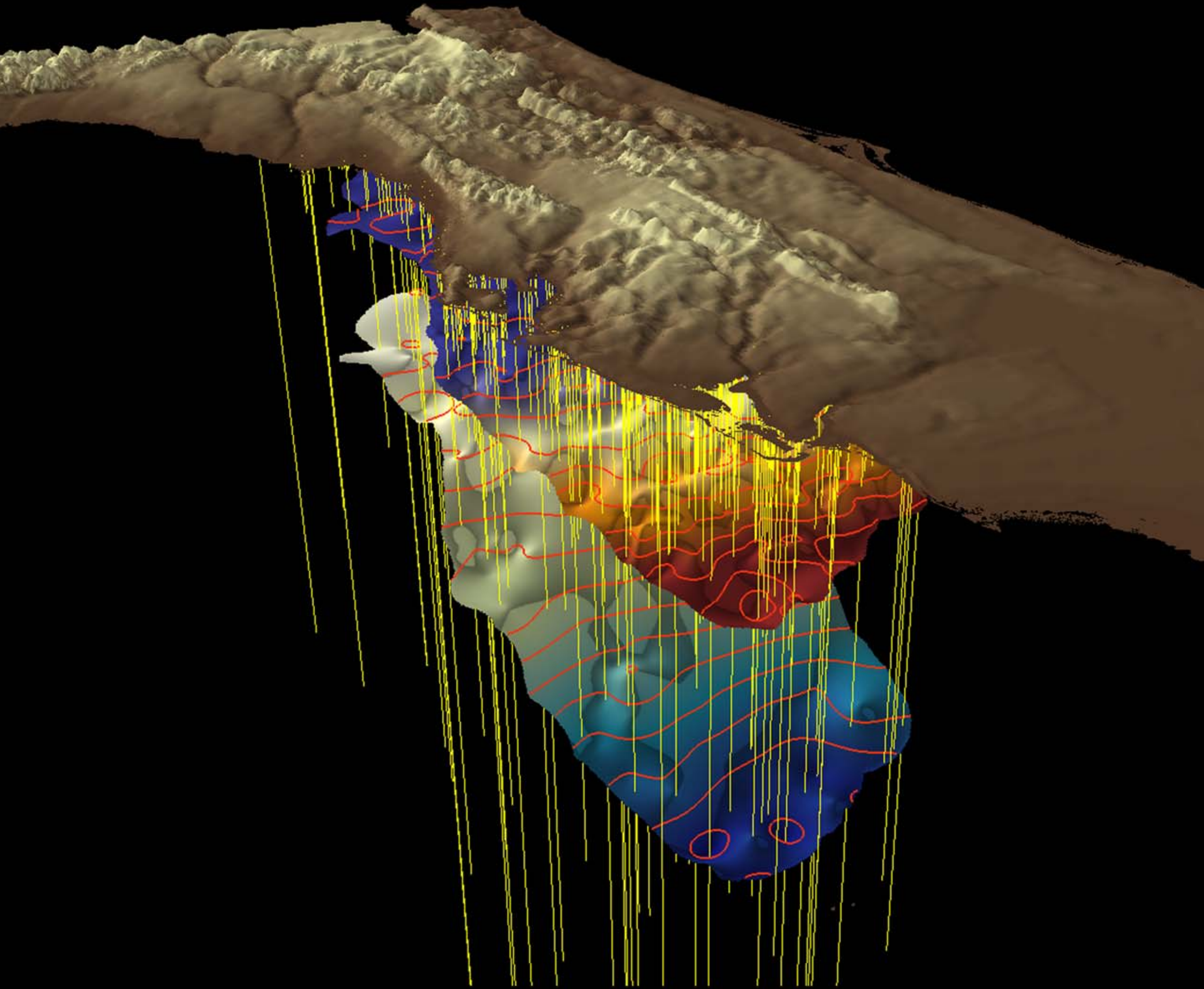
HYDROGEOLOGIC FRAMEWORK OF THE SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT



FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION

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Prepared in cooperation with the Southwest Florida Water Management District

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In memory of the spirited life and geoscience contributions of Rick Lee (1956 - 2007)

PREFACE

The Florida Geological Survey/Florida Department of Environmental Protection is publishing as its Bulletin 68, the *Hydrogeologic Framework of the Southwest Florida Water Management District*. The report summarizes a multi-year study of the three-dimensional framework of southwestern Florida's hydrogeology, with a focus on the subsurface distribution of aquifer systems and geologic units comprising these systems. As groundwater resources in Florida experience increased stress due to rapid population growth, an understanding of the aquifer systems is invaluable to environmental managers, scientists, planners and the public as decisions are made regarding use, protection and conservation of these vulnerable resources. The FDEP-FGS is pleased to have had the opportunity to partner with the Southwest Florida Water Management District to complete this report.

Walter Schmidt

State Geologist and Director
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ABBREVIATIONS, ACRONYMS AND CONVERSIONS

ASE	average standard error
BLS	below land surface
CFHUD II	Second Ad Hoc Committee on Florida Hydrostratigraphic Unit Definitions
CTD	closed topographic depression
DEM	digital elevation model
District	Southwest Florida Water Management District
FAS	Floridan aquifer system
FDCA	Florida Department of Community Affairs
FDEP	Florida Department of Environmental Protection
FGS	Florida Geological Survey
IAS/ICU	intermediate aquifer system/intermediate confining unit
IDW	inverse distance weighted
IP/FMNH	Invertebrate Paleontology, Florida Museum of Natural History
Kh	horizontal hydraulic conductivity
Kv	vertical hydraulic conductivity
L	leakance
LFA	Lower Floridan aquifer
LIDAR	light detection and ranging
MFCU	Middle Floridan confining unit
MSL	mean sea level
RMS	root mean squared
ROMP	Regional Observation and Monitor Well Program
S	storativity
SAS	surficial aquifer system
SWFWMD	Southwest Florida Water Management District
SY	specific yield
T	transmissivity
UFA	Upper Floridan aquifer
USGS	United States Geological Survey
~	approximately
γ	gamma

Multiply	By	To obtain
cubic foot (ft^3)	0.0283	cubic meter (m^3)
foot (ft)	0.305	meter (m)
foot per day (ft/d)	3.53×10^{-4}	centimeter/second (cm/s)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
gallon (gal)	3.79×10^{-3}	cubic meter (m^3)
gallon (gal)	3.79	liter (L)
gallon per minute (gal/min)	6.32×10^{-5}	cubic meter per second (m^3/s)
inch (in)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer (km)

ACKNOWLEDGEMENTS

This research was a cooperative effort between the Florida Department of Environmental Protection (FDEP) - Florida Geological Survey (FGS) and the Southwest Florida Water Management District (SWFWMD). Special thanks are extended to David L. Moore, SWFWMD Executive Director and Dr. Walter Schmidt, FDEP-FGS Director and State Geologist for administrative and financial support. Essential geology and hydrogeology data-collection programs in the SWFWMD, FDEP-FGS and the U.S. Geological Survey (USGS) have made the development of this comprehensive report possible. Numerous individuals and countless hours of well drilling and logging, aquifer and laboratory testing, database development and management, lithologic descriptions, formation boundary determinations, surface modeling, and map/cross section production have contributed to the development of this report.

The authors express their appreciation to the numerous individuals for their insightful review of the manuscript and plates. From the FDEP-FGS, these individuals include Carol Armstrong, Ken Campbell, Jackie Lloyd, Frank Rupert, Dr. Walter Schmidt, Dr. Tom Scott; from SWFWMD, Ron Basso, Michael Beach, Marty Clausen, Michael Gates, Tony Gilboy, Jason LaRoche, John Parker, Robert Peterson and Donald Thompson. Ken Campbell and Dr. Tom Scott are thanked for their contributions and discussions regarding the lithostratigraphy and hydrostratigraphy of the study area. Discussions with John J. Hickey, Rick Spechler, Dr. Tom Scott and Dr. Sam Upchurch helped refine our understanding of the hydrostratigraphy of the region. Doug Rapphun also contributed to our knowledge of the hydrogeology in the region.

The authors also gratefully acknowledge those staff of the FDEP-FGS who participated in this project. Lance Johnson and Paula Polson provided assistance with cross-section development. Surface interpolations during early phases of the project were completed by Bill Pollock, Amy Graves, John Marquez and Andrew Rudin. Developers of the database for this project included Mark Groszos, Marco Cristofari and Rob Stoner. Data management support included the assistance of Jackie Bone, Patricia Casey, Lance Johnson, Natalie Sudman, and Holly Tulpin. Lithologic descriptions of numerous borehole samples were completed by Alan Baker, Jim Cichon, Erin Dorn, Kris Esterson, Mabry Gaboardi, Diedre Lloyd, Matt Mayo, Sarah Ramdeen and Holly Williams. Many of the photos and photomicrographs of fossils presented in this report are provided courtesy of Roger Portell and Sean Roberts (Invertebrate Paleontology, Florida Museum of Natural History), Dr. Jonathan Bryan (Okaloosa-Walton Community College) and Frank Rupert. Dr. Rick Copeland was helpful with regard to discussions of quality assurance of hydrogeologic data and presentation of descriptive statistics.

HYDROGEOLOGIC FRAMEWORK OF THE SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT

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INTRODUCTION

Background

Groundwater comprises approximately 85 percent of the total water-resource supply in the Southwest Florida Water Management District (SWFWMD), where existing water demands are on the order of 435 billion gallons per year (Southwest Florida Water Management District, 2006a). By 2025, the population of the region is expected to increase more than 30 percent, placing further demands on water resources. Development of alternative water supplies and continued water-resource management and conservation are critically important toward the sustainability of groundwater resources within the aquifer systems of southwest Florida. These practices, however, require the accumulation, management and interpretation of hydrogeological data.

In the mid-1990's, the SWFWMD and the Florida Department of Environmental Protection - Florida Geological Survey (FDEP-FGS) entered into a cooperative project to develop a series of geologic and hydrogeologic cross sections throughout the 16-county SWFWMD region. The project was designed to characterize the relation and extent of lithostratigraphic[1] and hydrostratigraphic[2] units within the region with an emphasis on use of hydrogeologic data collected by the District's Regional Observation and Monitor-well Program (ROMP). This project was later expanded to include production of surface and thickness maps of the units represented in the cross sections.

To accomplish the goal of the regional cross section project, the District was divided into four study areas (three project phases): Phase IA includes Pinellas and Hillsborough Counties; Phase IB includes Manatee, Sarasota, Hardee, DeSoto and Charlotte Counties; Phase II includes the northern part of the District, from Levy, Marion and Lake to Pasco Counties; and Phase III includes the southeastern part of the District, encompassing all areas not covered in Phases IA, IB and II. Interim reports were published for Phase IA and II (Green et al., 1995 and Arthur et al., 2001a, respectively). Rather than separately publishing reports for the remaining phases, the cross sections are incorporated in this report.

Purpose and Scope

The purpose of this study is to refine the hydrogeological framework of the region to facilitate science-based decision making with regard to the protection, conservation and management of southwest Florida's water

[1] Lithostratigraphic units are laterally extensive sequences of rocks and sediments reflecting unique lithologic characteristics; each unit was deposited within a generally similar paleo-environment during a given period of time in Earth's history.

[2] Hydrostratigraphic units include laterally extensive sequences of rocks and sediments that are related by hydrogeologic characteristics. Hydrostratigraphic units may or may not correlate with lithostratigraphic units.

resources. Thirty-four cross sections have been produced for this study (Plate 1). Each of the cross sections illustrates regional lithostratigraphy of Eocene through Pliocene formations, lithology, mineralogy, gamma-ray logs, topographic profiles and hydrostratigraphic delineations. Although most of the data used to construct the cross sections was taken from wells drilled as part of ROMP (Gomberg, 1975), borehole data (e.g., from cores, cuttings and geophysical logs) from the FDEP-FGS and the U.S. Geological Survey (USGS) were utilized to fill in as many gaps as possible.

The mapping phase of the study facilitated development of a new geologic and hydrogeologic database, *FGS_Wells.* Structure contour (surface elevations) and isopach (thickness) maps for all regionally extensive lithostratigraphic and hydrostratigraphic units within the District were then developed. The maps include all units between land surface and the top of the Middle Floridan confining unit (Table 1).

Data from more than 1050 wells (including offshore boreholes) serve as control for these maps (Plate 2). In addition, synthetic wells were used to provide lateral (edge) control during map surface interpolation. These wells represent an artificial stratigraphic record for a given location based on interpolated elevations from existing maps or cross sections. The new surface and thickness maps presented herein were developed using the ESRI© geographic information system (GIS) program ArcMAP (see *Map Development and Data Management,* p. 24) for details on map production. Each map includes the lateral extent of each unit and locations of wells within the study area that were used to interpolate surfaces and thicknesses.

Study Area

Maps and cross sections produced for this study cover the entire SWFWMD region (Figure 1). To facilitate present and future hydrologic modeling and comparison of these maps to adjacent Water Management Districts, a 10 mi (16.1 km) wide buffer extending beyond the District boundary was included in the study area (Figure 1, Plate 2). Surface interpolation techniques, such as kriging, can produce non-representative contours along the margins of mapped units. To address these undesirable "edge effects," data from within a second 10 mi (16.1 km) wide buffer zone was utilized. The additional data helped stabilize surface interpolations and contours, and allowed for a more accurate delineation of the vertical and lateral extents of certain mapped units. The project study area, which covers approximately 14,340 mi2 (37,141 km2), does not include wells within the second (outermost) buffer.

Previous Investigations

Numerous researchers have focused on the regional geology and hydrogeology of southwest Florida. Sub-Floridan aquifer system geology, with an emphasis on pre-Cenozoic basement geology, is presented in several papers including Applin (1951), Applin and Applin (1965), Bass (1969), Barnett (1975), Smith (1982) and Chowns and Williams (1983). Arthur (1988) and Heatherington and Mueller (1997) focus on geochemistry of basement terrains, while Smith and Lord (1997) summarize the tectonic and geophysical aspects of the Florida basement. Gohn (1988) and Randazzo (1997) provide comprehensive overviews of Mesozoic and Cenozoic geology of the Atlantic Coastal Plain, including peninsular Florida. Mesozoic and Cenozoic paleoceanographic and structural evolution along the margin of the Florida peninsula is presented in Hine (1997).

Selected early studies of Cenozoic and younger formations include Applin and Applin (1944), Cooke (1945), Puri and Vernon, (1964) and Chen (1965). More recent stratigraphic research on units in south and southwest Florida has been completed by Miller (1986), Scott (1988), McCarten et al. (1995), Brewster-Wingard et al. (1997) and Cunningham et al. (1998). Missimer (2002) focused on Oligocene through Pliocene stratigraphic relationships in the southernmost part of the present study area (Charlotte County), as well as Lee and western Collier Counties. Pliocene and younger stratigraphy has been the focus of several studies

Table 1. Units mapped in this study. Map types are structure contour (SC) and isopach (I).

Lithostratigraphic Units	Map types	Hydrostratigraphic Units	Map types
Hawthorn Group	SC, I	surficial aquifer system	I
Peace River Formation	SC, I	intermediate aquifer system / intermediate confining unit	SC, I
Bone Valley Member	SC, I	Floridan aquifer system overburden	I
Arcadia Formation	SC, I	Floridan aquifer system	SC
Tampa Member	SC, I	Upper-Floridan aquifer system	I
Nocatee Member	SC, I	Middle Floridan confining unit	SC
Suwannee Limestone	SC, I		
Ocala Limestone	SC, I		
Avon Park Formation	SC		

(e.g.,Evans and Hine, 1991; Scott, 1997; Missimer, 2001).

Hydrogeologic framework studies that include the southwestern Florida region include Gilboy (1985), Johnston and Bush (1988), Miller (1986), Ryder (1985) and Reese and Richardson (2008). Maps depicting the thickness and extent of the Floridan aquifer system (FAS), the "intermediate aquifer" and intermediate "confining beds" include Buono and Rutledge (1978), Wolansky et al. (1979a), Wolansky et al. (1979b), Wolansky and Garbode (1981), Corral and Wolansky (1984) and Miller (1986). Allison et al. (1995) present a map of the top of rock of the FAS in the Suwannee River region, located along the northeast part of the SWFWMD study area. Meyer (1989) provides a comprehensive characterization of the hydrogeologic framework of southern Florida. Spechler and Kroening (2007) present a comprehensive study of Polk County hydrology. Reese (2000) and Missimer and Martin (2001) present the hydrogeology and water quality of the FAS in Lee, Hendry and Collier Counties.

Statewide hydrochemical characterizations of the upper FAS have focused on aquifer-system mineralogy and processes that led to observed native groundwater chemistry (e.g., Plummer, 1977; Sprinkle, 1989), and hydrochemical facies (Katz, 1992). Upchurch (1992) characterized not only hydrochemical facies, but also naturally occurring and anthropogenic constituents in the FAS. Other studies that focused on regional aspects of FAS hydrochemistry (i.e., salinity, solute transport and dolomitization) include Back and Hanshaw (1970), Cander (1994, 1995), Hanshaw and Back (1972), Jones et al. (1993), Maliva et al. (2002), Randazzo and Zachos (1984), Sacks (1996), Sacks and Tihansky (1996), Steinkampf (1982), Swancar and Hutchinson (1995), Trommer (1993), and Wicks and Herman (1994, 1996). Budd et al. (1993), Budd (2001, 2002) and Budd and Vacher (2004) have studied in detail the role of permeability, compaction and cementation in FAS carbonates of southwest Florida. An overview of surface-water and groundwater hydrology is provided by Wheeler et al. (1998). In contrast to these regional characterizations, Tihansky (2005) identified the complex relation between water quality, groundwater flow patterns and structural heterogeneity within the FAS in northeastern Pinellas County by employing diverse hydrogeological and geophysical analyses.

Hydrochemical studies of the intermediate aquifer system/intermediate confining unit

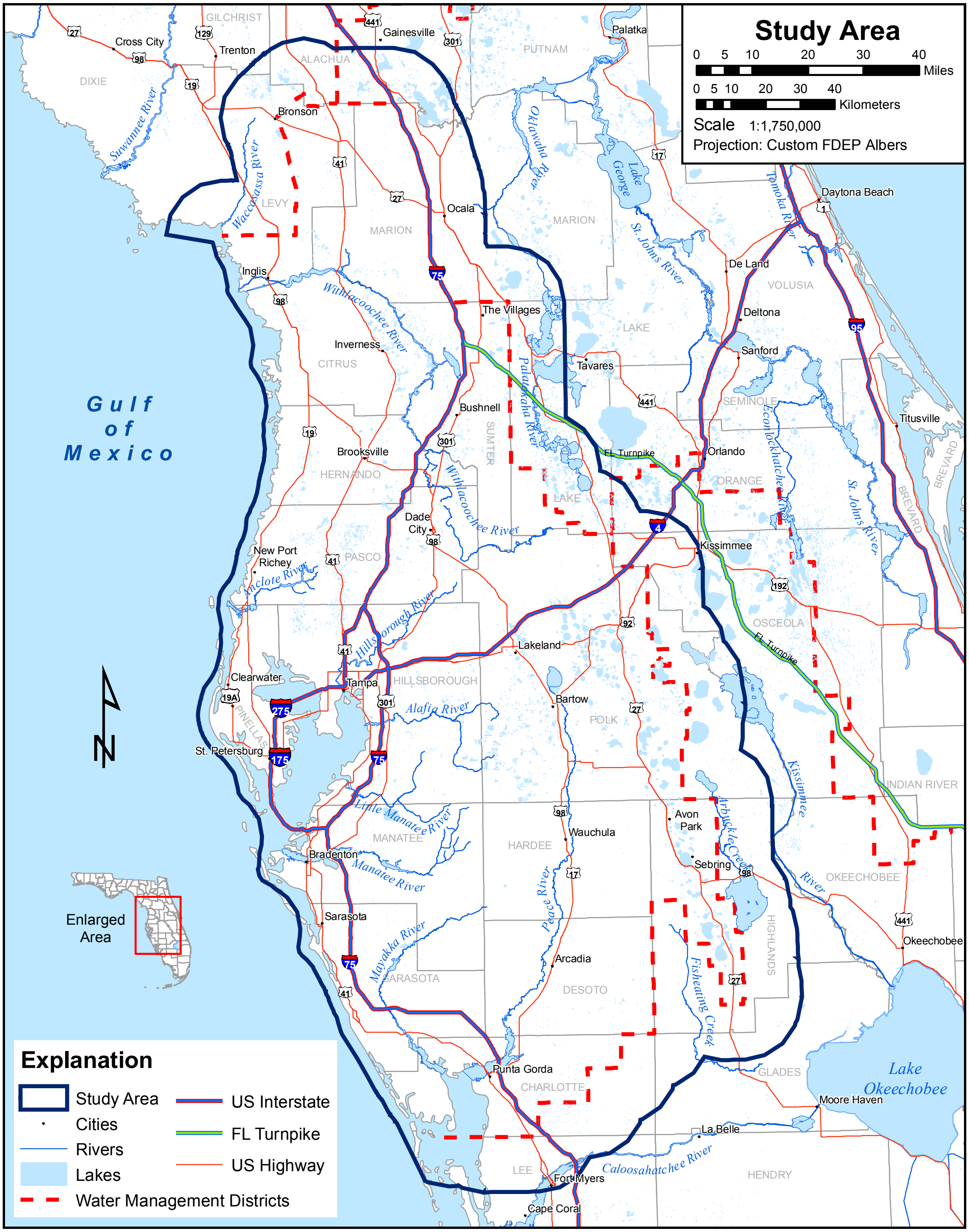

Figure 1. Study area.

include Joyner and Sutcliff (1976), Upchurch (1992), Kauffman and Herman (1993), Broska and Knochenmus (1996) and Torres et al. (2001). Knochenmus (2006) characterizes the water quality and hydraulic heterogeneity of the intermediate aquifer system in the southern part of the District. The study underscores that previously defined "permeable zones" of this aquifer system are hydraulically similar to "semi-confining units" in the upper Floridan Aquifer System. A statewide hydrochemical assessment of the surficial aquifer system was completed by Upchurch (1992).

Several groundwater flow models of the SWFWMD region have been published (e.g., Ryder, 1985; Barcelo and Basso, 1993; Yobbi, 1996), most of which are discussed in the comprehensive work of Sepulveda (2002), wherein he developed a groundwater flow model for peninsular Florida that includes the Intermediate and Floridan aquifer systems. Selected compilations of aquifer parameters on which many of these models are based are presented in *Hydrogeological Properties*, p. 52.

Physical Setting

Geology

Development of the Florida carbonate platform primarily occurred during the Late Cretaceous through middle Cenozoic and was generally free of intermixed sands and clays. Strong currents across northern Florida in a feature broadly referred to as the Georgia Channel System (Huddlestun, 1993) effectively precluded transport and deposition of these siliciclastics to the platform. During this period, deposition of the Cedar Keys Formation, Oldsmar Formation, Avon Park Formation, Ocala Limestone, and the Suwannee Limestone occurred. Huddleston (1993) proposed the Georgia Channel System recognizing spatially and temporally overlapping features (e.g., Suwannee Strait and Gulf Trough) proposed in the literature that described paleotopography (paleobathymetry) and associated paleocurrents. Randazzo (1997) provides an overview of this dynamic system and feature names.

During the Oligocene, the southern Appalachians experienced uplift and erosion (Scott, 1988). Southward transport and deposition of ensuing siliciclastic sediments began to fill the channel system, which allowed ocean currents to transport sediments southward across the well-developed carbonate platform. As a result, some of the first siliciclastic sediments in southern Florida carbonates appear as sand lenses in the Lower Oligocene Suwannee Limestone south of Charlotte County (Missimer, 2002). The influx of siliciclastic sediments, mixing with locally-formed carbonates led to Late Oligocene through the Early Pliocene deposition of the Hawthorn Group (Scott, 1988; Missimer et al., 1994) throughout most of Florida. In much of peninsular Florida phosphate deposition occurred yielding many economic phosphorite deposits. This period of phosphogenesis is described by Riggs (1979a, 1979b) and Compton et al. (1993); [see *Bone Valley Member*, p. 48, for more detail]. During the Late Pliocene to Recent, sediment deposition became even more siliciclastic dominant. Shell beds were deposited along coastal areas and migrated in response to sea-level fluctuations. The geology and depositional environment of lithostratigraphic units in the region are the subject of numerous studies in southwestern Florida; results of which are presented in the *Lithostratigraphy* section, p. 30, of this report. From deposition of the Cedar Keys Formation through Pliocene-Pleistocene shell beds, a dynamic transition from carbonate to siliciclastic-dominated depositional environments is reflected.

The surface distribution of lithostratigraphic units (Figure 2) in the study area is a function of post-depositional influences ranging from tectonic activity, platform stability, sea-level changes and karst processes. For example, the Avon Park Formation is the oldest exposed lithostratigraphic unit in the study area (Figure 2). This Eocene unit gently dips southward toward Charlotte County to depths exceeding 1500 ft (457.2 m) below land surface (BLS). In

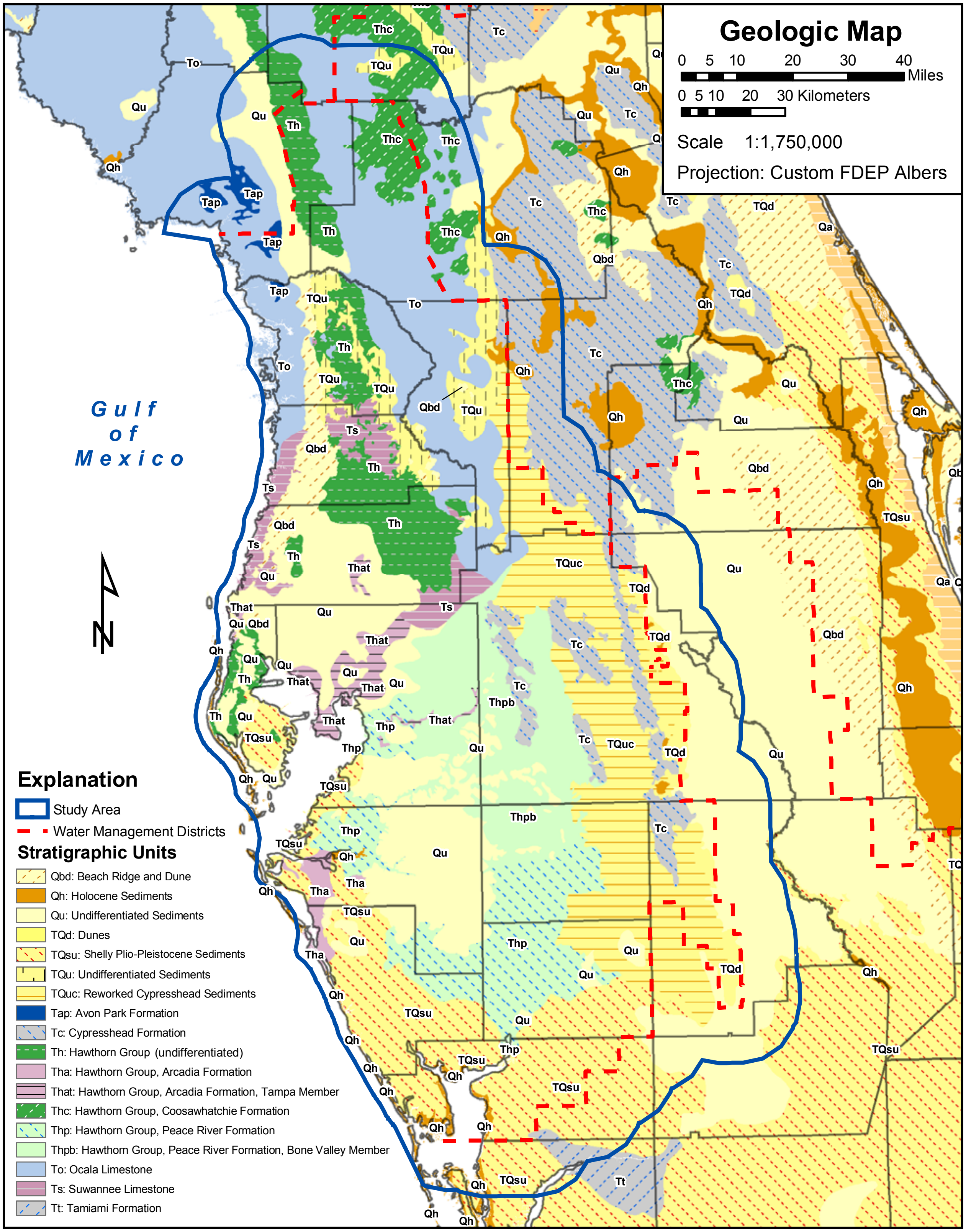

Figure 2. Geologic map of study area (from Scott et al., 2001) depicting the uppermost mappable units within 20 ft (6.1 m) of land surface.

general, the younger formations follow this pattern, however, many are not observed throughout the full extent of the study area (i.e., absence of the Peace River Formation [Hawthorn Group] in the northern third of the District). In the sections that follow, details of the features and processes affecting the overall geologic framework are discussed.

Structure

Numerous structural features affect the thickness and extent of geologic units in the study area (Figure 3). The oldest known "basement" feature in the region is the Bahamas Fracture Zone (Klitgord et al., 1983), which is also referred to as the Jay Fault (Pindell, 1985). This zone bisects the Florida peninsula basement from Tampa Bay southeast to the Lake Worth area on the east coast. Lithologic and geophysical data suggest that this basement feature represents an Early Mesozoic transform fault that was important to the development of the Gulf of Mexico. Christenson (1990), however, suggests that based on assessment of more recently acquired borehole geology and magnetic anomaly data, the feature represents a Triassic-Jurassic extensional rift margin with little to no lateral offset. He proposes the name "Florida Lineament" to describe this feature, which coincides with the Jay Fault and the Bahamas Fracture Zone across peninsular Florida (Christenson, 1990; see feature "A" in Figure 3).

The South Florida Basin (Applin and Applin, 1965; Winston, 1971) is a stratigraphic basin that contributed to southward thickening of Mesozoic and Early Cenozoic lithostratigraphic units in the southern Florida peninsula (Figure 3). A possible successor basin, the younger Okeechobee Basin (Riggs, 1979a) may have contributed to south - southeastward dipping of Oligocene and older lithostratigraphic units along the eastern margin of the study area (Highlands and Glades Counties).

The influence of "basement" structures on Cenozoic and younger stratigraphic units is poorly understood. For example, an apparent southeast plunging syncline ("B" in Figure 3) trends from Sarasota to Hendry Counties in the "sub-Zuni" (i.e., pre-Middle Jurassic) map presented in Barnett (1975). Shallower northwest-striking faults reported by Winston (1996) occur in the same region. Maps of the structural surface of Eocene rocks (Miller, 1986) indicate a generally south-plunging trough extending from central Charlotte County. Deepening and thickening of units in the Charlotte County region are observed in the present study (see *Lithostratigraphy*, p. 30). The Early Cretaceous "Broward Syncline" (Applin and Appin, 1965; "C" in Figure 3) is located approximately 20 mi (32 km) to the east of feature "B" and has a generally parallel strike. These inferred faults and basement relationships warrant further study, especially given their potential role in water quality and distribution of permeable zones. Knowledge of the distribution of low-permeability sediments beneath the FAS is also important as potential sites for CO_2 sequestration are explored.

The Ocala Platform ("D" in Figure 3) is the most dominant feature in the central peninsular region. Evidence of this platform is apparent in the geologic map (Figure 2) where the Eocene Avon Park Formation (Tap) and Ocala Limestone (To) are exposed at or near land surface. This feature is also evident in the Environmental Geology composite map (Figure 4), which reflects lithologic and sediment types within 10 ft (3.1 m) of land surface. Shallow or exposed carbonate rocks in Levy, Marion, Citrus and Sumter Counties reflect the influence of the platform. This structure is not thought to be an uplift (Winston, 1976) but rather a tectonically stable area on which disconformable marine sedimentation and differential subsidence has occurred (Scott, 2001). It is also a major controlling factor in the thickness and extent of lithostratigraphic units in central and southwestern Florida. As a result, this feature also has a very significant effect on the distribution of regional aquifer systems.

Remaining structural features are discussed in this section from north to south. Several northwest-trending faults, as well as orthogonal fracture traces (or lineaments), have been proposed within the Levy and Citrus County area by Vernon (1951). It is possible that some

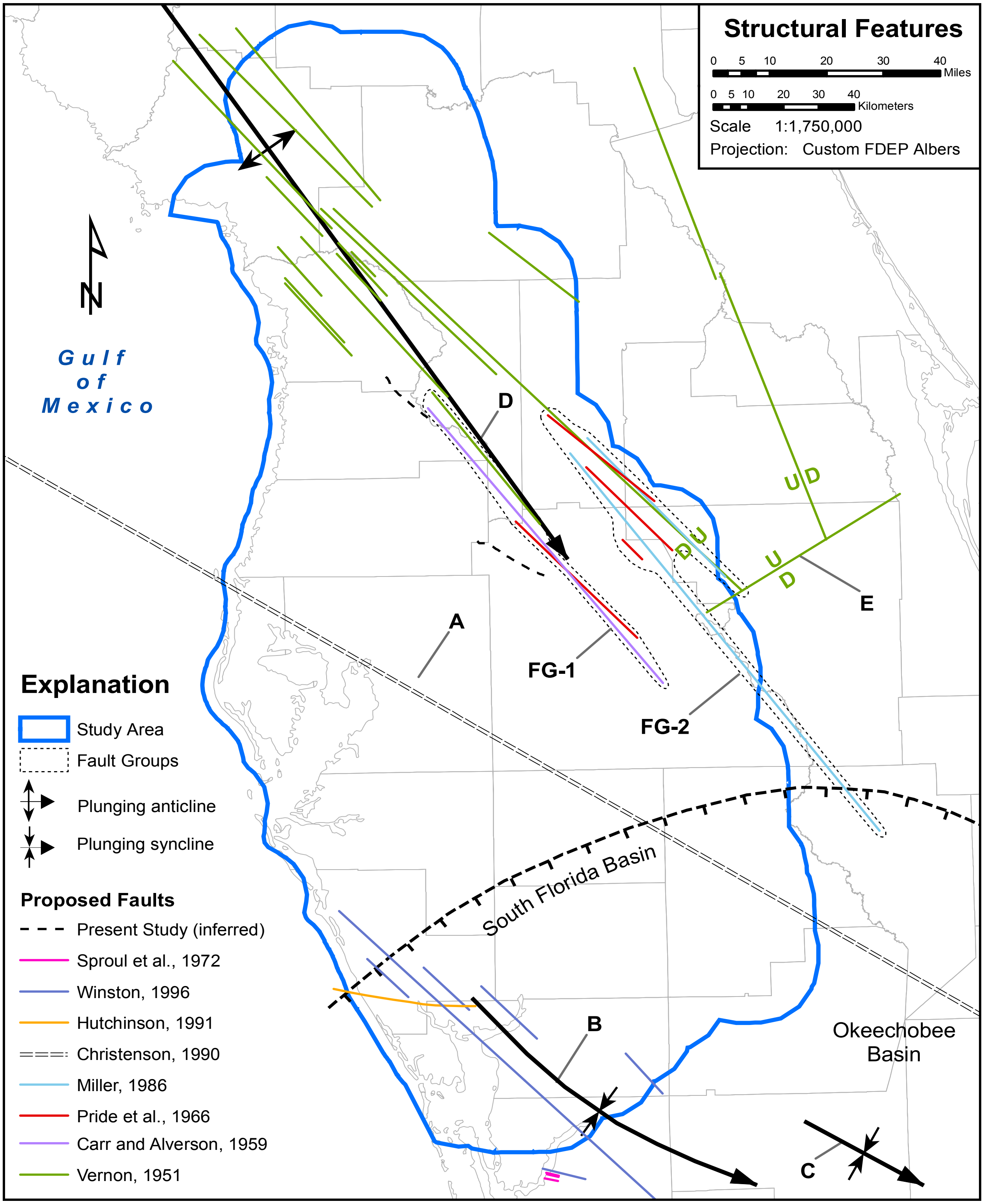

Figure 3. Structural features within the study area. A - Florida Lineament; B - pre-middle Jurassic plunging syncline inferred from Barnett's (1975) "sub-Zuni" map; C - "Broward Syncline;" D - Ocala Platform; E – Kissimmee Faulted Flexure; FG-1 - fault group along strike with fault inferred in present study; FG-2 - group of reported faults possibly affecting subcrop extent of the Ocala Limestone. U/D – upthrown/downthrown block.

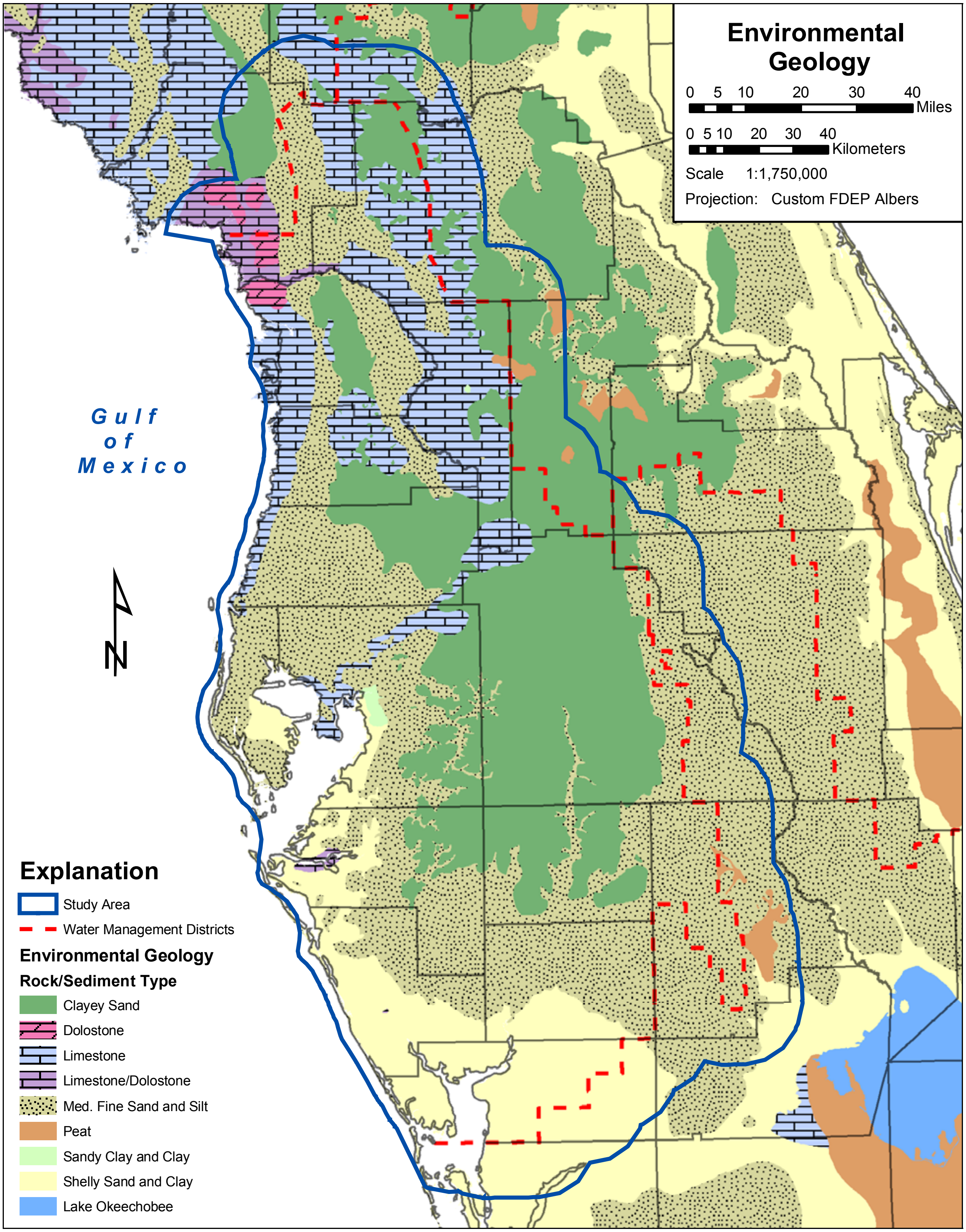

Figure 4. Environmental Geology of the study area (after Knapp, 1978; Scott, 1978; Scott, 1979; Lane, 1980; Lane et al., 1980; Knapp, 1980; Deuerling, 1981). Lithotypes depicted in this map are reported to occur less than or equal to 10 ft (3.0 m) from land surface.

of the inferred "offsets" in his study are due to wells having encountered buried karst pinnacles and paleo-sinks. Carr and Alverson (1959), Pride et al. (1966), and Vernon (1951) report a northwest trending normal fault(s) in northwestern Polk County (fault group "FG-1", Figure 3). Pride et al. (1966) suggest that the fault affects not only the Avon Park Formation, but also juxtaposes the Suwannee Limestone and Ocala Limestone. Carr and Alverson (1959) indicate that the fault penetrates Hawthorn Group sediments as well. Both studies report the northeast block of the inferred fault as the upthrown side. In the present study, evidence supports two possible northwest-trending faults along the northeastern extent of the Suwannee Limestone (Figure 3; see also *Suwannee Limestone*, p. 37). Both faults are similar in strike and offset direction (polarity) to fault group "FG-1" in Figure 3. One of the offsets proposed herein is a northwestern extension of a fault proposed by Carr and Alverson (1959).

Faults affecting Middle and Upper Eocene (e.g., Avon Park Formation and Ocala Limestone) strata are proposed along the Polk-Osceola County boundary (Pride et al., 1966; Miller, 1986). The Kissimmee Faulted Flexure (Vernon, 1951; "E" in Figure 3) occurs in the same area and was originally considered a wedge-shaped, fault-bounded block that had been tilted and rotated, with beds containing small folds and structural irregularities. Wells that penetrate the feature contain variably thick Pliocene-Miocene sediments that overly the Avon Park Formation. Scott (1988) and Davis et al., (2001) consider the Kissimmee Faulted Flexure to be an Avon Park Formation stratigraphic high with the Ocala Limestone and Hawthorn Group sediments locally absent due to erosion. Additional faults ("FG-2" in Figure 3) affecting the subcrop extent of the Ocala Limestone along the western margin of the Flexure have also been proposed. Data presented in this study support the interpretations of Scott (1988) and Davis et al., (2001).

Further to the south in the vicinity of Charlotte Harbor, a west-northwest trending reverse fault penetrating a dolostone layer in the Suwannee Limestone is proposed (Hutchinson, 1991). Maps presented herein do not lend support to the inferred reverse fault. In the same area, a series of northeast-trending lineaments along the northern margin of Charlotte Harbor (Michael Fies, personal communication, 2007) coincide with anomalously high groundwater temperatures in the upper FAS (Smith and Griffin, 1977) suggesting a potential line of further investigation (E. Richardson, written communication, May, 2006). The "North Port Fault" (Winston, 1996) strikes nearly coast-parallel (northwest) across North Port and Punta Gorda. Winston (1996) suggests that the downthrown side may occur on the southwest block, which more or less coincides with thickening and deepening of several units mapped in the present study (see *Lithostratigraphy*, p. 30, for further discussion). South of the study area, west-northwest trending normal and reverse faults offsetting Miocene Hawthorn Group sediments on the order of 50 to 100 ft (15 to 30.5 m; vertical) are reported (Sproul et al., 1972).

Evidence of some degree of vertical offset is present within cores in the study area; however, there is insufficient proximal well control to delineate faulting. Core from W-16913 (ROMP 5), for example, contains abundant high-angle fractures and slickensides that make some lithostratigraphic unit surfaces obscure. Regarding hydrostratigraphic units, brecciated and fractured zones in core from W-17392 (ROMP 13) contribute to difficulties correlating the Middle Floridan confining unit. These are only two of many examples of fractured intervals encountered during data collection that warrant further structural study.

Small irregular surfaces in Miocene and older lithostratigraphic units in the southern part of the study area raise many questions regarding the prevalence of structural deformation within Florida's relatively young carbonate platform. Missimer and Maliva (2004) suggest that observed disturbances in lithostratigraphic surfaces throughout Florida are due to "differential subsidence by tensional basement displacement." Their conclusions are based on seismic surveys and borehole data attained from areas of variable formation depths. Charlotte and Lee Counties are among the most widely studied of these areas. Seismic surveys reveal variations in depth to formations (i.e., relief of unit surface) between ~130 to ~230 ft (39.6 m to 70.1 m) (Missimer and Gardner, 1976). Other seismic profiles in the region also suggest deformation (Evans and Hine, 1991; Lewelling et al., 1998). Missimer and Maliva (2004) propose that these deformed surfaces, some of which extend more than a mile across, are tectonically induced folds. On the other hand, Wolansky et al. (1983), Evans and Hine (1991), Lewelling et al. (1998) and Cunningham et al. (2001) prefer the hypothesis that observed perturbations in seismic reflectors are the result of karstic processes rather than structurally or tectonically related deformation.

Geomorphology

The topography (Figure 5) and geomorphology (Figure 6) of Florida have been influenced by interactions of sea-level changes, karst processes and subtle tectonic forces (Rupert and Arthur, 1990; Schmidt, 1997). The rate of Florida's carbonate platform deposition was controlled by sea-level cycles and stand durations, which produced different physiographic features (e.g., Healy, 1975; Randazzo, 1997).

Prominent ridges formed in shallow-water marine environments during sea-level high stands. Paleo- water bodies, embayments, swales, relict coastal features and streams control where many present-day streams and lakes are located (White, 1970, Randazzo., 1997). Orthogonal patterns in modern drainage systems within the southern part of the study area may have been influenced by fractures (Lewelling et al., 1998) formed in response to peripheral Miocene-Pliocene stress fields associated with Caribbean tectonics (Missimer and Maliva, 2004).

Physiographic Provinces and Features

Aerially extensive and distinctive physiographic provinces in the study area are summarized in this section, starting with the coastal zone and working inland (Figure 6). The coastline along the SWFWMD has been classified into two zones (Tanner, 1960a, 1960b): 1) north of Pasco County the coastal zone is dominated by swamps, salt marshes, oyster reefs and drowned karst topography and 2) south of Pasco County, depositional marine environments contributed to the formation of barrier beaches, barrier islands, barrier spits and over-wash fans.

The Gulf Coastal Lowlands (White, 1970) include the western extent of the SWFWMD, ranging in width from less than 2 mi to approximately 45 mi (3.2 km to ~72 km). Elevations range from sea-level to approximately 100 ft (30.5 m) above mean sea level (MSL). Diverse ecosystems are present within the Gulf Coastal Lowlands including pine flatwoods, dry prairies and to a lesser extent, swamps, scrub and high pine and salt marshes (Crumpacker, 1992). The Gulf Coastal Lowlands do not coincide with any mappable marine terrace and are generally characterized by wide, flat marine karstic plains, including paleo-dunes (White, 1970). Significant updates and revisions to Florida's geomorphic nomenclature are ongoing, with an emphasis on geologic processes and framework geology (Scott, 2004). Re-classification of the Gulf Coastal Lowlands into the Chiefland Karst Plain, Crystal River Karst Plain, and the Land O' Lakes Karst Plain is proposed (Scott, 2004).

The Brooksville Ridge is a prominent upland east of the Gulf Coastal Lowlands, striking north-northwest discontinuously from Pasco to Levy Counties. The total length is approximately 110 mi (177 km) including the inter-ridge Dunellon Gap (Figure 6). The Ridge varies in width from approximately 4 to 10 mi (6.4 to 16.1 km) (White, 1970). Elevations along this upland range from approximately 70 to ~300 ft (21.3 to 91.4 m) above MSL. Fine-grained, low-permeability sediments within the Brooksville Ridge, particularly Hawthorn Group clays, reduce relative infiltration rates and provide a chemical buffer that inhibits carbonate dissolution. Areas without thick clay-rich siliciclastic deposits, through geologic time, are more vulnerable to a reduction in land surface elevation. This process, known as topographic

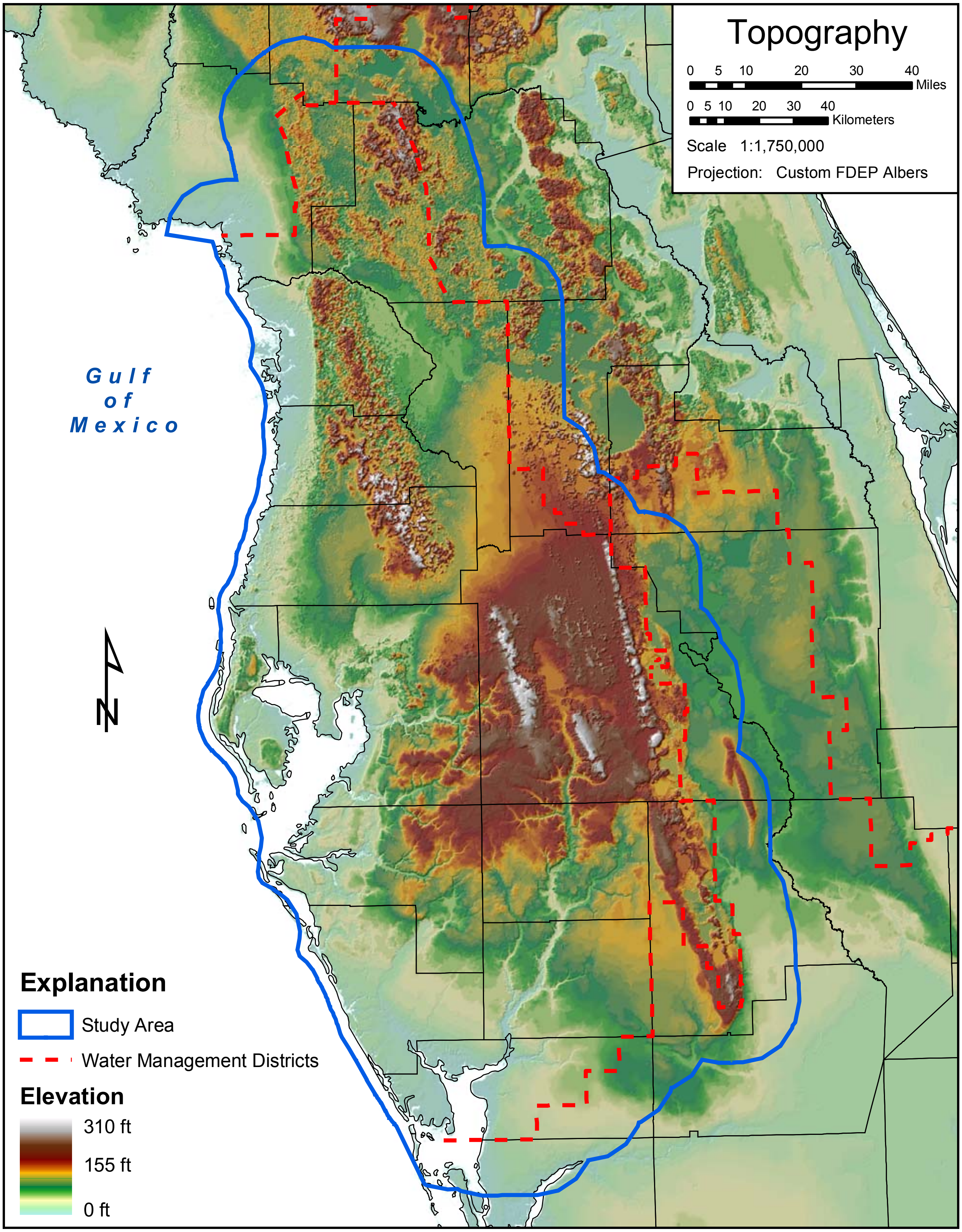

Figure 5. Shaded relief topography of the study area based on 15 m (49 ft) resolution digital elevation model DEM (digital elevation model) (Arthur et al., in review).

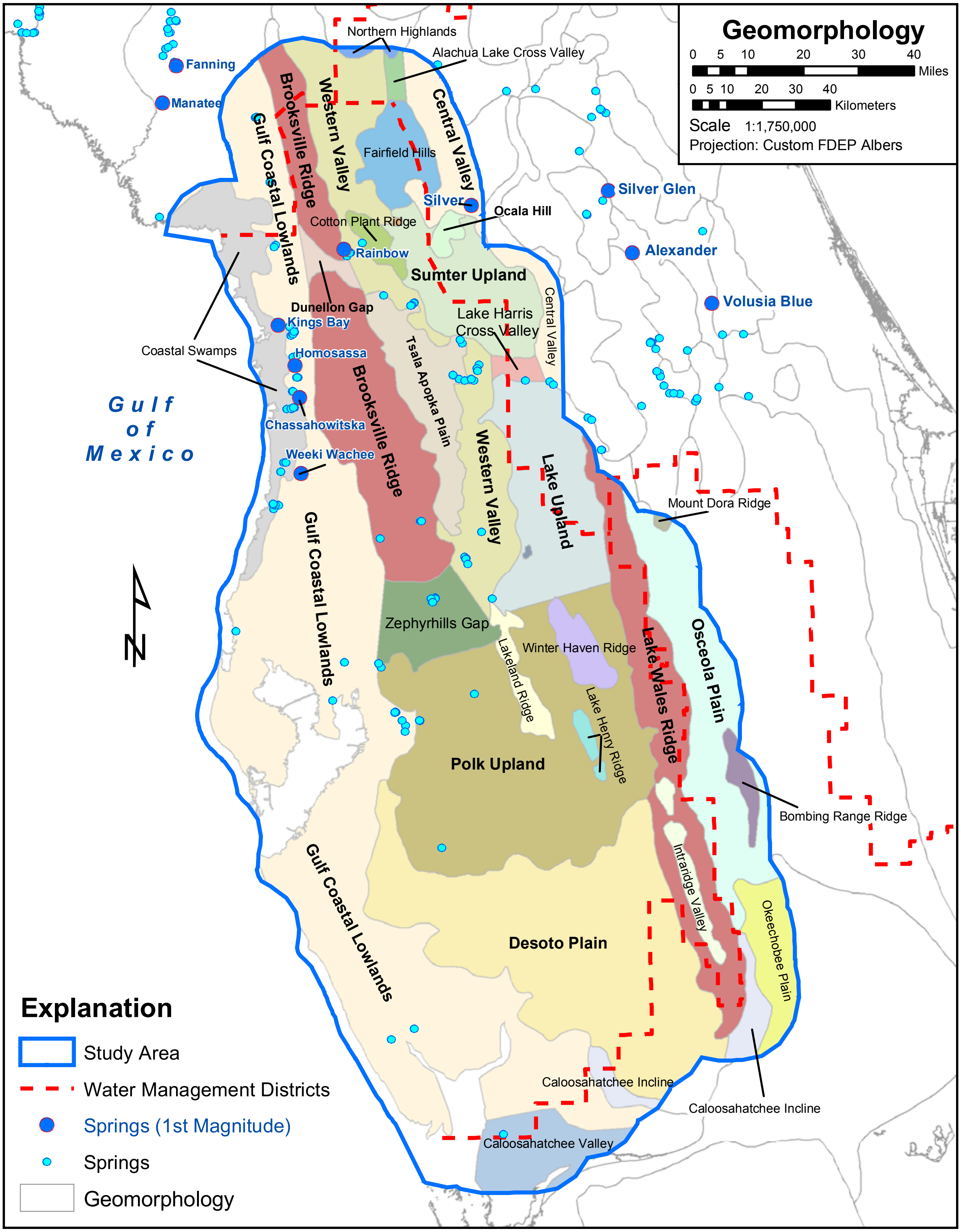

Figure 6. Geomorphology of the study area (from White, 1970 and Puri and Vernon 1964). Spring locations from Scott et al. (2004).

inversion, is thought to have been an important factor in the origin of the Brooksville Ridge (White, 1970; Knapp, 1977). Karst features are abundant along the axis of the Brooksville Ridge. These features are generally internally drained and locally breach the low-permeability sediments in the subsurface and serve as focal points of aquifer recharge. Ecosystems present within the Brooksville Ridge area include scrub and high pine, temperate hardwood forests (with less extensive swamps), pine flatwoods, and dry prairies (Crumpacker, 1992).

The Western Valley is located east of the Brooksville Ridge and Tsala Apopka Plain and west of the Sumter and Lake Uplands (Figure 6). It is also bound to the north by the Northern Highlands and the Polk Upland to the south. The Western Valley is approximately 140 mi (225 km) long and between 5 and 15 mi (8.0 to 24.1 km) wide; elevations average approximately 40 ft (12.2 m) MSL and range up to 100 ft (30.5 m) MSL. Ecosystems present in the Western Valley include temperate hardwood forest (to the north), scrub and high pine, minor swamps, pine flatwoods and dry prairies (Crumpacker, 1992). The Western Valley is characterized by its gently rolling limestone karst plains containing a veneer of Pleistocene sediments overlying Eocene carbonates (Rupert and Arthur, 1990). The Tsala Apopka Plain is believed to be a relict feature of a larger paleo-lake (White, 1970). Scott (2004) proposes reclassification of the Western Valley into the Williston Karst Plain and Green Swamp Karst Plain.

The Polk and Lake Uplands, located between the Gulf Coastal Lowlands and the Lake Wales Ridge are approximately 100 mi (161 km) in length and range in elevation from 80 ft (24.4 m) MSL to 130 ft (39.6 m) MSL. Pine flatwoods and dry prairies with lesser amounts of temperate hardwood forest, scrub and high pine comprise the ecosystems in these uplands (Crumpacker, 1992). A scarp with relief of approximately 25 ft (7.6 m) separates the Polk and Lake Uplands from the Gulf Coastal Lowlands and Western Valley (Arthur and Rupert, 1989). These two uplands contain three minor ridges: the Winter Haven Ridge, the Lake Henry Ridge and the Lakeland Ridge (White, 1970). The land surface is comprised mostly of mild to gently rolling hills gradually increasing in elevation eastward. Miocene-Pliocene clays in this region overlying older carbonates create a hydrogeologic environment conducive to the rapid formation of large cover-collapse sinkholes. Scott (2004) proposes to rename the Polk Uplands in combination with the DeSoto Plain: the Polk-DeSoto Plain. The part of the Lake Upland in the present study area is proposed to be renamed the Green Swamp Karst Plain (Scott, 2004).

The DeSoto Plain is a broad, gently sloping area south of the Polk Upland, east of the Gulf Coastal Lowlands and west of the Lake Wales Ridge. Elevations vary between 30 and 100 ft (9.1 to 30.5 m) MSL (Wilson, 1977). The DeSoto Plain varies from 10 to 40 mi (16.1 to 64.4 km) in length from north to south and 10 to 50 mi (16.1 to 80.5 km) in width from west to east. Ecosystems present within the area include pine flatwoods and dry prairie with minor swamp, scrub and high pine (Crumpacker, 1992). The lithology consists of thick sandy clays over Pliocene and Miocene limestones of poor induration.

The most prominent geomorphic feature in the study area is the Lake Wales Ridge. This large elongate upland extends from Lake County south to Highlands County, where it is flanked by paleodune fields on the eastern margin (Scott et al., 2001). Ecosystems on the Ridge include freshwater marsh, pine flatwoods and dry prairies (Crumpacker, 1992). A belt of lakes dominate the Intraridge Valley in the southern part of the Lake Wales Ridge. Geophysical investigations of lakes within the Intraridge Valley confirm a karst-related origin: irregular, discontinuous seismic reflectors underneath some lakes reveal breaches through confining beds overlying the FAS (Evans et al., 1994; Tihansky et al., 1996), thus indicating that the large collapse features occurred prior to or during Pliocene siliciclastic deposition (Arthur et al., 1995).

Elevations on the Lake Wales Ridge range from approximately 70 to 312 ft (21 to 95.1 m) MSL, the latter forming a hilltop feature known as Sugarloaf Mountain in Lake County. Unlike the geology of the Brooksville Ridge, the Lake

Wales Ridge contains a very thick sequence of permeable Pliocene-Pleistocene sediments (as much as 350 ft [107 m]; see also *Surficial aquifer system*, p. 53) overlying variably thick clays of the Peace River Formation. In the southern part of the Ridge, depth to carbonate rocks exceeds 325 ft (99.1 m) BLS.

Morphology of the eastern flank of the Lake Wales Ridge was likely controlled by high-energy shoreline currents throughout the Pleistocene (and perhaps the late Pliocene) as indicated by the sharp topographic relief on the eastern side of the Ridge. The presence of discoid quartz pebbles in these sediments (Cypresshead Formation) also indicates a high energy depositional environment (Tom Scott, personal communication, 2004). In contrast, the western side of the southern part of the Ridge is flanked by less pronounced topographic relief on the Polk Upland and DeSoto Plain.

The general topographic relief of the southern part of the Lake Wales Ridge mimics that of the emergent part of the Florida Platform with a steep shelf slope along the east and a broad gentle slope to the west. Along the southern margin of the Ridge (Figure 7), subtle topographic ridges that trend toward the west bear remarkable resemblance to the southern Florida peninsula and the Florida Keys suggesting that paleo-longshore and ocean currents (e.g., loop current) that existed during the Plio-Pleistocene are similar to those of present day. Petuch (1994) referred to this area as the Caloosahatchee Strait.

Sinkholes

In addition to paleo-sea levels and ocean currents, karst processes have sculpted the landscape of southwest Florida. Sinclair et al. (1985) mapped four types of sinkholes in the SWFWMD: 1) limestone dissolution: slow-developing, funnel-shaped with a growth rate similar to the rate at which the carbonate rocks dissolve, overburden is thin; 2) limestone collapse: forms abruptly and overburden is thin 3) cover- subsidence sinkholes: gradual formation and generally small diameter, where overlying sands infill limestone dissolution cavities, overburden is greater than 30 ft (9.1 m) thick; and 4) cover-collapse sinkholes: sudden formation and relatively large in diameter, forming upon a breach of clayey material overlying a cavity, overburden is greater than 30 ft (9.1 m) thick. These sinkholes significantly contribute to interaction between surface and groundwater, intra-aquifer and inter-aquifer communication (e.g., Tihansky, 1999) and the vulnerability of aquifers to surface sources of contamination (Arthur et al., 2007).

Plate 3 reflects the distribution of closed topographic depressions (CTD) throughout the SWFWMD region. This map is based on a 15 m (49.2 ft) resolution digital elevation model (DEM) produced by the FDEP-FGS in cooperation with other FDEP programs and Florida's water management districts. While not all CTDs reflect karst features (i.e., paleodunes, etc. may also be included), this depression coverage provides a good approximation of sinkhole distribution patterns within the study area. The coverage, however, does not reflect the tens of thousands (if not more) of buried sinkholes detectable by means of surface geophysical surveys (e.g., Wilson and Beck, 1988; Moore and Stewart, 1983), nor does it include small karst features detectable by LIDAR or sinkholes that formed since the USGS topographic maps were last updated.

Springs

Springs predominantly occur in the northern two-thirds of the study area (Figure 6). Submarine springs occur offshore of Lee County and between Pinellas County and Citrus County (Ryder, 1985; DeWitt, 2003). Five of Florida's thirty-three first magnitude springs ($\geq$100 ft^3/sec; $\geq$2.83 m^3/sec) occur within the study area: Kings Bay Springs Group, Homosassa Springs Group, Chassahowitzka Springs Group (all in Citrus County), Weeki Wachee Springs Group (Hernando County) and the Rainbow Springs Group (Marion County) (Champion and Starks, 2001). The Coastal Springs Groundwater Basin (Knochenmus and Yobbi, 2001) encompasses parts of Citrus, Hernando and Pasco Counties and includes three of the five first magnitude springs. The Coastal Springs Groundwater Basin is made up of four sub-basins: Aripeka, Weeki Wachee, Chassahowitzka and Homosassa Springs. These groundwater sub-basins comprise part of the total recharge area for these springs. Surface water basins comprise the other component. As defined and described in DeHan

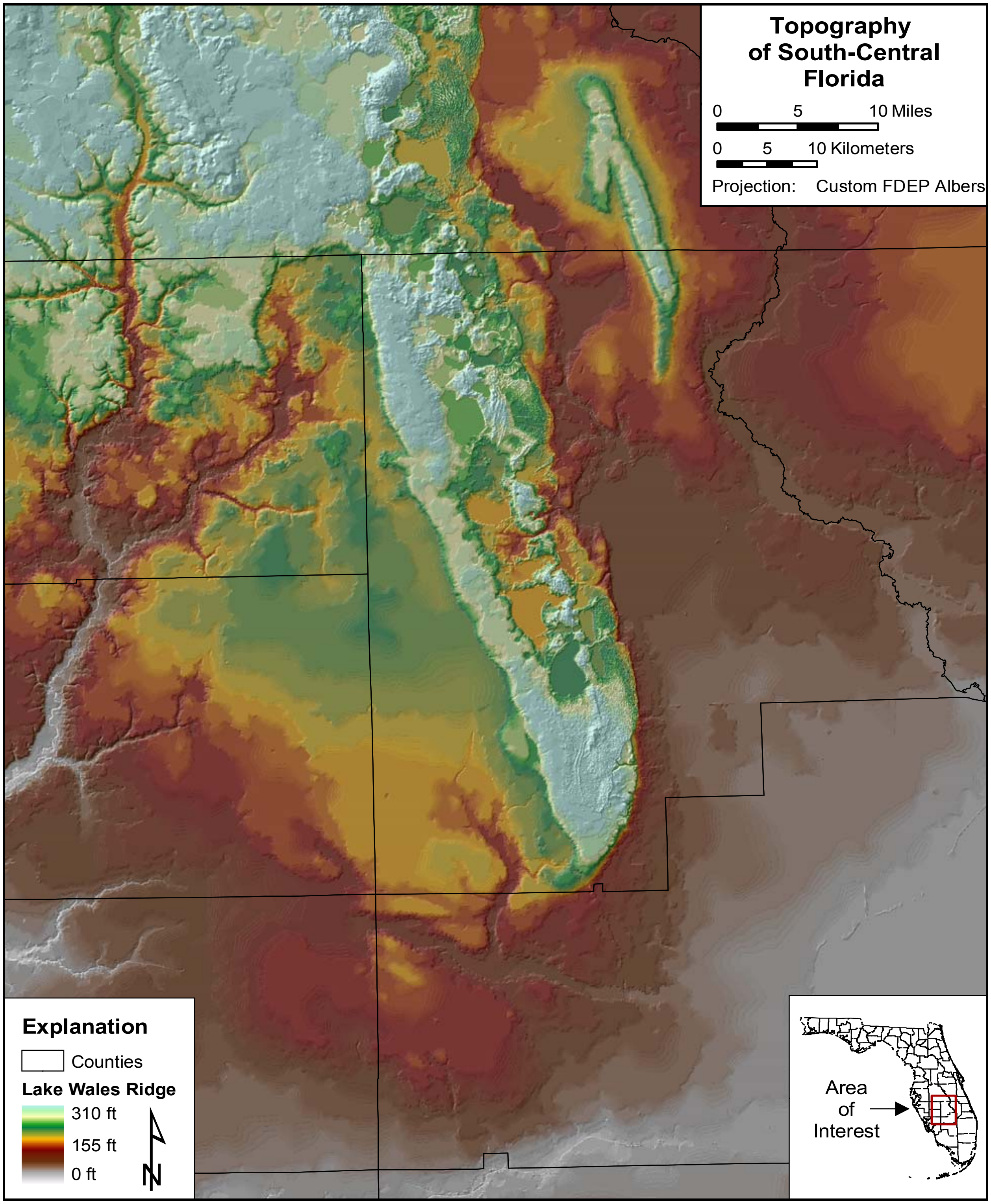

Figure 7. Shaded topographic relief of the southern extent of the Lake Wales Ridge.

(2004), "those parts of surface-water and groundwater basins that contribute to the flow of a spring" are called springsheds. Given the proximity and hydraulic interrelationships among the springsheds of the Coastal Springs Groundwater Basin, the term "Springshed Group," (analogous to a "Group" in lithostratigraphic nomenclature) is herein introduced to characterize this and similar regions of coalescing springsheds (e.g., Coastal Springs Springshed Group). Copeland (2003a) compiled a Florida springs classification system and glossary to facilitate standardized use of springs-related nomenclature among Florida's various technical (i.e. cave divers), scientific and regulatory/planning communities.

The Coastal Springs Springshed Group and the many other springs and springsheds in the study area support unique ecosystems that harbor diverse flora and fauna (Scott et al., 2004; Champion and Starks, 2001). When water quality and quantity decline, these ecosystems are adversely affected. The magnitude and nature of the threats varies within each springshed based on land use and geology (Hartnett, 2000; Florida Department of Community Affairs and Florida Department of Environmental Protection, 2002). It is noteworthy that springshed boundaries are time-dependent; they migrate in response to anthropogenic activity (e.g., pumping/withdrawal) and seasonal/climatic effects on the potentiometric surface (DeHan, 2004; Greenhalgh, 2004; Scott et al., 2004).

Since the 1970's scientists have documented a decline in water quality in most of Florida's springs especially with regard to nutrients (Jones et al., 1998; Hartnett, 2000; Copeland, 2003b). Nitrate is of particular concern as high amounts may lead to excessive growth and eventual eutrophication of surface water bodies. Nuisance and exotic plants can cause reduction of water flow, reduction of dissolved oxygen and habitat changes (Hartnett, 2000). Nitrate has been a concern in SWFWMD for many years as increased levels of nitrates are being detected at many springs (Jones et al., 1997). Natural background concentration of nitrates in the FAS is less than 0.01 mg/L (Champion and Starks, 2001). Florida government agencies have recently proposed best management practices (BMPs) to protect and conserve Florida's springs (Florida Department of Community Affairs and Florida Department of Environmental Protection, 2002).

Spring-water quantity is another issue associated with development and population growth. Under predevelopment conditions springs accounted for about 84 percent of water discharged from the FAS (Ryder, 1985). As development increases and more well fields are used, the potentiometric surface of the FAS is lowered. This results in lower spring discharge, which can then result in changes in water quality (Lee, 1998). Spring flows become dramatically reduced or eliminated by over-pumping water from the aquifer. Near coastal zones, changes in aquifer conditions can also affect the location of the transition zone between fresh and salt water (Scott et al., 2004). As spring discharge rates decrease, calcium and magnesium have been observed to increase possibly owing to upconing or the removal of water from intergranular storage (Rick Copeland, personal communication, 2006). Although not fully established at the current time, preliminary evidence suggests that the upconing of sulfates and other constituents (i.e., micronutrients) may be contributing to algal development in springs (Sam Upchurch, personal communication, 2006). Corresponding increases in chlorides may also be observed in the spring water as discharge rates decrease. These conditions also allow migration of saltwater further inland (Lee, 1998).

Hydrogeology

Three major hydrostratigraphic units occur in west-central Florida: the surficial aquifer system (SAS), the intermediate aquifer system/intermediate confining unit (IAS/ICU) and the Floridan aquifer system (FAS). Miller (1986) divides the FAS into two zones of higher permeability: the Upper Floridan aquifer (UFA) and the Lower Floridan aquifer (LFA), which are separated by one or more regional confining units (Middle Floridan confining unit; MFCU).

