survey (USGS) were utilized.

Interim reports on each project phase will be released as FGS Open File Reports (OFR). The present interim report, one of two reports on the Phase I region, covers Pinellas County, Hillsborough County, and part of Manatee County. The second OFR produced for Phase I includes Manatee, Sarasota and Charlotte Counties (Arthur et al., 1995). Similar reports for the Phase II and III regions will also be forthcoming. Three east-west cross sections across Pinellas and Hillsborough Counties and three north-south cross sections through the study area are presented in this report. The east-west cross sections spanning this region extend inland from the coast an average of 31 miles. Figure 1 is a location map for the cross sections (Plates 1 through 6).

CROSS SECTION CONSTRUCTION

Detailed lithologic descriptions, gamma-ray logs and hydrologic data comprise the bulk of the information used to develop the cross sections shown in Plates 1 through 6. The dominant source of information for cross-section control points are SWFWMD ROMP wells. In areas where ROMP data are limited, however, supplemental wells are included to provide appropriate data-point coverage. There are cases where the only available borehole data are geophysical logs (i.e., no lithologic data are available). Of these geophysical logs, gamma-ray logs are the most readily available and useful for correlative purposes within the study area. Gamma-ray logs are included in the cross sections to allow

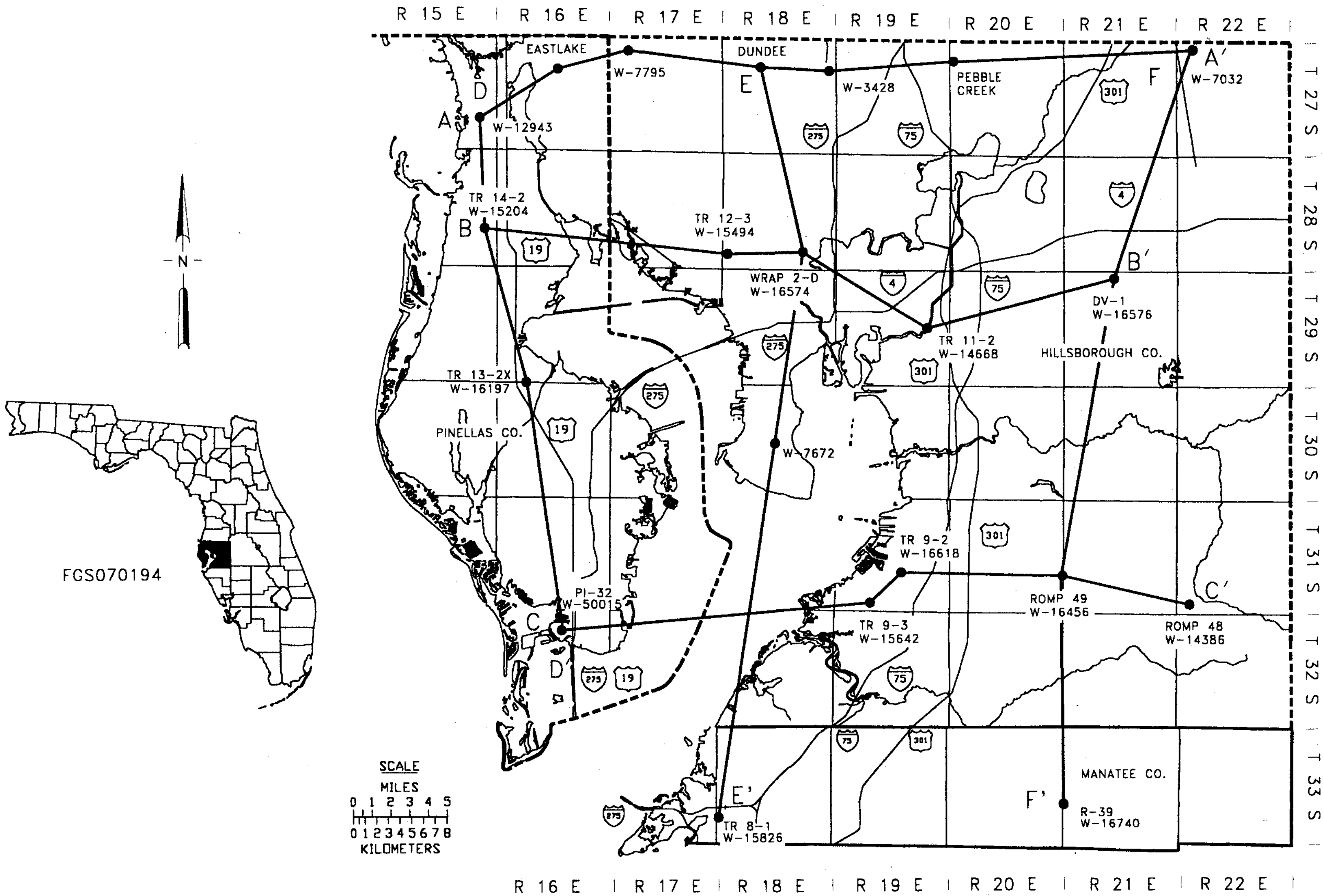


Figure 1. Location map for cross sections in Plates 1 through 6.

comparison of the gamma-ray signatures relative to each stratigraphic unit. The following discussion outlines the methods used for construction of the cross sections for this study.

Topographic profiles are included on each cross section to facilitate comparison of surface morphologies with subsurface stratigraphy. Data used to construct these profiles were taken from U.S. Geological Survey 1:24,000 (7.5 minute) quadrangle maps. Profiles are plotted above the cross sections, along with selected anthropomorphic features, cultural boundaries and landforms.

Lithology

For each well, a stratigraphic column was generated using existing lithologic data. In cases where no description (or one of poor quality) was available, borehole samples (core and/or cuttings) were described for this study. Hatching patterns depict primary lithologies the columns, with accessory minerals own on the right of the columns as text codes. Figure 2 lists the definitions of mineralogic and lithologic codes and patterns. Accessory-mineral codes are generally the same as those used in the FGS lithologic database (the Well Log Data System; GeoSys, Inc., 1992). The ed order of the accessory mineral codes does not always imply relative abundance since percentages of these minerals were not provided in the lithologic descriptions in many cases. For accessory sand (greater than five percent quartz + phosphate), where the percentages were available from the lithologic descriptions, the hatching pattern reflects sand content as a stippled overlay. If the amount of accessory sand-sized minerals is less than five percent, the accessories are listed in the text codes.

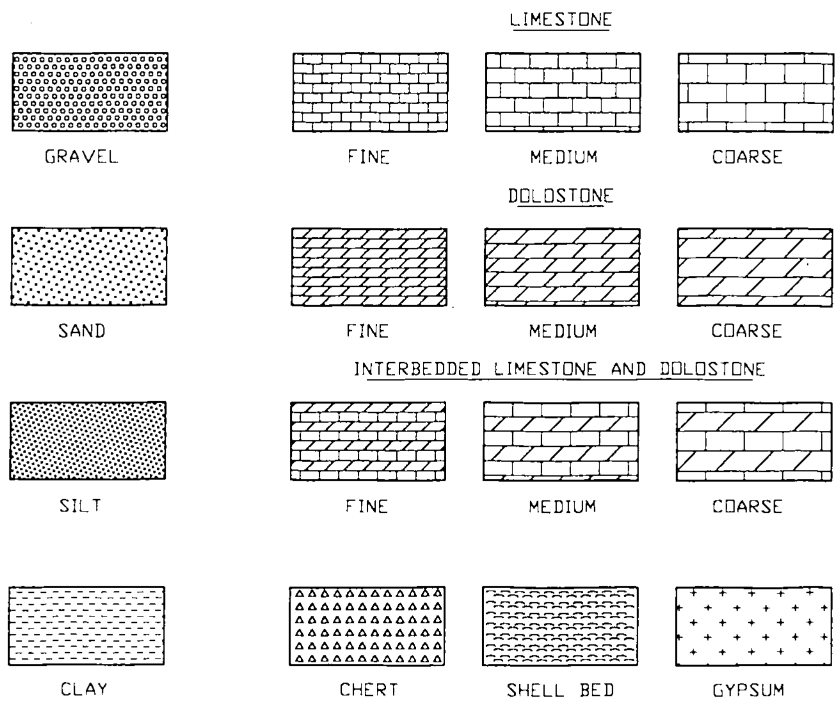
Comparison of the degree of lithologic detail between boreholes clearly shows a correlation with the type of material available for description. In general, more detail exists for the cores. Table 1 provides a listing of well-site information and sample type (e.g., cores, cuttings or both) available for this study.

Bed thicknesses on the stratigraphic columns are limited to no less than five feet due to graphical constraints. There are several examples where lithologies and accessory minerals have been averaged over a five to 10 foot interval to accommodate these requirements. Lithologic descriptions for all wells used in this study are available from the Florida Geological Survey or the Southwest Florida Water Management District.

Gamma-ray logs

Available gamma-ray logs are plotted to the right of each stratigraphic column on the cross sections. These logs facilitate delineation of formational boundaries and allow comparison of gamma-ray activity between the various lithostratigraphic and hydrostratigraphic units. Gilboy (1983) and Miller (1986) have both used this approach. Their cross sections, however, do not provide detailed lithology or topographic profiles. The phosphatic nature of the sediments comprising the Hawthorn Group, allowed gamma-ray logs to be quite successful for the delineation of stratigraphic units.

