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DEPARTMENT OF ENVIRONMENTAL PROTECTION

Jonathan P. Steverson, *Secretary*

REGULATORY PROGRAMS

Paula Cobb, *Deputy Secretary*

FLORIDA GEOLOGICAL SURVEY

Jonathan D. Arthur, *State Geologist and Director*



OPEN-FILE REPORT 105

**Text to accompany geologic map of the
USGS Jacksonville 30 x 60 minute quadrangle, Northeast Florida
(Open-File Map Series 108)**

By

Richard C. Green, Christopher P. Williams, P.G., Philip W. Bambach, Brianne Apolinar, Levi
M. Hannon, and Katherine M. White

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Richard C. Green (P.G. No. 1776), Christopher P. Williams, Philip W. Bambach, Brianne Apolinar, Levi M. Hannon, and Katherine M. White

ABSTRACT

The accompanying 1:100,000 scale geologic map (Open-File Map Series 108, Plate 1) depicts the areal distribution of bedrock and surficial geologic units for the U.S. Geological Survey (USGS) Jacksonville 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™ 10.3.1 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, and clay. Several springs, subsidence features, 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, and protection of springs, hazard mitigation planning, surface and groundwater quality.

Keywords: Florida, geologic map, Avon Park Formation, Ocala Limestone, Hawthorn Group, Penney Farms Formation, Marks Head Formation, Coosawhatchie Formation, Charlton Member, Cypresshead Formation, geomorphology, hydrogeology, springs, karst, sinkholes, Floridan aquifer system, Clay County, Duval County, Nassau County, St. Johns County, Jacksonville.

INTRODUCTION

Florida Geological Survey (FGS) Open-File Report (OFR) 105 accompanies Open-File Map Series (OFMS) 108, which is comprised of three plates. Plate 1 depicts the near-surface geology of the USGS Jacksonville 30 x 60 minute quadrangle on a digital elevation model (DEM). Plate 2 depicts six geologic cross-sections, a stratigraphic correlation chart, and representative photos for several of the lithologic units in the study area. Plate 3 depicts a geomorphology map, a DEM showing locations of known springs and subsidence features, and an inset detail of selected geomorphic features within the study area.

The study area is located along the Atlantic Ocean coastline of Florida (Figure 1). It includes the communities of Jacksonville, Jacksonville Beach, and Orange Park. The quadrangle, which includes portions of Clay, Duval, Nassau and St. Johns Counties, is bounded to the west by the USGS Lake City 30 x 60 minute quadrangle, to the south by the USGS Saint Augustine 30 x 60 minute quadrangle, previously mapped under the STATEMAP program (Green et al., 2014a,

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2014b) and to the north by the USGS Fernandina Beach 30 x 60 minute quadrangle (Figure 1). The Arlington, Broward, Guana, St. Johns, St. Marys, Tolomato and Trout rivers, along with several creeks and springs, occur in the map area (OFMS 108, Plate 1).