In this report, nomenclature and definitions of units are primarily based on that proposed by the "Ad Hoc Committee on Florida Hydrostratigraphic Unit Definitions" Southeastern Geological Society, 1986). A 2nd Ad Hoc Committee on Florida Hydrostratigraphic Unit Definitions (CFHUD II) is presently convened to address identified concerns regarding existing nomenclature and definitions (Copeland et al., in review). The CFHUD II is comprised of representatives from the FDEP-FGS, USGS, water management districts and consulting firms. Appendix 1 includes a commentary on nomenclatural issues with regard to Florida's hydrostratigraphy.

The present study adopts the following aquifer-system names and definitions, which are minor revisions of the widely accepted, yet dated Southeastern Geological Society (1986) proposal. These definitions are revised in the context of statewide application, and not limited to the study area. Appendix 2 provides explanation of changes from original Southeastern Geological Society (1986) definitions.

surficial aquifer system - the permeable hydrogeologic unit contiguous with land surface that is comprised principally of unconsolidated to poorly indurated siliciclastic deposits. It also includes carbonate rocks and sediments, other than those of the FAS where the Floridan is at or near land surface. Rocks and sediments making up the SAS belong to all or part of the Miocene to Holocene Series. The SAS contains the water table and water within it is under mainly unconfined conditions; however, beds of low permeability may cause semi-confined or locally confined conditions to prevail in its deeper parts. Locally perched water-table conditions occur as well. The lower limit of the SAS coincides with the top of laterally extensive and vertically persistent beds of much lower permeability.

intermediate aquifer system/
intermediate confining unit – includes all rocks that lie between and collectively retard the exchange of water between the overlying SAS (or land surface) and the underlying FAS. These rocks in general consist of coarse-to-fine-grained siliciclastic deposits interlayered with carbonate strata belonging to parts of the Oligocene and younger series. The aquifers within this system contain water under semi-confined - to - confined conditions. The top of the IAS/ICU coincides with the base of the SAS and on a local scale with land surface. The base of the IAS/ICU is hydraulically separated to a significant degree from the top of the FAS.

Floridan aquifer system – a thick, predominantly carbonate sequence that includes all or part of the Paleocene to Lower Miocene Series and functions regionally as a water-yielding hydraulic unit. Where overlain by the IAS/ICU, the FAS contains water under confined conditions. When overlain directly by the SAS, the FAS may or may not contain water under confined conditions depending on the extent of low permeability material within the base of the SAS. Where the carbonate rocks crop out or are covered by a veneer of permeable siliciclastics, the FAS generally contains water under unconfined conditions near the top of the aquifer system, but because of vertical variations in permeability, deeper zones may contain water under confined conditions. The FAS is present throughout the State and is the deepest part of the active groundwater flow system on mainland Florida. The top of the FAS generally coincides with the absence of significant thicknesses of siliciclastics from the section and with the top of the vertically persistent permeable carbonate section.

Generalized correlations between hydrostratigraphic units and lithostratigraphic units mapped in this study are presented in Table 2. The *Hydrostratigraphy* section, p. 52, of this report provides a more detailed discussion of these aquifer systems. Delineation of aquifer–system boundaries is described in *Methods*, p. 20.

Table 2. Generalized correlation chart for units mapped within study area (ages compiled from Covington, 1993, Missimer et al., 1994, Scott et al., 1994, and Wingard et al., 1994). Numbers are million years before present. Ages are included for reference only and are not scaled to correlate with all columns in the table. MFCU is Middle Floridan confining unit; UDSC includes the Tamiami, Ft. Thompson and Caloosahatchee Formations.

Erathem	System	Series	Lithostratigraphic unit	Hydrostratigraphic unit	Generalized lithology
Cenozoic	Quat-ernary	Holocene .01 Pleistocene 1.8	Undifferentiated sand, shell, and clay (UDSC)	surficial aquifer system (SAS)	Highly variable lithology ranging from unconsolidated sands to clay beds with trace amounts of shell fragments
	1.8-2.6 Neogene	Pliocene 5.3	Hawthorn Group: Bone Valley Mbr.; Peace River Fm.	intermediate aquifer system or intermediate confining unit (IAS/ICU)	Peace River Formation contains interbedded sands, clays and carbonates with siliciclastic component being dominant; variable phosphate sand content
		Miocene	Hawthorn Group: Arcadia Formation		Arcadia Formation is a fine-grained carbonate with low to moderate phosphate and quartz sand, variably dolomitic
		23.03	Tampa Member		
	Paleogene	Oligocene	Nocatee Member		
			Suwannee Limestone	Floridan aquifer system (FAS): Upper Floridan aquifer (UFA)	Suwannee Limestone is a fine-to medium-grained packstone to grainstone with trace organics and variable dolomite and clay content
		33.9 Eocene	Ocala Limestone		Ocala Limestone is a chalky, very fine-to fine-grained wackestone/packstone varying with depth to a biogenic medium- to coarse-grained packstone grainstone; trace amounts of organic material, clay and variable amounts of dolomite
			Avon Park Formation	MFCU	Avon Park is a fine-grained packstone with variable amounts of organic-rich laminations near top; limestone with dolostone interbeds typical in upper part, deeper beds are continuous dolostone with gypsum near base

Sediments comprising the SAS are predominately post-Hawthorn in age and generally consist of some combination of sands shells and clays. In parts of the northern District where the IAS/ICU is not laterally extensive, discontinuous clay lenses serve as basal SAS confinement, locally separating the SAS from the FAS. Some of these basal clays may be erosional remnants of (and correlative with) lithostratigraphic units comprising the IAS/ICU. In areas where Pliocene clayey sediments (see "clayey sand," Figure 4) are exposed at or near land surface, such as west-central Polk County, the SAS or water-table aquifer may not be present; instead, the setting reflects IAS/ICU overlying the FAS. Where hydraulic continuity exists between uppermost Hawthorn Group sands and younger sediments, the SAS includes those sands, which are generally less than 20 ft (6.1 meters) thick. In the southernmost part of the study area, the Ft. Thompson and Caloosahatchee Formations and upper permeable sediments of the Tamiami Formation comprise the SAS. Although mapping of these complex "post-Hawthorn" units is beyond the scope of this study, research did focus on the depth and extent of clays within the Pliocene Tamiami Formation, which are significant as they comprise the base of the SAS in the region (e.g., Reese, 2000; Weinberg and Cowart, 2001).

The IAS/ICU occurs throughout most of Florida (Scott, 1992a) and correlates with aquifer systems in parts of Georgia and Alabama. In the study area, it is comprised of mid- to upper Oligocene - Pliocene sediments and is generally continuous south of Pasco County. As this hydrostratigraphic unit thickens southward, interlayered permeable carbonates become important water-producing zones, especially south of Manatee County where the FAS water becomes less potable. In this area, three permeable zones are present; however, correlation and mapping of these zones is difficult, even with the use of hydrochemical parameters (Knochenmus and Bowman, 1998; Torres et al., 2001; Knochenmus, 2006). North of Hillsborough County, the IAS/ICU predominantly occurs within the uplands and ridges, where it functions hydrologically as a semi-confining to confining unit.

The FAS is one of the most productive aquifers in the world. It underlies all of Florida, southern Georgia and small parts of Alabama and South Carolina for a total area of about 100,000 mi^2 (~259,000 km^2) (Johnston and Bush, 1988). In parts of southwest Florida, south from Sarasota, Charlotte, Glades and Lee Counties, the FAS contains mineralized, non-potable water. As a result, relatively permeable zones within the IAS/ICU comprise the main source of water supply (Miller, 1986; Torres et al., 2001) in this region. The FAS is confined except in parts of the northern third of the study area where it occurs at or just below land surface (Ryder, 1985). Throughout the study area, the FAS predominately consists of carbonate rocks (Southeastern Geological Society, 1986) ranging in age from Paleocene to Miocene.

METHODS

Sample Description

More than 250 detailed lithologic descriptions of borehole cores and cuttings were completed for this study. These descriptions record standard rock, mineral, fossil and textural features. Selected parameters include color, induration, grain size and range, sorting, roundness, mineral percentages and special descriptive, depositional or sedimentary features. Descriptions of carbonate material were based on the Dunham (1962) classification system, which focuses on depositional texture and whether the rock is mud-supported or grain-supported: 1) mudstone - muddy carbonate rock containing less than 10 percent grains, 2) wackestone - mud supported rock containing more than 10 percent grains, 3) packstone - grain supported muddy carbonate, 4) grainstone – mud-free carbonate rock which is grain supported and 5) boundstone - carbonate rock showing signs of being bound (e.g. cementation) during deposition and reflecting original position of growth. It should be noted that the Dunham (1962) classification considers a "grain" as having a diameter greater than 20 microns, while "mud" is less than 20 microns. As a result, a very fine grained grainstone may appear as a mudstone even under a low-power binocular microscope (David Budd, 2004, personal communication). It is likely that this factor has biased identification of mudstones in lithologic descriptions that may technically be fine-grained grainstones.

During archiving of borehole cuttings, samples are gently washed in a 63 micron sieve to remove any drilling mud (e.g., silt and clay-sized material). When describing lithologic characteristics of borehole cuttings, care was taken to inspect the washed and unwashed archival fractions of the samples. In many cases, especially for older wells, the washed sample fraction may under-represent the clay fraction of the sample. For example, cuttings representing the sandy clayey Nocatee Member (Arcadia Formation) may have been washed to the degree that only sand remains in the archived sample. In such cases, the unwashed sets of samples provide a better representation of the original clay-rich lithology.

The descriptions are coded within the aforementioned Microsoft® Access™ database – *FGS_Wells*. This database is undergoing continued enhancements including migration to a more robust enterprise-level platform. These and other lithologic descriptions are available from the Florida Geological Survey web site: *http://www.dep.state.fl.us/geology/.*

Delineation of Boundaries

Formations/Members

Formation and member boundaries were determined for all described samples and for cores, cuttings and geophysical logs from an additional ~600 wells. Florida Geological Survey published and unpublished data (e.g., Stewart, 1966; Hickey, 1982, 1990; Johnson, 1986; Miller, 1988; Scott, 1988; Campbell, 1989; DeWitt, 1990; Campbell et al., 1993, 1995; Clayton, 1994, 1999; Green et al., 1995, 1999; Sacks, 1996; Arthur et al., 2001a; Gates, 2001; Missimer, 2002; and O'Reilly et al., 2002) provided lithostratigraphic and hydrostratigraphic boundary information on an additional ~200 wells. Gamma-ray logs and fossil assemblages are used only to supplement the lithologic data in the determination of the boundaries. Where uncertainty exists regarding the exact position of the formation boundary, or where the boundary is inferred within an interval of poor or no sample recovery, a dashed rather than solid line is shown on the cross sections. 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 often true with cuttings, the gamma-ray logs become more important in the determination of formation boundaries.

Uncertainties in lithostratigraphic unit boundaries were recorded in a database of elevations and thicknesses. These uncertainties exist for several reasons. In the case of inspecting cores, it is not uncommon for two experienced geologists to disagree on a formation boundary, especially when it is subtle or gradational. Moreover, the core may have poor recovery, resulting in missing intervals. Regarding cuttings, samples often contain borehole cavings, whereby the sampled interval contains sediment or rock fragments from overlying units. For example, in an extreme case, dolostone cuttings from the Avon Park Formation may contain phosphatic sands from the upper Hawthorn Group. As a result, it is not uncommon for a formation boundary estimation based on cuttings to include an uncertainty range on the order of 20 ft (6.1 m) based solely on sample quality. Other uncertainties with respect to mapped unit elevations also exist (see *Map Development and Data Management*, p. 24).

Table 2 summarizes the lithostratigraphic units shown on the maps. The same units are also shown on the cross sections. For the purposes of this study, post-Hawthorn units are depicted as Pliocene-Pleistocene sediments (undifferentiated) and Pleistocene - Holocene undifferentiated sand and shell or sand and clay (UDSS or UDSC, respectively).

Aquifer Systems

Delineations of hydrostratigraphic units in this report are based on the following: 1) available hydrogeologic data collected during drilling, 2) borehole geophysical logs,

3) hydrogeologic characteristics of the samples (e.g., estimated porosity and permeability, hydraulic continuity between lithostratigraphic units), 4) potentiometric data from nested monitor wells, and 5) in the absence of other data, correlation to lithostratigraphic units. Application of the first four methods is highly preferred; the majority of this data originates from ROMP wells.

Contacts between aquifer systems can be very subtle or abrupt depending on the hydrogeologic properties of the rocks and sediments. When only lithologic material from a borehole is available on which to base an aquifer-system boundary, further complications arise. Preferential removal of clay-sized particles, either during drilling or sample archiving (e.g., sorting during material transfer or washing of cuttings), tend to bias toward interpretations of higher sample permeability.

Delineation of the basal contact of the SAS is perhaps the most susceptible to the aforementioned bias. If the contact is based solely on estimates of hydrogeologic properties of lithologic data, misrepresentation of clay content, especially in borehole cuttings may result in the interpretation of a preferentially deep base of the SAS. This issue may become a factor where the SAS may include sediments as old as the upper Hawthorn Group. On the other hand, permeable sands along the top of the upper Peace River Formation in Manatee County (Tom Scott, personal communication, 2006) comprise the lower part of the SAS. If there is reason to believe that the two units (Hawthorn and post-Hawthorn Group sediments) are hydraulically connected, both would be considered part of the SAS. Alternatively, sandy clays overlying clay-rich Hawthorn Group sediments would be considered part of the IAS/ICU (assuming sufficient lateral extent). Further south, the Tamiami Formation is included within both the SAS and IAS/ICU.

Noting the above exceptions, the lateral extent of the IAS/ICU broadly corresponds to the extent of Hawthorn Group sediments, except where those sediments are part of the FAS (e.g., the Tampa Member [Arcadia Formation] along the upper reaches of the Hillsborough River). For consistency, in areas where the IAS/ICU is mapped owing to sufficient lateral continuity, the SAS is mapped over the same extent. In areas where the SAS and IAS/ICU are discontinuous, the FAS is generally characterized as unconfined to semi-confined (see *Hydrostratigraphy*, p. 52, for more detail).

Figure 8 represents a compilation of hydrogeological data to provide correlation between hydrostratigraphic units and lithostratigraphic units. In most areas, the correlation is readily apparent, such as the relation between the top of the Suwannee Limestone in Sarasota County with the top of the FAS. In another example, the Tampa Member (Arcadia Formation) is hydraulically connected to the FAS in Pinellas County and therefore comprises the uppermost part of the FAS. The correlations, however, are not always straightforward, such as the area denoted as "variable" (Suwannee Limestone and Nocatee Member, Arcadia Formation) in DeSoto County (Figure 8).

Cross-Section Construction

Detailed lithologic descriptions, gamma-ray logs and hydrologic data comprise the bulk of the information used to develop the cross sections. The dominant sources of information for cross-section control are SWFWMD ROMP wells; FDEP-FGS wells were included to fill out appropriate data-point coverage for the cross sections. Where no lithologic data was available, borehole geophysical logs were used. Of these geophysical logs, gamma-ray logs were the most readily available and generally useful for correlative purposes within the study area. Gamma-ray logs were included in the cross sections to allow 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.

Topography

Topographic profiles were included on each cross section to facilitate comparison of surface morphologies with subsurface stratigraphy. Data used to construct these profiles was taken from U.S. Geological Survey 1:24,000 (7.5 minute) quadrangle maps. The profiles include selected anthropogenic features, cultural boundaries and landforms.

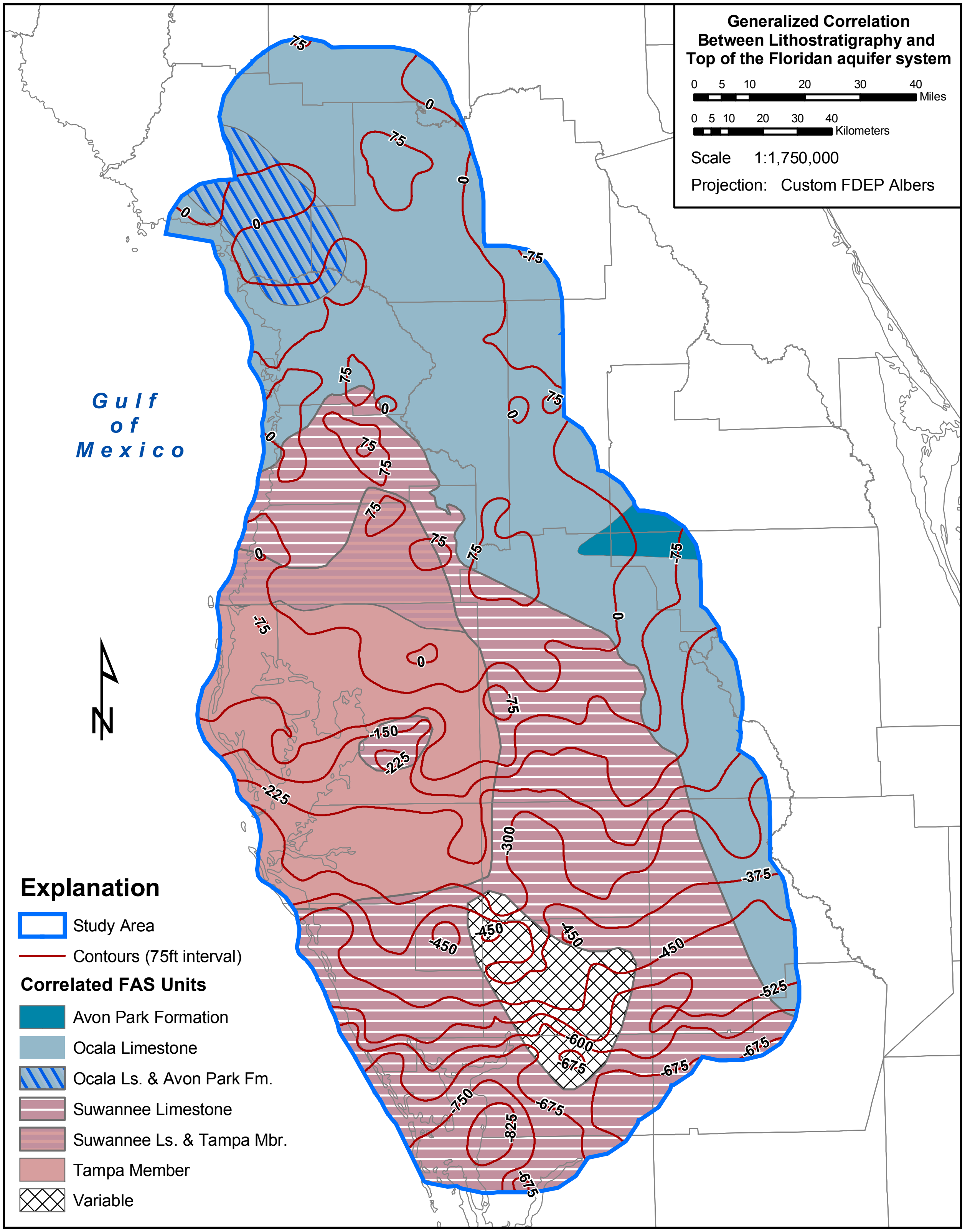

Figure 8. Generalized correlation between lithostratigraphic units and the surface of the FAS. The area labeled "Variable" includes parts of the Nocatee Member (Arcadia Formation, Hawthorn Group) and the Suwannee Limestone.

Lithology

For each well in a cross section, a stratigraphic column was developed to represent borehole lithology. The columns were based on either existing descriptions or new descriptions generated for this report. Hatch patterns depict primary lithologies in the columns, with accessory minerals shown on the right of the columns as text codes. Where space is available, the cross sections contain an explanatory legend that defines mineralogic and lithologic codes and patterns. For those cross-sections without sufficient space to include the "Explanation," it is also provided for reference in Figure 9. Accessory-mineral codes are generally the same as those used in the FDEP-FGS lithologic database (*FGS_Wells*). If the volume of reported accessory sand-sized minerals exceeds 5 percent, the content is represented by a stippled sand pattern. If the amount of accessory sand-sized minerals is less than 5 percent, or if the amount is not known based on existing descriptions, the accessories are listed in the text codes. The mineral text codes are listed in decreasing order of abundance if the relative mineral abundance has been reported.

The degree of detail within each lithologic column generally reflects the type of material available for description as well as the degree of detail in the description. In most cases, more detailed lithology exists for the cores. The minimum bed thickness represented on the stratigraphic columns is 5 ft (1.5 m) due to graphical constraints. There are several examples where lithologies and accessory minerals have been averaged over a 5 to 10 foot (1.5 to 3.0 m) interval to accommodate this graphical limitation.

Gamma-ray Logs

Selected gamma-ray logs are plotted to the right of stratigraphic columns on the cross sections. These logs are used as a supplement to delineate formation boundaries and allow comparison of gamma-ray activity between the various lithostratigraphic and hydrostratigraphic units (e.g. Gilboy, 1983; Green et al., 1995; Scott, 1988 and Davis et al., 2001). Gamma-ray intensity units, when known, are shown on the logs (horizontal axis) in counts per second (CPS) or in American Petroleum Institute (API) units. Inconsistencies between logs exist due to different log settings (e.g., time constant, range) and borehole characteristics (e.g., depth of casing and lack of caliper logs to determine sediment wash-out or cavities), making quantitative comparison difficult. To allow assessment of the high degree of variability in the logs and to represent their natural response, the intensity scales have not been normalized. The logs are very useful in the identification of correlative "packages" of gamma-ray peaks and for comparison of the overall gamma-ray signature within formational units. Relatively high gamma-ray activity is generally correlative with phosphate, organic materials, heavy minerals and high-potassium clays. More subtle changes may reflect dolomite and accessory mineral content. Figure 10 summarizes general relationships between gamma-ray activity and mineralogy, the details of which are included in the discussion of each lithostratigraphic unit (see *Lithostratigraphy*, p. 30).

Aquifer Systems

Aquifer systems on the cross sections appear as hachured brackets on the left of each lithologic column. Patterns used in the hydrostratigraphic columns identify the three major aquifer systems present in the study area, as well as the MFCU.

Map Development and Data Management

For wells used in this study, elevations of lithostratigraphic and hydrostratigraphic units were recorded in a database that also included the corresponding FDEP-FGS well accession number (W-number), well name, comments about the well, the geologist(s) who made the determinations and well location (elevation, latitude and longitude). The unit elevations on which the maps are based are recorded in feet BLS; a separate column calculates the elevation

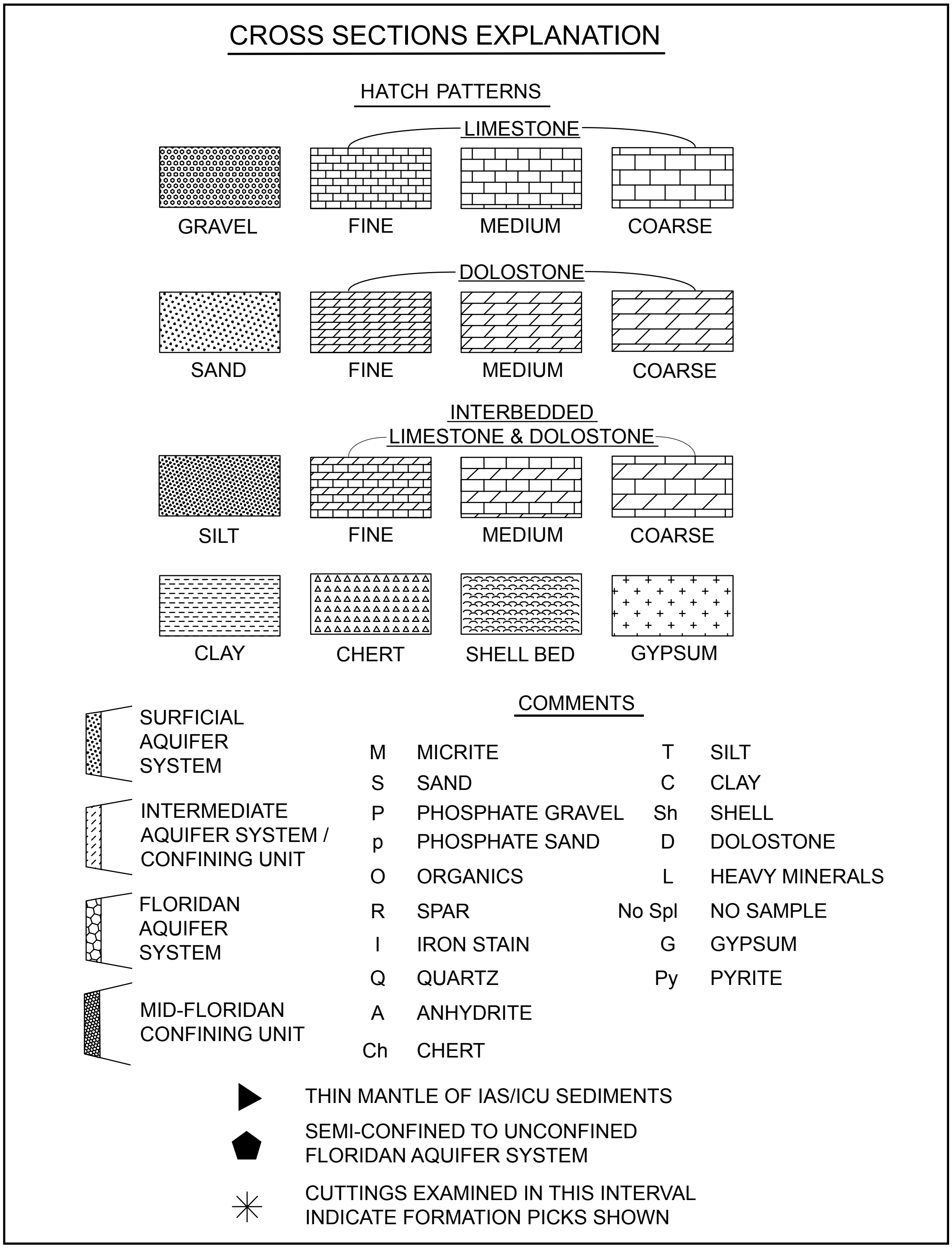

Figure 9. Explanation (legend for cross sections).

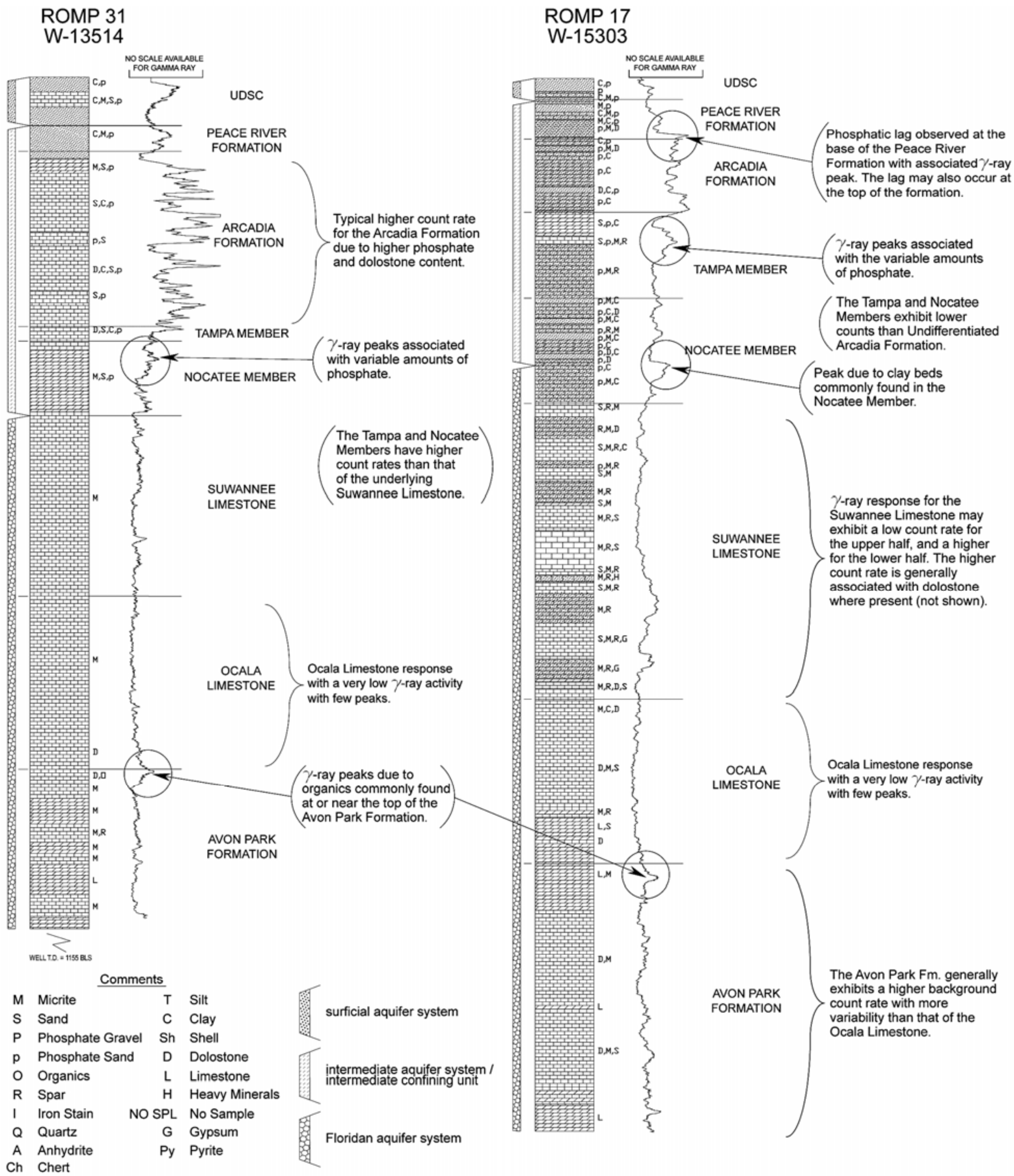

Figure 10. Characteristic gamma-ray (γ) log responses.

relative to MSL. The database also records uncertainty in the unit elevations. Synthetic wells were added to the database to serve as contour control along the margins of the study area in order to facilitate a more accurate interpolated surface. Quality assurance of all well-head elevations was accomplished by comparing the reported elevation with a 15 m (49 ft) DEM. The data on which the maps and cross sections are based is available from *http://www.uflib.ufl.edu/ufdc/?b=UF00087428&v=00001*

Map Interpolation and Spatial Accuracy

As the GIS database was developed, preliminary contour maps were generated to allow identification of anomalous elevations and data gaps. ArcView® with the Spatial Analyst extension was used to generate the initial contour maps. For each map, a grid surface model was calculated using a surface interpolation method. Contours were then generated from the surface model. The inverse distance weighted (IDW) interpolator was found to provide a very useful surface model for identifying problem areas and outliers that required additional research. As these issues were identified, borehole cuttings were retrieved from the FDEP-FGS core repository and re-evaluated in context of: 1) proximal stratigraphy, 2) sample quality, and 3) stratigraphic boundary uncertainty. This process of generating and reviewing maps and re-examining samples was repeated numerous times through the course of this study. Arthur and Pollock (1998) suggested that the IDW interpolation method is not suitable for geologic mapping of stratigraphic data. The IDW method was used only as an iterative review tool. Interim maps for the initial phases of this project were generated using the spline interpolator. Arthur and Pollock (1998) found the spline-tension method preferable to IDW because spline yielded surface models that were more accurate and geologically characteristic.

Upon review of subsequent interim maps generated for this project, several shortcomings in application of the spline interpolator were recognized. These include false highs and lows in the model surface that do not reflect any well control and loss of contour accuracy along the margins of the maps. Moreover, as the interpolator was adjusted to yield smoother contours, the interpolated surface became less accurate. With the exception of accuracy at a given well location, it was also difficult to assess the error associated with the maps in data-poor areas. Due to the "overshooting contour" effect (e.g., false topographic highs), shallow map units may exceed land surface elevations in certain areas, especially along areas of high topographic relief.

Prior to generation of the final maps, a re-assessment of interpolation methods was completed. Through an iterative process, kriging was identified as the most robust and accurate surface interpolator. The GIS project was then migrated to ESRI® ArcMap 8.3. The map-unit elevation database was imported into ArcMap® and projected in the FDEP standard projection (custom Albers equal-area conic projection). Individual surfaces were then interpolated using the ordinary kriging function within the ESRI® Geostatistical Analyst. Iterations of krige data models were produced for each map unit to minimize the map error. Prediction errors and other descriptive statistics for each map were recorded and used to identify appropriate contour intervals (see *Contour interval selection*, p. 30). When evaluating krige statistics, the variability of the prediction (as standard deviation) is overestimated when the root mean squared prediction error (RMS) is less than the average standard error (ASE) of the prediction error (Table 3; Johnston et al., 2001).

The krige error automatically reported by the software is based on the error within a rectangular area defined by the distribution of the data (i.e., wells). For nearly all of the maps in this report, these results are misleading because the datasets have an irregular spatial distribution. As a result, for each kriged surface, a prediction standard error map was also created and masked to the spatial extent of the unit being mapped. The average standard error of this prediction standard error map was then calculated and recorded (Table 3).

As an extra measure to assess map accuracy, a script was written to allow comparison of the observed map-unit elevations (i.e., top of the Suwannee Limestone in a given well) with the value of the final interpolated grid cell in which the well is located. On Table 3, this data is summarized in the "Grid to Point" column, where the "mean" represents the average of the difference between grid cells and map unit elevations for each well located within its respective grid cell. In every case, the mean "Grid to Point" value is less than ±3 ft, (0.9 m) for all maps, and the standard deviation (s) is less than 20 ft (6.1 m) for 18 of the 22 maps and less than or equal to 30 ft (9.1 m) for the remaining 4 maps (Table 3). Qualitative evaluation of these errors suggests they are normally distributed.

The standard deviations for the "Grid to Point" calculations (Table 3) are well within acceptable limits, especially when considering: 1) geologic processes that can create perturbations in a mapped surface (e.g., faults, paleo-karst, paleo-environmental features [e.g., wave-cut scarps, river valleys]), 2) well location error or uncertainty, 3) sample quality (e.g., cuttings interval and borehole cavings) and 4) formation pick uncertainty (i.e., gradational contacts, differences in professional opinion, etc.).

Once the kriged surfaces were optimized for each map unit, the shallow surfaces (i.e., top of the Peace River Formation) were compared to land surface elevations. To accomplish this, the kriged surface was converted to a raster file (grid) using a 400 m^2 (4305.6 ft^2) cell size, which was then subtracted from the FDEP-FGS 15 m (49.2 ft.) resolution DEM to remove interpolated elevations that exceeded land surface. The grid was clipped (i.e., masked) to the lateral extent of its respective map unit. For most of the mapped units, contours generated from the kriged and the DEM-trimmed surfaces were generally irregular or jagged. This characteristic is not only atypical for maps depicting subsurface elevations and thicknesses, but it also overemphasizes the level of resolution represented by the maps. To remove these localized and misrepresentative contour anomalies, the grids were smoothed using the neighborhood statistics function in Spatial Analyst. Color shading, contour lines and labels were then added.

It is noteworthy that substantial effort was devoted to surface interpolations that would allow weighting of data from cores preferentially over that of cuttings and geophysical logs. Combinations of grid averages, weights, and point buffering applied within various interpolators were evaluated during extensive sensitivity analyses and validation. In the final assessment, too many negative attributes were associated with what was considered the optimal core-weighting technique. As a result, the well data from cores, cuttings and geophysical logs are all considered equally in the maps.

Unlike hand-drawn contours, the smoothed contours generated from krige-interpolated surfaces do not always reflect highly anomalous elevation data points. While this may be considered a disadvantage, it is substantially outweighed by numerous advantages of the digital products developed during this study: 1) the interpolated surfaces are supported by accuracy and precision statistics, 2) the calculated grids can be used in a variety of groundwater flow models and 3D applications, 3) GIS compatibility exists, including inherent scalability and flexibility, and 4) the maps can be readily updated with new information. As a result, manual modification (editing) of the contours to reflect anomalous values would create discrepancies between the maps and the grid coverages. In cases where contour adjustments were deemed necessary to reflect sharp-relief surface trends (as opposed to single anomalous well values), synthetic control points were added to improve map accuracy while maintaining consistency with the calculated grids.

Table 3. Summary of krige interpolation statistics for each map; ASE is average standard error of the prediction error; RMS is root mean square of the prediction error. Gray pattern indicates that the prediction error may be overestimated (i.e., ASE>RMS).

Map Unit (s)=surface (t)=thickness	Prediction error (1s)[3]		Prediction error (1s; map)[4]		Map Contour Interval	"Grid to Point" Error Calculation		Number of Wells[5]	Model Algorithm
	ASE	RMS	Mean of the ASE (1s)	2 X Mean of the ASE (2s)		mean	s		
Hawthorn Group (s)	23	34	22	44	25	1.64	11	526	Exponential
Hawthorn Group (t)	57	68	56	112	75	-0.25	21	321	Spherical
Peace River (s)	25	35	22	44	25	0.64	9	349	Exponential
Peace River (t)	27	34	37	74	30	0.33	25	324	Exponential
Bone Valley Mbr. (s)	26	35	23	46	40	2.61	10	33	Exponential
Bone Valley Mbr. (t)	7	7	10	20	20	0.26	3	38	Spherical
Arcadia Fm. (s)	29	35	25	50	30	0.7	11	466	Exponential
Arcadia Fm. (t)	67	65	61	122	75	-0.27	19	341	Exponential
Tampa Member (s)	50	39	44	88	50	0.6	11	235	Exponential
Tampa Member (t)	40	40	39	78	50	0.13	30	190	Exponential
Nocatee Member (s)	64	48	55	110	75	1.11	12	117	Exponential
Nocatee Member (t)	38	36	37	74	50	-0.24	21	105	Exponential
Suwannee Limestone (s)	75	51	68	136	75	0.98	18	414	Exponential
Suwannee Limestone (t)	43	47	37	74	50	0.1	12	265	Exponential
Ocala Limestone (s)	67	47	63	126	75	0.97	14	527	Spherical
Ocala Limestone (t)	34	49	30	60	50	-0.15	10	325	Exponential
Avon Park Fm. (s)	84	53	79	158	100	0.77	13	391	Circular
SAS (t)	25	29	25	50	25	0.41	18	703	Exponential
IAS/ICU (s)	24	34	21	42	25	-1.27	13	488	Exponential
IAS/ICU (t)	58	62	54	108	75	0.02	18	334	Spherical
FAS (s)	68	46	64	128	75	0.87	16	655	Exponential
MFCU (s)	166	122	167	334	150	0.83	12	101	Spherical

[3] krige statistics based on rectangular fit around distribution of wells
[4] krige statistics based on irregular extent of mapped unit, which more accurately represents error within the study area
[5] total number of wells used to produce each map, including wells (not shown on plates) within the outer 10 mile buffer zone

Contour Interval Selection

Contour intervals for each map were selected based on the mean of the ASE for each respective krige model trimmed to the map unit extents (Table 3 - Footnote 2). If one assumes normality, the ASE of the prediction error is essentially the standard deviation (s) of the interpolated surface and represents a 68 percent level of significance. If one were to double the error (i.e., 2s), a 95 percent level of significance is achieved. To avoid inflating implied accuracy of the krige surfaces, the contour interval for all but two maps was selected between 1s and 2s. In other words, the selected contour interval is always greater than or equal to the mean of the ASE prediction error, except for the IAS/ICU thickness map and the MFCU surface map. Per Table 3, the error for these maps is over-predicted. For every contour map in this study, the standard deviation for the "Grid to Point" calculation described above (Table 3) is less than the contour interval.

STRATIGRAPHY

The stratigraphic framework of the west-central Florida peninsula, encompassing the SWFWMD region, is presented from north to south in the following geographic subdivisions: *northern region* (eastern Levy, western Marion, Citrus, Sumter, western Lake, Hernando and Pasco Counties), *central region* (including Pinellas, Hillsborough, western Polk, Manatee and Hardee Counties), *southern region* (Sarasota, DeSoto and Charlotte Counties) and the *eastern region* (e.g., the Lake Wales Ridge, including eastern Polk and Highlands Counties). The framework discussion is subdivided into lithostratigraphy and hydrostratigraphy, and is characterized through a series of cross sections and maps (surfaces and thicknesses). East-west trending cross sections presented in this report (see Plate 1 for locations) are ordered from the north to south (i.e., the northern to southern regions; Plates 4-19), then north to south within the eastern region (Plates 20-28). Cross sections trending north-south are ordered from west to east as follows: Plates 29 and 30 in the northern region, Plates 31-35 in the central/eastern regions and Plates 36 and 37 in the southern region. Maps of lithostratigraphic units are presented from oldest to youngest (Plates 38 - 54) and hydrostratigraphic units are presented from shallow to deep (Plates 55 - 59).

Lithostratigraphy

Introduction

Structure contour (surface) and isopach maps (thickness) in this report include Lower Eocene through Lower Pliocene lithostratigraphic units, which are described in detail in this section. Characterization of the mapped units includes age, lithology, mineralogy, porosity, significant fossils, distribution, nature of vertical and lateral contacts, distinguishing gamma-ray activity responses, relation to hydrostratigraphic units and environment of deposition. Superjacent and subjacent lithostratigraphic units (i.e., the Oldsmar Formation) are also presented.

Eocene Series

Oldsmar Formation

The Lower Eocene Oldsmar Formation ("Oldsmar Limestone" of Applin and Applin, 1944) underlies the entire Florida peninsula. Miller (1986) describes the Oldsmar Formation as a white to gray limestone with variably thick interbeds of gray to light brown, crystalline dolostone that increases in abundance with depth. Thin beds of chert and evaporites, including pore-filling gypsum occur within the unit (Miller, 1986). Reese and Richardson (2008) report a glauconite marker horizon that occurs intermittently within upper ~200 ft (~ 61 m) of the Oldsmar Formation in the study area. Porosity types include intergranular, intragranular and fracture (e.g., "Boulder Zone"). Braunstein et al. (1988) indicate that the unit may have an unconformable contact with the subjacent Cedar Keys Formation; however, the contact with the overlying Avon Park Formation is possibly conformable.

In the study area, the Oldsmar Formation limestones vary from packstone to wackestone.

Dolostone is common as well. The microfossil *Helicostegina gyralis* (Figure 11) is common but not unique to the unit (Miller, 1986). In the southeastern Florida peninsula, this microfossil is common within a glauconitic bed that serves as an excellent geophysical marker (Duncan et al., 1994). Within the study area, the uppermost Oldsmar Formation contains gypsum as nodules, laminations and as pore-filling material. Stewart (1966) reports "selenite impregnation" in the unit and proposes that the gypsum is altered from anhydrite. In some areas, these gypsiferous, low-permeability carbonates comprise the upper part of the MFCU, whereas deeper in the section, the carbonates comprise the upper part of the LFA. Cander (1994) suggests that the Oldsmar Formation represents a shallow subtidal to supratidal carbonate paleo-environment.

Avon Park Formation

The Middle Eocene Avon Park Formation (Miller, 1986) occurs in the subsurface throughout the study area and is the oldest lithostratigraphic unit exposed in Florida (Scott et al., 2001). This unit was originally described by Applin and Applin (1944) as two units, the Lake City Limestone and the Avon Park Limestone. Due to the inability (except locally) to distinguish these two formations based on lithology or fauna, Miller (1986) proposed that the term Lake City Limestone be abandoned and formalized the Avon Park Formation to include the two units of Applin and Applin (1944).

Lithology of the Avon Park Formation varies between limestone and dolostone. The limestone is generally cream to light brown, poorly to well indurated, variably fossiliferous, skeletal/peloidal wackestone to grainstone with minor mudstone. The limestone can be interbedded with dark brown to tan very-fine to coarse-grained, vuggy, fossiliferous dolostones. Incomplete to complete dolomitization of limestone is also observed. Dolostone textures range from very fine-grained to coarsely recrystalized (sucrosic). Minor clay beds and organic-rich laminations may occur, especially at or near the top of the unit. Although not common, sedimentary structures include cross-beds and burrows. The burrows (*Callianassa* sp.) generally occur in the uppermost thinly bedded updip part of the formation (e.g., crops out in Levy County). Accessory minerals include chert, pyrite, celestine, gypsum and quartz (some as doubly-terminated euhedral crystals "floating" in vugs). Gypsum tends to be more abundant with depth. Reese and Richardson (2008) report a glauconite marker horizon that occurs intermittently within lower ~200 ft (~ 61 m) of the Avon Park Formation.

Porosity in the Avon Park Formation is generally intergranular in the limestone section. Fracture porosity occurs in the more densely recrystallized dolostone and intercrystalline porosity is characteristic of sucrosic textures. Pinpoint vugs and fossil molds are present to a lesser extent. Total porosity measured for 16 Avon Park Formation samples averages 31.7 percent (median = 30.0 percent) and ranges from 22.3 percent to 42.0 percent.

Diagnostic fossils include the foraminifera *Cushmania americana* (*Dictyoconus americanus)* and *Fallotella (Coskinolina) floridana* and the echinoid *Neolaganum* (*Peronella*) *dalli* (Figure 12). The foraminfer *Fallotella* (*Dictyoconus*) *cookei* occurs in the Avon Park Formation as well as the Suwannee Limestone; however, presence of *Cushmania americana* is unique to the Avon Park Formation. Other fossils include algae, mollusks and carbonized plant remains (e.g., *Thalassodendron* sp.) (Scott, 2001).

Miller (1986) reports the top of Lower Eocene rocks (the approximate base of Avon Park Formation) at depths ranging from -1,000 ft to -2,400 ft (-304.8 to -731.5 m) MSL within the study area. The Avon Park Formation varies in thickness across the study area, from 1,000 ft to 1,600 ft (304.8 to 487.7 m), with the thickest area occurring along northeastern Polk County (Miller, 1986). Maximum observed elevations exceed 50 ft (15.2 m) MSL in northern Polk County (Plate 20). In the southernmost extent of the study area, the unit is encountered at depths exceeding -1500 ft (-457.2 m) MSL (Plate 38). The area, which is centered along eastern Charlotte Harbor, may be related to structural deformation (Winston, 1996).

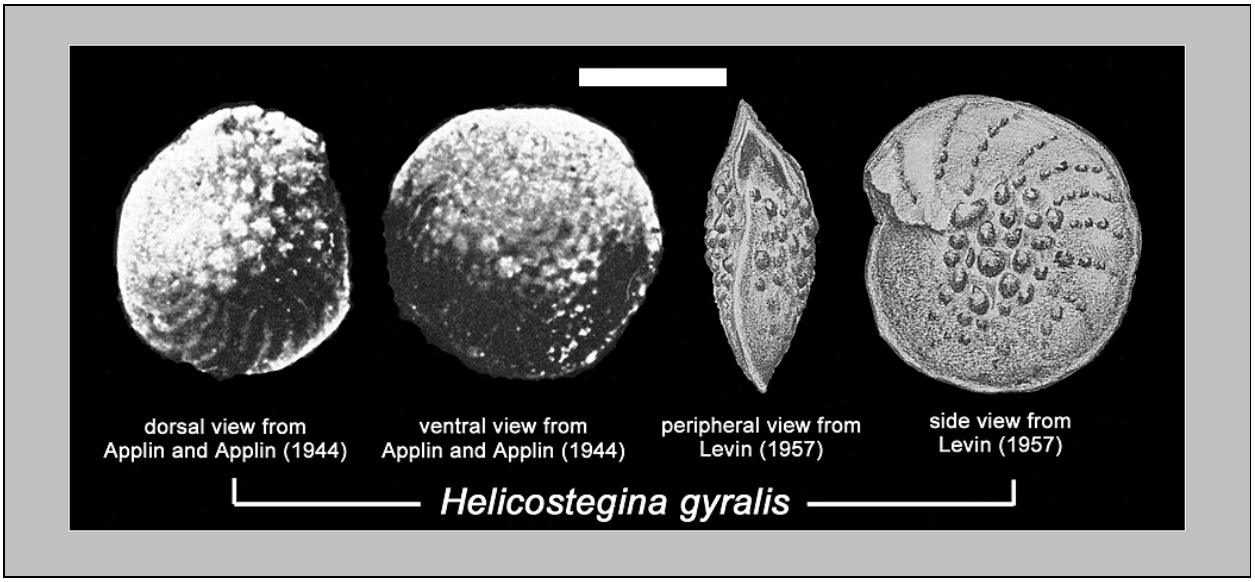

Figure 11. *Helicostegina gyralis*, a foraminifer common within the Oldsmar Formation (bar = 1 mm).

The contact relations between the Oldsmar and Avon Park Formations are generally subtle and difficult to identify within the study area, which supports the interpretation that the contact is possibly conformable (Braunstein et al., 1988). In general, the contact grades from a dolostone to a chalky white limestone. In many cases, however, these characteristics are not present. A useful faunal indicator of the transition into the Oldsmar Formation is the appearance of abundant *Helicostegina gyralis* (Figure 12; Miller, 1986). Although this foraminifer does not exclusively occur in the Oldsmar Formation, it generally appears in lowermost Avon Park Formation and increases in abundance in the Oldsmar Formation carbonates.

The Ocala Limestone unconformably overlies the Avon Park Formation throughout nearly the entire study area; exceptions include parts of Levy and Citrus Counties (Avon Park Formation exposures) or where the Ocala Limestone is absent in the subsurface (northwestern Osceola County). The contact between these two units is readily apparent in many up-dip locations and difficult to determine down dip. The more obvious contact relations occur where: 1) lithology of the Avon Park Formation is tan to brown dolostone, overlain by white to cream limestone of the Ocala Limestone (e.g., W-16456 [ROMP 49], Plates 14 and 33; W-9059, Plates 23 and 34) and 2) in the case where both units are limestone, the uppermost Avon Park Formation is grain-supported and contains disseminated organics or thin (less than 2 inches; ~ 5 cm) beds of peat (in some cases varying toward lignite), whereas the lowermost Ocala Limestone is finer grained and skeletal (e.g., W-720, Plates 6 and 29; W-12943 Plates 12 and 21). Although the Avon Park Formation is not defined based on bio-assemblages, additional contact indicators include the appearance of diagnostic foraminifera and echinoids listed above, as well as abundance of coralline algae.

Throughout most of the southwestern part of the study area, including nearly all of Manatee and Sarasota Counties, the contact between the Avon Park Formation and the Ocala Limestone is dolomitized (e.g., Plate 18) and as a result, formation boundary delineation is difficult. In this situation, subtle characteristics can be used to delineate the two units. Dolomitization of the limestones with slightly varying textures may yield differences in dolostone textures and dolomite grain sizes. Fossil molds are another useful indicator, because fossil molds of diagnostic fossils may help narrow the uncertainty. For example, narrow, discoid vugs may represent prior *Lepidocyclina* sp. whereas smaller cone-shaped vugs may represent where *Cushmania* or *Fallotella* sp. were present prior

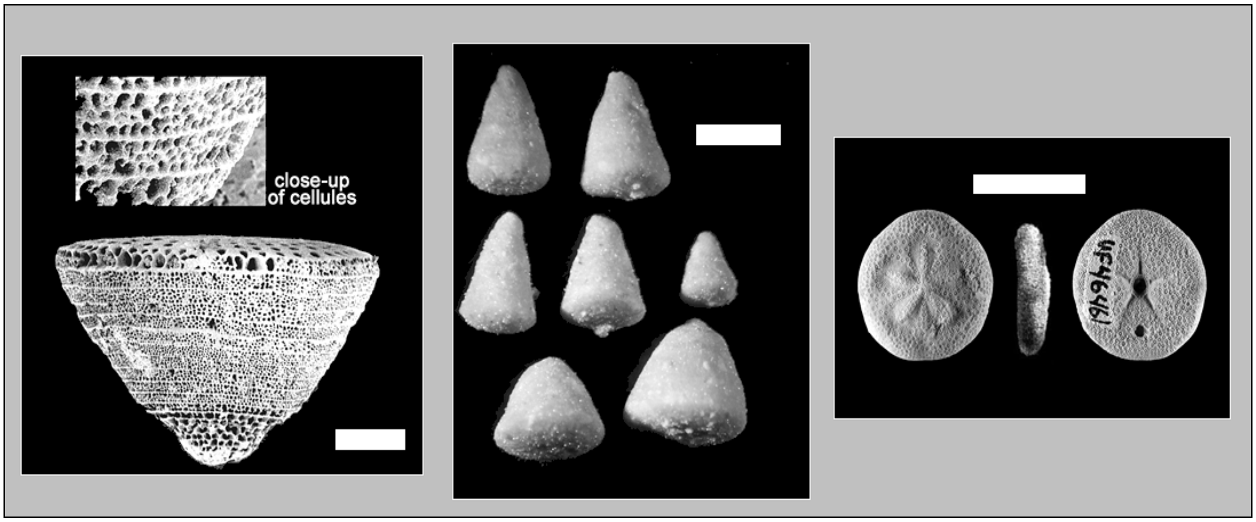

Figure 12. Selected diagnostic fossils common within the Avon Park Formation. From left to right: *Cushmania americana* (*Dictyoconus americanus)* (bar = 0.5 mm; Rupert, 1989), *Fallotella* (*Coskinolina) floridana* (bar = 1 mm; photo courtesy of Jonathan Bryan) and *Neolaganum* (*Peronella*) *dalli* (bar = 15 mm; photo courtesy of Invertebrate Paleontology, Florida Museum of Natural History [IP/FMNH]).

to dolomitization/leaching (e.g., Plate 27; W-17056 [ROMP 9]). In rare instances, selective dolomitization occurs where the original limestone matrix is dolomitized, however, the faunal assemblage (foraminifera and echinoids) remain as calcite.

Gamma-ray response in the Avon Park Formation is generally due to variable dolomite and organic content. In many wells, high gamma-ray activity at or near the top of the Avon Park Formation corresponds to thin layers of organic material (e.g., Plate 16; W-16303 [ROMP TR 7-4]; Figure 10). Similar observations have been made east of the study area (Davis et al., 2001). In cases where the top of the Avon Park Formation has been dolomitized or recrystallized, this organic-associated gamma-ray peak tends to be a broadened, more subdued signal. The degree to which the signal remains is likely a function of the extent of recrystallization and amount of organic impurities remaining in the carbonate. Relative to the overlying Ocala Limestone, the Avon Park Formation gamma-ray signature has higher background count rates and is more variable throughout the unit. In general, a relatively higher gamma-ray peak is observed at the top of the Avon Park Formation throughout the study area, except for the west-central region, including northern Hillsborough and Pinellas Counties as well as eastern Polk and northern Manatee Counties. Several gamma-ray logs from wells in the study area also exhibit a peak at depths greater than 350 ft (106.7 m) below the top of the unit. Preliminary analysis attributes this peak to organic content.

All major parts of the FAS (the UFA, MFCU and LFA) can include the Avon Park Formation. The “Avon Park permeable zone” (Reese and Richardson, 2008) generally occurs 200 to 400 ft (60.9 m to 121.9 m) beneath the top of the Avon Park Formation in the study area, and is analogous to the “Avon Park highly permeable zone” reported by Hutchinson (1992) for southwestern Florida. Reese and Richardson (2008) map this permeable zone throughout most of the southern half of peninsular Florida, describing it as a thick dolostone unit with interbedded limestone and dominated by fracture porosity that may occur in either the UFA or the LFA.

With increasing depth in the Avon Park Formation, interbedded and intergranular evaporites (gypsum/selenite and anhydrite) reduce formation porosity and permeability throughout much of the region. Water-quality data, (Sacks and Tihansky, 1996; Jack Hickey, personal communication, 2004), geophysical and lithologic evidence indicate that most of the MFCU surface (Plate 59) correlates with the middle to lower carbonates of the Avon Park Formation. In parts of Marion, Osceola and Pinellas Counties, however, the MFCU occurs in the upper third of the unit. In the southern region, a shallower discontinuous MFCU unit occurs within the middle to upper part of the formation (Plate 59). The relation between the Avon Park Formation and the MFCU in east-central part of the study area (i.e., the vicinity of southeastern Polk County; Plate 59) requires further data and research.

The Avon Park Formation was deposited within a broad, distally steepened carbonate platform (Budd, 2002). The deposition is characterized by peritidal carbonate sediments that may be significantly dolomitized. Highly cyclical deposits in supratidal to shallow subtidal environments are represented in the vertical sediment sequence (Randazzo et al., 1990; Budd, 2002). The sediments reflect repeated short-term changes in relative sea level throughout Middle Eocene deposition documenting transgressive, regressive and open marine to shoreline cycles (Randazzo et al., 1990). Some researchers propose that dolomitization within the Avon Park Formation took place during or proximal in time to deposition (e.g., Randazzo and Hickey, 1978; Cander, 1994). Miller (1986) suggests that thin evaporite beds deposited during the Middle Eocene may have been formed in a tidal flat or sabkha environment.

Ocala Limestone

The Upper Eocene Ocala Limestone was first named by Dall and Harris (1892). Puri (1953) later proposed three separate formations: the Inglis, Williston and Crystal River Formations, which were based upon distinct faunal assemblages. In 1953, Puri elevated the sequence to Group status. Miller (1986) noted that these formations were neither easily recognizable nor mappable and therefore applied the name Ocala Limestone; however, he acknowledged that a two-fold division (upper and lower Ocala Limestone) proposed by Applin and Applin (1944) was still in use. Recognizing the biostratigraphic basis of the division on which the Ocala Group was based, Scott (1991) identified the Ocala Limestone as a formation in accordance with the North American Stratigraphic Code. Despite this rather complex history in nomenclature leading to recognition of the unit as a single formation, upper and lower Ocala Limestone lithologies are generally recognized.

The lower Ocala Limestone varies from white to light gray and is variably indurated, ranging from a packstone to a grainstone. Where present, dolomite content increases with depth in the Ocala Limestone, especially in the southwestern part of the study area where the base of the unit is often dolomitized (see *Avon Park Formation*, p. 31, for more details). Gaswirth (2004) also noted this pattern and documented textural end-members within these dolostones: 1) friable, light to medium brown, sucrosic and 2) indurated, dark gray to dark brown, dense, crystalline. The upper part of the Ocala Limestone varies from white to light orange and tends to be more mud-supported (i.e., mudstone to wackestone) and chalky.

Mineralogy of the Ocala Limestone unit is predominantly calcite, and to a lesser extent, dolomite. Siliciclastics are rare; however, chert occurs throughout the formation and is generally more common where the unit occurs at or near land surface. Trace amounts of organics and clay (Green et al., 1995) likely represent post-depositional infilling. Pyrite is also present as a trace mineral, but to a lesser extent than the overlying Suwannee Limestone or underlying Avon Park Formation. Sedimentary structures in the Ocala Limestone include cross bedding, fine laminations and bioturbation. The latter is dominant at the base of the unit in the form of burrows (Loizeaux, 1995). The Ocala Limestone has a diverse fossil assemblage (Figure 13), including *Lepidocyclina* sp., *Nummulites (Operculinoides)* sp., milliolids, bryozoans, gastropods, mollusks, pelecypods, echinoids (e.g., *Eupatagus antillarum*) and *Rotularia* (*Spirolina*) *vernoni*.

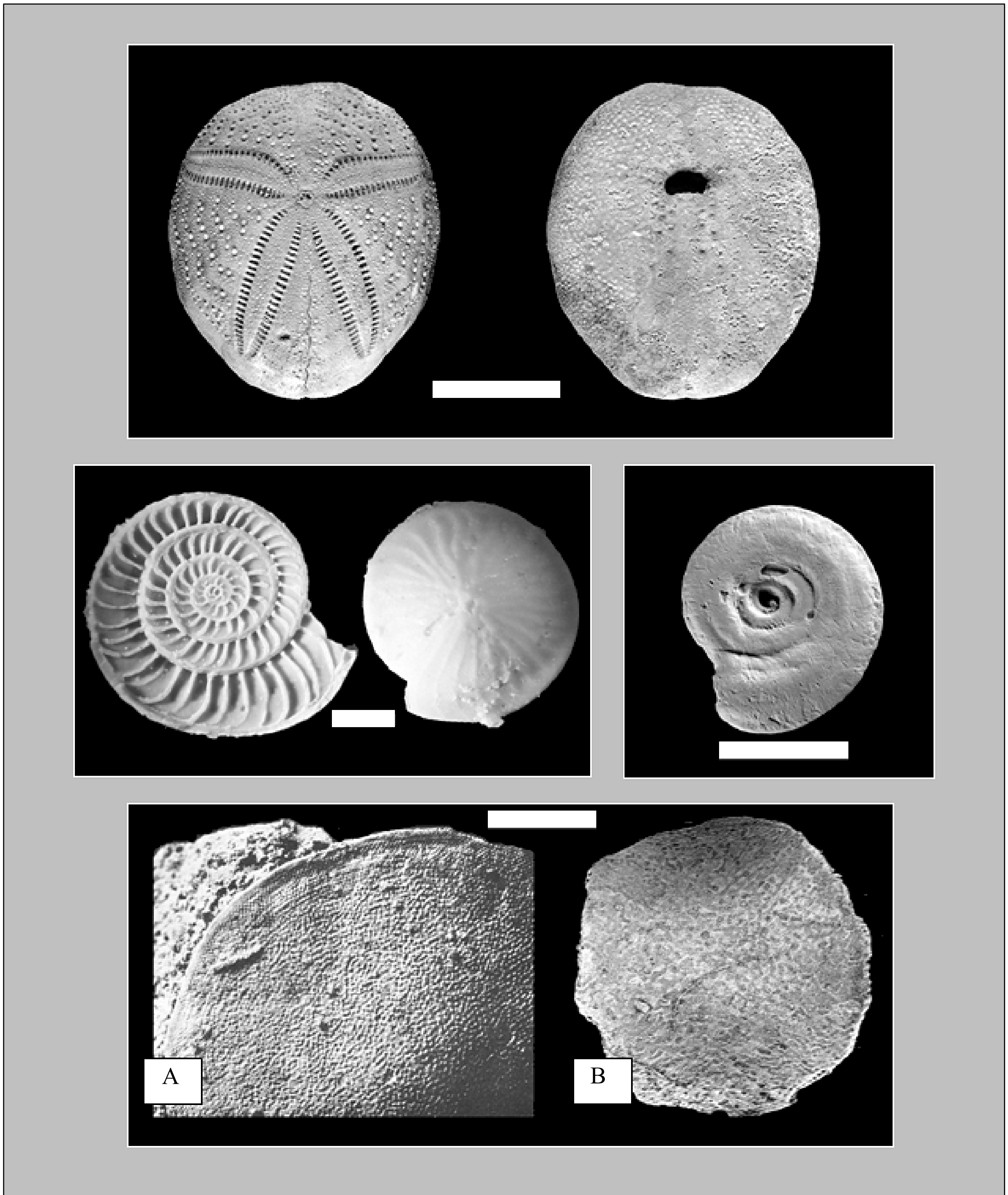

Figure 13. Selected diagnostic fossils within the Ocala Limestone. Top photo: *Eupatagus antillarum (*bar = 2.5 cm; photo courtesy of IP/FMNH). Middle row, left: *Nummulites* (*Operculinoides*) sp. (bar = 1mm; photo courtesy of Jonathan Bryan), right: *Rotularia* (*Spirolina*) *vernoni* (bar = 1 cm, photo courtesy of IP/FMNH). Bottom: *Lepidocyclina ocalana*, (bar = 3 mm); (A) from Cushman (1920), (B) from Rupert (1989).

Grainstones of the Ocala Limestone comprise the most permeable zones in the UFA. Porosity within the unit is generally moldic and intergranular with occasional macrofossil molds. Secondary porosity owing to carbonate dissolution is extensive and has greatly enhanced permeability, especially where confining beds are breached or absent (Berndt et al., 1998). Based on analyses of 70 samples, total porosity of the Ocala Limestone averages 39.8 percent (median = 41.0 percent) and ranges from 17.6 percent to 53.5 percent. Of the end-member dolostone lithologies reported by Gaswirth (2004), porosity of the "indurated" type averages 24 percent (n=30) and the "sucrosic" type averages 35 percent (n=28), (Gaswirth et al., 2006).

The Ocala Limestone occurs throughout the study area except where locally removed by erosion on the Ocala Platform in the southeastern part of Levy County and southwestern part of Marion County. In southwestern Orange County and northwestern Osceola County, the Ocala Limestone is also absent possibly due to structural offset and erosion. Miller (1986) proposes a graben-like fault system striking along the Polk-Osceola County boundary; however, data presented herein does not confirm its presence. An area of "locally absent" Ocala Limestone (Plate 39) does, however, approximately coincide with Miller's (1986) fault-bound area. The top of the Ocala Limestone occurs at or near land surface in the northern region (Figure 2) and deepens to approximately -1275 ft (-388.6 m) MSL in the southern region (Plate 39). The thickness of the unit exceeds 400 ft (121.9 m) in Charlotte and Highlands Counties (Plate 40). This lithostratigraphic unit is generally thought to be bound by unconformities (Braunstein et al., 1988; Loizeaux, 1995).

Two proposed structural features are significant with regard to the Ocala Limestone. A fault striking northwest in northwestern Polk County is proposed by Carr and Alverson (1959). Vernon (1951) and Stewart (1966) present contour maps of the "Inglis" (i.e., basal Ocala Limestone) suggesting local offset in the same area with the shallower "Inglis" sediments toward the northeast. This offset is consistent with Carr and Alverson's (1959) proposed fault. Although local thickness variations of the Ocala Limestone in this area are generally consistent with the proposed fault, the present study does not have sufficient well control to confirm the hypothesis. A fault proposed by Winston (1996) that trends northwest across Charlotte Harbor may be related to the deepening and thickening of the Ocala Limestone in this area.

Contact relationships between the Ocala Limestone and Avon Park Formation are discussed under *Avon Park Formation*, p. 31. In the northern and central regions, the boundary between the Ocala Limestone and the overlying Suwannee Limestone is usually not difficult to distinguish. Not only is the gamma-ray character different (Figure 10), but the uppermost Ocala Limestone is generally "cleaner" (i.e., significantly less non-calcitic material) finer-grained and more skeletal than the overlying unit. In some cases, Ocala Limestone lithoclasts are found at the base of the Suwannee Limestone (Loizeaux, 1995). Moreover, the fossil assemblage differs significantly, with the disappearance of *Lepidocyclina ocalana* and the appearance of *Fallotella* sp. (Suwannee Limestone) shallower in the section. There are, however, areas where the two units are difficult to distinguish. The transition from Ocala Limestone to Suwannee Limestone can be gradational toward the south, showing some evidence of interbedding and thus a possible conformable contact. Moreover, some areas contain basal Suwannee carbonates that range from fine-grained grainstones to mudstones, which can be difficult to distinguish from the underlying, sometimes altered, chalky mudstones and wackestones of the upper Ocala Limestone. Torres et al. (2001) and Brewster-Wingard et al. (1997) have also noted that the boundary is often difficult to pinpoint and suggest that foraminifera are often useful to distinguish the units.

Gamma-ray logs for the Ocala Limestone consistently exhibit very low gamma-ray activity (low, background-level count rates) and relatively fewer peaks than the overlying and underlying formations (Figure 10). In cases where the Ocala Limestone is dolomitized, the gamma-ray logs may exhibit a slightly higher and more sporadic signature (Arthur et al., 2001a). Many peaks in the gamma-ray logs for this unit correlate with the presence of trace organics or pyrite (e.g., W-12640 [ROMP 59]; Plate 21 and 32).

In peninsular Florida, Ocala Limestone deposition is interpreted to have occurred on a homoclinal distally steepened carbonate ramp in shallow (probably less than 10 m [32.8 ft]) subtidal to intertidal, somewhat high-energy, open marine environment (Randazzo et al., 1990; Cander, 1994; and Loizeaux, 1995). The Ocala Limestone represents a more constant and stable depositional environment than the underlying Avon Park Formation (Randazzo et al., 1990). Specifically, deposition of the Ocala Limestone occurred during a long-term eustatic high stand representing an overall transgressive sequence of sedimentation with shoreline progradation (Randazzo et al., 1990; Loizeaux, 1995). The lower Ocala Limestone represents a deepening upward sequence with the sediments becoming muddier through time and then shoaling in the uppermost Ocala (Randazzo et al., 1990). This appears to coincide with the post-middle Eocene marine transgressions followed by a fall in eustatic sea level at the end of late Eocene (Loizeaux, 1995).

Oligocene Series

Suwannee Limestone

The Lower Oligocene Suwannee Limestone was first identified by Cooke and Mansfield (1936). This formation ranges from light-gray to white, variably moldic packstones and grainstones. Carbonate grains are generally miliolids and peloids. Small amounts of sand (< 3 percent) and clay generally occur within the uppermost part of the unit when overlain by Hawthorn Group sediments. South of the study area, however, Missimer (2002) reports local sand beds in the Suwannee Limestone. Trace amounts of pyrite and organics (finely disseminated and as laminations) also occur throughout this formation (Arthur et al., 2001b; Price, 2003). The Suwannee Limestone is also variably dolomitized. For example, Green et al., (1995) noted a relatively consistent dolostone or dolomitic limestone bed (10-20 ft thick [~3-6 m]) occurring within the lower third of the unit in the central part of the study area. Chert is present throughout the unit, especially within the updip part of the unit. In Hernando County, for example, partial silicification of the limestone is observed, leaving echinoids in their original calcite form. Sedimentary structures include cross bedding and bioturbation (Budd, 2002). Porosity types include moldic and intergranular. Measured total porosity, based on analysis of 29 samples, averages 36.3 percent (median = 37.1 percent) and ranges from 2.3 percent to 55.8 percent. Fossils within the Suwannee Limestone include mollusks, gastropods, echinoids (most commonly the index fossil *Rhyncholampus gouldii*), abundant miliolids and other benthic foraminifera including *Fallotella* (*Dictyoconus) cookei, Discorinopsis gunteri* (Figure 14) and *Fallotella* (*Coskinolina) floridana* (Figure 12).

For the most part, the Suwannee Limestone unconformably overlies the Ocala Limestone and is unconformably overlain by Hawthorn Group sediments; however, there exists some question regarding the lateral extent of both unconformities. The contact between the subjacent Ocala Limestone and the Suwannee Limestone can be locally gradational, showing some evidence of interbedding. In some areas, the lower Suwannee Limestone increases in carbonate mud content, which can be difficult to distinguish from the sometimes chemically weathered, chalky upper Ocala Limestone. Torres et al. (2001) and Brewster-Wingard et al. (1997) have also noted that the boundary is often difficult to pinpoint. These researchers, as well as the authors of this report, suggest that foraminifera are often useful to distinguish the units.