The "signal quality" of these logs varies from poor to very good. This variation is primarily due to non-ideal instrument settings, the most common of which are the time constant (TC) and full scale. The TC is a setting used to average gamma-ray activity over a given period of time during a borehole reading. On logs where the trend is very smooth, the TC is probably set too high, whereas, in cases where the log response is extremely erratic, the TC was probably set too low. The full scale, which results from the rate and variable span settings, should be adjusted to provide good contrast between the gamma-ray peaks and the background count rates. In addition, except for anomalously high gamma-ray peaks, the full scale should be set to avoid peak truncation.



CODES

M	MICRITE	T	SILT
S	SAND	C	CLAY
P	PHOSPHATE GRAVEL	Sh	SHELL
p	PHOSPHATE SAND	D	DOLOSTONE
O	ORGANICS	L	LIMESTONE
R	SPAR	H	HEAVY MINERALS
I	IRON STAIN	NO SPL	NO SAMPLE
Q	QUARTZ	G	GYPSUM
A	ANHYDRITE	Py	PYRITE
Ch	CHERT	K	GLAUCONITE

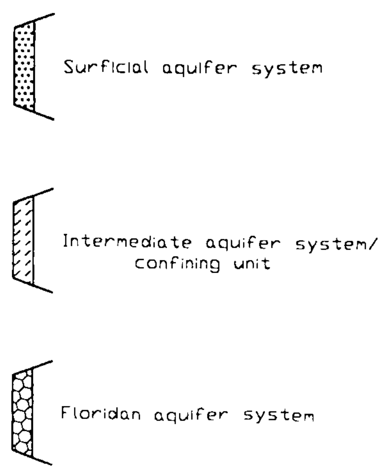


Figure 2: Explanation of hatching patterns and codes used in Plates 1 through 6.

Table 1. Borehole data on all wells used in this study. Footnotes are in parentheses.

WELL ID (1)	SITE NAME	TOWNSHIP, RANGE, SECTION (2)	LAT/LONG	TD (BLS) (3)	ELEVATION (NGVD) (4)	GAMMA-RAY LOG	SAMPLE TYPE	WORKED BY:
A - A'								
W-12943	N/A (5)	T27S R15E S25 A	28 06 37 82 45 46	1700	17	X	CUTTINGS	K. KING
N/A	EAST LAKE	T29S R16E S10 AC	28 08 52 82 41 43	774	40	X	N/A	N/A
W-7795	N/A	T27S R17E S06 DB	28 09 46 82 38 05	510	37		CORE	C. COLEMAN
N/A	DUNDEE	T27S R18E S09 CA	28 09 01 82 31 04	693	59	X	N/A	N/A
W-3428	N/A	T27S R18E S12 AD	28 08 52 82 27 30	320	68		CORE	C. COLEMAN
N/A	PEBBLE CRE	T27S R20E S07 AA	28 09 21 82 21 01	482	50	X	N/A	N/A
W-7032	N/A	T27S R22E S06 DB	28 09 59 82 08 30	400	84		CUTTINGS	C. COLEMAN
B - B'								
W-15204	TR 14-2	T28S R15E S25 BA	28 01 32 82 45 28	604	55	X	CORE	G. HENDERSON
W-15494	TR 12-3	T28S R18E S31 DB	28 00 05 82 32 05	540.5	27	X	CUTTINGS/ CORE	G. HENDERSON J. DECKER
W-16574	WRAP 2D	T28S R18E S35	28 00 33 82 28 49	1180	28	X	CUTTINGS	M. CLAUSEN (CH2M HILL)
W-14668	TR 11-2	T29S R19E S23 BB	27 57 05 82 22 11	589	15	X	CORE	UNKNOWN
W-16576	DV-1	T29S R21E S04	27 59 26 82 12 34	850	112	X	CUTTINGS/ CORE	G. KINSMAN
C - C'								
W-50015	PI-32	T32S R16E S10 AB	27 43 04 82 41 17	1438	7	X	CUTTINGS	UNKNOWN
W-15642	TR 9-3	T31S R19E S32 AD	27 44 18 82 25 37	785	8	X	CUTTINGS	J. DECKER
W-16618	TR 9-2	T31S R19E S22 DC	27 45 54 82 23 38	1260	13	X	CUTTINGS/ CORE	J. DECKER
W-16456	ROMP 49	T31S R20E S25 BB	27 45 46 82 15 16	1575	146	X	CUTTINGS/ CORE	J. DECKER & G. KINSMAN
W-14386	ROMP 48	T31S R22E S31	27 44 27 82 08 37	925	102	X	CUTTINGS	G. STRASSER

Footnotes:

(1) Well ID is FGS "W" number.
(2) Section quarters are coded as A= NW 1/4; B= NE 1/4; C= SW 1/4; D= SE 1/4.
(3) TD - total depth; BLS - below land surface in feet.
(4) NGVD - National Geodetic Vertical Datum of 1929 (in feet).
(5) N/A - Not applicable.

Table 1. (Continued).

WELL ID (1)	SITE NAME	TOWNSHIP, RANGE, SECTION (2)	LAT/LONG	TD (BLS) (3)	ELEVATION (NGVD) (4)	GAMMA-RAY LOG	SAMPLE TYPE	WORKED BY:
D - D'								
W-12943	N/A	T27S R15E S25 A	28 06 37 82 45 46	1700	17	X	CUTTINGS	K. KING
W-15204	TR 14-2	T28S R15E S25 BA	28 01 32 82 45 28	604	55		CORE	G. HENDERSON
W-16197	TR 13-2X	T29S R16E S32 CD	27 54 30 82 43 14	677.5	17	X	CUTTINGS/ CORE	J. CLAYTON
W-50015	PI-32	T32S R16E S10 AB	27 43 04 82 41 17	1438	7	X	CUTTINGS	UNKNOWN
E - E'								
N/A	DUNDEE	T27S R18E S09 CA	28 09 01 82 31 04	693	59	X	N/A	N/A
W-16574	WRAP 2D	T28S R18E S35	28 00 33 82 28 49	1180	28	X	CUTTINGS	M. CLAUSEN (CH2M HILL)
W-7672	N/A	T30S R18E S22	27 51 27 82 29 40	1000	20	N/A	CUTTINGS	CHRISTOPHER
W-15826	TR 8-1	T33S R18E S30 AA	27 34 58 82 32 47	1260	14	X	CORE	TOM SCOTT
F - F'								
W-7032	N/A	T27S R22E S06 DB	28 09 59 82 08 30	400	84		CUTTINGS	C. COLEMAN
W-16576	DV-1	T29S R21E S04	27 59 26 82 12 34	850	112	X	CUTTINGS/ CORE	G. KINSMAN
W-16456	ROMP 49	T31S R20E S25 BB	27 45 46 82 15 16	1575	146	X	CUTTINGS/ CORE	J. DECKER & G. KINSMAN
W-16740	ROMP 39	T33S R21E S19 AC	27 35 21 82 15 05	1013	125	X	CORE	JIM CLAYTON DOUG RAPPUHN

Footnotes:

(1) Well ID is FGS "W" number.
(2) Section quarters are coded as A= NW 1/4; B= NE 1/4; C= SW 1/4; D= SE 1/4.
(3) TD - total depth; BLS - below land surface in feet.
(4) NGVD - National Geodetic Vertical Datum of 1929 (in feet).
(5) N/A - Not applicable.

Other factors that limit the utility of the logs include unknown log history (e.g., the older logs may have been run through casing in all or part of the borehole) and logs that reflect instrument "drift" or a slowly changing baseline. Most of the logs shown on the cross sections were run at a logging speed of 20 to 25 feet/minute.

The intensity units shown on the logs (horizontal axis) are in counts per second (CPS). Due to inconsistency between logs with respect to different logging-parameter settings and borehole characteristics (e.g., depth of casing and lack of caliper logs to determine wash out of poorly consolidated units), it is not possible to quantitatively compare the logs shown in Plates 1 through 6. The logs are very useful, however, in the identification of correlative "packages" of gamma-ray peaks and for comparison of the overall gamma-ray signature within formational units.

Delineation of boundaries

Formations

Delineation of formational boundaries is based on inspection of available borehole samples (cores and/or cuttings) by geologists from SWFWMD, the FGS, or both. Formation boundaries are primarily based on lithologic character. Gamma-ray logs and fossil assemblages are used only to supplement the lithologic descriptions in the determination of the boundaries. The following general comments pertain to the lithostratigraphic contacts shown on Plates 1 through 6. In cases where distinctly different lithologies of two lithostratigraphic units are interlayered, the top of the uppermost occurrence of the underlying unit is used as the formation "contact." In determining the position of formational members (e.g., Tampa Member of the Arcadia Formation) within the section, a conservative approach was taken: when a unit has characteristics of both the member and the broader formational unit, the sequence is shown as part of the formation (undifferentiated). Where there exists uncertainty regarding the exact position of the formation boundary, or when the boundary is inferred within an interval of poor or no sample recovery, a dashed rather than solid line is shown. Dashed contacts are also drawn where only a gamma-ray log was used and no samples were available for inspection. In cases where sample quality is poor, as is sometimes true with cuttings, the gamma-ray logs become more important in the determination of formational boundaries.

