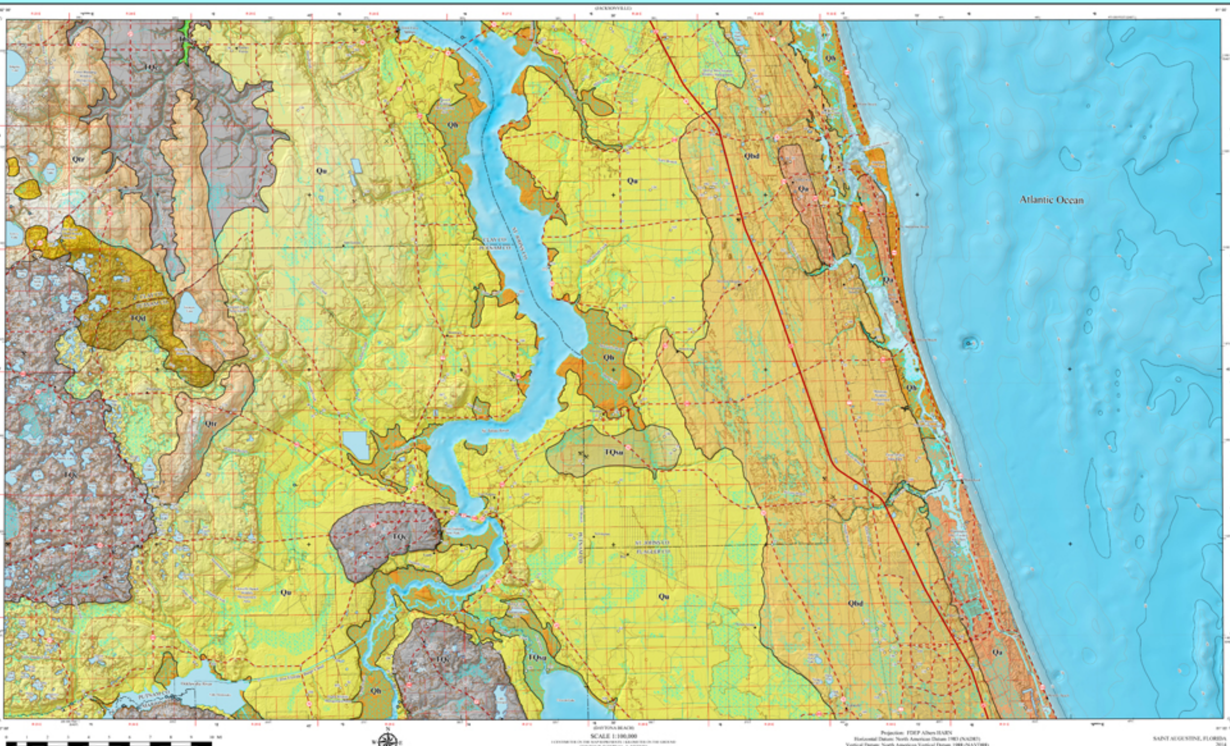
This geologic map was funded in part by the USGS National Cooperative Geologic Mapping Program

Herschel T. Vinyard Jr.
Secretary

OPEN-FILE MAP SERIES 106, Plate 1
GEOLOGIC MAP OF THE USGS SAINT AUGUSTINE 30 X 60 MINUTE QUADRANGLE, NORTHEAST FLORIDA
2014

BY
RICHARD C. GREEN, CHRISTOPHER P. WILLIAMS, KENNETH M. CAMPBELL, PHILIP W. BAMBACH, LEVI M. HANNON, SETH W. BASSETT, WILLIAM L. EVANS III, DAVID T. PAUL AND BRIANNE APOLINAR

Jonathan D. Arthur
State Geologist and Director



SCALE 1:100,000
CONTOUR INTERVAL 5 METERS
BATHYMETRIC INTERVAL 2 METERS
Elevations shown to the nearest meter

Projection: FDEP Albers HARN
Horizontal Datum: North American Datum 1983 (NAD83)
Vertical Datum: North American Vertical Datum 1988 (NAVD88)
Basemap: Digital data compiled by the
Florida Department of Environmental Protection / Florida Geological Survey (2014)

SAINT AUGUSTINE, FLORIDA
2014

Holocene Sediments

Qh Sediments mapped as Holocene (Qh) may include quartz sands, marls, organics, humate and minor carbonate sands and mud. They may also include fresh-water mollusks. Within the study area, they occur as modern barrier islands and floodplain deposits in the vicinity of Crescent Lake, the St. Johns and Ocklawaha Rivers and along the east coast.

Quaternary Beach Ridge and Dune

Qbd Quaternary beach ridge and dune sediments (Qbd) are a subdivision of the undifferentiated Quaternary sediments that are noted on the basis of surficial expression of relict beach ridges and dunes. While not a formally recognized lithostratigraphic unit, Qbd are mapped in order to facilitate a better understanding of Florida's geology. Beach ridge and dune sediments are dominantly siliciclastic sands and are unconsolidated to poorly consolidated. Organics typically occur as disseminated organic matrix, roots and plant debris, carbonized remains or charcoal.

Quaternary Sediments

Qu While not a formally recognized lithostratigraphic unit Undifferentiated Quaternary (Qu) sediments are mapped in order to facilitate a better understanding of Florida's geology. Generally, Qu consist of white to gray to orange to blue-green, fine to coarse grained, clean to clayey unfossiliferous sands, sandy clays and clays with variable admixtures of organics.

Anastasia Formation

Qa The Anastasia Formation (Qa) is present within the Atlantic Coastal Ridge in a narrow band along the eastern edge of the study area. The formation is composed of interbedded coquina and quartz sands. The unit typically occurs as an orangish-brown to very pale orange, unconsolidated to moderately indurated coquina of whole and broken mollusc shells in a quartz sand matrix. The coquinas are commonly cemented by sparry calcite. The sands occur as light gray to tan and orangish-brown, unconsolidated to moderately indurated, unfossiliferous to very fossiliferous beds.

Trail Ridge Sands

Qtr Sediments mapped as Quaternary Trail Ridge Sands (Qtr) include heavy-mineral bearing sediments associated with Trail Ridge, but are not limited to just the ridge itself. They also include sediments of the Baywood Promontory of Pirkle et al., (1970)*. While not a formally recognized lithostratigraphic unit, they are mapped following the convention of Scott et al., (2001)* in order to facilitate a better understanding of Florida's geology. These sediments consist of unconsolidated to slightly indurated white to tan, medium to fine quartz beach ridge sands. They contain an average of three percent heavy minerals in some areas, of which approximately 45 percent are titanium-rich minerals consisting of ilmenite, leucoxene, and rutile. Other common heavy minerals in the unit include staurolite, zircon, kyanite, sillimanite, corundum, topaz, and tourmaline.

Tertiary/Quaternary Dunes

TQd Tertiary/Quaternary dune sediments (TQd), while not a formally recognized lithostratigraphic unit, are mapped in order to facilitate a better understanding of Florida's geology. Where LiDAR is available these dunes are readily differentiated from other units by their distinct topographic expression. These dune sediments are fine to medium quartz sand with varying amounts of disseminated organic matter. They are generally found at elevations above 100 feet (30.5 meters) MSL, although there are areas along the flanks of the Trail Ridge where elevations of these dune sands can be lower. Sands forming these dunes are thought to be derived from reworking of sediments from the Cypresshead Formation (TQc) and undifferentiated Quaternary sediments (Qu).

Undifferentiated Pliocene/Pleistocene Shelly Sediments

TQsu Undifferentiated Pliocene/Pleistocene shelly sediments (TQsu) consist of fine-to-medium quartz sand with variable amounts of calcilutite, shell and clay. Shells, which are often weathered, may vary from whole to fragments and may become the dominant lithology. Other accessory minerals may include calcite, aragonite, clay, mica, heavy minerals and minor phosphate. Colors range from light gray to light olive gray. While not a formally recognized lithostratigraphic unit, TQsu are mapped in order to facilitate a better understanding of Florida's geology.

Cypresshead Formation

TQc The Pliocene/Pleistocene Cypresshead Formation (TQc) is a mottled reddish-brown to reddish-orange to white, unconsolidated to poorly consolidated, fine to very coarse grained, variably clayey to clean quartz sand. Cross-beds are common within this formation. Discoid quartzite pebbles, mica, and ghosts of nearshore marine molluscs are often present. Cypresshead Formation sediments are present throughout much of the study area and form the core of the various ridges present in the region (see OFMS106 Plate 3 for more discussion). East of the St. Johns River, these sediments typically become a more weathered, fine-grained, well-sorted sand and silt. In cores, the unit is often characterized by beds of fine-grained, well sorted sand with thin layers of clay dispersed through the sand.

Coosawhatchie Formation (Hawthorn Group)

Thc The Miocene Coosawhatchie Formation (Thc) consists of quartz sands, dolostones and clays. The unit ranges in color from greenish-gray and light gray to olive gray. The most common lithology in the upper section of the unit is characteristically a sandy to very sandy dolostone which may be interbedded with quartz sands and clays. Quartz sands and clays dominate and dolostones become subordinate in the lower portion of the section. The quartz sands are generally phosphatic, clayey and dolomitic. Sand grains are fine to medium grained and poorly to moderately sorted. In many instances, the sands grade into dolostones and clays. Clay content is variable and may range from five to more than 30 percent. Phosphate content is highly variable, ranging from a trace to more than 20 percent. Coarse phosphate sands and pebbles are present but not common.

LEGEND

- Primary highway
- Secondary highway
- Light duty road, principal street
- Railroad
- County boundary
- National or state reservation boundary
- Contours: Index, Intermediate
- Bathymetry: Index, Intermediate
- River or stream
- Core
- Cuttings
- Archived M-Series sample
- Outcrop / exposure
- Quarry
- Borrow pit
- Spring
- City/town
- Lake or pond
- Wetland
- U.S. Public Lands Survey Township/Range
- U.S. Public Lands Survey Section
- 7.5 Minute quadrangle tick marks

* Wells numbered 1 - 38 are used in cross-sections on OFMS 106, Plate 2
* Refer to Open-File Report 102, Appendix A for well information

*Note: See OFR 102 for references

Basemap Coordinate Explanation
10,000-meter grid, zone 17 North Universal Transverse Mercator
25,000-foot grid ticks based on Florida coordinate system, east and north zones

1:24,000 QUADRANGLE GRID

ADJOINING MAPS

1 Lake City
2 Jacksonville
3
4 Gainesville
5 Saint Augustine
6
7 Ocala
8 Daytona Beach
9 New Smyrna Beach

For more information or to order maps contact:

Librarian, Florida Geological Survey
903 W Tennessee Street
Tallahassee, FL 32304-7700
(850)617-0320
http://www.dep.state.fl.us/geology/programs/statemap.htm

This map was created using Florida Department of Environmental Protection (FDEP) databases and data obtained by the Florida Geological Survey (FGS). It was completed August 31, 2014, by the FDEP/FGS, Geological Investigations Section. This document was prepared for the presentation of the geologic information shown and is not intended to replace site-specific or use-specific investigations. The FGS does not guarantee this document to be free from errors or inaccuracies and disclaims any responsibility or liability for inappropriate change of scale, interpretations, or decisions based thereon. Cooperatively funded by the FGS and the U.S. Geological Survey (USGS), National Cooperative Geologic Mapping Program, under USGS assistance award number G13AC00148. The views and conclusions in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S.

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Florida Department of Environmental Protection
Florida Geological Survey

Herschel T. Vinyard Jr.
Secretary

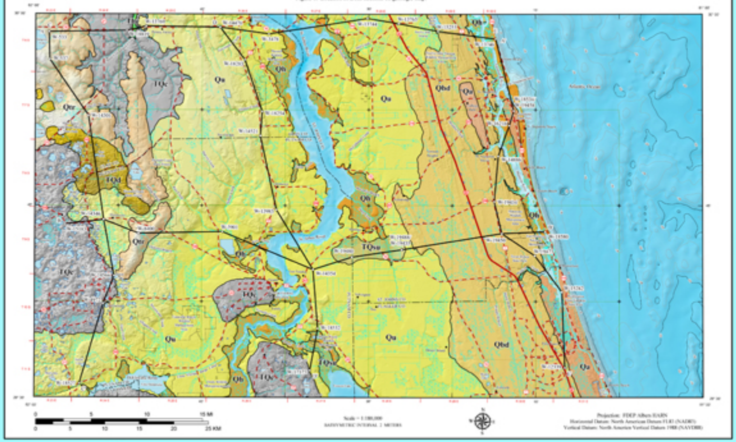
OPEN-FILE MAP SERIES 106, Plate 2
GEOLOGIC CROSS-SECTIONS FOR THE USGS SAINT AUGUSTINE 30 X 60 MINUTE QUADRANGLE, NORTHEAST FLORIDA

2014

BY
RICHARD C. GREEN, CHRISTOPHER P. WILLIAMS, KENNETH M. CAMPBELL, PHILIP W. BAMBACH, LEVI M. HANNON, SETH W. BASSETT, WILLIAM L. EVANS III, DAVID T. PAUL AND BRIANNE APOLINAR

Jonathan D. Arthur
State Geologist and Director

Figure 1. Location of cross-sections on geologic map.



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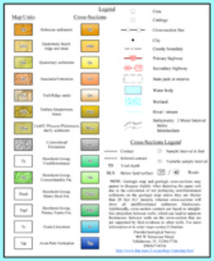
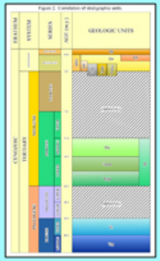


Figure 2. Correlation of stratigraphic units.



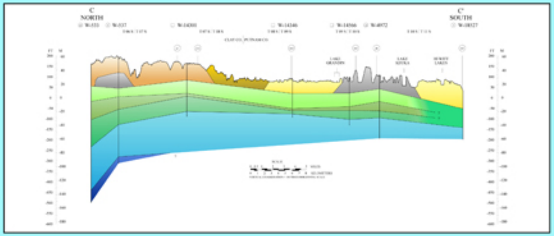
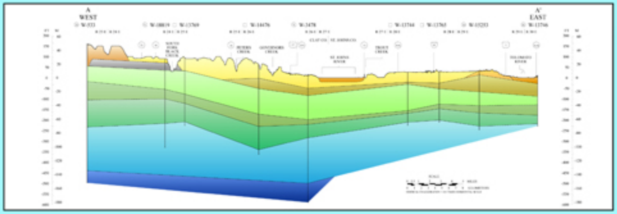
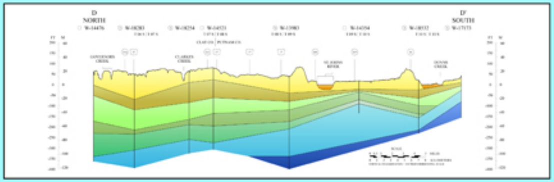
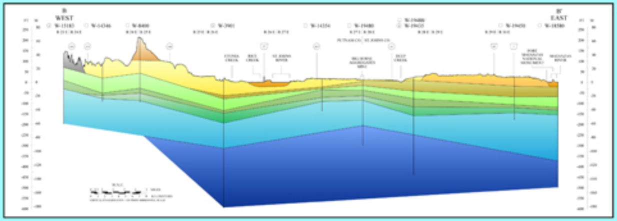
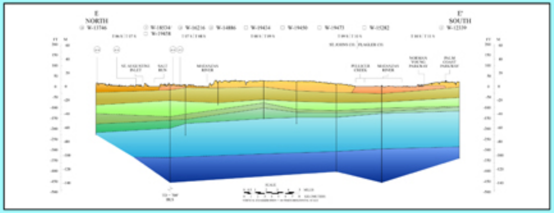


Figure 3. Core Sample Photos









Herschel T. Vinyard Jr.
Secretary

OPEN-FILE MAP SERIES 106, Plate 3

GEOMORPHOLOGY, SPRINGS, AND KARST FEATURES OF THE USGS SAINT AUGUSTINE 30 X 60 MINUTE QUADRANGLE, NORTHEAST FLORIDA

2014

BY

RICHARD C. GREEN, CHRISTOPHER P. WILLIAMS, KENNETH M. CAMPBELL, PHILIP W. BAMBACH, LEVI M. HANNON, SETH W. BASSETT, WILLIAM L. EVANS III, DAVID T. PAUL AND BRIANNE APOLINAR

Jonathan D. Arthur
State Geologist and Director

Barrier Island Sequence District

[illegible]

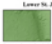
Atlantic Coastal Complex

[illegible]

Duval Upland

[illegible]

Lower St. Johns River Valley



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Central Lakes District

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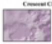
Crescent City Ridge



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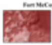
Fort McCoy Plain



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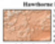
Hawthorne Lakes Region



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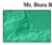
Mt. Dora Ridge



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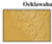
Ocklawaha River Valley



[illegible]

Palatka Hill

[illegible]

St. Johns River Offset

[illegible]

Trail Ridge

[illegible]

Figure 1. Geomorphic terranes (modified from Scott et al., in preparation), springs, and karst features shown with LiDAR and digital elevation model (DEM) mosaic.