The upper contact of the Suwannee Limestone is locally gradational with the overlying Tampa Member (Arcadia Formation) in northeastern Hillsborough and Pinellas Counties. Researchers faced with the difficulty of making formation picks in this area have come to informally refer to this transitional zone as "SuwTampaHaw" (Tom Scott, personal communication, 2004). The Suwannee Limestone is also locally overlain by green clays

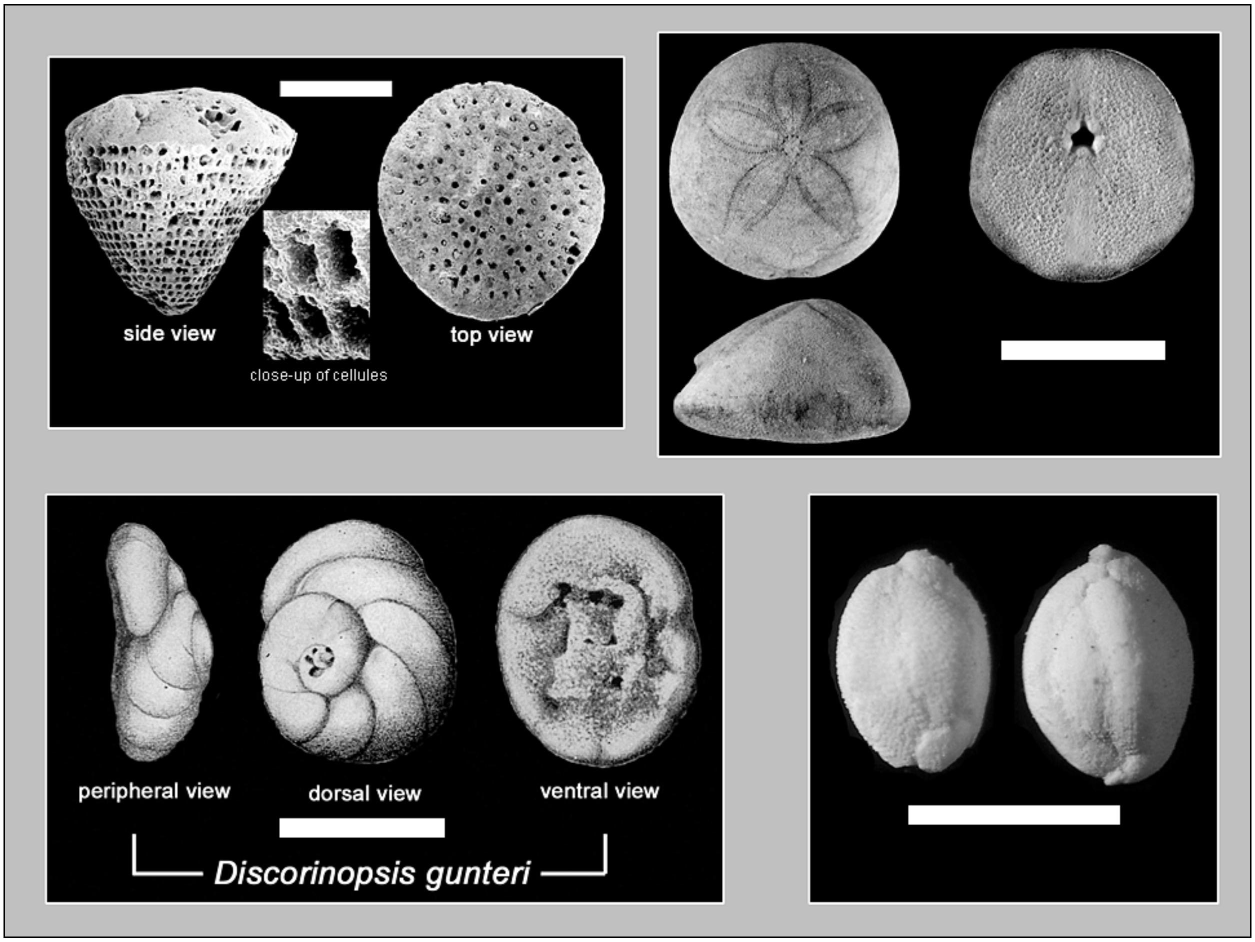

Figure 14. Selected diagnostic Suwannee Limestone fossils. Top row - left: *Fallotella* (*Dictyoconus*) *cookei* (bar = 1 mm; from Rupert, 1989), right: *Rhyncholampus gouldii* (bar = 2.5 cm, photo courtesy of Sean Roberts). Bottom row – left: *Discorinopsis gunteri* (bar = 2 mm; Cooke, 1945), right: milliolid (bar = 1 mm; photo courtesy Jonathan Bryan).

comprising the base of the Tampa Member (Arcadia Formation) in parts of northern and central Pinellas County, south-central Hillsborough County and eastern Polk County. In other areas, lack of phosphate sand in the Suwannee Limestone distinguishes it from overlying phosphatic (i.e., non-Tampa Member) Hawthorn Group sediments. South of the study area, however, Suwannee Limestone carbonates include minor occurrences of blackened (possibly francolite) discontinuity surfaces (Missimer, 2002).

The northern extent of the Suwannee Limestone occurs in Citrus County based on isolated outcrops and discontinuous borehole data. The approximate northern limit of laterally continuous Suwannee Limestone, however, occurs in southernmost Citrus County (Plates 41 and 42). In the eastern region, the subcrop limit occurs beneath the Lake Wales Ridge. In Highlands County, the eastern extent of the unit is uncertain and denoted with a dashed line (Plates 41 and 42). Two wells east of the line contain limited thicknesses of the Suwannee Limestone; however, nearby wells deep enough to have encountered the unit do not contain it. This suggests the two wells represent outliers. Maximum elevation of the unit exceeds 75 ft (22.9 m) MSL in parts of Hillsborough and Polk Counties as well as along the Brooksville Ridge, while in the southern region, depths exceed -825 ft (-251.5 m) MSL (Plate 41). Maximum thickness of the Suwannee Limestone in the study area exceeds 450 ft (137.2 m) in south-central Charlotte County (Plate 42).

Evidence supporting previously identified faults in the Suwannee Limestone exists to some degree within two areas. The feature most supported by the data presented herein is an inferred northwest-striking fault in northwestern Polk County (Figure 3). The Suwannee Limestone thickness map (Plate 42) indicates an abrupt change in thickness; wells reflecting more than 100 ft (30.5 m) of the unit are proximal to wells that contain no Suwannee Limestone even though the wells are deep enough to have encountered the unit (assuming similar regional dip). The strike and polarity of this particular feature, indicated as an inferred fault on Plate 41 and 42, roughly agrees with a fault proposed by Pride et al. (1966). Northeast of the fault, the Suwannee Limestone is reported to occur as exposed remnant boulders in Sumter County (Campbell, 1989).

A second inferred fault may occur along the updip limit of the Suwannee Limestone in northeastern Hernando County (Figure 3). Vernon (1951) reports a fault intersecting the "Inglis Member" in the area, with the upthrown side to the northeast. Data represented in Plates 41 and 42 support the location and polarity of Vernon's (1951) fault for the Suwannee Limestone. Thicknesses greater than 50 ft (15.2 m) terminate along the northeastern subcrop limit of the unit (Plate 41 and 42). In the Charlotte Harbor area, the "North Port" fault (Winston, 1996) may have affected the Suwannee Limestone surface and thickness, similar to that of the Ocala Limestone and Avon Park Formation. Other faults and lineaments are reported in this area (Hutchinson, 1991; Winston, 1996; Michael Fies, personal communication, 2007) suggesting a complex geologic setting.

The Suwannee Limestone is characterized by a gamma-ray log response (i.e., activity) that is generally more variable within the lower half of the unit (e.g., Plate 11 and 12; Figure 10). Relative to the Ocala Limestone, it has an overall higher background rate and exhibits much more variability. This variability is likely due to higher amounts of dolomite, organic material and other non-calcitic constituents in the Suwannee Limestone relative to the Ocala Limestone. Although the gamma-ray log is generally useful for providing corroborative evidence for the lithostratigraphic boundary between the Eocene - Oligocene carbonates, use of the logs for determination of the upper boundary of the Suwannee Limestone is not always as straightforward. For example, where the Tampa Member (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 (e.g., Plate 31, W-15204 [TR14-2] and Plate 33, W-16740 [ROMP 39]).

A generally consistent pattern in the Suwannee Limestone gamma-ray logs, especially for wells in Gulf-coastal counties, is the presence of a 50- to 100-ft (15.2 to 30.5 m) thick interval of high gamma-ray activity within the central to lower parts of the Suwannee Limestone. This interval varies in thickness and depth and apparently does not correlate with a given stratigraphic horizon. Inspection of lithologic logs suggests that this high gamma-ray activity zone is associated with dolomite and/or minor organic content.

The Suwannee Limestone, where present, comprises most of the FAS surface; exceptions being where hydraulic continuity exists between the Tampa Member (Arcadia Formation) and Suwannee Limestone in Pasco, Pinellas, most of Hillsborough and northern Manatee Counties (Figure 8). Along the updip limit of the Tampa Member in Pasco County, the top of the FAS includes the Tampa Member (where present) and the Suwannee Limestone (Figure 8). Grainstones within the Suwannee Limestone are among the most permeable zones in the UFA.

Suwannee Limestone deposition occurred in shallow open marine to peritidal environments on the Florida Platform (Cander, 1994) until the Late Oligocene sea-level low stand (Hammes, 1992). During deposition of the unit in the study area, the Georgia Channel System (Huddlestun, 1993) acted as a barrier to a southward influx of clastic sediments from the Appalachian Mountains. Deposition of the predominantly skeletal lithologies was cyclic and controlled by the pre-existing topography as well as fluctuating sea level. Restricted marine facies and skeletal shoal facies developed on previous highs and deeper subtidal facies occurred in the lows. Hammes (1992) describes the Suwannee

Limestone as three megacycles each composed of several shallowing upward cycles: 1) the outer ramp characterized by skeletal-rich, grain supported to muddy, open-marine, shallow and deep-ramp facies, 2) shallow ramp facies – composed of wave dominated skeletal banks and shoal complexes and shallow and deep subtidal lagoonal deposits, and 3) restricted marine – deposition in a restricted marine, brackish lagoon and mud-rich tidal flat environment.

Oligocene-Pliocene Series

Hawthorn Group

Hawthorn Group sediments range in age from mid-Oligocene (Brewster-Wingard et al., 1997) to Early Pliocene (Scott, 1988; Covington, 1993; Missimer et al., 1994) and generally consist of phosphatic siliciclastics (sands, silts and clays) and carbonates. Trace amounts of pyrite occur throughout the Hawthorn Group section in southwestern Florida (Lazareva and Pichler, 2007). In the study area, the Hawthorn Group consists of the Arcadia Formation, the Peace River Formation and undifferentiated sediments, all of which generally lie unconformably above the Suwannee Limestone and unconformably beneath undifferentiated Pliocene and younger sands, shells and clays. Benthic foraminifera characteristic of the Hawthorn Group include *Archaias* sp., *Sorites* sp., *Amphistegina lessoni* and *Cassigerinella (Cassidulina) chipolonsis* (Figure 15). Predominant formational members of the Hawthorn Group present in the study area include the Tampa and Nocatee Members (Arcadia Formation) and the Bone Valley Member (Peace River Formation). The extent of all Hawthorn Group sediments (Plate 43) generally includes those areas where undifferentiated confining beds of the IAS/ICU (Plate 56) are present beyond the mapped extent of the Arcadia and Peace River Formations (Plates 45 and 51, respectively) such as Marion County, Pinellas County and central Pasco County. The maximum observed thickness of the Hawthorn Group exceeds 825 ft (251.5 m) in south-central Charlotte County (Plate 44).

The Hawthorn Group was deposited in a shallow marine to nonmarine fluvial and deltaic environment that prograded over the older carbonate platform (Scott, 1988; Ward et al., 2003). Similar to other units mapped in this study, the top of the Hawthorn Group can demonstrate variable local relief, as exhibited by its irregular erosional and karstic surface (Berndt et al., 1998). Based on mineralogy of Hawthorn Group sediments, incipient stages of phosphogenesis occurred during the Late Oligocene during deposition of the lower Arcadia Formation (Brewster-Wingard et al., 1997). Sea-level fluctuations strongly influenced deposition and exerted a major control on phosphogenesis and sedimentation (Riggs, 1979a, 1984; Compton et al, 1993). During sea-level transgressions a large part of the Florida platform was submerged. Meandering of the Gulf Stream resulted in upwelling over the platform, which increased organic productivity and enhanced phosphogenesis in the shallow waters of the shelf (Compton et al, 1993). Maximum phosphorite precipitation is thought to have occurred in shallow-water coastal and nearshore shelf platforms or other submarine topographic highs (Riggs, 1979a). Sea-level fluctuations and ocean currents facilitated transport, deposition and concentration of phosphate grains (Scott, 1988, 1992b). Primary depositional features such as graded bedding and cross beds provide evidence of this high-energy depositional environment (Scott, 1988). The height of phosphate deposition and reworking was synchronous with Peace River Formation deposition (Middle to Early Pliocene).

Arcadia Formation

The Upper Oligocene (Brewster-Wingard et al., 1997) to Middle Miocene Arcadia Formation is comprised of a yellowish gray to white, variably sandy (quartz and phosphorite) carbonate with interbeds of siliciclastic-dominant sediments. Although limestone is present, dolostones are most common, ranging in grain size from microcrystalline to medium sand, with the more coarse material being sucrosic. Minor clays and chert beds (some comprised of silicified clay) also occur (Upchurch et al., 1982; Scott, 1988). Porosity types include intergranular and moldic.

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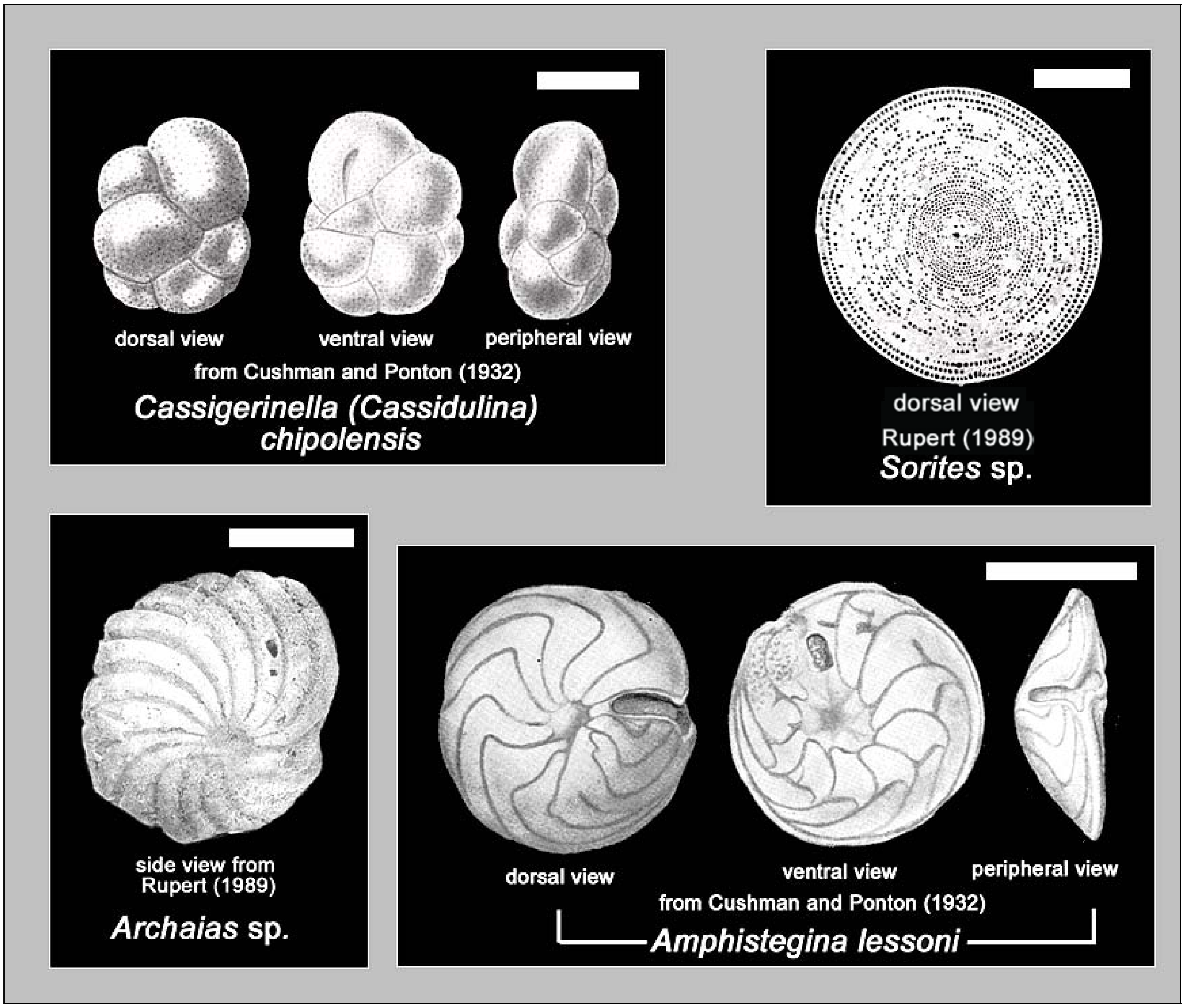

Figure 15. Diagnostic foraminifera in Hawthorn Group units. Upper left bar = 0.1 mm; upper right bar = 1 mm; bottom row, bar = 0.5 mm.

Measured total porosity of 25 Arcadia Formation samples averages 34.1 percent, with a median value of 32.4 percent and a range from 12.4 percent to 54.5 percent.

The updip limit of the unit occurs in northern Pasco and Polk Counties where maximum elevations exceed 90 ft (27.4 m) MSL (Plate 34 and 45). The top of the Arcadia Formation occurs at depths exceeding -270 ft (-82.3 m) MSL beneath the Lake Wales Ridge in the southeastern part of the study area. The unit ranges in thickness to greater than 750 ft (229 m) in south-central Charlotte County (Plate 46). Sporadically throughout much of the central and southern regions, the Arcadia Formation (undifferentiated) is observed below the Tampa and Nocatee Members. In several wells, the contacts between the Tampa and Nocatee Members and the underlying Arcadia Formation (undifferentiated) are gradational. The Arcadia Formation is unconformably overlain by the Peace River Formation (where present); however, apparent gradational contacts between these two units are locally observed.

In general, the Arcadia Formation comprises the most permeable parts of the IAS/ICU in the study area (see *IAS/ICU*, p. 57, for more details). In addition, the uppermost part of the FAS is comprised of the Tampa Member where it is in hydraulic connection with the subjacent

Suwannee Limestone (Figure 8).

Gamma-ray activity in the Arcadia Formation is distinctive, with strong gamma-ray peaks characterizing the upper undifferentiated part of the unit (e.g., W-16784 [ROMP 33], Plates 16 and 37; Figure 10). Lithostratigraphic members within and below the formation are characterized by significantly weaker gamma-ray responses. For example, where the undifferentiated Arcadia Formation overlies the Suwannee Limestone, the gamma-ray response for the older unit is often contrastingly low in gamma-ray activity (e.g., W-15683 [TR 3-3], Plate 19 and W-15333 [TR 2-1], Plates 19, 28 and 37). Although the high gamma-ray activity sequence in the Arcadia Formation is distinctive, it is not always useful as a diagnostic tool for identifying the upper formational boundary. Phosphate lag deposits locally comprising the base of the Peace River Formation have gamma-ray peaks as high as that of the Arcadia Formation.

Deposition of the Arcadia Formation is somewhat unique owing to its composition of mixed carbonate and siliciclastic sediments. In most depositional environments, an influx of siliciclastic sediments usually inhibits the production of carbonates. During the Oligocene, siliciclastics began to deposit along the Florida Platform (Hammes, 1992; Missimer, 2002). This influx of siliciclastics, during low sea-level stands, began to slowly bypass the Georgia Channel System (Huddlestun, 1993) as it filled. By Late Oligocene the lower part of the Arcadia Formation was being deposited and a more continuous influx of quartz sand was occurring (Missimer and Ginsburg, 1998). These siliciclastics were transported south several hundred kilometers to the southern part of the Florida carbonate platform by longshore currents (Scott, 1988; Missimer and Ginsburg, 1998). The rate of siliciclastic transport was initially episodic and sufficiently low to minimize interruption of the production of carbonates. Differences in shoreline positions caused by fluctuating sea levels allowed siliciclastics to mix over a broad area. Mixing of the carbonates and siliciclastics was achieved by tidal transport, storms, longshore currents, bioturbation and aeolian processes (Scott, 1988; Missimer and Ginsburg, 1998; Missimer, 2002). Missimer and Ginsburg (1998) list three important factors that allowed the homogenized, co-deposition of Arcadia Formation carbonates and siliciclastics to occur: 1) a relatively slow rate of siliciclastic sediment influx, 2) the lack of mud or clay, and 3) marine transport without river or stream transport. Freshwater input would have caused an increase in finer-grained siliciclastics (e.g., silts and clays), increased turbidity and decreased salinity, all of which would have diminished carbonate production.

Noteworthy topographic features occur along the surface of the Arcadia Formation. In the Tampa Bay area, interpreted seismic data indicate subsurface relief of up to ~197 ft (60 m; Hine et al., in press). These features are attributed to “spatially restricted, semi-enclosed, siliciclastic-filled karst” that may coalesce into larger collapse systems (Hine et al., in press). A karst basin identified in their study due south of the Pinellas County peninsula in Tampa Bay correlates well with a trough extending northward into the peninsula (Plate 45; see also Tampa Member surface map, Plate 49).

Along the southern part of the Lake Wales Ridge, the Arcadia Formation deepens sharply (Plate 45). This elongate depression (or trough) also occurs in the overlying Peace River Formation (Plate 51). Although topographic relief of the troughs are similar (~175 to ~200 ft; ~53 to ~61 m), the Arcadia Formation exhibits little evidence of thinning, unlike the Peace River Formation (Plate 52). Periods of erosion (scouring?) or non-deposition owing to sea-level fluctuations and paleo-ocean currents are likely factors contributing to the origin of this trough. Miocene-Pliocene structural control of the feature is not indicated by the thickness of either formation. The thickness of post-Hawthorn Group sediments (see Plate 55 for approximation) suggests that the trough may have become a depoaxis for Pliocene-Pleistocene siliciclastics.

A third significant topographic feature occurs in south-central Charlotte County, where the surface of the Arcadia Formation deepens to more than 200 ft (60.9 m) MSL and notably thickens to more than 700 ft (213 m; Plates 45 and 46). Locations of depocenters within subjacent lithostratigraphic units occur in roughly the same locale: the Ocala Limestone, Suwannee Limestone and Hawthorn Group deepen in this area (Plates 39, 41 and 43, respectively), and the units thicken as well (Plates 40, 42 and 44, respectively). This basin is also observed in the surface of the Avon Park Formation (Plate 38); however, due to lack of well control, Miller's (1986) Middle Eocene maps do not reflect this feature. These observations suggest that the area experienced continued subsidence and infilling from Middle Eocene through at least Late Miocene. Alternatively, the apparent depocenters may have structural control owing to the proximity of the "North Port" fault (Winston, 1996).

Nocatee Member

The Upper Oligocene (Brewster-Wingard et al., 1997) Nocatee Member of the Arcadia Formation is an interbedded sequence of quartz sands, clays and carbonates all containing variable amounts of phosphate (Scott, 1988) that generally average five percent but locally can reach ten percent or more. The unit is predominately siliciclastic and generally interbedded with lower percentages of carbonate. Original macrofossil material is not common in this unit; however, fossil molds of mollusks, algae and corals are observed. Diatoms are commonly found within the clay units. Porosity of the Nocatee Member is generally intergranular, with highly variable permeability. Total porosity of five core samples from the Nocatee Member average 27.5 percent (median = 24.7 percent) and range from 20.4 percent to 35.4 percent.

The subcrop extent of the Nocatee Member includes west-central Polk County south to Charlotte and Glades Counties and extends as far west as central Sarasota County. The northeastern limits of the unit are generally well defined and comprise a stratigraphic pinchout (e.g., Polk and Highlands Counties); however, the southwest extent is more subjective as the unit grades laterally into the undifferentiated Arcadia Formation, or locally into the Tampa Member. In an area extending south from southwestern Polk County, the Nocatee Member is conformably overlain by the Tampa Member of the Arcadia Formation. Elsewhere in the study area, the upper and lower limits of the Nocatee Member are gradational into the undifferentiated Arcadia Formation.

The top of the Nocatee Member ranges in elevation from greater than 50 ft (15.2 m) MSL in west-central Polk County to depths exceeding -600 ft (-183 m) MSL in the southeastern part of the study area (Plate 47). Although the Nocatee Member ranges in thickness to more than 240 ft (73.2 m), it averages approximately 75 ft (22.9 m) thick (Plate 48).

Gamma-ray activity within the Nocatee Member is generally less than or equal to that of the overlying Hawthorn Group units (i.e., Tampa Member and Arcadia Formation; e.g., Figure 10 and Plate 26). Where the Nocatee Member is underlain by (and generally grades into) the undifferentiated Arcadia Formation, gamma-ray logs are not as useful in distinguishing between the two units. On the other hand, where the Nocatee Member overlies the Suwannee Limestone, the gamma-ray activity can be very useful for distinguishing the two units.

Although most of the Nocatee Member correlates with the IAS/ICU, this lithostratigraphic unit is hydraulically connected to the UFA within part of DeSoto County (Figure 8) and thus locally comprises the uppermost UFA in those areas.

The Nocatee Member was deposited on the southeast edge of the carbonate bank prior to and during deposition of the Tampa Member. The Nocatee represents a higher energy, more open near-shore environment and grades westward into a very sandy facies of the undifferentiated Arcadia Formation and northwestward into the carbonate facies of the Tampa Member (Scott, 1988).

Tampa Member

The Upper Oligocene to Lower Miocene (Brewster-Wingard et al., 1997) Tampa Member of the Arcadia Formation is white to yellowish gray in color and ranges from a wackestone to packstone with varying amounts of quartz sand and clay (Scott, 1988). Minor phosphate (less than 3 to 5 percent), dolomite and chert (siliceous limestone, silicified corals; see also Upchurch et al., 1982) are also observed. Fossil molds of foraminifera, mollusks, gastropods and algae are all common within the Tampa Member (Scott, 1988). Pinkish gray to light olive gray dolostones also occur with a similar accessory mineral assemblage and fossil assemblage as the limestones. Thin sand and clay beds can be found sporadically within the unit (Scott, 1988). Porosity of the Tampa Member is generally intergranular and moldic, with measured total porosity values (17 samples) ranging from 10.4 percent to 49.6 percent, averaging 32.3 percent (median value = 33.6 percent).

The subcrop limit of the Tampa Member extends from Pasco County to the northernmost part of Charlotte County and eastward into the western half of Polk, DeSoto and Hardee Counties (Plate 49 and 50). The top of the Tampa Member ranges from more than 100 ft (30.5 m) MSL in Pasco County to deeper than -350 ft (-107 m) MSL in Sarasota County (Plate 49) and exhibits variable thickness. The maximum observed thickness of the Tampa Member is 292 ft (89.0 m) (Plate 17; W-14882 [TR 6-1]); however, some would propose that the lower Tampa Member in this well is more characteristic of the undifferentiated Arcadia Formation.

In the northern third of its extent, the Tampa Member overlies the Suwannee Limestone and the contact appears to be locally conformable. In Pinellas and northwest Hillsborough Counties, for example, samples have been informally referred to as "SuwTampaHaw" due to the subtle transition between the units. In the central and southern regions, this unit overlies the Arcadia Formation (undifferentiated), or the Nocatee Member of the Arcadia Formation. In many wells, the transition between the Tampa Member and the underlying Arcadia Formation is gradational, with phosphorite content increasing with depth. The Tampa Member is conformably overlain by the Arcadia Formation (undifferentiated) in many areas (e.g., Plate 14); however numerous exceptions exist. In parts of Pasco and northern Hillsborough Counties, the unit is unconformably overlain by UDSC or undifferentiated clay-rich Hawthorn Group sediments. East of this area, the Tampa Member is unconformably overlain by the Peace River Formation. Toward the east and south, the Tampa Member facies grades laterally into the Arcadia Formation. In Sarasota County, the unit appears to grade laterally into the Nocatee Member as it becomes increasingly more sandy. Scott (1988) also reports this lateral facies change in northern Hardee County.

The Tampa Member generally exhibits variable gamma-ray activity (Figure 10; Arthur et al., 2001a) that limits the value of this log to discern unit boundaries. For example, when underlain by the Arcadia Formation (undifferentiated), the Nocatee Member or the Suwannee Limestone, it is difficult to distinguish these units from the Tampa Member based on gamma-ray activity. On the other hand, where the Tampa Member is overlain by the Arcadia Formation, the two units are usually readily distinguishable due to higher gamma-ray activity in the undifferentiated Arcadia Formation.

Along the updip erosional pinchout of the Tampa Member, where it forms an irregular subcrop contact with the Suwannee Limestone (Plate 49), the top of the FAS generally coincides with the uppermost carbonate unit occurrence (Figure 8). In the west-central part of the study area, the Tampa Member is the uppermost lithostratigraphic unit within the FAS (Figure 8); however, based on lithologic and hydrologic data from wells in south-central Hillsborough County, the Tampa Member is locally hydraulically separated from the Suwannee Limestone and is therefore considered part of the IAS/ICU (Figure 8). This latter hydrogeologic setting occurs locally in northern Pinellas County as well.

The depositional environment of the Tampa Member was that of a quiet water lagoon, much like present day Florida Bay (King, 1979). An influx of siliciclastics nearly devoid of phosphorite distinguishes Tampa Member deposition from older and younger Hawthorn Group units in the stratigraphic section.

"Venice Clay"

The Venice Clay is an informal unit originally considered part of the lower Tamiami Formation (Pliocene); however, microfossil data suggest an age of Early to Middle Miocene (Scott, 1993). Scott (1992b) suggests informal placement of the Venice Clay in the upper half of the Arcadia Formation based on subjacent and suprajacent lithologies and preliminary fossil evidence. The Venice Clay is gray-green magnesium-rich clay, variably dolomitic with minor amounts of quartz sand and silt. The unit rarely contains phosphorite and becomes increasingly silty toward its upper and lower contacts (Campbell et al., 1993).

The subcrop extent of the Venice Clay includes Sarasota County and adjacent parts of Manatee, DeSoto and Charlotte Counties; the unit may also extend offshore (Barr, 1996). Based on data collected in the present study, the top of the unit generally occurs between -10 ft MSL and -100 ft MSL (-3.1 to -30.5 m). Barr (1996) reports that thickness of the unit ranges up to approximately 30 ft (9.1 m). Gamma-ray activity is diagnostically very low for this unit, (note clay beds near top of the Arcadia Formation in W-15683 [TR 3-3]; Plate 19), suggesting the mineral assemblage does not include abundant potassium-rich illite-group clays. The Venice Clay was likely deposited in a quiet shallow water marine environment - possibly an estuary (Tom Scott, personal communication, 2004).

The Venice Clay acts as a confining unit in the upper part of the IAS/ICU. Specifically, Barr (1996) suggests that it comprises the confining unit below "permeable zone 1." Owing to its limited thickness and aerial extent, as well as recent mapping by Barr (1996), the Venice Clay is not mapped in the present study.

Peace River Formation

The Middle Miocene to Lower Pliocene (Scott, 1988; Covington, 1993) Peace River Formation is comprised of yellowish gray to olive gray, interbedded sands, clays and carbonates with the siliciclastic component being dominant (Scott, 1988). The relative abundance of carbonate beds generally increases toward the south, especially near the base of the unit. Variable amounts of phosphate sand and gravel are interspersed throughout the unit; however, they are most common within the uppermost beds. The Peace River Formation contains a diverse fossil assemblage of marine and terrestrial fauna (e.g., shark teeth and vertebrae, ray spines, horse teeth, dugong and whale ribs, etc.), especially within the Bone Valley Member (Figure 16). Porosity types in the formation are generally intergranular, except in the carbonate-rich zones, where moldic porosity is also present. Only two total porosity analyses of Peace River Formation samples have been measured in this study. The results, 34.4 percent and 39.4 percent, should not be taken as representative of the unit given its diverse lithology.

Lithologic characteristics of the Peace River Formation are generally consistent; however, the carbonate component becomes more prevalent from north to south as the unit thickens. Throughout most of its extent, the Peace River Formation does not contain shell material, with possible exception of southeast DeSoto County, where barnacles are present within the unit (Green et al., 1999). These barnacle-rich sediments may be the equivalent of "unit 11" from Petuch (1982). Missimer (2001) reports shell material in the Peace River Formation south of Charlotte County. In the same region, calcareous nannofossils occur in the unit (Covington, 1993).

The Peace River Formation generally has an unconformable contact with the underlying Arcadia Formation. In an isolated area in north-east-central Hillsborough County, the Peace River Formation directly overlies the Tampa Member (Plates 13 and 33). The Peace River Formation also has an unconformable contact with the underlying Ocala Limestone in northern Polk County (Plates 11 and 34; W-14389 [ROMP 76]). In this area, reworked Peace River Formation sediments may occur unconformably above the Avon Park Formation where the Ocala

Figure 16. Assemblage of typical Bone Valley Member fossils. Clockwise from upper left: ray spines, shark vertebra, shark teeth, horse teeth, alligator tooth in matrix, (nickel for scale) dugong rib, mammoth tooth and bone fragment. Background is a slab of Avon Park Formation dolostone with *Thalassodendron* sp. carbonized impressions. (Photo credit: Jon Arthur, FDEP-FGS).

Limestone is locally absent (Plate 39).

Delineation of the Peace River – Arcadia Formation contact is problematic in some localities. In many cores, the two units appear to be conformable, with phosphate-rich siliciclastics grading with depth to more siliciclastic-interbedded carbonates containing generally finer-grained and less abundant phosphorite. Thickness of this transition zone may exceed tens of feet. With increasing depth, Arcadia Formation lithologies become more dominant. In such cases, the lower contact of the Peace River Formation is estimated based on sedimentary structures as well as a best approximation of where the overall lithologic sequence becomes more carbonate dominant. In contrast to the locally gradational contacts, other areas provide strong evidence of an unconformity, where a phosphatic rubble zone occurs at the base of the Peace River Formation (Scott, 1988).

Post-Pliocene/Miocene sediments disconformably overlying the Peace River Formation in the study area are comprised of fossiliferous sands, clays and shell beds with variable amounts of limestone and reworked phosphorite (e.g., Plate 11, W-14389 [ROMP 76] and Plate 13, W-16576 [ROMP DV-1]). The contact of these sediments with the Peace River Formation can be difficult to determine because of lithologic similarities (e.g., clays and phosphorite), especially where the uppermost beds of the Peace River Formation have been leached by groundwater, giving the sediments an appearance similar to that of some post-Hawthorn Group lithologies. In addition, it can be very difficult to distinguish Peace River Formation sediments from those of reworked Peace River sediments (e.g., post-Hawthorn Group undifferentiated sands and clays) when studying cores (the distinction is extremely difficult to impossible when evaluating cuttings).

Similar to basal Peace River Formation lag deposits, reworked Miocene-Pliocene sediments may also yield a phosphate lag deposit at the base of overlying (e.g., post-Hawthorn Group) sediments. Units superjacent to the Peace River Formation include the Tamiami, Ft. Thompson and Caloosahatchee Formations. In most cases, the Peace River Formation is readily distinguished from these overlying sand/shell/carbonate lithofacies.

Lateral facies transitions of the Peace River Formation are most evident along the northwestern extent of the unit in Hillsborough and Polk Counties (Plate 51). In this area, sediments characteristic of the Peace River Formation grade into clay-rich and phosphate-poor sediments of the undifferentiated Hawthorn Group (e.g., Plate 13).

Maximum elevations of the Peace River Formation occur in the vicinity of the Polk Upland and Lakeland Ridge, where the unit exceeds 125 ft (38.1 m) MSL (Plate 51). The maximum observed depth of the Peace River Formation exceeds -200 ft (-60.9 m) MSL along the Lake Wales Ridge. Thicknesses range to over 120 ft (36.6 m) along the southeastern third of the unit's mapped extent (Plate 52).

Gamma-ray activity in the Peace River Formation is highly variable. In some areas, due to the high-phosphorite content in the sediments, strong gamma-ray peaks are readily observed in contrast to lower gamma-ray activity of the Arcadia Formation (e.g., W-16576 [ROMP DV-1], Plate 33). The opposite occurs as well, where gamma-ray activity in the Peace River Formation is lower than that of the Arcadia Formation (Figure 10). Where the Peace River Formation lies above Eocene carbonates, the difference is also pronounced, with the younger unit exhibiting a stronger gamma-ray signal (Plate 20). In many wells, a lack of gamma-ray contrast between the Peace River Formation and the Arcadia Formation is observed (W-16740 [ROMP 39], Plate 33). In wells where the base of Peace River Formation contains a reworked phosphate lag deposit, a characteristically strong gamma-ray peak is observed (e.g., W-15938, Plate 22). The unit may also be overlain by a similar lag deposit within undifferentiated post-Hawthorn Group sediments.

The Peace River Formation is a regional confining to semi-confining lithostratigraphic unit within the upper part of the IAS/ICU. North of central Hillsborough and Polk Counties, the Peace River Formation and undifferentiated Hawthorn Group sediments comprise a low-permeability confining to semi-confining facies of the IAS/ICU. South of this region, permeable, water-producing zones exist within interlayered carbonate lenses (e.g., Ryder, 1985, Torres et al., 2001). In some areas, the uppermost sediments of the Peace River Formation are in hydraulic connection with overlying sands due to a low-to-absent clay content (e.g., Plate 17, W-14382 [ROMP 23]). As a result, the Peace River Formation may comprise the lower part of the SAS. Clay-poor sediments occur within the uppermost Peace River Formation in eastern Sarasota County and western Manatee County (Tom Scott, personal communication, 2006).

The Middle Miocene – Lower Pliocene Peace River Formation sediments characterize a complex depositional environment strongly influenced by sea-level fluctuations (Missimer et al., 1994). The northern extent of the unit was deposited in a shallow marine, deltaic to brackish water environment while further south open marine conditions prevailed (Scott, 1988). Carbonate deposition in the unit was periodically restricted by a flood of siliciclastics from the north and a rise in sea level (Scott, 1988). Missimer (2001) suggests that the Peace River Formation immediately south of the study area was deposited in a variety of depositional environments ranging from inner ramp to deltaic to beach and can be explained by shoaling upward or lateral accretion of sediment. Sea-level transgressions or highstands appear to favor phosphogenesis, while reworking of the sediments during sea-level regressions or lowstands concentrate the phosphorite (Compton et al., 1993). Phosphorite concentrations are considered economic ore deposits in the central region and are locally mined.

Bone Valley Member

The Middle Miocene to Lower Pliocene (Webb and Crissinger, 1983) Bone Valley Member of the Peace River Formation has a limited areal extent, centered in southwestern Polk County (Plate 53). It occurs in the Central Florida Phosphate District which is among the world's largest economic phosphorite deposits (Freas and Riggs, 1968). Due to mining, most of the Bone Valley Member sediments have been removed. Although similar in lithology to the Peace River Formation, the Bone Valley Member contains greater amounts of phosphorite (more than 30 percent by volume) that is coarser-grained, ranging up to gravel-size nodules. Phosphorite occurs as carbonate-fluorapatite (francolite) nodules, peloids, fecal pellets, intraclasts and grain coatings. Some pebble-sized grains show evidence of reworking, boring structures and multiple stages of phosphatization. The non-phosphorite component of the Bone Valley Member is comprised of quartz sand with clay (e.g., palygorskite and sepiolite; Scott, 1988) generally exceeding 20 percent by volume. Carbonate beds are not present; however limestone and dolostone cobbles and larger fragments are observed (Tom Scott, personal communication, 2005).

An extremely diverse fossil assemblage exists within the unit (Webb and Crissinger, 1983) ranging from dugong and whale ribs, shark teeth and turtle scutes to petrified wood and teeth from horses and alligators (Figure 16). Thicknesses of the Bone Valley Member exceed 40 ft (15.2 m) (Plate 54). In terms of hydrologic function, the unit is a localized, yet efficient confining unit within the IAS/ICU. On the other hand, due to the significant economic value of phosphorite deposits, the unit has been extensively mined thereby reducing or eliminating local confinement.

Owing to the high phosphorite content, gamma-ray log intensities for Bone Valley Member sediments are very high. For example, the truncated, high-intensity gamma-ray peak at the top of the Peace River Formation for W-14385 (ROMP 45; Plate 22) represents Bone Valley Member sediments.

Many questions exist regarding the genesis of phosphate in Florida. Given the diverse fossil assemblage, it reflects near-shore marine conditions and is unlike other large phosphate deposits of the world. Parts of the Bone Valley Member were deposited in a high-energy nearshore environment (topographic highs) while other parts were deposited in a shallow marine environment such as an embayment or lagoon (Scott, 1988). The stratigraphy of the unit is complicated by rapid facies changes and post-depositional erosion, redeposition and weathering (Freas and Riggs, 1968; Webb and Crissenger, 1983).

Hawthorn Group (Undifferentiated)

Undifferentiated Hawthorn Group sediments lie unconformably above Eocene and Oligocene carbonates and unconformably below undifferentiated Pliocene and younger sands and clays along the upland geomorphic provinces within the northern region, as well as in parts of Pinellas, Hillsborough and Polk Counties. In Marion, Sumter and Lake Counties, sediments mapped as undifferentiated Hawthorn Group may be comprised of one or more of the following lithostratigraphic units (from oldest to youngest): the Penney Farms Formation, the Marks Head Formation and the Coosawhatchie Formation (Scott, 1988). These formations are not delineated owing to their limited extent and stratigraphic pinch-out along the northeastern part of the study area. Moreover, Scott (1988) reported on the difficulty of distinguishing the uppermost Coosawhatchie Formation from undifferentiated Hawthorn Group sediments in central Florida. In the north-central part of the study area, undifferentiated Hawthorn Group sediments occur along the Brooksville Ridge (e.g., W-6903, Plate 5 and W-15933, Plate 9) as well as within karst features and isolated lenses flanking the ridge. Vernon (1951) describes "Miocene Hawthorn formation" sediments along the Brooksville Ridge in Citrus County as greenish-gray montmorillonitic clays. The distribution of these sediments, as well as the occurrence of hard-rock phosphate in the region lend support to the proposal by Scott (1988) that Hawthorn Group sediments once covered the entire Florida peninsula. Upchurch (1992) also suggests that Hawthorn sedimentation occurred on the crest of the Ocala Platform.

Undifferentiated Hawthorn Group sediments are generally comprised of clay beds with variable amounts of carbonate, quartz sand and silt, phosphorite, organic material and minor shell fragments. Maximum elevations of undifferentiated Hawthorn Group sediments exceed 100 ft (30.5 m) MSL along inland uplands and ridges north of Pasco County. In Pinellas County, these sediments generally occur deeper than -25 ft (-7.6 m) MSL. Undifferentiated Hawthorn Group sediments occurring in Hillsborough, Pinellas and Pasco Counties grade laterally southeastward into the Peace River Formation. In central Pinellas County undifferentiated Hawthorn Group sediments exceed 100 ft (30.5 m) thick and grade southward into the Arcadia Formation (Plate 31).

Gamma-ray response of the undifferentiated Hawthorn Group sediments varies from low-background counts where the unit is dominated by clays, to broad and diffused patterns where phosphorite is more abundant. Gamma-ray logs are generally not very useful as a tool to determine the contact with underlying and overlying units.

In the northern region, undifferentiated siliciclastic sediments of the Hawthorn Group comprise discontinuous semi-confinement between the SAS and FAS. The lateral extent and effectiveness of this lower-permeability layer is difficult to define due to factors such as: 1) variable lithology (e.g., percent clay) and thickness, 2) desiccation cracking of thin clay-rich beds during long-term low-water table conditions and 3) breaches due to fractures and sinkholes. As a result, many areas in this region are denoted on Plate 55 as "discontinuous basal confinement of SAS." These same areas are likewise labeled "discontinuous" on Plates 56 and 57.

Pliocene and younger Series

Post-Hawthorn Group Sediments

Sediments overlying Hawthorn Group and older units in the study area are generally comprised of varying percentages of undifferentiated sand, shell and clay. Within the eastern half of the study area, the Cypresshead Formation dominates most uplands (Figure 2) and is well exposed along the Lake Wales Ridge. In the southern region, three Pliocene-Pleistocene formations are recognized: the Tamiami Formation, the Caloosahatchee Formation and the Fort Thompson Formation. The latter two formations are faunally rather than lithologically based. As a result, Scott (1992c) provides a conceptual framework to include Caloosahatchee and Fort Thompson sediments as part of the Okeechobee formation (informal). The framework also includes informal "Bermont formation" sediments.

Although mapping post-Hawthorn Group sediments is beyond the scope of this study, general descriptions of the units are provided herein. These undifferentiated surficial sediments and formations generally comprise the SAS. In the southern region, the lower Tamiami Formation is considered part of the IAS/ICU. In the cross sections (Plates 4-37), undifferentiated sediments are broadly classified as sand and clay (UDSC) or sand and shell (UDSS). Existing lithologic descriptions may identify "Pliocene – Pleistocene" sediments (often referred to as "PCPC"); however in the present study, these sediments are labeled "UDSC" due to difficulty in distinguishing the two undifferentiated types as well as inconsistent usage of PCPC. Gamma-ray activity in post-Hawthorn Group sediments is highly variable (Plates 4-37; Davis et al., 2001). In some areas, however, a consistent peak at the base of these sediments represents a phosphate lag deposit reworked from Hawthorn Group sediments (Scott, 1988; Green et al., 1995; see also W-16303 [TR 7-4] and W-17057 [TR 7-2], Plate 16).

Tamiami Formation

Lithology of the Lower- to mid - Pliocene (Missimer, 2002) Tamiami Formation (Mansfield, 1939) is difficult to characterize due to the large number of sediment facies it contains. These facies occur over a large region of southern Florida and represent a complex set of depositional environments (Berndt et al., 1998). The Tamiami Formation consists of a wide range of mixed carbonate/siliciclastics (sandy limestone, sand and clay with varying percentages of phosphate grains) and shell beds that are subdivided as members (e.g., Ochopee Limestone Member) south of the study area (Missimer, 1993). The Tamiami Formation is unconformably overlain by the Caloosahatchee Formation and overlies the Peace River Formation either conformably or unconformably.

Where present in the study area, the Tamiami Formation is part of the IAS/ICU and SAS (Berndt et al., 1998). A semi-regionally extensive clay layer within the Tamiami Formation comprises the top of the IAS/ICU, whereas the uppermost higher permeability sediments are hydraulically connected with the SAS.

Sands and finer-grained facies probably represent deposition in a regressing Tamiami sea in the brackish water of a lagoon or bay (DuBar, 1962). Deposition of the shell beds are most likely the result of storms and processes occurring in shallow coastal waters (Missimer, 2001). Phosphatic quartz sand facies containing giant barnacles and echinoids exposed along Alligator Creek and in pits near Acline (Charlotte County) are thought to represent deposition in a shallow water, nearshore environment (DuBar, 1962).

Cypresshead Formation

The Upper Pliocene Cypresshead Formation (Huddlestun, 1988) is composed entirely of siliciclastics, predominantly quartz and clay minerals (Scott, 1992b; Berndt et al., 1998). It consists of characteristically mottled reddish brown to reddish orange, unconsolidated to poorly consolidated, fine to very coarse grained, clean to clayey sands (Scott, 2001), some of which are cross bedded. Discoid quartz pebbles and mica are also often present. Clay beds are generally thin and discontinuous. Overall, the clay content varies from trace amounts to more than 50 percent, averaging 10-20 percent (Scott, 1992b). Due to weathering, the clays are often altered to kaolinite. Davis et al. (2001) describe three lithozones within the unit, which are based on color, sedimentary structures and varying proportions of siliciclastics. Original fossil material is not present in the sediment but poorly preserved casts and molds of mollusks and burrow structures are occasionally present (Scott, 2001).

The Cypresshead Formation occurs in the central uplands of the Florida peninsula south into Highlands County (Arthur, 1993; Scott et al., 2001). Exposure of the formation generally occurs above 100 ft. (30.4 m) MSL (Scott, 1992b, 2001). In the northern half of the study area, the unit lies unconformably on Eocene carbonates, whereas in the southern half it unconformably overlies Hawthorn Group sediments. The Cypresshead Formation can be readily distinguished from the Hawthorn Group because the younger unit is non-phosphatic, contains prominent horizontal bedding and cross bedding, is largely nonfossiliferous and contains burrow and bioturbation structures (Huddlestun, 1988). Along the Lake Wales Ridge, the SAS is comprised of sediments from the Cypresshead Formation and undifferentiated sediments (Scott, 1992b). Huddlestun (1988) suggests that the depositional environment was coastal marine (see also discussion of Figure 7 on p. 15).

Caloosahatchee Formation

The Caloosahatchee Formation was first recognized by Heilprin (1887) as a Pliocene formation he called the “Floridan Beds.” Dall (1887) also considered the deposits Pliocene and described many of the fossils; he referred to them as the Caloosahatchee Beds or Marls. Scott (1992c) includes sediments informally referred to as the Bermont formation within the

Caloosahatchee Formation and reports a Late Pliocene to Early Pleistocene age. The Caloosahatchee Formation consists of marls composed primarily of quartz sand, silt and shells with varying amounts of carbonate in the matrix. It varies from poorly indurated to well indurated and the fauna is varied and often well preserved. Usually moderately to abundantly fossiliferous, some sands are almost or completely barren of fossils (DuBar, 1958). Freshwater limestones are commonly present.

The extent of the Caloosahatchee Formation is shown on previous geologic maps by Cooke (1945) and Vernon and Puri (1964). The contact between the subjacent Tamiami Formation and the Caloosahatchee Formation is generally unconformable. The Tamiami Formation was subjected to significant subaerial erosion and the deposition of the Caloosahatchee Formation gradually filled in old “Tamiami valleys” (DuBar, 1958). The Caloosahatchee Formation comprises part of the SAS. In most hydrogeological investigations, the Caloosahatchee Formation is not differentiated from the Fort Thompson Formation (Scott, 1992a). The depositional environment was subtropical with predominantly carbonate deposition and a coastal influx of quartz sand. Tropical and subtropical mollusks and corals abundant in the unit reflect an environment similar to the present area between Cape Sable and Florida Bay (Missimer, 2001).

Fort Thompson Formation

Sellards (1919) proposed the name Fort Thompson Beds, which were informally designated a formation by Cooke and Mossom (1929). DuBar (1958) recognized the unit as upper Pleistocene. The Fort Thompson Formation is a sandy limestone deposited under freshwater and marine conditions. The sand is fine to medium grained and is interlayered with shell beds and limestones. The shell beds are slightly indurated to unconsolidated and variably sandy (Scott, 1992b; Berndt et al., 1998). A characteristic Fort Thompson marine fossil is *Chione elevata* and *Helisoma scalare* (Figure 17) is typical of freshwater beds in the unit (DuBar, 1958).

The Fort Thompson Formation is thin, does not exceed 30 ft (9.1 m) in thickness, and has an unconformable relationship to the variable units above and below. It is most commonly underlain by the Caloosahatchee Formation or the Tamiami Formation (DuBar, 1958). The Fort Thompson Formation is part of the undifferentiated sediments in southern Florida (Scott, 1992b) and comprises part of the SAS. The extent of the Fort Thompson Formation is shown on geologic maps by Cooke (1945) and Vernon and Puri (1964). On the most recently published geologic map of Florida (Scott et al., 2001), the Ft. Thompson and Caloosahatchee Formations are mapped as undifferentiated Tertiary – Quaternary shell-bearing sands (TQsu; Figure 2).

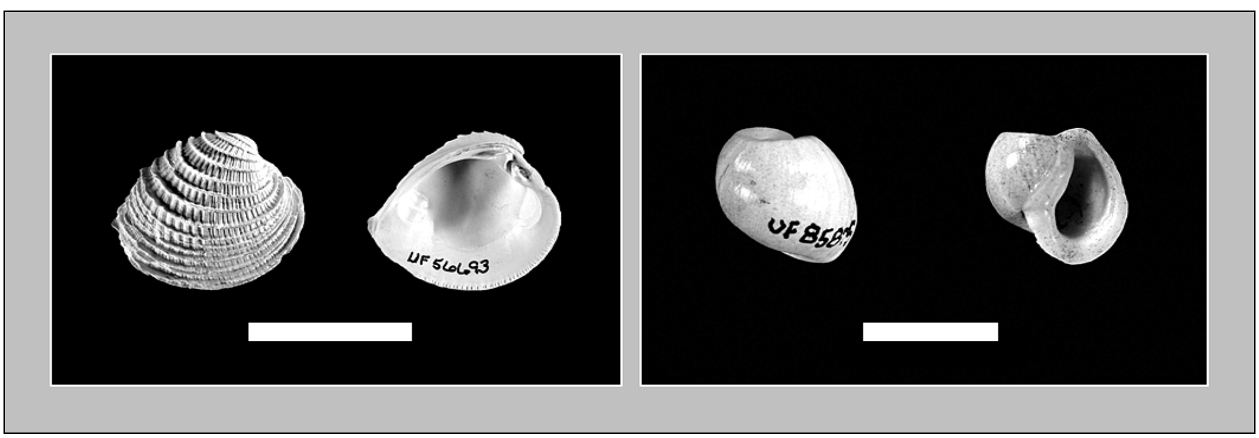

Figure 17. Characteristic Ft. Thompson Formation fossils *Chione elevata* (left) and *Helisoma scalare* (right; photos courtesy of IP/FMNH); bar = 12 mm.

Hydrostratigraphy

Introduction

The hydrostratigraphic setting of the study area varies from a locally exposed single aquifer system in the north, to three aquifer systems in the central and southern parts of the study area. In the northern region, the FAS ranges from variably confined to unconfined; clayey sediments of the IAS/ICU or basal SAS are locally present; IAS/ICU confining sediments are present especially within the uplands and ridges. The SAS, where present, is intersected by numerous karst features (Trommer, 1987; see also Plate 3) which may act as direct hydraulic connection between the SAS and the FAS. Increased permeability of the IAS/ICU occurs where the Hawthorn Group sediments thicken southward from central Hillsborough and Polk Counties. In the central and southern regions, the IAS/ICU collectively forms a thick confining unit with intervening permeable zones that separate the FAS from the SAS. As noted earlier, the nomenclature applied herein is based on aquifer system nomenclature as modified from Florida Geological Survey Special Publication 28 (see *Hydrogeology*, p. 17; Appendix 2).

Hydrogeological properties

Numerous studies provide details on hydrogeologic properties of aquifer systems in the study area. For detailed information on aquifer transmissivity, storativity, leakance coefficients, etc., the reader is referred to USGS publications (e.g., Ryder, 1985; Wolansky and Corral, 1985; Metz, 1995; Yobbi, 1996; Knochenmus, 2006), numerous SWFWMD ROMP technical reports (e.g., Clayton, 1994, 1999; Gates, 2001; LaRoche, 2004); SWFWMD hydrogeological studies (e.g., Barcelo and Basso, 1993; Hancock and Basso, 1993; Basso, 2002, 2003) and especially the Southwest Florida Water Management District (2006b) compilation: "Aquifer Characteristics within the Southwest Florida Water Management District, July 2005."

To provide a general characterization of these hydrogeologic parameters, two datasets are statistically and graphically summarized in the discussion of each aquifer system: 1) data in Southwest Florida Water Management District (2006b) that meet certain quality assurance/quality control (QA/QC) standards[6] and 2) results of more than 200 hydraulic conductivity and total porosity analyses measured at the FDEP-FGS on cores from within the study area. Both datasets are presented to represent laboratory and field-scale conditions. The Southwest Florida Water Management District (2006b) compilation represents properties measured during aquifer pumping and performance tests, while the FDEP-FGS dataset represents matrix permeability (vertical) and porosity of core samples. In Florida's dual-porosity (e.g, intergranular and conduit flow) heterogeneous carbonate terrain, it is widely recognized that permeability calculated from field-scale aquifer-test data (e.g., Basso, 2002) may differ by orders of magnitude from that of laboratory measurements. These data summaries are presented herein to characterize expected ranges of these parameters for use in hydrologic models and to provide a frame of reference for those collecting hydrological data in the field or lab. For further details on matrix permeability, as well as discussion of its significance and limitations, the reader is referred to Budd (2001, 2002) and Budd and Vacher (2004).

In the descriptive statistics for each aquifer system, standard parameters are summarized, including mean, median, range, quartile values, and number of analyses. Also included are distribution descriptors: skewness, kurtosis and

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[6] QA/QC screening guidelines: 1) used data with "acceptable" and "good" test-reliability scores as defined and assigned in Southwest Florida Water Management District (2006b); 2) avoided aquifer tests where partial penetration was noted and no corrections applied; 3) avoided tests where aquifer penetration thicknesses were inconsistent with casing and total depth data; 4) avoided use of well pairs in which the observation well open interval differed from the open interval in the test well by more than 15 percent; 5) avoided short-duration tests; and 6) evaluated comments with respect to quality of test data.

the Anderson-Darling test for normality. In the Anderson-Darling test, the A^2 value is the test statistic for normality; if the probability (P-value) is greater than 0.05, the data are normally distributed. Graphical summaries of the hydrogeological data include histograms, box plots and 95 percent confidence interval range charts. The histograms include a log-normal curve fit for all parameters except for the porosity data and SAS vertical hydraulic conductivity. The vertical (y) axis on the histograms reflects the total number of analyses (N), which are listed in each statistical summary. Units for each parameter are listed in the figure header. The horizontal (x) axis of the box plots corresponds to the histogram x-axis. Asterisks in the box plots denote statistical outliers.

Surficial aquifer system

The surficial aquifer system (SAS) is predominately comprised of Late Pliocene to Holocene sediments and is contiguous with land surface. This hydrostratigraphic unit occurs throughout the study area, with the exception of two hydrogeologic settings: 1) where an unobstructed vertical hydraulic connection exists between surficial sediments and the FAS (e.g., unconfined FAS) and 2) where the very low-permeability sediments of the Hawthorn Group (e.g., Peace River Formation) locally occur at or near land surface (e.g., SAS absent and FAS is confined). This latter setting occurs in the central and southern Polk Upland physiographic province (Figure 6). The extents of either of these settings are too localized or disturbed by mining to delineate accurately within the scale and scope of this project. The SAS generally consists of unconsolidated quartz sand with variable amounts of shell, clay, phosphate and organic material. Shell content in the SAS increases significantly toward the southern part of the study area (Vacher et al., 1993; see also "UDSS" comprising the SAS in the southernmost cross sections [e.g., Plates 18, 19]). Excluding the ridges, thickness of the SAS averages ~30 ft (~9 m). Along the Lake Wales Ridge in the southeastern part of the study area, SAS thicknesses range to more than 300 ft (99.4 m) (Plates 26 and 55). In the southern region, the areas with relatively thick SAS generally correspond to localities where the permeable upper Tamiami Formation sediments are included within the SAS.

The SAS is delineated in areas where laterally extensive, sufficiently confining clayey sediments of the IAS/ICU occur beneath unconsolidated surficial sediments. In parts of the northern region, the SAS locally may directly overly the FAS. Iron-cemented zones ("hardpan") and intermittent basal clays may result in a "perched" water table or local SAS-like unit. On the other hand, basal confinement breached by sinkholes or fractures precludes characterizing much of the northern region as a laterally extensive and functional SAS due to lack of regional hydraulic continuity. In this hydrogeologic setting, delineation of the SAS becomes subjective. To account for such areas, a hachured pattern is included on Plate 55 to reflect "discontinuous basal confinement of the SAS." It is noteworthy that this subjective delineation could also be applied to the northern, significantly karstified part of the Brooksville Ridge; however, in recognition of available data and to maintain consistency with the IAS/ICU, the SAS is delineated in this area.

Groundwater withdrawals from the SAS are minimal compared to that of the IAS/ICU or FAS. Based on data from Marella (2004), the SAS yielded between 1 percent and 5 percent of total groundwater withdrawals in Charlotte, Citrus, Levy, Marion, and Sumter Counties during 2000. In Lee County, the SAS comprised more than 55 percent of total withdrawals (Marella, 2004). Each of the remaining counties in the study area withdrew less than 1 percent groundwater from the SAS (Marella, 2004).

Throughout the study area, the local water table mimics topography (Sepulveda, 2002; Arthur et al., in review). Elevation of the water table varies widely throughout the study area, ranging to more than 175 ft (53.3 m) MSL (Arthur et al., in review). Along much of the Lake Wales Ridge, such as in the Intraridge Valley (Figure 6) the water table is often less than 10 ft (3.0 m) below land surface. The water table in other parts of the Lake Wales Ridge, as well as other upland areas, can exceed 50 ft (15.2 m) below land surface. Movement of SAS groundwater is dynamic, due to complex interactions between recharge, discharge (including pumping and mining operations), runoff, infiltration, evapotranspiration and seepage to and from underlying aquifers (Lewelling et al., 1998). Evidence from paired monitor wells confirms local semi-permeable hydrologic connection between the SAS and FAS in parts of the Lake Wales Ridge due in part to interaquifer connectivity through sinks or paleosinks (Tihansky et al., 1996). Depending on hydraulic conditions, karst density, and the leakance of basal SAS clays (or IAS/ICU clays), the SAS may locally recharge the FAS in parts of the northern study area. Local pumping, rainfall events, seasonal and climatic variations add to the complex dynamics of this relationship.

Surface-water/groundwater interactions are evident throughout the study area, such as coastal springs and base flow in rivers and streams. An outstanding example of these dynamic interactions occurs within the Peace River basin. Along the upper part of the basin, maximum river-flow losses exceed 11 million gallons per day ($4.2x10^7$ liters per day), locally recharging underlying aquifers due to a downward head gradient, riverbed sinkholes and inferred buried subsidence structures (Lewelling et al., 1998). Further downstream in the lower part of the basin, the river receives intergranular (rather than karst-related) seepage from the SAS and possibly the IAS/ICU (Lewelling et al., 1998). Understanding such surface-water/groundwater interactions is essential toward the establishment of effective minimum flows and levels (MFL) and total maximum daily loads (TMDL). Some karst-related features, however, do not affect these interactions. For example, the closed topographic depressions in eastern Sarasota County (Plate 3) are likely “sags” formed due to the dissolution of carbonate shell material (Sam Upchurch, personal communication, 2004). These sags likely do not function as preferential recharge pathways from the SAS to underlying aquifer systems.

Correlation of the SAS with lithostratigraphic units in the study area generally places the system within post-Hawthorn Group sediments. In the northern region, these Pliocene and younger sands and clays are undifferentiated (UDSC). Along the eastern region, the sediments correlate with the Cypresshead Formation. Further south, the Ft. Thompson, Caloosahatchee and Tamiami Formations comprise most of the SAS. Basal SAS clays may represent low-permeability undifferentiated Hawthorn Group sediments, or re-worked Hawthorn Group sediments in the northern and central region. In the central and eastern regions, the base of the SAS generally coincides with the top of the Peace River Formation (Hawthorn Group); however, relatively clean sands of the Peace River Formation comprise part of the SAS in localized areas (e.g., W-14382 [ROMP 23], Plate 17). In the southern region, the base of the SAS not only overlies the Peace River Formation, but also the fine-grained dolostones of the Arcadia Formation (parts of western/coastal Manatee and Sarasota Counties) and middle-Tamiami clays (e.g., southeastern Charlotte and Lee Counties; Reese, 2000; Weinberg and Cowart, 2001). Note however, that Missimer and Martin (2001) report two aquifers within the SAS in Lee County, the lowermost being the “Lower Tamiami Aquifer;” whereas researchers such as Knochenmus and Bowman (1998) and Torres et al. (2001) place the entire Tamiami Formation within the IAS/ICU. The relation between the Tamiami Formation and hydrostratigraphic units from Lee County north to Sarasota County warrants further investigation.

Vadose-zone hydrogeologic characteristics of the SAS can be approximately inferred from a comparison of environmental geology and soil permeability maps (Figures 4 and 18, respectively). Patterns in both of these maps roughly correlate with major geomorphic provinces (Figure 6). The most permeable soils and shallow sand-dominated sediments or carbonate lithologies are located in the Coastal Swamps, Gulf Coastal Lowlands, the Lake Wales Ridge, whereas some of the least permeable soils occur along the southern extent of the Brooksville Ridge and parts of the Western Valley.

In the northern region, surficial deposits may be missing, having been eroded away and exposing limestone at the surface (e.g., unconfined FAS; see Plates 29 and 30). In contrast, these same deposits may locally exceed 100 ft (30.5 m) thick where they infill karst features (including paleo-sinks represented by W-15075 and W-10829; Plates 5, 6 and 29). Depending on the permeability of infilling sediments, the karst features may provide hydraulic connection between the SAS and the FAS.

Topographic inversion (i.e., differential carbonate dissolution due to chemical buffering and confinement) also contributes to the highly variable thickness of the SAS in the northern region. Along the axis of the Brooksville Ridge, for example, more than 50 ft (15.2 m) of SAS is locally observed. Much of the Ridge, however, is perforated by sinkholes (Plate 3), making delineation of the SAS problematic. Although lithologic data from wells support presence of the SAS along the Brooksville Ridge, extent of the unit is even more subjective in the surrounding region. Assessment of regional mapping (geology [Figure 2], environmental geology [Figure 4], and soil permeability [Figure 18]) warrants the dashed (i.e., approximate) extent of the SAS in the region (Plate 55). These hachured areas are considered semi-confined to unconfined FAS.

In addition to lithologic evidence, hydraulic data support local delineation of the SAS in parts of the northern region. Well W-15647 (ROMP 90; Plate 10) provides a classic example of confinement between the SAS and the FAS in this region. Water levels measured during drilling rose 3 ft (0.9 m) when the clays underlying the SAS were fully penetrated and artesian conditions of the FAS became evident. The IAS/ICU in this well is too thin to depict graphically in Plate 10. Moreover, given the proximity of the well to the IAS/ICU extent, whether the clays are basal SAS or IAS/ICU is subjective. Confined and semi-confined areas of Citrus County have been identified (Lee, 1998).

Water levels in paired monitor wells also provide valuable information regarding the presence of the SAS (i.e., basal confinement) in the absence of an extensive IAS/ICU. This data, however, should be interpreted with caution: similar water levels may reflect “leaky” confinement and seasonal or local pumping conditions should be considered. The “Floridan” water levels in W-14336 (ROMP 93, Plate 10), are at least 5 ft (1.5 m) lower than SAS water levels (U.S. Geological Survey, 1990) indicating a well-defined hydraulic separation between the two aquifer systems. Hydrologic data from W-16644 (ROMP LP-6), located approximately 2 mi (3.2 km) north of cross section D-D’ (Plate 7) indicates that FAS water levels are typically more than one foot (0.3 m) above the surficial water table. At W-16644, 12 ft (3.7 m) of clay and clayey sand provide sufficient confinement between the FAS and SAS.

As noted above, effectiveness of the hydraulic separation between the SAS and the subjacent FAS varies locally. Water levels in the paired wells L11KD and L11KS (northeast of W-5054, Plate 2), are nearly indistinguishable, thus indicating leaky to unconfined conditions between the FAS and "water table" levels in surficial sediments (U.S. Geological Survey, 1998). In contrast, water levels from the monitor-well pair L11MM and L11MS (southeast of W-5054, Plate 2) confirm existence of SAS conditions because “water-table” elevations differ from the FAS potentiometric surface (U.S. Geological Survey, 1998). Paired monitor wells with inconsistent trends in water levels suggest that there may be some degree of confinement of the FAS, either as low permeability horizons in the base of the SAS or in the uppermost carbonates of the FAS (e.g., mudstones/micrites or densely recrystallized zones).

A SWFWMD Technical Memorandum (Basso, 2004) provides detail on the hydrogeologic setting of the Hernando-Pasco County (or “Northern Tampa Bay”) region. In the memorandum, the location of wetlands, soil properties, lithologic data and hydrographs from nested wells and lakes are used to delineate three zones: unconfined UFA, locally perched water table (generally restricted to the southern

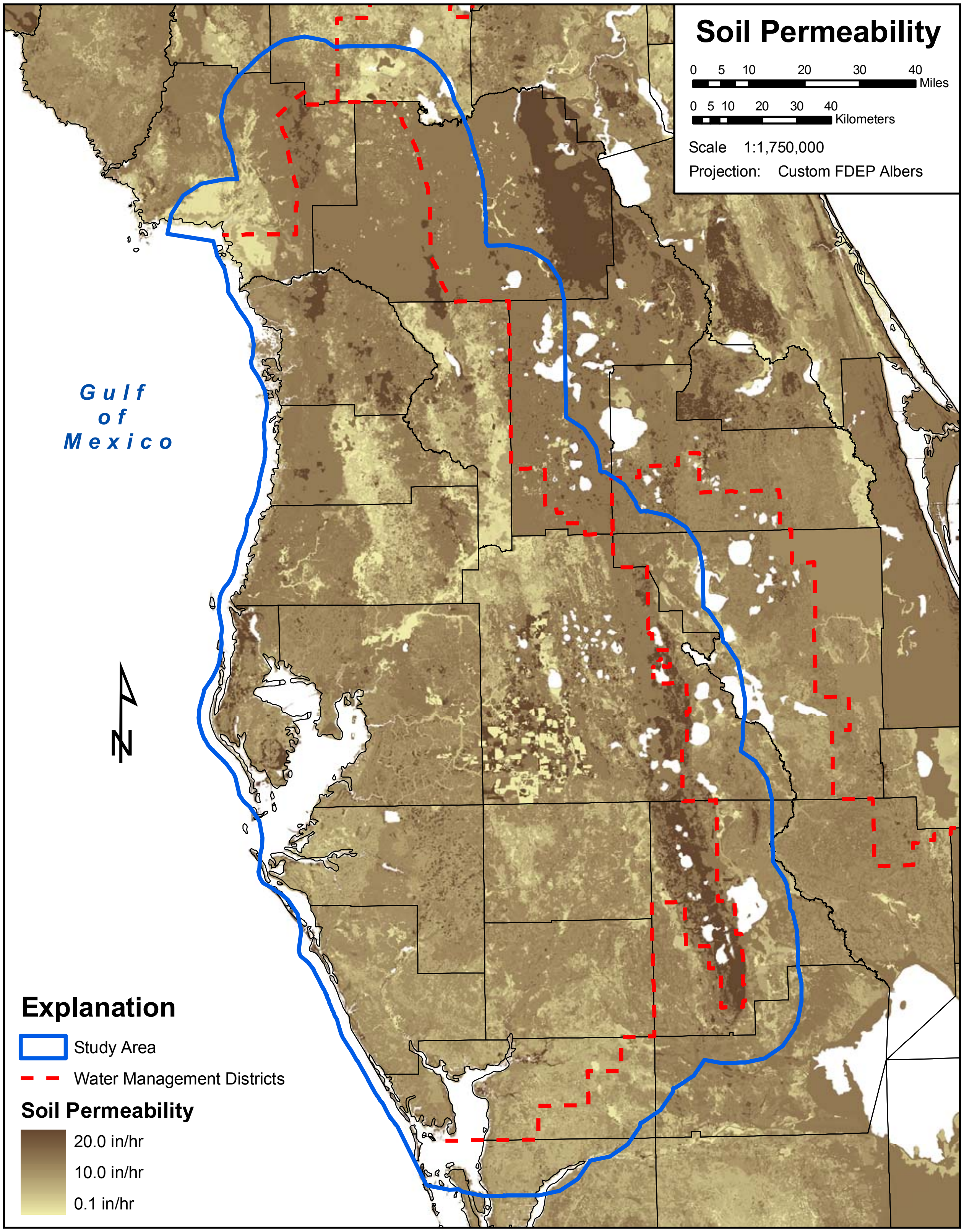


Figure 18. Soil permeability of study area (Arthur et al., in review); (data compiled on per county basis from U.S. Department of Agriculture, Natural Resource Conservation Service, 2002 and the Florida Geographic Data Library [www.fgdl.org]).