Lithostratigraphic units shown on the cross sections include the Avon Park Formation through the Hawthorn Group. Stratigraphic relationships, ages, extent and nomenclature of post-Miocene units within the southwest Florida region are complicated (Scott and Allmon, 1992) and their delineation is not within the scope of this study. On a regional basis, the post-Hawthorn Group units are components of the surficial aquifer system. For the purposes of this study, the various post-Miocene units are combined as undifferentiated sand and clay (UDSC) or undifferentiated sand, clay and shells (UDSS).

Aquifer systems

Generalized aquifer-system delineations are shown on the cross sections (Plates 1 through 6) as hydrostratigraphic columns to the left of the lithologic columns. Hatching patterns used in the hydrostratigraphic columns identify the three aquifer systems present in the study area (Figure 2). Delineation of the aquifer systems is based on available hydrogeologic data collected during drilling. Criteria for delineation of hydrostratigraphic units include hydrogeological characteristics of the samples (e.g., porosity types, measured and estimated permeability) and observed changes in potentiometric-head levels between permeable rock units, both during drilling and in completed monitor wells at the sites. Where reliable hydrogeologic data are not available,

Plate 1. Cross section A-A', Pinellas/Hillsborough Counties

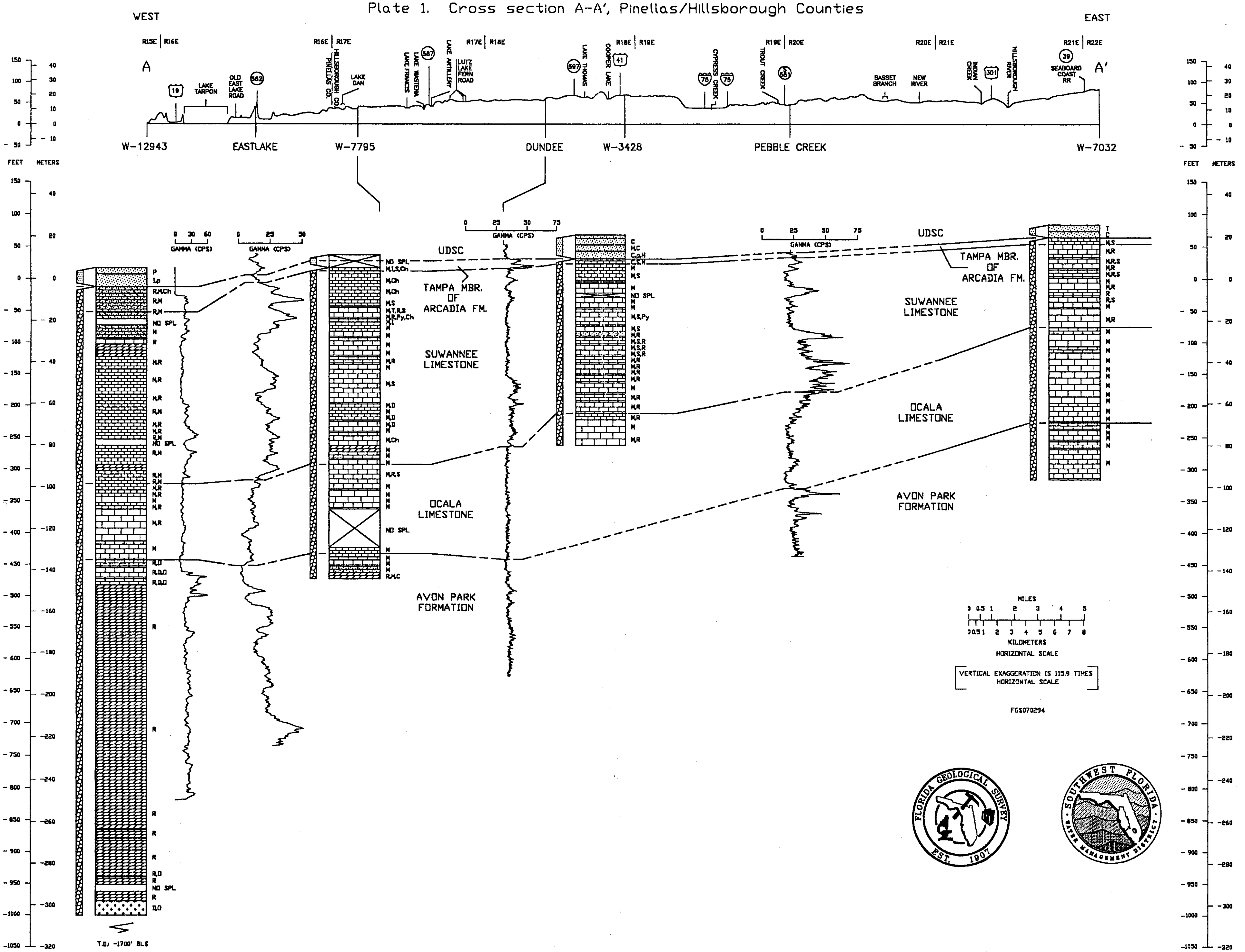


Plate 2. Cross section B-B', Pinellas/Hillsborough Counties

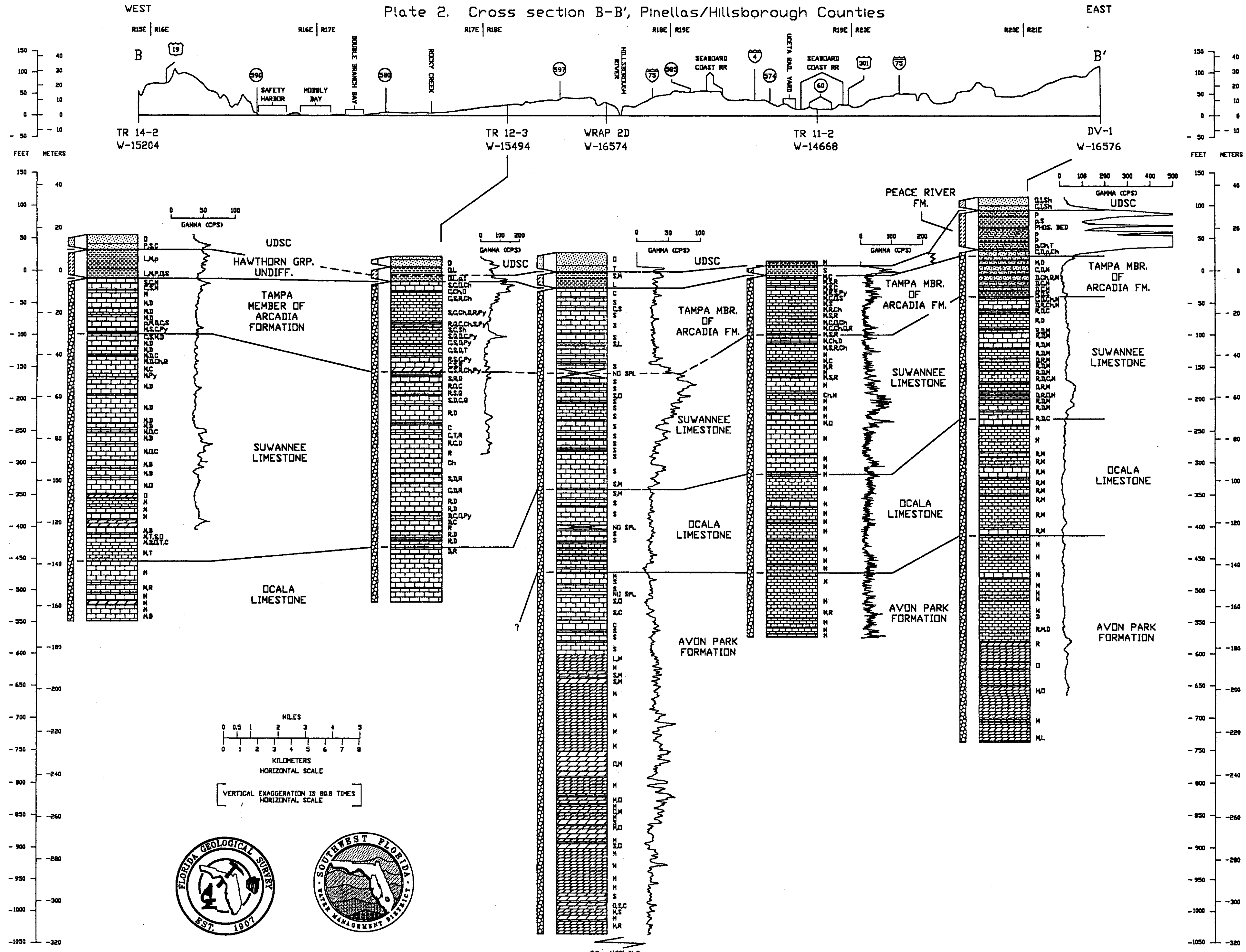


Plate 3. Cross section C-C', Pinellas/Hillsborough Counties

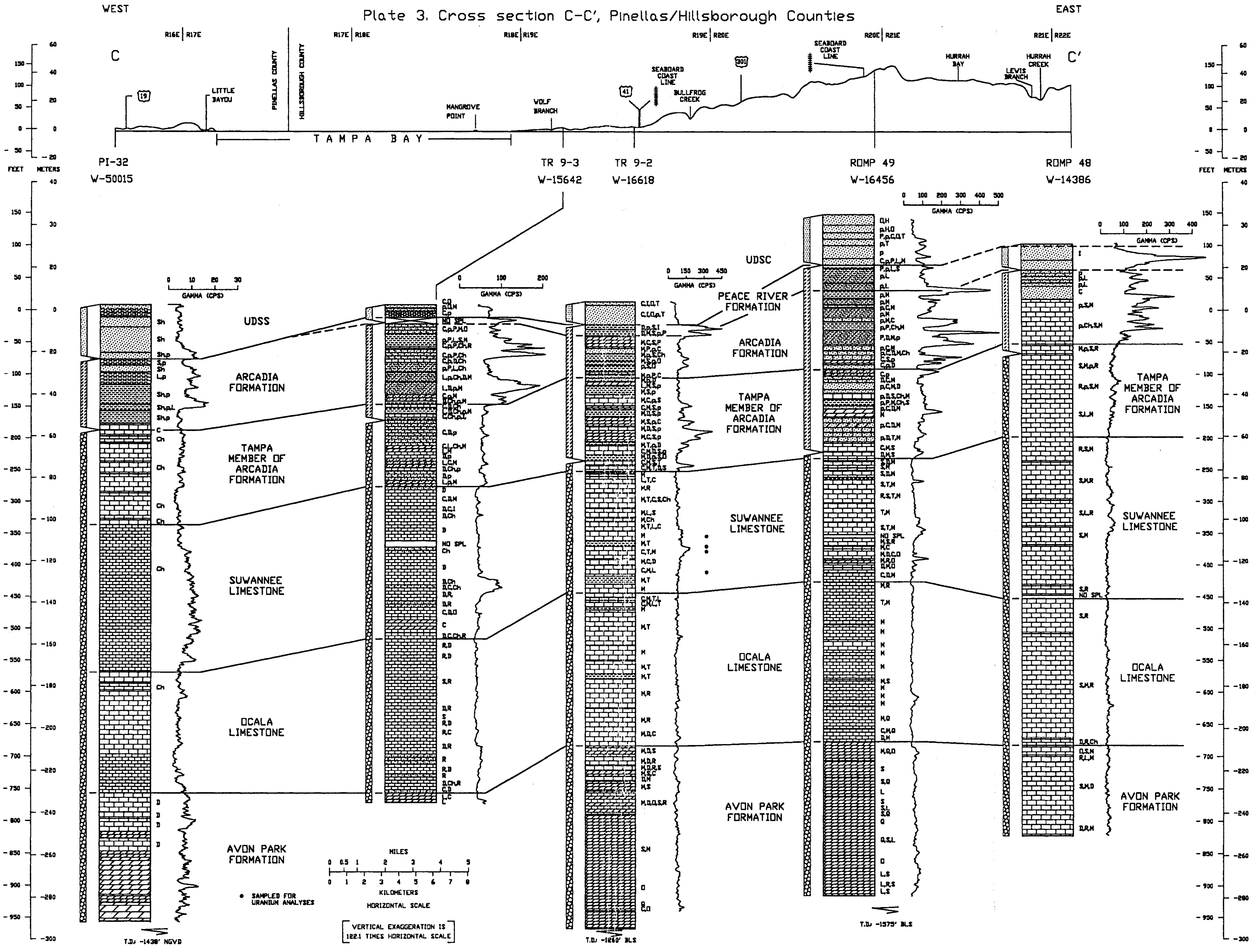


Plate 4. Cross section D-D', Pinellas County

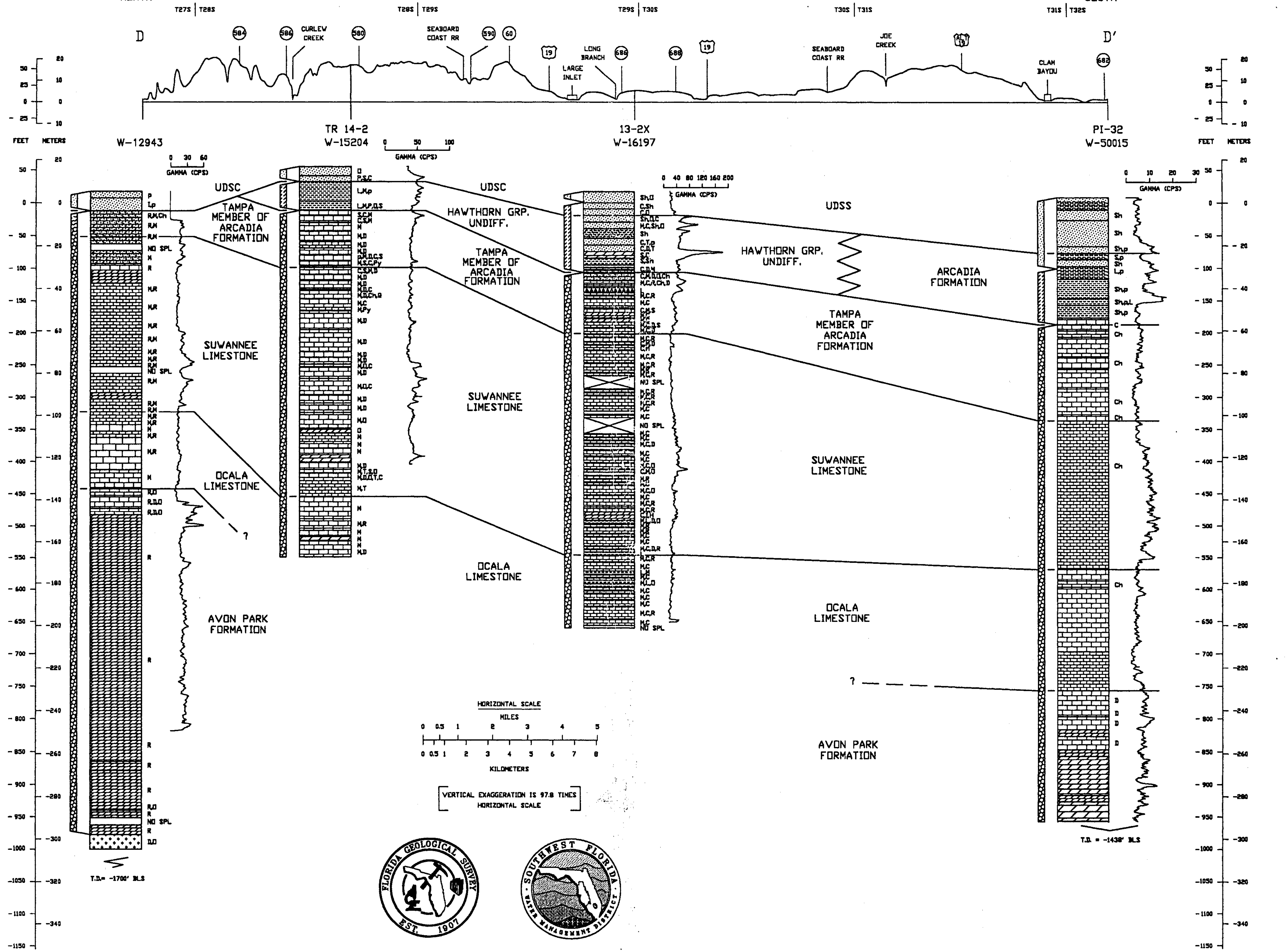


Plate 5. Cross section E-E', Hillsborough/Manatee Counties

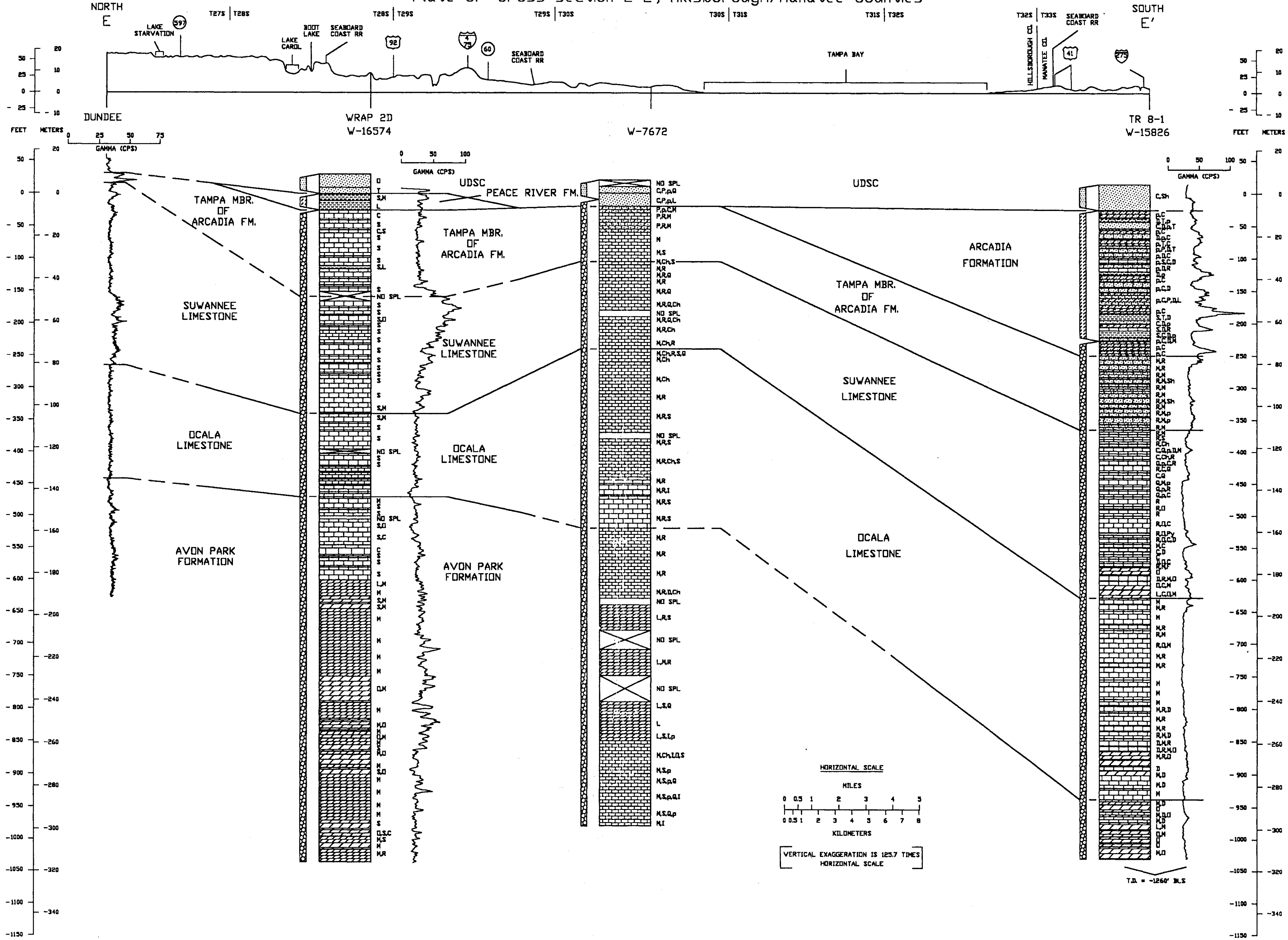
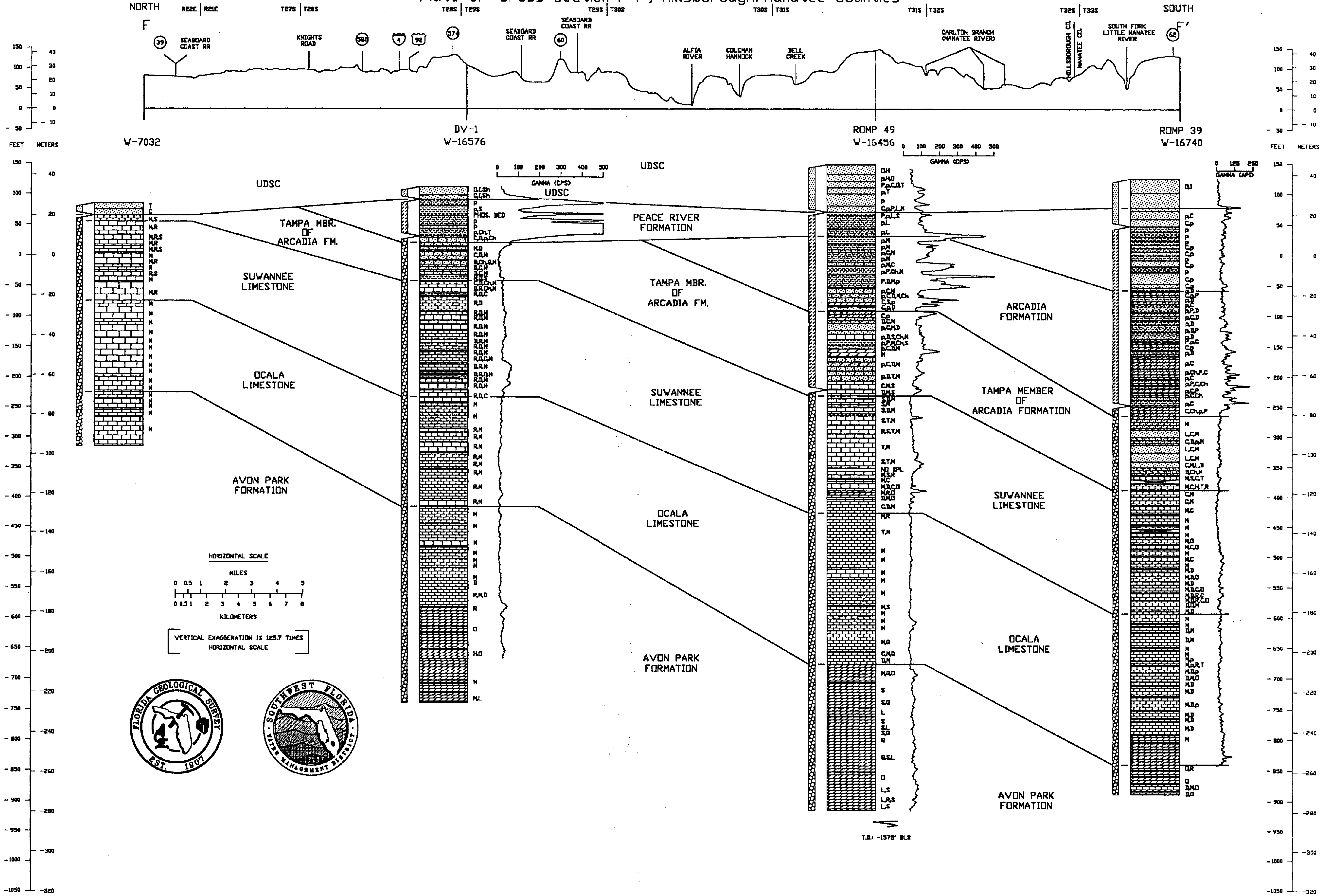