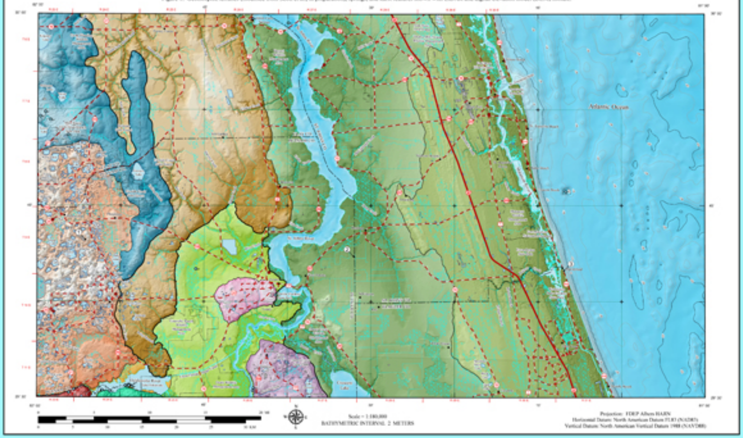


Figure 2. Springs and karst features shown with LiDAR and digital elevation model (DEM) mosaic.

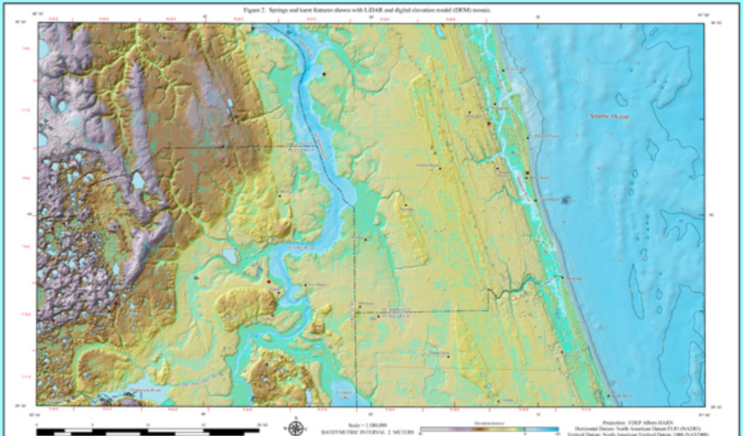
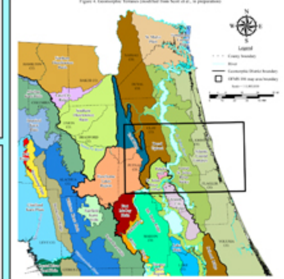


Figure 3. Geomorphic Districts (modified from Scott et al., in preparation).

Figure 4. Geomorphic Terranes (modified from Scott et al., in preparation).



Legend for Figures 1 & 2

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SELECTED PHOTOGRAPHS

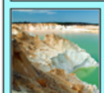

Photo 1: Cypresshead Formation at Grandin Sand Mine in Putnam County.
Location: T 9 S, R 24 E, S 17
Photo by FGS Staff
Date taken: 12/2006

Photo 2: Coring at Big Horse Aggregates.
Location: T 9 S, R 27 E, S 25,
SE 1/4 of SE 1/4
Photo by Rick Green
Date taken: 3/14/2014

Photo 3: Scott Barrett Dyer and Phil Bambach examine exposed Anastasia Fm. at Marineland.
Location: T 10 S, R 31 E, S 5
Photo by Rick Green
Date taken: 3/15/2014

STATE OF FLORIDA

DEPARTMENT OF ENVIRONMENTAL PROTECTION
Herschel T. Vinyard Jr., *Secretary*

REGULATORY PROGRAMS
Cliff Wilson, *Deputy Secretary*

FLORIDA GEOLOGICAL SURVEY
Jonathan D. Arthur, *State Geologist and Director*

OPEN-FILE REPORT 102

Text to accompany geologic map of the USGS Saint Augustine 30 x 60 minute quadrangle, Northeast Florida (Open-File Map Series 106)

By

Richard C. Green, Christopher P. Williams, Kenneth M. Campbell, Philip W. Bambach, Levi M. Hannon, Seth W. Bassett, William L. Evans III, Brianne Apolinar and David T. Paul

2014
ISSN 1058-1391

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Text to accompany geologic map of the USGS Saint Augustine 30 x 60 minute quadrangle, Northeast Florida (Open File Map Series 106)

Richard C. Green (P.G. No. 1776), Christopher P. Williams, Kenneth M. Campbell, Philip W. Bambach, Levi M. Hannon, Seth W. Bassett, William L. Evans III, David T. Paul and Brianne Apolinar

ABSTRACT

The accompanying 1:100,000 scale geologic map (Open-File Map Series 106, Plate 1) depicts the areal distribution of bedrock and surficial geologic units for the U.S. Geological Survey (USGS) Saint Augustine 30 x 60 minute quadrangle. The map was constructed using a combination of field mapping (at 1:24,000 scale), compilation of data from existing maps (various scales), core and cuttings analyses and descriptions, geophysical log analyses and analyses of various Geographic Information System (GIS) data sources. The resulting data were compiled in ESRI® ArcGIS® ArcMap™ 10.2 software for publication as part of the Florida Geological Survey Open-File Map Series. Mapped units range from Middle Miocene to Quaternary. Important resources in the mapped area include potable groundwater, springs, sand, clay and coquina. Numerous springs, sinkholes and other karst features are present in the study area. The geologic maps produced for this area not only provide a greater understanding of the interaction between the geologic units, associated karst, springs and ecosystems, but have utility as a land management tool for economic development, mineral and energy production, and environmental protection for Florida. Examples include designing new construction projects, siting new water supply wells, energy production facilities, waste management and storage facilities, locating sources of mineable resources for aggregate supply, and protection of springs, surface and groundwater quality.

Keywords: Florida, geologic map, Avon Park Formation, Ocala Limestone, Hawthorn Group, Penney Farms Formation, Marks Head Formation, Coosawhatchie Formation, Cypresshead Formation, Anastasia Formation, geomorphology, hydrogeology, springs, karst, sinkholes, Floridan aquifer system, Clay County, Flagler County, Marion County, Putnam County, St. Johns County, Saint Augustine.

INTRODUCTION

Florida Geological Survey (FGS) Open-File Report (OFR) 102 accompanies Open-File Map Series (OFMS) 106, which is comprised of three plates. Plate 1 depicts the near-surface geology of the USGS Saint Augustine 30 x 60 minute quadrangle on a digital elevation model (DEM). Plate 2 depicts five geologic cross-sections, a stratigraphic correlation chart, and representative photos for several of the lithologic units in the study area. Plate 3 is a geomorphology map along with a DEM, showing locations of known springs and sinkholes, along with photographs of selected exposures within the study area.

The study area is located along the Atlantic coastline of Florida (Figure 1). It includes the communities of Saint Augustine, Palatka, Green Cove Springs, Crescent Beach and Beverley Beach. The quadrangle, which includes portions of Clay, Flagler, Marion, Putnam and St. Johns

Counties, is bounded to the west by the USGS Gainesville 30 x 60 minute quadrangle, previously mapped under the STATEMAP program (Green et al., 2005), to the south by the USGS Daytona Beach 30 x 60 minute quadrangle, previously mapped under the STATEMAP program (Green et al., 2013a, 2013b) and to the north by the USGS Jacksonville 30 x 60 minute quadrangle (Figure 1). The St. Johns, Matanzas and Ocklawaha Rivers, along with numerous creeks and springs, occur in the map area. Recharge to and discharge from the Floridan aquifer system (FAS) occurs throughout the study area. The FAS is the primary source of water for springs and drinking water in the region.

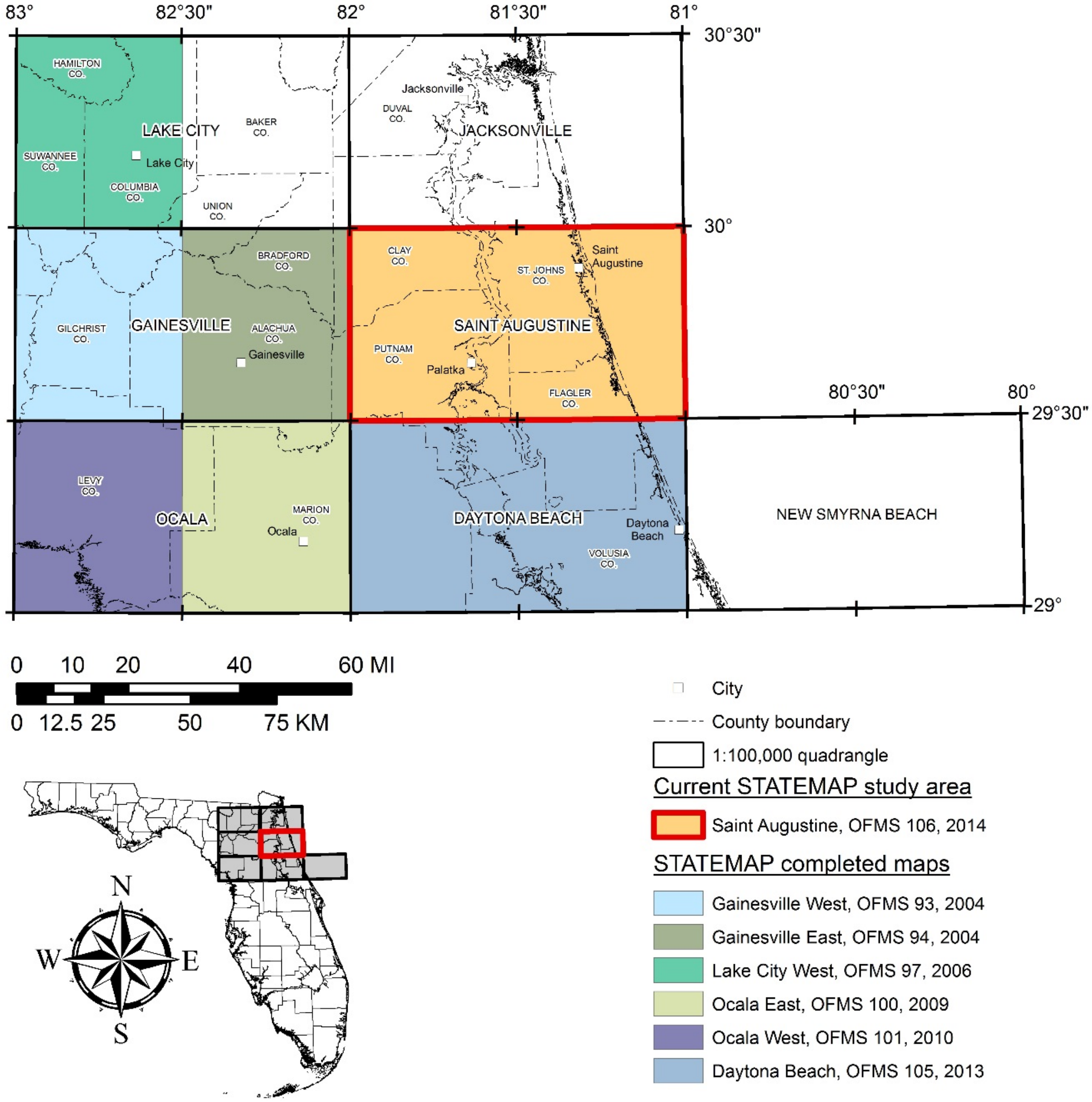

Figure 1. Nearby areas mapped under the FGS STATEMAP Program.

One objective for this report is to provide basic geologic information for the accompanying OFMS 106. Information provided by this report and the plates in OFMS 106 is intended for a diverse audience of professionals in geology, hydrology, engineering, environmental and urban planning, and laypersons, all of whom have varying levels of geologic knowledge. The maps can help users identify and interpret geologic features which impact activities related to groundwater quality and quantity, as well as aid in locating mineral resources, land-use planning and construction project design. Applied uses of the maps and data in this report include: 1) identifying potential new mineral resources, 2) characterizing zones of potential aquifer recharge and confinement, 3) aiding water-management decisions on groundwater flow and usage, 4) providing information on aquifer vulnerability to potential pollution, 5) ecosystem, wetlands and environmental characterization, and 6) recreation.

Methods

Mapping efforts consisted of: 1) compiling and reviewing existing geologic literature and data, 2) mapping geologic units in the field at 1:24,000 scale using standard techniques, 3) analyses of existing core and cuttings samples from the FGS sample repository, 4) new core drilling and analyses, 5) collecting and describing outcrop samples, and 6) preparing a geologic map, geological cross-sections and geomorphic map of the area. Fieldwork, performed during the fall of 2013 through the summer of 2014, consisted of sampling and describing numerous outcrops, river and borrow pit exposures and drilling of new cores.

Twenty new samples of geologic material were added to the FGS surface-sample archives (M-Series) and six cores (1079 feet or 238.9 meters total) were drilled for the project. Approximately 60 outcrops and exposures were also examined during the project. In addition to new cores collected for this study, approximately 250 sets of cores and cuttings archived in the Florida Geological Survey sample repository were examined and formation picks were made for mapped geologic units. In addition to the data from the cores and cuttings, several hundred formation picks derived from geophysical logs (see discussion beginning on page 22 for geophysical log interpretation) were utilized in developing various modeled surfaces. Figure 2 shows the locations of FGS cores, cuttings and St. Johns River Water Management District (SJRWMD) data points within the study area. Appendix A includes FGS wells with core and/or cuttings samples which were examined by the authors and/or used for the top of rock model or for determining the geologic surface and subsurface formations. An interpolated top of rock surface was developed using kriging along with a Digital Elevation Model (DEM) to generate an overburden thickness model. The map and accompanying plates were developed in ESRI® ArcGIS® ArcMap™ 10.2 software for publication as part of OFMS 106.

Due to a lack of complete LiDAR coverage in the study area, a custom elevation model was created for this product. Two products were used to create this elevation model: a standard LiDAR elevation model with horizontal resolutions of five feet (1.5 meters), and a much coarser elevation model based off of topographic contours with a horizontal resolution of 100 feet (30.5 meters). LiDAR coverage existed for the entirety of St. Johns County, along with the Atlantic coastal shoreline and the St. Johns River valley. Portions of the remaining counties in the study area also had LiDAR available. The majority of both Clay and Putnam Counties lacked LiDAR coverage.

The hybrid elevation model was created by first combining all of the existing LiDAR and DEMs into a single raster. The 100 foot (30.5 meter) resolution (contour-based) DEM was re-sampled and aligned to match the resolution of the five foot (1.5 meter) LiDAR elevation models. A conditional statement was then used in ESRI® ArcGIS® ArcMap™ 10.2 (ArcGIS) to create a new hybrid raster by selecting an elevation value from the LiDAR coverage if available; where LiDAR was not available, elevation values were drawn from the coarser, contour-based DEM. The elevation model that was generated by this process created “seams” along the join between the two different elevation models where parallel cells have large differences in their values. Attempts were made to fix the discrepancies by using smoothing techniques to average the cell values along the artifact boundary. Even with various smoothing algorithms applied to the merged dataset, it was not possible to achieve a perfectly smooth transition between the different types of elevation models. Examination of the resultant DEM will reveal one example of this along the border of northern Flagler County and southern St. Johns County (OFMS 106; Plate 3, Figure 2).