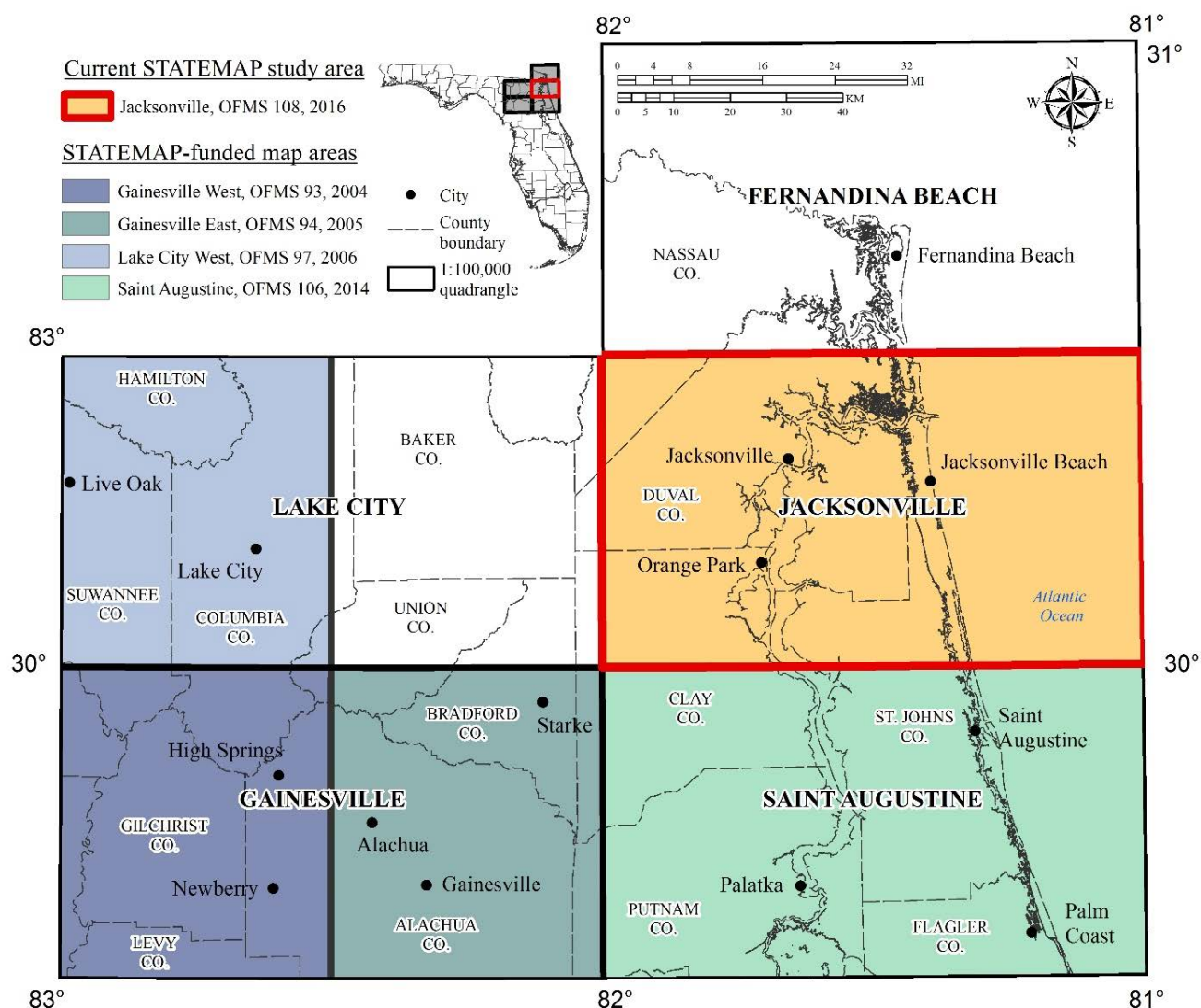


Figure 1. Nearby areas mapped under the FGS STATEMAP Program.

One objective for this report is to provide basic geologic information for the accompanying OFMS 108. Information provided by this report and the plates in OFMS 108 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, 6) hazard mitigation planning, and 7) 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 2015 through the summer of 2016, consisted of sampling and describing numerous outcrops, river and borrow-pit exposures, and drilling of new cores.

Fifteen new samples of geologic material were added to the FGS surface-sample archives (M-Series) and three cores (989.5 feet or 301.6 meters total) were drilled for the project. Approximately 40 outcrops and exposures were also examined during the project. In addition to new cores collected for this study, approximately 200 sets of cores and cuttings archived in the Florida Geological Survey sample repository were examined and formation contacts were picked for mapped geologic units. Appendix A includes FGS wells with core and/or cuttings samples which were examined by the authors, used for formation surface models, or for determining the geologic surface and subsurface formations. Interpolated surface models were developed using kriging along with a Digital Elevation Model (DEM) to generate an overburden thickness model for several units. The map and accompanying plates were developed in ESRI® ArcGIS® ArcMap™ 10.3 software for publication as part of OFMS 108.

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 more coarse elevation model, based off of topographic contours, with a horizontal resolution of 100 feet (30.5 meters). LiDAR coverage exists for the entirety of Duval and St. Johns counties, 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 Nassau 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™ 10.3 (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 more coarse, 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 had 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 Clay County and southern Duval County (OFMS 108; Plate 3, Figure 2).

Along with the mosaicked elevation model, a bathymetric surface was generated for the Atlantic Ocean and St. Johns River portions of the quadrangle. Bathymetric elevations were derived from NOAA navigational charts at a 1:24,000 scale. USGS five-foot contours, the NOAA bathymetric elevation points, and the Florida Fish and Wildlife Conservation Commission

shoreline were used in the Topo to Raster tool in ArcGIS to generate an elevation surface. The Topo to Raster tool is primarily designed to map elevation surfaces because of its ability to interpolate contour and point elevations. The tool allows for changes in elevation values that are influenced by terrain changes, making surfaces more characteristic of actual terrain. Once the bathymetric surface was generated, smoothing techniques were used to average the cell values. Bathymetric contours were then generated at two meter intervals.