Plate 6. Cross section F-F', Hillsborough/Manatee Counties



aquifer delineations are based primarily on lithology and compared with hydrostratigraphy established at adjoining data points in the cross section. A summary of aquifer intervals for cross section data points is given in Table 2. Descriptions of the hydrogeologic properties of aquifer systems present in the study area is presented in an ensuing section entitled **Hydrostratigraphy**.

LITHOSTRATIGRAPHY

The deepest boreholes used in this study penetrate Middle Eocene lithostratigraphic units. Following is a discussion of lithologic characteristics of Middle Eocene and younger units and their general gamma-ray log characteristics, which are shown in the cross sections (Plates 1 through 6). Table 3 summarizes the tops of these units relative to National Geodetic Vertical Datum of 1929 (NGVD).

Eocene Series

Avon Park Formation

The Middle Eocene Avon Park Formation (Miller, 1986) underlies all of Pinellas, Hillsborough, and Manatee counties. Its lithology is generally comprised of tan to buff dolostones and dolomitic limestones with occasional organic-rich laminations. The uppermost portion of the Avon Park Formation within the study area is, however, a very light-orange to yellowish-gray calcarenitic limestone with variable amounts of organic-rich laminations and dolomite. Porosity in this formation is generally intergranular in the limestone section. Fracture porosity in the dolostone is common, as well as intercrystalline porosity in the sucrosic textures. Pinpoint vugs and fossil molds are present to a lesser extent. The most diagnostic fossils include the foraminifers *Dictyoconus americanus* and *Coskinolina floridana*. The echinoid *Neolaganum (Peronella) dalli* is common within the upper portions of the unit.