As a preliminary step for modeling, points from each of the datasets (cores, cuttings and geophysical logs) were used to generate a Triangular Irregular Network (TIN) of the surface. This TIN was then used as a method of examining and discarding any points that appeared anomalous compared to their surrounding values. During this step, any point which differed substantially from the surrounding points were indicated by a sharp depression or peak in the TIN surface; points found that differed by 75 or more feet from surrounding points were then removed from the dataset.

After this step was completed, an ordinary kriging method was used to generate a top of rock surface using the "stable" algorithm. Lag size was empirically calculated based on the total spatial extent of the combined datasets, and then adjusted slightly to improve model performance. The error values for all data were examined after each iteration of the model, and any points with a standardized error greater than five, or less than negative five, were discarded in order to improve the final model performance.

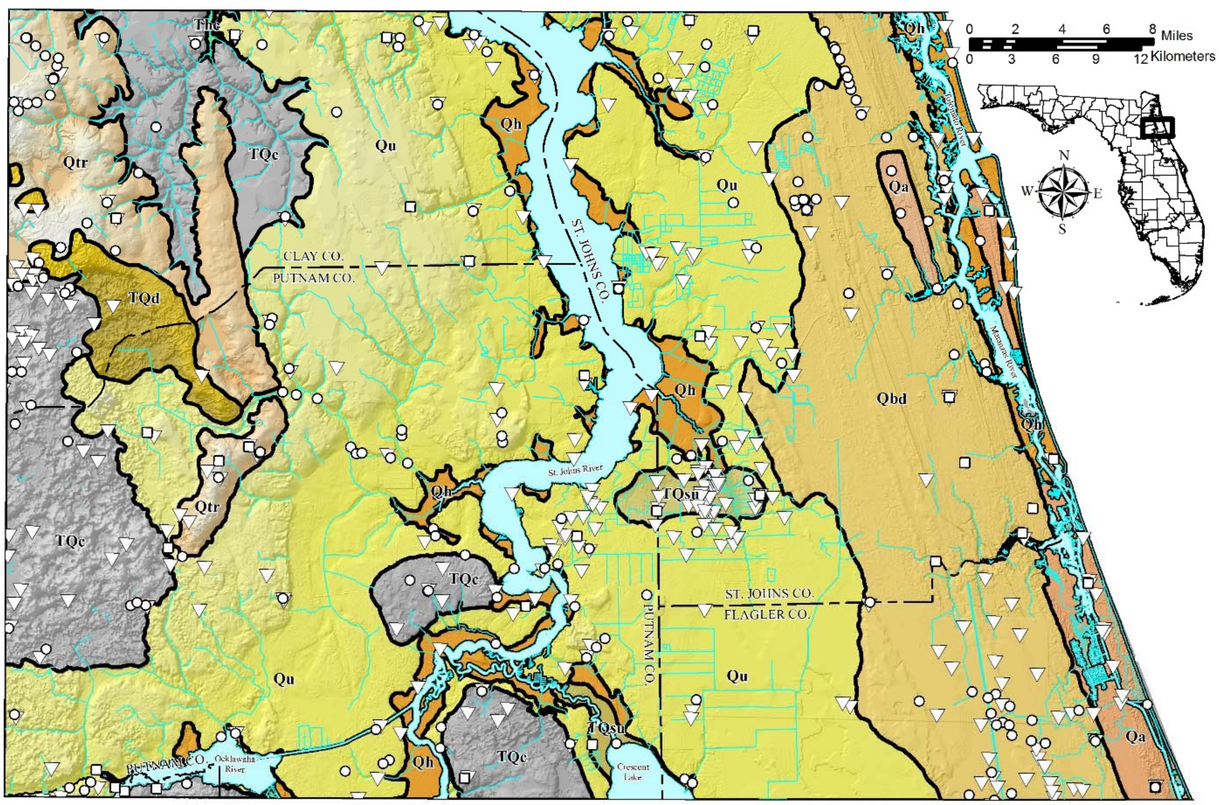

Figure 2. FGS cores (squares), cuttings (circles) and St. Johns River Water Management District geophysical logs (triangles) utilized for top of rock models. See discussion starting on page 14 for lithostratigraphic unit abbreviations and descriptions.

Much of the study area is blanketed by a veneer of undifferentiated Tertiary and Quaternary sediments and soils. For this reason, and in keeping with geologic mapping practices developed by Scott et al. (2001), the authors have adopted the policy of mapping the first named geologic unit within 20 feet (6.1 meters) of the surface. If Tertiary/Quaternary dune (TQd), undifferentiated Quaternary (Qu), Holocene (Qh) or Quaternary beach ridge and dune (Qbd) sediments attain a thickness greater than 20 feet (6.1 meters), then they appear as the mapped unit. If these undifferentiated sediments are less than 20 feet (6.1 meters) thick, then the underlying lithostratigraphic unit appears on the map. It is noted that the geologic map (OFMS 106, Plate 1) and geologic cross sections (OFMS 106, Plate 2) may appear to disagree slightly when depicting the upper unit due to this convention. This is due to the fact that geologic cross-section contacts are based on straight-line projection between wells and thus may lead to apparent thicknesses of units between wells that are not supported by field evidence or other wells nearby.

Parts of the region are heavily vegetated, and public access in several large sections of the mapped area was hindered by the presence of numerous wetlands, farms, ranches and privately owned land. Additionally, much of the coastal area is heavily developed with sub-divisions, many of which are gated communities. In instances where access was limited by these factors, the authors had to rely on existing well and core data. Fieldwork access was typically limited to public roads, Federal, State and County-owned lands.

Previous Work

The current study builds on many previous geologic investigations in and around the present map area which were useful in preparing this report. Preliminary county geologic maps for Clay, (Scott, 1992a) Flagler (Scott, 1992b), Marion (Scott, 1992c), Putnam (Scott, 1992d), and St. Johns (Scott, 1992e) Counties at 1:126,720 scale were previously published by the FGS. However, each of these geologic maps were constructed in an average time-frame of two weeks utilizing selected in-house geologic data with approximately one week of field work per county. Although these maps provided a starting point for the detailed geologic mapping undertaken for this project, significant refinement of prior geologic maps was possible as a result of this project. A statewide geologic map (Scott et al., 2001) also provided a framework for the current, more detailed mapping.

Scott (1988) published detailed descriptions, structure contour maps, and isopach maps for units of the Hawthorn Group. Huddlestun (1988) defined and discussed the Cypresshead Formation. This study also benefited greatly from the work performed during geologic mapping of the eastern portion of the USGS Gainesville 30 x 60 minute quadrangle (Green et al., 2005) and mapping of the USGS Daytona Beach 30 x 60 minute quadrangle (Green et al., 2013a; Green et al., 2013b). Williams et al., (2014, in review) mapped detailed geomorphology and geology for five quadrangles along the eastern edge of the study area as part of work on four National Park Service units in northeastern Florida. Some of the field relationships and stratigraphic problems were worked out during these projects and data gathered during work on them proved invaluable to the completion of this project.

GEOLOGIC SUMMARY

The near surface geology of the USGS 30 x 60 minute Saint Augustine quadrangle is composed of a complex mixture of Middle Eocene to Quaternary carbonate and siliciclastic sediments. A combination of factors, including fluvio-deltaic deposition, marine deposition, dissolution of underlying carbonates (karstification), erosion of sediments as a result of eustatic changes in sea level and structural features have influenced the geology of the study area.

The oldest unit to crop out in the Saint Augustine quadrangle is the Tertiary/Quaternary Cypresshead Formation (TQc). Core and cuttings data indicate that the Tertiary Coosawhatchie Formation of the Hawthorn Group (Thc) is within 20 feet (6.1 meters) of the surface in the vicinity of South Fork Black Creek east of Trail Ridge (see OFMS 106, Plate 1). Although field exposures were not seen, our mapping convention and models led us to depict the unit on the geologic map.

Detailed description of the lithology of all units found in the study area begins on page 14 of this publication. Along with lithologic descriptions, several diagnostic foraminifera and echinoids aid in distinguishing Ocala Limestone from the underlying Avon Park Formation. The Avon Park Formation contains *Cushmania* [*Dictyoconus*] *americana* and *Discorinopsis gunteri* which are not found in the Ocala Limestone. The occurrence of *Nummulites* spp. and *Lepidocyclina* spp. in the Ocala Limestone helps to distinguish it from the Avon Park Formation in the mapped area.

Much of the Saint Augustine quadrangle is located within the Ocklawaha, Upper East Coast, and Lower St. Johns River Basins (Figure 3). There are numerous springs and spring-fed rivers within the study area, including five springs in Clay County, seven springs in Marion County, six springs in Putnam County and two in St. Johns County.

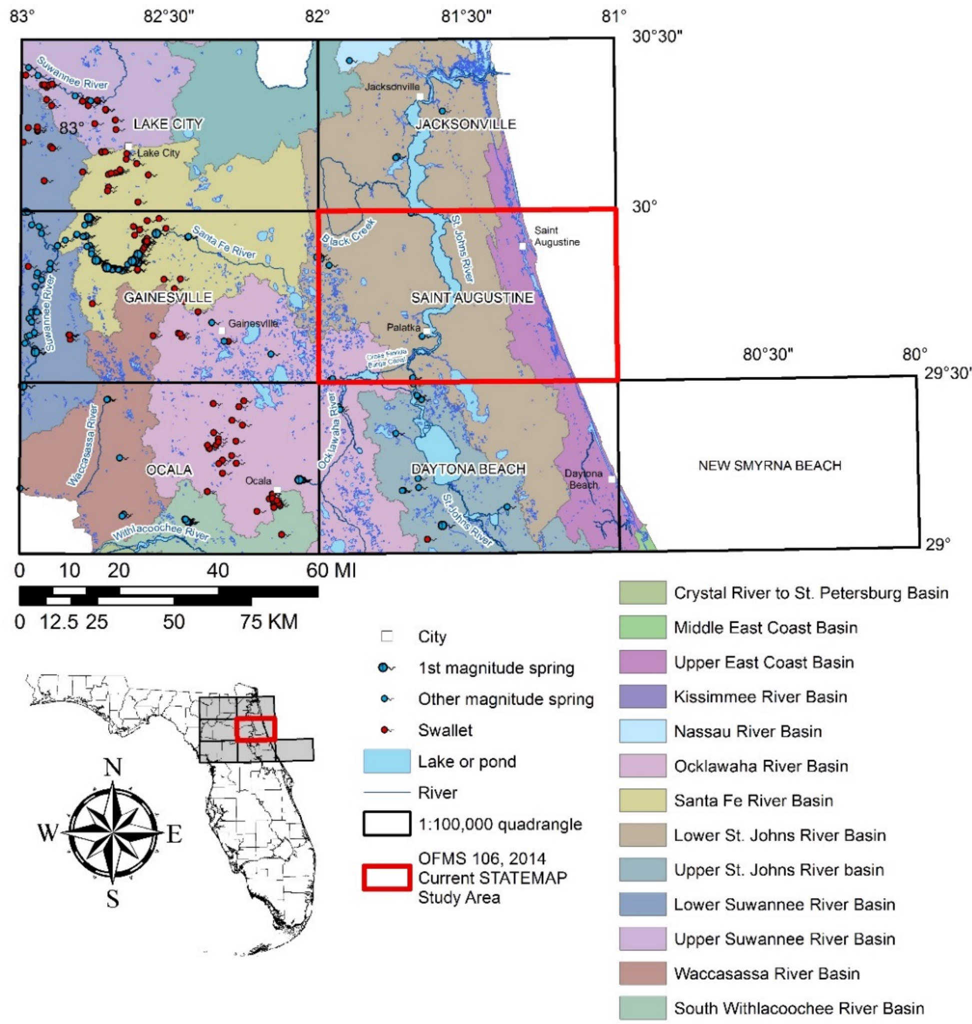

Figure 3. Location of selected river basins, springs and other water bodies.

Portions of the recharge areas for many of the aforementioned springs are located within the study area. Many of these springs have shown significant increases in pollutants in the last few decades, particularly nitrate (Phelps, 1994, 2004; Jones et al., 1996; Scott et al., 2002; Upchurch et al., 2004; Copeland et al., 2009). Detailed geologic mapping of lithostratigraphic units in this area provides critical data needed for future assessments of the vulnerability of the aquifer systems and springs to contamination. Understanding the surficial geology of the map area is a key factor in developing management and protection plans, not only for the springs, but for the Floridan aquifer system.

Karst processes have extensively modified the topography of the region, and continue to actively shape it today. Karst topography is characterized by solutional features, subterranean drainage, and caves (Poucher and Copeland, 2006). Downward infiltration of slightly acidic rain and surface water through preferential pathways, such as joints, fractures, and bedding planes, combined with groundwater fluctuations, cause dissolution of the carbonate rocks (Waltham et al., 2005).

The variability of the karst observed within the study area is closely related to the thickness of overburden and the presence/absence of Cypresshead Formation and Hawthorn Group clays within the overburden mantling the region's carbonate rocks. These clays are often the sediments which create a bridge over any cavities which have formed within the carbonates. The study area can be divided into two main karst regions: the Central Lakes District and the Barrier Island Sequence District (see OFMS 106, Plate 3). Generally, the overburden sediments are thickest and contain a higher percentage of clay and clayey sediments, resulting more frequently in the occurrence of cover-collapse sinkholes, to the west and south of Trail Ridge. To the east of Trail Ridge, extending towards the St. Johns River valley, the overburden sediments are generally thinner (see OFMS 106, Plates 2 and 3) resulting in both cover-subsidence and cover-collapse sinkholes (Sinclair and Stewart, 1985).

Structure

Several structural features have affected the geology of the region (Figure 4). The Peninsular Arch, a structurally high area which affected deposition from the Cretaceous to the early Cenozoic, is the dominant subsurface feature of the Florida peninsula (Applin and Applin, 1944; Applin, 1951; Puri and Vernon, 1964; Williams et al., 1977; Schmidt, 1984; Miller, 1986; Scott, 1997). The axis of the Peninsular Arch, which lies just west of the study area, extends from southeastern Georgia to the vicinity of Lake Okeechobee in southern Florida in a general northwest to southeast trend. The crest of the arch passes beneath Alachua County and is highest in Union and Baker Counties northwest of the study area. The arch was a topographic high during most of the Cretaceous Period and had Upper Cretaceous sediments deposited upon it (Applin, 1951). It formed a relatively stable base for Eocene carbonate deposition (Williams et al., 1977). The arch did not affect mid-Tertiary to Holocene sediment deposition (Williams et al., 1977; Scott, 1997).

The Sanford High, named by Vernon (1951a), is a positive feature located in Volusia and Seminole Counties just south of the study area. It is a prominent structure affecting the near surface depositional and post-depositional environments within the map area (Figure 4). Vernon (1951a) described this feature as "a closed fold that has been faulted, the Sanford high being located on the upthrown side". The Ocala Limestone and Hawthorn Group are missing over this feature and post-Hawthorn Group sediments (undifferentiated Pliocene/Pleistocene shelly sediments) directly overlie the Avon Park Formation in the vicinity of the Sanford High (Green et al, 2013a).

The St. Johns Platform, introduced by Riggs (1979a, 1979b), extends northward from the Sanford High into St. Johns County. This platform, which is expressed on the erosional surface of the Ocala Limestone, dips gently north-northwest towards Jacksonville (Scott, 1983). This is evident throughout the map area (OFMS 106; Plate 2). Undifferentiated sediments, thickest on Trail Ridge and its flanks, have been deposited on the Miocene Hawthorn Group (Th), Tertiary/Quaternary Cypresshead Formation (TQc) and undifferentiated Pliocene/Pleistocene shelly sediments (TQsu). These consist of residual clays, shells, quartz sands, and aeolian sands deposited during the Miocene to Holocene (Scott, 1997).