As a preliminary step for modeling, points from each of the datasets (cores and cuttings) 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 50 or more feet from surrounding points were then removed from the dataset.

An ordinary kriging method was then 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 30, or less than negative 30, were discarded in order to improve the final model performance. The lack of quality samples in the area caused discrepancies among the unit surfaces. With sample intervals as large as 30 feet, a standardized error of 30 or negative 30 helped to alleviate large fluxes of predicted unit surface elevations.

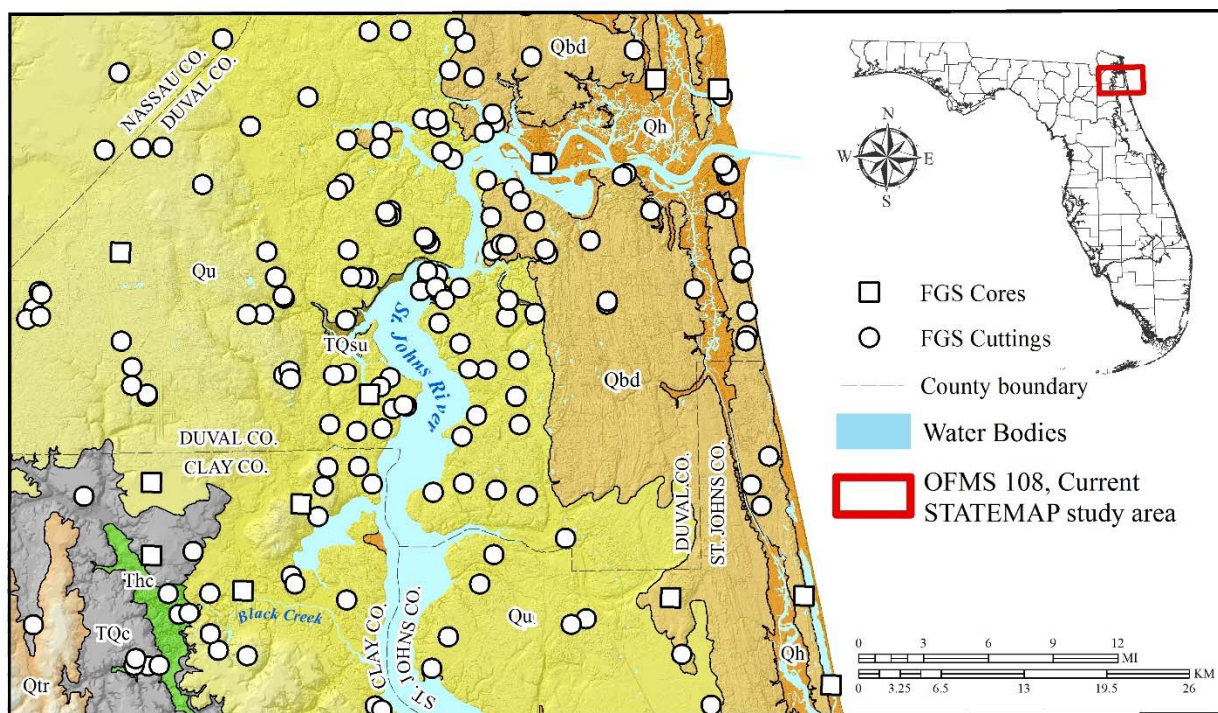


Figure 2. FGS cores (squares) and cuttings (circles) utilized for project. See discussion starting on page 12 for lithostratigraphic unit abbreviations and descriptions.

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 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 108, Plate 1) and geologic cross sections (OFMS 108, 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 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 and 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), Duval, (Scott, 1992b), Nassau, (Scott, 1992c), and St. Johns (Scott, 1992d) 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. Huddleston (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 St. Augustine 30 x 60 minute quadrangle (Green et al., 2014a; Green et al., 2014b). Williams et al., (2016, in review) mapped detailed geomorphology and geology for five quadrangles along the eastern edge of the study area as part of work on several National Park Service units in northeastern Florida. A variety of field relationships and stratigraphic problems were worked out during these projects and the data gathered while working on them proved invaluable to the completion of this project.