The Lower to Middle Eocene (Braunstein and others, 1988) Oldsmar Limestone is subjacent to the Avon Park Formation in this region. Miller (1986) reports the base of Middle Eocene rocks (approximately the base of Avon Park Formation) at depths ranging from -1700 to -2400 feet NGVD. The Avon Park Formation varies in thickness beneath Pinellas, Hillsborough, and Manatee Counties, ranging from approximately 1250 feet in northeastern Manatee County to 1500 feet in Pinellas County (Miller, 1986). According to Miller (1986), the top of the formation is between -500 and -900 feet NGVD; however, the present study has found this horizon at higher levels, the shallowest being -226 feet NGVD (Plates 1 and 6). The Avon Park Formation is unconformably overlain by the Ocala Limestone.

Gamma-ray log response for the Avon Park Formation is somewhat different from that of the overlying Ocala Limestone. In general, Avon Park lithologies give rise to a more variable signal with a slightly higher background count rate. This variability is probably due to the dolomite content. In some cases, near the top of the Avon Park a set of diagnostic gamma-ray peaks occur, which may be a response to the presence of organic laminations in the uppermost part of the section. These organics may contain elevated amounts of uranium, which would cause increased gamma-ray activity.

Ocala Limestone

The Upper Eocene Ocala Limestone, first named by Dall and Harris (1892), consists of white to light-gray to light-orange limestone with a diverse fossil assemblage. More specifically, the lithology of this formation ranges from a weathered wackestone to packestone with a variable amount of calcilutite matrix (chalky) in the upper portions, to a biogenic packstone to grainstone in the central and lower portions of the unit. Trace amounts of organics, clay and variable amounts of dolomite are also present. Porosity is variable within this unit and is generally moldic and intergranular with

Table 2. Upper boundaries of aquifer-system units wthin the study area; datum is NGVD, units are in feet.