Brooksville Ridge) and semi-confined UFA. This localized study provides a refinement of confining conditions within the northern Tampa Bay region. Although differences in nomenclature and scale of study exist, the areas delineated by Basso (2004) are broadly consistent with regional representations of the SAS in Plate 55. Basso suggests, however, that the locally perched water table aquifer (SAS in this report) along the southern part of the Brooksville Ridge terminates northward near the Hernando-Citrus County boundary. This conclusion is consistent with an increase in soil permeability and a relative abundance of closed topographic depressions within the Brooksville Ridge in Citrus County (Figure 18 and Plate 3). Moreover, the potentiometric surface for paired SWFWMD monitor wells in southern Citrus County ("Lecanto 1" [deep] and "Lecanto 2" [shallow]), which have been measured since 1965, track almost perfectly indicating unconfined FAS. On the other hand, lithologic data from wells in the Brooksville Ridge, Citrus County, documents more than 30 ft (9.1 m) of local confinement. These observations serve as additional examples of the complex and variable degrees of confinement in the northern region and underscore the subjective nature of the SAS extents shown in Plate 55.

The SAS occurs throughout most of the central and southern regions, except where IAS/ICU sediments crop out (e.g., central Polk County). Several paired monitor wells document the SAS, for example, discrete monitor wells constructed in both the SAS and the FAS at W-12943 (Plates 12 and 31) reveal head differences between the two aquifer systems (Coffin and Fletcher, 1992). Other complementary pairs of monitor wells in the northern Pinellas and Hillsborough Counties support the presence of a "water table" that is distinguishable from FAS potentiometric levels, suggesting that some degree of laterally extensive confinement exists between the two aquifer systems. In the southern region, the SAS is isolated from the FAS by thick intervening permeable and less permeable siliciclastics and carbonates of the IAS/ICU. High-density karst areas (Plate 3) such as the Lake Wales Ridge increase the potential for inter-aquifer communication between the SAS and subjacent aquifers.

Hydraulic properties for the SAS vary widely, owing to its heterogeneous composition and thickness. Selected hydrogeologic data from SWFWMD (2006b; see also p. 52) and Florida Geological Survey laboratory data are summarized in Figures 19-22. Surficial aquifer system parameters include transmissivity, specific yield and horizontal and vertical hydraulic conductivity, respectively. Note that the horizontal hydraulic conductivity (Kh) is calculated from the unsaturated aquifer thickness and the transmissivity. In the vertical hydraulic conductivity (Kv) data, if outliers are excluded, the range in Kv is similar to that reported by Vacher et al. (1993). A difference of several orders of magnitude exists between Kv and Kh values. One factor influencing this difference pertains to sampling bias, where many Kv samples were selected to characterize the degree of basal confinement of the SAS. Arguably, some of these sediments may represent the semi-confining facies of the IAS/ICU.

Intermediate aquifer system/ intermediate confining unit

The IAS/ICU occurs throughout much of Florida (Scott, 1992a) and is comprised of all rocks "that lie between and collectively retard the exchange of water" between the SAS and the FAS (Southeastern Geological Society, 1986). In general, this aquifer system correlates with Oligocene-Pliocene clays, sands and carbonates of the Hawthorn Group, and Pliocene clays, sands, limestone and shell beds of the Tamiami Formation (e.g., Berndt et al., 1998; Arthur et al., 2001a; Torres et al., 2001; Ward et al., 2003). In the study area, the IAS/ICU is broadly characterized by three hydrogeologic settings: 1) relatively thin, laterally discontinuous low-permeability confining to semi-confining sediments that provide local hydraulic separation between the SAS and the FAS (hachured area in Plates 56 and 57), 2) low-permeability confining to semi-confining sediments hydraulically separating the SAS from the FAS (non-hachured areas in the northern region, Plate 56 and 57), and 3) interlayered sequences of permeable and less-permeable rocks and sediments separating the SAS from the FAS (central and southern regions; Figure 23 and Plates 56-57).

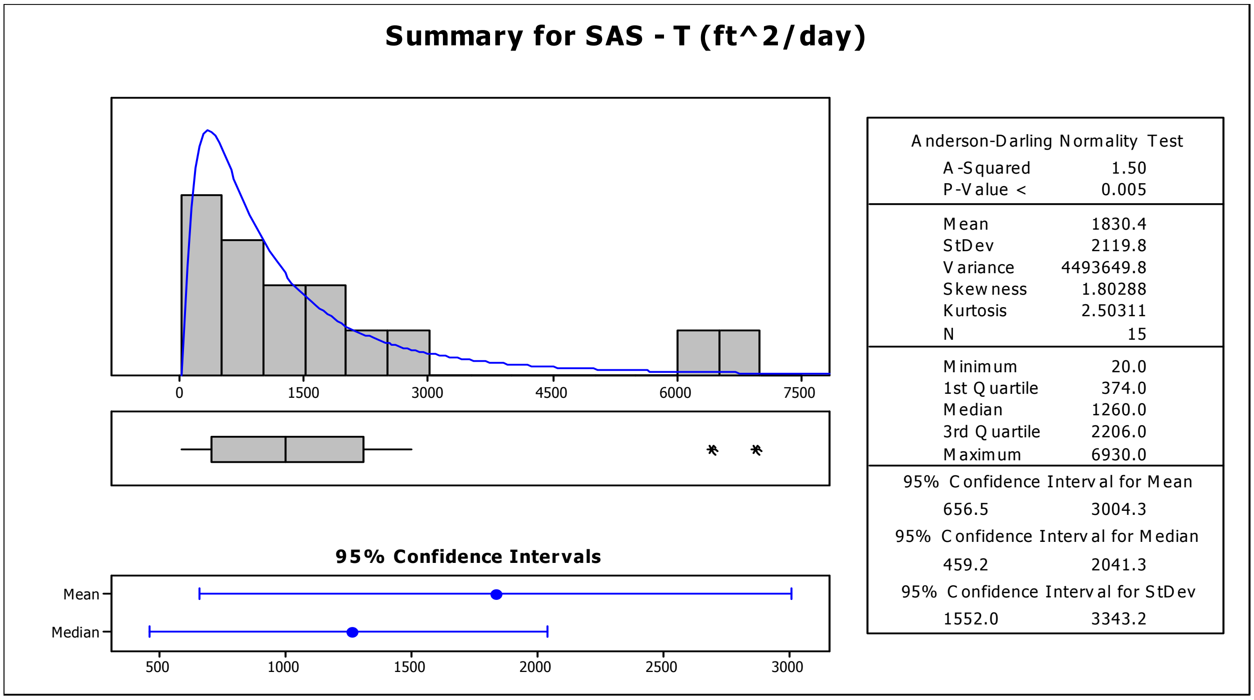


Figure 19. Statistical summary of SAS transmissivity data from Southwest Florida Water Management District (2006b). The horizontal (x) axis of the box plots corresponds to the histogram x-axis. Asterisks in the box plot denote statistical outliers.

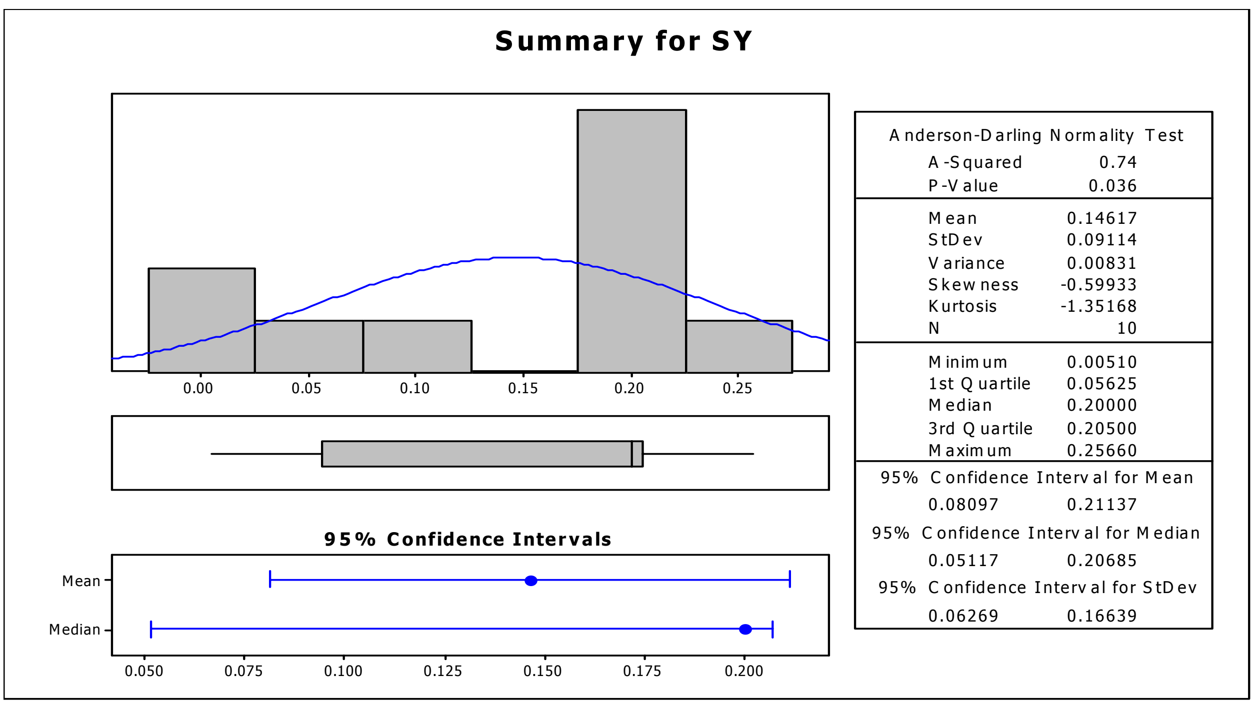


Figure 20. Statistical summary of SAS specific yield data from Southwest Florida Water Management District (2006b).

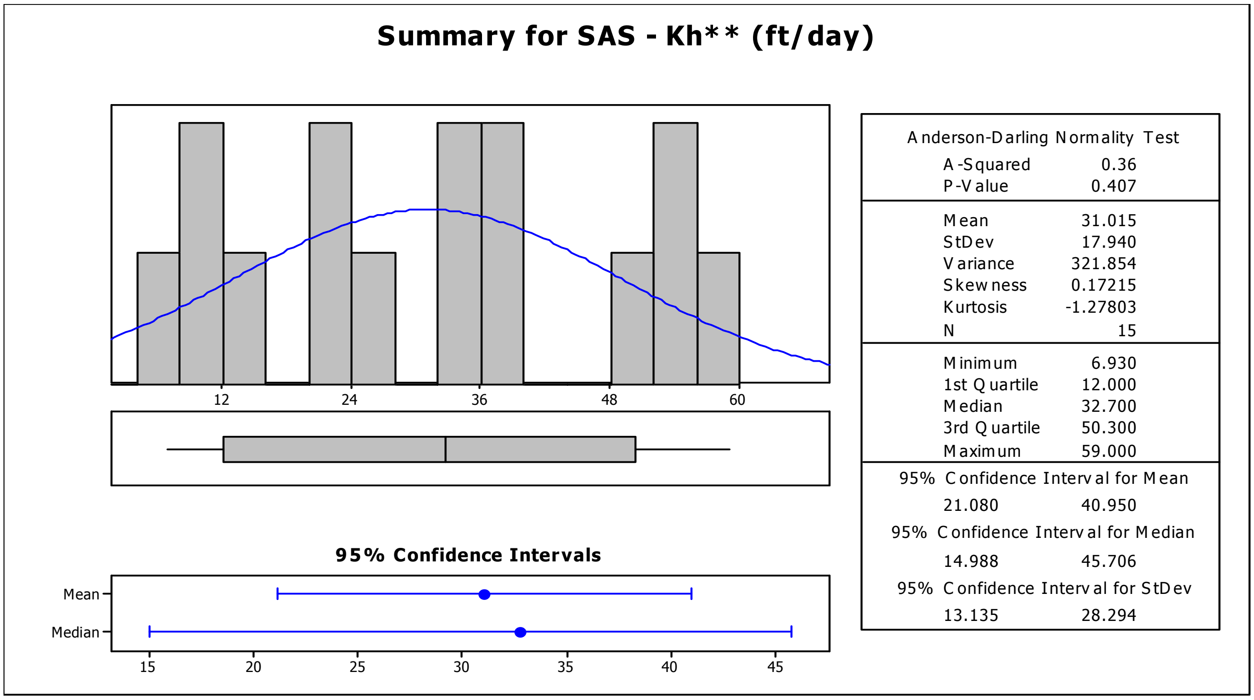


Figure 21. Statistical summary of SAS horizontal hydraulic conductivity data from Southwest Florida Water Management District (2006b). ** - calculated from transmissivity and saturated aquifer thickness.

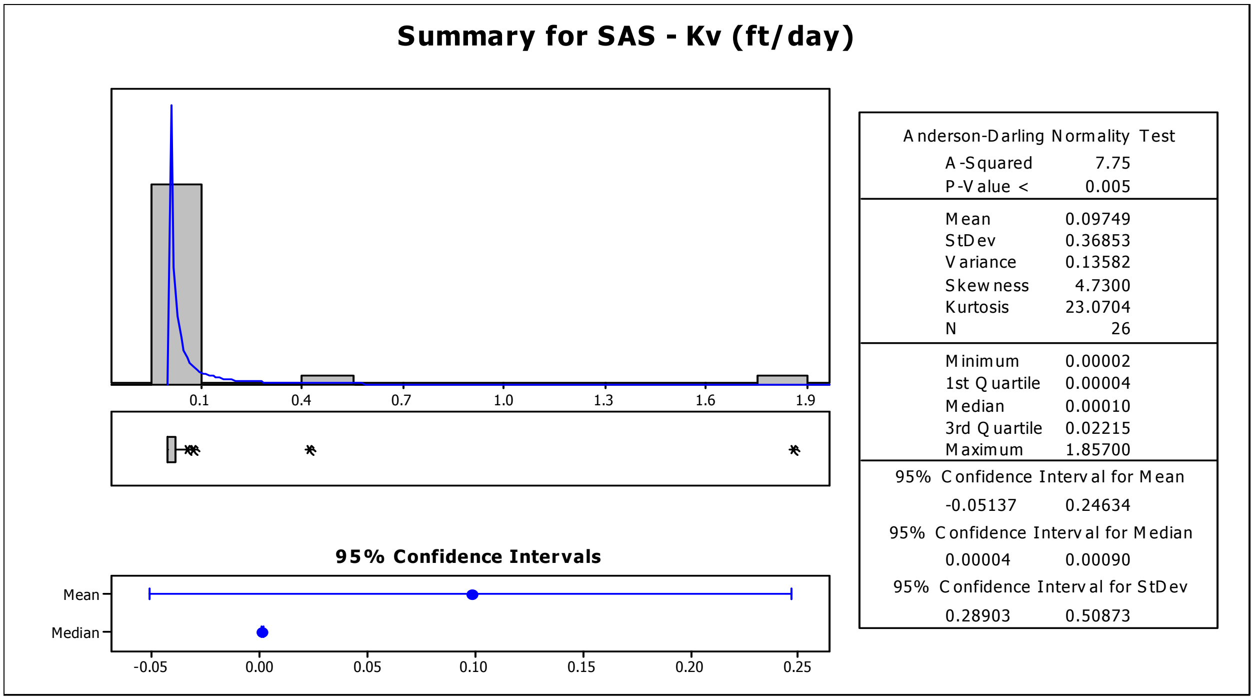


Figure 22. Statistical summary of SAS vertical hydraulic conductivity data based on falling-head permeameter analyses of core samples completed at the FDEP-FGS. Due to sampling bias, most samples represent clay-bearing sediments. Asterisks in the box plot denote statistical outliers.

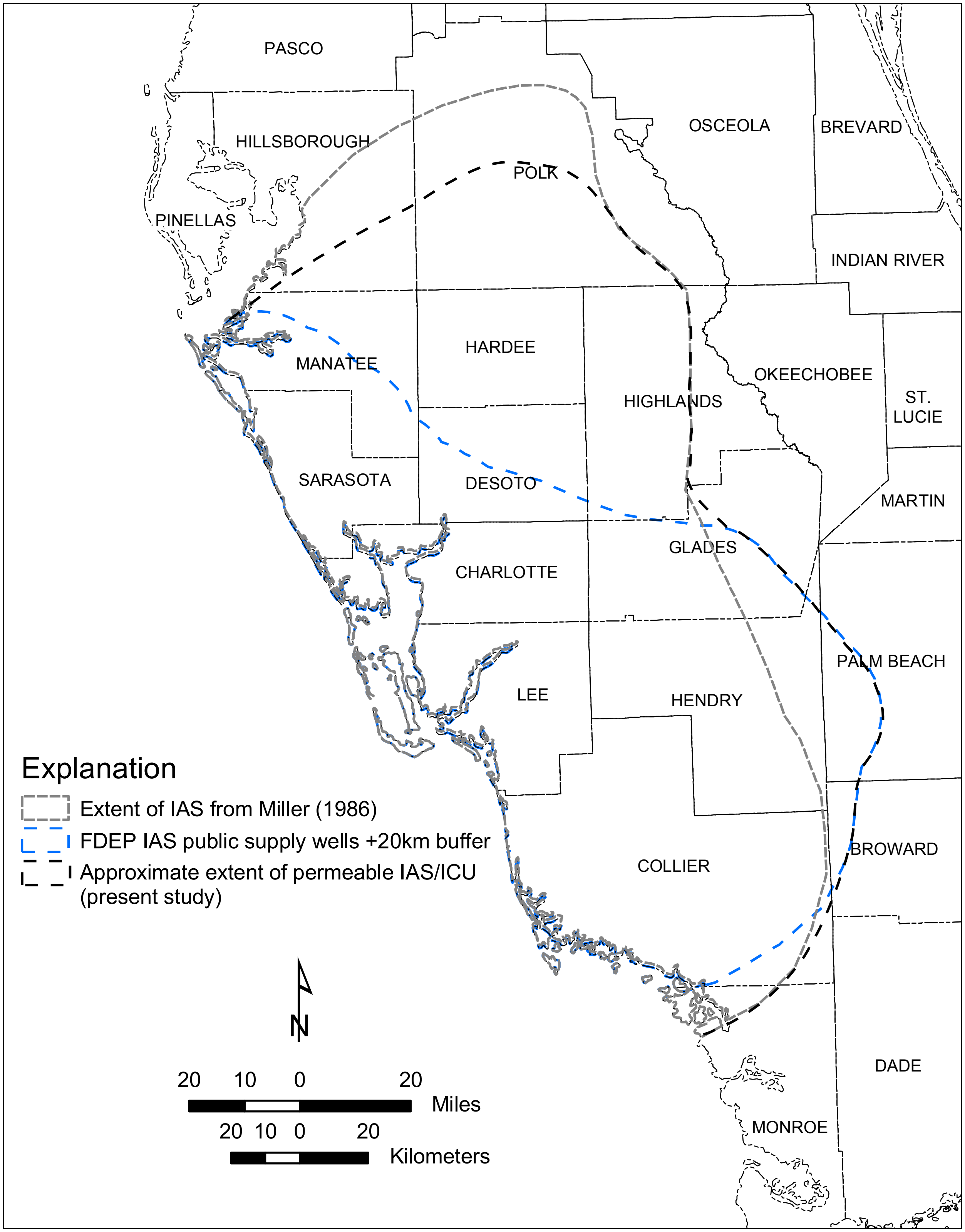


Figure 23. Approximate extent of IAS/ICU permeable zones. The region mapped as IAS/ICU (Plates 56 and 57) north of this line is dominated by lower permeability hydrogeologic facies.

Up to three relatively more permeable water-yielding zones exist in the latter regions (Corral and Wolansky, 1984; Trommer, 1993; Torres et al., 2001; Knochenmus, 2006), which provide groundwater to municipalities, industries and agriculture. During 2000, the IAS/ICU was the source of approximately 10 percent to 15 percent of total groundwater withdrawals in DeSoto, Hardee, and Highlands Counties (Marella 2004). In Sarasota and Charlotte Counties, the usage was 32 percent and 75 percent respectively (Marella, 2004).

Lithology and hydrology of IAS/ICU permeable zones is heterogeneous and complex. Where multiple water-producing zones exist, they are generally laterally discontinuous and difficult to map, even with the aid of hydrochemical assessment (Knochenmus and Bowman, 1998; Knochenmus, 2006). Moreover, the hydraulic character of the IAS/ICU is unpredictable due to varying degrees of vertical and lateral permeability within the unit. In the northern region, IAS/ICU sediments generally occur along upland features such as the Brooksville Ridge, Fairfield Hills and Sumter and Lake Uplands (Figure 6, Plate 56). This hydrostratigraphic unit also occurs throughout the central and southern regions. Maximum IAS/ICU elevations exceed 125 ft (38.1 m) MSL along the Brooksville and Lakeland Ridges. Thickness of the IAS/ICU ranges to more than 900 ft (274 m) in the southernmost part of the study area (Plate 57).

Various extents of IAS/ICU water-producing zones have been proposed within the study area (Figure 23). In the Florida Aquifer Vulnerability Assessment (FAVA), (Arthur et al., in review) the extent includes Miller's (1986) delineation plus a region defined by the distribution of FDEP-regulated public water supply wells that utilize the IAS/ICU (Figure 23). Included among the FDEP supply-well region is a 12.4 mile (20 km) buffer, which was added to account for lateral uncertainty (Arthur et al., in review). In the present study, however, lithologic data represented in cross sections were assessed to re-define an approximate northern limit of IAS/ICU permeable zones (Figure 23). This redefined extent is comparable to that proposed by Basso (2003). The region north of the zone is dominated by variably low-permeability IAS/ICU sediments, except for localized relatively permeable sediments within the Brooksville Ridge (e.g., W-15933; Plate 9).

Within the northeastern part of the study area, the IAS/ICU is comprised of the Coosawhatchie Formation (Hawthorn Group) and possibly other Hawthorn Group units (i.e., the Marks Head and Penney Farms Formations) (W-8883, Plate 5; W-12794, Plate 8). In the central part of the northern region, the IAS/ICU occurs along the axis of the Brooksville Ridge and is comprised of undifferentiated Hawthorn Group sediments (e.g., W-6903, Plate 5; W-15933, Plate 9). Scott (1988) suggests that these sediments at one time likely blanketed the entire northern region. In the lowlands flanking the Brooksville Ridge, laterally discontinuous Hawthorn Group remnants (possibly reworked) or Pliocene-Pleistocene clayey sediments (e.g., W-707, Plate 9) function hydrologically as semi-confining sediments that promote local FAS artesian and perched water-table conditions.

As indicated by the hachured areas in Plates 56 and 57, at least half of the northern region is discontinuous with respect to semi-confining sediments of the IAS/ICU. This qualitative delineation is based on inspection of borehole lithologic data, assessment of the state geologic map (Scott et al., 2001) and topographic analysis (i.e., comparing Hawthorn Group distribution and depth to carbonate rocks with the 15 m (49.2 ft) resolution DEM. In some of these areas, the IAS/ICU is absent and local aquifer conditions range from SAS overlying FAS (with varying degrees of hydraulic separation) to unconfined FAS. Thickness of the IAS/ICU along the Brooksville Ridge and the northeastern part of the study area averages ~35 ft (~11 m) and locally exceeds 100 ft (30.5 m) (W-15933, Plate 9). Highly variable and localized IAS/ICU thicknesses in these areas are due in part to infilling of paleosinks. Plates 5 and 6 reflect this scenario, however, due to the localized occurrence, the IAS/ICU was not delineated.

In the central region, hydrogeologic properties of the IAS/ICU are highly variable due to lithologic heterogeneity and complex interbedding typical of the Hawthorn Group sediments. The IAS/ICU primarily correlates with the Hawthorn Group in this region; however, some post-Hawthorn siliciclastics may also be included in the uppermost IAS/ICU (e.g. reworked Hawthorn Group sediments in southern Pasco and northern Hillsborough Counties).

Throughout most of Pinellas and Hillsborough Counties, vertical hydraulic continuity generally exists between the Tampa Member (Arcadia Formation) and the Suwannee Limestone, thereby placing the base of the IAS/ICU at the top of the Tampa Member (Broska and Barnette, 1999). In northern Pinellas County, however, roughly a third of the wells penetrating the Suwannee Limestone encounter clay beds at the base of the Tampa Member. Given the discontinuous nature of these clays, the base of the IAS/ICU is considered to correlate with the top of the Tampa Member although local-scale head differences may occur between this unit and the Suwannee Limestone. In southern Hillsborough County, however, lithologic data from six adjacent wells indicate that basal Tampa Member clays are more laterally extensive, suggesting contiguous hydraulic separation from the Suwannee Limestone. In this area (Figure 8), the Tampa Member is considered part of the IAS/ICU (Green et al., 1995; Figure 8; Plates 14, 21 and 20). As additional hydrologic and lithologic data become available, the base of the IAS/ICU should be reassessed in these areas.

Mixed siliciclastic-carbonate deposits of the IAS/ICU thicken southward from ~75 ft (22.8 m) in central Polk County to more than 900 ft (274 m) in Charlotte County (Plate 57) creating several water-bearing zones (Trommer, 1993). In most of west central Florida the IAS/ICU is less permeable than the underlying FAS and restricts movement of water between the SAS and FAS (Ryder, 1985).

Where multiple permeable zones exist in the IAS/ICU in the central and southern regions, flow regimes are not fully understood. Extents of these permeable zones need to be better defined along with groundwater flow patterns in order to improve management of the IAS/ICU as a water supply source (Torres et al., 2001). The hydrologic parameters for these zones have been well characterized by Basso (2002) for southern Hillsborough, Manatee and northern Sarasota Counties. Additional details regarding depths, thicknesses, extents and hydraulic properties of these permeable zones are presented in Duerr and Enos (1991), Barr (1996), Knochenmus and Bowman, (1998), Torres et al. (2001), Basso (2003) and Knochenmus (2006).

Distinct differences exist among potentiometric levels representing IAS/ICU permeable zones (Duerr, 2001). Regional IAS/ICU potentiometric maps, however, are generally constructed from wells open to multiple permeable zones. As a result, the potentiometric surface of the IAS/ICU represents a composite of permeable zones, which likely contributes to its high variability across the study area. In May 2001, the composite head level in the IAS/ICU ranged from more than 120 ft (36.6 m) MSL in the "Four Corners" area (northwestern Hardee County) to approximately 50 ft (15.2 m) MSL in Highlands County (Duerr, 2001). Within the study area, IAS/ICU potentiometric elevation lows occur in southern Hillsborough County and northern Sarasota County (Duerr, 2001).

Selected hydrogeologic data compiled in SWFWMD (2006; see also discussion on p.52) are statistically summarized in Figures 24-27 (transmissivity, storativity, leakance and Kh, respectively). Laboratory data from the FDEP-FGS, including falling-head Kv analyses (Figure 28) and total porosity (Figure 29) are also presented. Basso (2002) presents similar hydrologic data subdivided based on IAS/ICU permeable zones. A five order-of-magnitude difference exists between Kv and Kh mean values reported herein.

Similar to the SAS data, sampling bias may account for some of this variation; Kh values predominately reflect data from IAS/ICU permeable zones while samples from which Kv was measured may have been somewhat biased toward less permeable zones or more indurated core samples. Moreover, as with all Kv data in heterogeneous strata, the measured values are affected by lower-permeability horizons within the analyzed core segments.

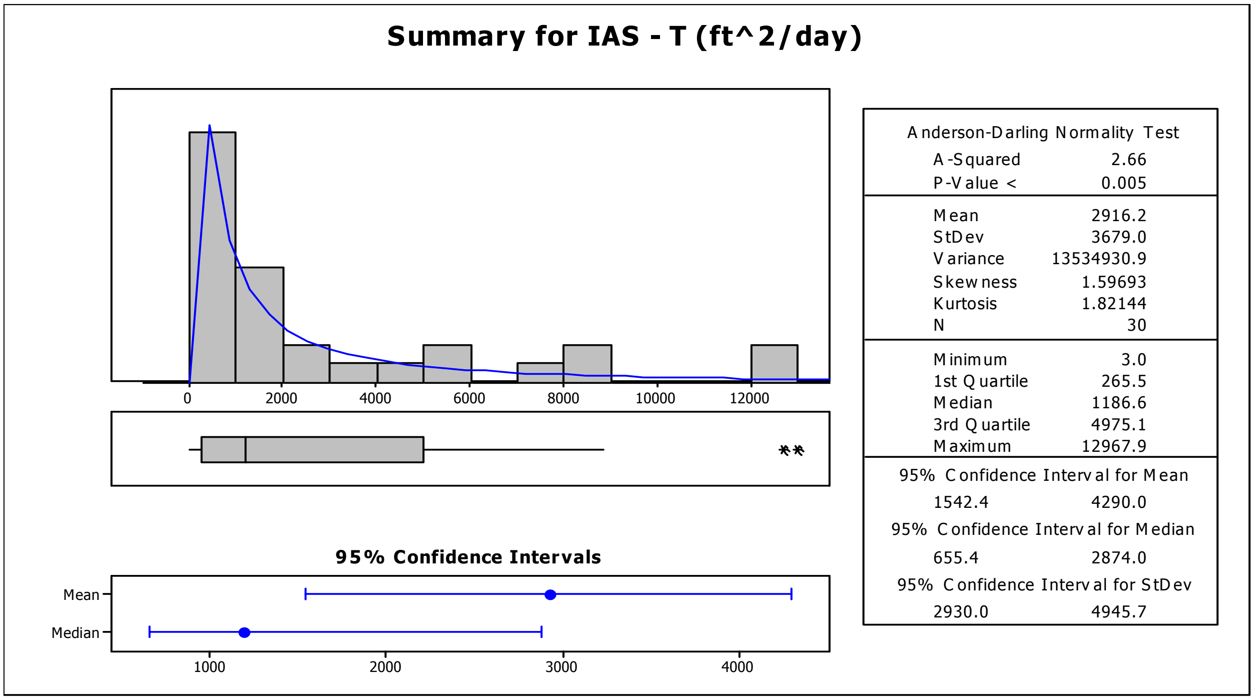


Figure 24. Statistical summary of IAS/ICU transmissivity data from Southwest Florida Water Management District (2006b).

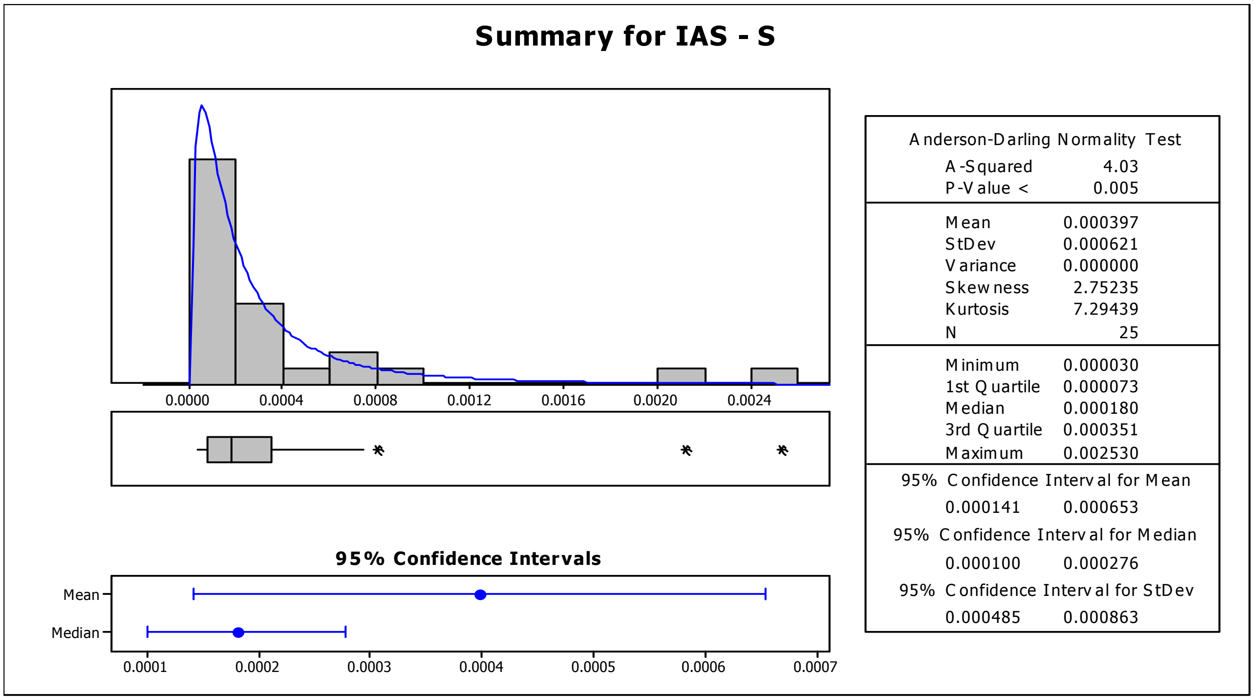


Figure 25. Statistical summary of IAS/ICU storativity data from Southwest Florida Water Management District (2006b). Asterisks in the box plot denote statistical outliers.

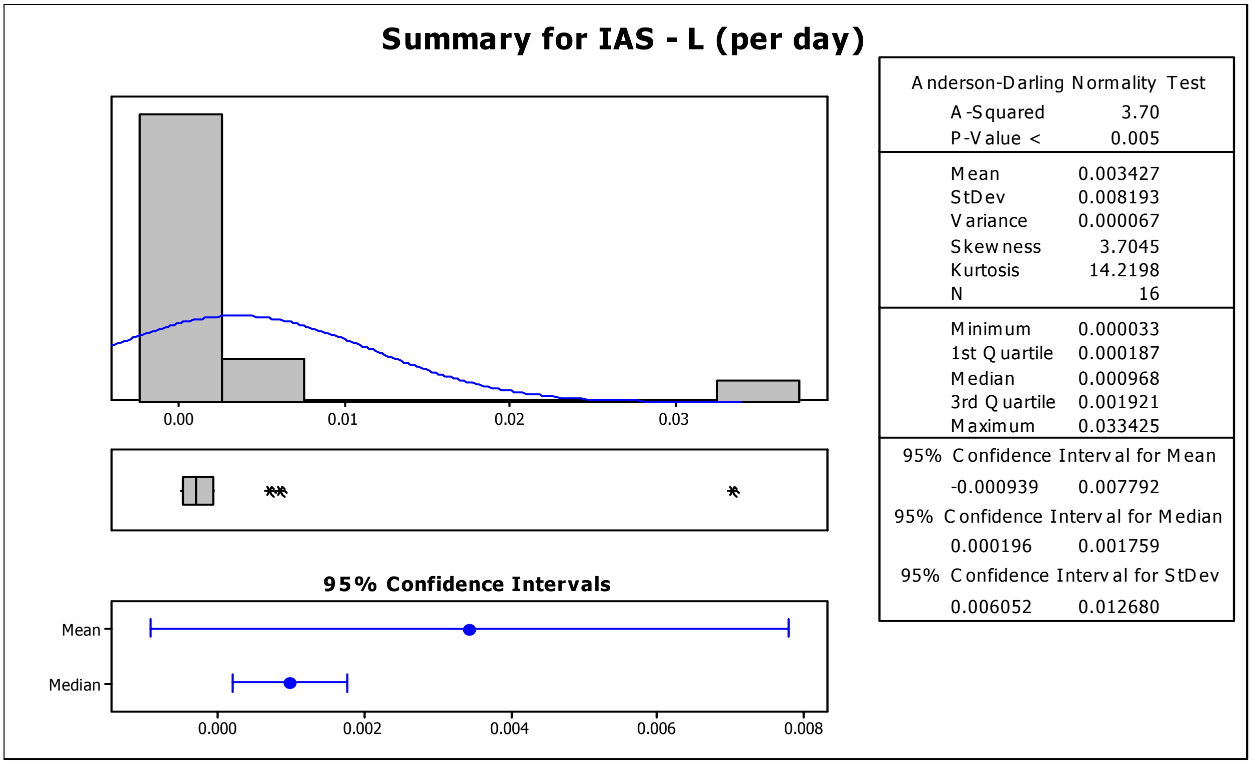


Figure 26. Statistical summary of IAS/ICU leakance data from Southwest Florida Water Management District (2006b). Asterisks in the box plot denote statistical outliers.

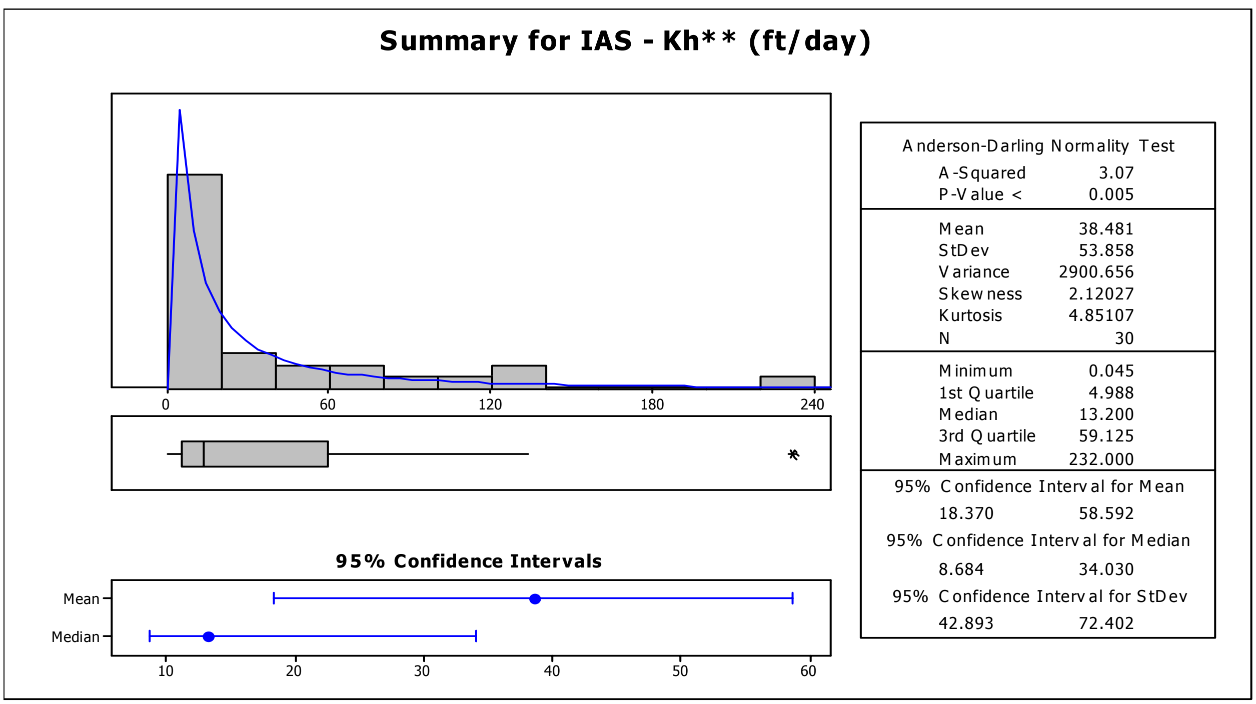


Figure 27. Statistical summary of IAS/ICU horizontal hydraulic conductivity data from Southwest Florida Water Management District (2006b). Asterisk in the box plot denotes statistical outliers.

**** - calculated from transmissivity and permeable zone thickness.**

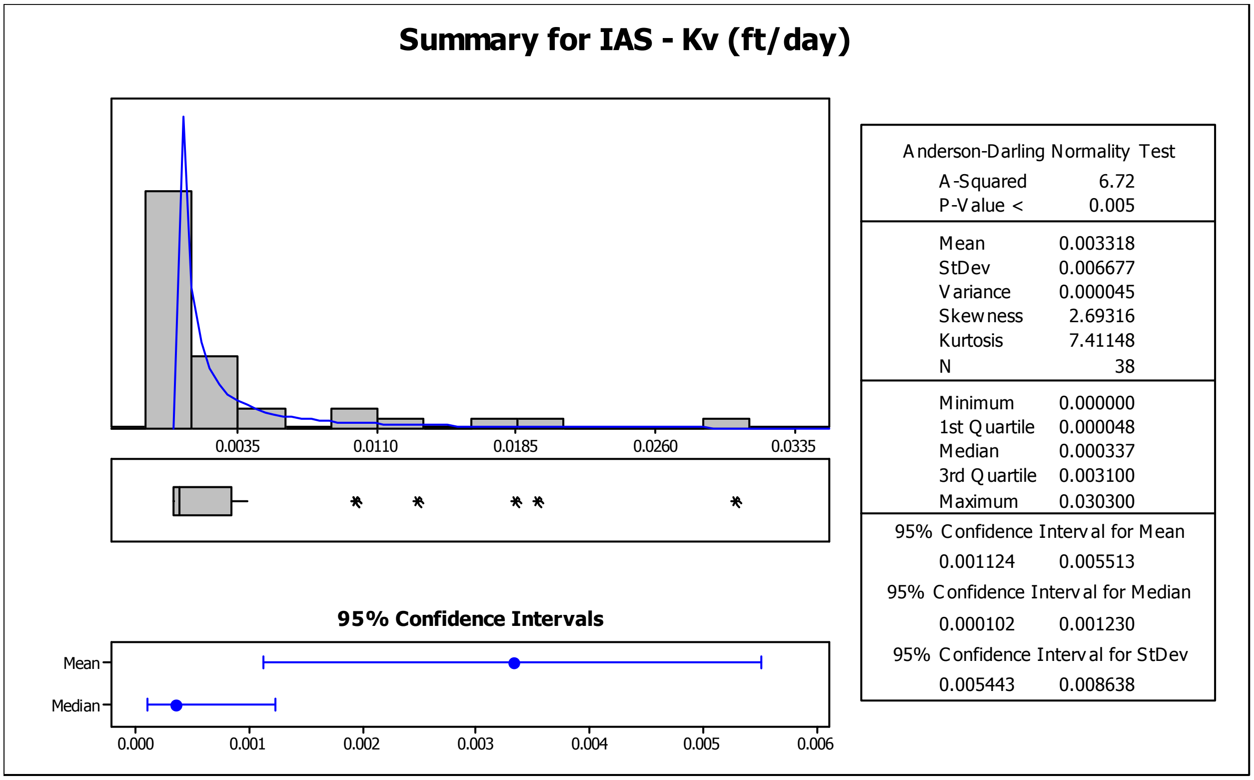


Figure 28. Statistical summary of IAS/ICU vertical hydraulic conductivity data based on falling-head permeameter analyses of core samples completed at the FDEP-FGS. Asterisks in the box plot denote statistical outliers.

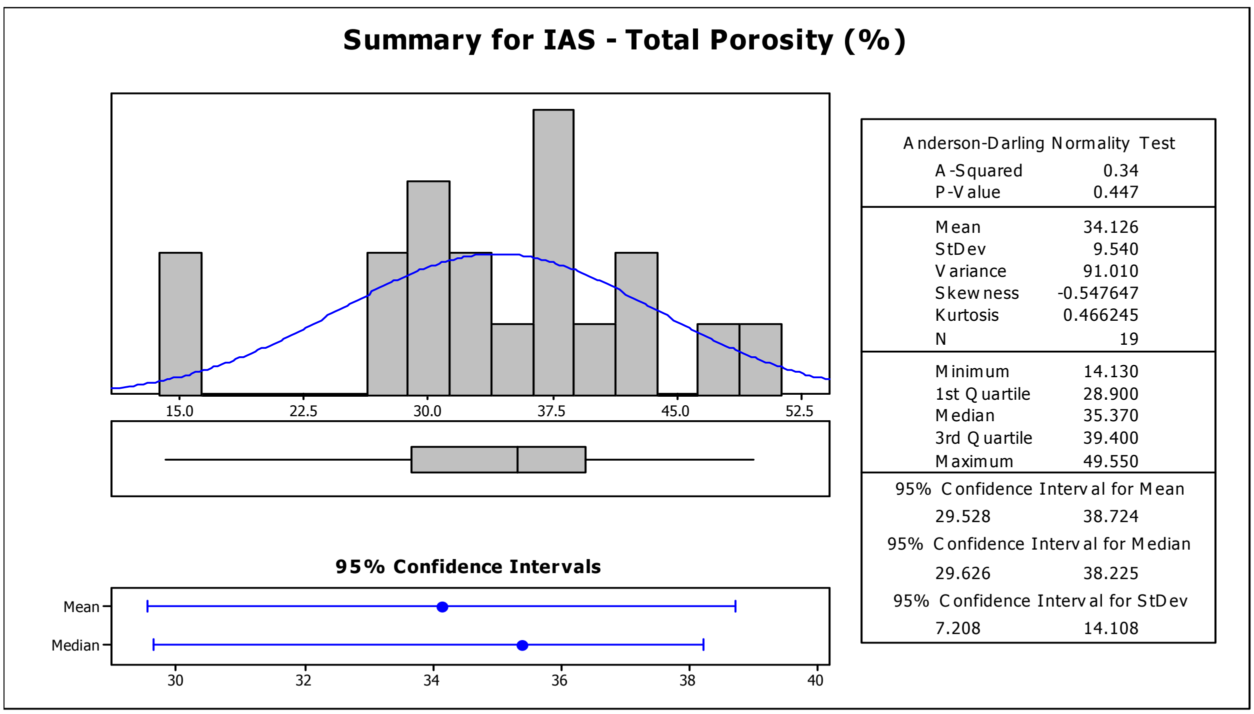


Figure 29. Statistical summary of IAS/ICU total porosity data based on core sample volumetric analyses completed at the FDEP-FGS.

Floridan aquifer system

The FAS occurs throughout Florida and is often an artesian aquifer. Artesian conditions may vary with seasonal rainfall and pumping conditions. In the study area, springs flow year-round along parts of coastal Citrus, Pasco and Hernando Counties (Figure 6; Healy, 1974; Scott et al., 2004). Other common areas of FAS discharge include wetlands in the Tsala Apopka Plain, southern Pasco County, and the Green Swamp (northwest Polk County). The FAS discharges into the SAS along the northern part of the Lake Wales Ridge and also provides baseflow to surface-water bodies (e.g., Hillsborough River). Along the trace of the Peace River, the FAS discharges into permeable zones of the IAS/ICU (Sepulveda, 2002). Similar conditions exist within southern Sarasota County, southwestern DeSoto County and most of Charlotte County. Throughout the remainder of the study area, the FAS is recharged from overlying aquifer systems.

The top of the FAS does not always coincide with a specific lithostratigraphic unit. Instead, it is defined by permeability and hydraulic connection (Johnston and Bush, 1988). Moreover, per the Southeastern Geological Society (1986) definition, the top of the FAS "generally coincides with the absence of significant thicknesses of (silici)clastics from the section and with the top of the vertically persistent permeable carbonate section." In the study area, the surface of this hydrostratigraphic unit may include the following formations in ascending order: Avon Park Formation, Ocala Limestone, Suwannee Limestone, and units within the Hawthorn Group (Trommer, 1993; Ryder, 1985; Berndt et al., 1998; Corral and Wolansky, 1984).

Figure 8 summarizes the extent of lithostratigraphic units that comprise the FAS surface. The top of the FAS correlates regionally with the Oligocene Suwannee Limestone where present; however, in west-central Florida, the Tampa Member (Arcadia Formation) of the Hawthorn Group coincides with the top of the FAS where it is hydraulically connected to the underlying Suwannee Limestone (generally Pinellas [e.g., Hickey, 1982; Broska and Barnette, 1999], southern Pasco, Hillsborough and Manatee Counties [Green et al., 1995]). In the absence of the Tampa Member or Suwannee Limestone, Eocene rocks (Avon Park Formation or Ocala Limestone) comprise the top of the FAS (Figure 8; Miller, 1986). Based on lithostratigraphic correlation and the FAS definition applied herein (see also Appendix 2), the top of the unit ranges in age from Middle Eocene to Early Miocene.

In the northern region, the FAS (Plates 4 through 8) includes the Avon Park Formation, Ocala Limestone and Suwannee Limestone. In Pasco County (Plate 11), hydrogeologic data suggest that the Tampa Member is also hydraulically connected to the FAS. For example, water levels measured at well W-16609 (TR 18-2A; Plates 11 and 29) increased only ~1.2 inches (~ 3 cm) in elevation while coring through the Tampa Member into the Suwannee Limestone (DeWitt, 1990). Overall, the FAS is unconfined to semi-confined in the region. Along parts of the northern coastal zone, laterally extensive confining units are thin to absent (Plate 56) and hydraulic head differences allow local recharge to the FAS, which in turn enhances development of secondary porosity along fractures and bedding planes in the FAS. These dissolution-widened channels have a much higher hydraulic conductivity. For example, dissolution channels in the Ocala Limestone are highly developed in Hernando, Citrus and Marion Counties (Trommer, 1993). Abundant sinkholes in the region, indicated by the region's pattern of closed topographic depressions (Plate 3), locally breach confining beds.

As indicated by the hydrologic data presented in the *Surficial aquifer system* section, p. 53, local unconfined to semi-confined FAS conditions exist in the northern region. For example, water levels in a FAS monitor well and a "surficial" monitor well at site W-16311 (ROMP LP-4, Plate 7) exhibit nearly identical elevations, suggesting that confinement is leaky or absent between surficial sediments and the carbonates of the FAS. Along the Brooksville Ridge and parts of the northeastern margin of the study area, IAS/ICU Hawthorn Group sediments provide increased confinement of the FAS. Numerous sinkholes (Plate 3) and paleo-sinks breach confining clayey sediments that would otherwise justify delineation of confined FAS (Plates 6, 7 and 8; Trommer, 1987). As a result, characterization of certain areas along the Brooksville Ridge as IAS/ICU and SAS is very subjective.

In the central, southern and eastern regions, the zero MSL (sea-level) contour of the FAS surface (central Hillsborough and Polk Counties; Plate 58) represents a hinge-line, south of which the dip of the FAS markedly increases. As noted in Figure 8, the FAS surface generally correlates with lithostratigraphic units. The surfaces of these units have been affected by depositional, erosional or structural features (e.g., dissolution, basins, channel scouring, fracture-controlled drainage systems, possible faults, etc.). Other variations in the FAS surface (Plate 58) are due to sub-regional confinement between lithostratigraphic units. For example, several wells in central Hillsborough County indicate that confinement exists between the Suwannee Limestone and the Tampa Member (Arcadia Formation), resulting in correlation of the FAS surface with the Suwannee Limestone. Uncertainty in the area with regard to vertical hydraulic connectivity between these two lithostratigraphic units and lateral/regional groundwater flow warrant further study.

In the southern region, the FAS surface generally coincides with the top of the Oligocene Suwannee Limestone. Along western DeSoto County, however, the FAS surface correlates poorly with any specific lithostratigraphic unit (Figure 8). In some boreholes, such as W-18117 (ROMP 35, northwest DeSoto County, Plate 2), the FAS surface occurs approximately 90 ft (27.4 m) below the top of the Suwannee Limestone (LaRoche, 2004). Along the eastern margin of the study area, the Ocala Limestone comprises the surface of the FAS, except for a small area in northeastern Osceola County, where the Ocala Limestone is absent and the Avon Park Formation is the uppermost unit (Figure 8; Gates, 2006). Plate 34 is a representative cross section of the FAS surface, where it occurs nearly 100 ft (30.4 m) MSL in well W-15650 (ROMP 88; northern Polk County) and deepens significantly toward the south where it occurs at -861 ft (-262 m) MSL in well W-15289.

The FAS potentiometric surface within the study area (Figure 30) is highly variable and contains several prominent features. Maximum elevations (exceeding +130 ft [39.6 m] MSL) occur in north-central Polk County, near Polk City and within the Green Swamp. This maximum is located in the center of a ridge-like potentiometric high that extends north-northwest into Marion and Sumter Counties, and south-southeast along the axis of the Lake Wales Ridge. Another topographically associated high occurs along the Brooksville Ridge in Pasco and Hernando Counties. At least two distinct potentiometric highs with more than 20 ft (6.1 m) of relief also occur: 1) the Dunellon Gap (Levy County), and 2) the Big Cypress Swamp (central Pasco County). Minimum elevations occur within a few feet below sea level in southwestern Hillsborough County. Troughs in the UFA potentiometric surface align with the Withlacoochee River in Hernando and Pasco Counties, the Hillsborough and Alafia Rivers (Hillsborough County), indicating significant baseflow contributions to these rivers (Figure 30). A less distinct trough is associated with lakes in eastern Citrus County (i.e., Tsala-Apopka Lake and Lake Panasofkee). Flow directions vary considerably in response to these highs/ridges and lows/troughs; however, in a very broad sense the groundwater flow in the UFA for the region west of the Lake Wales Ridge is generally toward the Gulf coast.

Seasonal perturbations in the potentiometric surface are generally due to variable recharge rates and pumping. Regionally, the most notable difference between the May 2005 (Ortiz and Blanchard, 2006) and September 2005 potentiometric surface (Ortiz, 2006) is a broadening of the ridge-like high along the Lake Wales Ridge in response to the rainy season. Relative to a predicted “pre-development” potentiometric surface, Bush and Johnston (1988) report drawdown exceeding 20 ft (6.1 m) in a region encompassing roughly one-third of the District centered on northwest Hardee County.

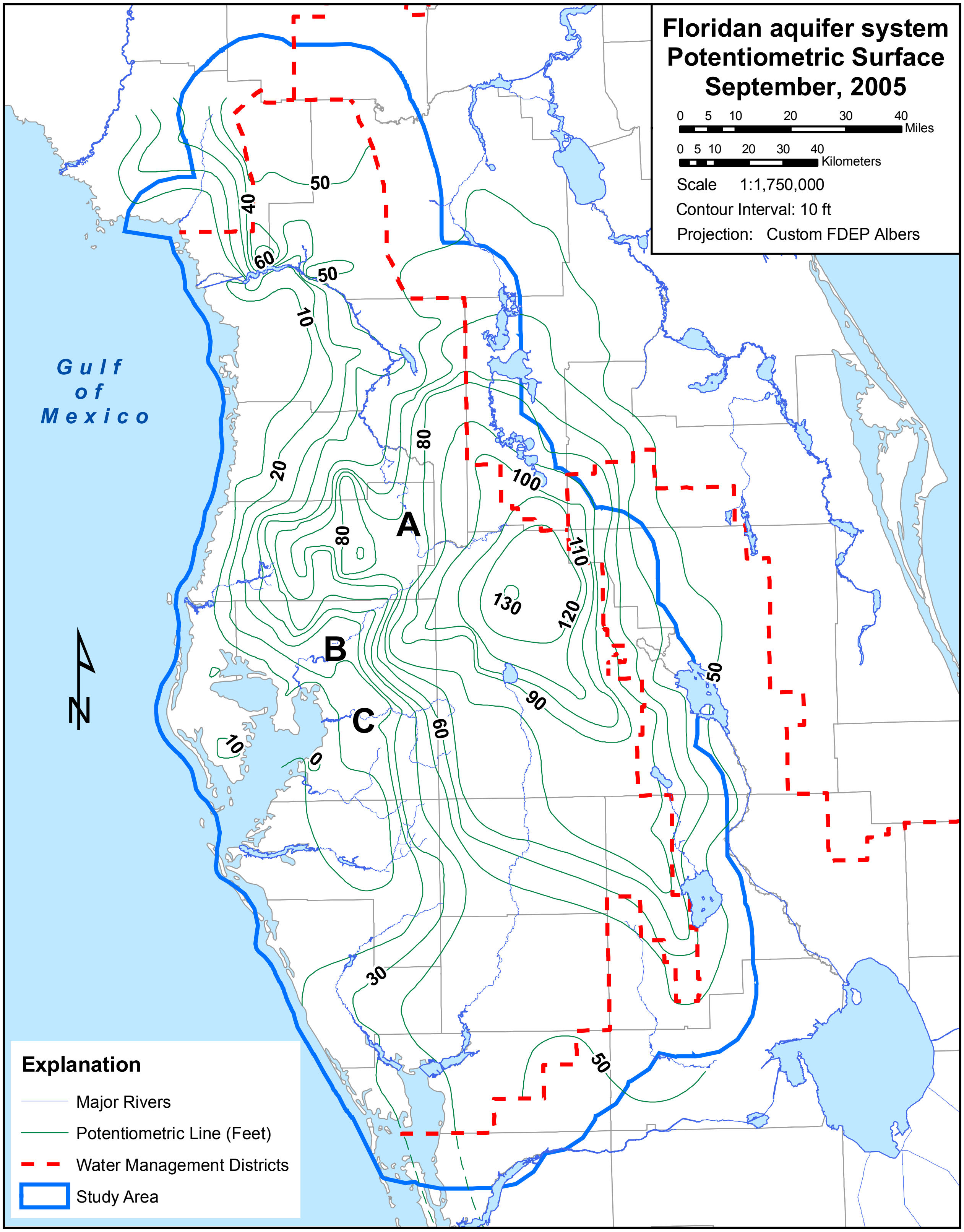


Figure 30. Potentiometric surface of the Floridan aquifer system, September, 2005 (from Ortiz, 2006); A – Withlacoochee River, B – Hillsborough River and C – Alafia River. See Figure 1 for additional river labels.

A meaningful comparison of the IAS/ICU potentiometric surface (Duerr, 2001) with that of the FAS is qualitative at best (see discussion starting on page 62). A more accurate, although site-specific method for assessing the recharge/discharge relation between the IAS/ICU and FAS is to compare water levels in nested wells, many of which are located at District ROMP sites. As noted above, Miller (1986) subdivided the FAS into the Upper Floridan aquifer (UFA) and the Lower Floridan aquifer (LFA). The UFA is the principal source of groundwater throughout the study area except for Charlotte County, where only 20 percent of total withdrawals originate from the UFA (based on data from 2000 as compiled by Marella, 2004) due to naturally poor water quality. The most productive units of the UFA are located within the Avon Park Formation, Ocala Limestone and the Suwannee Limestone (Ryder, 1985).

A highly permeable facies of the FAS, referred to as the "Boulder Zone" (Kohout, 1965), is characterized by cavernous, fractured dolostones with very high transmissivities (Puri et al., 1973). Vernon (1970) reported "Boulder Zone" facies throughout the Florida peninsula. More recently, however, this hydrogeologic facies has been recognized as discontinuous and found to be limited to the southern third of the Florida peninsula (Miller, 1986). The facies does not occur within the same lithostratigraphic unit throughout its extent (Miller, 1986). Maliva et al. (2001) report occurrences of "Boulder Zone" facies in the Early Eocene Oldsmar Formation in Charlotte, Lee and Collier County injection wells. This facies has been reported to occur at depths shallower than -1300 ft (-396.2 m) MSL in Charlotte County (Maliva et al., 2001), which corresponds to Avon Park Formation carbonates. In the southernmost peninsula, the facies occurs within the Paleocene Cedar Keys Formation as well as the Eocene Avon Park Formation and Ocala Limestone (Puri and Winston, 1974).

Wolansky et al. (1980) mapped "the highly permeable dolomite zone" of the Avon Park Formation throughout the southern two-thirds of the District. These well-indurated dolostones are commonly fractured and contain large dissolution channels. The zone occurs ~100 ft (~ 30.5 m) below the top of the Avon Park Formation in the central part of the study area and ~ 400 ft (~ 122 m) below the Avon Park Formation surface in the southern region. The SAS and IAS/ICU generally provide confinement of the UFA (Berndt et al., 1998) except for areas in the northern region where the UFA may be unconfined and where karst and paleokarst promote inter-aquifer connectivity. Hydrogeologic conditions vary considerably between the northern and southern regions depending on the degree of confinement.

The interpolated surface of the UFA ranges from greater than 75 ft (22.9 m) MSL along the Brooksville Ridge to less than -825 ft (-251 m) MSL in southern Charlotte County (Plate 58). Locally, maximum elevations exceed 130 ft (39.6 m) along the Brooksville Ridge (W-14917 [ROMP 109], Plate 7). A map of overburden thickness provides a different perspective on the depth to the top of the UFA (Figure 31). This map, developed by subtracting the UFA surface from a 15 m (49.2 ft) resolution DEM (Arthur et al., in review), allows comparison of the aquifer system to geomorphic features. For example, note the thin overburden along the Brooksville Ridge compared to the Lake Wales Ridge, as well as the maximum overburden thickness of ~900 ft (~274 m) in Charlotte County.

The base of the UFA occurs within the lower Avon Park Formation, where vertically and laterally persistent evaporite minerals (gypsum and anhydrite) are present in the carbonate rocks (e.g., Ryder, 1985; Hickey, 1990; see *Middle Floridan confining unit* [MFCU], p. 75, for more information). Thickness of the UFA, calculated as a "grid difference map," ranges from less than 300 ft (91.4 m) to more than 1500 ft (457 m; Figure 32). Regional subjacent confinement of the UFA is comprised of the MFCU where present. Examples of basal UFA confinement are represented in several cross sections (e.g., Plates 7, 9, 21 and 31). Note, however, that Miller's (1986) delineation of overlapping MFCU units by default suggests that the base of the UFA in these areas is a complex discontinuous surface. This aspect of the UFA is described in more detail in the next section.

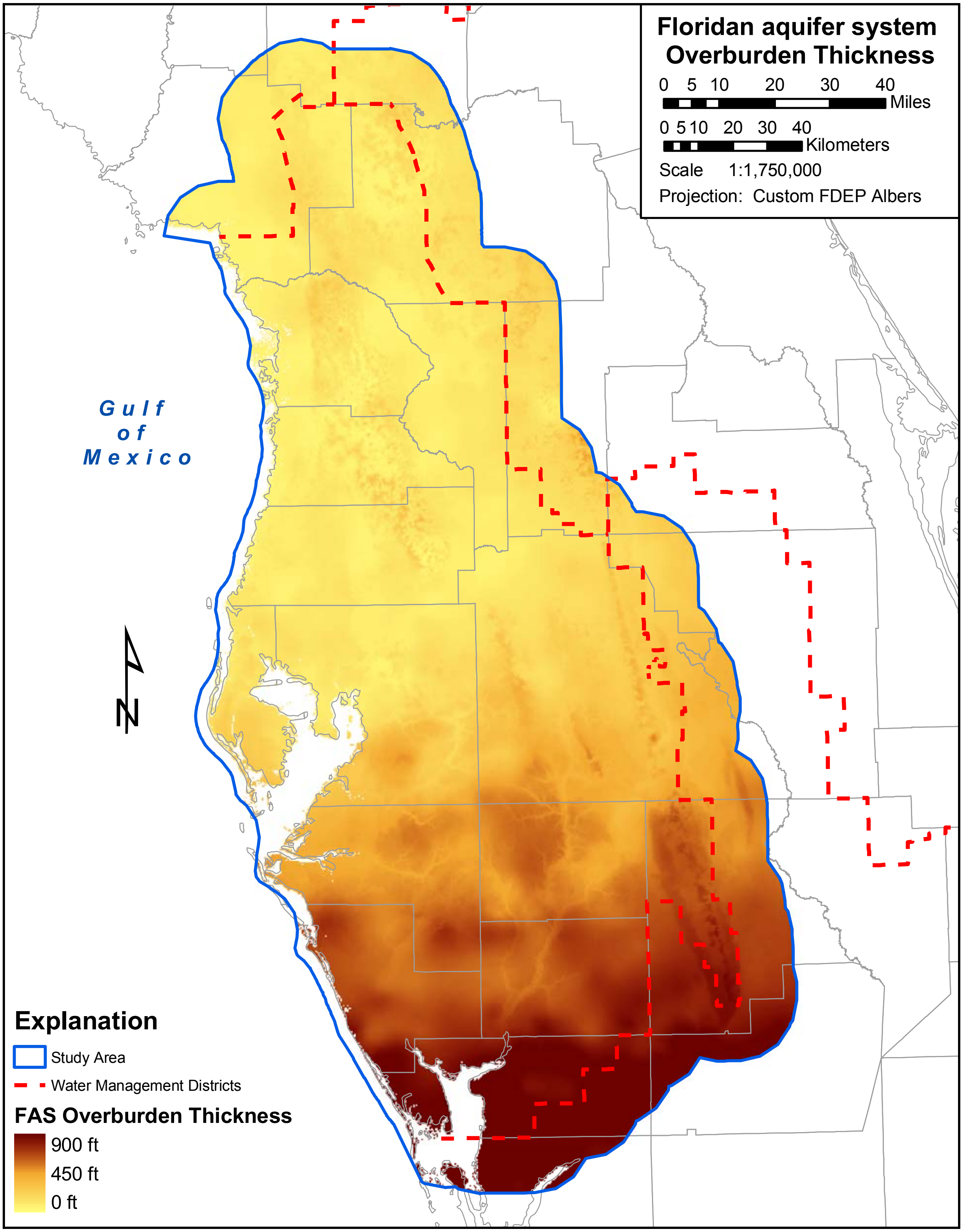


Figure 31. Floridan aquifer system overburden thickness as predicted from geospatial modeling (i.e., DEM minus top of FAS). The map is not contoured due to extreme resolution differences in source grids.

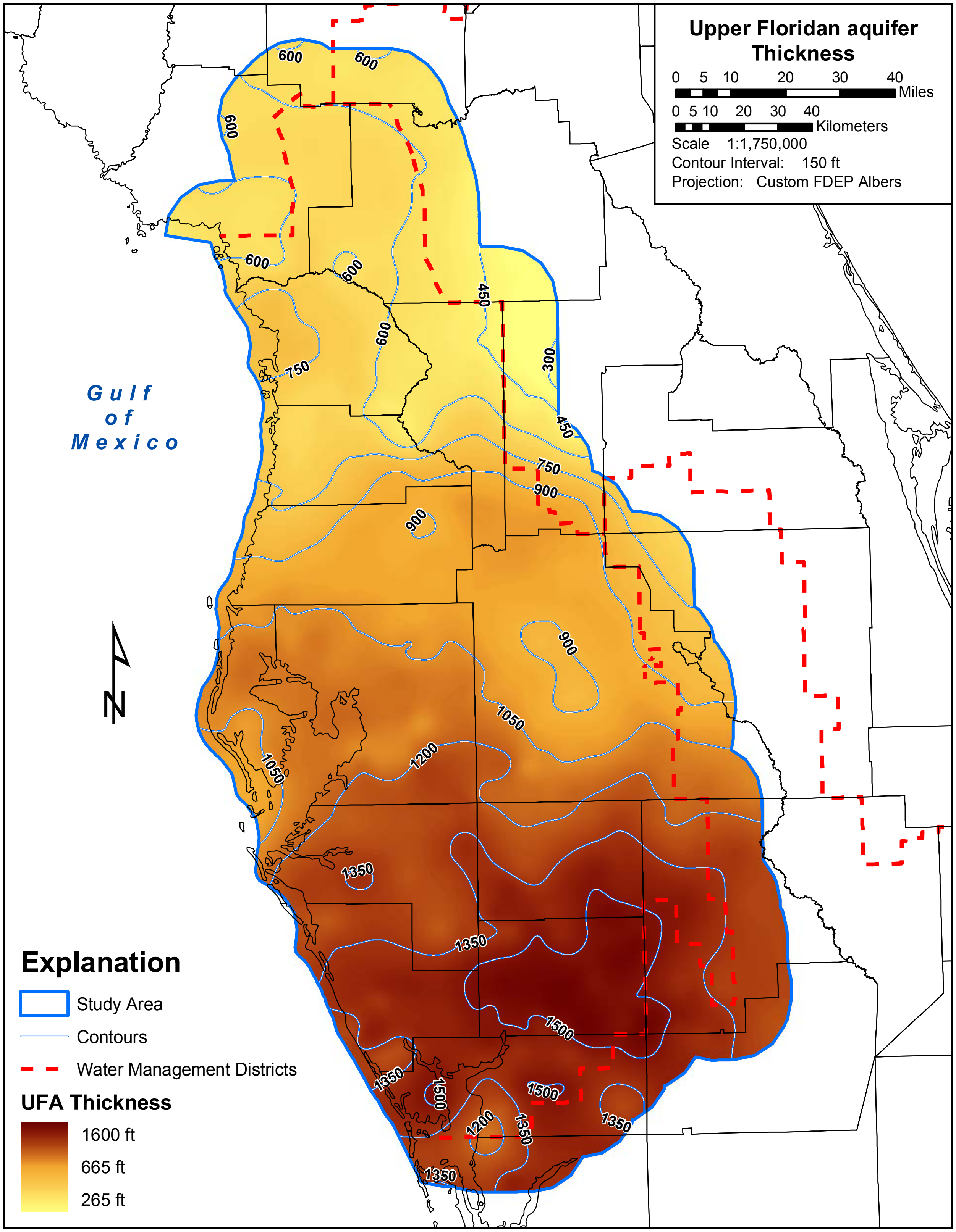
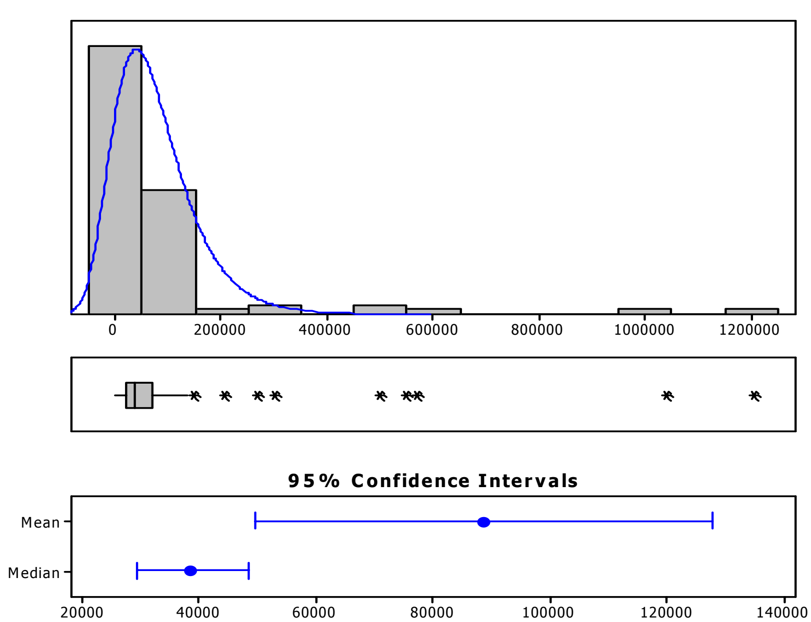


Figure 32. Thickness of the Upper Floridan aquifer (includes non-potable).

The LFA lies beneath MFCU strata and consists of the lower part of the Avon Park Formation, the Oldsmar Formation and the upper part of the Cedar Keys Formation (Miller, 1997). The Cedar Keys Formation forms the lower boundary of the LFA and generally consists of persistently dolomitized carbonates with widespread bedded and intergranular gypsum and anhydrite. Except for the northeastern part of the study area, the LFA is commonly highly saline and not used as a potable or an economically treatable water source. Research on use of the LFA as a sustainable fresh water resource for the northeastern part of the District is underway (Southwest Florida Water Management District, 2006a).