GEOLOGIC SUMMARY

The near surface geology of the USGS 30 x 60 minute Jacksonville 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 Jacksonville quadrangle is the Middle Miocene Coosawhatchie Formation of the Hawthorn Group (Thc; Figure 4). Several outcrops were sampled

along Black Creek and its tributaries (see OFMS 108, Plate 1). Additionally, 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 the north and south forks of Black Creek east of Trail Ridge.

Detailed description of the lithology of all units found in the study area begins on page 12 of this publication. Along with lithologic descriptions, several diagnostic foraminifera and echinoids aided in distinguishing Ocala Limestone from the underlying Avon Park Formation. The Avon Park Formation contains *Cushmania* [*Dictyoconus*] *americana* and *Discorinopsis gunteri* which were not found in the Ocala Limestone. The occurrence of *Nummulites* spp. and *Lepidocyclina* spp. in the Ocala Limestone occasionally helped to distinguish it from the Avon Park Formation in the mapped area.

Much of the Jacksonville quadrangle is located within the Lower St. Johns River Basin, with smaller parts of the mapped area in the Nassau, St. Marys and Upper East Coast River Basins (Figure 3). There are several springs within the study area, including five in Clay County, two in Duval County, and one in Nassau County. Portions of the recharge areas for many of the aforementioned springs are located within the study area. Many of the springs in Florida have shown significant increases in pollutants in the last few decades, particularly nitrate (Scott et al., 2002; Scott, et al., 2004; 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 as well.

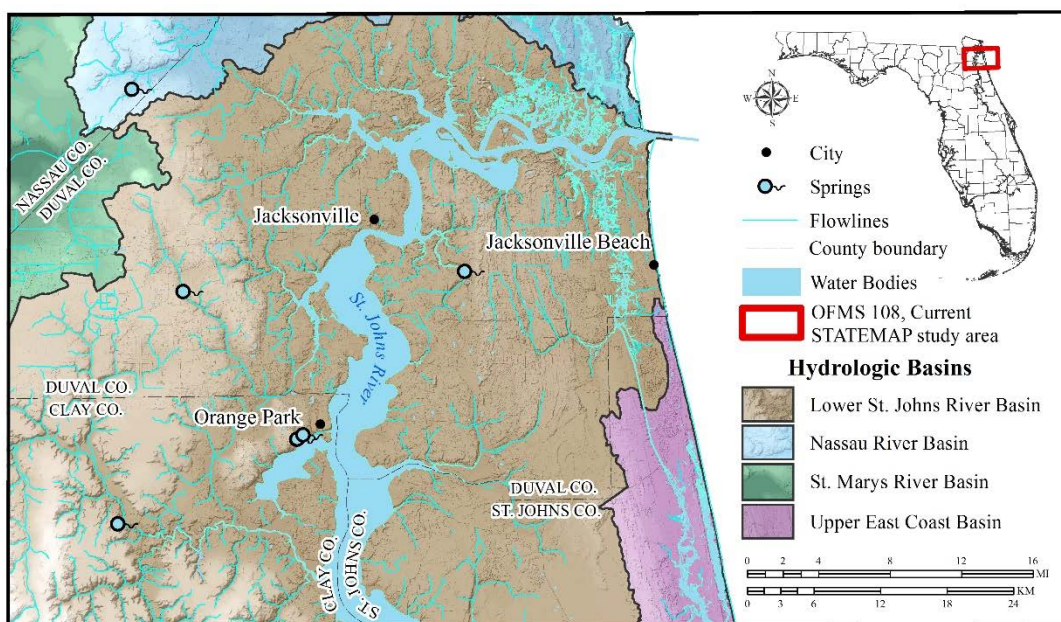


Figure 3. Location of selected river basins, springs and other water bodies.

Structure

Several structural features have affected the geology of the region (Figure 4). The Peninsular Arch, a structurally high area which influenced 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; 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 and has a northwest to southeast trend. The crest of the arch passes beneath Alachua County and is highest in Columbia 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). This feature formed a 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 St. Johns Platform, introduced by Riggs (1979a, 1979b), extends northward from the Sanford High into St. Johns County just south of the study area. This platform, which is expressed on the erosional surface of the Ocala Limestone, dips gently north-northwest towards the Jacksonville Basin (Scott, 1983).