WELL ID	SITE NAME	SURFICIAL AQUIFER SYSTEM	INTERMEDIATE AQUIFER SYSTEM/CONFINING UNIT	FLORIDAN AQUIFER SYSTEM
A - A'				
W-12943	N. PINELLAS INJ. WELL NO. 1	17	NOT OBSERVED	-13
W-7795	---	37	NOT OBSERVED	17
W-3428	---	68	NOT OBSERVED	31
W-7032	---	84	NOT OBSERVED	64
B - B'				
W-15204	ROMP TR 14-2	55	32	-7
W-15494	ROMP TR 12-3	27	6	1
W-16574	NW HILLSBOROUGH WRAP 2D	28	-2	-27
W-14668	ROMP TR 11-2	15	5	-75
W-16576	ROMP DV-1	112	92	32
C - C'				
W-50015	PI-32 TEST HOLE ST. PETE WWTP	7	-73	-198
W-15642	ROMP TR 9-3	8	-20	-172
W-16618	ROMP TR 9-2	13	-25	-236
W-16456	ROMP 49	146	68	-203
W-14386	ROMP 48	102	62	-68
D - D'				
W-12943	N. PINELLAS INJ. WELL NO. 1	17	NOT OBSERVED	-13
W-15204	ROMP TR 14-2	55	32	-7
W-16197	ROMP TR 13-2X	17	1	-107
W-50015	PI-32 TEST HOLE ST. PETE WWTP	7	-73	-198
E - E'				
W-16574	NW HILLSBOROUGH WRAP 2D	28	-2	-27
W-7672	---	20	NOT OBSERVED	[-20]
W-15826	ROMP TR 8-1	14	-24	-225
F - F'				
W-7032	---	84	NOT OBSERVED	64
W-16576	ROMP DV-1	112	92	32
W-16456	ROMP 49	146	68	-203
W-16740	ROMP 39	125	50	-251

Table 3. Upper boundaries of lithostratigraphic units delineated in cross sections for this report; datum is NGVD, units are in feet. All estimated contacts are indicated by brackets.

WELL ID	SITE NAME	AVON PARK FORMATION	OCALA LIMESTONE	SUWANNEE LIMESTONE	HAWTHORN GROUP (UNDIFF.)	ARCADIA FORMATION	TAMPA MEMBER	PEACE RIVER FORMATION	UDSC/UDSS THICKNESS
A - A'									
W-12943	---	-443	-323	-53	---	-13	-13	---	30
GAMMA	EASTLAKE	[-452]	[-318]	[-6]	---	[5]	[5]	---	[34]
W-7795	---	-433	-293	12	---	28	[28]	---	9
GAMMA	DUNDEE	[-442]	[-264]	[16]	---	[31]	[31]	---	[28]
W-3428	---	---	-212	23	---	31	31	---	37
GAMMA	PEBBLE CREEK	[-329]	[-179]	[33]	---	[41]	[41]	---	[4]
W-7032	---	-226	-76	54	---	64	64	---	20
B - B'									
W-15204	TR 14-2	---	-455	-99	32	-12	-12	---	67
W-15494	TR 12-3	---	-432.5	-157.5	[-6.5]	-16.5	-16.5	---	43.5
W-16574	WRAP 2D	-470	-342	[-159.5]	-2	-27	-27	---	55
W-14668	TR 11-2	-473	-318	-100	8	-7	-7	---	22
W-16576	DV-1	-415	-232	-41	---	22	22	91	21
C - C'									
W-50015	PI-32	-758	-570	-338	---	-78	-189	---	85
W-15642	TR 9-3	-757	-517	-277	---	[-22]	-147	-12	20
W-16618	TR 9-2	-684	-444	-243	---	-40	-106	-23	36
W-16456	ROMP 49	-679	-429	-233	---	30	-93	68	78
W-14386	ROMP 48	-683	-453	-198	---	[62]	-53	[98.5]	3.5
D - D'									
W-12943	---	-443	-323	-53	---	-13	-13	---	30
W-15204	TR 14-2	---	-455	-99	32	-12	-12	---	---
W-16197	13-2X	---	-546	-201	-22	-106	-106	---	---
W-50015	PI-32	-758	-570	-338	---	-78	-189	---	85
E - E'									
GAMMA	DUNDEE	[-442]	[-264]	[16]	---	[31]	[31]	---	[28]
W-16574	WRAP 2D	-470	-342	[-159.5]	-2	-27	-27	---	55
W-7672	---	-520	-240	-105	---	-20	-20	---	40
W-15826	TR 8-1	-940	-627	-365	---	-20	-250	---	35
F - F'									
W-7032	---	-226	-76	54	---	64	64	---	20
W-16576	DV-1	-415	-232	-41	---	22	22	91	21
W-16456	ROMP 49	-679	-429	-233	---	30	-93	68	78
W-16740	ROMP 39	-840	-592	-388		-58	-264.5	[67.5]	[57.5]

occasional macrofossil molds. This formation contains characteristic fossils such as the foraminifera *Lepidocyclina* spp., Nummulites (Operculinoides) and echinoids such as *Eupatagus antillarum*. Other fossils observed in the unit include pelecypods, bryozoans, gastropods and rare *Rotulina (Spirolina) vernoni*.

The Ocala Limestone is typically bound by unconformities. Depths to the top of the formation range from approximately -76 to -627 feet NGVD (Plates 1 through 6). Analysis of well cuttings and cores selected for this study indicates that the Ocala Limestone, which averages 195 feet thick, ranges in thickness from 120 feet in the northern part of the study area (Plate 1) to 313 feet in the southern part (Plate 5). The dip of the Ocala Limestone in this area is approximately 0.1 to 0.2 degrees towards the southwest.

Relative to the overlying Suwannee Limestone and the underlying Avon Park Formation, the gamma-ray signature for the Ocala Limestone is muted, with consistently low background rates and a characteristic lack of peaks. In cases where the Ocala is dolomitized, the gamma-ray logs may exhibit a slightly higher and more sporadic baseline.

Lower Oligocene Series

Suwannee Limestone

The lithology of the Lower Oligocene Suwannee Limestone (Cooke and Mansfield, 1936) ranges from a light-gray to yellowish-gray packestone to grainstone. These carbonates are variably moldic with trace amounts of sand and clay within the upper portions. Trace amounts of chert and organics occur throughout the unit. A dolostone or dolomitic limestone layer, approximately 10 to 20 feet thick, commonly occurs within the lower one-third of the unit in the study area. Fossils in the unit include gastropods, pelecypods, echinoids (e.g., *Rhyncholampus gouldii*), abundant miliolids and other benthic foraminifers including *Coskolina floridana* and *Dictyoconus cookei*.

This formation unconformably overlies the Ocala Limestone and is unconformably overlain by Hawthorn Group sediments. It should be noted that, in some cases, the upper Suwannee lithologies appear to grade upward into the Hawthorn Group. Where the two lithologies are intercalated, the uppermost occurrence of the older formation is selected as the formational "boundary." The top of the Suwannee Limestone occurs between +54 and -388 feet NGVD. The unit thickens to the south and west, ranging from 130 to 356 feet and averaging approximately 219 feet (Plates 1 through 6). The dip of the Suwannee Limestone is approximately 0.1 degrees toward the southwest.

The Suwannee Limestone is characterized by a gamma-ray signature which has an overall higher background rate than the underlying Ocala Limestone. In addition, there exists much more variability in its signature from bed to bed relative to the Ocala Limestone. This variability in the gamma-ray signature is probably due to variable dolomite and organic content from bed to bed within the formation. The lower portion of the Suwannee is generally more variable than the upper portions of the unit with respect to its gamma-ray response. Although the gamma-ray log is generally useful for providing corroborative evidence for the lithostratigraphic boundary between the Eocene - Oligocene carbonates, the utility of the logs for determination of the upper boundary of the Suwannee Limestone is not always as stratightforward. For example, where the Tampa Member of the Arcadia Formation is in contact with the Suwannee Limestone, gamma-ray signatures for the two units are quite similar, both in their background count rates and distribution of peaks.

Another consistent observation in the gamma-ray logs is the presence of a 50- to 100-foot thick interval of high gamma-ray activity within the central to lower portions of the Suwannee Limestone. The gamma-ray log for the Pebble Creek borehole (Plate 1) and W-16574 (Plate 2) are exceptions, where the interval is in the upper part of the unit. This interval varies in thickness and depth and apparently does not correlate with a given stratigraphic horizon. This suggests that the high-gamma activity interval may be post-depositional in origin.

Lower Oligocene to Pliocene Series

Hawthorn Group

Hawthorn Group sediments (Scott, 1988) are Lower Oligocene (Wingard and others, 1993, 1994, 1995) Lower Pliocene (Covington, 1993; Missimer and others, 1994) in age and generally consist of phosphatic siliciclastics (sands, silts and clays) and carbonates. These sediments in Pinellas, Hillsborough, and Manatee Counties lie unconformably above the Suwannee Limestone. In the study area, the Hawthorn Group consists of the Arcadia Formation, the Peace River Formation and undifferentiated Hawthorn Group. Also observed in the region is the Tampa Member of the Arcadia Formation. Overall, the top of the Hawthorn Group occurs from +100 to -106 feet NGVD, and ranges in thickness from less than 10 feet to approximately 345 feet (Plates 1 through 6). Unconsolidated post-Pliocene sediments lie unconformably above the Hawthorn Group throughout the study area.