The LFA is the lowermost known and well-defined aquifer, ranging in elevation from -400 ft (-122 m) MSL in the northeastern part of the study area to more than -2500 ft (-762.0 m) MSL in Sarasota and Charlotte counties; LFA thicknesses exceed 2,400 ft (731.5 m) in the southeast part of the study area (Miller, 1986). Per findings of the CFHUD II (Copeland et al., in review) the low-transmissivity strata lying at the base of the FAS (e.g., the "sub-Floridan confining unit" referenced in Southeastern Geological Society, 1986) is informally referred to as "undifferentiated aquifer systems."

Hydraulic properties of the FAS are summarized in Figures 33-38 for the parameters transmissivity, storativity, leakance, Kh, and total porosity, respectively. A large degree of vertical anisotropy exists in the FAS (e.g., Ryder et al., 1980; Ryder, 1982) due to variations in grain size and diagenetic factors affecting permeability (e.g., Budd, 2002; Budd and Vacher, 2004). Median horizontal and vertical hydraulic conductivity values differ by three orders of magnitude, which is notably less than the difference between these same parameters in the SAS and IAS/ICU. This is due in part to a relative lack of sampling bias in the analyzed FAS core samples. A greater degree of anisotropy in the SAS and IAS/ICU relative to the FAS is another possible contributing factor.
Anomalously high transmissivity values (Figure 33) likely reflect the influence of dual-porosity (i.e. fracture/conduit flow). It is also noteworthy that spatial analysis of dolines (e.g., sinkholes) in the northern and central region indicates a statistically significant correlation between FAS hydraulic conductivity and doline-area ratios (Armstrong et al., 2003).



Anderson-Darling Normality Test	
A-Squared	18.49
P-Value <	0.005
Mean	88602
StDev	187201
Variance	35044192303
Skewness	4.4198
Kurtosis	21.3092
N	90
Minimum	1300
1st Quartile	18650
Median	38369
3rd Quartile	69789
Maximum	1203210
95% Confidence Interval for Mean	
49393	127810
95% Confidence Interval for Median	
29279	48540
95% Confidence Interval for StDev	
163279	219401

Figure 33. Statistical summary of UFA transmissivity data from Southwest Florida Water Management District (2006b). Asterisks in the box plot denote statistical outliers.

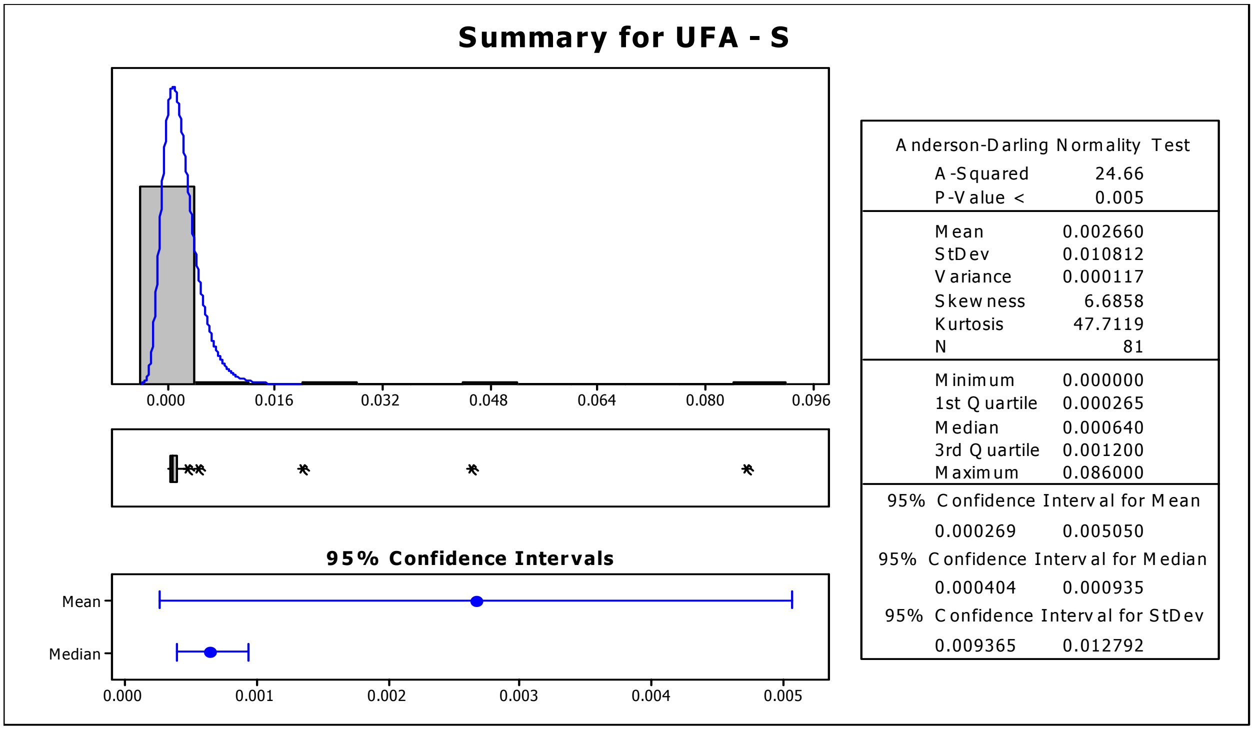


Figure 34. Statistical summary of UFA storativity data from Southwest Florida Water Management District (2006b). Asterisks in the box plot denote statistical outliers.

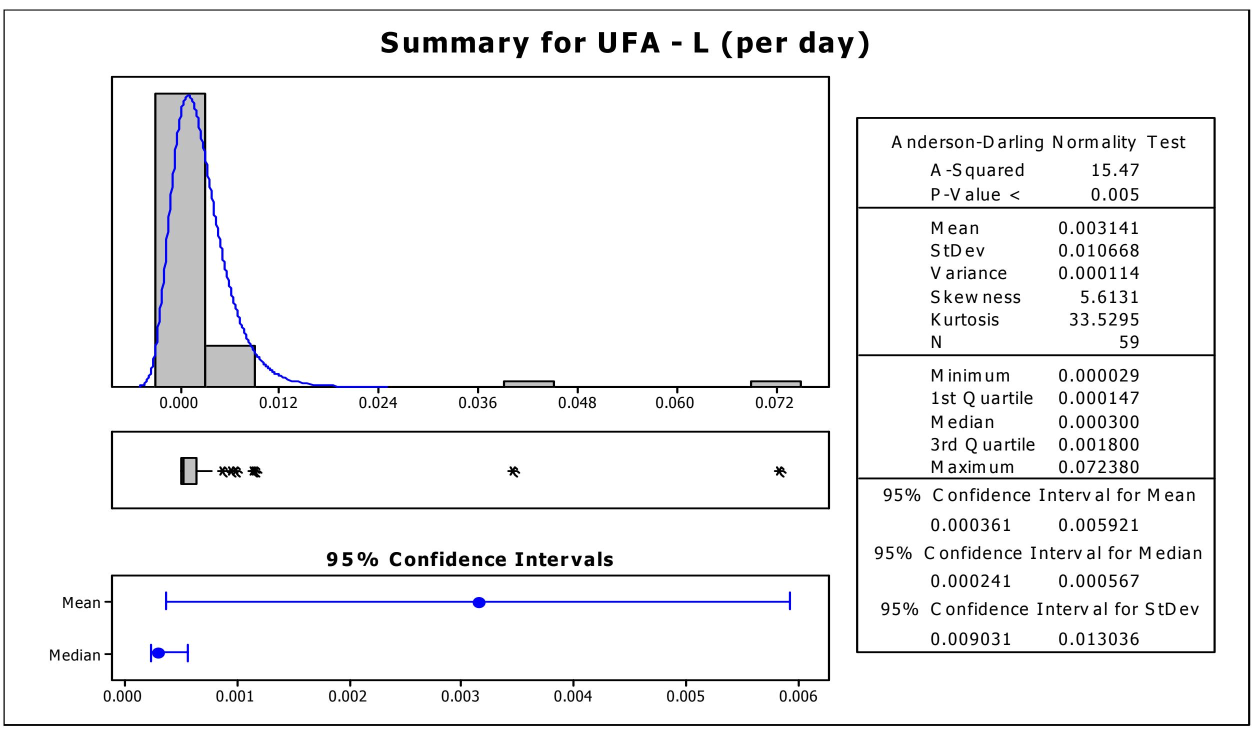


Figure 35. Statistical summary of UFA leakance data from Southwest Florida Water Management District (2006b). Asterisks in the box plot denote statistical outliers.

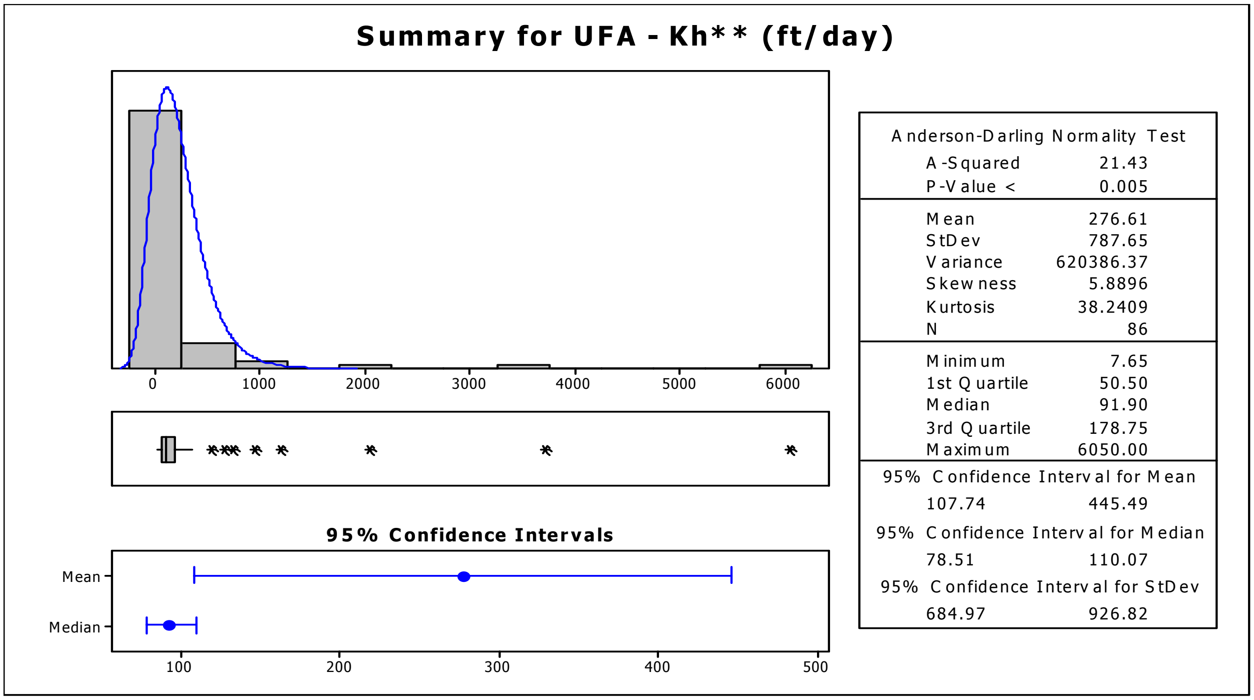


Figure 36. Statistical summary of UFA horizontal hydraulic conductivity data from Southwest Florida Water Management District (2006b). ** - calculated from transmissivity and permeable zone thickness. Asterisks in the box plot denote statistical outliers.

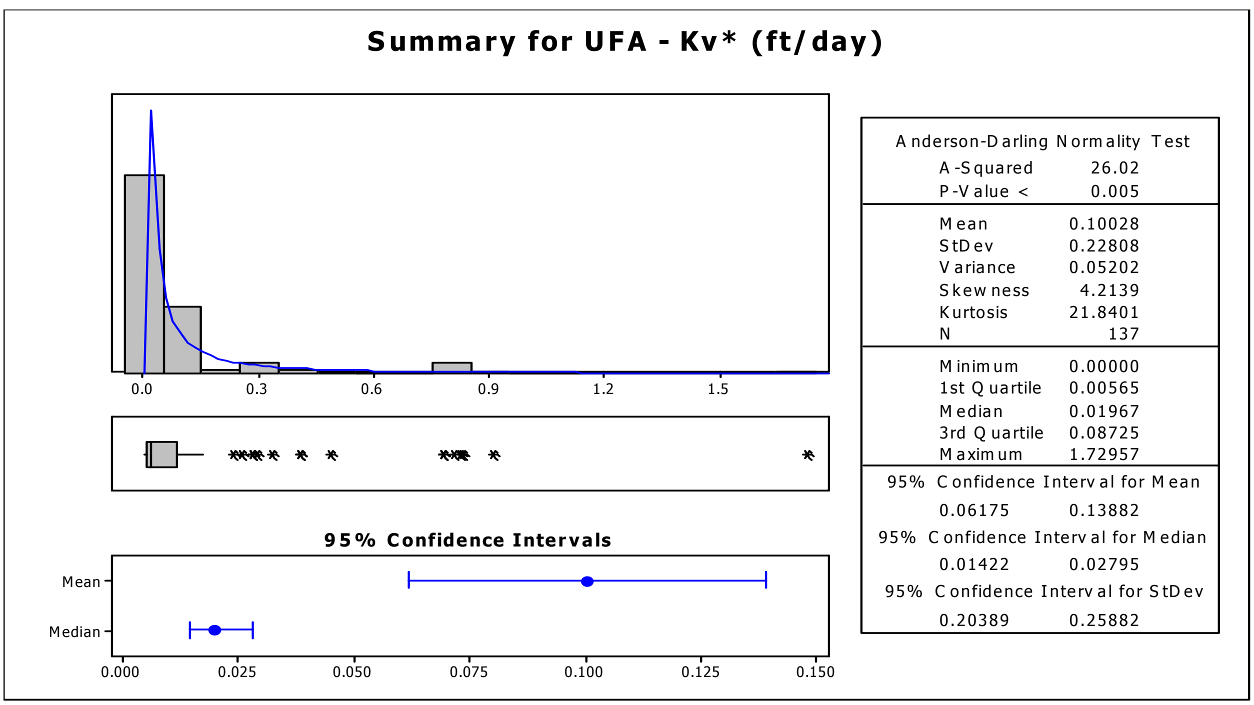


Figure 37. Statistical summary of UFA vertical hydraulic conductivity data based on results of falling-head permeameter analyses of core samples completed at the FDEP-FGS. Asterisks in the box plot denote statistical outliers.

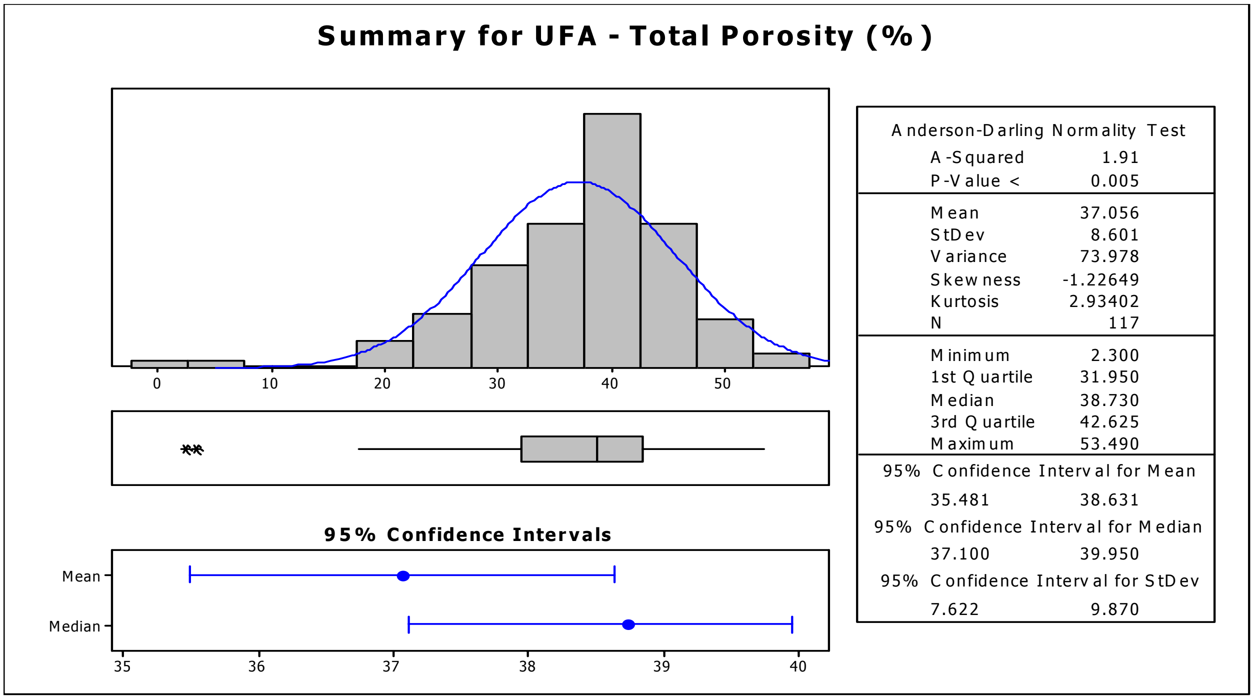


Figure 38. Statistical summary of UFA total porosity data based on results of core sample volumetric analyses completed at the FDEP-FGS. Asterisks in the box plot denote statistical outliers.

Middle Floridan confining unit

Miller (1986) recognizes three confining units within the study area (Units I, II and VI) that separate the UFA from the LFA; however, in context of the overall FAS he states: "… the units act as a single confining unit within the main body of permeable limestone that constitutes the aquifer system." In the present study, we adopt a more descriptive hydrostratigraphic name for the Miller's (1986) "middle confining unit" of the FAS: the Middle Floridan confining unit (MFCU). This name simply associates the confining units with the aquifer system in which they reside. This nomenclature has also been adopted by the CFHUD II (Copeland, et al., in review). Complexity of the MFCU within and beyond the study area is readily apparent given the seven units mapped by Miller (1986) separating the UFA from the LFA in Florida. On a more local scale, delineation of the base of the UFA becomes challenging where overlapping confining units of the MFCU occur.

Within the study area, unit I occurs along the eastern margin and is identified as a leaky confining unit that is "…not much different from that of the permeable zones vertically adjacent to it…" (Miller, 1986). Units II and VI are identified as carbonates (primarily dolostone) with intergranular gypsum and comprise a hydrogeologically significant confining facies that separates the UFA from the LFA in the study area.

The MFCU mapped herein includes Miller's (1986) units II and VI and is principally identified based on lithology and mineralogy: borehole samples that contain thin gypsum/anhydrite beds or intergranular gypsum/anhydrite ≥ five percent (by volume). While some may consider five percent too conservative (e.g., too high), a notable relative increase in matrix confining properties is the emphasis herein, recognizing that transition zones may occur, as well as zones where variable precipitation and dissolution of these minerals may have occurred. Geophysical logs and water-quality data are also used to identify or infer evidence of the MFCU. In addition to data generated for this report, data from Miller

(1988), Hickey (1982), Sacks (1996), Stewart (1966), O'Reilly et al. (2002) and unpublished SWFWMD ROMP reports are also used to interpolate the MFCU surface.

Miller's (1986) unit II, which reaches depths of -1,900 ft (-579.1 m) MSL in Sarasota County correlates with most of the MFCU surface (Plate 59). Unit VI (Miller, 1986) reaches depths of -2,100 ft (-640.1 m) MSL in southeastern DeSoto County and along the southern half of Charlotte County. According to data from Miller (1988), the two units overlap in western Highlands/eastern DeSoto Counties as well as western Charlotte and Lee Counties. Several wells investigated by Miller (1986, 1988) and in the present study indicate that the MFCU may not be laterally continuous throughout the study area; however for purposes of regional mapping, the MFCU is contoured continuously and the areas in question are annotated (Plate 59).

The initial protocol for mapping the MFCU was to reflect the uppermost occurrence of the unit in a borehole using the lithologic criteria outlined above. This method, however, yielded anomalous surface patterns and vertical discontinuities where Miller's (1986) units II and VI coexist in a well. A MFCU surface map based on this initial protocol yielded two dome-like features in the southern region in the vicinity of these wells. The domes represented unit II overlying unit VI, separated by high permeability zones (Miller, 1988) and thus did not reflect a contiguous mappable surface. The distribution of well control for unit II (Plate 59) also brings into question the degree to which unit II is laterally continuous. Many sufficiently deep wells within the extent of unit II do not encounter the unit. It is also noteworthy that Miller (1986) describes units II and VI as having nearly indistinguishable lithologic characteristics.

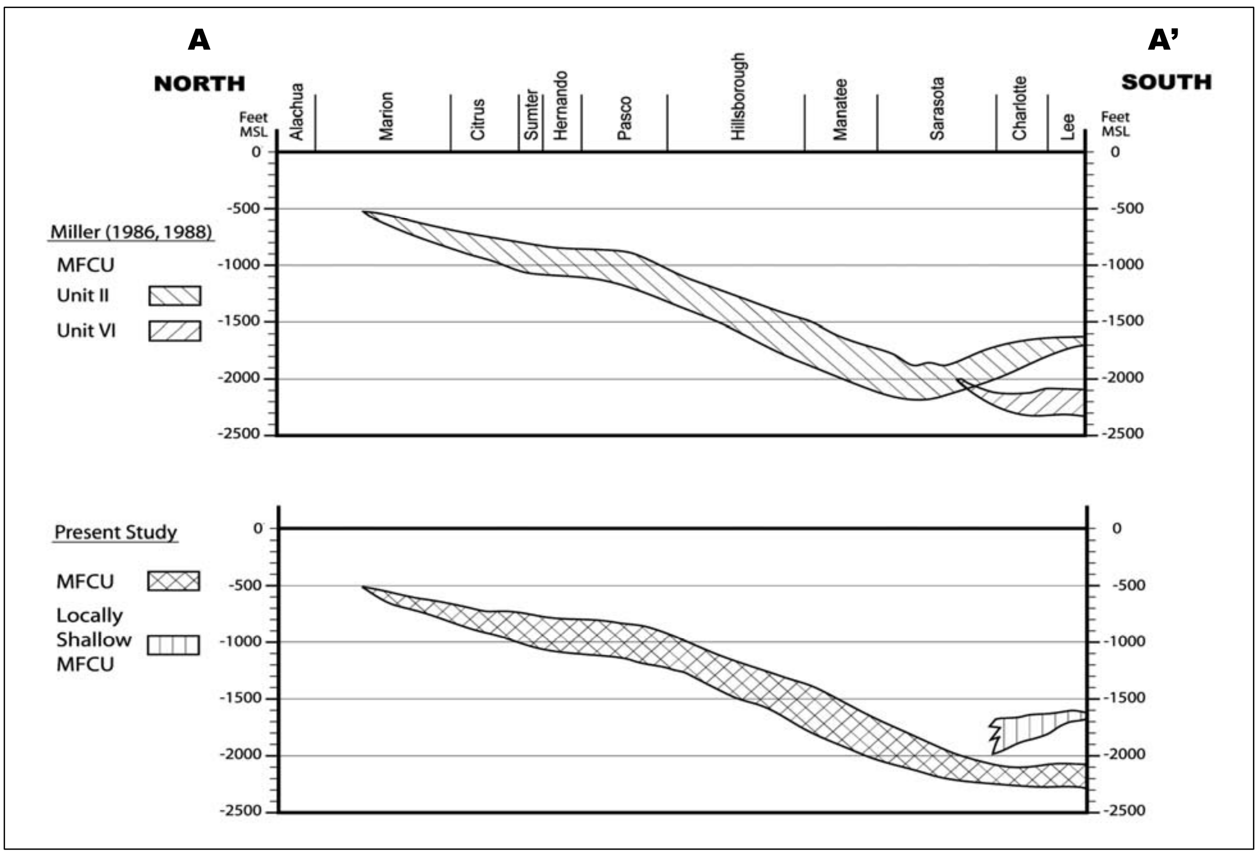


Figure 39. Interpretations of the MFCU in the study area. Upper cross section reflects MFCU units mapped by Miller (1986); lower cross section reflects alternate interpretation showing continuity between Miller's units II and VI, with isolated MFCU middle to upper Avon Park confinement overlying the deeper, more laterally continuous unit. See Plate 59 for cross-section location.

Evaluation of the regional slope of the MFCU, lithologic similarities between the units, and sparse data for unit II lead to an alternate interpretation: unit II north of Manatee and Hardee Counties may correlate with unit VI south of these counties (Figure 39). In this interpretation, isolated MFCU facies occur approximately 400 ft (122 m) above the lower MFCU unit in southwestern Highlands and western Charlotte Counties. Plate 59 and Figure 39 (bottom half) reflect this latter interpretation. Wells that encountered both MFCU facies (II and VI) are represented by green symbols (Plate 59) and are labeled with the elevation of the shallower discontinuous MFCU facies, which is informally referred to as the "middle to upper Avon Park confining unit." Data in Miller (1988) indicate a high permeability zone between the base of the "middle to upper Avon Park confining unit" and the MFCU as mapped herein within all wells containing both of Miller's MFCU facies (II and VI).

Based on comparison of Plate 38 with Miller's (1986) Middle Eocene isopach, the MFCU as defined and mapped in this study generally occurs within the lower half of the Avon Park Formation. Exceptions to the generalization include Marion, Osceola and Pinellas Counties, where the MFCU occurs within the upper third of the Avon Park Formation. Several cross sections contain wells that penetrate the MFCU (e.g., Plates 7, 9, 21, 29, 30 and 34). In the northwestern part of the study area, the elevation of the MFCU is generally deeper than -400 ft (-122 m) MSL. The unit dips southward to depths below –2100 ft (-640.1 m) MSL in Charlotte County. South of the study area, Reese (2000) mapped the "dolomite-evaporite unit in the middle confining unit" of the FAS, recognizing the significance of dense unfractured dolostones in his study area. He also notes that this unit may locally be considered the top of the MFCU, which is generally supported by the MFCU surface in Plate 59. It is possible that the few wells with shallower elevations in Reese's (2000) "dolomite – evaporite unit" map are related to the discontinuous "middle to upper Avon Park confining unit" described herein.

Presence of the MFCU is debatable for two regions within the eastern half of the study area. Throughout most of Marion County (including parts of Alachua, Sumter and Lake Counties), the MFCU is inferred. Borehole cuttings from multiple wells in the area show no evidence of gypsum/anhydrite; however, anomalously high sulfate concentrations (some exceeding 500 mg/L; Sacks, 1996) in FAS groundwater samples suggest the MFCU may be present. As such, this area is denoted on Plate 59 as "MFCU inferred based on water quality data." In eastern Polk County, Miller (1986) mapped the MFCU; however, available well control (this study and Miller, 1988), as well as water quality data for the area, yields no direct evidence that it is present. Sprinkle (1989) and Katz (1992) report relatively low sulfate concentrations (< 50 mg/L) within the UFA in the area. To emphasize this uncertainty the MFCU in this area is labeled "MFCU possibly absent: limited data" (Plate 59).

Hydraulic conductivity analyses of MFCU rocks were not completed for this study; however, data exists in SWFWMD and consultant's reports. For example, Hickey (1982) reports hydraulic conductivities ranging from 1.1 ft/day to $6.0\text{x}10^{-7}$ ft/day ($3.8\text{x}10^{-4}$ to $2.1\text{x}10^{-10}$ cm/sec) based on core representing the "lower confining bed" (greater than -1000 ft [-305 m] MSL) in Pinellas County. To provide characterization of MFCU hydraulic conductivity and total porosity, data has been compiled from three injection well sites: Knight's Trail, Sarasota County, (Law Environmental, Inc., 1989), Burnt Store Utilities, Charlotte County, (ViroGroup, Inc., 1995) and Punta Gorda, Charlotte County, (City of Punta Gorda, Water Resource Solutions, Inc., and Boyle Engineering Corporation, 2001). Data from Stewart (1966) and Hickey (1982) and Montgomery Watson Americas (1997) are also included. Hydraulic conductivity (Kv) for the 21 MFCU cores analyzed in these studies range from $1.5\text{x}10^{-1}$ ft/day to $1.0\text{x}10^{-6}$ ft/day ($5.3\text{x}10^{-5}$ to $3.53\text{x}10^{-10}$ cm/sec), with a median value of $1.84\text{x}10^{-3}$ ft/day ($6.5\text{x}10^{-7}$ cm/sec; Figure 40). Total porosity for these samples average 17.2 percent (median = 19.6 percent) and range from 5 percent to 30 percent (Figure 41). Basso (2002) reports Kh values ranging from .002 to .04 ft/day ($7.06\text{x}10^{-07}$ to $1.4\text{x}10^{-5}$ cm/sec). Transmissivity data range from 0.08 to 2.9 ft^2/day (0.86 to 31.2 m^2/day).

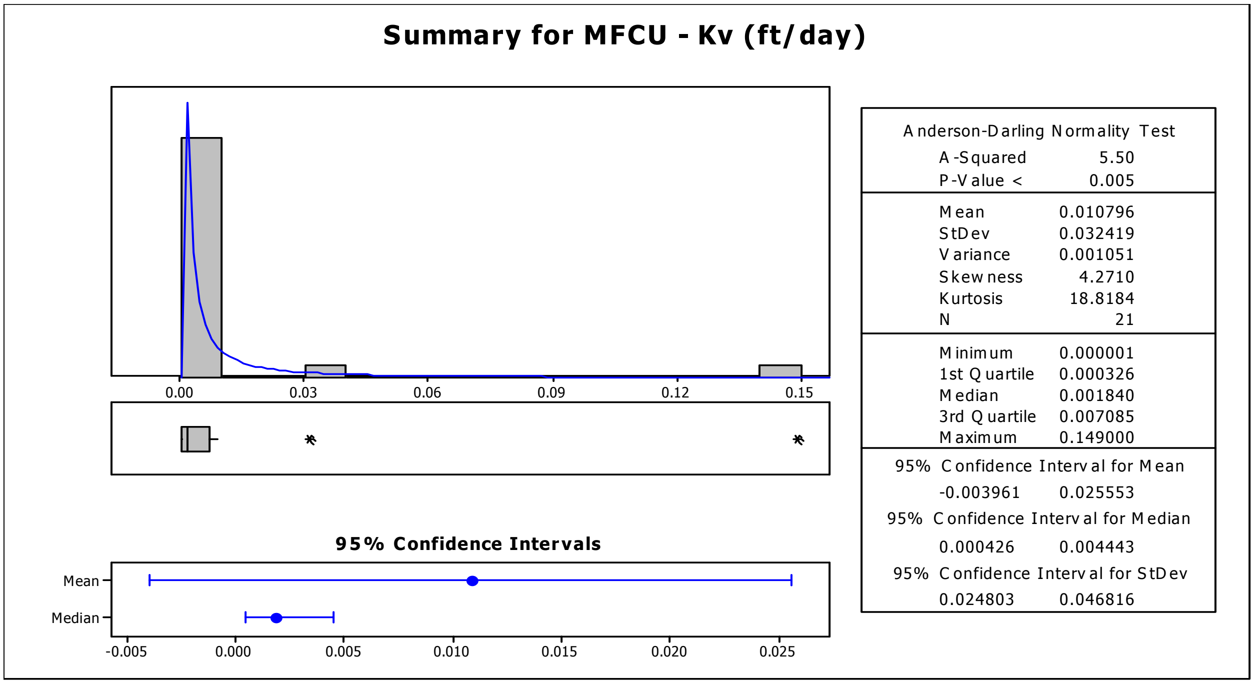


Figure 40. Statistical summary of MFCU vertical hydraulic conductivity data based on results of falling-head permeameter analyses of core samples; compiled from Stewart (1966), Hickey (1982), Law Environmental (1989), ViroGroup (1995), Montgomery Watson Americas, Inc., (1997), City of Punta Gorda, et al., (2001). Asterisks in the box plot denote statistical outliers.

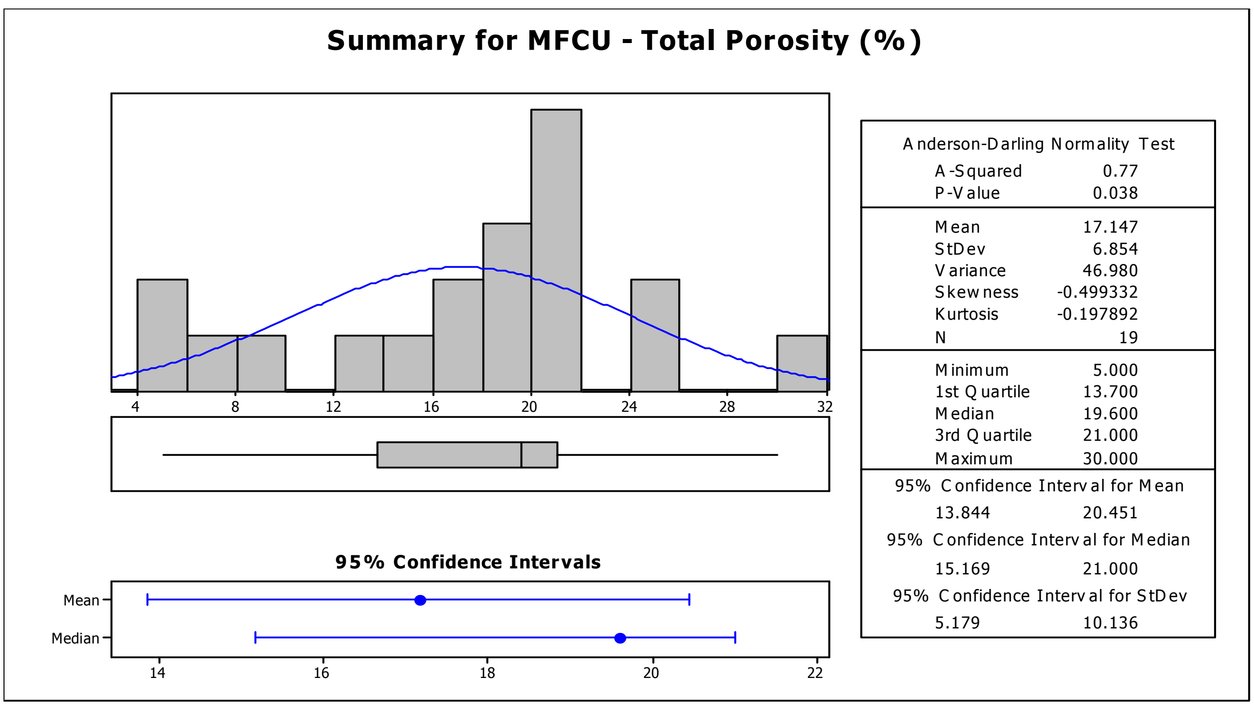


Figure 41. Statistical summary of MFCU total porosity data based on volumetric analyses of core samples; compiled from Stewart (1966), Law Environmental (1989), ViroGroup (1995), Montgomery Watson Americas, Inc. (1997), City of Punta Gorda, et al., (2001).

SUMMARY

The hydrogeologic framework of the Southwest Florida Water Management District region described in this report is spatially characterized through a series of 32 maps (plates and figures) and 34 cross sections. Lithologic, hydrologic and geophysical data from more than 1050 wells comprise a database of subsurface elevations and thicknesses for nine lithostratigraphic and four hydrostratigraphic units represented in these maps and cross sections. Elevations of unit boundaries for most of the wells used in the maps and cross sections have been confirmed through visual inspection of cores and cuttings by the authors and those acknowledged in this report. Additional data on which the maps and cross sections are based are incorporated from peer-reviewed reports and interpreted from geophysical logs and existing lithologic descriptions. The lithostratigraphic units are discussed in terms of age, lithology, mineralogy, common fossils, sedimentary structures, porosity/permeability, contact relations with other units, facies changes, spatial distribution (vertical and lateral), gamma-ray log responses, hydrostratigraphic unit correlations and depositional environments. Hydrostratigraphic units are similarly discussed in terms of spatial distribution, regional and local hydraulic characteristics, hydrogeologic properties and correlation with lithostratigraphic units.

Among the challenges that exist when creating subsurface stratigraphic maps based on well data is the need to balance three factors: 1) accuracy of the interpolated contours relative to the data on which each map is based, 2) the implicit resolution of the map, which is depicted by the contour interval and the degree of perturbations in the contours and 3) an accurate regional characterization of the unit being mapped. For example, a map that is 100 percent accurate with respect to elevations or thicknesses may overemphasize local anomalies such as karst features. Although a small percentage of wells represent these anomalous elevations, the wells also represent an infinitesimal fraction of the total number of anomalous features in the mapped surface. In other words, thousands of paleosink features may exist in the top of a carbonate unit; however, less than five percent of the wells in the database may have encountered one of these features. Hence, a regional-scale map would be more representative of the true regional character of the surface (or thickness) if the local anomalies had less influence on the interpolated surface. Moreover, a highly accurate map may also result in jagged, irregular contours, which may imply changes in elevation (or thickness) at a scale that is not justified by the distribution and density of the well data.

To achieve an appropriate balance of the aforementioned factors, an iterative process of data evaluation, sample inspection, data interpretation, and spatial and statistical analysis was completed. For the final maps, kriging was used to interpolate map surfaces, which were then corrected as needed for consistency with land surface and other mapped units. The interpolated surfaces were then smoothed to reflect the regional character of each mapped unit. The surface interpolations also provide GIS coverages that can be applied in groundwater flow models and 3D applications.

The cross sections focus on data from cores, with an emphasis on those collected through the SWFWMD Regional Observation and Monitor-well Program (ROMP). Data from geophysical logs as well as cores and cuttings archived in the Florida Geological Survey sample repository were used to fill gaps in the cross-section well coverage. Of the 34 cross sections, nine trend approximately north-south, averaging approximately 60 mi (~96 kilometers) in length, while the remaining sections generally trend east-west and average approximately 35 mi (~56 km) in length. Graphical representation of borehole data from 149 wells used in the cross sections include lithostratigraphic and hydrostratigraphic boundaries and cross-well correlations, lithology, mineralogy and gamma-ray log response. Each section also includes topographic profiles labeled with selected anthropogenic features.

The relationship between lithostratigraphic and hydrostratigraphic units is straightforward in many parts of the study area; however, the association can be locally complex and indistinct. In either case, the relationship depends on the degree of hydraulic continuity between and among lithostratigraphic units. The variable hydrogeologic setting in the northern region serves as an example: characterization of the SAS (water-table aquifer) is complicated by lateral hydraulic discontinuities. Regionally, the water table may reflect the potentiometric surface of the unconfined FAS (e.g., west of the Brooksville Ridge); however, local hydraulic separation between the SAS and the FAS may exist. As a result, delineation of a regionally extensive SAS that is significant as a water-producing unit is the subject of some debate.

The framework of stratigraphy and hydrogeology developed during this investigation serves as a foundation for numerous applications, ranging from more refined hydrogeological mapping to mineral resource assessments, well-field designs and groundwater models. Regardless of the application, it is our hope that this study facilitates science-based decision making regarding the protection, conservation and management of the solid-earth and water resources of southwestern Florida.

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APPENDIX 1. COMMENTARY ON FLORIDA HYDROSTRATIGRAPHIC NOMENCLATURE.

Considerable debate exists with regard to hydrostratigraphic nomenclature in the study area. While it is beyond the scope of the present study to formally rename principal aquifer systems in southwestern Florida, especially given the pending recommendations of the CFHUD II (Copeland et al., in review), some discussion is warranted. This is due in part to the lack of a formal hydrostratigraphic code (Seaber, 1988), unlike that available for lithostratigraphic nomenclature (North American Commission on Stratigraphic Nomenclature, 2005). Hydrostratigraphic unit definitions and nomenclatural guidelines, however, do exist. Poland et al. (1972) define an aquifer system as “A heterogeneous body of intercalated permeable and poorly permeable material that functions regionally as a water-yielding hydraulic unit; it comprises two or more permeable beds separated at least locally by aquitards that impede groundwater movement but do not greatly affect the regional continuity of the system.” Neuendorf et al. (2005) define an aquifer system as “A heterogeneous body of intercalated permeable and less permeable material that acts as a water-yielding hydraulic unit of regional extent.” According to nomenclature guidelines set forth by Laney and Davidson (1986), aquifer system names should not be derived from relative position. In consideration of these definitions and guidelines, all or part of the SAS and IAS/ICU may be considered inappropriately named. On the other hand, Macfarlane (2000) suggests that aquifer system names should be retained if they are entrenched in the scientific literature or legally defined in a state’s regulatory framework.

With regard to naming confining units, Laney and Davidson (1986) suggest that the name could be based on the aquifer it confines (i.e., the aquifer it overlies). Intuitively, a confining unit may also be named after the aquifer system in which it resides, especially if that unit crosses multiple lithostratigraphic units precluding a lithostratigraphic-based name. The MFCU, which has been adopted by the CFHUD II accordingly follows this line of reasoning.

Any proposed changes in Florida’s hydrostratigraphic nomenclature will hopefully address the IAS/ICU, in which relative permeability is an important consideration. In the northern part of the study area, confining to semi-confining sediments are dominant, whereas in the southern part of the study area, distinct local to sub-regional zones of higher permeability exist. Some hydrogeologists prefer to characterize the northern area as ICU and the southern area as IAS; however, it is noteworthy that a system (IAS) and a unit (ICU) are not at the same hierarchical level (Aadland et al., 1995). As a result, the ICU would be a unit of the IAS.

The concept of a *confining system* should also be considered for the IAS/ICU. Jorgenson et al. (1993) define a confining system as “two or more confining units separated at most locations by one or more aquifers that are not in the same hydraulic system.” Renken (1998) clarifies this definition by stating “…confining units that may contain local aquifers, but which function together to retard the vertical movement of water, are called confining systems.” In consideration of these definitions, and Laney and Davidson’s (1986) suggestion on nomenclature (i.e., avoid naming based on relative position), the IAS may be more appropriately named the *Upper Floridan confining system*, which would allow for presence of hydraulically disconnected permeable zones within a system that confines the FAS. In the study area, the northern lateral equivalent of this confining system could be named the *Upper Floridan confining unit*. Alternatively, the area could simply be recognized as part of the *Upper Floridan confining system*.

Naming these systems or units relative to the FAS may be more appropriate than using a lithostratigraphic reference because the FAS, as well as its overlying confining/semi-confining sediments are not limited to a single lithostratigraphic formation or group. For example, to name the IAS/ICU based on association with the Hawthorn Group may lead to confusion given that part of this lithostratigraphic package is included in the UFA.

Another option is to consider the IAS as a complex system of nearly statewide extent, recognizing that aquifers within this predominantly confining/semi-confining system are sub-regional to regional, yet the overall correlative hydrostratigraphic package is unique relative to the surficial and Floridan aquifer systems. Along this line of reasoning, one may consider the confining/semi-confining sediments in the northern part of the study area as a low-permeability hydrogeologic facies of the IAS. It is noteworthy that hydraulic characteristics of semi-confining zones identified in Florida are considered “aquifers” or “permeable zones” in other parts of the country, thus lending support to the statewide IAS concept. Fetter (2001) describes an aquifer as a “geologic unit that can store and transmit water at rates fast enough to supply reasonable amounts to wells. The intrinsic permeability of aquifers would range from about 10^{-2} darcy upward.” Albeit subjective, clayey sands often considered part of semi-confining (and “confining?”) units in Florida fall within Fetter’s (2001) aquifer definition.

The proposal of a statewide IAS, however, may lead to perception issues for the lay public as well as concerns regarding aquifer-system definitions. Many geoscientists contend that statewide use of the IAS name is inconsistent with existing aquifer-system definitions. Moreover, use of the IAS name in the northern study area may incorrectly imply to the non-scientist that significant water-yielding “intermediate” strata exist in the region, which is not the case.

APPENDIX 2. EXPLANATION OF REVISIONS TO FDEP-FGS SPECIAL PUBLICATION 28 AQUIFER DEFINITIONS

Changes to original Southeastern Geological Society (1986) text are denoted by brackets (additions) and strikethroughs to reflect definitions applied in this report. Footnotes provide explanation.

surficial aquifer system: " - the permeable hydrogeologic unit contiguous with land surface that is comprised principally of unconsolidated to poorly indurated [silici]clastic deposits. It also includes ~~well-indurated~~ carbonate rocks [and sediments], other than those of the [FAS] ~~Floridan aquifer system~~ where the Floridan is at or near land surface. Rocks [and sediments] making up the [SAS] ~~surficial aquifer system~~ belong to all or part of the ~~upper~~[7] Miocene to Holocene Series. [The SAS] ~~It~~ contains the water table and water within it is under mainly unconfined conditions; [however,] ~~but~~ beds of low permeability may cause semi-confined or locally confined conditions to prevail in its deeper parts. The lower limit of the [SAS] ~~surficial aquifer system~~ coincides with the top of laterally extensive and vertically persistent beds of much lower permeability."[8]

intermediate aquifer system or the intermediate confining unit: " – includes all rocks that lie between and collectively retard the exchange of water between the overlying [SAS] ~~surficial aquifer system~~ [(or land surface)][9] and the underlying [FAS] ~~Floridan aquifer system~~. These rocks in general consist of [coarse to] fine grained [silici]clastic deposits interlayered with carbonate strata belonging to ~~all or~~ parts of the [Oligocene] ~~Miocene~~[10] and younger ~~S~~[s]eries. [*Section omitted.*[11]] The aquifers within this system contain water under [semi-confined to] confined conditions. The top of the ~~intermediate aquifer system or the intermediate confining unit~~ [IAS/ICU] coincides with the base of the [SAS] ~~surficial aquifer system~~ [and on a local scale with land surface]. The base of the [IAS/ICU] ~~intermediate aquifer is at~~ [is hydraulically separated to a significant degree from] the top of the [FAS][12] ~~vertically persistent permeable carbonate section that comprises the Floridan aquifer system, or, in other words, that place in the section where clastic layers of significant thickness and permeable carbonate rocks are dominant~~. [*Section omitted.*[13]]."

Floridan aquifer system: " – [a] thick [predominantly] carbonate sequence [that] ~~which~~ includes all or part of the Paleocene to ~~early~~ [Lower] Miocene Series and functions regionally as a water-yielding hydraulic unit. Where overlain by [the IAS/ICU] ~~either the intermediate aquifer system or the intermediate confining unit~~, the [FAS] ~~Floridan~~ contains water under confined conditions. When overlain directly by the [SAS] ~~surficial aquifer system~~, the [FAS] may or may not contain water under confined conditions depending on the extent of low permeability material [within the base of] ~~in~~ the [SAS] ~~surficial aquifer system~~. Where the carbonate rocks crop out [or are covered by a veneer of siliciclastics], the [FAS] ~~Floridan~~ generally contains water under unconfined conditions near the top of the aquifer system, but because of vertical variations in permeability, deeper zones may contain water under confined conditions. The [FAS] ~~Florida aquifer system~~ is present throughout the State and is the deepest part of the active groundwater flow system on mainland Florida. The top of the [FAS] ~~aquifer system~~ generally

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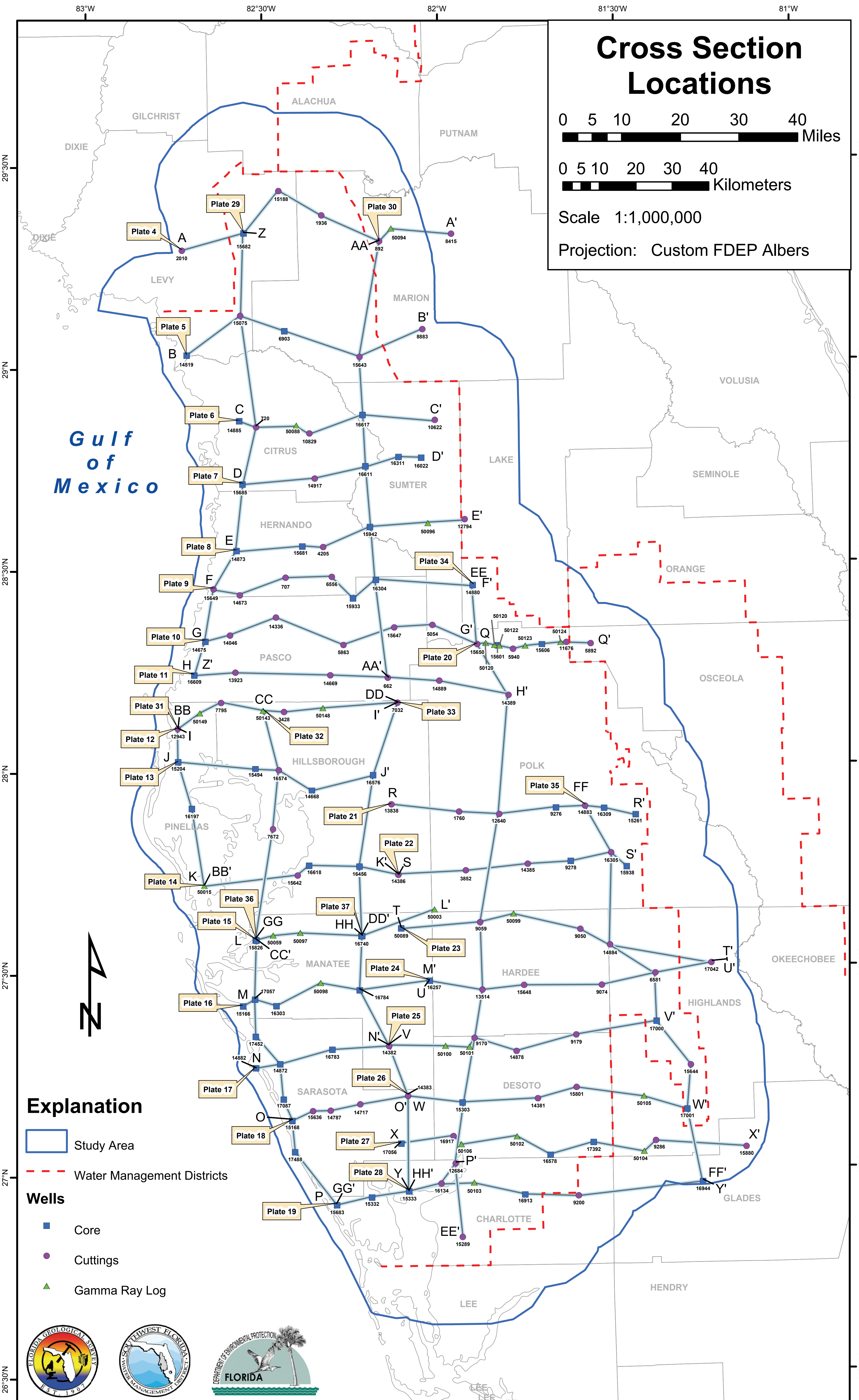
[7] Although aquifer systems are based on hydraulic properties, correspondence with age does exist; "upper" is deleted to allow more flexibility with regard to this correlation.
[8] Second paragraph describing SAS in Southeastern Geological Society (1986) is omitted.
[9] For example, the Peace River Formation is locally exposed at land surface in Polk County.
[10] Now recognized as Late Oligocene based on the work of Scott et al. (1994).
[11] Related nomenclatural issues pertaining to the IAS/ICU are being addressed by the CFHUD II.
[12] The lower extent of the IAS/ICU in the present study is also based on the relative degree of hydraulic separation from the FAS.
[13] Related nomenclatural issues pertaining to the IAS/ICU are being addressed by the CFHUD II.

coincides with the absence of significant thicknesses of [silici]clastics from the section and with the top of the vertically persistent permeable carbonate section [*Section omitted*.[14]]."

[14] Remainder of the Southeastern Geological Society (1986) definition relevant to this study is discussed in other sections of this report.


Cross Section Locations
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0 5 10 20 30 40 Kilometers
Scale 1:1,000,000
Projection: Custom FDEP Albers
83°W
82°30'W
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81°30'W
81°W
29°30'N
29°N
28°30'N
28°N
27°30'N
27°N
26°30'N
Gulf of Mexico
GILCHRIST
DIXIE
ALACHUA
PUTNAM
LEVY
MARION
VOLUSIA
CITRUS
LAKE
SUMTER
SEMINOLE
HERNANDO
ORANGE
PASCO
OSCEOLA
HILLSBOROUGH
POLK
PINELLAS
MANATEE
HARDEE
OKEECHOBEE
HIGHLANDS
SARASOTA
DESOTO
CHARLOTTE
GLADES
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LEE
Plate 4
Plate 5
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Plate 11
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Plate 13
Plate 14
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Plate 16
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Plate 30
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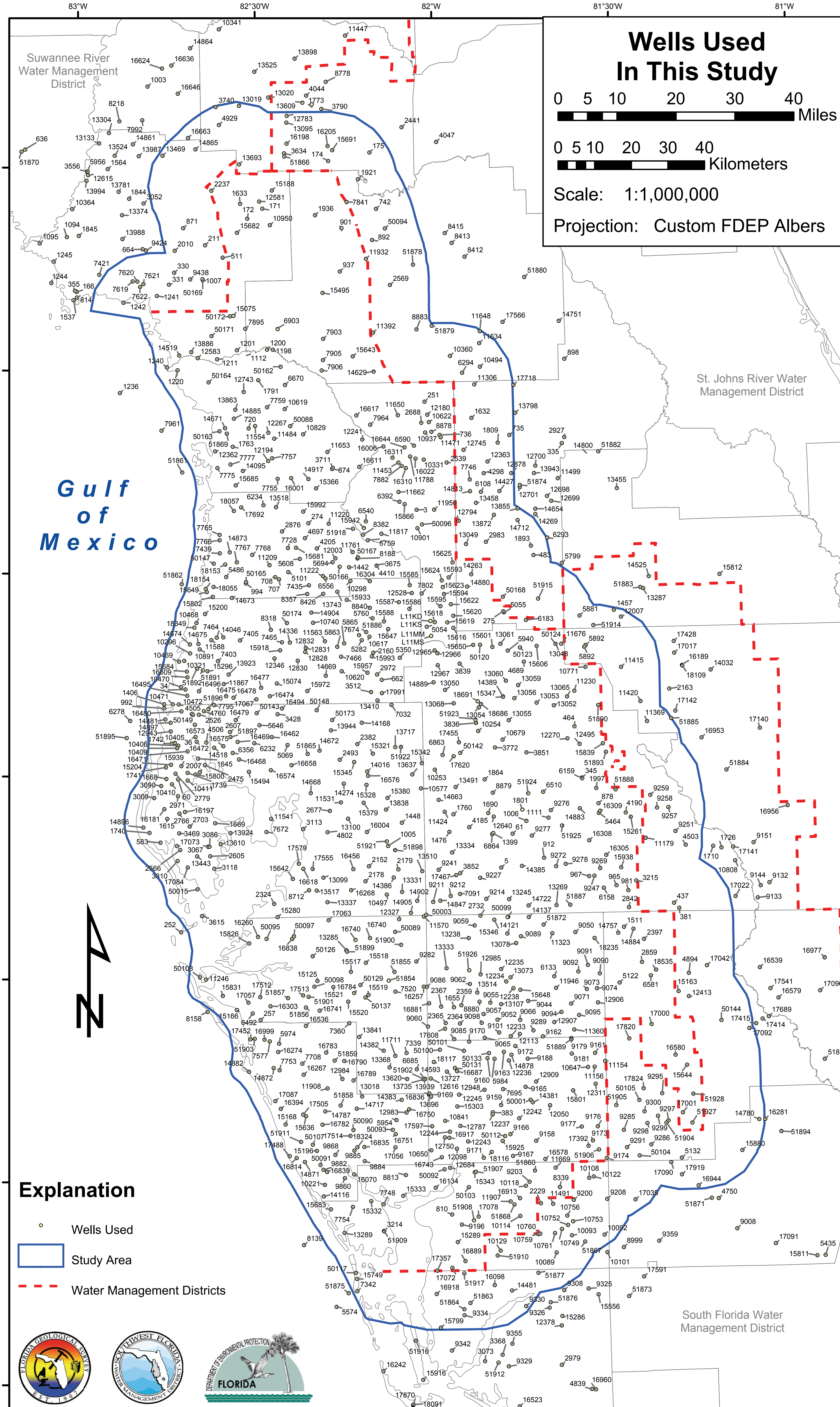
Plate 32
Plate 33
Plate 34
Plate 35
Plate 36
Plate 37
Explanation
Study Area
Water Management Districts
Wells
Core
Cuttings
Gamma Ray Log
FLORIDA GEOLOGICAL SURVEY EST. 1907
SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT
DEPARTMENT OF ENVIRONMENTAL PROTECTION FLORIDA

PLATE 1


Wells Used
In This Study
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Miles
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Kilometers
Scale: 1:1,000,000
Projection: Custom FDEP Albers
Suwannee River Water Management District
St. Johns River Water Management District
South Florida Water Management District
Gulf of Mexico
83°W
82°30'W
82°W
81°30'W
81°W
29°30'N
29°N
28°30'N
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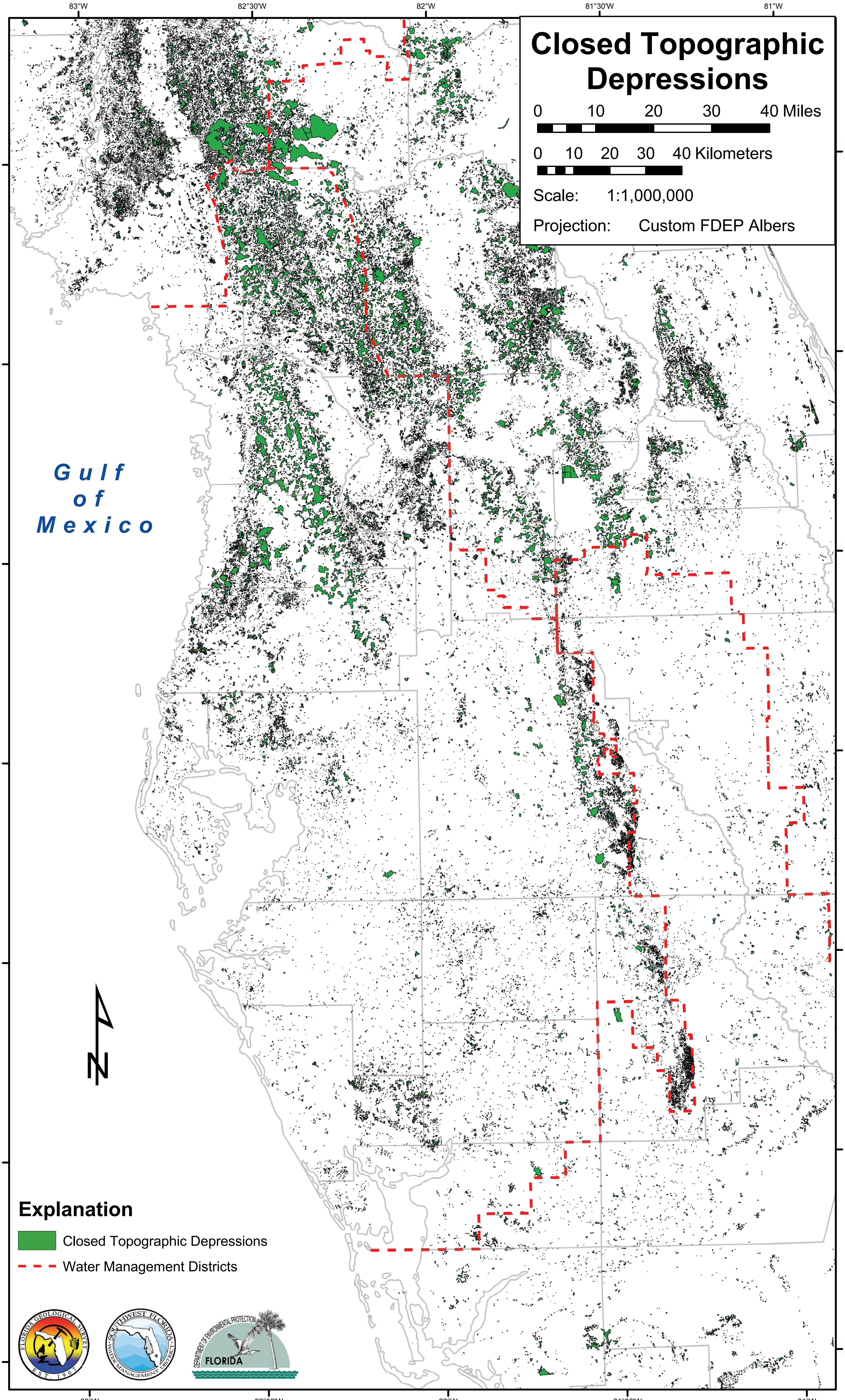
27°30'N
27°N
26°30'N
Explanation
Wells Used
Study Area
Water Management Districts
FLORIDA

PLATE 2


Closed Topographic Depressions
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Scale: 1:1,000,000
Projection: Custom FDEP Albers
Gulf of Mexico
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Explanation
Closed Topographic Depressions
Water Management Districts
83°W
82°30'W
82°W
81°30'W
81°W
29°30'N
29°N
28°30'N
28°N
27°30'N
27°N
26°30'N
FLORIDA