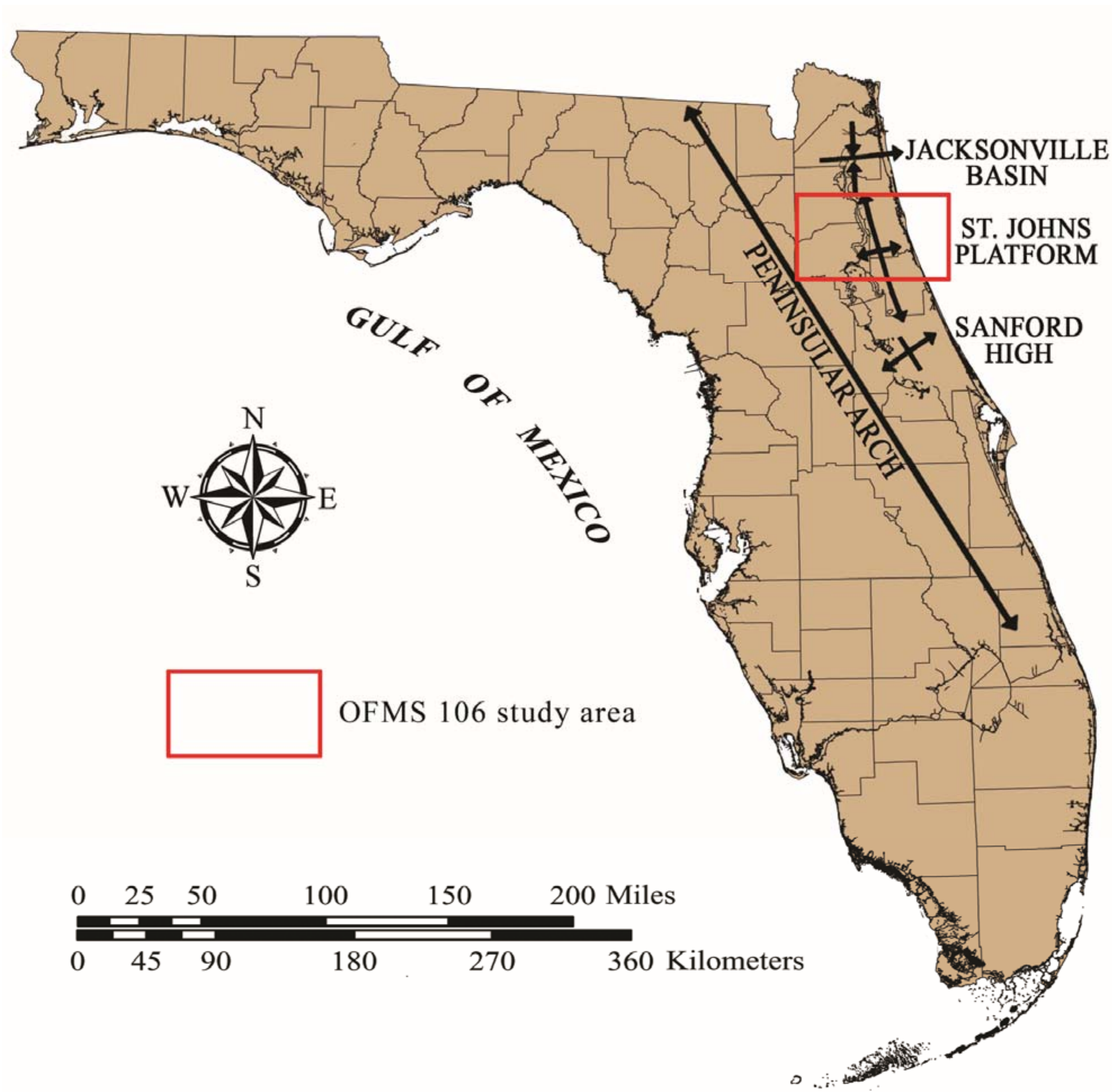

Figure 4. Principal subsurface structures of north Florida (modified from Scott, 1988).

Geomorphology

Healy (1975) recognized eight possible marine terraces within the study area (Figure 5) based upon elevations above mean sea level (MSL): the Silver Bluff terrace at elevations between 1 and 10 feet (0.3 and 3 meters), the Pamlico terrace at elevations between 10 and 25 feet (3 and 7.6 meters), the Talbot terrace at elevations between 25 and 42 feet (7.6 and 12.8 meters), the Penholoway terrace at elevations between 42 and 70 feet (12.8 and 21.3 meters), the Wicomico terrace at elevations between 70 to 100 feet (21.3 to 30.5 meters), the Sunderland/Okefenokee terrace at elevations between 100 and 170 feet (30.5 and 51.8 meters) and the Coharie terrace at elevations between 170 and 215 feet (51.8 and 65.5 meters). He combined the Hazlehurst (Cooke 1939), Coastwise delta plain (Vernon, 1951b), and part of the high Pliocene terrace of MacNeil (1950) which range in elevation from 215 to 320 feet (65.5 and 97.5 meters). Detailed discussions and correlations of these marine terraces and relict shorelines have been attempted by many authors, including Matson and Sanford (1913), Cooke (1931, 1939), Flint (1940, 1971), MacNeil (1950), Alt and Brooks (1965), Pirkle et al. (1970), Healy (1975), and Colquhoun et al. (1991).

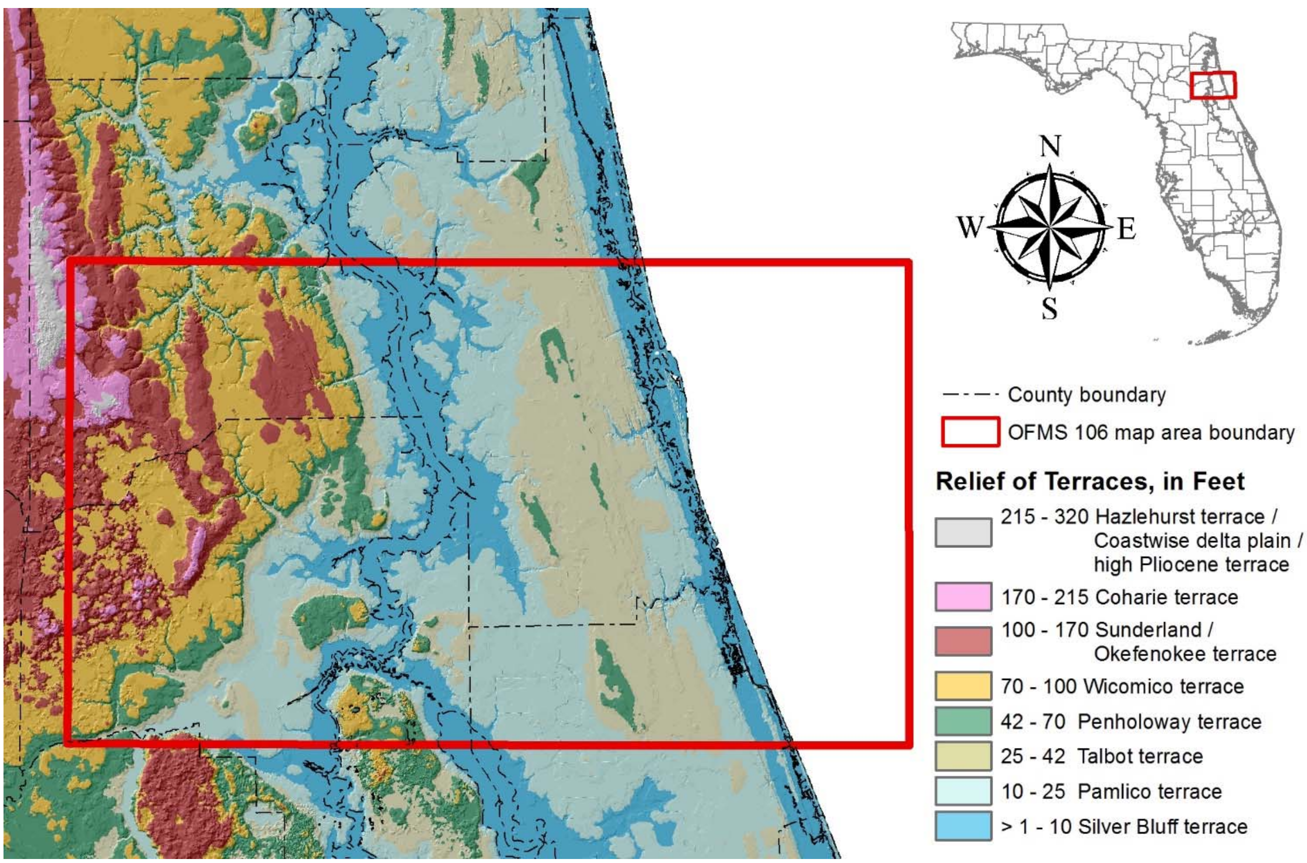

Figure 5. Terraces in the study area (after Healy, 1975).

According to Scott et al., (in preparation), the study area falls within two geomorphic districts: the Barrier Island Sequence District and the Central Lakes District (OFMS 106; Plate 3, Figure 3). These districts are further subdivided into terranes (OFMS 106; Plate 3, Figure 4) by Scott et al., (in preparation).

Barrier Island Sequence District

The Barrier Island Sequence District extends into Florida from Georgia. The district is characterized by beach ridges, dunes and paleo-lagoons. The district extends from the Georgia-Florida state line southward to the vicinity of Lake Okeechobee. It lies to the east of the Central Lakes District and north of the Everglades District (OFMS 106; Plate 3, Figure 3). Within the mapped area, the District is divided into three terranes (OFMS 106; Plate 3, Figure 4): the Atlantic Coastal Complex, the Duval Upland and the Lower St. Johns River Valley. Elevations within the District range from sea level to more than 145 feet (44.2 meters) above MSL. The surficial and shallow subsurface sediments of the district, presumably deposited during the Pliocene to Holocene, lie unconformably on sediments ranging from the Middle Eocene Avon Park Formation to the Oligocene-Miocene Hawthorn Group.

Beach ridge plains occur in several areas of the Barrier Island Sequence District at elevations ranging from near sea level to more than 75 feet (23 meters) above MSL. In the study area, these mostly occur in the Atlantic Coastal Complex (OFMS 106; Plate 3, Figure 1). Drainage patterns in these areas may be strongly controlled by the relict beach ridges, forming a distinct trellis pattern. The beach ridge swales are often swampy and control the development of lakes.

The Barrier Island Sequence District also contains relict (or paleo) lagoons. The occurrence of the lagoonal features is most prominent in the southern portion of the district near the headwaters of the St. Johns River. White (1970) thought that this area was not a paleo-lagoon but a beach ridge plain that had been reduced in stature by dissolution of incorporated shell material. He stated that there were relict beach ridges in the area and that the ridges controlled the drainage. Modern topographic maps, however, do not show the beach ridges nor do they reveal a drainage pattern indicative of beach ridges.

This paleo-lagoon lies between the Atlantic Coastal Ridge on the east and a prominent erosional scarp on the west. The scarp toe occurs at approximately 30 feet (9.1 meters) above MSL and extends nearly continuously from the southernmost portion of the Barrier Island Sequence District northward to the Florida-Georgia state line. The paleo-lagoon extends uninterrupted from the southern end of the district to southern Volusia County. Northward from southern Volusia County the relict lagoon is either interrupted or partially covered by beach ridges. However, the lagoon can be recognized as far north as the vicinity of Jacksonville in Duval County.

Atlantic Coastal Complex

The Atlantic Coastal Complex extends from the St. Johns River in Duval County to northern Brevard County (OFMS 106; Plate 3, Figure 4). In the study area, this terrane consists of Pleistocene through recent barrier beach ridges and dunes that are consistent with the terrane as a whole. Elevations range from sea level to 90 feet (27.4 meters) above MSL. There are multiple coast parallel creeks and swamps in the swales separated by ridges and broad scale development of trellis drainage. Some of the major water features include the Matanzas, Tolomato and Guana rivers, and Pellicer, Moses and Moultrie creeks. The Intracoastal Waterway, particularly in the southeastern part of the study area, separates the modern barrier island from the mainland to the west. The terrane has varying thickness of undifferentiated Quaternary sediments, undifferentiated Tertiary and Quaternary shelly sediments and outcrops of the Pleistocene Anastasia Formation near the Atlantic coast (OFMS 106, plate 2).

Duval Upland

The Duval Upland is a broad feature extending from Putnam County in the south to Nassau County and the Georgia boundary with Florida along the St. Marys River in the north (OFMS 106; Plate 3, Figure 4). It is an area of higher elevation to the west of the Lower St. Johns River Valley and the St. Marys Plain (OFMS 106; Plate 3, Figure 3). It is underlain by sediments of the Cypresshead Formation along the western edge and undifferentiated Quaternary sands along the eastern edge. Notably, across the Duval Upland, mixed dendritic and trellis drainage reveal that, at least in part, this terrane was originally deposited having some aspect of ridge and swale topography akin to the Atlantic Coastal Complex. This affinity is why the Duval Upland terrane is included within the Barrier Island Sequence District. Statewide, and within the mapped area, elevations range from sea level to approximately 145 feet (44.2 meters) above MSL.

Lower St. Johns River Valley

The Lower St. Johns River Valley has been hypothesized by Scott (2013, personal communication) as part of a paleo-lagoon. The relict lagoon feature extends nearly continuously from the headwaters of the St. Johns River in Palm Beach County to central Duval County. In Volusia County, the paleo-lagoon is either partially interrupted or partially covered by beach ridges. The southern end of this interruption corresponds to the westward turn of the St. Johns River as it occupies the St. Johns River Offset (OFMS 106; Plate 3, Figure 4). The southern end of the Lower St. Johns River Valley includes Crescent Lake and extends northward to central Duval County where the St. Johns River turns east toward the Atlantic Ocean and some beach ridge uplands separate the St. Johns River Valley from the drainages associated with the Nassau and St. Marys rivers. Elevations within the terrane range from sea level to more than 95 feet (29.0 meters) above MSL. Within the study area, elevations range from sea level to 90 feet (27.4 meters) above MSL. Variable thicknesses of undifferentiated Quaternary sediments lie on undifferentiated Tertiary/Quaternary shelly sediments or the Hawthorn Group in the terrane.

Central Lakes District

The Central Lakes District occupies most of the Central Highlands of Cooke (1939) in peninsular Florida. The district extends from eastern Alachua County, southeastern Bradford County and southern Clay County to southernmost Highlands County (OFMS 106; Plate 3, Figure 3). A thick (up to 200 feet [61 meters]) sequence of siliciclastic and carbonate sediments of the Hawthorn Group and siliciclastic sediments of the Cypresshead Formation and undifferentiated sediments overlie the Ocala Limestone in the district. Dissolution of the limestone and subsequent subsidence or collapse has created the characteristic rolling hills, sinkhole lakes and dry sinks that dominate the landscape. Much of the district is internally drained due to the karst features and the permeable sand cover. District-wide elevations range from near sea level to over 300 feet (91.4 meters) above MSL. Within the mapped area, elevations vary from near sea level along portions of the St. Johns River to 285 feet (86.9 meters) above MSL on Trail Ridge. In the study area, the Central Lakes District includes the Crescent City Ridge, the Fort McCoy Plain, the Hawthorne Lakes Region, the Mt. Dora Ridge, the Ocklawaha River Valley, Palatka Hill, the St. Johns River Offset, and Trail Ridge (OFMS 106; Plate 3, Figure 4). Many of these features were once part of a more extensive Cypresshead Formation upland that subsequently was erosionally altered leaving remnant highs.

Crescent City Ridge

The Crescent City Ridge lies in northwestern Volusia County and southeastern Putnam County (OFMS 106; Plate 3, Figure 4). It is located between the St. Johns River Offset and the Lower St. Johns River Valley. Crescent Lake, which likely represents a portion of the paleo-pathway of the ancestral St. Johns River abandoned when the river began to occupy the St. Johns River Offset, lies at the eastern toe of the ridge. Elevations vary from approximately MSL to 125 feet (38.1 meters) above MSL. Relief on the ridge can be substantial due to karst influences. The terrain is a rolling, karstic landscape with closed-basin lakes. A thin sequence of undifferentiated Quaternary sediments overlies the Cypresshead Formation and undifferentiated Tertiary/Quaternary shelly sediments.

Fort McCoy Plain

The Fort McCoy Plain is a relatively flat, poorly to moderately drained area just east of the Ocala Karst Hills and southeast of the Hawthorne Lakes Region in the southwest corner of the study area (OFMS 106; Plate 3, Figure 4). Scattered sinkholes are present within the terrane and elevations range from approximately 15 feet (4.6 meters) to approximately 90 feet (27.4 meters) above MSL within the study area. The Fort McCoy Plain is underlain by sediments of the Hawthorn Group, which are mantled with variable thicknesses of undifferentiated Quaternary sediments (Scott et al., 2001; Green et al., 2009a, 2009b).