Arcadia Formation

The Lower Oligocene to Middle Miocene (Wingard and others, 1995) Arcadia Formation (undifferentiated) is a yellowish-gray to light-olive gray, clayey carbonate with highly variable amounts of quartz sand and sand-size to gravel-size phosphate. Highly dolomitic layers occur throughout the formation and many of the finer-grained carbonate beds are dolomitic. Some of the descriptions on which the stratigraphic columns are based did not always note the presence of dolomite/dolostone. Upon re-inspection of samples during this study, however, it was noted that many of the "clay" units are comprised of fine-grained dolomite with a subordinate clay matrix. Scott (1988) reports that most of the carbonate in this formation is dolomite.

The Upper Oligocene (Wingard and others, 1993) to Lower Miocene Tampa Member of the Arcadia Formation is white to yellowish gray in color, and ranges from a wackestone to packestone with varying micrite, quartz sand and clay (Scott, 1988). Minor phosphate, dolomite and chert are also observed. Porosity of this unit is generally intergranular and moldic.

The top of the Arcadia Formation ranges from +65 to -105 feet NGVD, and ranges in thickness from less than 10 to 345 feet. In the southern part of the study area, (Plate 3) where the Tampa Member is not equal to the entire thickness of the Arcadia Formation, the Tampa Member top occurs at -50 to -190 feet NGVD and averages 140 feet thick. In other locations, the top of the Tampa Member is equivalent to the top of the Arcadia Formation.

Peace River Formation

The Middle Miocene to Lower Pliocene (Covington, 1993; Missimer and others, 1994) Peace River Formation is comprised of yellowish gray to olive gray, interbedded sands, clays and carbonates with the siliciclastic component being dominant (Scott, 1988). Variable amounts of phosphate sand and gravel, as well as occasional carbonate beds, are interspersed throughout the unit. This formation is limited to the central and southern portions of the study area.

The top of the Peace River Formation varies between +98 to -12 feet NGVD, and the unit attains thicknesses of up to 70 feet along the eastern margin of Hillsborough County (Plate 2). The cross sections illustrate cases where the described lithologic package is clearly part of the Hawthorn Group, but further subdivision of the unit is limited by sample quality and lack of stratigraphic control. In these cases, only the Hawthorn Group (undifferentiated) is delineated (Plates

2 and 4).

Gamma-ray signatures in the Hawthorn Group are highly variable. In the study area, the overall signature in the Arcadia Formation and the Peace River Formation is similar, with both having well-defined peaks and higher backgrounds than the underlying Tampa Member. This similarity is atypical because the gamma-ray signature of the Peace River Formation in other areas is usually more subdued than that of the Arcadia Formation (undifferentiated).

In the study area, the Arcadia Formation generally contains an interval of numerous peaks whereas the Peace River is limited to three peaks or less, which in some cases are at least two times greater than the maximum Arcadia peaks. Very high magnitude gamma-ray peaks in the Peace River Formation occur in the easternmost wells (Plates 2 and 3), which may be indicative of the Bone Valley Member of the Peace River Formation (i.e., responding to abundant phosphorite). Due to limited samples and variable sample quality, the Bone Valley Member is not delineated on the cross sections. Scott (1988) shows the western subcrop limit of the Bone Valley Member to occur in the area.

As a general rule, the gamma-ray signature for the Tampa Member of the Arcadia Formation is relatively subdued in comparison to the undifferentiated Arcadia Formation. In some cases, the gamma-ray response of the Tampa Member is variable, with sets of moderate-intensity peaks. Relative to the Suwannee Limestone, the Tampa Member gamma-ray log occasionally has higher background levels.

Post-Hawthorn Group

Undifferentiated Sands and Clays

Post-Hawthorn Group sediments occur throughout the study area and range in thickness from approximately 5 to 85 feet (Plates 1 through 6). These sediments are primarily comprised of varying proportions of sand, shell and clay. Lithostratigraphic units in this sequence can include the Ft. Thompson and Caloosahatchee Formations. Variable amounts of organic and re-worked phosphate may occur in these sediments as well.

Gamma-ray activity is variable in these sediments; however, moderate basal peaks are observed in some logs, possibly reflecting deposits of re-worked phosphorite. In the cross sections, straight line (zero baseline) gamma-ray signals at the top of some of the logs indicate a lack of data collected over the interval shown.

Uranium-Reconnaissance Analyses

Reconnaissance U-series isotopic analyses of four core samples from the Suwannee Limestone in a core from Hillsborough County (W-16618) were performed to further evaluate the above observations. The results of these analyses are presented in Table 4.

Two methods were utilized to analyze these four samples: 1) acid-dissolution of the carbonate fraction of each sample, and 2) leaching of splits from each of the samples with a 0.2 normal solution of potassium carbonate. Green (1994) provides more detailed information on these methods.

The acid-dissolution method was utilized in order to obtain uranium concentration and $^{234}U/^{238}U$ activity ratio of the acid-soluble fraction of the samples, which allows comparison with expected values. The $^{234}U/^{238}U$ activity ratio of a sample is expected to be 1.0 (secular equilibrium) after approximately one million years of time have passed since the deposition of the uranium in the sediments (Osmond and Cowart, 1976). Given that the samples analyzed were all from the Suwannee Limestone, their $^{234}U/^{238}U$ activity ratios were expected to be in equilibrium. Several of the samples analyzed had activity ratios less than unity (Table 4), indicating that uranium has been mobilized in these sediments within the last one million years.

In general, the average U concentration

Table 4. Uranium geochemical data for selected samples from W-16618 (TR 9-2), Hillsborough Co., Florida.

SAMPLE DEPTH (FEET NGVD)	WT. PERCENT INSOLUBLE RESIDUE	URANIUM SPIKE YIELD (PERCENT)	URANIUM (234/238) ACTIVITY RATIO	ACTIVITY RATIO ERROR	URANIUM CONCENTRATION (ug/g)	URANIUM CONCENTRATION ERROR	LEACHABLE URANIUM (PERCENT)
	SAMPLES DISSOLVED IN MIXTURE OF 8 NORMAL NITRIC AND HYDROCHLORIC ACIDS						
-368.0	1.40	49.2	1.00	0.01	8.86	0.16	N/A
-382.5	2.10	52.7	0.98	0.01	6.94	0.10	N/A
-392.0	12.1	22.0	0.89	0.01	29.7	0.70	N/A
-425.0	8.40	36.5	0.96	0.02	2.93	0.06	N/A
	SAMPLES LEACHED 24 HOURS WITH 0.2 NORMAL SOLUTION OF POTASSIUM CARBONATE						
-368.0	N/A	53.4	0.53	0.03	0.71	0.03	8.0
-382.5	N/A	43.9	0.44	0.02	1.47	0.04	21.2
-392.0	N/A	1.0 *	0.59	0.03	9.60	0.52	32.3
-425.0	N/A	44.0	0.85	0.06	0.17	0.01	5.8

* NOTE: The low yield of spike for this sample makes the data for Uranium concentration questionable.

in limestone is approximately 1 part per million (ppm; Osmond and Cowart, 1976). Table 4 shows that the average uranium concentration in the four samples analyzed from the Suwannee Limestone is 12.1 ppm. This indicates that there has been significant enrichment in uranium in these samples relative to average limestones. The analytical methods used, however, cannot determine if the uranium was emplaced during the deposition of the limestone, or if the high uranium content is due to some sort of post-depositional enrichment process.

It is interesting to note that the sample with the highest uranium concentration also has a high organic content. Uranium is immobile under reducing conditions and mobile under oxidizing conditions. Therefore, if a uranium-rich water were to come into contact with an organic-zone within the sediments, the uranium could become reduced, leading to precipitation of a secondary coating of uranium on the aquifer matrix (Osmond and Cowart, 1976). Conversely, if an oxidized source of ground water were to come into contact with such a secondary coating of uranium in an aquifer, the uranium could potentially be re-mobilized into the ground water.

In order to test the mobility of the uranium, leaching experiments were performed on splits of each of the samples. Green (1994) demonstrated that a solution of 0.2 normal potassium carbonate could effectively leach uranium from carbonates without fractionating the uranium. Leaching experiments performed on these four samples indicated that the uranium associated with this zone is relatively mobile. The "percent leachable uranium" listed in Table 4 represents the amount of leachable uranium relative to the total uranium present in the sample. This value gives an approximation of uranium mobility in a given sample is under laboratory oxidizing conditions. The leaching data for the samples from 382.5 feet and 392 feet below land surface indicate that the uranium present can be highly mobile under oxidizing conditions. This observation should be considered in the design of groundwater storage and recovery programs, where relatively oxygen-rich waters are injected into the subsurface for later recovery. If a source of relatively mobile uranium is present in the aquifer, then the oxygenated water could potentially re-mobilize the uranium into the stored water.

For a more detailed discussion of leaching of uranium-rich carbonates and the significance of low $^{234}U/^{238}U$ activity ratios of the leached uranium, see Green (1994). Further investigation of this uranium-enriched zone in the Suwannee Limestone is the subject of planned research.