PLATE 3

Plate 4. Cross section: A - A' Levy and Marion Counties

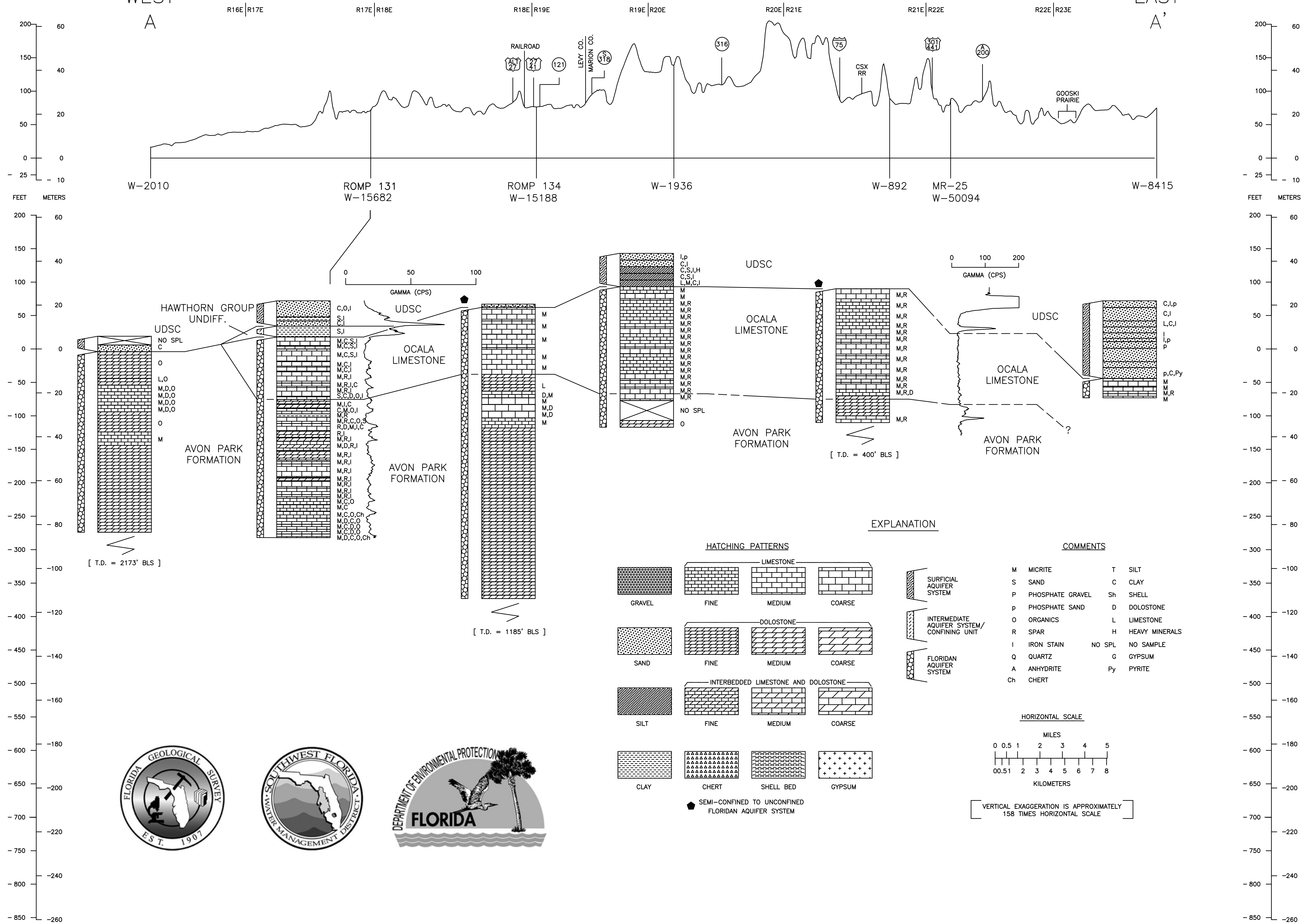


Plate 5. Cross section: B – B' Levy and Marion Counties

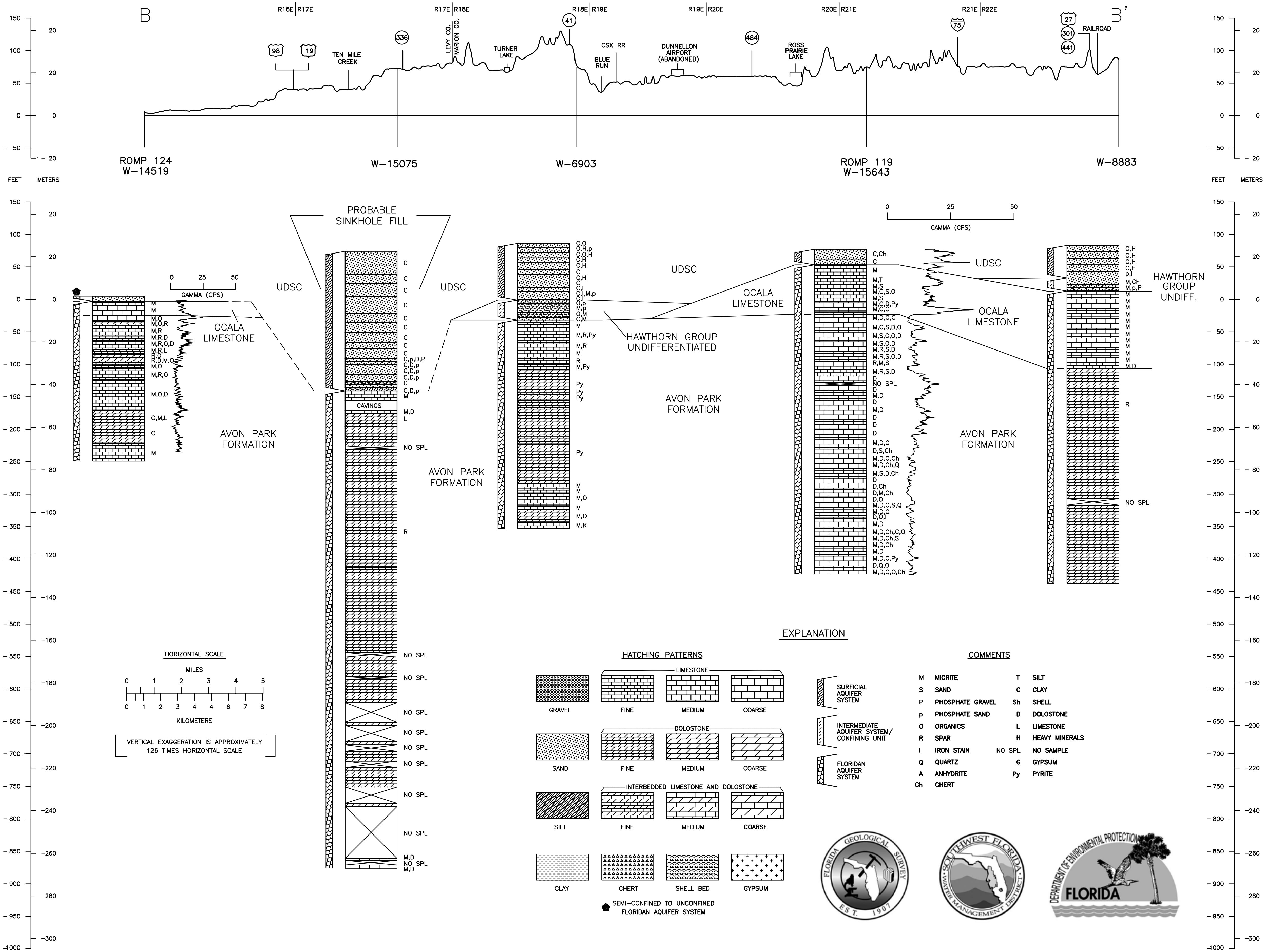


Plate 6. Cross section: C – C' Citrus and Sumter Counties

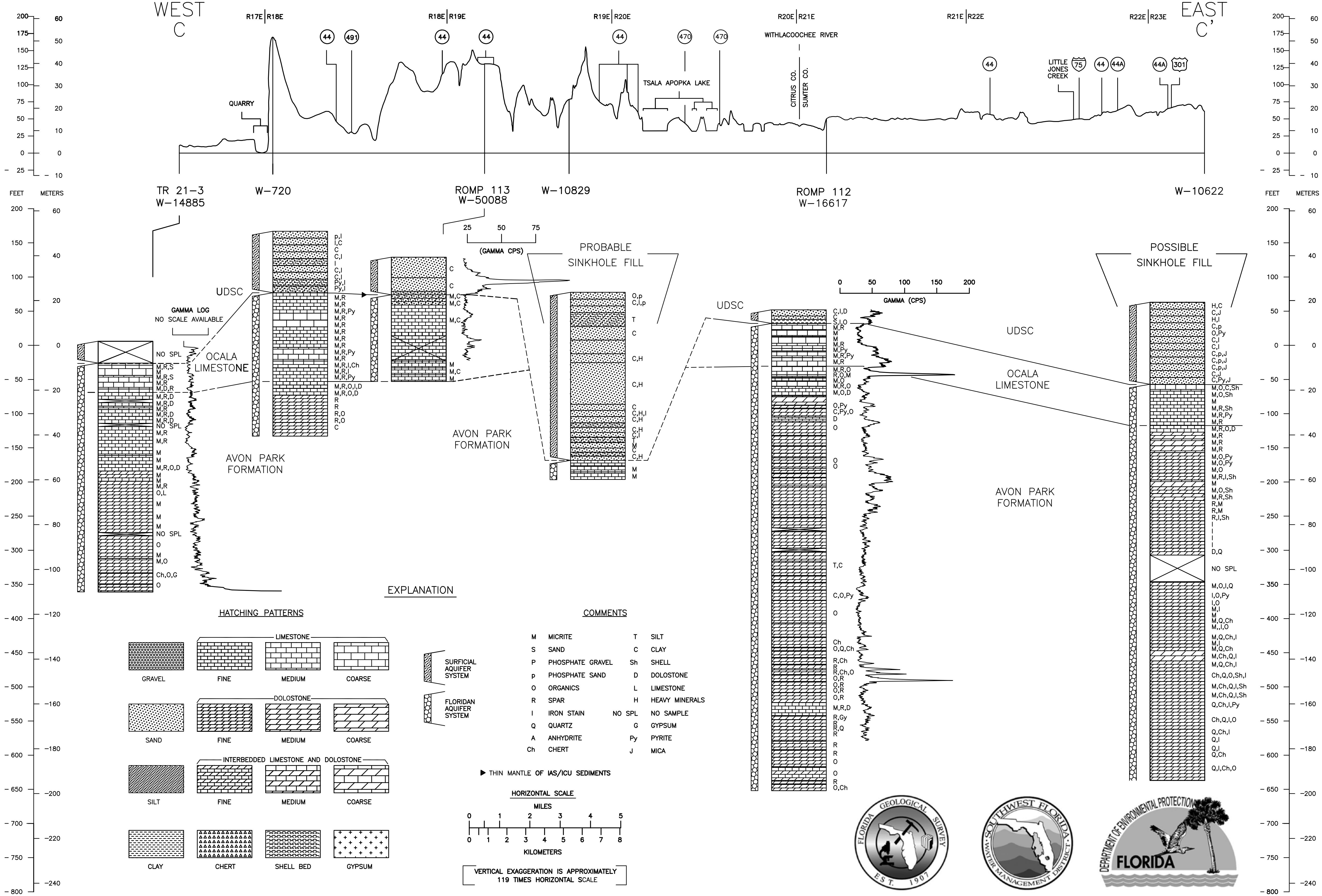


Plate 7. Cross section: D - D' Citrus and Sumter Counties

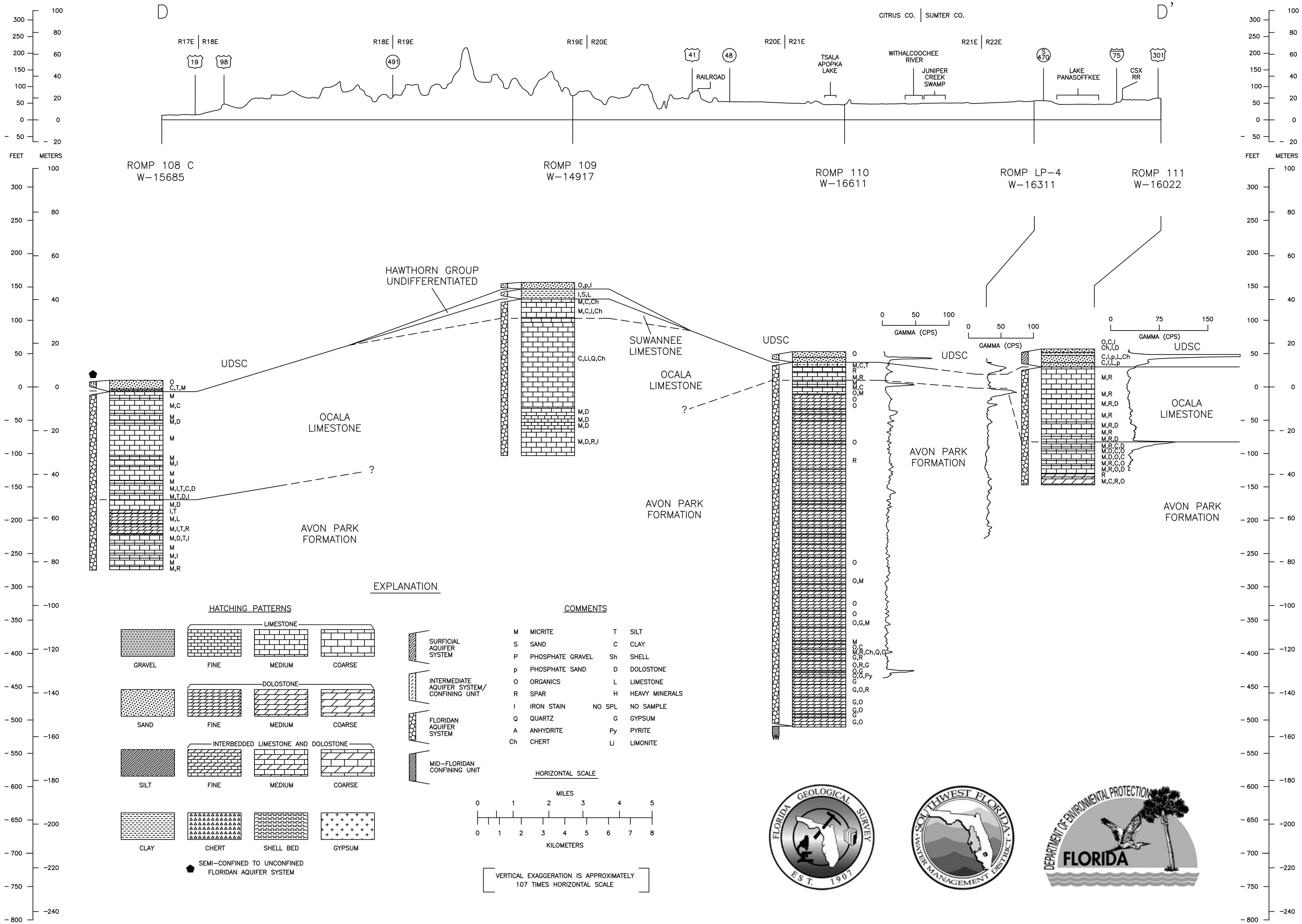


Plate 8. Cross section: E – E' Hernando, Sumter, and Lake Counties

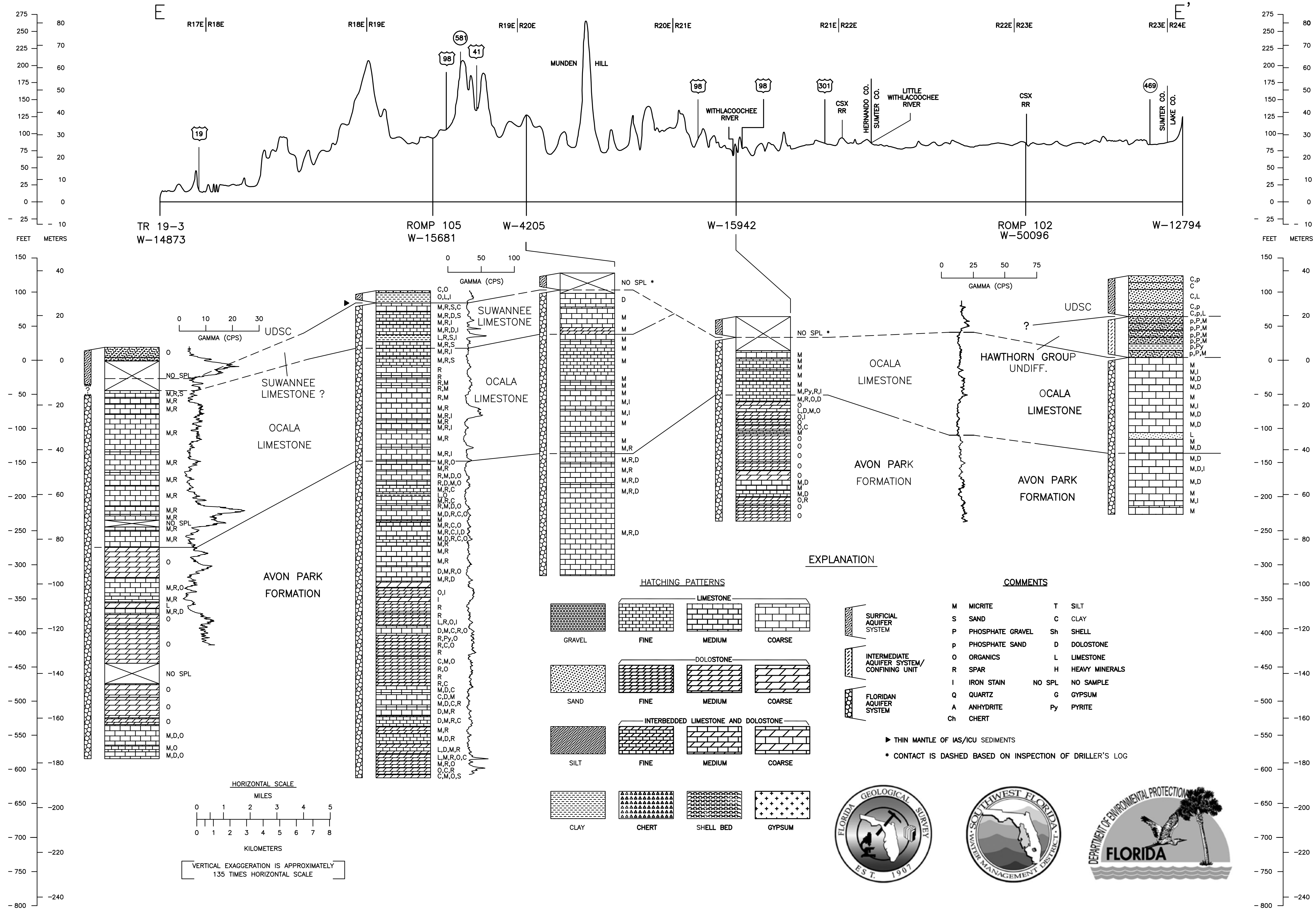


Plate 9. Cross section: F – F' Hernando, Pasco, Sumter, and Lake Counties

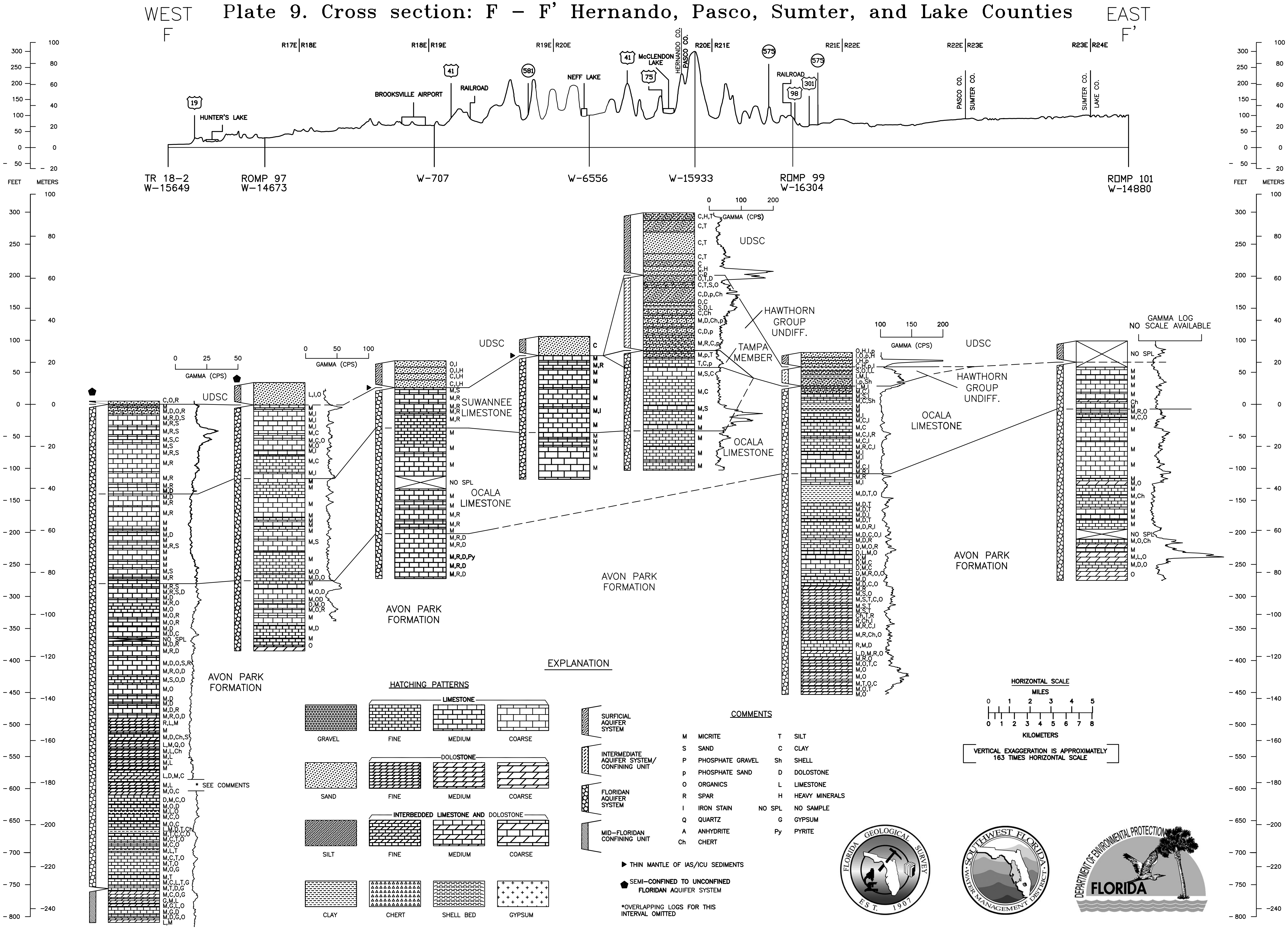


Plate 10. Cross section: G – G' Pasco, Sumter and Polk Counties

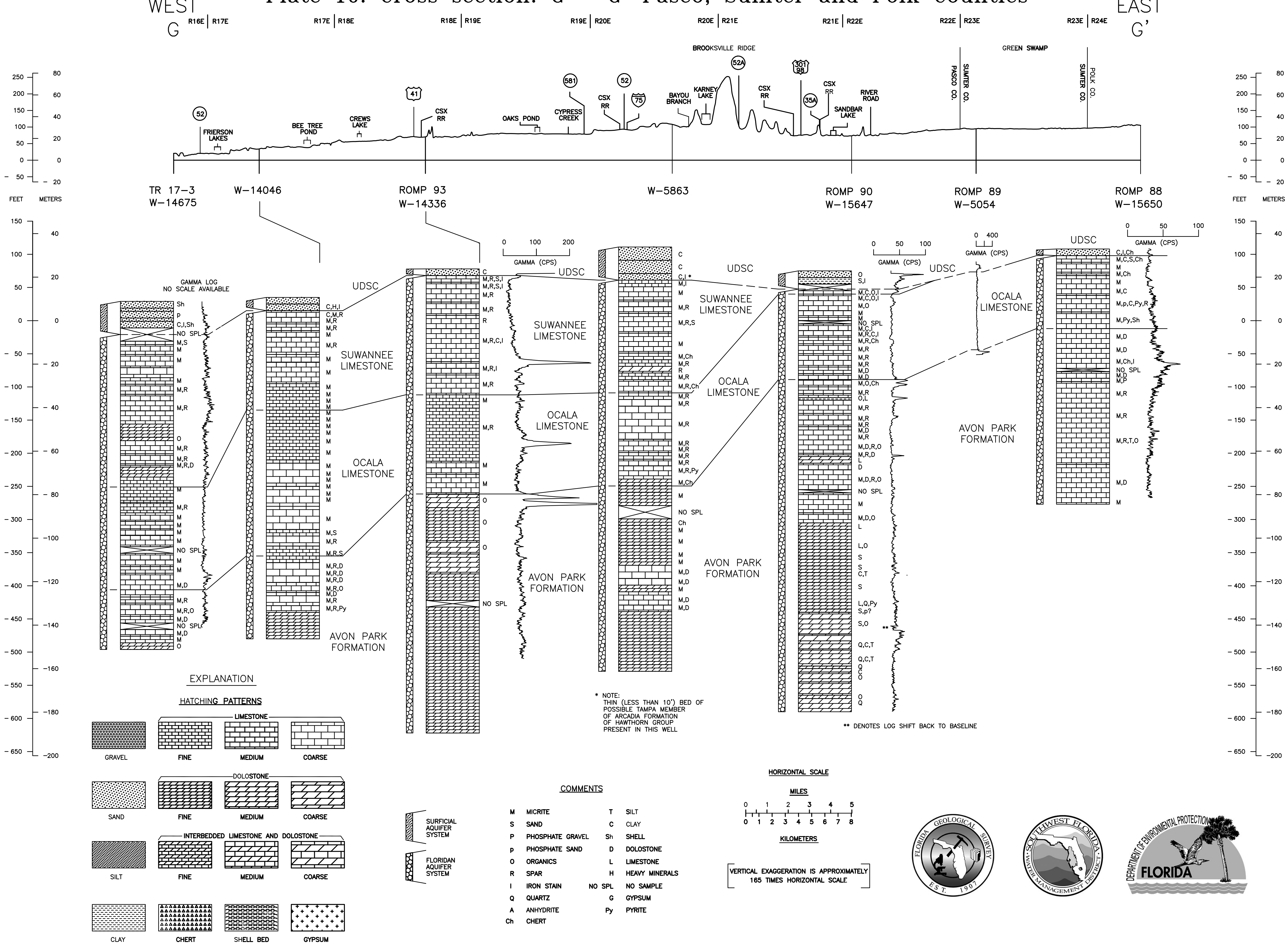


Plate 11. Cross section: H – H' Pasco and Polk Counties

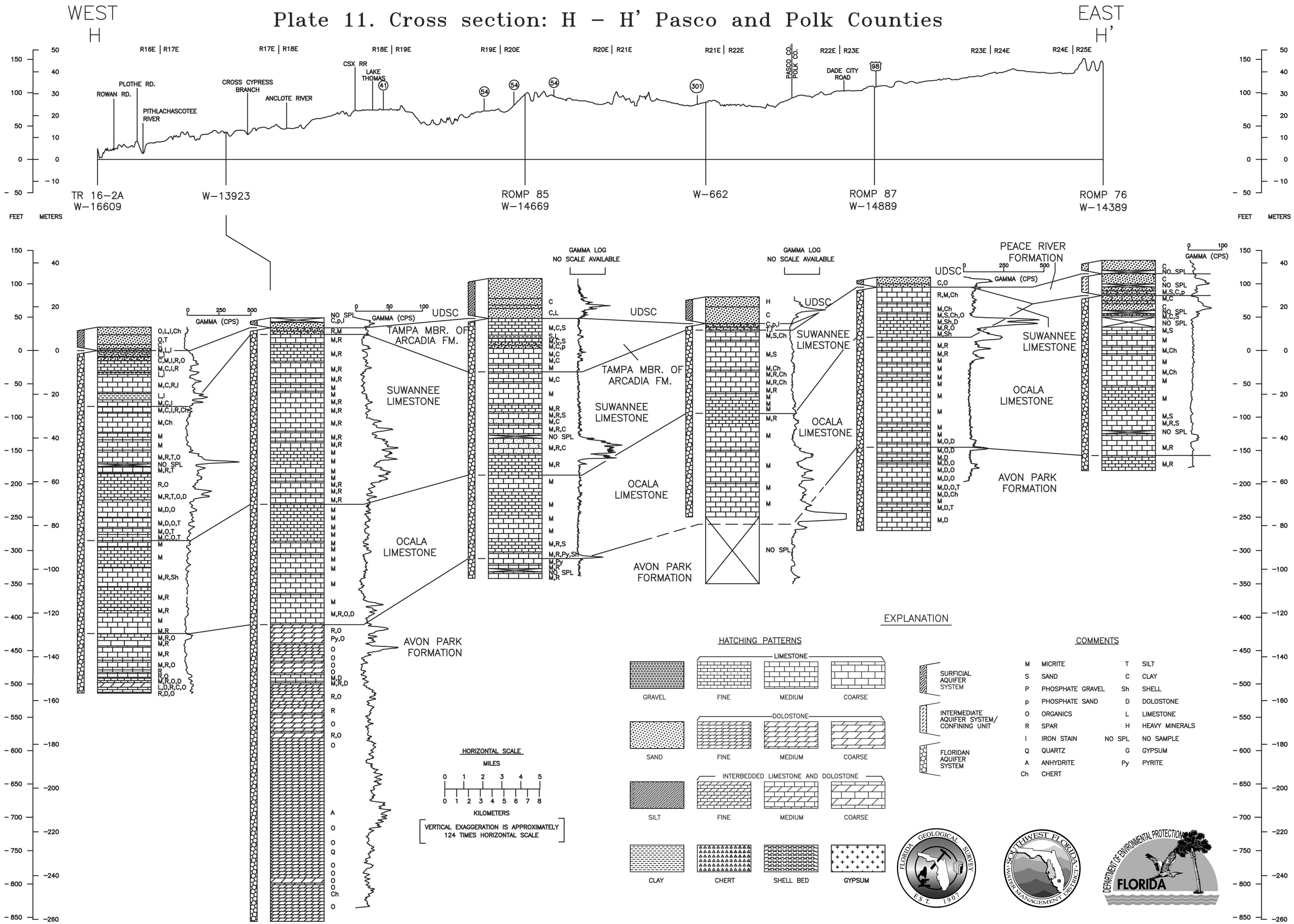


Plate 12. Cross section: I–I' Pinellas and Hillsborough Counties

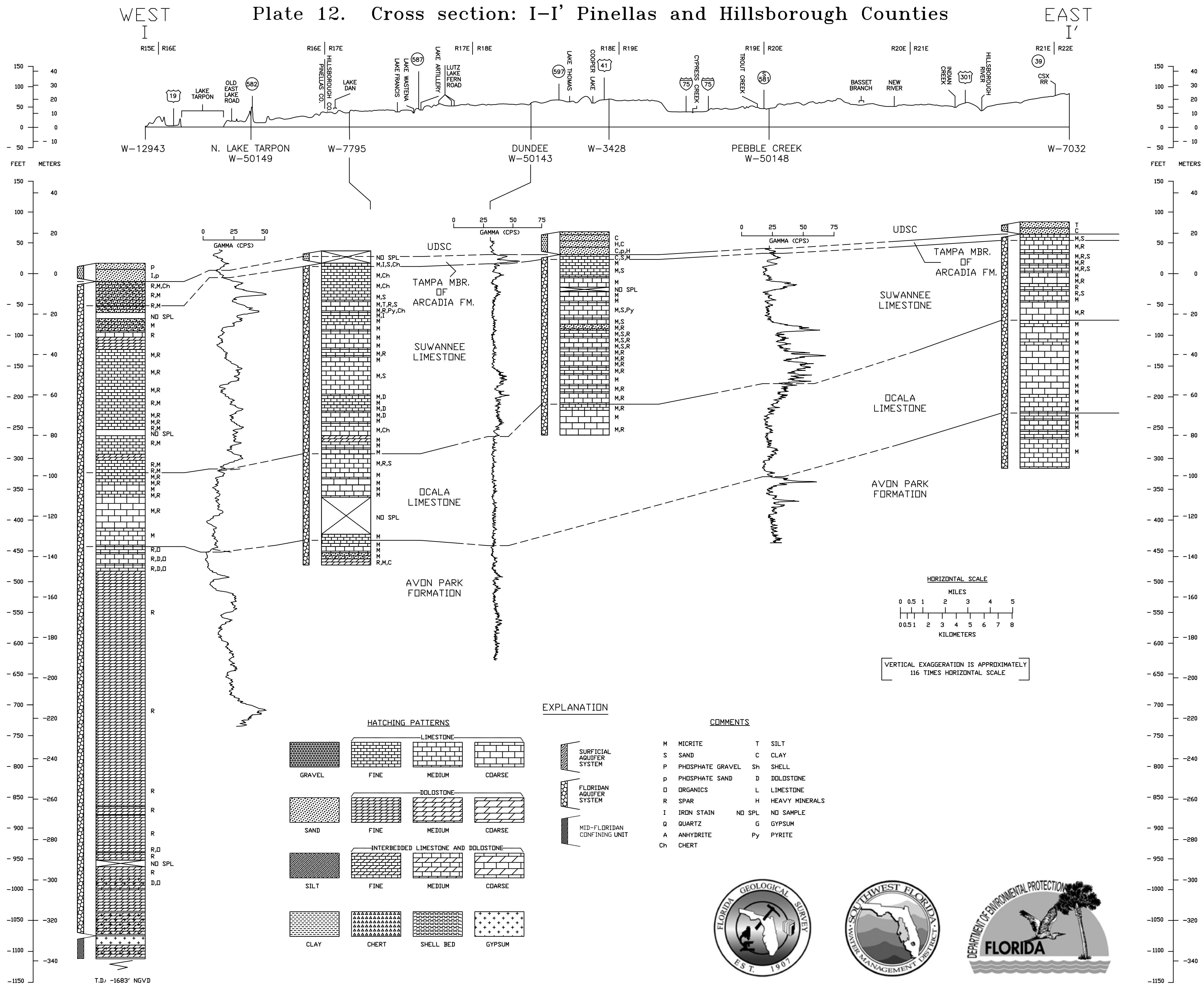


Plate 13. Cross section: J–J' Pinellas and Hillsborough Counties

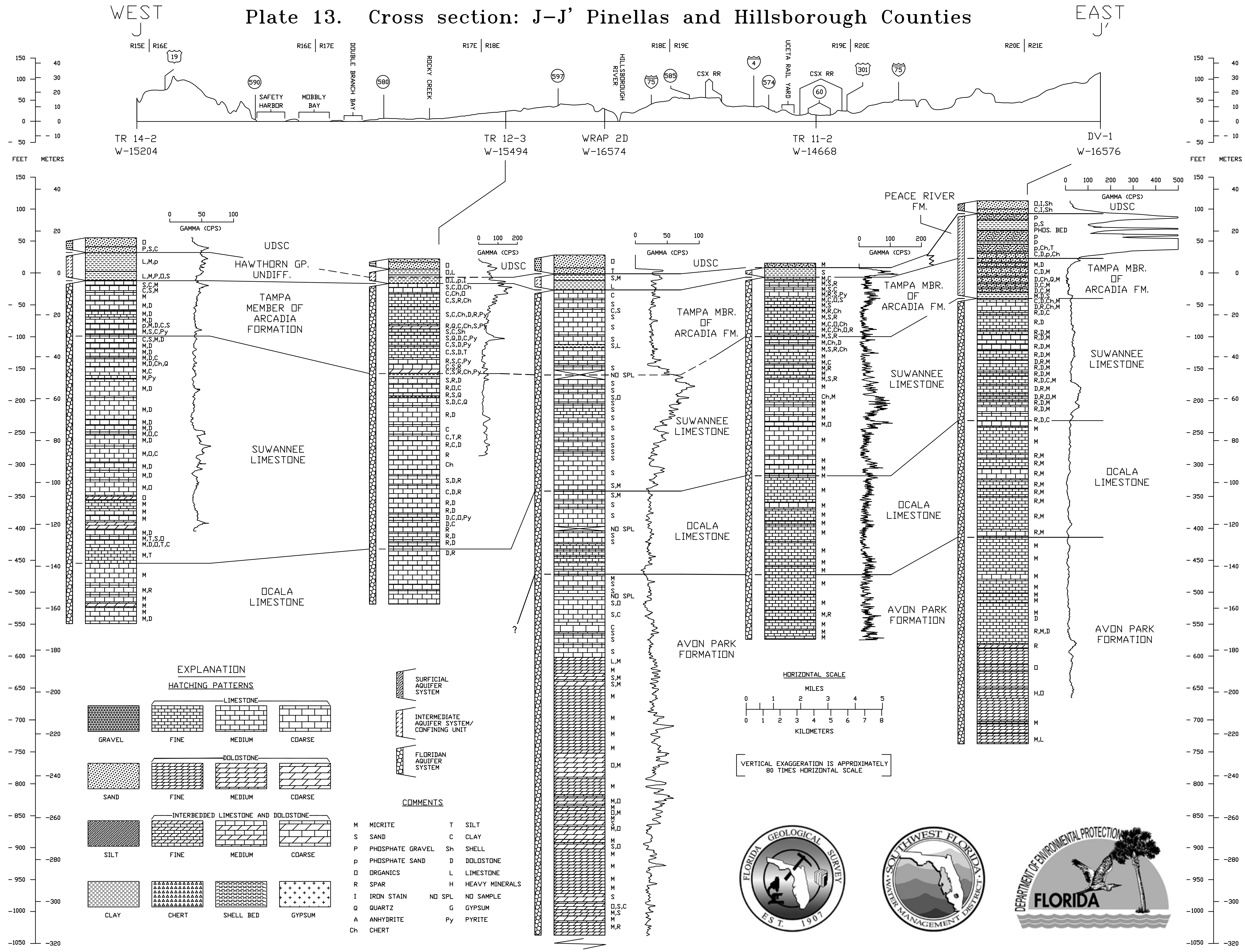
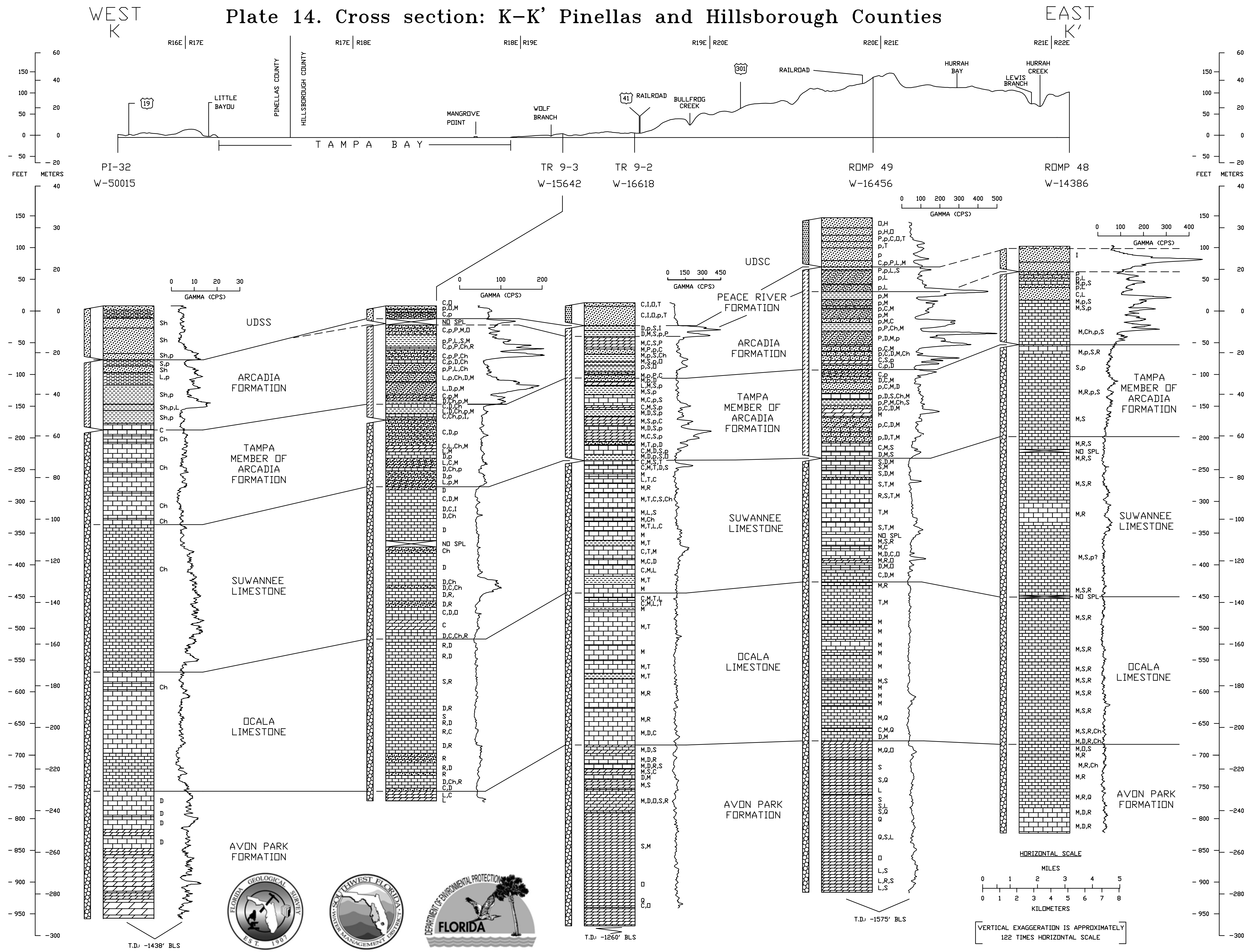


Plate 14. Cross section: K–K' Pinellas and Hillsborough Counties



(SEE TEXT FIGURE 9 FOR EXPLANATION OF HATCH PATTERNS)

Plate 15: Cross section: L–L' Manatee, Hillsborough and Polk Counties

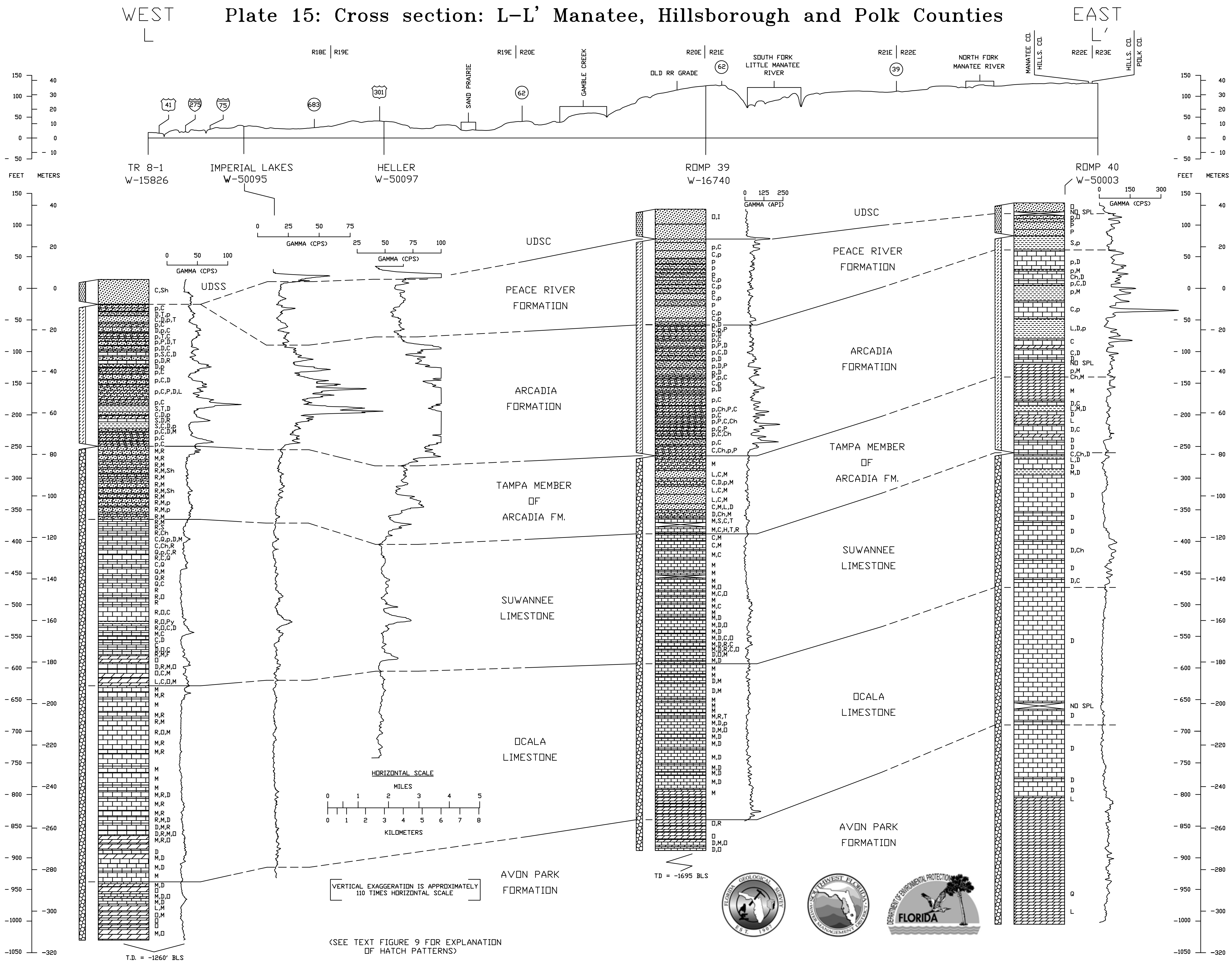


Plate 16: Cross section: M–M' Manatee County

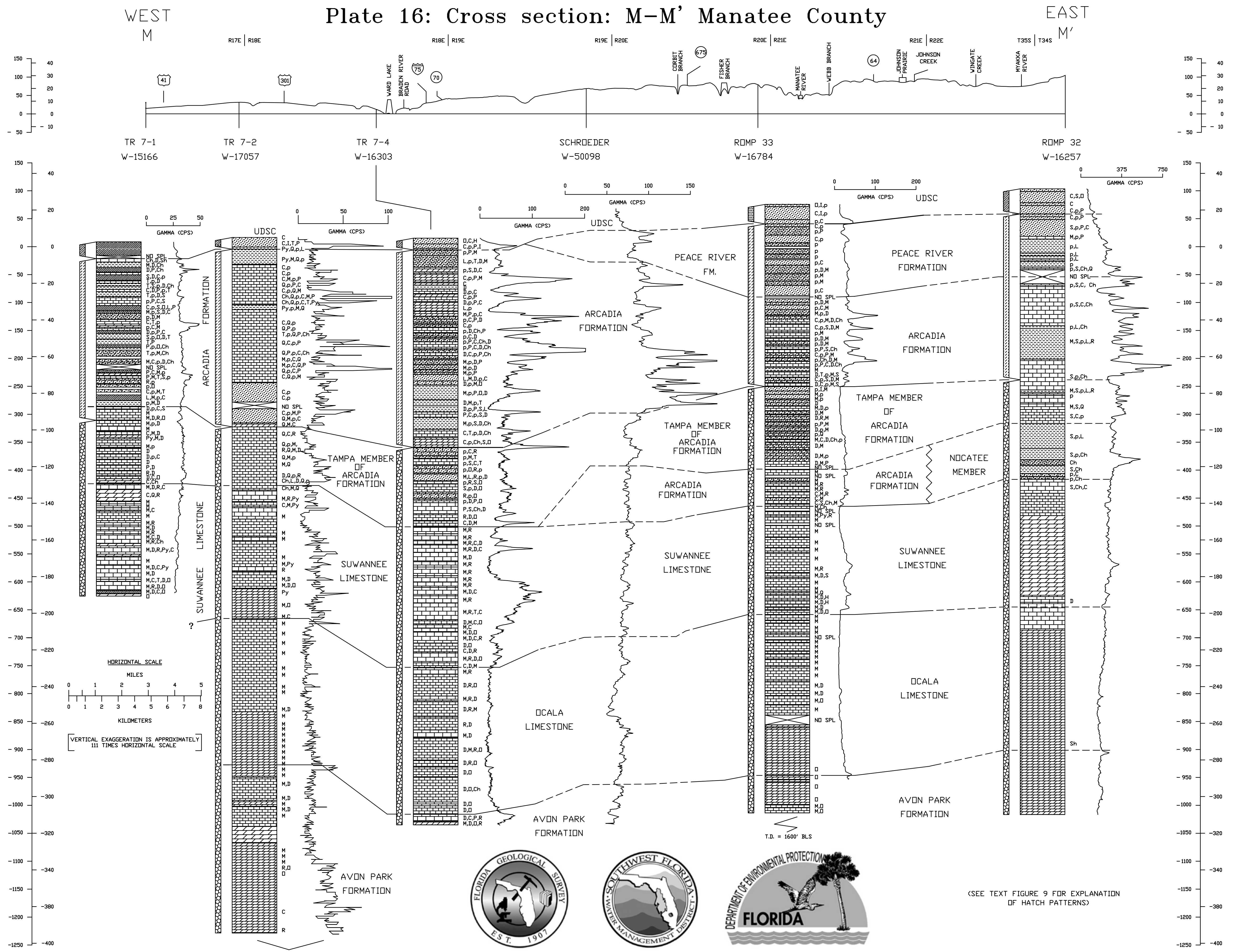


Plate 17: Cross section: N-N' Sarasota and Manatee Counties

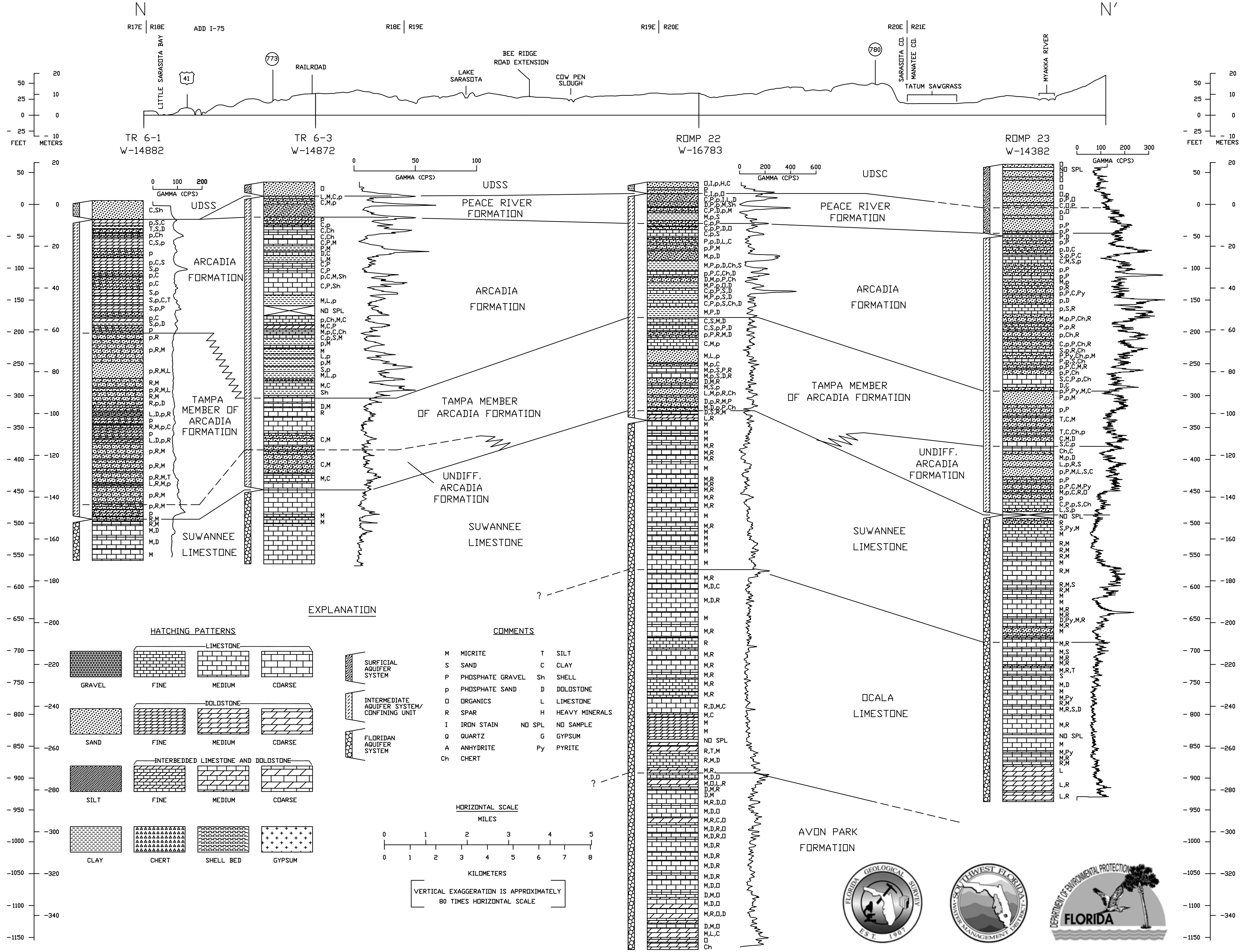


Plate 18: Cross section: O-O' Sarasota County

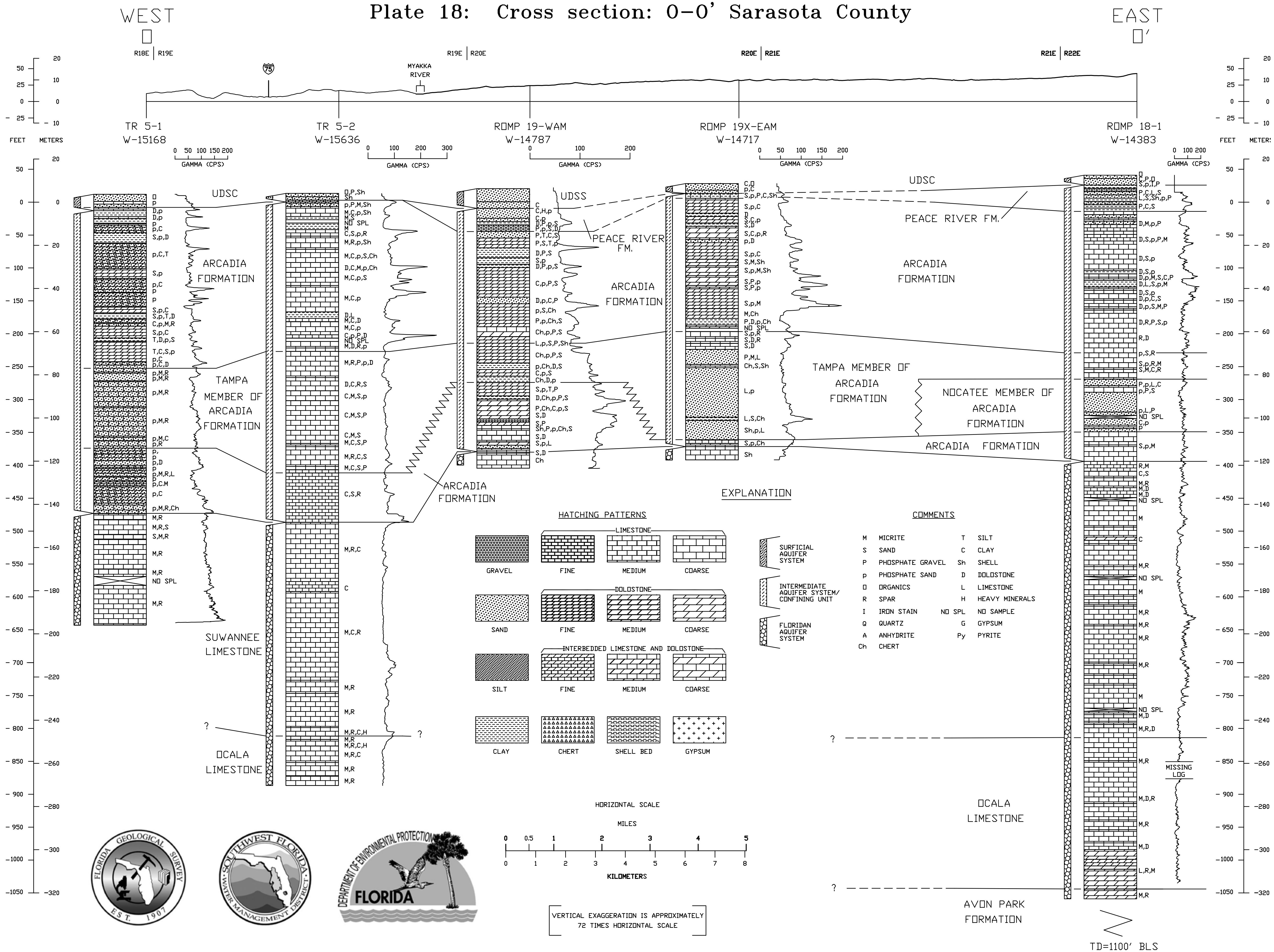


Plate 19: Cross section: P–P' Charlotte County

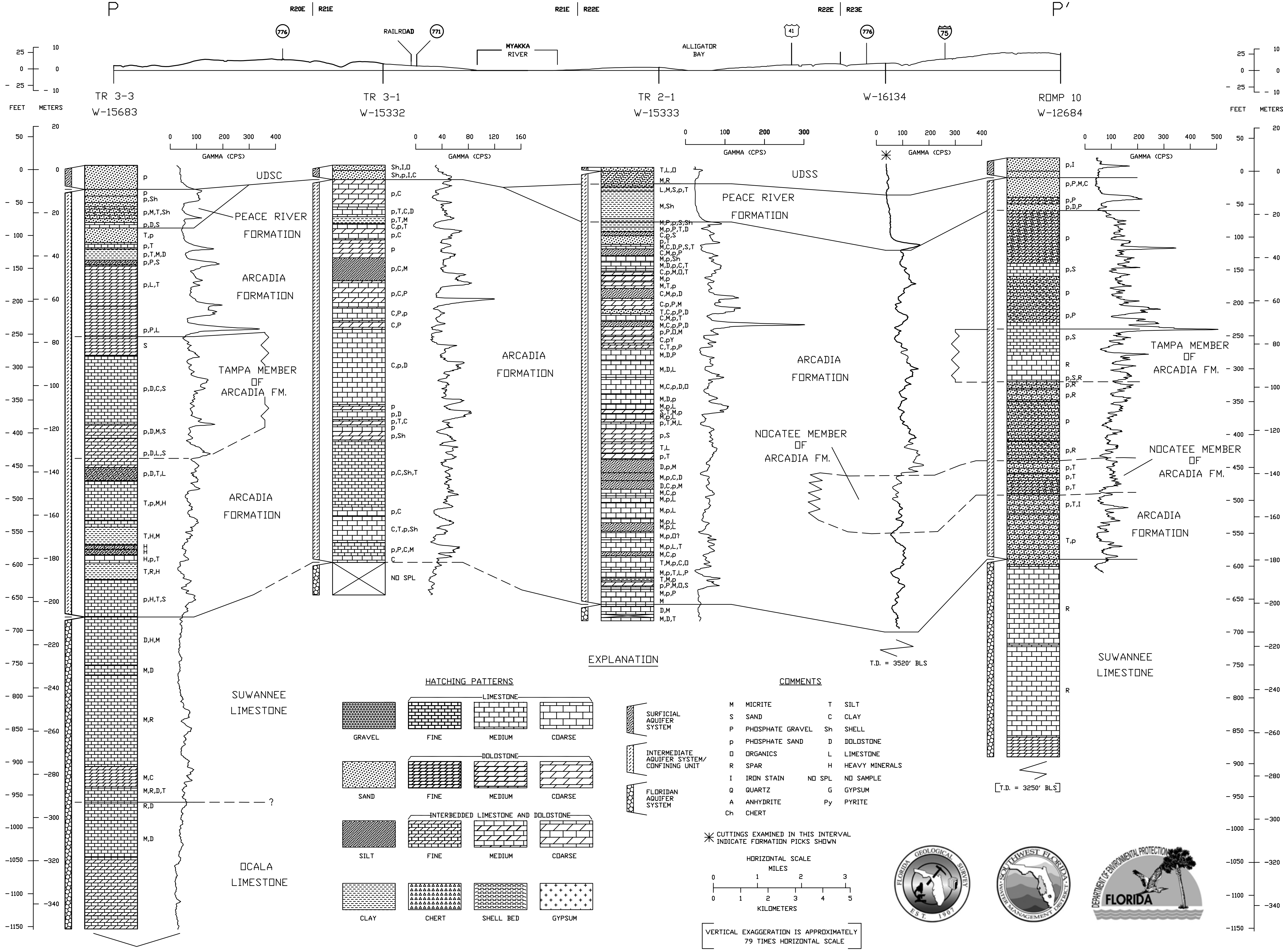


Plate 20. Cross section: Q–Q' Polk and Osceola Counties

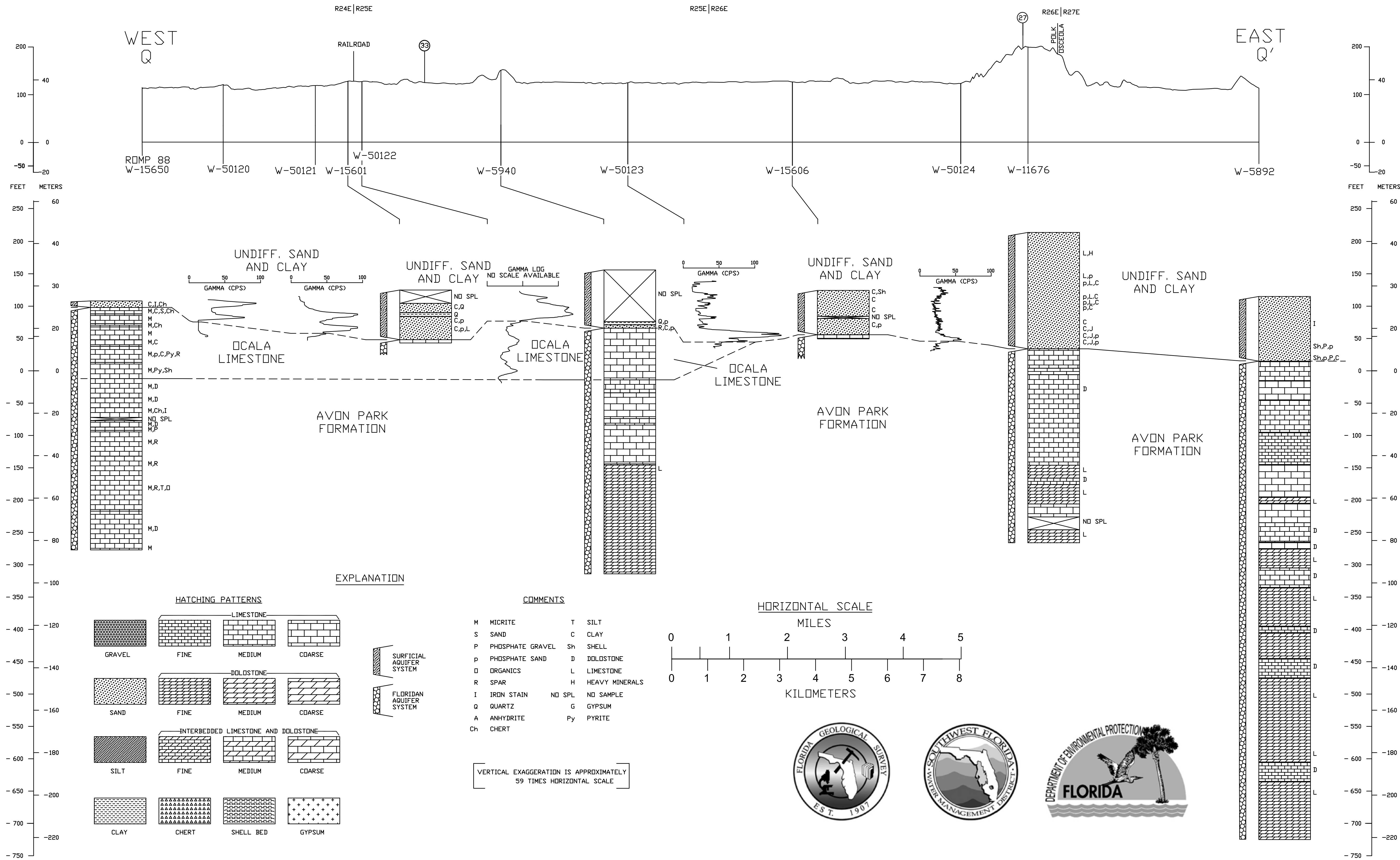


Plate 21. Cross section: R–R' Hillsborough and Polk Counties

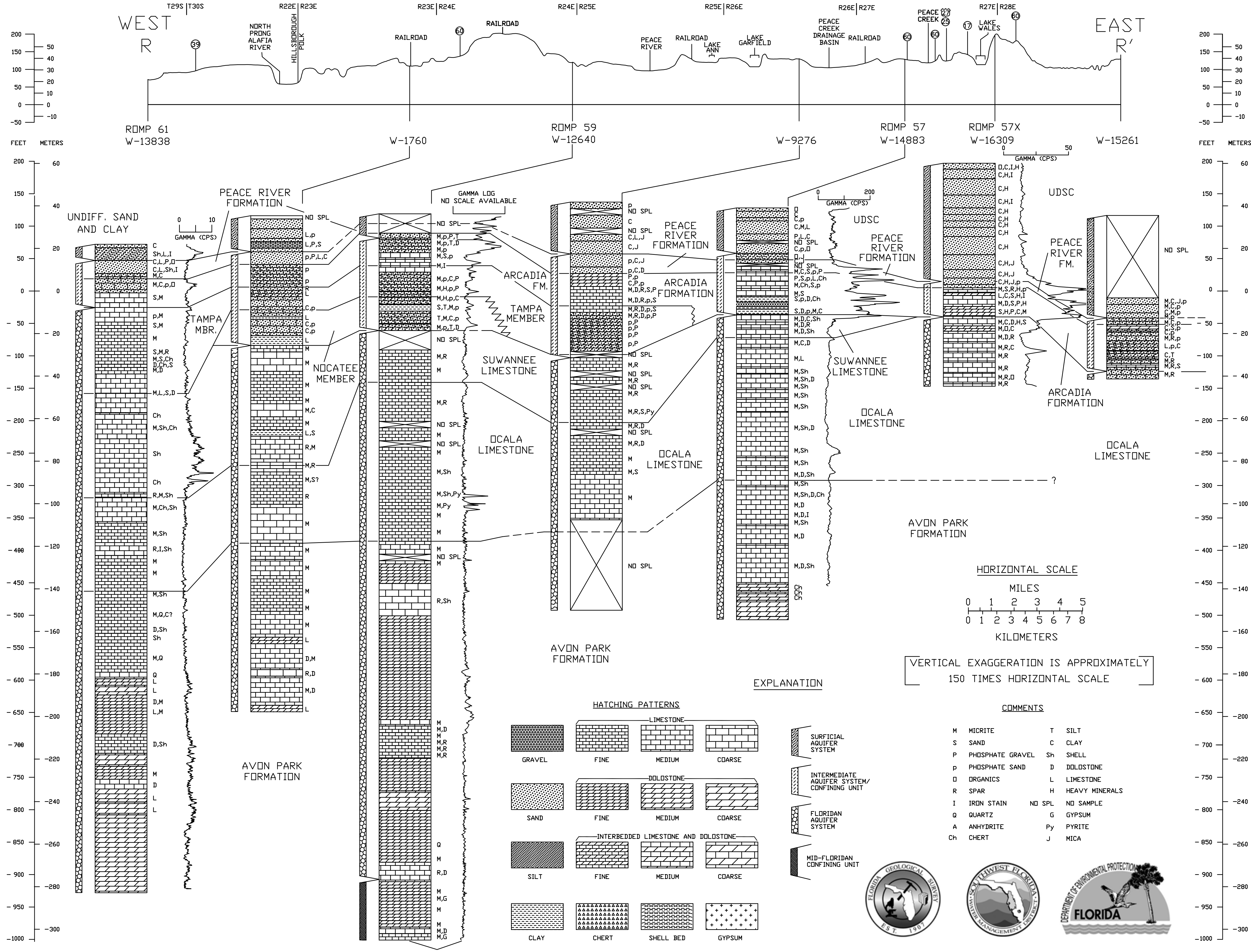


Plate 22. Cross section: S-S' Hillsborough and Polk Counties

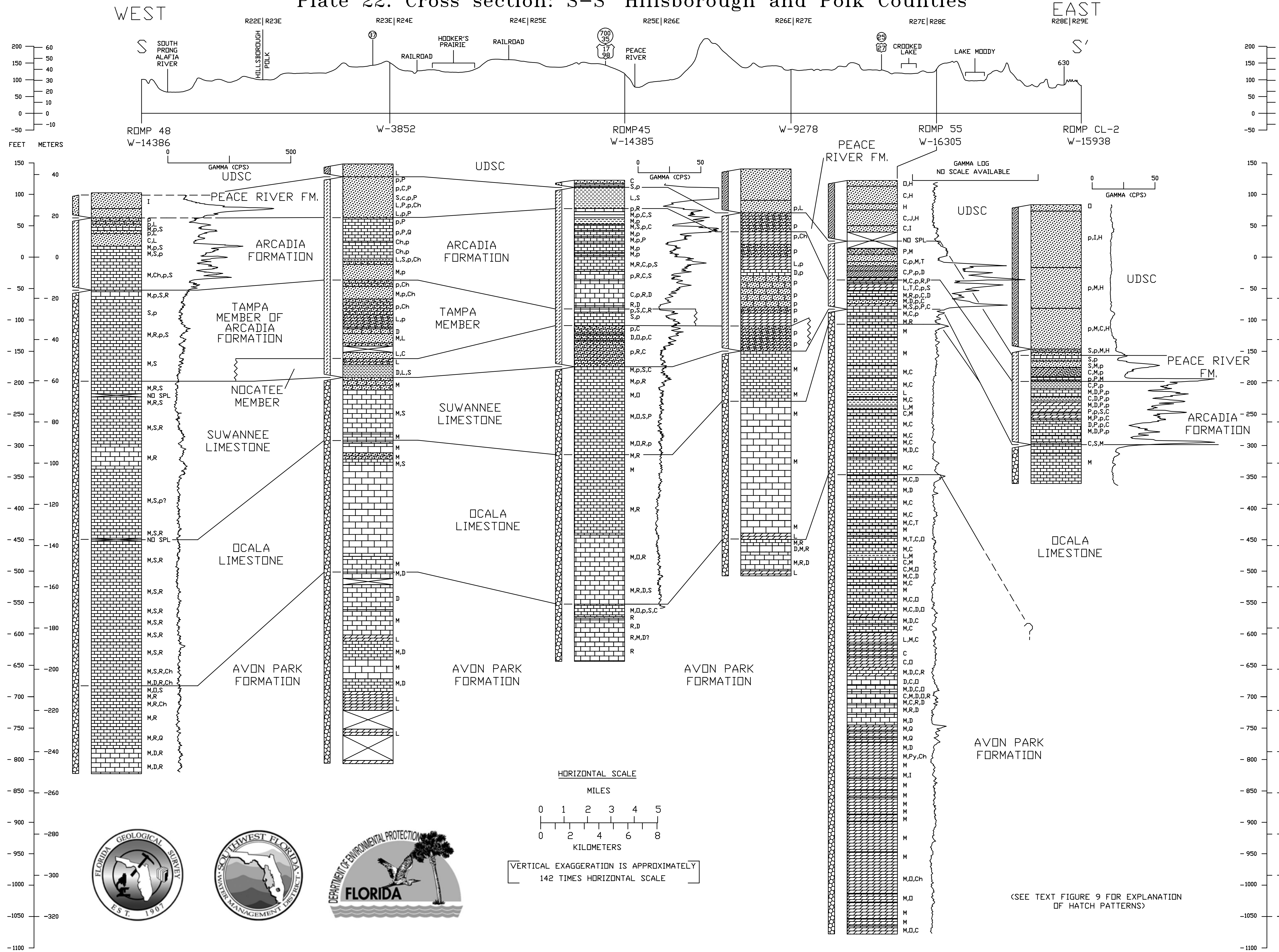


Plate 23. Cross section: T–T' Manatee, Hardee, and Highlands Counties

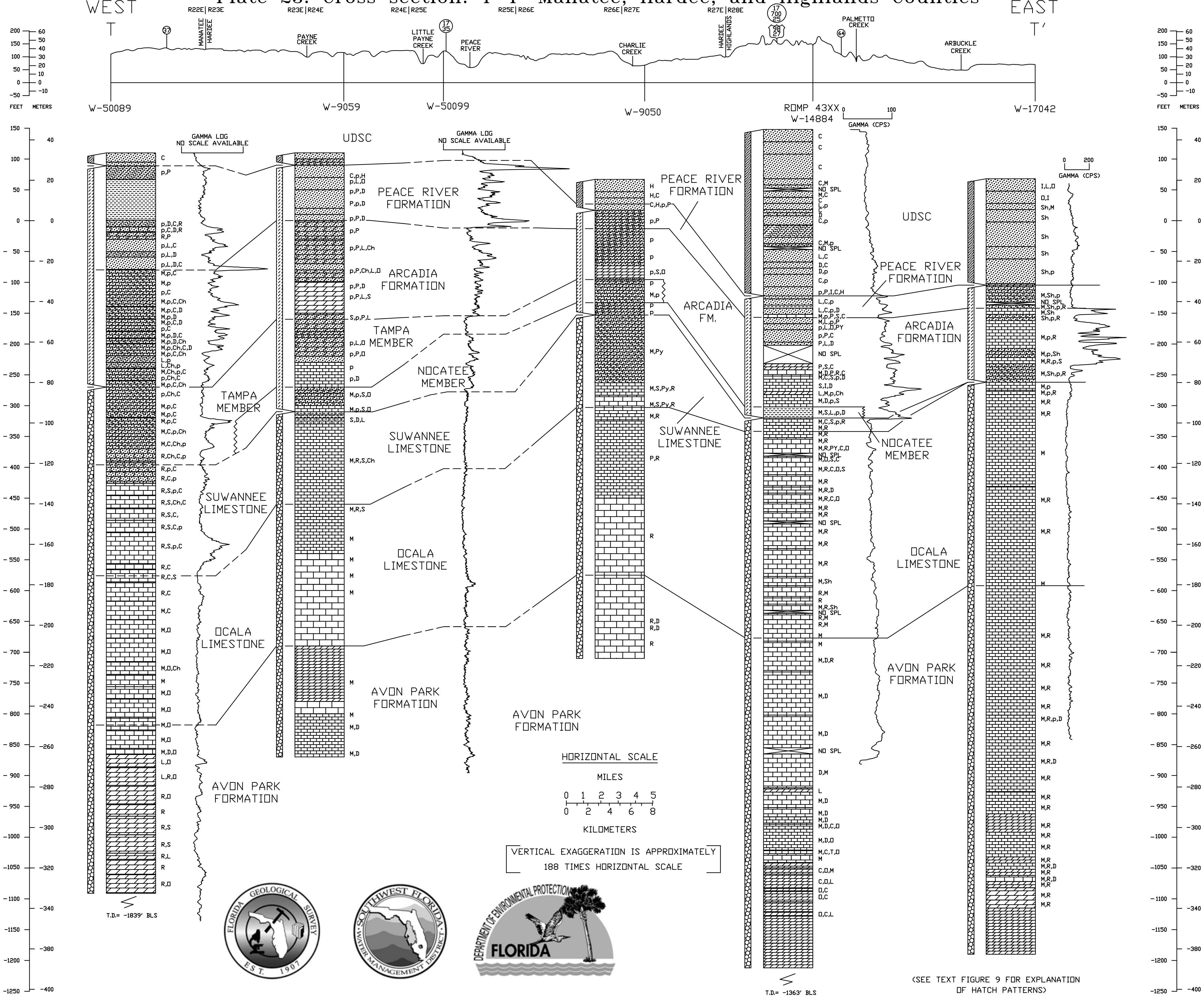


Plate 24. Cross section: U–U' Manatee, Hardee, and Highlands Counties

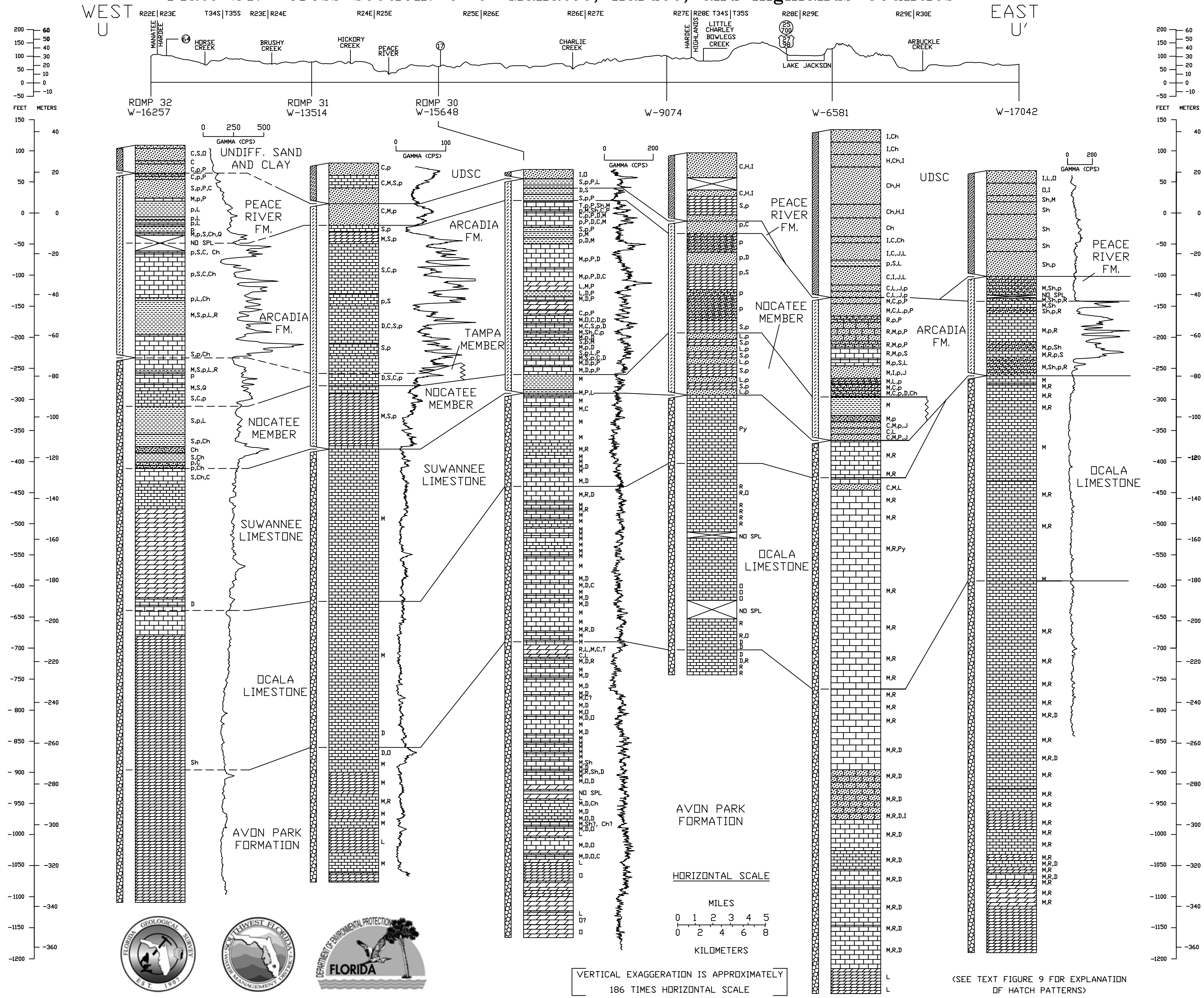
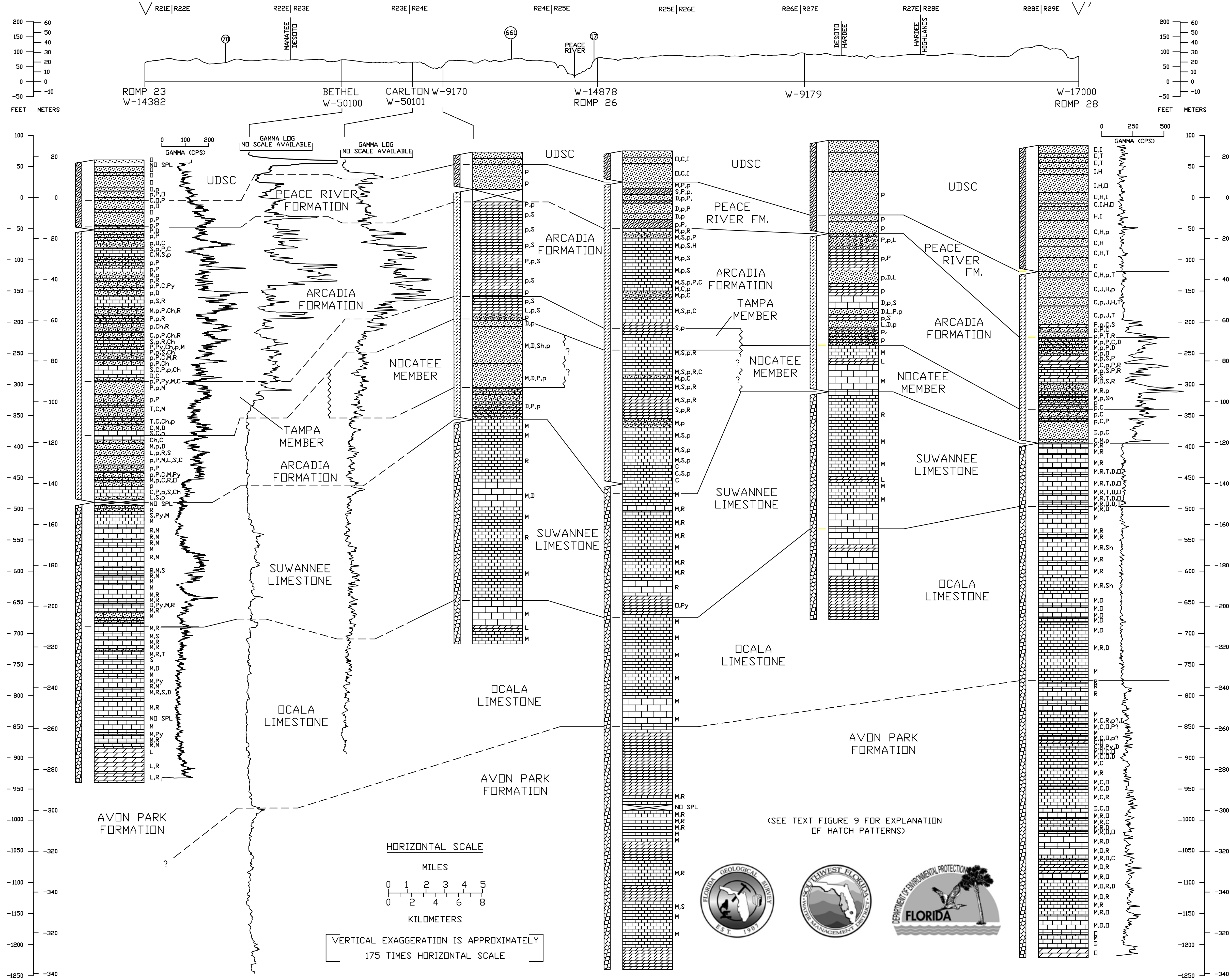