Hawthorne Lakes Region

The Hawthorne Lakes Region is bounded to the north and east by Trail Ridge, to the east by the Duval Upland, to the south by the Fort McCoy Plain and the Ocklawaha River Valley and to the northwest by the Southern Okeefenokee Basin (OFMS 106; Plate 3, Figure 4). The lakes in the Hawthorne Lakes Region formed through karst processes and were modified by subsequent surficial erosion. Surficial erosion has caused some of the formerly closed basins to coalesce and develop outflow streams. Elevations in the terrane range from approximately 10 feet (3.1 meters) above MSL for the water level in the lakes to approximately 225 feet (68.6 meters) above MSL on the hills. Relief generally decreases to the south, as does the elevation range. The Hawthorne Lakes Region is underlain by sediments of the Cypresshead Formation and undifferentiated Quaternary sediments.

Mt. Dora Ridge

The Mt. Dora Ridge occurs from western Orange County to Marion and Putnam Counties, where it terminates near the southwestern corner of the study area (OFMS 106; Plate 3, Figures 1 and 4). It is bound to the west by the Ocklawaha River Valley, Tavares Lakes Region, Lake Wales Ridge Complex, to the south and east by the Osceola Plain, and to the east by the Orlando Ridge, Wekiva Plain, Lake Plain and St. Johns River Offset Valley. The terrain is a rolling karstic landscape with numerous lakes. Elevations on the Mt. Dora Ridge range from 5 feet (1.5 meters) to 195 feet (59.4 meters) above MSL statewide and from 5 feet (1.5 meters) to 170 feet (51.8 meters) above MSL within the study area. Relief often exceeds 100 feet (30.5 meters). Karst processes acting through a thick sequence of siliciclastic sediments (deep-cover karst) created the landscape. Dissolution of the Ocala Limestone and carbonates within the Hawthorn Group is responsible for the development of the Mt. Dora Ridge's distinctive landscape. Tertiary/Quaternary dune sediments overlie the Cypresshead Formation on part of the Mt. Dora Ridge. Elsewhere, the Cypresshead Formation lies on the Hawthorn Group.

Ocklawaha River Valley

The Ocklawaha River Valley extends from near the Lake-Marion County line northward to the Marion-Putnam County line (OFMS 106; Plate 3, Figure 4). In the study area, the valley abuts the St. Johns River Offset, Mt. Dora Ridge, Fort McCoy Plain, the Hawthorne Lakes Region and the Duval Upland where the river becomes confined to a narrow corridor (OFMS 106; Plate 3, Figures 1 and 4). The headwaters of the Ocklawaha River occur in Lake Griffin in the Tavares Lakes Region, a broader and more karstic portion of the Central Lakes District. The terrane is underlain by the Ocala Limestone, Hawthorn Group, Cypresshead Formation and undifferentiated Quaternary sediments. Elevations of the valley range from sea level to 105 feet (32.0 meters) above MSL statewide and sea level to 70 feet (21.3 meters) above MSL within the study area.

Palatka Hill

Palatka Hill, in Putnam County, appears as a remnant hill stranded in the broader feature of the St. Johns River valley. Where the St. Johns River Offset turns toward the east-northeast, the river has followed its current course south of Palatka Hill, but there is also an extensive eroded plain to the west and north of Palatka Hill. This remnant feature is at the junction of the St. Johns River Offset and the Lower St. Johns River Valley where the St. Johns River turns to the north-northwest, continuing the coastal sub-parallel trend in line with the Upper St. Johns River Valley further south. The Palatka Hill terrane appears to share affinity to both the Crescent City Ridge to the southeast and the Duval Upland to the north and northwest (OFMS 106; Plate 3, Figures 1 and 4). It exhibits overland drainage incision like the Duval Upland, as may be observed at Ravine Gardens State Park, but is not devoid of isolated karst lakes as are found in the Crescent City Ridge. Palatka Hill elevations range from 5 feet (15 meters) to 100 feet (30.5 meters) above MSL. The terrane consists of undifferentiated Quaternary sediments on Cypresshead Formation.

St. Johns River Offset

The St. Johns River flows northward from the headwaters in Palm Beach County, flowing into the Atlantic Ocean in Duval County (OFMS 106; Plate 3, Figure 4). The upper and lower St. Johns River valleys follow pathways that are closer to the Atlantic coastline than the middle reach of the river between Sanford and Palatka. At the approximate latitude of Sanford, Seminole County, the river jogs westward then northward in a narrow valley bounded in the study area by the Mt. Dora Ridge on the west and the Crescent City Ridge on the east. White (1970) named and described the St. Johns River Offset. Elevations in the terrane vary from sea level to 75 feet (22.9 meters) above MSL statewide and sea level to 60 feet (18.3 meters) above MSL in the study area. White believed that this portion of the St. Johns River's pathway was first developed in the

Pliocene or early Pleistocene by dissolution of the underlying Eocene carbonate sediments. Pirkle (1971) suggested that the dissolution along the west to east trend resulted from faulting and fracturing of the Eocene rocks. White (1970) believed that a complex geomorphic history was necessary to force the St. Johns River out of its coast parallel course and into a more inland, older valley. Within the Offset there are varying thicknesses of undifferentiated Quaternary sediments overlying the Ocala Limestone.

Trail Ridge

Trail Ridge is a 130 mile (209 kilometer) long sand ridge that extends southward from the Altamaha River in southern Georgia to northern Putnam County in the west-northwest portion of the study area (OFMS 106; Plate 3, Figure 4). It is bound to the west by the Southern Okeefenokee Basin, to the east by the Duval upland and to the south by the Hawthorne Lakes Region (OFMS 106; Plate 3, Figure 4). This feature as mapped includes the Baywood Promontory of Pirkle et al., (1970). Elevations of the terrane range from 50 feet (15.2 meters) above MSL to 305 feet (93.0 meters) above MSL statewide and 50 feet (15.2 meters) to 285 feet (86.9 meters) above MSL within the mapped area. Trail Ridge sands consist of unconsolidated to slightly indurated white to tan, medium to fine quartz beach ridge sands in some areas containing an average of 3 percent heavy minerals, of which approximately 45 percent are titanium-rich minerals, consisting of ilmenite, leucoxene, and rutile. The average TiO_2 content of these minerals is approximately 69 percent. Other common heavy minerals include staurolite, zircon, kyanite, sillimanite, corundum, topaz, and tourmaline.

LITHOSTRATIGRAPHIC UNITS

Tertiary System

Eocene Series

Avon Park Formation

The Middle Eocene Avon Park Formation (Tap), first described by Applin and Applin (1944), is entirely a subsurface unit within the USGS Saint Augustine 30 x 60 minute quadrangle. It was encountered in many of the wells utilized for this study and efforts were made to include it in the geologic cross sections where suitable well coverage existed (see OFMS 106, Plate 2).

Lithology of the Avon Park Formation varies between limestone and dolostone. The limestones consist of cream to light brown to tan, poorly to well-indurated, variably fossiliferous grainstone and wackestone, with rare mudstone. The limestones are often interbedded with tan to brown, very poorly to well-indurated, very fine to medium crystalline, fossiliferous (molds and casts), vuggy dolostones. Minor clay beds and organic-rich laminations may occur, especially at or near the top of the unit. Accessory minerals include chert, pyrite, celestine, gypsum and quartz (some as doubly-terminated euhedral crystals “floating” in vugs).

Fossils present in the unit include molluscs, foraminifera (*Spirolina* sp., *Lituonella floridana*, *Bolivina* spp., *Cushmania* [*Dictyoconus*] *americana*), *Cribrobulimina cushmani*, and *Fabiana cubensis*, echinoids (*Neolaganum* [*Peronella*] *dalli*), algae and carbonized plant remains. 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.

Distinguishing between the Middle Eocene Avon Park Formation and the unconformably overlying unit, the Upper Eocene Ocala Limestone, can at times be difficult in the study area. Dolomitization of the Avon Park Formation and common recrystallization of the lowermost Ocala Limestone has significantly altered the original rock lithology and fabric. Fossil indicators are only somewhat helpful because the latest deposits of the Avon Park Formation and the earliest deposits of the Ocala Limestone are both bank assemblages, consistent with deposition in a shallow-water limestone bank or plateau, not unlike the present day Bahama Banks (Bryan, 2004).

The top of the Avon Park ranges from approximately 80 feet (24.4 meters) below MSL in W-17173 (OFMS 106; Plate 2, cross-section D-D') to approximately 500 feet (152.4 meters) below MSL in W-3478 (OFMS 106; Plate 2, cross-sections A-A'). Due to limited coverage of deeper wells, the total thickness of the Avon Park Formation was not investigated in this study. The Avon Park Formation forms part of the FAS (Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986).

Ocala Limestone

The Upper Eocene Ocala Limestone (To), first described by Dall and Harris (1892), is a biogenic marine limestone comprised largely of foraminifera, molluscs, echinoids and bryozoans. The Ocala Limestone, which sits unconformably on the Avon Park Formation throughout the study area, is thin to absent in the vicinity of the Sanford High (Green et al., 2013a, 2013b).

Based on lithologic differences, the Ocala Limestone can be informally subdivided into an upper and lower unit (Scott, 1991). This subdivision, while often apparent in cores and quarries, is not readily apparent in cuttings. As a consequence of this, the geologic cross-sections do not break out the upper and lower Ocala Limestone. The upper unit is typically a white to cream, fine- to coarse-grained, poorly to well-indurated, moderately to well-sorted, very fossiliferous limestone (wackestone, packstone, and grainstone). Fossils commonly include foraminifera, bryozoans, molluscs, and a rich diversity of echinoids. The lower unit is typically a white to cream, fine- to medium-grained, poorly to moderately indurated, moderately to well-sorted limestone (grainstone to packstone). Fossils include foraminifera (*Lepidocyclina ocalana*, *Amphistegina pinarensis*, *Nummulites* [*Camerina*] *vanderstoki*, *Nummulites* [*Operculinoides*] *ocalana*), bryozoans, algae, molluscs, echinoids, and crustaceans.

The Ocala Limestone occurs throughout the study area and is highest along the southwestern portion of the map area (OFMS 106, Plate 2). The top of the Ocala Limestone ranges from 27 feet (8.2 meters) below MSL in W-17173, (OFMS 106; Plate 2, cross-section D-D') to 340 feet (103.6 meters) below MSL in W-14476 (OFMS 106; Plate 2, cross-sections D-D' and A-A'). Only a few wells utilized for geologic cross-sections penetrated the entire thickness of the Ocala Limestone. In these wells, the thickness of the Ocala Limestone ranges from 53 feet (16.2 meters) in W-17173 (OFMS 106; Plate 2, cross-section D-D') to 217.5 feet (82.4 meters) in W-18580 (OFMS 106; Plate 2, cross-section B-B'). The Ocala Limestone is generally thickest in the eastern portion of the study area. The Ocala Limestone forms part of the FAS (Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986).

Miocene Series

Hawthorn Group

Sediments of the Miocene Hawthorn Group are thought to have been deposited over the Peninsular Arch throughout the study area, but erosion and karstification have removed these sediments from the crest of the Ocala Platform (Cooke, 1945; Espenshade and Spencer, 1963; Scott, 1983). The unit is also missing in the vicinity of the Sanford High (Scott, 1988). Hawthorn Group sediments within the study area consist of phosphatic siliciclastics (sands, silts and clays) and carbonates (dolostone with minor limestone). Fossils in the Hawthorn Group are sparse but may include vertebrates, corals, and molluscs. Benthic foraminifera characteristic of the Hawthorn Group include *Archaias* spp. and *Sorites* sp. Williams et al. (1977) report that the most commonly found fossils are oysters and coral heads.

Within the mapped area, the Hawthorn Group is composed of (in ascending order) the Penney Farms Formation (Thpf), the Marks Head Formation (Thmh) and the Coosawhatchie Formation (Thc; OFMS 106, Plate 2, Figure 2). While these formations can be identified and delineated in cores, they often can be difficult to differentiate in cuttings, particularly where cavings cause mixing of the sediments during drilling. In these instances, they are referred to as undifferentiated Hawthorn Group (Th) on the cross-sections. This is most common in the southwestern portion of the map area (OFMS 106; Plate 2, cross-section C-C'). Unit descriptions for the Hawthorn Group listed below are summaries and the reader is referred to Scott (1988) for a more complete discussion of lithologies, variability and relationships of these lithologically complex formations. Hawthorn Group sediments are unconformably overlain by undifferentiated Tertiary/Quaternary shelly sediments (TQsu), Cypresshead Formation (TQc), Tertiary/Quaternary dunes (TQd), undifferentiated Quaternary sediments (Qu) and Trail Ridge sands (Qtr).

Hawthorn Group sediments occur throughout the mapped area (OFMS 106, Plate 2). The top of the Hawthorn Group ranges between 70 feet (21.3 meters) above MSL in W-15183 (OFMS 106; Plate 2, cross-section B-B') to 88 feet (26.8 meters) below MSL in W-13746 (OFMS 106; Plate 2, cross-section A-A'). The Hawthorn Group sediments range in thickness from 22 feet (6.7 meters) in well W-17173 (OFMS 106; Plate 2, cross-section D-D') to 290 feet (88.4 meters) in well W-14476 (OFMS 106; Plate 2, cross-section A-A'). Sediments of the Hawthorn Group form the Intermediate aquifer system/Intermediate confining unit (IAS/ICU; Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986).

Penney Farms Formation

The Lower Miocene Penney Farms Formation (Thpf) consists of variable admixtures of dolostone, quartz sand, phosphatic sand and clay. The sand content is variable and at times the unit becomes a dolomitic sand. Phosphatic sand is common and may be present in amounts exceeding 25 percent with an average of 5 to 10 percent (Scott, 1988). Clay percentages are generally minor (less than five percent) and often increase towards the top of the unit in the dolostones. The dolostones are medium-gray to pale-yellowish brown and are generally moderately- to well-indurated. Mollusc molds are common in the dolostones. Bored hardgrounds, burrows and intraclasts are common in the hard, finer-grained dolostones in the lower portion of the unit. These intraclasts are composed of dolomite similar to the rest of the unit, but they often have rims of phosphate replacement along the edges of the clasts (OFMS 106; Plate 2, Figure 3). Limestone, which occurs sporadically in the lower portion of the unit, is generally dolomitic, phosphatic, and quartz sandy. The Penney Farms Formation unconformably overlies the Ocala Limestone within the mapped area. Where present in the mapped area, it is overlain unconformably by the Marks Head Formation (Hawthorn Group). The base of the Marks Head Formation is placed at the contact between the darker-colored sands and clays of the upper Penney Farms and the generally lighter-colored interbedded sands, clays, and dolostone of the Marks Head Formation. Sediments of the Penney Farms Formation occur throughout most of the mapped area (OFMS 106, Plate 2). The top of the Penney Farms Formation ranges from near sea level in W-14301 (OFMS 106; Plate 2, cross-section C-C') to 230 feet (70.1 meters) below MSL in W-14476 (OFMS 106; Plate 2, cross-sections A-A' and D-D'). The Penney Farms Formation ranges in thickness from non-existent in W-15183 (OFMS 106; Plate 2, cross-section B-B') and W-17173 (OFMS 106; Plate 2, cross-section D-D') to 129 feet (39.3 meters) in well W-533 (OFMS 106; Plate 2, cross-sections A-A' and C-C').

Marks Head Formation

The Lower Miocene Marks Head Formation (Thmh) consists of interbedded sands, clays and dolostones. Limestone, while uncommon, does occur within the unit (Scott, 1988). Dolostones are generally quartz sandy, phosphatic and clayey. Colors of the dolostones range from yellowish-gray to olive gray. Induration, which varies inversely with the clay content, ranges from poorly consolidated to well indurated. Phosphate content typically ranges up to five percent but may occasionally be significantly higher. Quartz sand content ranges from five percent to greater than 50 percent. The unit is overlain unconformably by the Coosawhatchie Formation, although this unconformity is often not readily apparent. In general, the contact between the Coosawhatchie and Marks Head formations is placed at the top of the first hard carbonate bed or light-colored clay unit below the darker-colored, clayey, dolomitic quartz sands and dolostones of the basal Coosawhatchie Formation (Scott, 1988). Sediments of the Marks Head Formation occur throughout most of the mapped area (OFMS 106, Plate 2). The top of the Marks Head Formation ranges from 10 feet (3.1 meters) above MSL in W-15183 (OFMS 106; Plate 2, cross-section B-B') to 195 feet (59.4 meters) below MSL in W-3478 (OFMS 106; Plate 2, cross-section A-A'). The Marks Head Formation ranges in thickness from non-existent in well W-17173 (OFMS 106; Plate 2, cross-section D-D') to 87 feet (26.5 meters) in well W-533 (OFMS 106; Plate 2, cross-sections A-A' and C-C').