HYDROSTRATIGRAPHY

The hydrostratigraphy of the study area consists of a variably complex, two- and three-layer aquifer system. The three aquifers present in descending order are the surficial aquifer system (SAS), the intermediate aquifer system/intermediate confining unit (IAS/ICU), and the Floridan aquifer system (FAS; Southeastern Geological Society, 1986). The relationship between geologic formations and hydrostratigraphic units in the study area is shown in Plates 1 through 6. Correlation between aquifer systems and geologic formations generally coincides with lithostratigraphic boundaries established on the cross sections.

The SAS is composed of unconsolidated clastic (and locally, carbonate) deposits that are generally referred to as post-Hawthorn Group undifferentiated sand and clays. As noted above, these sediments may include all or parts of the Pleistocene Fort Thompson and Caloosahatchee Formations, as well as Pleistocene-Holocene marine terrace deposits. Clays present in the base of the SAS most likely represent reworked Hawthorn Group sediments.

The IAS/ICU is composed of interbedded clays and carbonates of the Peace River Formation, and some carbonates of the undifferentiated Arcadia Formation and the Tampa Member. The IAS/ICU in the study area is generally restricted to the Hawthorn Group sediments, although post-Hawthorn confining (clay) beds may locally occur above the carbonates of the IAS/ICU.

The FAS, the principle artesian aquifer in the region, is primarily a carbonate aquifer which includes all or part of the Tampa Member (Arcadia Formation), and all of the Suwannee Limestone, Ocala Limestone, and Avon Park Formation.

Hydrostratigraphy in the study area varies from a simple two-aquifer system in the northern portion of the study area (Plate 1), where the FAS is directly overlain by sediments of the SAS, to a more complex system in the southern portion of the study area, where two confined aquifers are present below the SAS. The FAS in the northern portion of the map area exists as a poorly confined or semi-confined artesian aquifer, where siliciclastic sediments of the upper Hawthorn Group become thin and discontinuous. The SAS is also intersected by numerous karst features (Trommer, 1987) in which sinkholes may act as direct conduits between the SAS and the FAS. Increased hydrogeologic importance of the IAS/ICU occurs where the Hawthorn Group sediments thicken from north to south, overlying regional southwest-dipping carbonate rock sequences of the FAS (Plates 4 through 6). Permeable carbonates interbedded with lower permeability clastics within the Hawthorn Group facilitate artesian conditions within the IAS/ICU. Collectively, the IAS/ICU forms a thick confining unit separating the FAS from the SAS in the southern region of the study area.

Surficial Aquifer System

The surficial aquifer system (SAS) occurs throughout the study area and is composed primarily of unconsolidated quartz sand with variable amounts of shell, clay, phosphate, and organic material. Thickness of the SAS ranges from ten feet in the northern region of the study area to 80 feet in areas of southern Pinellas and Hillsborough Counties. Delineation of the SAS in the cross sections is based on water level measurements collected during drilling, and on interpretation of lithology from well cuttings and/or core samples.

The SAS is normally identified by the presence of a phreatic water level that is distinct from potentiometric water levels occurring in deeper confined aquifer systems. A surficial or "water table" aquifer may occur where there are sufficient confining materials such as clay at the base of the unconsolidated sediments, or if hardpan intervals within the surficial sand provides a permeability barrier, resulting in a "perched" water table.

Hydrostratigraphic correlation of the SAS with geologic units in the study area places the system in the post-Hawthorn undifferentiated sands and clays (UDSC). The base of the aquifer generally coincides with the first occurrence of clay at the top of the Peace River Formation (Hawthorn Group). Where the Peace River Formation is absent in the northern portion of the study area (Plate 1), the SAS directly overlies the FAS. Sandy clays typically form the base of the SAS, providing some hydraulic separation between the SAS and the FAS, but the stratigraphic columns shown in Plate 1 do not detail the presence of clay. This is probably due to either poor-quality well samples or no samples being collected from the unconsolidated surficial sediments.

Discrete monitor wells constructed in both the SAS and the FAS at the western wellsite (W-12943), cross section A-A' of Plate 1, indicate head differences between the two aquifer systems (Coffin and Fletcher, 1992, p. 177-178). Other complimentary pairs of monitor wells in the area of cross section A-A' support the presence of a surficial aquifer system "water table" that is distinguishable from FAS potentiometric levels, suggesting some degree of confinement exists between the two aquifer systems. The thickness and continuity of this intermediate confining unit is highly variable across the northern region of the study area (Sinclair, 1981; Ryder and others, 1980). A thin sequence of clay coupled with existing karst features increases the hydraulic connection and recharge potential between the SAS and the underlying artesian aquifers. The SAS in central and southern regions of the study area is relatively isolated from the FAS by intervening siliciclastics and low-permeability carbonates that comprise the IAS/ICU. Localized areas of karst terrain will increase the potential for recharge from the SAS to both the IAS and FAS.

Intermediate Aquifer System/Intermediate Confining Unit

The intermediate aquifer system (IAS) and intermediate confining unit (ICU) occur across most of the study area, except in the vicinity of cross section A-A' (Figure 1). Hydrogeologic properties of the IAS/ICU are highly variable, due to lithologic variations and complex interbedding typical of the Hawthorn Group sediments. The IAS/ICU is primarily contained within the Hawthorn Group, although some post-Hawthorn siliciclastics may also occur in the uppermost portions of the ICU. Parts of the Tampa Member may not be included in the IAS/ICU if vertical hydraulic connection exists between the Tampa Member and the Suwannee Limestone of the Floridan aquifer system.

The heterogeneous nature of the IAS/ICU makes hydrostratigraphic correlation between well sites difficult. Detailed site-specific hydrogeologic data exists for most sites where core drilling was conducted, but variables such as well-casing depth, length of uncased wellbore, and the composition of borehole fluids can affect the parameters being measured. Relative changes in water levels measured in the well during drilling can be correlated with core samples to identify permeable zones within the IAS/ICU, or the contact between the IAS/ICU and the underlying FAS. Interpolating these observations between data points on the cross-section maps is not practical due to limitations on vertical scale resolution, and the reliability of the drilling data. Therefore the IAS/ICU, as depicted on the hydrostratigraphic columns, is treated as a complete system of variably interbedded permeable sections and confining units within the Hawthorn Group.

The IAS/ICU in the study area is present as a confining unit in the central study area depicted in Plate 2, and also along the western coastal area, shown in the north-south cross section through Pinellas County (Plate 4). Sediments comprising the ICU in these two sections are composed primarily of low-permeability clays and carbonates of the Peace River and upper Arcadia Formations. In these cross sections, permeable limestone of the Tampa Member forms the uppermost section of the Floridan aquifer system.

Several factors influence the effectiveness of the ICU in restricting hydraulic connection between the SAS and the Floridan aquifer system. For example, the thickness and mineral composition of the ICU are important in the west and central portions of the study area. An increased sand component within the clays generally limits the effectiveness of those beds as confining units. Fracturing can also have a substantial effect on the effectiveness of the ICU. Although fractures have been observed in core samples within this hydrostratigraphic unit, their cumulative affect on the confining nature of the ICU is difficult to quantify without field studies. The occurrence of karst features may also provide a more direct path for localized downward movement of ground water through the ICU in this region.

Permeable carbonate beds in the Peace River Formation, and all or portions of the Tampa Member make up the IAS in the southern region of the study area (Plate 3). Less permeable limestones in the lower Tampa Member separate the IAS from the underlying FAS. The base of the IAS/ICU generally coincides with the stratigraphic top of the Suwannee Limestone in this area, but permeable beds in the lowermost Tampa Member are included in the FAS where hydraulic connection exists.

Floridan Aquifer System

The Floridan aquifer system (FAS), which is present throughout the study area, is composed of heterogenous Lower Eocene to Lower Miocene carbonate rocks. In the study area, the FAS is typically considered an artesian aquifer having a distinct potentiometric water level based on wells open to the system. The top of the FAS is generally placed at the first occurrence of vertically persistent carbonates below siliciclastic materials of the SAS and IAS/ICU. The base of the FAS is identified by the presence of vertically and laterally persistent evaporite (e.g., gypsum and anhydrite) beds of regional extent (Southeastern Geological Society, 1986). These evaporites comprise the sub-Floridan confining unit, which underlies the FAS throughout the region.

The top of the FAS occurs near land surface in the northern part of the study area, and dips to over 200 feet below land surface in the southern portion. The base of the FAS occurs in the lower Avon Park Formation where bedded or interstitial evaporites retard vertical movement of water. The stratigraphic column for W-12943 (Plates 1 and 4) extends to the base of the FAS at depth of about 980 feet below NGVD. Average thickness of the FAS is approximately 1100 feet in the study area (Wolansky and Garbode, 1981).

A large degree of vertical anisotropy exists in the Floridan aquifer system (Ryder and others, 1980; Ryder, 1981) due to variations in grain size and other lithologic controls such as fossil content, diagenesis, and cementation. Vertical variations in porosity and permeability cannot be resolved at the level of detail and scale depicted on the cross-section plates. Variations in hydraulic properties are present where changes in lithologic properties occur within formations or at formation contacts. Data presented by Arthur and others (1995) indicate that lower permeability lithologies in the FAS have vertical hydraulic conductivity values on the order of 10^{-4} feet/day, whereas the more permeable rocks have vertical hydraulic conductivity values on the order of 10^{-1} feet/day.

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