Plate 25. Cross section: V–V' Manatee, DeSoto, Hardee, and Highlands Counties



WEST W Plate 26. Cross section: W-W' Sarasota, DeSoto, and Highlands Counties EAST W'

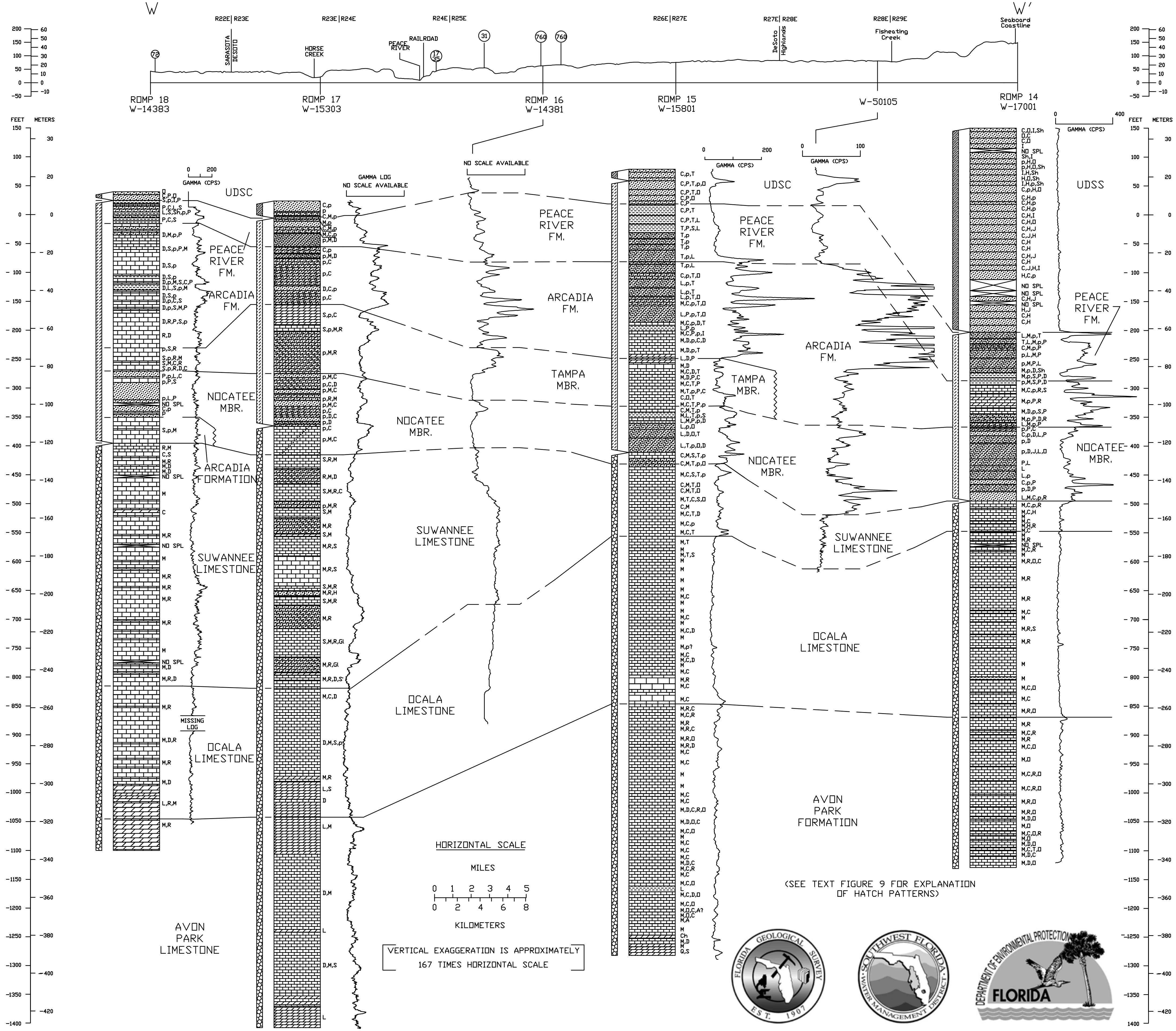


Plate 27. Cross section: X–X' Sarasota, DeSoto, Highlands, and Glades Counties

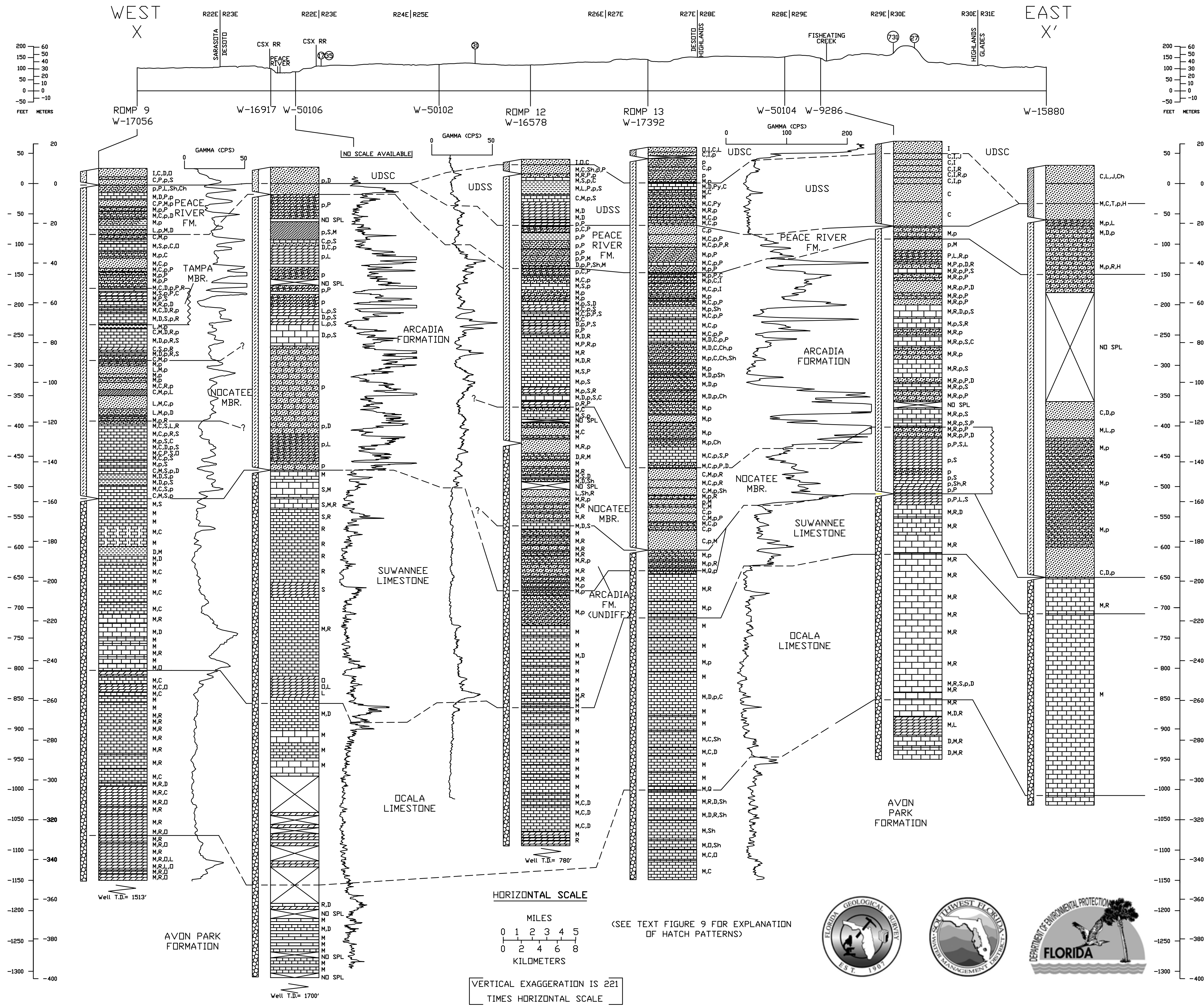


Plate 28. Cross section: Y-Y' Charlotte and Glades Counties

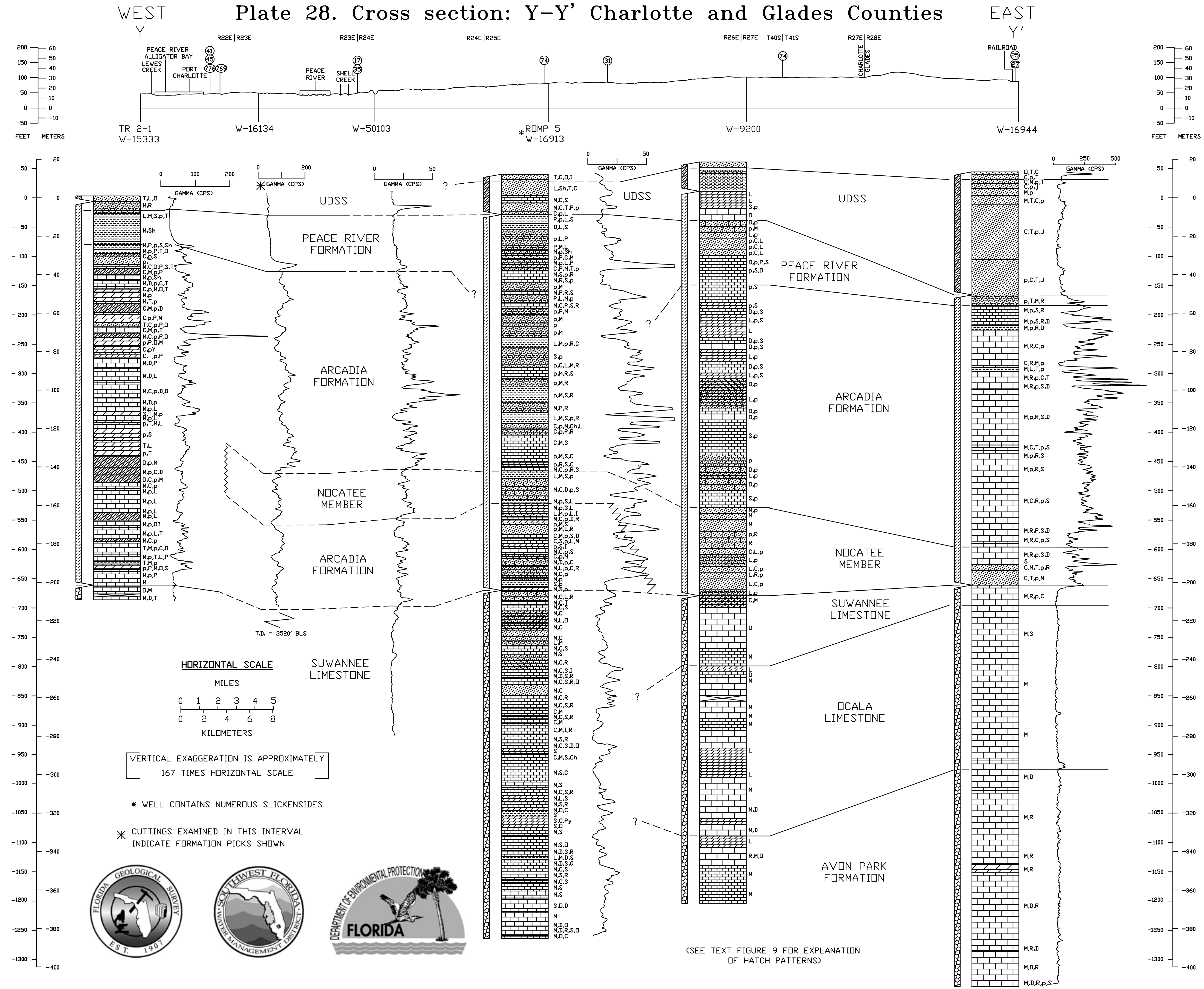


Plate 29. Cross section: Z–Z' Levy, Citrus, Pasco, and Hernando Counties

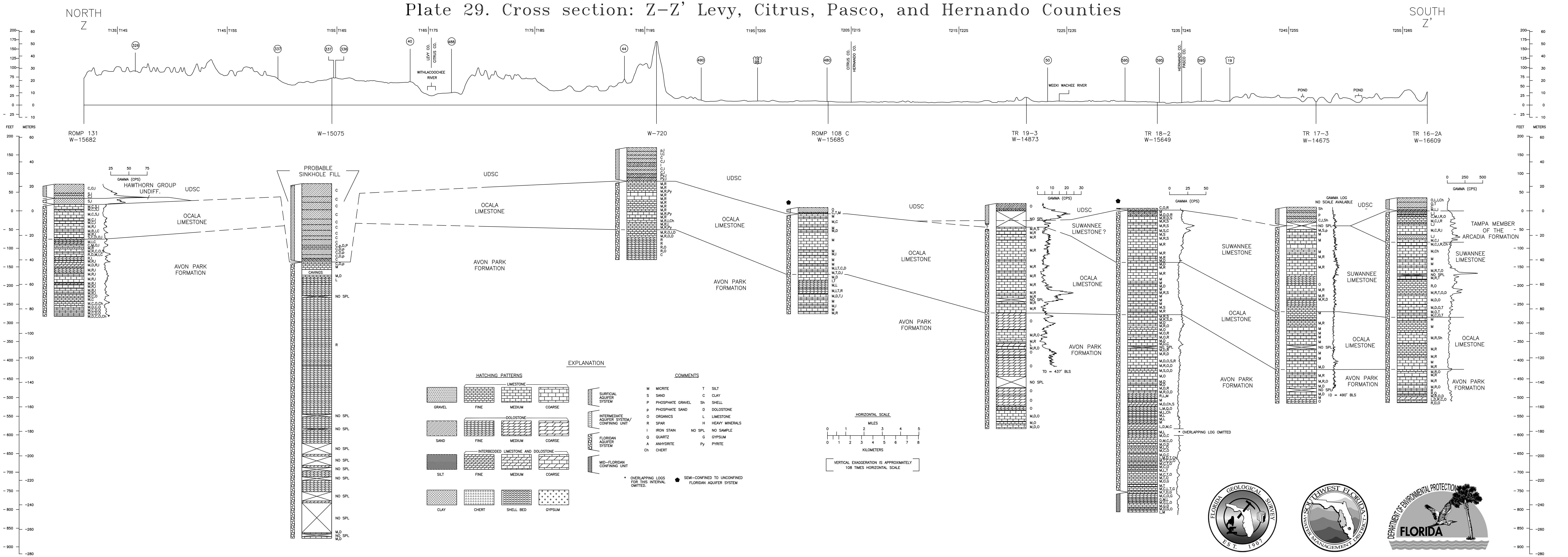


Plate 30. Cross section: AA - AA' Marion, Sumter, Hernando, and Pasco Counties

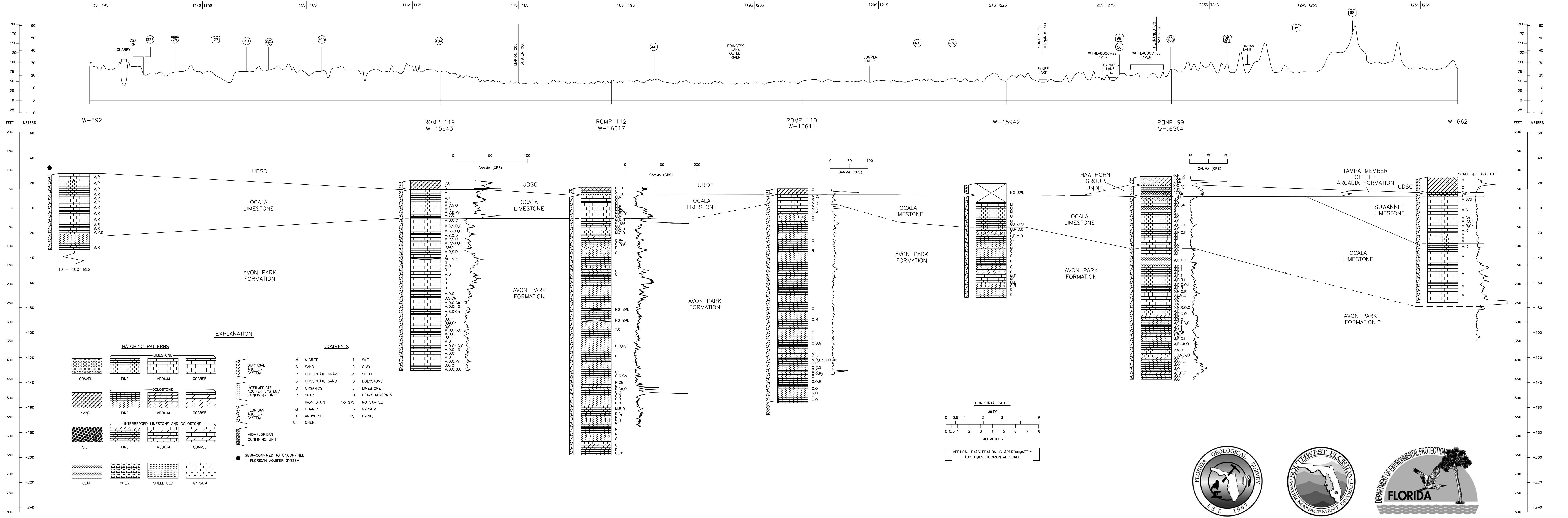


Plate 31. Cross section: BB-BB' Pinellas County

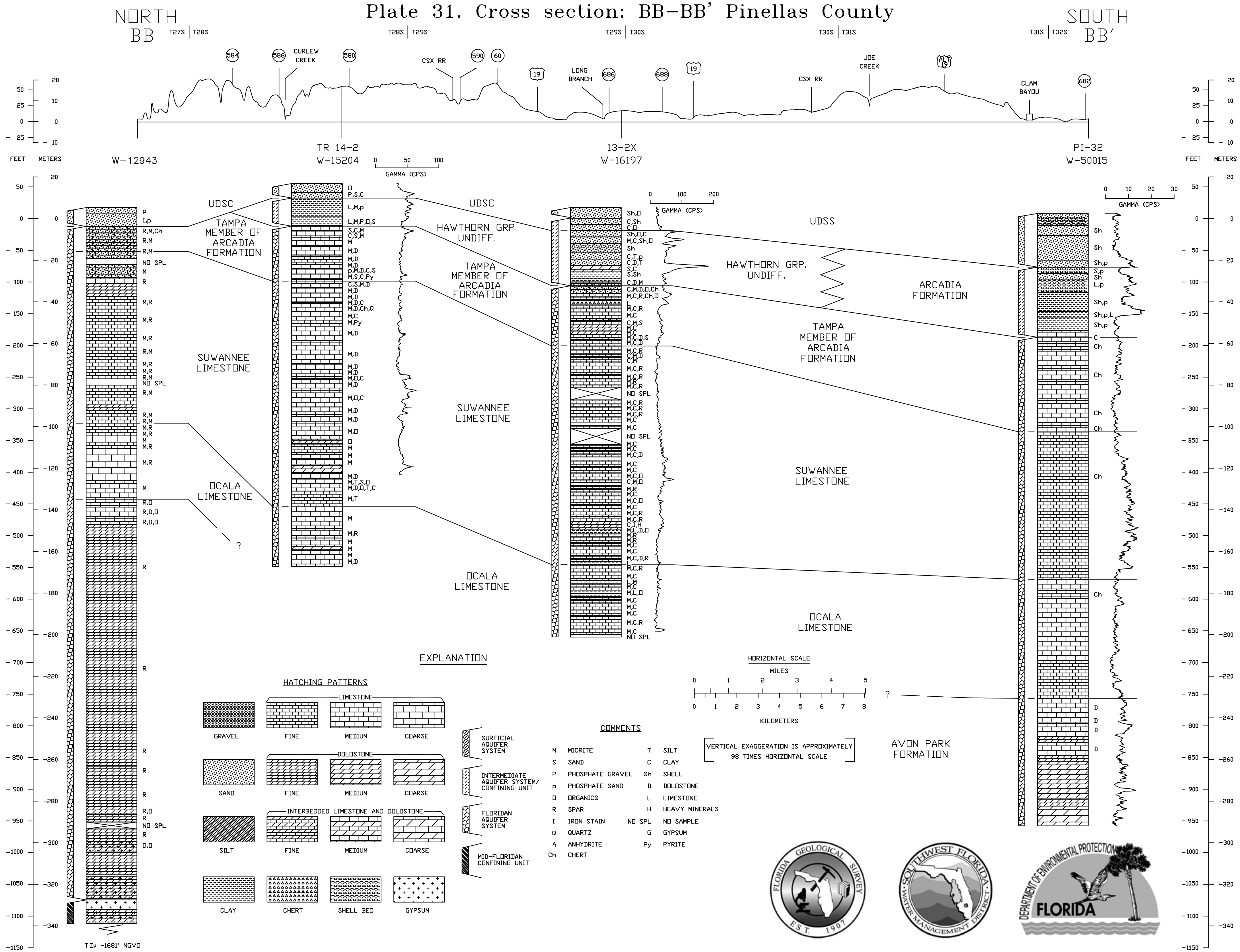


Plate 32. Cross section: CC–CC' Hillsborough and Manatee Counties

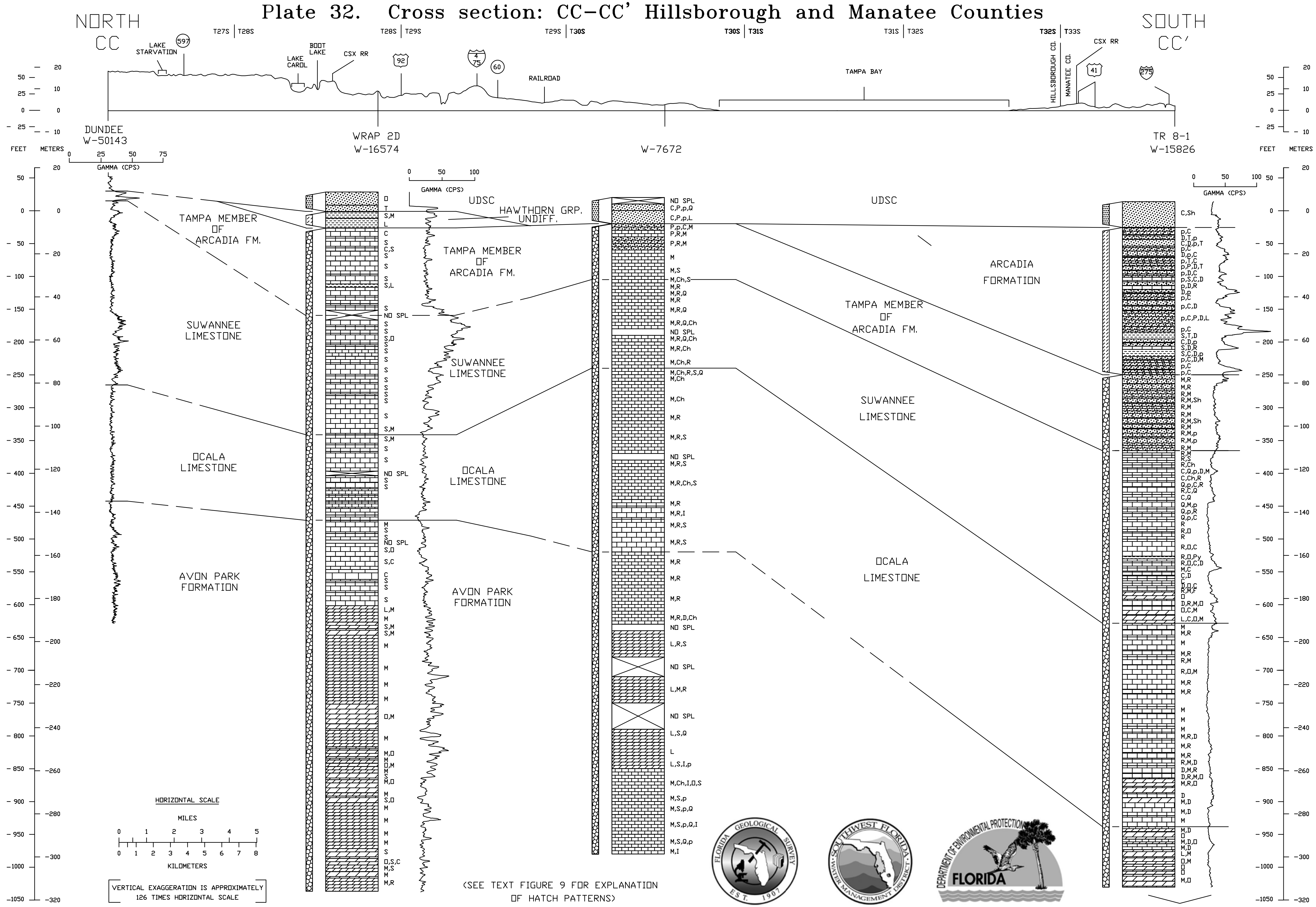


Plate 33. Cross section: DD–DD' Hillsborough and Manatee Counties

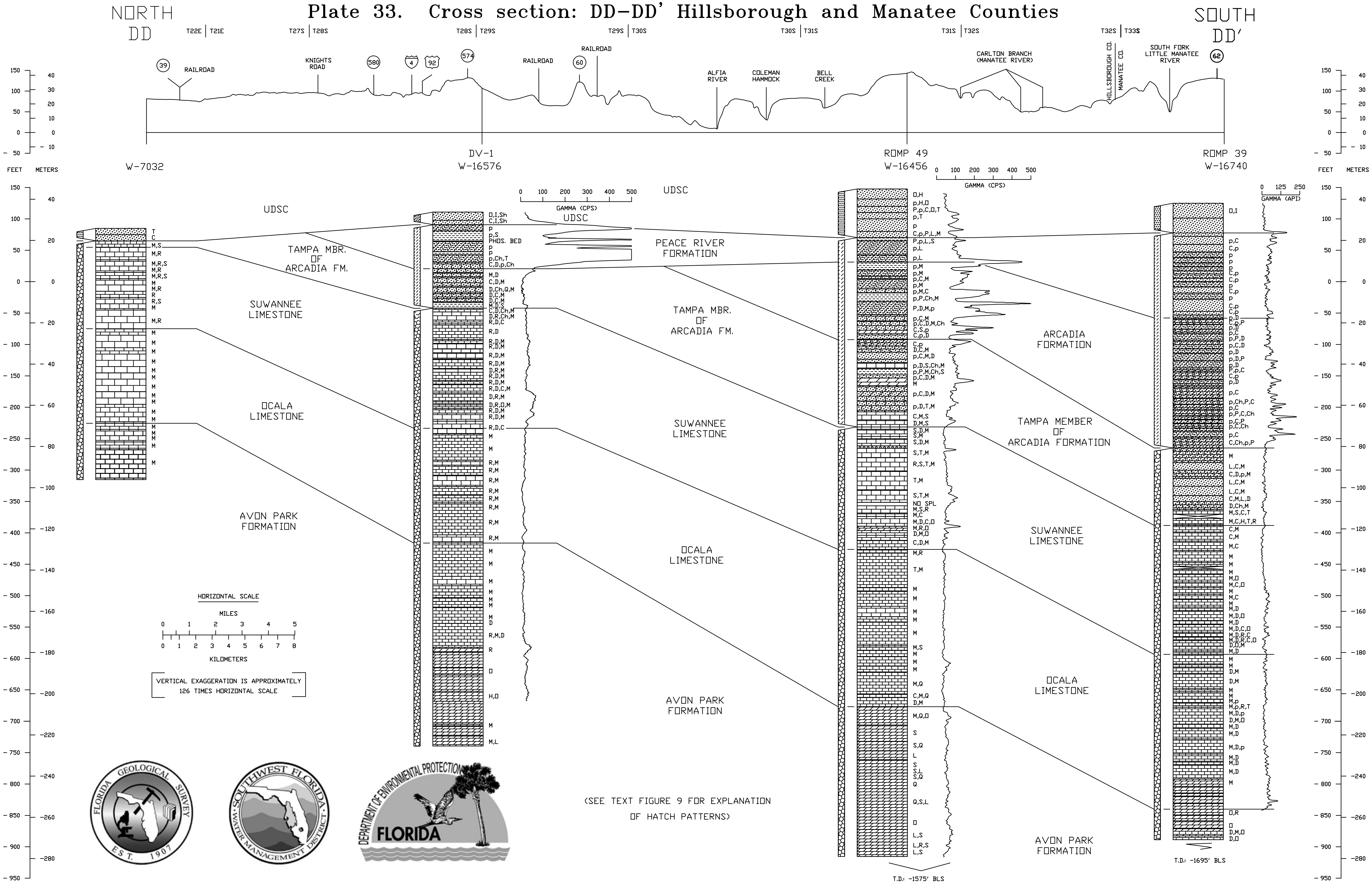


Plate 34. Cross section: EE–EE' Lake, Polk, Hardee, DeSoto, and Charlotte Counties

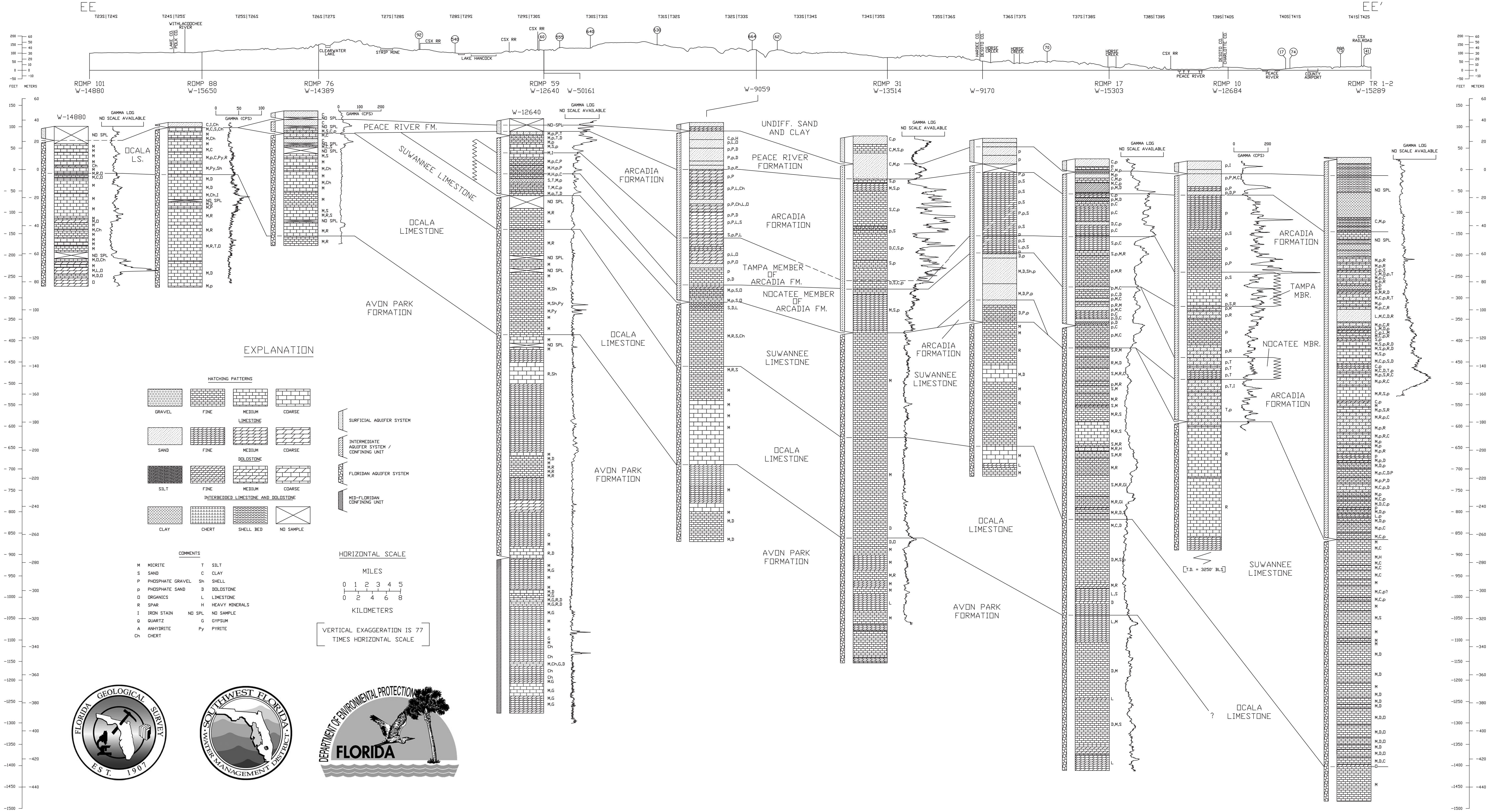


Plate 35. Cross section: FF–FF' Polk, Highland, and Glades Counties

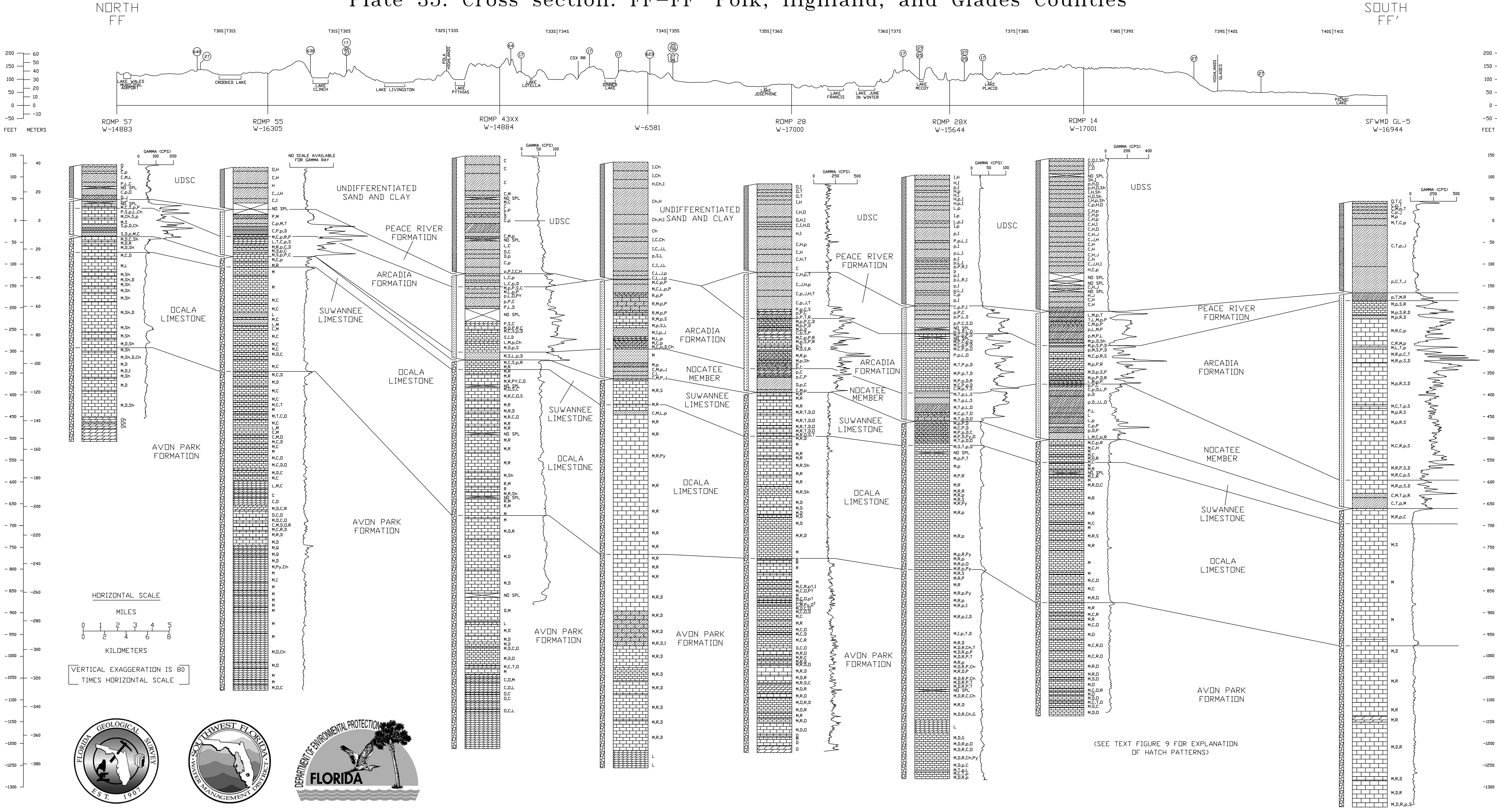


Plate 36: Cross section: GG-GG' Manatee, Sarasota, and Charlotte Counties

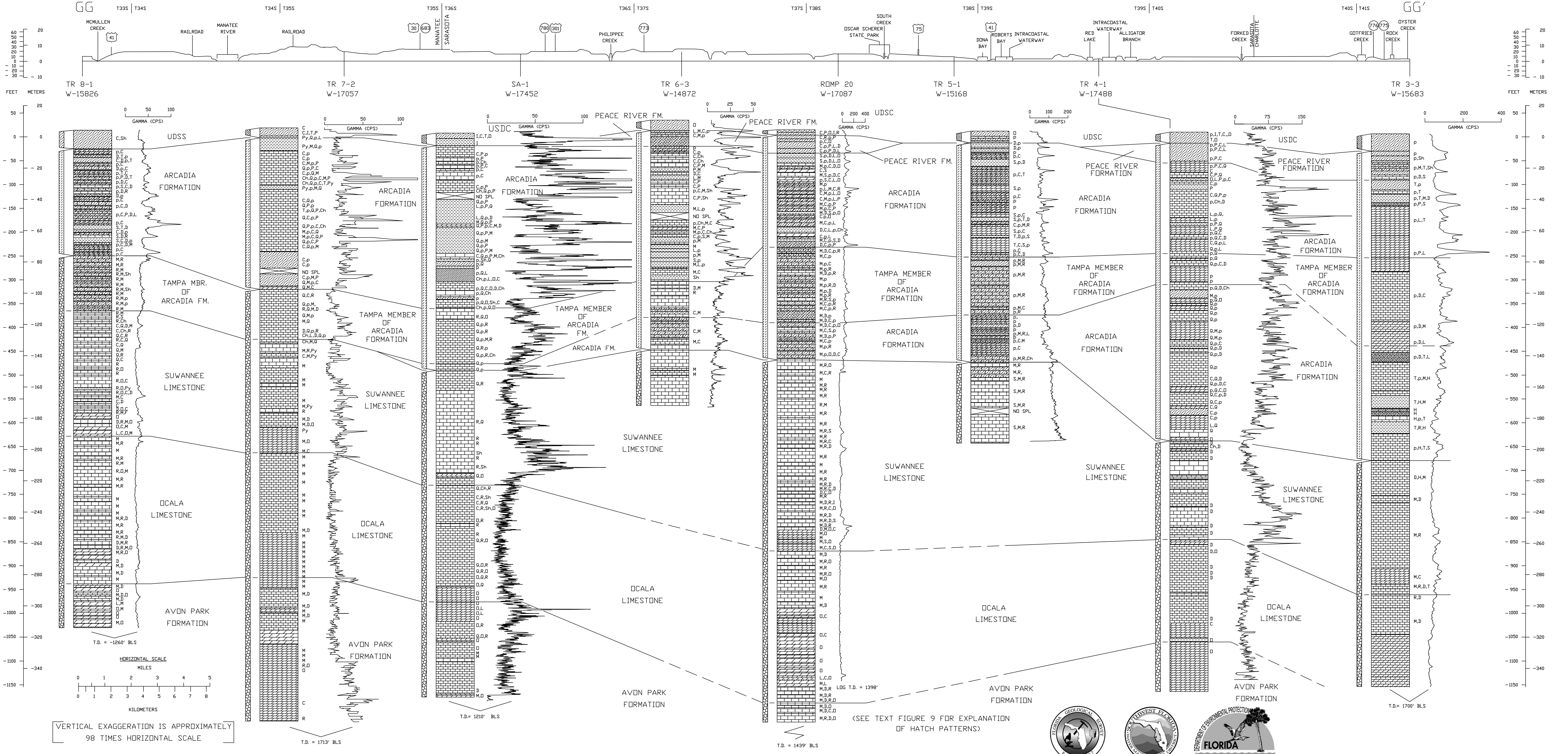
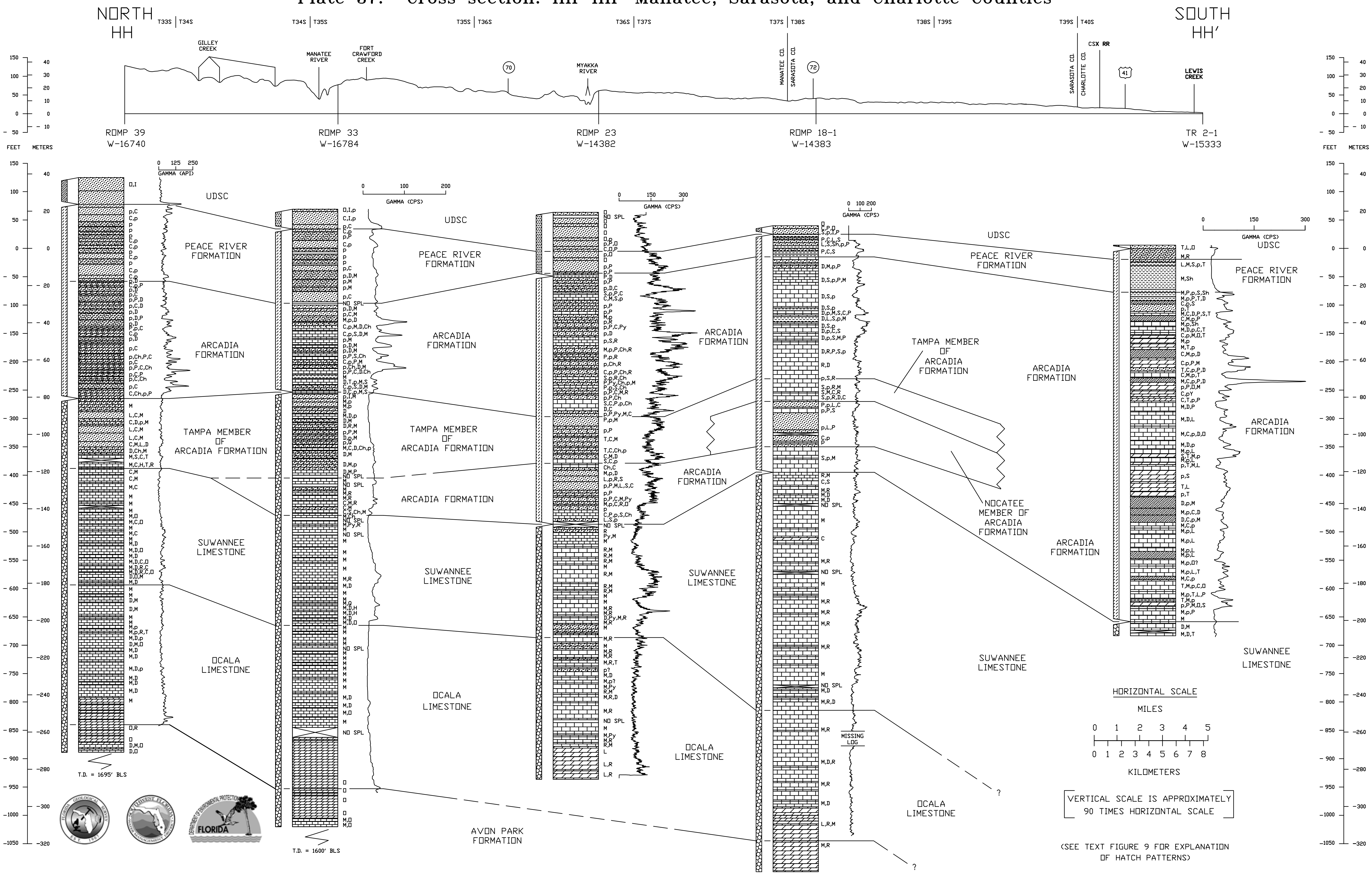
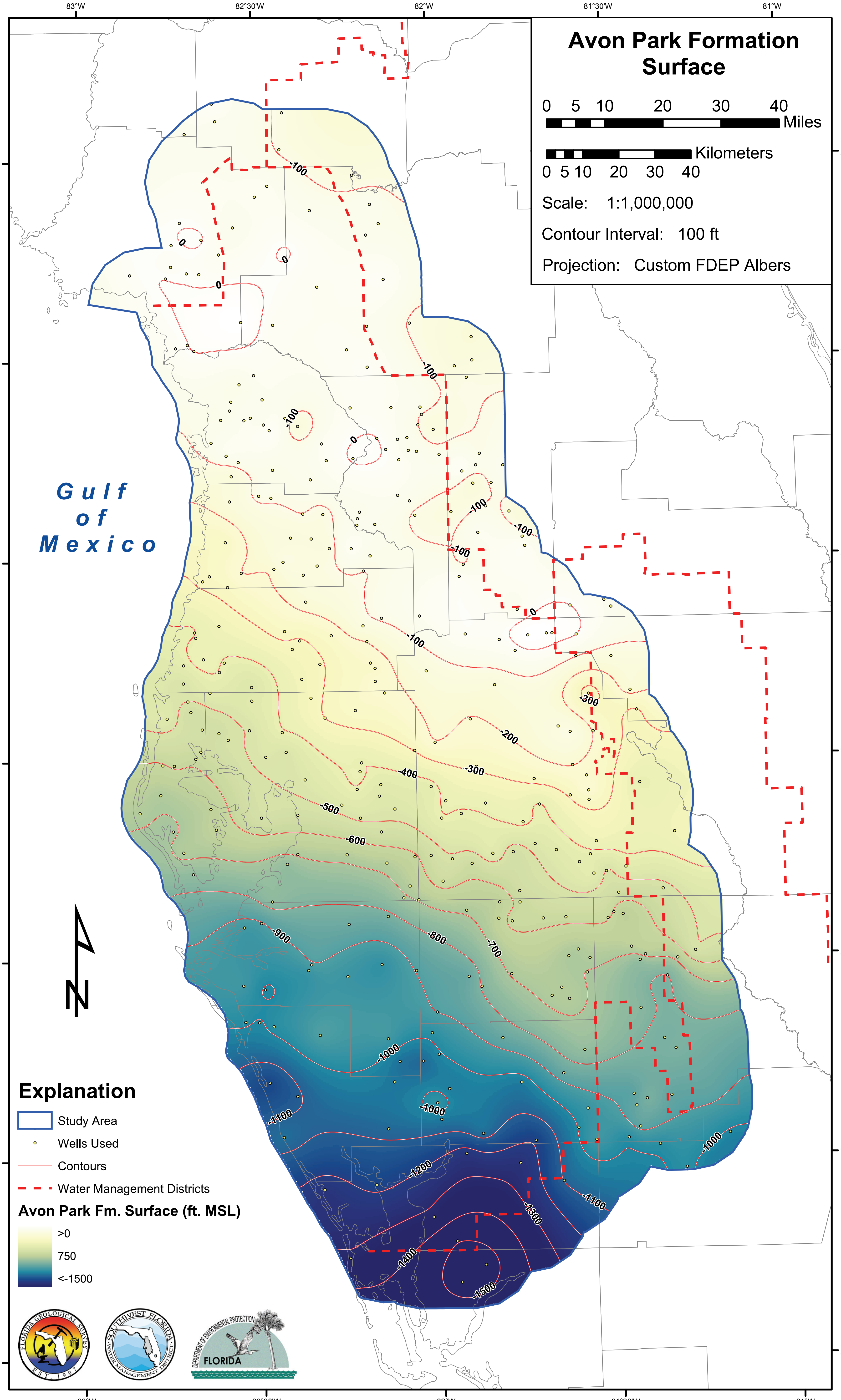


Plate 37: Cross section: HH-HH' Manatee, Sarasota, and Charlotte Counties





Avon Park Formation Surface
0 5 10 20 30 40 Miles
Kilometers
0 5 10 20 30 40
Scale: 1:1,000,000
Contour Interval: 100 ft
Projection: Custom FDEP Albers
Gulf of Mexico
Explanation
Study Area
Wells Used
Contours
Water Management Districts
Avon Park Fm. Surface (ft. MSL)
>0
750
<-1500
83°W
82°30'W
82°W
81°30'W
81°W
29°30'N
29°N
28°30'N
28°N
27°30'N
27°N
26°30'N

PLATE 38

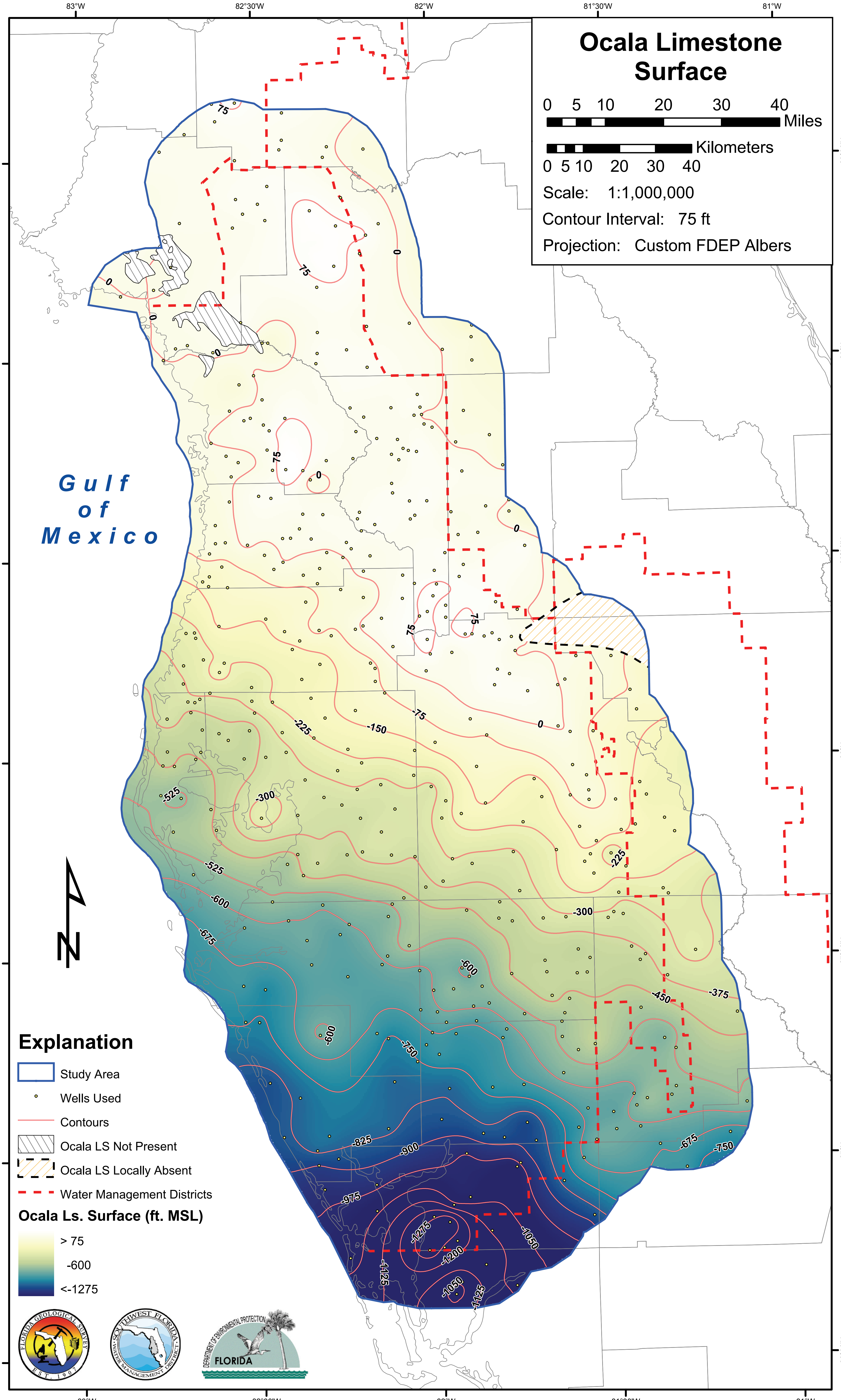
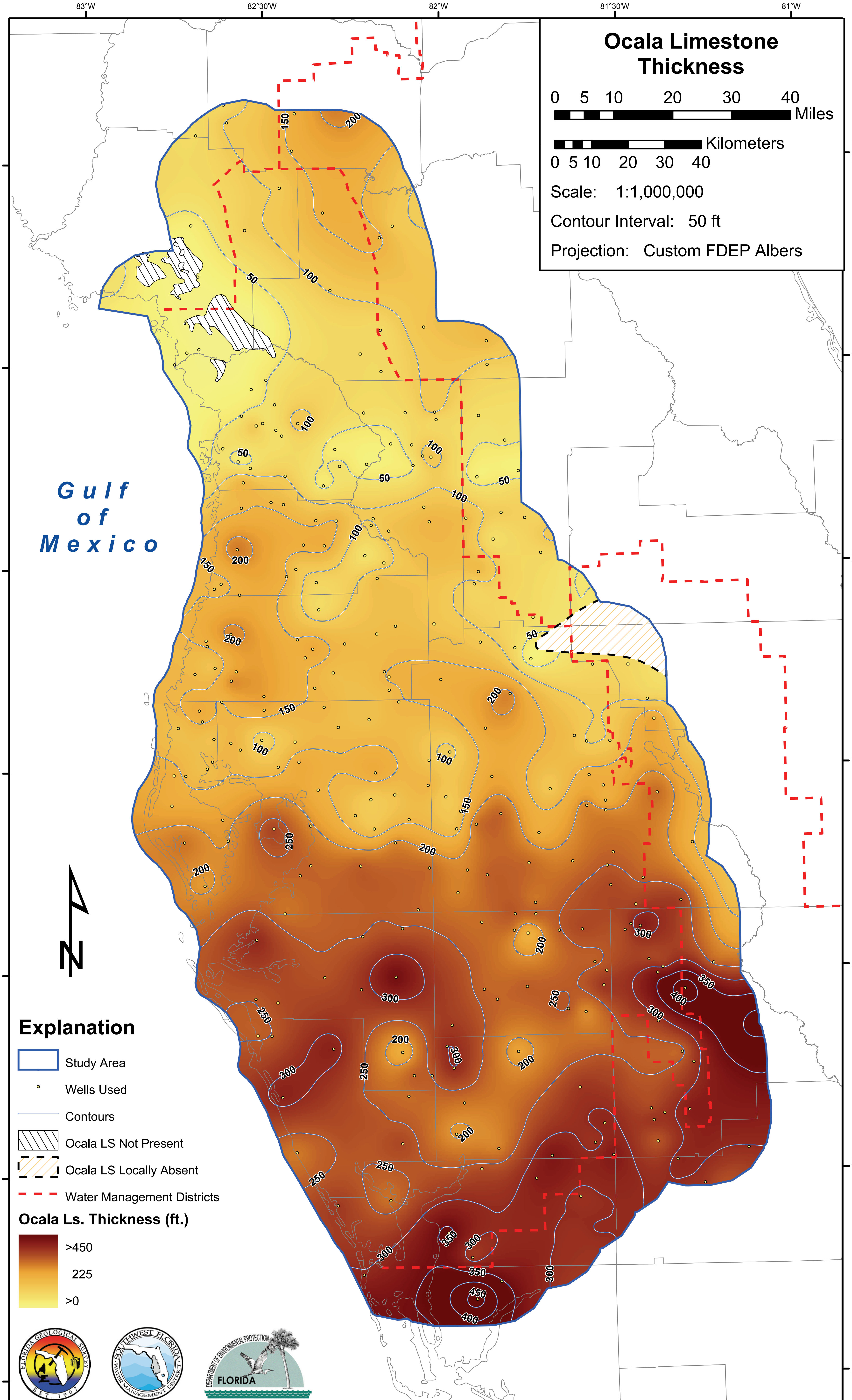
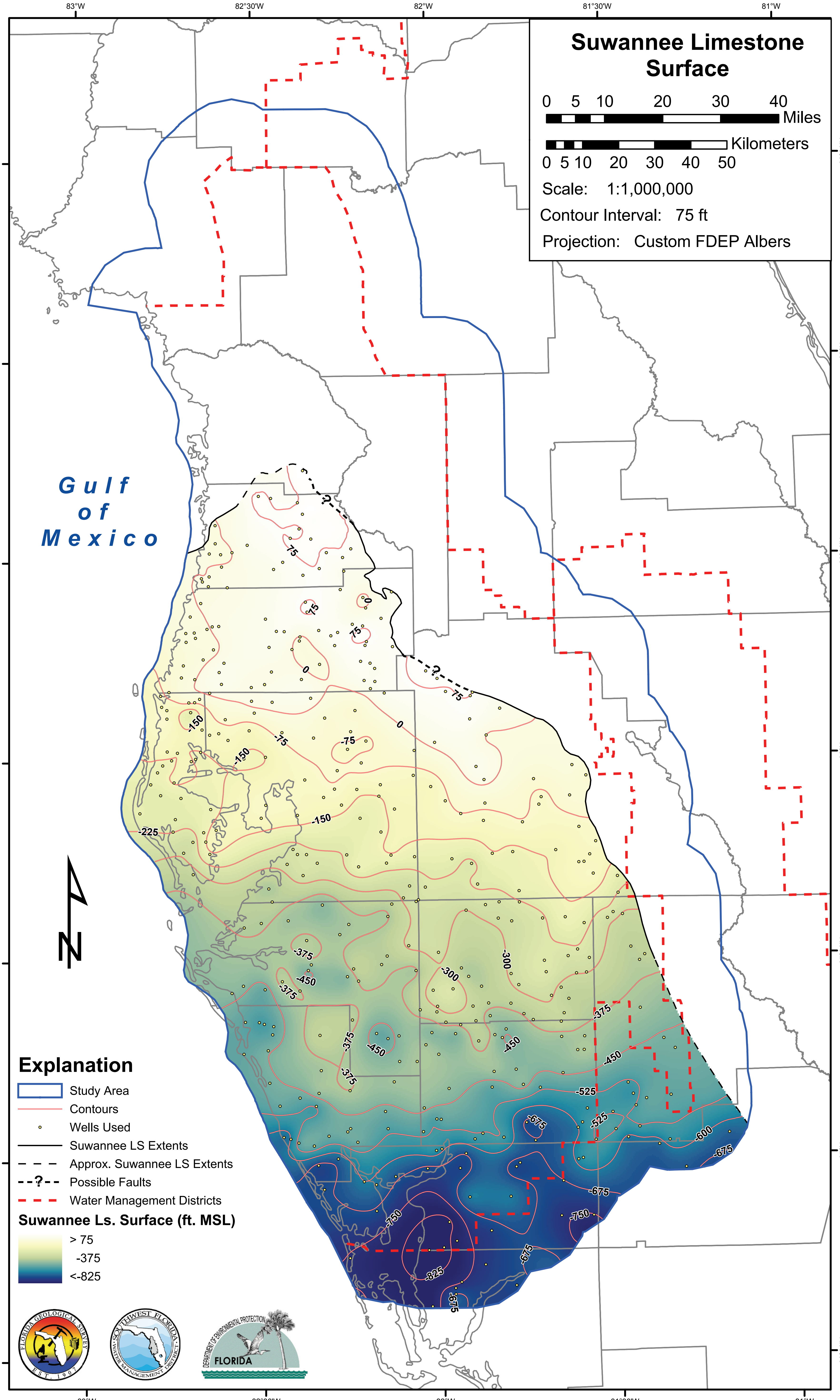

Ocala Limestone Surface
0 5 10 20 30 40 Miles
Kilometers
0 5 10 20 30 40
Scale: 1:1,000,000
Contour Interval: 75 ft
Projection: Custom FDEP Albers
Gulf of Mexico
Explanation
Study Area
Wells Used
Contours
Ocala LS Not Present
Ocala LS Locally Absent
Water Management Districts
Ocala Ls. Surface (ft. MSL)
> 75
-600
<-1275
83°W
82°30'W
82°W
81°30'W
81°W
29°30'N
29°N
28°30'N
28°N
27°30'N
27°N
26°30'N

PLATE 39



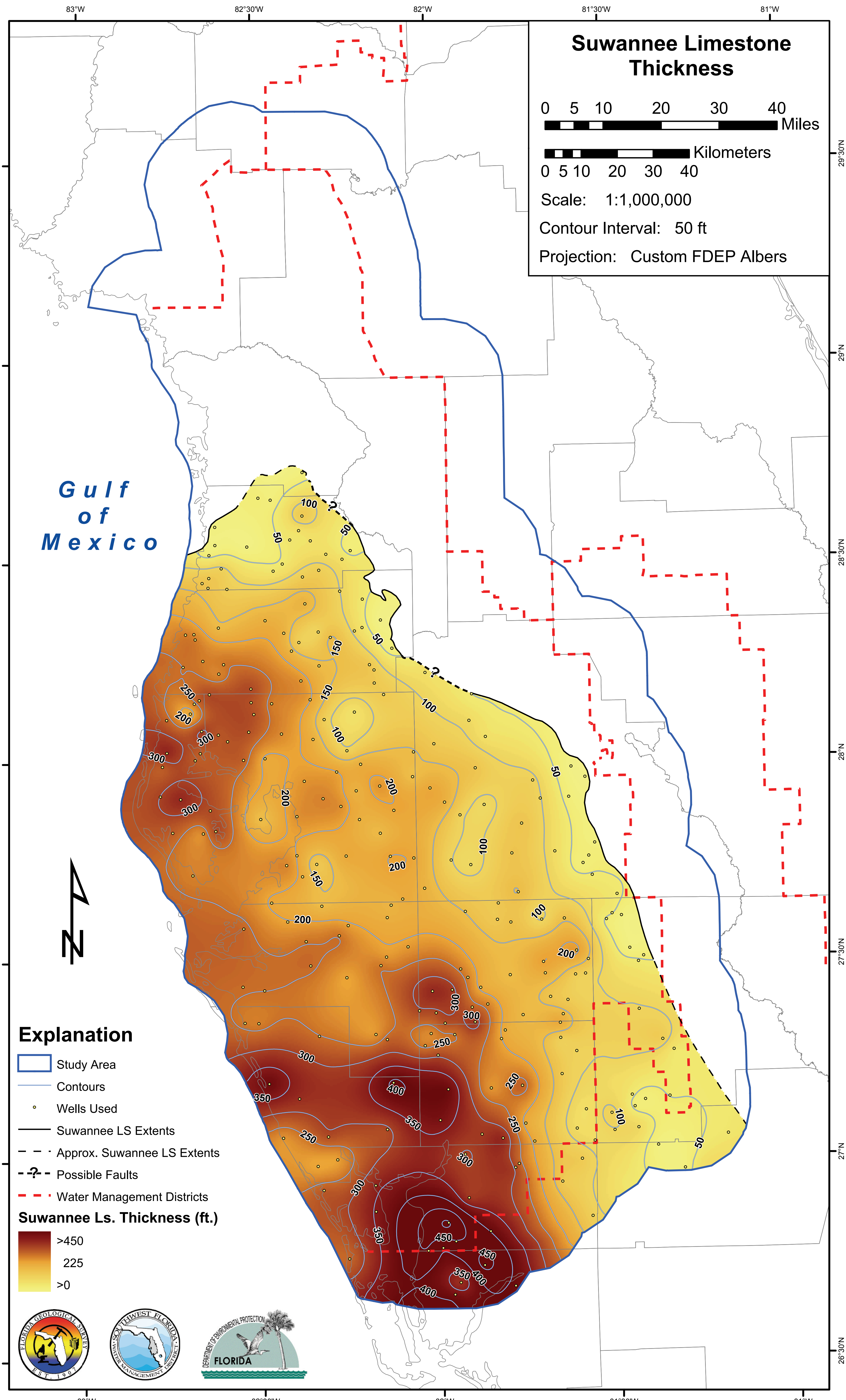
Ocala Limestone Thickness
0 5 10 20 30 40 Miles
Kilometers
0 5 10 20 30 40
Scale: 1:1,000,000
Contour Interval: 50 ft
Projection: Custom FDEP Albers
Gulf of Mexico
Explanation
Study Area
Wells Used
Contours
Ocala LS Not Present
Ocala LS Locally Absent
Water Management Districts
Ocala Ls. Thickness (ft.)
>450
225
>0
83°W
82°30'W
82°W
81°30'W
81°W
29°30'N
29°N
28°30'N
28°N
27°30'N
27°N
26°30'N

PLATE 40



Suwannee Limestone Surface
0 5 10 20 30 40 Miles
Kilometers
0 5 10 20 30 40 50
Scale: 1:1,000,000
Contour Interval: 75 ft
Projection: Custom FDEP Albers
Gulf of Mexico
Explanation
Study Area
Contours
Wells Used
Suwannee LS Extents
Approx. Suwannee LS Extents
Possible Faults
Water Management Districts
Suwannee Ls. Surface (ft. MSL)
> 75
-375
<-825
83°W
82°30'W
82°W
81°30'W
81°W
29°30'N
29°N
28°30'N
28°N
27°30'N
27°N
26°30'N
FLORIDA

PLATE 41



Suwannee Limestone Thickness
0 5 10 20 30 40 Miles
Kilometers
0 5 10 20 30 40
Scale: 1:1,000,000
Contour Interval: 50 ft
Projection: Custom FDEP Albers
Gulf of Mexico
Explanation
Study Area
Contours
Wells Used
Suwannee LS Extents
Approx. Suwannee LS Extents
Possible Faults
Water Management Districts
Suwannee Ls. Thickness (ft.)
>450
225
>0
83°W
82°30'W
82°W
81°30'W
81°W
29°30'N
29°N
28°30'N
28°N
27°30'N
27°N
26°30'N
FLORIDA