Coosawhatchie Formation

The Middle Miocene Coosawhatchie Formation (Thc) consists of quartz sands, dolostones and clays. The unit ranges in color from greenish-gray and light gray to olive gray. The most common lithology in the upper section of the unit is characteristically a sandy to very sandy dolostone which may be interbedded with quartz sands and clays (Scott, 1988). Quartz sands and clays dominate and dolostones become subordinate in the lower portion of the section. The quartz sands are fine- to medium-grained, generally phosphatic, clayey and dolomitic. In many instances, the sands grade into dolostones and clays. Clay content is variable and may range from five to more than 30 percent (Scott, 1988). Phosphate content is highly variable, ranging from a trace to more than 20 percent. Coarse phosphate sands and pebbles are present but not common in the unit. The unit is unconformably overlain by undifferentiated Pliocene/Pleistocene shelly sediments (TQsu) throughout most of the mapped area (OFMS 106, Plate 2). It is unconformably overlain by the Pliocene/Pleistocene Cypresshead Formation (TQc) and undifferentiated Quaternary sediments (Qu) in the vicinity of Trail Ridge where the TQsu sediments are missing (OFMS 106, Plate 2, cross-sections A-A' and B-B'). The Coosawhatchie Formation occurs throughout the mapped area, except in the southwestern corner where they grade into undifferentiated Hawthorn Group sediments (Th; OFMS 106, Plate 2). The top of the Coosawhatchie Formation ranges between 70 feet (21.3 meters) above MSL in W-15183 (OFMS 106; Plate 2, cross-section B-B') to 88 feet (26.8 meters) below MSL in W-13746 (OFMS 106; Plate 2, cross-section A-A'). The Coosawhatchie Formation ranges in thickness from 5 feet (1.5 meters) in well W-14354 (OFMS 106; Plate 2, cross-section D-D') to 125 feet (38.1 meters) in well W-13744 (OFMS 106; Plate 2, cross-section A-A').

Hawthorn Group (Undifferentiated)

The Coosawhatchie, Marks Head and Penney Farms formations often become difficult to break out lithologically, especially in cuttings, in the areas between the Sanford High and the Peninsular Arch. In these cases, the sediments are mapped as undifferentiated Hawthorn Group (Th; Scott, 1988). There are a few wells in the very southwestern portion of the study area where the formations of the Hawthorn Group could not be reliably differentiated (OFMS 106, Plate 2; cross-section C-C', W-18527).

Where exposed, west of the mapped area, the undifferentiated Hawthorn Group is light olive gray and blue gray in unweathered sections and reddish-brown to reddish-gray in weathered sections (Green et al., 2009a). It consists of poorly to moderately-consolidated, clayey sands to silty clays and relatively pure clays with little-to-no phosphate due to leaching and transport (Scott, 2001). It is typically deeply weathered. Where present, the undifferentiated Hawthorn Group unconformably overlies the Ocala Limestone (Scott et al., 2001). It is unconformably overlain by undifferentiated Quaternary (Qu) sediments (OFMS 106, Plate 2; cross-section C-C', W-18527). There were not enough wells with undifferentiated Hawthorn Group sediments penetrated in the study area to give reliable estimates of thickness or elevation ranges for the unit.

Due to the karstic nature of the Central Lakes District, elevations of the Hawthorn Group are highly variable. Undifferentiated Hawthorn Group sediments are often clayey sands and only rarely consist of relatively pure clays. The Hawthorn Group generally has low permeability and forms part of the IAS/ICU (Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986).

Tertiary/Quaternary Systems

Pliocene/Pleistocene Series

Cypresshead Formation

The Pliocene/Pleistocene Cypresshead Formation (TQc), named by Huddlestun (1988), is a mottled reddish-brown to reddish-orange to white, unconsolidated to poorly consolidated, fine- to very coarse-grained, variably clayey to clean quartz sand. Cross-beds are common within this formation. Discoid quartzite pebbles, mica, and ghosts of nearshore marine molluscs are often present. The Cypresshead Formation is present throughout part of the western and southern edges of the study area and forms the core of the Crescent City Ridge and Palatka Hill (OFMS 106, Plate 1 and Plate 3). East of the St. Johns River, it typically becomes a more weathered, finer-grained, well-sorted sand and silt. In cores, the unit is often characterized by beds of fine grained, well sorted sand with thin layers of clay dispersed through the sand.

Elevations range from approximately 70 feet (21.3 meters) above MSL to over 100 feet (30.5 meters) above MSL in the northwestern corner of the mapped area. The Cypresshead Formation thickness ranges between 10 feet (3.1 meters) to 100 feet (30.5 meters) in study area wells.

These sediments sit unconformably on the Coosawhatchie Formation (Hawthorn Group; Thc) in the vicinity of the Trail Ridge terrane (OFMS 106; Plates 2 and 3). Permeable sediments of the Cypresshead Formation form part of the surficial aquifer system (SAS; Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986).

Pliocene/Pleistocene Shelly Sediments

A sequence of undifferentiated Pliocene/Pleistocene shelly sediments lies east of Trail Ridge. Huddlestun (1988) named this unit the Nashua Formation. Much of the evidence listed by Huddlestun (1988) was based on biostratigraphic correlation and not lithologic distinction. Efforts were made by the authors to locate the type section of the Nashua Formation, as defined by Huddlestun (1988), but it was inundated. Three cores were drilled in the Big Horse Aggregates pit in an attempt to determine the lithology of the unit. In these cores, the lithology of the unit was found to be highly variable even over short distances. As a result of the lithologic variability of the unit, the use of biostratigraphic correlation of Huddleston (1988) and minimal field exposures, these authors have decided to utilize the convention of the Scott et al. (2001) and map these sediments as undifferentiated Pliocene/Pleistocene shelly sediments (TQsu). While not a formally recognized lithostratigraphic unit, TQsu are mapped following the convention of Scott et al., (2001) in order to facilitate a better understanding of Florida’s geology. The unit sits unconformably on the Coosawhatchie Formation of the Hawthorn Group (OFMS 106; Plate 2, cross-sections A-A', B-B', D-D' and E-E’). Huddlestun (1988) indicated that the unit grades laterally into the Cypresshead Formation (TQc) in the vicinity of the Trail Ridge. Evidence from this study and Green et al., (2013a, 2013b), however, indicates that the unit is, at least in part, older than the Cypresshead Formation in the vicinity of Crescent City Ridge. This may be a result of prograding of Cypresshead Formation sediments over TQsu marine sediments during changes in sea level. Work underway at the Florida Museum of Natural History indicates that some of these shelly sands are Pliocene (Roger Portell, personal communication). These undifferentiated shelly sands are overlain by the Cypresshead Formation in the Crescent City and DeLand ridges just south of the current study area (Green et al., 2013a, 2013b). Elsewhere, the unit is unconformably overlain by undifferentiated Quaternary sediments (Qu), Quaternary beach ridge and dune sediments (Qbd), Holocene sediments (Qh), or the Anastasia Formation (Qa; OFMS 106, Plate 2).

Undifferentiated Pliocene/Pleistocene shelly sediments (TQsu) typically consist of fine-to-medium quartz sand with variable amounts of calcilutite, shell and clay. Shells, which may be very weathered, vary from whole to fragments and may occasionally become the dominant lithology. Other accessory minerals may include calcite, aragonite, clay, mica, heavy minerals and minor phosphate. Colors range from light gray to light olive gray.

The top of the undifferentiated Pliocene/Pleistocene shelly sediments ranges from 24 feet (7.3 meters) above MSL in W-14521, (OFMS 106; Plate 2, cross-section D-D') to 70 feet (21.3 meters) below MSL in W-18283 (OFMS 106; Plate 2, cross-section D-D'). The thickness of the undifferentiated Pliocene/Pleistocene shelly sediments in the cross-section wells varies from 10 feet (3.1 meters) in W-14354 (OFMS 106; Plate 2, cross-sections B-B' and D-D') to 95 feet (28.9 meters) in W-18254 (OFMS 106; Plate 2, cross-section D-D'). Permeable sediments of the undifferentiated Pliocene/Pleistocene shelly sediments form part of the SAS (Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986).

Tertiary/Quaternary Dunes

Tertiary/Quaternary dunes (TQd), while not a formally recognized lithostratigraphic unit, are mapped following the convention of Scott et al. (2001). Where LiDAR is available these dunes are readily differentiated from other units by their distinct topographic expression. These dune sediments are fine-to-medium quartz sand with varying amounts of disseminated organic matter. They are generally found at elevations above 100 feet (30.5 meters) MSL, although there are areas along the western flanks of the Trail Ridge sediments (Qtr) where elevations of these dune sands can be lower. Sands forming these dunes are thought to be derived from re-working of sediments from the Cypresshead Formation (TQc) and undifferentiated Quaternary sediments (Qu; OFMS 106, Plate 1). These sediments are considered part of the SAS (Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986).

Pleistocene to Holocene Series

Anastasia Formation

The Anastasia Formation (Qa) is present within the Atlantic Coastal Complex in a narrow band along the eastern edge of the study area. The formation, named by Sellards (1912), is composed of interbedded coquinoid limestone and quartz sands. It typically occurs as an orangish-brown to very pale orange, unconsolidated to moderately indurated coquina consisting of whole and broken mollusc shells in a quartz sand matrix. The coquina is commonly cemented by sparry calcite. The sands occur as light gray to tan and orangish-brown, unconsolidated to moderately indurated, unfossiliferous to very fossiliferous beds. The unit sits unconformably on undifferentiated Pliocene/Pleistocene shelly sediments (TQsu; OFMS 106, Plate 2, cross-section E-E'). The top of the Anastasia Formation ranges from 5 feet (1.5 meters) above MSL (OFMS 106; Plate 2, cross-section E-E', W-15282), to near MSL (OFMS 106; Plate 2, cross-section E-E'). The thickness of the Anastasia Formation in the cross-section wells varies from 20 feet (6.1 meters) in W-19458 to 38 feet (11.6 meters) in W-15282 (OFMS 106; Plate 2, cross-section E-E'). This formation is considered part of the SAS (Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986).

Undifferentiated Quaternary Sediments

Undifferentiated Quaternary sediments (Qu) in the study area lie unconformably on the Hawthorn Group, undifferentiated Pliocene/Pleistocene shelly sediments or Cypresshead Formation (OFMS 106, Plate 2). While not a formally recognized lithostratigraphic unit, Qu are mapped following the convention of Scott et al., (2001) in order to facilitate a better understanding of Florida’s geology. The undifferentiated Quaternary sediments present in the mapped area may be highly variable in thickness. Generally, these undifferentiated Quaternary sediments consist of white to gray to orange to blue-green, fine- to coarse-grained, clean to clayey unfossiliferous sands, sandy clays and clays with variable admixtures of organics. The undifferentiated Quaternary sediments form part of the SAS (Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986).

Quaternary Trail Ridge Sands

Sediments mapped as Quaternary Trail Ridge Sands (Qtr) include heavy-mineral bearing sediments associated with Trail Ridge, but are not limited to just the ridge itself. They also include sediments of the Baywood Promontory of Pirkle et al., (1970). While not a formally recognized lithostratigraphic unit, they are mapped following the convention of Scott et al., (2001) in order to facilitate a better understanding of Florida's geology. These sediments consist of white to tan, medium to fine quartz beach ridge sands, unconsolidated to slightly indurated. They contain an average of three percent heavy minerals in some areas, of which approximately 45 percent are titanium-rich minerals consisting of ilmenite, luecoxene, and rutile. Other common heavy minerals in the unit include staurolite, zircon, kyanite, sillimanite, corundum, topaz, and tourmaline.

Quaternary Beach Ridge and Dune

Quaternary beach ridge and dune sediments (Qbd) are a subdivision of the undifferentiated Quaternary sediments that are noted on the basis of surficial expression of relict beach ridges and dunes. While not a formally recognized lithostratigraphic unit, Qbd are mapped following the convention of Scott et al., (2001) in order to facilitate a better understanding of Florida's geology. This unit unconformably overlies undifferentiated Pliocene/Pleistocene shelly sediments (TQsu), or the Anastasia Formation (Qa) in the eastern part of the study area (OFMS 106; Plates 1 and 2).

Beach ridge and dune sediments are dominantly siliciclastic sands and are unconsolidated to poorly consolidated. Organics typically occur as disseminated organic matrix, roots and plant debris, carbonized remains or charcoal. The unit is considered part of the SAS (Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986).

Holocene Sediments

Sediments mapped as Holocene (Qh) may include quartz sands, marls, organics, humate, and minor carbonate sands and mud. They may also include fresh-water molluscs. Within the study area, they occur as modern barrier islands and floodplain deposits in the vicinity of Crescent Lake, the St. Johns and Ocklawaha Rivers and along the east coast. These sediments are considered part of the SAS (Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986).

HYDROGEOLOGY

Hydrostratigraphic units within the map area, in ascending order, consist of the Floridan aquifer system (FAS), the Intermediate aquifer system/Intermediate confining unit (IAS/ICU), and the Surficial aquifer system (SAS; Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986). The FAS, the primary source for springs and drinking water in the region, is generally comprised of carbonate units of the Avon Park Formation and the

Ocala Limestone. The sands, silts, clays and carbonates of the Hawthorn Group comprise the IAS/ICU. The IAS/ICU is highly variable and in the study area. The SAS is comprised of the Cypresshead Formation, undifferentiated Pliocene/Pleistocene shelly sediments (TQsu), Tertiary/Quaternary dune sediments (TQd), undifferentiated Quaternary sediments (Qu), beach ridge and dune sediments (Qbd), and Holocene sediments (Qh).

Where clayey siliciclastic sediments of the Hawthorn Group and younger units are thick and continuous, they provide confinement for the FAS, but where the clayey siliciclastic sediments of the Hawthorn Group and younger units are thin, missing or lack significant clay component, karst features often occur. Several of these are found in the Crescent City and DeLand ridges.

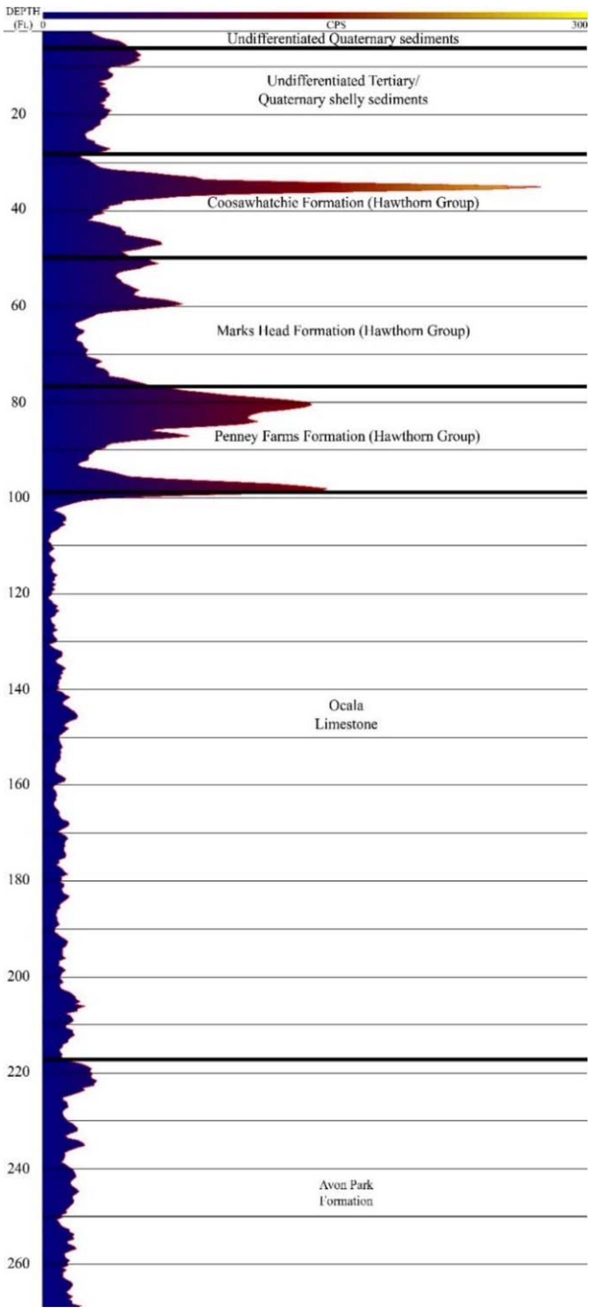

Figure 6. Gamma Log of W-19480 (see OFMS 106, plate 2, cross section B-B').

GEOPHYSICAL LOGGING

As part of this project, the St. Johns River Water Management District (SJRWMD) conducted geophysical logging on new wells drilled in the study area by the Florida Geological Survey. Boreholes were logged with a variety of geophysical tools, including Gamma (natural gamma log), Caliper, and Induction logs (Fluid Resistivity and Fluid Conductivity). The geophysical log of particular interest in this study was the gamma log for its usefulness in differentiating the various lithostratigraphic units by recording the naturally occurring gamma-ray activity in the lithology of the borehole wall.

By comparing gamma-ray activity between lithostratigraphic units it is often possible to differentiate them. This log is particularly useful for differentiating between Hawthorn Group units and subjacent and superjacent formations. Kwader (1982) and Scott (1988) discuss the gamma-ray response from clay minerals and phosphate typical to the formations in the Hawthorn Group. Development of high gamma activity occurs when minerals incorporate high percentages of potassium, uranium or thorium in their lattice structures. Potassium-rich sources include potassium feldspar, mica, and illitic clay. Uranium and thorium tend to be found in phosphorite, apatite, organic material and dolomite.

Gamma-ray intensity units were measured in counts per second (CPS). In Figure 6, gamma-ray intensity units are shown on the log horizontal axis in CPS for W-19480 (see OFMS 106, Plate 2, cross-section B-B'). Carbonates of the Ocala Limestone and Avon Park Formation have the lowest intensity gamma peaks in contrast to the high intensity radioactivity of the Hawthorn Group. Formations above the Hawthorn Group, such as the Cypresshead Formation and undifferentiated Tertiary-Quaternary shelly sediments (TQsu), typically have much lower intensity signatures. In the study area, elevated radioactivity primarily results from the inclusion of phosphate grains. Medium intensity gamma-ray signatures are from moderately radioactive clay minerals and from organic material or peat (Davis et al., 2001).

Stratigraphy and Gamma-Ray Log Interpretation

Avon Park Formation

Logs from the Avon Park Formation typically show a combination of low gamma-ray intensity dolostone with distinct beds of relatively higher gamma-ray intensity lignite or organic layers. The top of the Avon Park Formation characteristically ranges from a yellow-gray dolomitic wackestone to a yellow-brown recrystallized dolostone. Below this initial lithology, but usually at or near the top of the unit, there can be variable amounts of black to dark brown, finely particulate to fibrous, partially decomposed organic material or lignite. The organic matter can occur as finely disseminated particles, sand to pebble sized blebs, identifiable leaf or sea-grass fossils, laminations or as discrete beds. The top of the Avon Park Formation is at approximately 218 feet (66.4 meters) below land surface (BLS) in W-19480 (see OFMS 106, Plate 2, cross-section B-B').

Ocala Limestone

In contrast to the higher intensity gamma-ray signature of the Hawthorn Group, the Ocala Limestone is easily identified on the gamma-ray log. This unit characteristically produces the lowest gamma-ray intensity in the Eocene stratigraphic sequence and can be used as a low baseline for relative gamma-ray intensity (Davis et al., 2001).

In general, the Ocala Limestone has lower gamma-ray intensity than the underlying Avon Park Formation. In the study area, however, dolomitization of the Avon Park Formation and recrystallization of the lowermost Ocala Limestone has significantly altered the original rock lithology and fabric making the distinction of the gamma-ray signatures between these units more difficult. The presence of organics when at or near the top of Avon Park Formation (e.g., Figure 6) can assist in determining the contact between these two formations. The contrast between the sediments of the lower Penney Farms Formation and upper Ocala Limestone generally makes this an easy break to pick out on gamma-ray logs (Figure 6).

Hawthorn Group

The Hawthorn Group consists of a complex sequence of siliciclastics and carbonates with varying percentages of phosphate minerals. The resulting gamma-ray peaks are, in general, significantly higher than those of the formations above and below the Hawthorn Group, which makes this unit easily discernible on geophysical logs (Figure 6).

The Hawthorn Group in the study area consists of the Penney Farms, Marks Head and Coosawhatchie formations. The gamma-ray logs from the cores drilled for this study show a pattern of three generalized zones corresponding with these formations. However, the pattern shows a variation in the intensities and thickness of peak groups dependent on the lithologic variation of the sample. For example, in W-19480 (OFMS 105; Plate 2, cross-section B-B') the higher gamma-ray intensity zones at approximately 27-50 feet (8.2-15.2 meters) BLS correlate with the Coosawhatchie Formation. The Coosawhatchie Formation in this well consists primarily of siliciclastics with varying amounts of dolomitic clay and fine to pebble sized phosphate ranging in content between 3 and 15 percent. The second zone is a lower intensity gamma-ray zone of the Marks Head Formation (between 50-76 feet [15.2-23.2 meters] BLS) consisting of a well-indurated, light gray recrystallized dolosilt with 1 to 3 percent fine-to-medium phosphate. The third zone correlates with the Penney Farms Formation 76-97.7 feet (23.2-29.8 meters). The gamma log of the Penny Farms Formation shows an upper, high gamma-ray intensity zone consisting of sands, clays and dolosilts with 7 to 30 percent phosphate, followed by a low gamma-ray intensity zone consisting of clays and dolosilts with low phosphate content. The base of the Penny Farms in this core consists of a thin, hard dolomite with 7 to 10 percent phosphate which is represented on the log by a high intensity spike.

The Penney Farms Formation in this core is highly variable in lithology and phosphate content as reflected in the gamma-ray log. The Penney Farms Formation unconformably overlies the Ocala Limestone. At this contact, the gamma-ray log intensity drops significantly and the delineation of these two formations is readily apparent (Figure 6).

Pliocene/Pleistocene shelly sediments

In the study area east of the St. Johns River, undifferentiated Pliocene/Pleistocene shelly sediments (TQsu) lie unconformably over the Hawthorn Group, and below the undifferentiated Quaternary sediments (OFMS 106, Plate 2). Undifferentiated Pliocene/Pleistocene shelly sediments present in the mapped area may be highly variable in thickness and typically consist of fine to medium quartz sand with variable amounts of calcilutite, shell, phosphate and clay. Other accessory minerals may include calcite, aragonite, clay, mica and heavy minerals. The presence of phosphate and heavy minerals can cause spikes in the gamma-ray log making this unit readily distinguishable from the underlying Coosawhatchie Formation (Hawthorn Group).

DERIVATIVE PRODUCTS

Several derivative products will come from this project. During the mapping project, data from approximately three hundred wells with samples were analyzed. Formation picks, made on all available wells with cores and cuttings samples, allow creation of a structure contour map of the top of the FAS, along with the construction of structure contour and isopach maps of the IAS/ICU in the area. Additional derivative data anticipated to come from this mapping effort include aquifer vulnerability assessment maps. Data derived from prior STATEMAP products have often been used to augment other Florida Geological Survey and Florida aquifer vulnerability assessment (FAVA) projects in the state (Arthur et al., 2007; Baker et al., 2007).

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APPENDIX A: FGS WELLS UTILIZED FOR STUDY

This table lists FGS wells within the boundaries of the USGS Saint Augustine 30 x 60 minute quadrangle utilized for the top of rock model and/or geologic mapping. Due to graphical constraints, not all wells will appear on Plate 1 of OFMS 106. The first 38 wells in the table were utilized for geologic cross-sections and appear on Plates 1 and 2 of OFMS 106.

Map ID	Well Label	Data Source	Sample Type	Latitude	Longitude	24K Quad	Elevation (ft.)	Total Depth (ft.)
1	W-533	FGS	Cuttings	29.97248	-81.97971	KINGSLEY	163	658
2	W-537	FGS	Cuttings	29.93971	-81.97947	KINGSLEY	189	580
3	W-3478	FGS	Cuttings	29.96917	-81.69329	GREEN COVE SPRINGS	13	600
4	W-3901	FGS	Cuttings	29.71596	-81.7193	PALATKA	8	600
5	W-4972	FGS	Cuttings	29.62191	-81.89716	KEUKA	108	300
6	W-8400	FGS	Core	29.71351	-81.84449	BAYWOOD	211	302
7	W-12339	FGS	Cuttings	29.53858	-81.20673	BEVERLY BEACH	22	398
8	W-13744	FGS	Core	29.99413	-81.50214	PICOLATA	27	252
9	W-13746	FGS	Cuttings	29.96734	-81.30984	SAINT AUGUSTINE	13	240
10	W-13765	FGS	Core	29.98752	-81.45545	BAKERSVILLE	30	242
11	W-13769	FGS	Core	29.98389	-81.83417	PENNEY FARMS	95	319
12	W-13983	FGS	Cuttings	29.74468	-81.63833	PALATKA	41	440
13	W-14301	FGS	Core	29.872	-81.92028	GOLD HEAD BRANCH	164	252
14	W-14346	FGS	Core	29.73134	-81.89679	PUTNAM HALL	89	179
15	W-14354	FGS	Core	29.66667	-81.58334	HASTINGS	17	152
16	W-14476	FGS	Core	29.97615	-81.72222	GREEN COVE SPRINGS	63	425
17	W-14521	FGS	Core	29.8459	-81.65477	BOSTWICK	79	385
18	W-14566	FGS	Core	29.65831	-81.88104	PUTNAM HALL	97	226
19	W-14886	FGS	Cuttings	29.81454	-81.30592	SAINT AUGUSTINE BEACH	18	110
20	W-15183	FGS	Cuttings	29.72542	-81.95459	PUTNAM HALL	133	350
21	W-15253	FGS	Cuttings	29.97738	-81.39648	BAKERSVILLE	34	280
22	W-15282	FGS	Core	29.63722	-81.21083	MATANZAS INLET	6	462
23	W-16216	FGS	Cuttings	29.85444	-81.2896	SAINT AUGUSTINE BEACH	9	240
24	W-17173	FGS	Cuttings	29.53528	-81.5875	SAN MATEO	45	200
25	W-18254	FGS	Cuttings	29.87278	-81.65972	BOSTWICK	66	390
26	W-18283	FGS	Cuttings	29.94028	-81.68584	GREEN COVE SPRINGS	45	440
27	W-18527	FGS	Cuttings	29.5175	-81.9325	KEUKA	33	230
28	W-18532	FGS	Cuttings	29.58972	-81.57611	SAN MATEO	21	260
29	W-18534	FGS	Cuttings	29.87361	-81.28278	SAINT AUGUSTINE BEACH	9	95
30	W-18580	FGS	Core	29.71579	-81.23597	MATANZAS INLET	3	500
31	W-18819	FGS	Cuttings	29.97806	-81.86305	PENNEY FARMS	91	420
32	W-19434	FGS	Core	29.75528	-81.31194	SAINT AUGUSTINE BEACH	27	181
33	W-19435	FGS	Core	29.69278	-81.45	SPUDS	22	180
34	W-19450	FGS	Core	29.71363	-81.30077	DINNER ISLAND NE	24	200
35	W-19458	FGS	Core	29.87361	-81.28278	SAINT AUGUSTINE BEACH	9	700
36	W-19473	FGS	Core	29.6847	-81.25121	DINNER ISLAND NE	12	416
37	W-19480	FGS	Core	29.68281	-81.52512	HASTINGS	12	310
38	W-19488	FGS	Core	29.6925	-81.4503	SPUDS	24	193.5
39	W-136	FGS	Cuttings	29.97673	-81.81301	PENNEY FARMS	97	550
40	W-145	FGS	Cuttings	29.99344	-81.54733	PICOLATA	17	436
41	W-152	FGS	Cuttings	29.66945	-81.49583	SPUDS	16	320
42	W-179	FGS	Cuttings	29.53888	-81.84177	RODMAN	24	75
43	W-236	FGS	Cuttings	29.89278	-81.31583	SAINT AUGUSTINE	5	1440
44	W-237	FGS	Cuttings	29.89226	-81.31522	SAINT AUGUSTINE	5	265
45	W-321	FGS	Cuttings	29.82159	-81.9535	GOLD HEAD BRANCH	123	202
46	W-353	FGS	Cuttings	29.82159	-81.9535	GOLD HEAD BRANCH	149	181
47	W-482	FGS	Cuttings	29.97979	-81.98806	KINGSLEY	185	290
48	W-512	FGS	Cuttings	29.97979	-81.98806	KINGSLEY	188	522
49	W-534	FGS	Cuttings	29.96885	-81.97136	KINGSLEY	153	700
50	W-535	FGS	Cuttings	29.96149	-81.96296	KINGSLEY	153	680
51	W-536	FGS	Cuttings	29.9451	-81.97314	KINGSLEY	164	581
52	W-538	FGS	Cuttings	29.93976	-81.99635	KINGSLEY	221	718
53	W-539	FGS	Cuttings	29.93608	-81.99212	KINGSLEY	198	695
54	W-540	FGS	Cuttings	29.96971	-81.96407	KINGSLEY	151	685
55	W-613	FGS	Cuttings	29.85721	-81.97256	GOLD HEAD BRANCH	213	560