PLATE 42

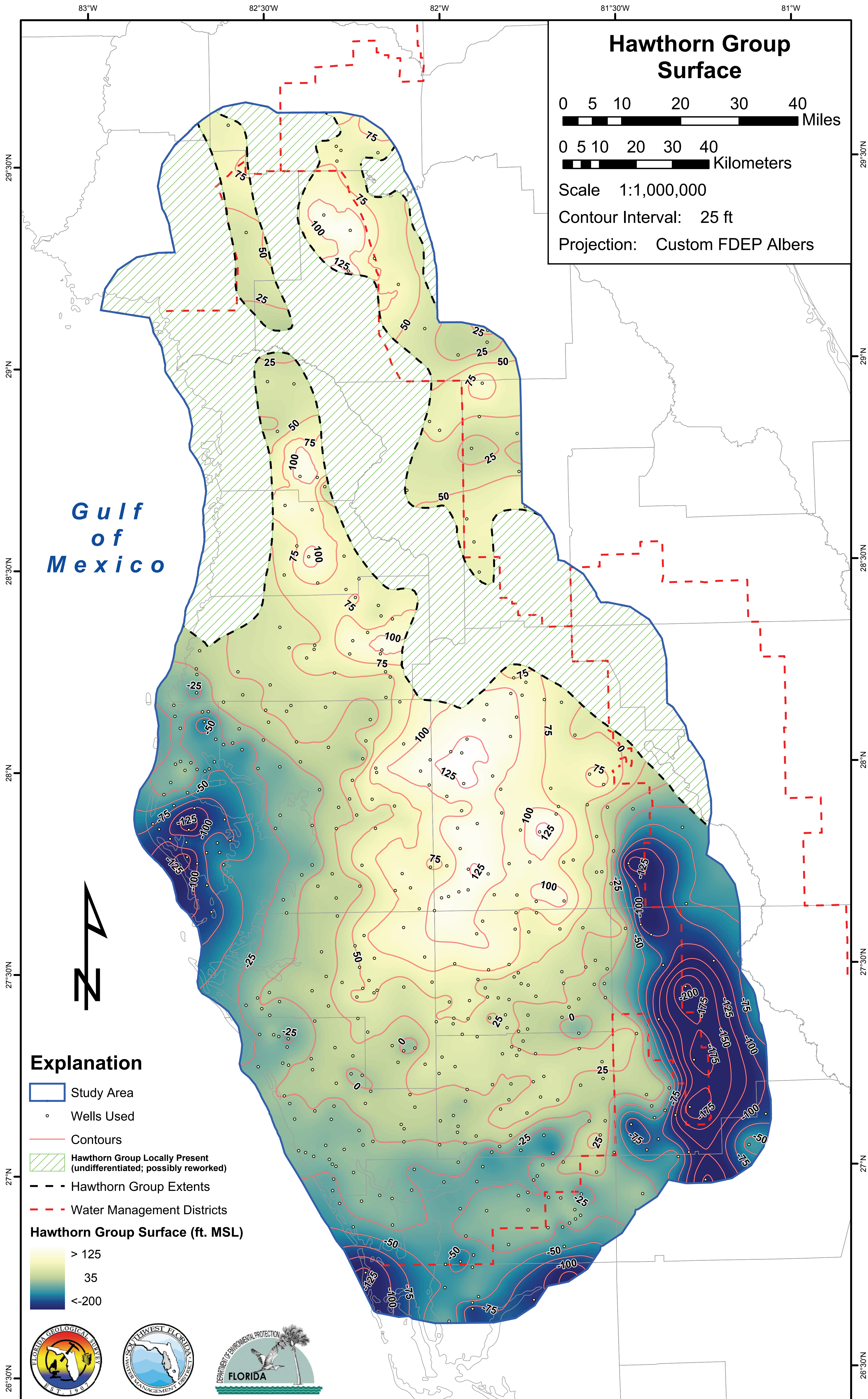
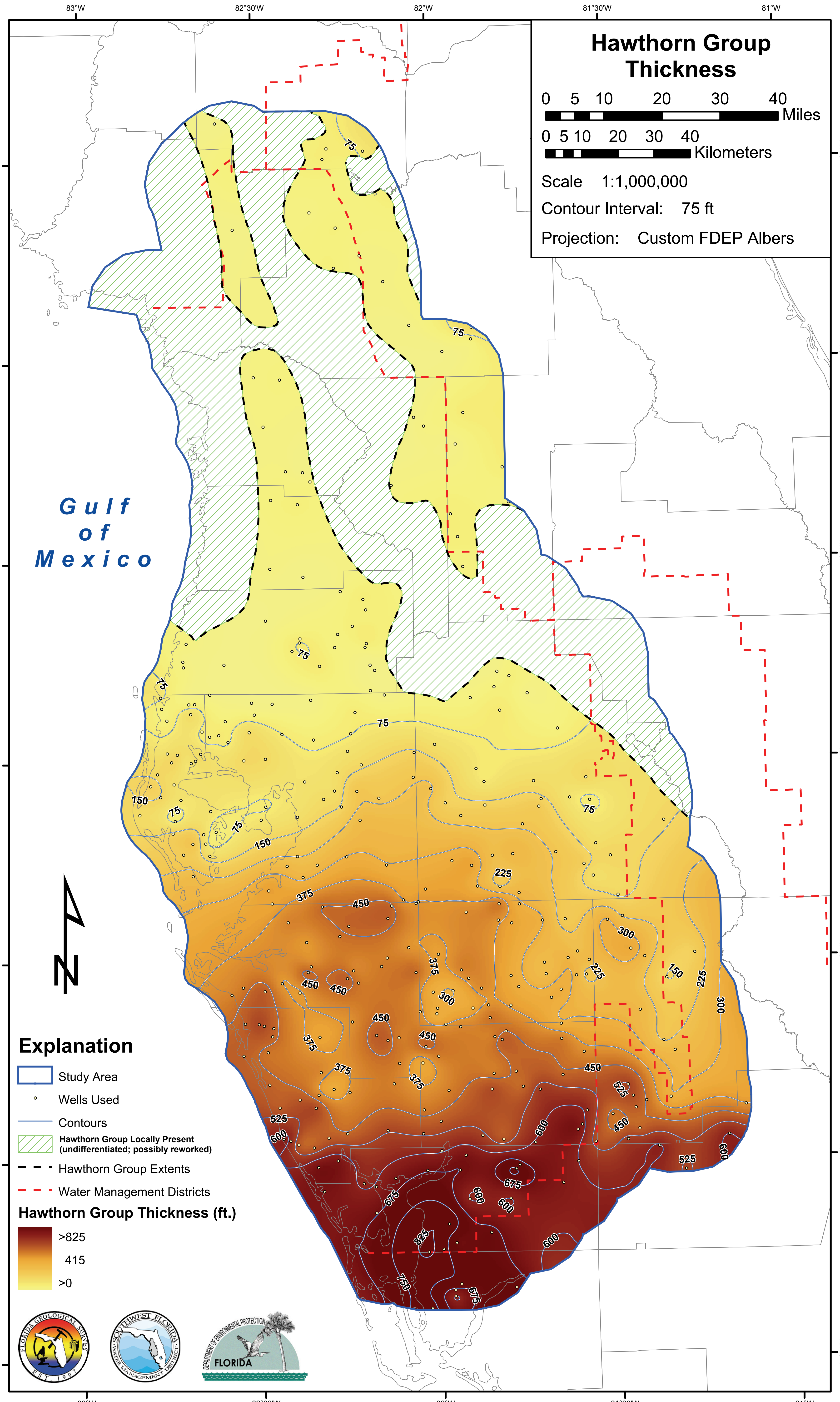

Hawthorn Group Surface
0 5 10 20 30 40 Miles
0 5 10 20 30 40 Kilometers
Scale 1:1,000,000
Contour Interval: 25 ft
Projection: Custom FDEP Albers
Gulf of Mexico
Explanation
Study Area
Wells Used
Contours
Hawthorn Group Locally Present (undifferentiated; possibly reworked)
Hawthorn Group Extents
Water Management Districts
Hawthorn Group Surface (ft. MSL)
> 125
35
<-200
83°W
82°30'W
82°W
81°30'W
81°W
29°30'N
29°N
28°30'N
28°N
27°30'N
27°N
26°30'N

PLATE 43



Hawthorn Group Thickness
0 5 10 20 30 40 Miles
0 5 10 20 30 40 Kilometers
Scale 1:1,000,000
Contour Interval: 75 ft
Projection: Custom FDEP Albers
Gulf of Mexico
Explanation
Study Area
Wells Used
Contours
Hawthorn Group Locally Present (undifferentiated; possibly reworked)
Hawthorn Group Extents
Water Management Districts
Hawthorn Group Thickness (ft.)
>825
415
>0
83°W
82°30'W
82°W
81°30'W
81°W
29°30'N
29°N
28°30'N
28°N
27°30'N
27°N
26°30'N

PLATE 44

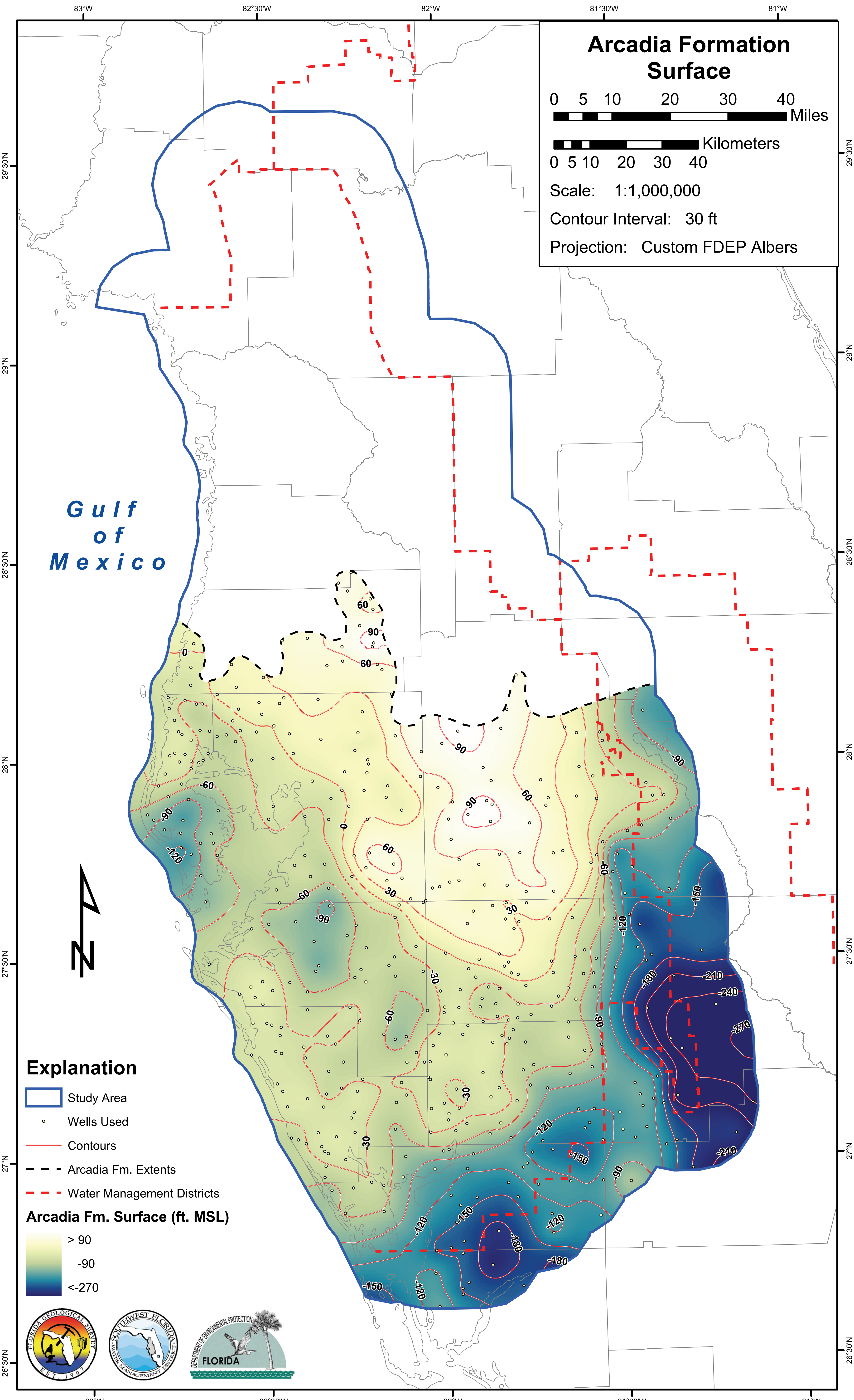

Arcadia Formation Surface
0 5 10 20 30 40
Miles
Kilometers
0 5 10 20 30 40
Scale: 1:1,000,000
Contour Interval: 30 ft
Projection: Custom FDEP Albers
Gulf of Mexico
83°W
82°30'W
82°W
81°30'W
81°W
29°30'N
29°N
28°30'N
28°N
27°30'N
27°N
26°30'N
N
Explanation
Study Area
Wells Used
Contours
Arcadia Fm. Extents
Water Management Districts
Arcadia Fm. Surface (ft. MSL)
> 90
-90
<-270
FLORIDA

PLATE 45

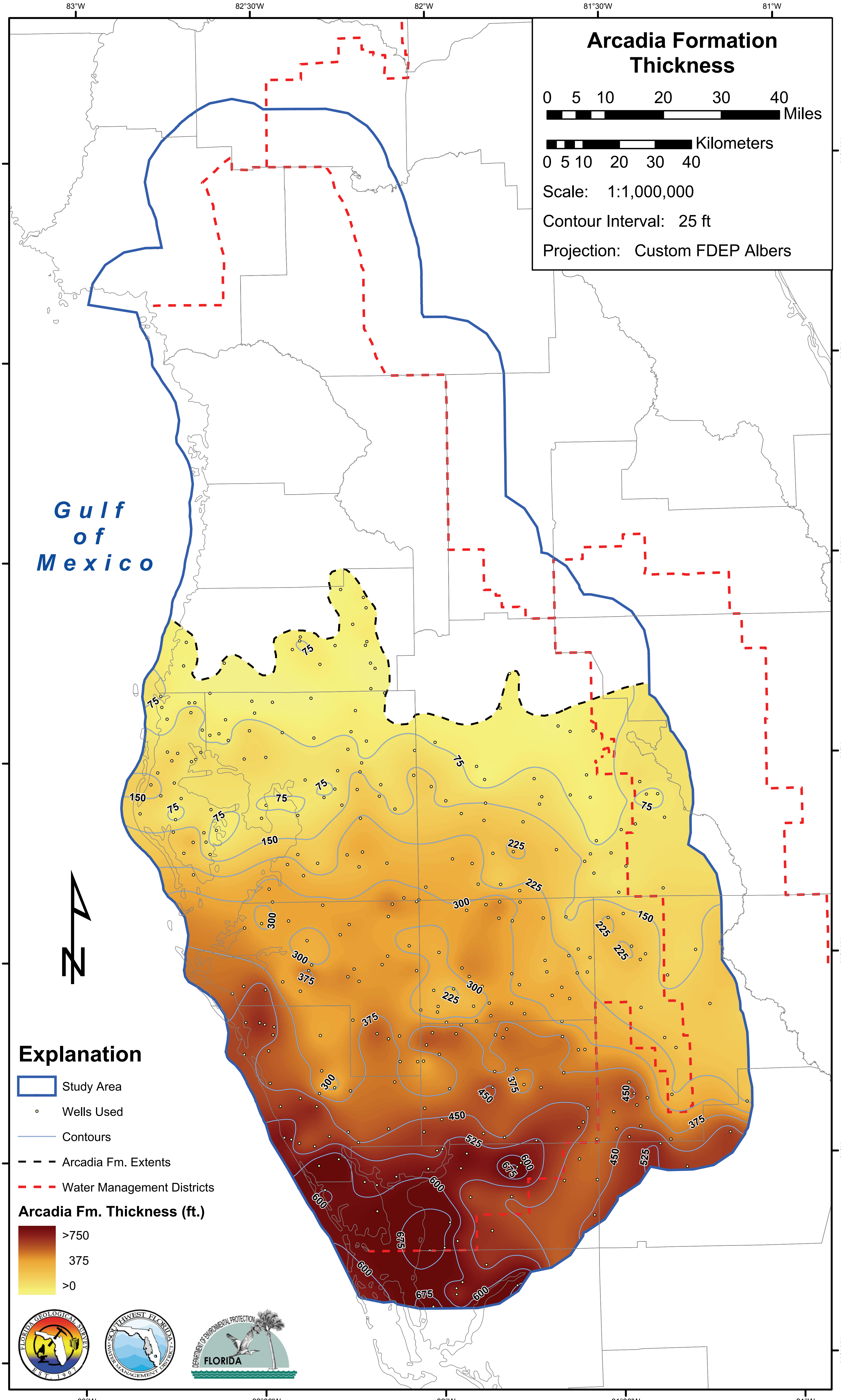

Arcadia Formation Thickness
0 5 10 20 30 40
Miles
Kilometers
0 5 10 20 30 40
Scale: 1:1,000,000
Contour Interval: 25 ft
Projection: Custom FDEP Albers
Gulf of Mexico
Explanation
Study Area
Wells Used
Contours
Arcadia Fm. Extents
Water Management Districts
Arcadia Fm. Thickness (ft.)
>750
375
>0
83°W
82°30'W
82°W
81°30'W
81°W
29°30'N
29°N
28°30'N
28°N
27°30'N
27°N
26°30'N
FLORIDA

PLATE 46

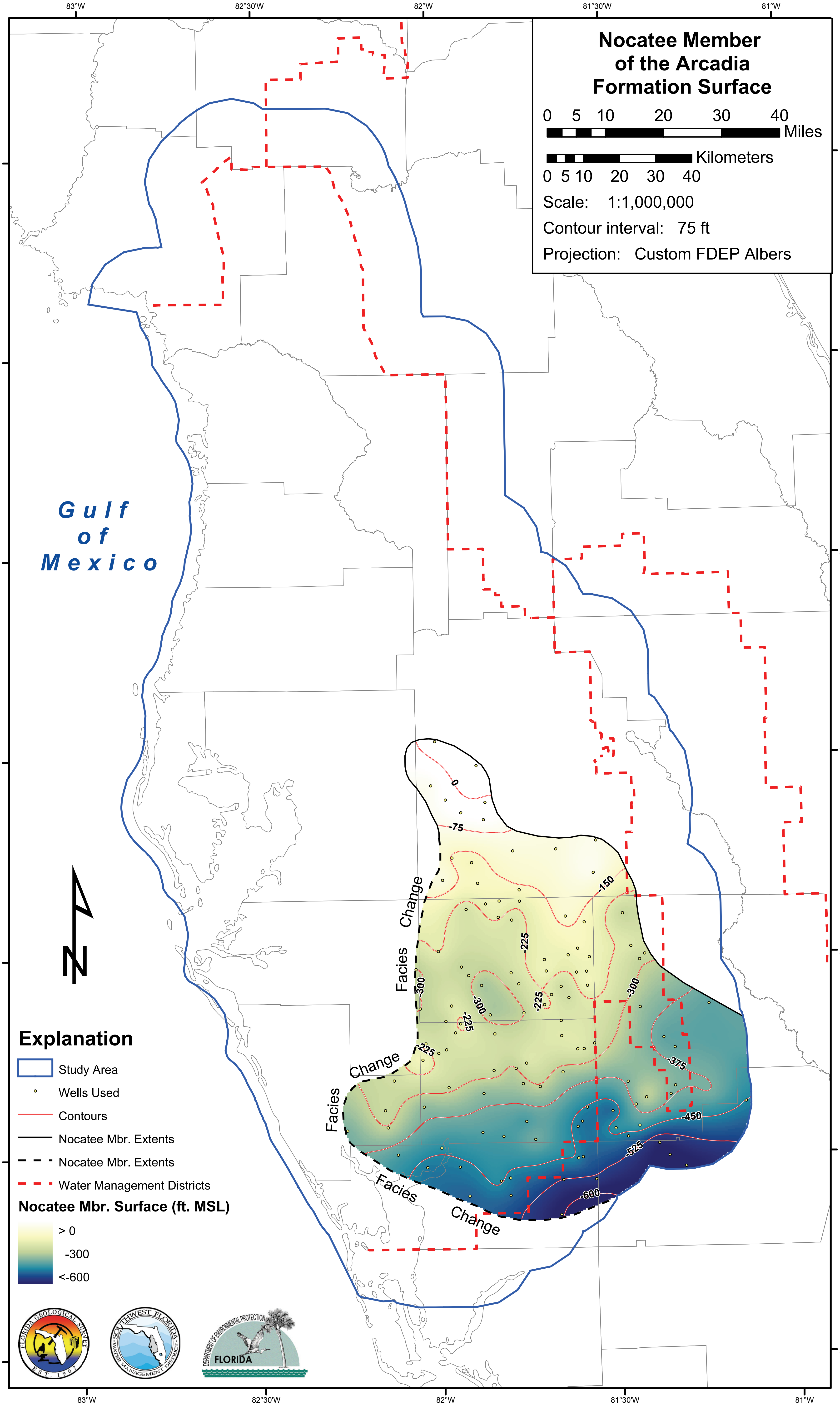

Nocatee Member
of the Arcadia
Formation Surface
0 5 10 20 30 40
Miles
Kilometers
0 5 10 20 30 40
Scale: 1:1,000,000
Contour interval: 75 ft
Projection: Custom FDEP Albers
Gulf
of
Mexico
Explanation
Study Area
Wells Used
Contours
Nocatee Mbr. Extents
Nocatee Mbr. Extents
Water Management Districts
Nocatee Mbr. Surface (ft. MSL)
> 0
-300
<-600
Facies Change
Facies Change
Facies Change
0
-75
-150
-225
-225
-225
-300
-300
-300
-375
-450
-525
-600
83°W
82°30'W
82°W
81°30'W
81°W
29°30'N
29°N
28°30'N
28°N
27°30'N
27°N
26°30'N
FLORIDA

PLATE 47

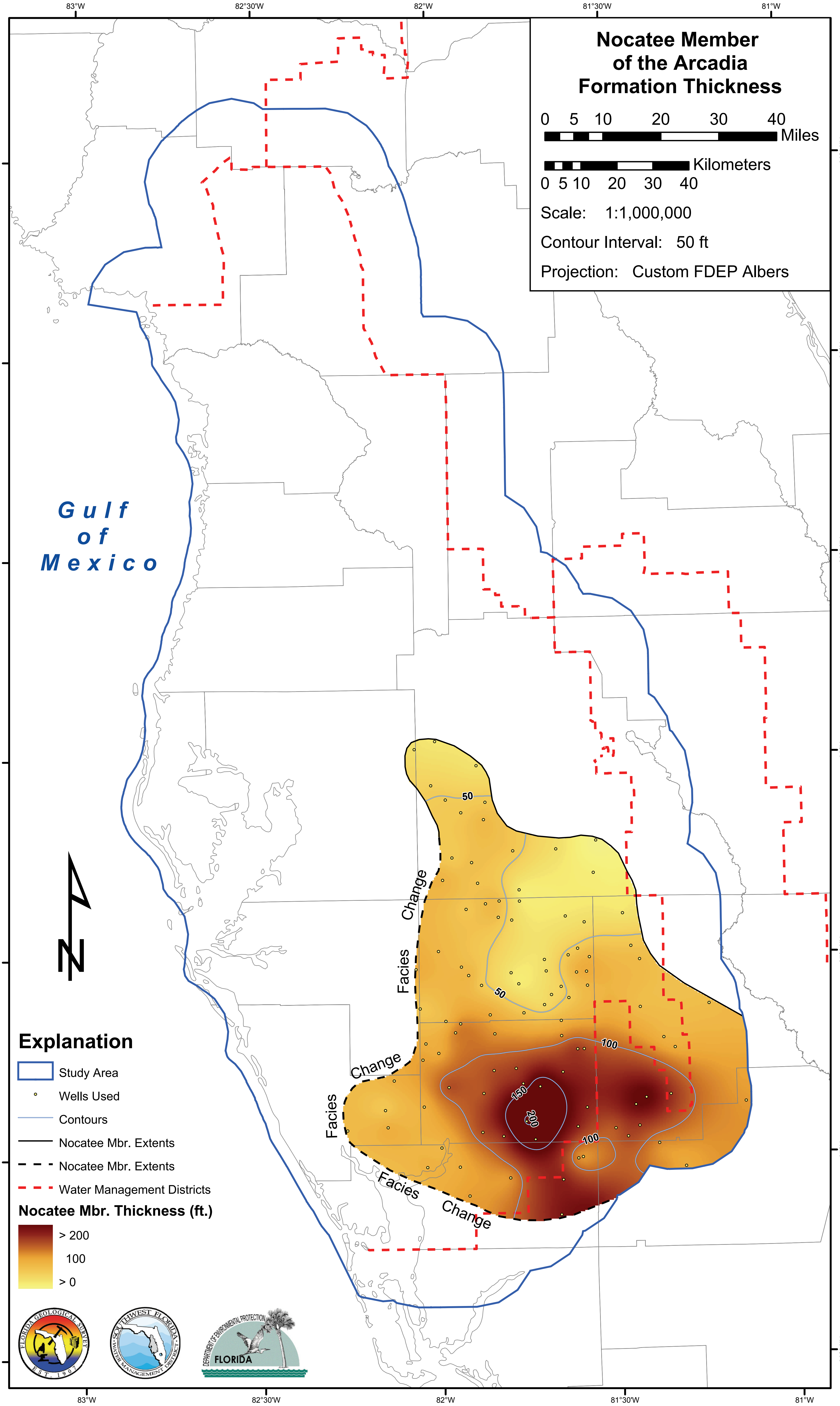

Nocatee Member
of the Arcadia
Formation Thickness
0 5 10 20 30 40 Miles
Kilometers
0 5 10 20 30 40
Scale: 1:1,000,000
Contour Interval: 50 ft
Projection: Custom FDEP Albers
Gulf
of
Mexico
Facies Change
Facies Change
Facies Change
50
100
150
200
Explanation
Study Area
Wells Used
Contours
Nocatee Mbr. Extents
Nocatee Mbr. Extents
Water Management Districts
Nocatee Mbr. Thickness (ft.)
> 200
100
> 0
83°W
82°30'W
82°W
81°30'W
81°W
29°30'N
29°N
28°30'N
28°N
27°30'N
27°N
26°30'N
FLORIDA

PLATE 48

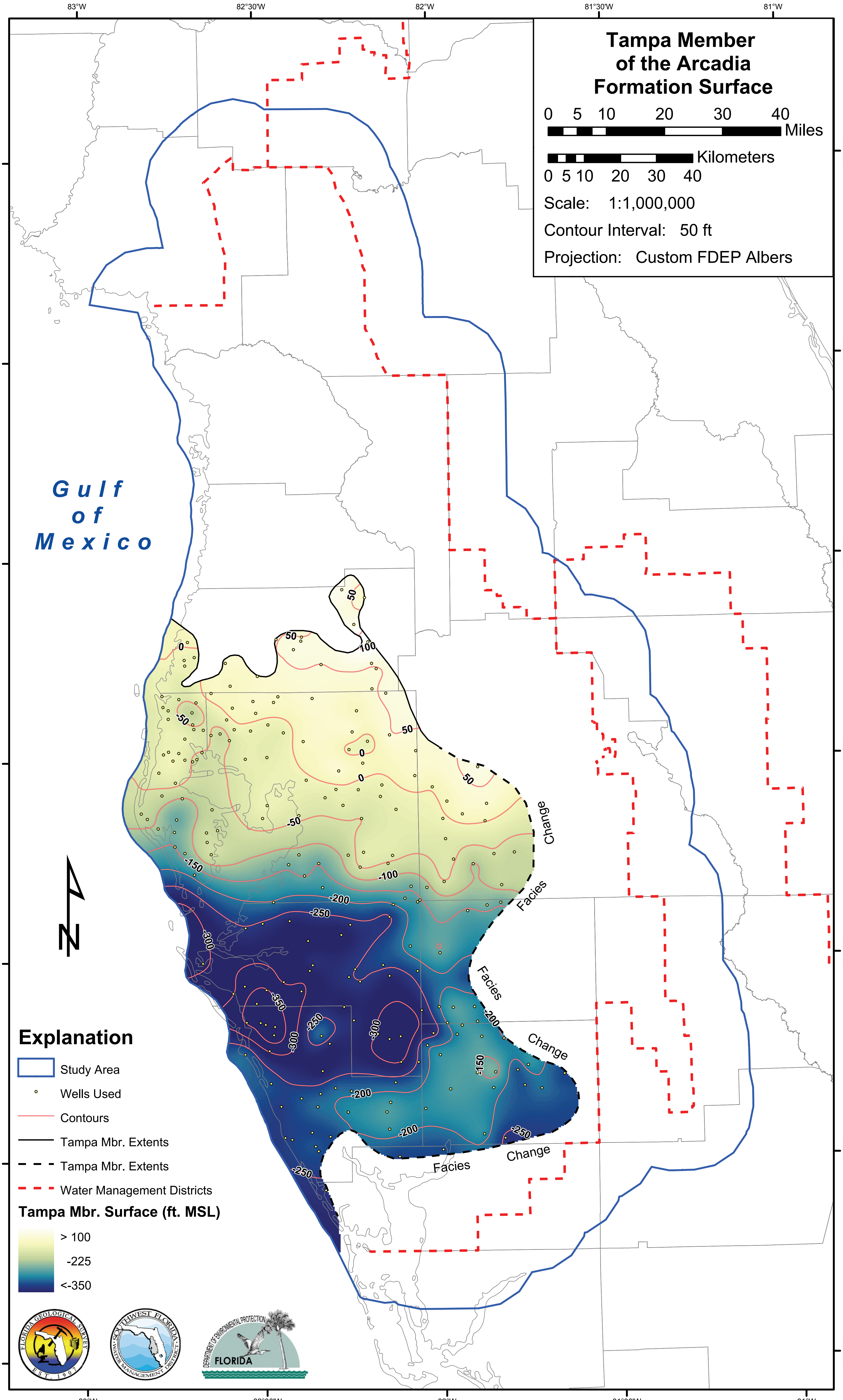
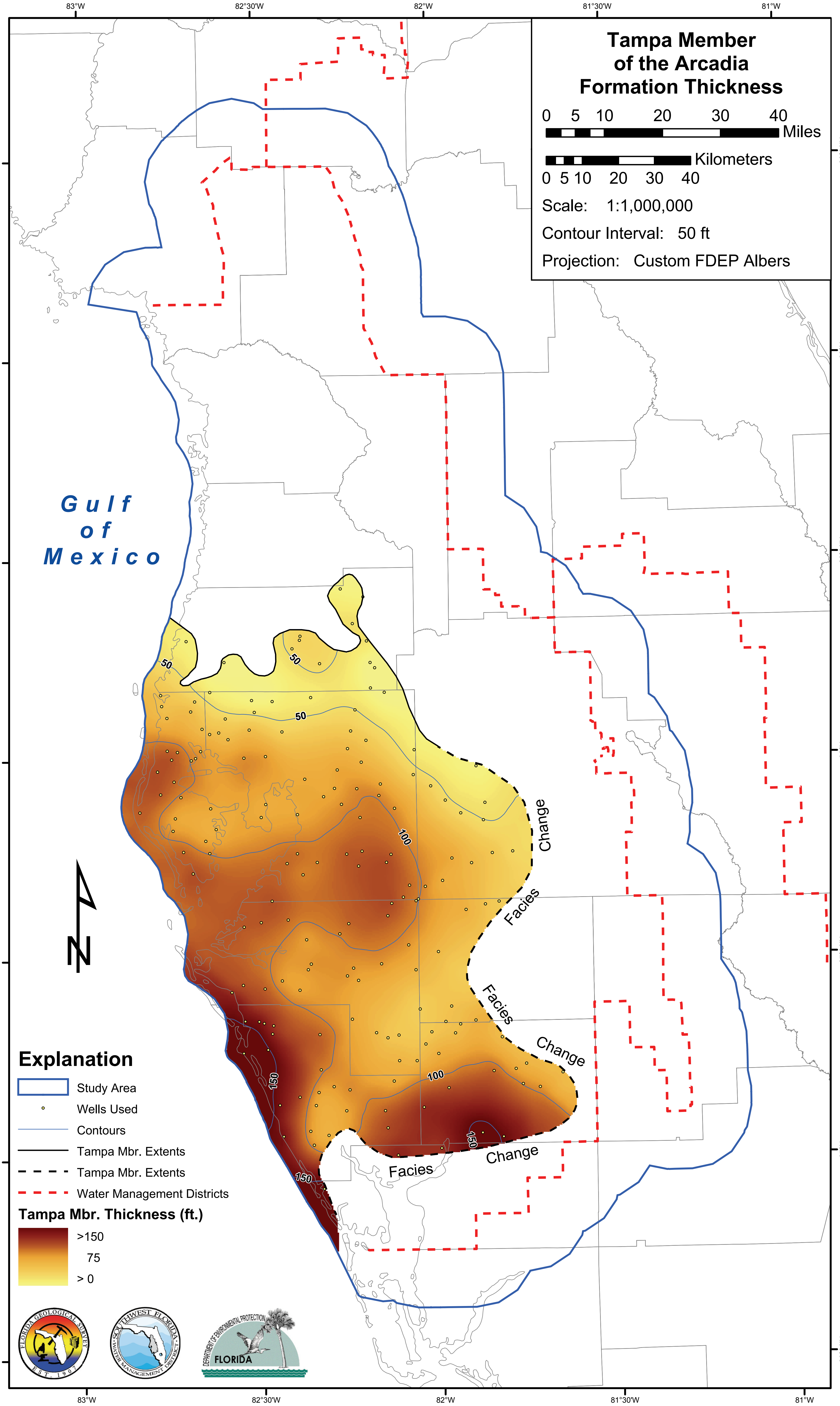
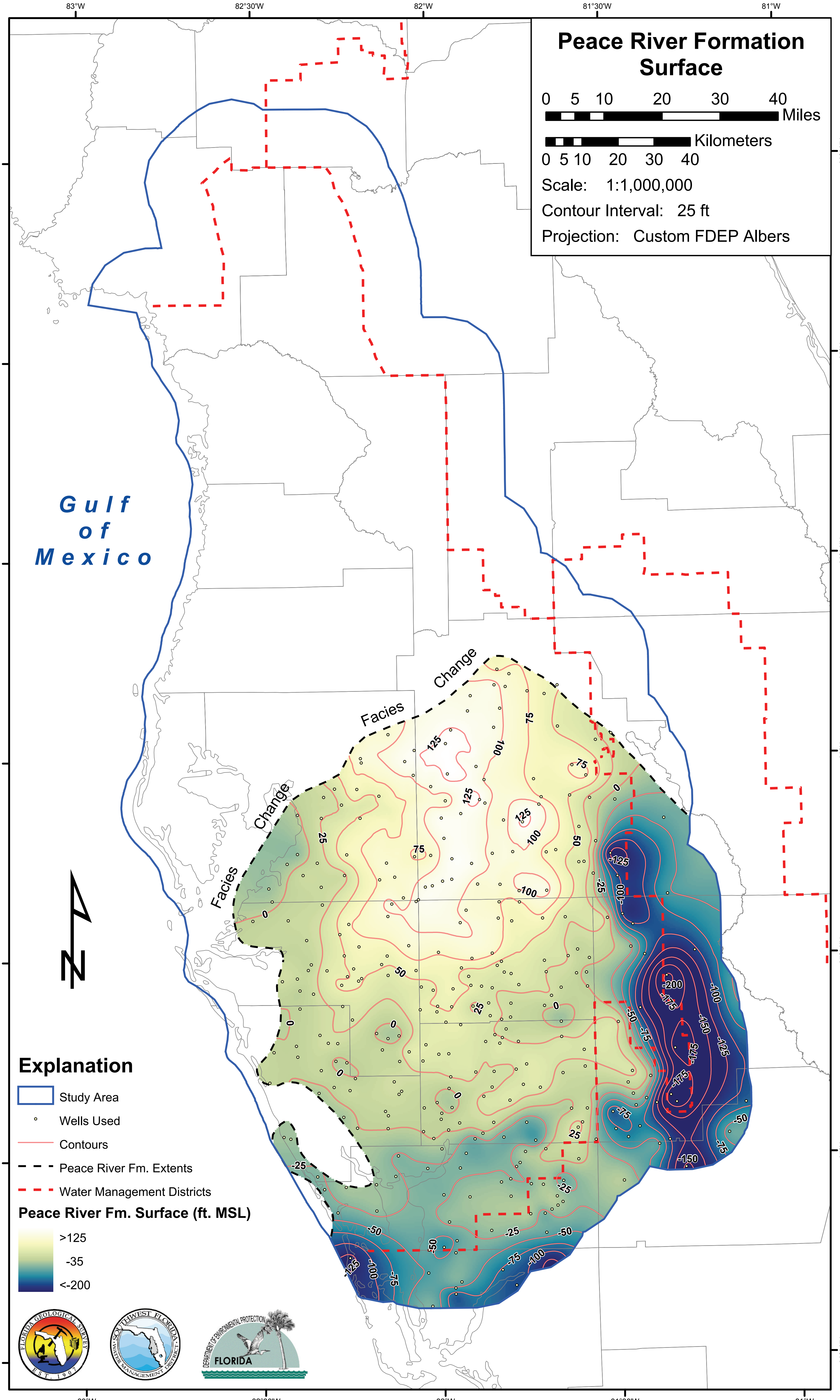

Tampa Member of the Arcadia Formation Surface
0 5 10 20 30 40 Miles
0 5 10 20 30 40 Kilometers
Scale: 1:1,000,000
Contour Interval: 50 ft
Projection: Custom FDEP Albers
Gulf of Mexico
Facies Change
Explanation
Study Area
Wells Used
Contours
Tampa Mbr. Extents
Tampa Mbr. Extents
Water Management Districts
Tampa Mbr. Surface (ft. MSL)
> 100
-225
<-350
83°W
82°30'W
82°W
81°30'W
81°W
29°30'N
29°N
28°30'N
28°N
27°30'N
27°N
26°30'N

PLATE 49



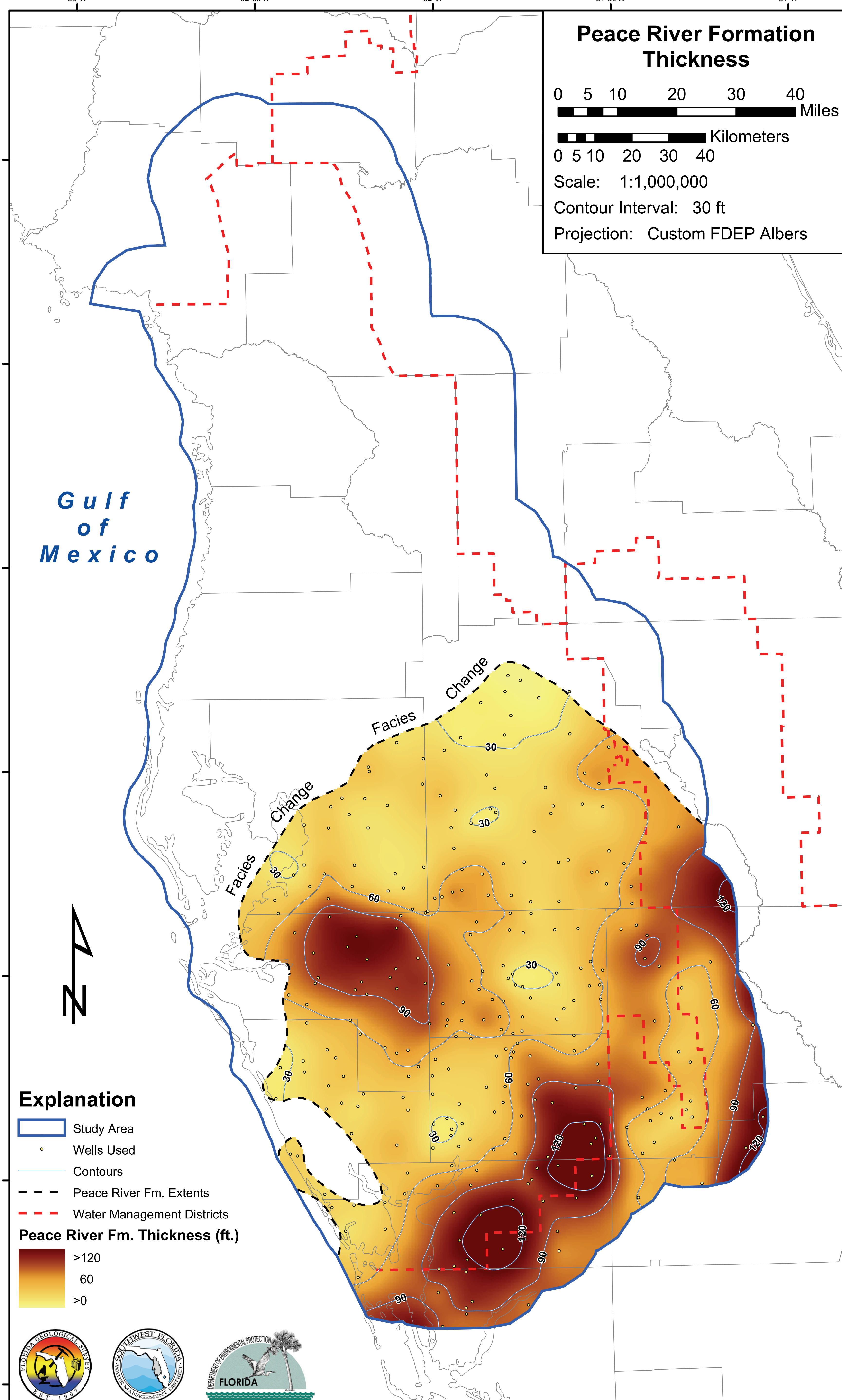
Tampa Member
of the Arcadia
Formation Thickness
0 5 10 20 30 40
Miles
Kilometers
0 5 10 20 30 40
Scale: 1:1,000,000
Contour Interval: 50 ft
Projection: Custom FDEP Albers
Gulf of Mexico
Explanation
Study Area
Wells Used
Contours
Tampa Mbr. Extents
Tampa Mbr. Extents
Water Management Districts
Tampa Mbr. Thickness (ft.)
>150
75
> 0
Facies Change
Facies Change
Facies Change
50
100
150
83°W
82°30'W
82°W
81°30'W
81°W
29°30'N
29°N
28°30'N
28°N
27°30'N
27°N
26°30'N
N
FLORIDA

PLATE 50



Peace River Formation Surface
0 5 10 20 30 40 Miles
0 5 10 20 30 40 Kilometers
Scale: 1:1,000,000
Contour Interval: 25 ft
Projection: Custom FDEP Albers
Gulf of Mexico
Facies Change
Facies Change
Explanation
Study Area
Wells Used
Contours
Peace River Fm. Extents
Water Management Districts
Peace River Fm. Surface (ft. MSL)
>125
-35
<-200
83°W
82°30'W
82°W
81°30'W
81°W
29°30'N
29°N
28°30'N
28°N
27°30'N
27°N
26°30'N

PLATE 51



Peace River Formation Thickness
0 5 10 20 30 40
Miles
Kilometers
0 5 10 20 30 40
Scale: 1:1,000,000
Contour Interval: 30 ft
Projection: Custom FDEP Albers
Gulf of Mexico
Facies Change
Facies Change
Facies Change
30
60
90
120
Explanation
Study Area
Wells Used
Contours
Peace River Fm. Extents
Water Management Districts
Peace River Fm. Thickness (ft.)
>120
60
>0
83°W
82°30'W
82°W
81°30'W
81°W
29°30'N
29°N
28°30'N
28°N
27°30'N
27°N
26°30'N
N
FLORIDA

PLATE 52

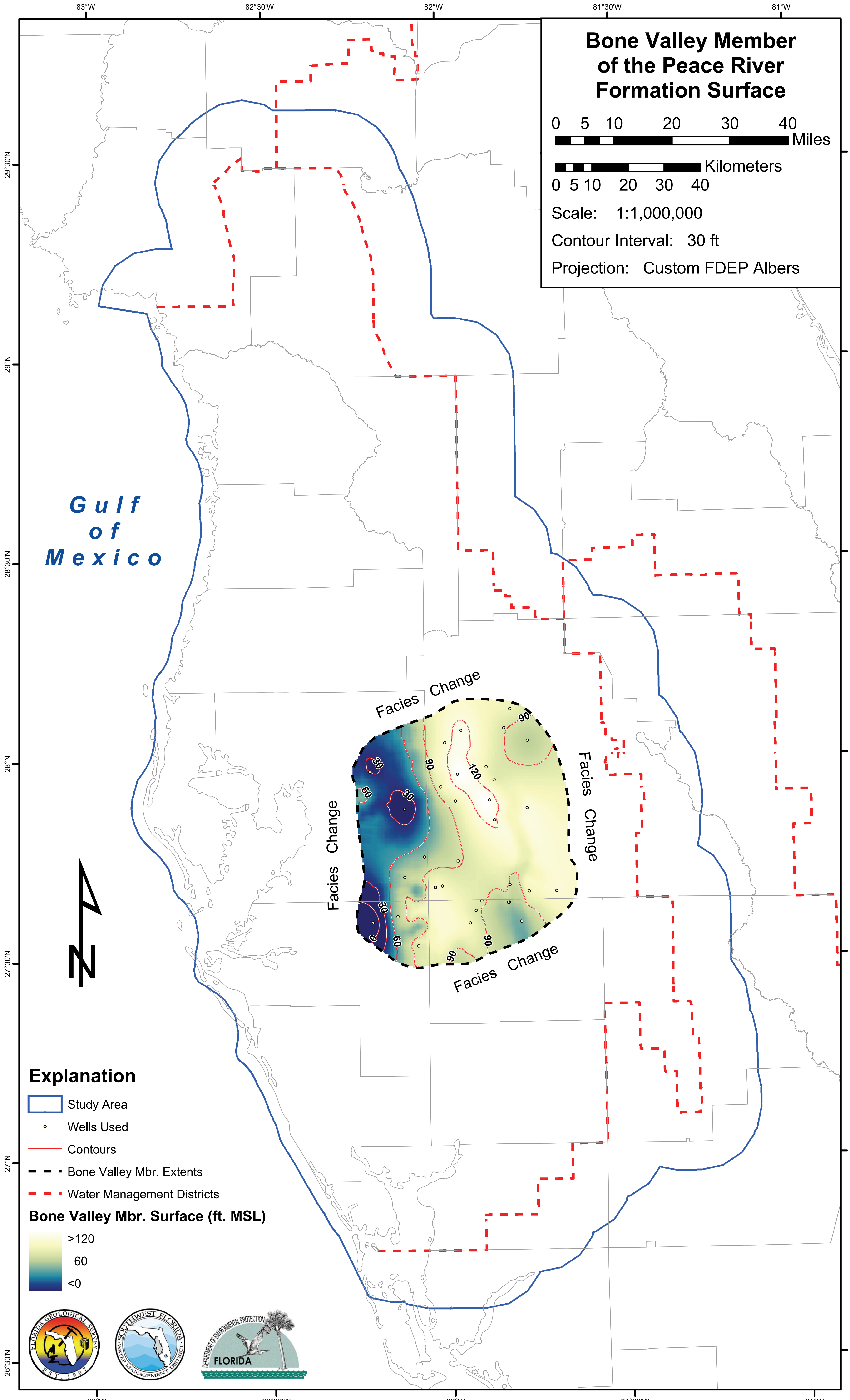
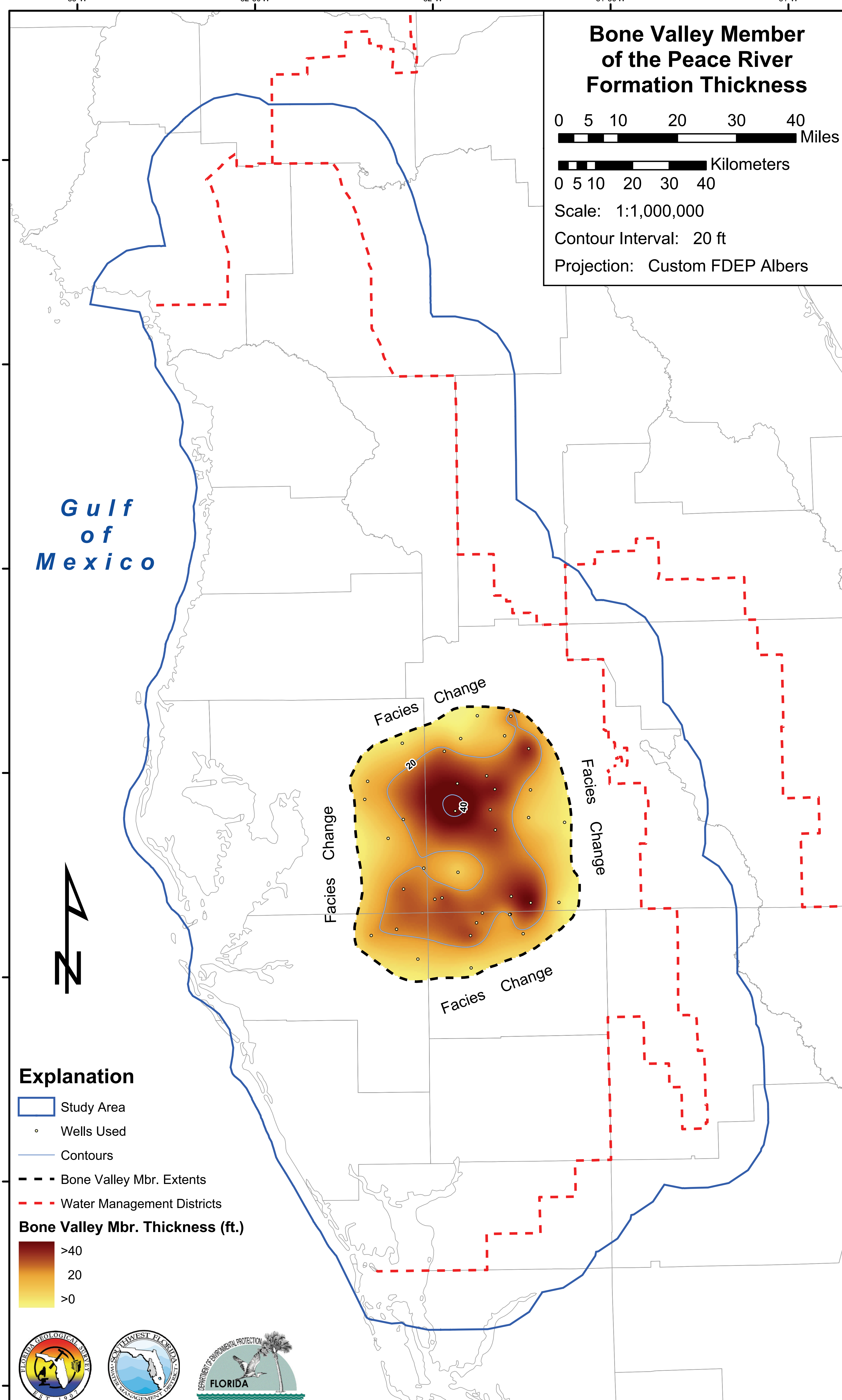

Bone Valley Member of the Peace River Formation Surface
0 5 10 20 30 40
Miles
Kilometers
0 5 10 20 30 40
Scale: 1:1,000,000
Contour Interval: 30 ft
Projection: Custom FDEP Albers
Gulf of Mexico
Facies Change
Facies Change
Facies Change
Facies Change
0
30
60
90
120
Explanation
Study Area
Wells Used
Contours
Bone Valley Mbr. Extents
Water Management Districts
Bone Valley Mbr. Surface (ft. MSL)
>120
60
<0
FLORIDA
83°W
82°30'W
82°W
81°30'W
81°W
29°30'N
29°N
28°30'N
28°N
27°30'N
27°N
26°30'N

PLATE 53



Bone Valley Member of the Peace River Formation Thickness
0 5 10 20 30 40 Miles
Kilometers 0 5 10 20 30 40
Scale: 1:1,000,000
Contour Interval: 20 ft
Projection: Custom FDEP Albers
Gulf of Mexico
Facies Change
Facies Change
Facies Change
Facies Change
20
40
N
83°W
82°30'W
82°W
81°30'W
81°W
29°30'N
29°N
28°30'N
28°N
27°30'N
27°N
26°30'N
Explanation
Study Area
Wells Used
Contours
Bone Valley Mbr. Extents
Water Management Districts
Bone Valley Mbr. Thickness (ft.)
>40
20
>0
FLORIDA

PLATE 54

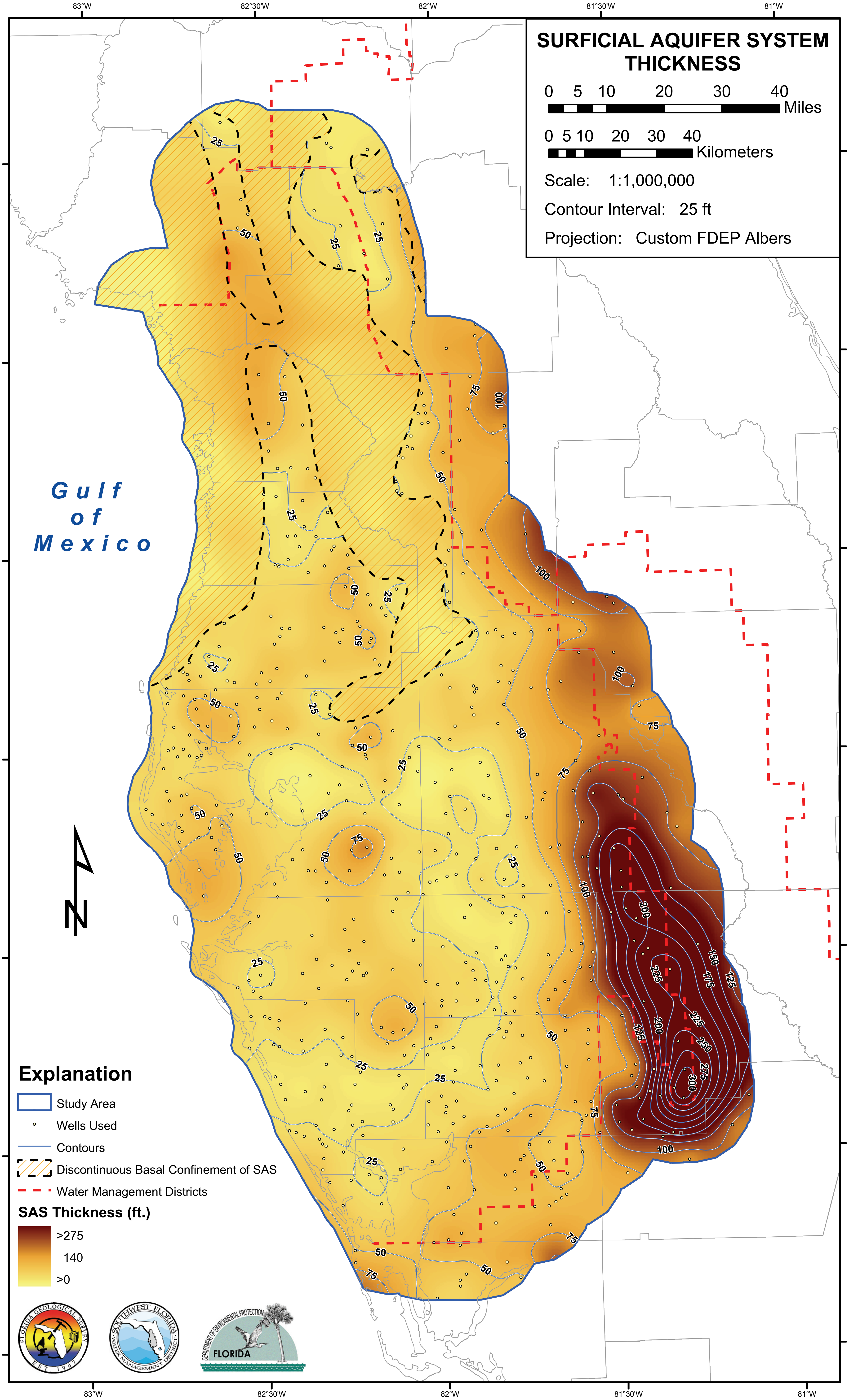

SURFICIAL AQUIFER SYSTEM THICKNESS
0 5 10 20 30 40 Miles
0 5 10 20 30 40 Kilometers
Scale: 1:1,000,000
Contour Interval: 25 ft
Projection: Custom FDEP Albers
Gulf of Mexico
Explanation
Study Area
Wells Used
Contours
Discontinuous Basal Confinement of SAS
Water Management Districts
SAS Thickness (ft.)
>275
140
>0
83°W
82°30'W
82°W
81°30'W
81°W
29°30'N
29°N
28°30'N
28°N
27°30'N
27°N
26°30'N
FLORIDA

PLATE 55

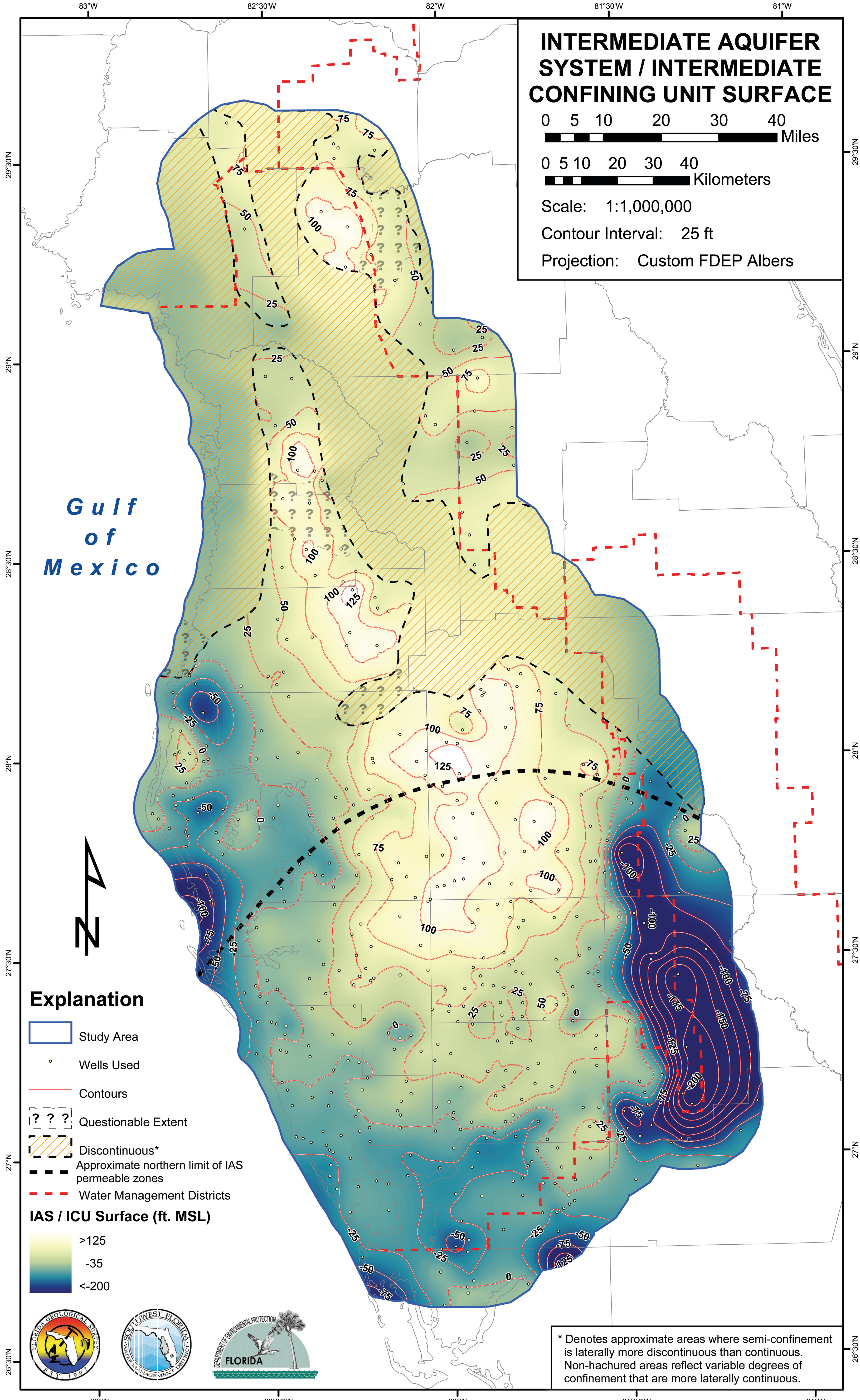

INTERMEDIATE AQUIFER SYSTEM / INTERMEDIATE CONFINING UNIT SURFACE
0 5 10 20 30 40 Miles
0 5 10 20 30 40 Kilometers
Scale: 1:1,000,000
Contour Interval: 25 ft
Projection: Custom FDEP Albers
83°W
82°30'W
82°W
81°30'W
81°W
29°30'N
29°N
28°30'N
28°N
27°30'N
27°N
26°30'N
Gulf of Mexico
N
Explanation
Study Area
Wells Used
Contours
Questionable Extent
Discontinuous*
Approximate northern limit of IAS permeable zones
Water Management Districts
IAS / ICU Surface (ft. MSL)
>125
-35
<-200
FLORIDA
* Denotes approximate areas where semi-confinement is laterally more discontinuous than continuous. Non-hachured areas reflect variable degrees of confinement that are more laterally continuous.

PLATE 56

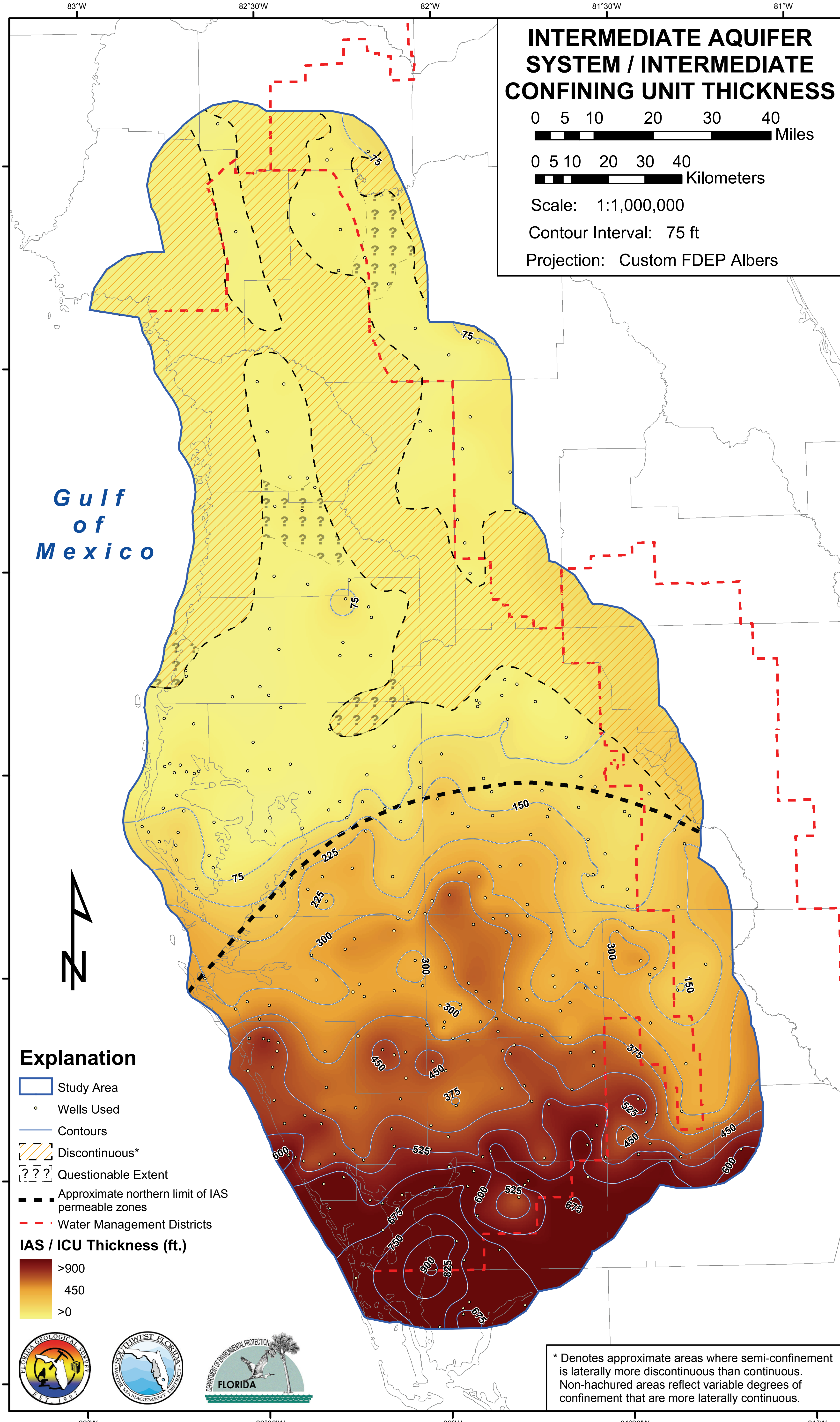
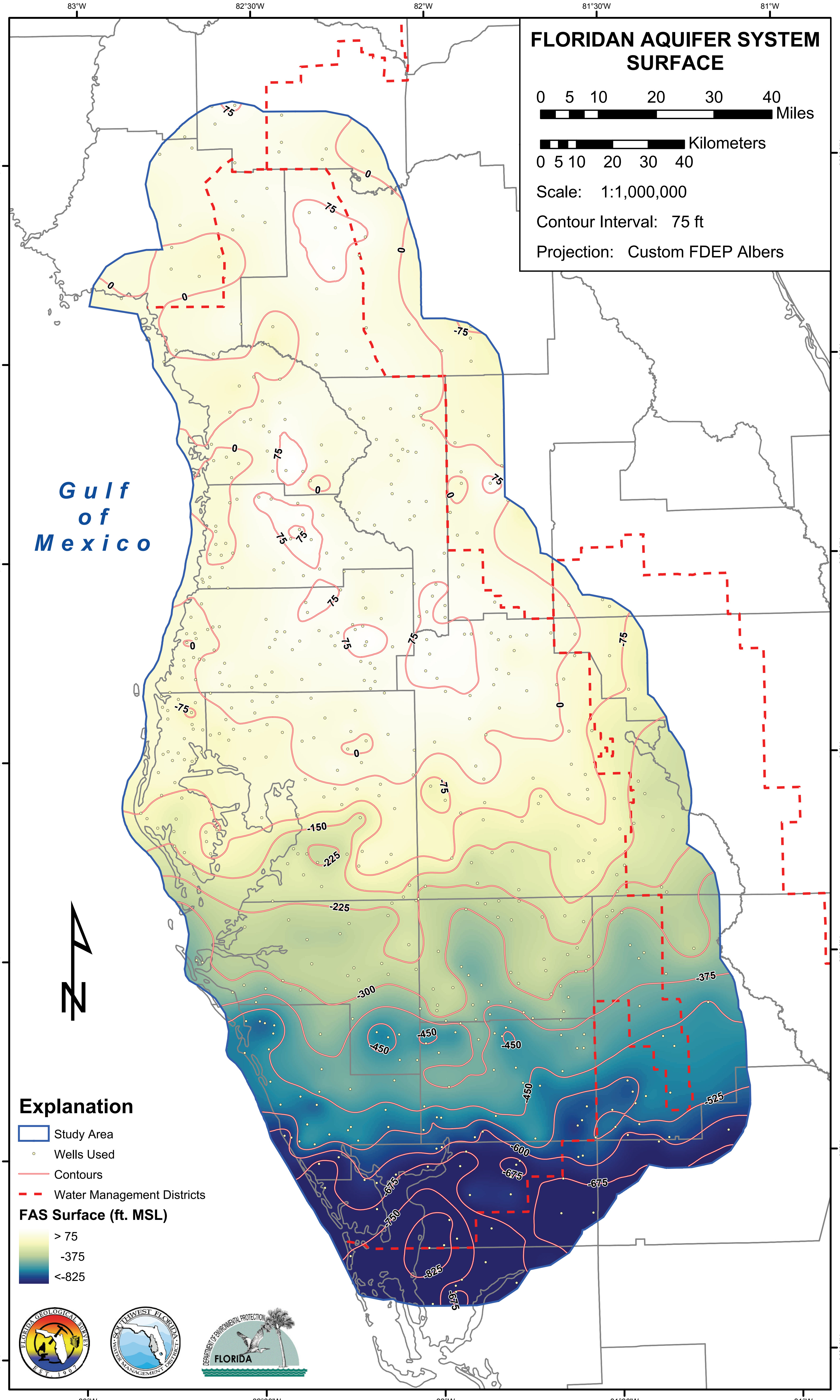

INTERMEDIATE AQUIFER SYSTEM / INTERMEDIATE CONFINING UNIT THICKNESS
0 5 10 20 30 40 Miles
0 5 10 20 30 40 Kilometers
Scale: 1:1,000,000
Contour Interval: 75 ft
Projection: Custom FDEP Albers
Gulf of Mexico
Explanation
Study Area
Wells Used
Contours
Discontinuous*
Questionable Extent
Approximate northern limit of IAS permeable zones
Water Management Districts
IAS / ICU Thickness (ft.)
>900
450
>0
* Denotes approximate areas where semi-confinement is laterally more discontinuous than continuous. Non-hachured areas reflect variable degrees of confinement that are more laterally continuous.
FLORIDA

PLATE 57



FLORIDAN AQUIFER SYSTEM SURFACE
0 5 10 20 30 40 Miles
0 5 10 20 30 40 Kilometers
Scale: 1:1,000,000
Contour Interval: 75 ft
Projection: Custom FDEP Albers
Gulf of Mexico
Explanation
Study Area
Wells Used
Contours
Water Management Districts
FAS Surface (ft. MSL)
> 75
-375
<-825
83°W
82°30'W
82°W
81°30'W
81°W
29°30'N
29°N
28°30'N
28°N
27°30'N
27°N
26°30'N

PLATE 58

MIDDLE FLORIDAN CONFINING UNIT SURFACE

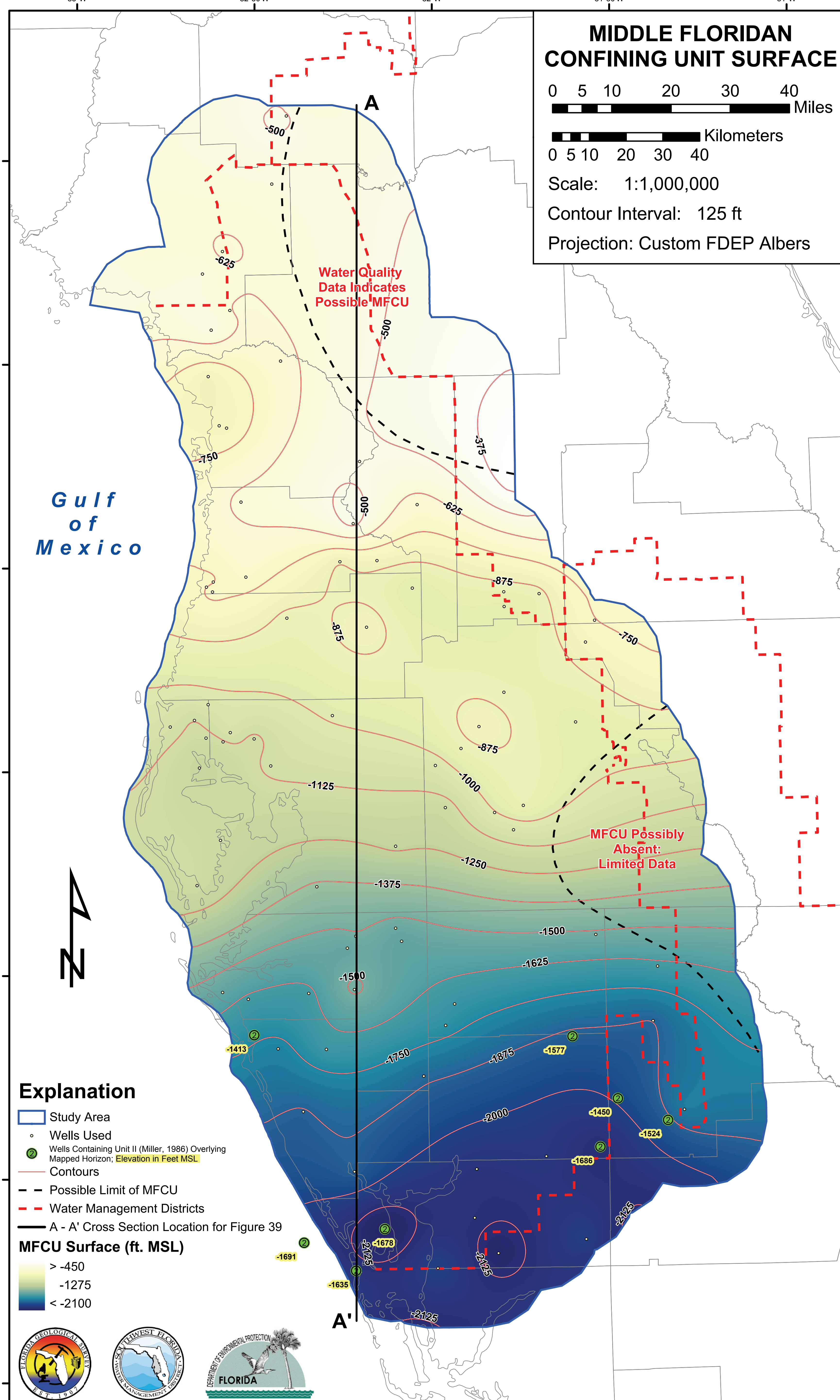


PLATE 59