Map ID	Well Label	Data Source	Sample Type	Latitude	Longitude	24K Quad	Elevation (ft.)	Total Depth (ft.)
56	W-617	FGS	Cuttings	29.95968	-81.9734	KINGSLEY	164	766
57	W-867	FGS	Cuttings	29.87197	-81.34769	SAINT AUGUSTINE BEACH	34	115
58	W-1120	FGS	Cuttings	29.59847	-81.6422	SATSUMA	0	21.1
59	W-1122	FGS	Cuttings	29.53229	-81.68233	SATSUMA	26	45.1
60	W-1123	FGS	Cuttings	29.53229	-81.68233	SATSUMA	26	116
61	W-1126	FGS	Core	29.504	-81.91187	KEUKA	15	129
62	W-1127	FGS	Core	29.5065	-81.91882	KEUKA	28	91
63	W-1440	FGS	Cuttings	29.55788	-81.49823	DINNER ISLAND	19	1822
64	W-1480	FGS	Cuttings	29.59641	-81.56889	SAN MATEO	36	150
65	W-1481	FGS	Cuttings	29.90694	-81.49028	BAKERSVILLE	18	140
66	W-1488	FGS	Cuttings	29.53229	-81.68233	PALATKA	12	230
67	W-1496	FGS	Cuttings	29.60197	-81.56272	SAN MATEO	29	165
68	W-1498	FGS	Cuttings	29.62668	-81.79722	BAYWOOD	79	190
69	W-1512	FGS	Cuttings	29.62214	-81.58461	HASTINGS	17	155
70	W-1514	FGS	Cuttings	29.70478	-81.74413	BAYWOOD	203	3328
71	W-1803	FGS	Cuttings	29.83883	-81.97639	GOLD HEAD BRANCH	191	55
72	W-1804	FGS	Cuttings	29.65291	-81.87064	BAYWOOD	112	65
73	W-1805	FGS	Cuttings	29.65291	-81.87064	BAYWOOD	112	65
74	W-1806	FGS	Cuttings	29.65291	-81.87064	BAYWOOD	112	65
75	W-1807	FGS	Cuttings	29.65291	-81.87064	BAYWOOD	112	65
76	W-1838	FGS	Cuttings	29.53229	-81.68233	SATSUMA	21	3892
77	W-2753	FGS	Cuttings	29.96917	-81.69329	GREEN COVE SPRINGS	6	670
78	W-2898	FGS	Cuttings	29.94063	-81.9827	KINGSLEY	220	757
79	W-2903	FGS	Cuttings	29.95413	-81.96709	KINGSLEY	160	660
80	W-2907	FGS	Cuttings	29.99241	-81.69998	GREEN COVE SPRINGS	25	600
81	W-3058	FGS	Cuttings	29.71589	-81.51056	HASTINGS	7	110
82	W-3636	FGS	Cuttings	29.71376	-81.73799	PALATKA	30	740
83	W-3748	FGS	Cuttings	29.71895	-81.74018	PALATKA	18	740
84	W-3856	FGS	Cuttings	29.71265	-81.70689	PALATKA	3	590
85	W-3902	FGS	Cuttings	29.73006	-81.71116	PALATKA	11	600
86	W-3903	FGS	Cuttings	29.73353	-81.71119	PALATKA	20	700
87	W-3954	FGS	Cuttings	29.50889	-81.93667	KEUKA	62	85
88	W-3955	FGS	Cuttings	29.5062	-81.93552	KEUKA	71	168
89	W-3980	FGS	Cuttings	29.71861	-81.81506	BAYWOOD	124	266
90	W-4000	FGS	Cuttings	29.7276	-81.75494	PALATKA	25	1000
91	W-4047	FGS	Cuttings	29.52307	-82.02532	KEUKA	96	170
92	W-4060	FGS	Cuttings	29.50889	-81.86667	RODMAN	114	142
93	W-4061	FGS	Cuttings	29.7096	-81.58555	HASTINGS	16	148
94	W-4244	FGS	Cuttings	29.89899	-81.35458	SAINT AUGUSTINE	36	60
95	W-4245	FGS	Cuttings	29.8988	-81.35434	SAINT AUGUSTINE	38	60
96	W-4485	FGS	Cuttings	29.82545	-81.97005	GOLD HEAD BRANCH	183	460
97	W-4978	FGS	Cuttings	29.62525	-81.36975	DINNER ISLAND NE	38	622
98	W-5014	FGS	Cuttings	29.79933	-81.45314	ELKTON	28	350
99	W-5019	FGS	Cuttings	29.56264	-81.33388	ESPANOLA	46	112
100	W-5020	FGS	Cuttings	29.80552	-81.5784	RIVERDALE	3	238
101	W-5022	FGS	Cuttings	29.62164	-81.90967	KEUKA	127	533
102	W-5025	FGS	Cuttings	29.73006	-81.63828	PALATKA	72	279
103	W-5026	FGS	Cuttings	29.64064	-81.7043	PALATKA	69	256
104	W-5027	FGS	Cuttings	29.71198	-81.82134	BAYWOOD	126	266
105	W-5028	FGS	Cuttings	29.65668	-81.57639	HASTINGS	16	547
106	W-5030	FGS	Cuttings	29.53229	-81.68233	SATSUMA	28	66
107	W-5032	FGS	Cuttings	29.72709	-81.47749	SPUDS	15	414
108	W-5033	FGS	Cuttings	29.50848	-81.49507	SAN MATEO	0	100
109	W-5035	FGS	Cuttings	29.56053	-81.16784	BEVERLY BEACH	1	152
110	W-5036	FGS	Cuttings	29.51608	-81.39743	DINNER ISLAND	0	167.5
111	W-5041	FGS	Cuttings	29.55944	-81.26792	ESPANOLA	36	136
112	W-5042	FGS	Cuttings	29.94068	-81.48501	BAKERSVILLE	22	412.3
113	W-5043	FGS	Cuttings	29.73489	-81.99439	PUTNAM HALL	107	131
114	W-5162	FGS	Cuttings	29.8216	-81.99085	GOLD HEAD BRANCH	171	39
115	W-5164	FGS	Cuttings	29.7818	-81.94888	GOLD HEAD BRANCH	95	25
116	W-5166	FGS	Cuttings	29.74924	-81.98199	PUTNAM HALL	117	39
117	W-5168	FGS	Cuttings	29.84461	-81.92037	GOLD HEAD BRANCH	150	14
118	W-5172	FGS	Cuttings	29.98001	-81.92097	KINGSLEY	150	16
119	W-5173	FGS	Cuttings	29.9767	-81.86204	PENNEY FARMS	91	24

Map ID	Well Label	Data Source	Sample Type	Latitude	Longitude	24K Quad	Elevation (ft.)	Total Depth (ft.)
120	W-5174	FGS	Cuttings	29.85915	-81.94563	GOLD HEAD BRANCH	206	38
121	W-5175	FGS	Cuttings	29.89942	-81.89966	KINGSLEY	111	16
122	W-5176	FGS	Cuttings	29.92506	-81.89542	KINGSLEY	92	18
123	W-5179	FGS	Cuttings	29.77446	-81.98215	GOLD HEAD BRANCH	135	44
124	W-5321	FGS	Cuttings	29.77444	-81.98628	GOLD HEAD BRANCH	116	249
125	W-5347	FGS	Cuttings	29.86849	-81.7812	RICE CREEK	100	319
126	W-5627	FGS	Cuttings	29.60683	-81.99679	KEUKA	82	150
127	W-5959	FGS	Cuttings	29.62214	-81.58461	SAN MATEO	22	126
128	W-5963	FGS	Cuttings	29.65462	-81.66468	PALATKA	31	210
129	W-6452	FGS	Cuttings	29.756	-81.78818	RICE CREEK	88	1000
130	W-6549	FGS	Cuttings	29.75764	-81.79815	RICE CREEK	92	1000
131	W-6568	FGS	Cuttings	29.75357	-81.77286	RICE CREEK	36	171
132	W-6643	FGS	Cuttings	29.77252	-81.7935	RICE CREEK	46	1404
133	W-6914	FGS	Cuttings	29.64185	-81.60522	HASTINGS	11	249.5
134	W-7515	FGS	Cuttings	29.87851	-81.46975	BAKERSVILLE	23	105
135	W-7873	FGS	Cuttings	29.50612	-81.95194	KEUKA	45	100
136	W-7995	FGS	Cuttings	29.93188	-81.75581	PENNEY FARMS	116	100
137	W-8498	FGS	Cuttings	29.62778	-81.63177	PALATKA	16	415
138	W-10307	FGS	Core	29.5058	-81.88453	KEUKA	15	130
139	W-10481	FGS	Core	29.87506	-81.70526	GREEN COVE SPRINGS	91	108
140	W-10637	FGS	Cuttings	29.78233	-81.30851	SAINT AUGUSTINE BEACH	26	755
141	W-10653	FGS	Cuttings	29.95274	-81.40752	BAKERSVILLE	35	4850
142	W-10797	FGS	Cuttings	29.97622	-81.70602	GREEN COVE SPRINGS	61	640
143	W-10947	FGS	Cuttings	29.97622	-81.70602	GREEN COVE SPRINGS	64	1120
144	W-11044	FGS	Cuttings	29.97622	-81.70602	GREEN COVE SPRINGS	64	1045
145	W-11084	FGS	Cuttings	29.8498	-81.45296	ELKTON	28	4584
146	W-11326	FGS	Cuttings	29.59375	-81.96951	KEUKA	80	160
147	W-11414	FGS	Cuttings	29.92056	-81.33833	SAINT AUGUSTINE	3	300
148	W-11722	FGS	Cuttings	29.55056	-81.25174	ESPANOLA	31	250
149	W-12382	FGS	Cuttings	29.55679	-81.21758	BEVERLY BEACH	22	330
150	W-13351	FGS	Cuttings	29.96456	-81.49072	BAKERSVILLE	23	250
151	W-13440	FGS	Cuttings	29.53602	-81.2421	BEVERLY BEACH	28	86
152	W-13532	FGS	Cuttings	29.86696	-81.32758	SAINT AUGUSTINE BEACH	31	65
153	W-13585	FGS	Cuttings	29.82444	-81.32088	SAINT AUGUSTINE BEACH	9	58
154	W-13586	FGS	Cuttings	29.82441	-81.32088	SAINT AUGUSTINE BEACH	9	58
155	W-13710	FGS	Cuttings	29.52415	-81.71362	SATSUMA	18	3903
156	W-13844	FGS	Core	29.66917	-81.25889	DINNER ISLAND NE	8	178
157	W-13984	FGS	Cuttings	29.74468	-81.63833	PALATKA	41	440
158	W-14105	FGS	Cuttings	29.92008	-81.41562	BAKERSVILLE	44	110
159	W-14306	FGS	Cuttings	29.5375	-81.25222	ESPANOLA	28	134
160	W-14353	FGS	Core	29.51126	-81.66266	SATSUMA	86	165
161	W-14376	FGS	Core	29.62214	-81.58334	SAN MATEO	7	252
162	W-14393	FGS	Cuttings	29.67122	-81.68794	PALATKA	1	300
163	W-14413	FGS	Core	29.79389	-81.49389	ELKTON	20	258
164	W-14452	FGS	Cuttings	29.95035	-81.38397	BAKERSVILLE	35	100
165	W-14453	FGS	Cuttings	29.96955	-81.39217	BAKERSVILLE	37	100
166	W-14477	FGS	Core	29.77483	-81.57153	RIVERDALE	13	237
167	W-14560	FGS	Cuttings	29.73006	-81.63828	PALATKA	76	550
168	W-14964	FGS	Cuttings	29.51752	-81.28121	ESPANOLA	28	305
169	W-14965	FGS	Cuttings	29.50321	-81.29755	ESPANOLA	28	220
170	W-14966	FGS	Cuttings	29.51746	-81.28114	ESPANOLA	28	220
171	W-14967	FGS	Cuttings	29.49992	-81.27909	BUNNELL	27	220
172	W-14968	FGS	Cuttings	29.50411	-81.2666	ESPANOLA	28	220
173	W-14971	FGS	Cuttings	29.56861	-81.29529	ESPANOLA	31	100
174	W-14972	FGS	Cuttings	29.54918	-81.27306	ESPANOLA	31	100
175	W-14973	FGS	Cuttings	29.55486	-81.28152	ESPANOLA	31	100
176	W-14974	FGS	Cuttings	29.56706	-81.27814	ESPANOLA	35	100
177	W-14975	FGS	Cuttings	29.56477	-81.28375	ESPANOLA	31	90
178	W-14976	FGS	Cuttings	29.55486	-81.28152	ESPANOLA	31	110
179	W-14977	FGS	Cuttings	29.54761	-81.27753	ESPANOLA	28	100
180	W-14978	FGS	Cuttings	29.54742	-81.26839	ESPANOLA	28	80
181	W-14979	FGS	Cuttings	29.54104	-81.26643	ESPANOLA	28	100
182	W-14990	FGS	Cuttings	29.88054	-81.42018	BAKERSVILLE	45	94
183	W-14997	FGS	Cuttings	29.87664	-81.4241	BAKERSVILLE	40	95

Map ID	Well Label	Data Source	Sample Type	Latitude	Longitude	24K Quad	Elevation (ft.)	Total Depth (ft.)
184	W-15039	FGS	Cuttings	<Null>	<Null>	PALATKA	11	300
185	W-15254	FGS	Cuttings	29.98688	-81.40313	BAKERSVILLE	33	120
186	W-15255	FGS	Cuttings	29.97572	-81.39542	BAKERSVILLE	36	380
187	W-15256	FGS	Cuttings	29.95421	-81.38528	BAKERSVILLE	38	105
188	W-15257	FGS	Cuttings	29.96205	-81.38839	BAKERSVILLE	37	120
189	W-15258	FGS	Cuttings	29.95819	-81.38648	BAKERSVILLE	37	100
190	W-15657	FGS	Core	29.53477	-81.57167	SAN MATEO	0	96
191	W-16167	FGS	Cuttings	29.62357	-81.90345	KEUKA	125	310
192	W-16168	FGS	Cuttings	29.92004	-81.35806	SAINT AUGUSTINE	28	100
193	W-16176	FGS	Cuttings	29.77691	-81.43435	ELKTON	34	160
194	W-16210	FGS	Cuttings	29.8896	-81.63848	GREEN COVE SPRINGS	13	340
195	W-16220	FGS	Cuttings	29.82118	-81.38541	ELKTON	42	100
196	W-16230	FGS	Cuttings	29.71806	-81.50025	HASTINGS	1	180
197	W-16807	FGS	Cuttings	29.62959	-81.53231	HASTINGS	25	400
198	W-17059	FGS	Cuttings	29.81972	-81.95722	GOLD HEAD BRANCH	130	350
199	W-17152	FGS	Cuttings	29.70222	-81.45834	SPUDS	19	245
200	W-17547	FGS	Cuttings	29.5175	-81.75139	RODMAN	24	21.5
201	W-17611	FGS	Core	29.87387	-81.41584	ELKTON	41	100
202	W-17698	FGS	Cuttings	29.77651	-81.28619	SAINT AUGUSTINE BEACH	19	26
203	W-17699	FGS	Cuttings	29.77139	-81.28472	SAINT AUGUSTINE BEACH	2	22
204	W-17784	FGS	Cuttings	29.63167	-81.69195	PALATKA	59	146
205	W-17932	FGS	Cuttings	29.95917	-81.61528	PICOLATA	7	201
206	W-18008	FGS	Cuttings	29.54389	-81.72916	SATSUMA	27	51
207	W-18011	FGS	Cuttings	29.53555	-81.55417	SAN MATEO	0	90
208	W-18016	FGS	Cuttings	29.95917	-81.61528	PICOLATA	7	1177
209	W-18017	FGS	Cuttings	29.63194	-81.69139	PALATKA	59	280
210	W-18177	FGS	Cuttings	29.87722	-81.92694	KINGSLEY	170	187
211	W-18221	FGS	Cuttings	29.87722	-81.92694	KINGSLEY	170	340
212	W-18275	FGS	Cuttings	29.83333	-81.3575	SAINT AUGUSTINE BEACH	26	290
213	W-18280	FGS	Cuttings	29.56833	-81.65222	SATSUMA	56	500
214	W-18294	FGS	Cuttings	29.83333	-81.3575	SAINT AUGUSTINE BEACH	26	195
215	W-18382	FGS	Cuttings	29.93444	-81.37639	BAKERSVILLE	36	800
216	W-18383	FGS	Core	29.7225	-81.8225	BAYWOOD	158	200
217	W-18384	FGS	Cuttings	29.93444	-81.37639	BAKERSVILLE	36	200
218	W-18385	FGS	Cuttings	29.80029	-81.80793	RICE CREEK	87	125
219	W-18433	FGS	Cuttings	29.80445	-81.80611	RICE CREEK	98	215
220	W-18483	FGS	Cuttings	29.54111	-81.83139	RODMAN	24	210
221	W-18526	FGS	Core	29.50803	-81.16203	BEVERLY BEACH	18	139
222	W-18528	FGS	Core	29.5175	-81.9325	KEUKA	33	160
223	W-18530	FGS	Core	29.82389	-81.55334	RIVERDALE	4	195
224	W-18531	FGS	Cuttings	29.82389	-81.55334	RIVERDALE	4	260
225	W-18533	FGS	Cuttings	29.98417	-81.56111	PICOLATA	16	211
226	W-18582	FGS	Cuttings	29.98416	-81.56088	PICOLATA	16	340
227	W-18785	FGS	Cuttings	29.8742	-81.41635	ELKTON	42	695
228	W-18786	FGS	Cuttings	29.8742	-81.41635	ELKTON	42	450
229	W-18787	FGS	Cuttings	29.8742	-81.41635	ELKTON	42	475
230	W-18788	FGS	Cuttings	29.97888	-81.48952	BAKERSVILLE	27	750
231	W-18789	FGS	Cuttings	29.95738	-81.52483	PICOLATA	12	475
232	W-18790	FGS	Cuttings	29.8804	-81.41738	BAKERSVILLE	40	460
233	W-18791	FGS	Cuttings	29.89183	-81.4226	BAKERSVILLE	40	455
234	W-18792	FGS	Cuttings	29.88085	-81.40932	BAKERSVILLE	37	450
235	W-18793	FGS	Cuttings	29.88002	-81.4251	BAKERSVILLE	40	455
236	W-18825	FGS	Cuttings	29.50805	-81.16202	BEVERLY BEACH	18	290
237	W-19040	FGS	Cuttings	29.94363	-81.38018	BAKERSVILLE	33	500
238	W-19042	FGS	Cuttings	29.88049	-81.41846	BAKERSVILLE	42	425
239	W-19423	FGS	Cuttings	29.53722	-81.20556	BEVERLY BEACH	20	144
240	W-19436	FGS	Cuttings	29.90722	-81.49	BAKERSVILLE	16	201
241	W-19457	FGS	Core	29.6511	-81.3219	DINNER ISLAND NE	29	340