The Jacksonville Basin, named by Goodell and Yon (1960), is the most prominent low in northeast Florida (Scott, 1988). According to Scott, (1983), this was likely a shallow basin in late Eocene time while the Ocala Limestone was being deposited. The influence of the Jacksonville Basin is evident throughout the map area (OFMS 108; Plate 2). The Hawthorn Group thickens towards the basin which contains over 400 feet (121.9 meters) of Hawthorn Group sediments in the deepest part within the study area (OFMS 108, Plate 2). Leve (1965) thought that the basin was, at least in part, fault controlled.

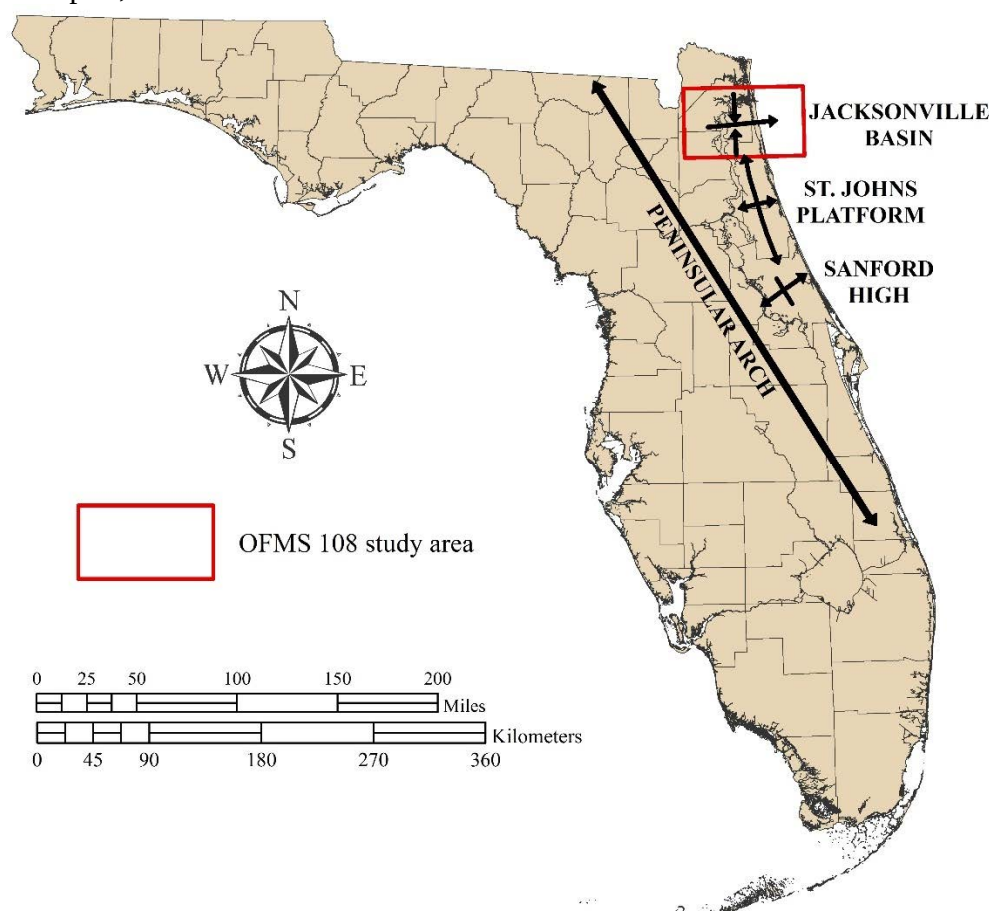


Figure 4. Principal subsurface structures of north Florida (modified from Scott, 1988).

Geomorphology

The Florida Geological Survey is producing a new statewide geomorphic map of Florida (Williams et al., in preparation). The new map synthesizes over a century of geomorphic writings and maps about Florida. *The Geomorphology of the Florida Peninsula* (White, 1970), in addition to significant work by former Assistant State Geologist for Florida, Thomas Scott, are central to the new statewide map. More recent data and technology, particularly the addition of significant coverage of LiDAR data and new possibilities for digital geomorphological mapping that employ spatio-temporal and geocomputational approaches to data, are allowing the FGS to revise nomenclature and refine boundaries for some units in Florida. In the section which follows, all geomorphology unit names and discussions are from Williams et al. (in preparation).

This new map will divide the geomorphology into regional units (districts) and sub-regional to local units (terrains; Figure 5). Districts are defined by regional groupings in which the geomorphology and near-surface geology are combined to form map polygons that are distinct from adjacent districts. Definition of the more localized terrains and their morphologies are important for the characterization of the districts. Given the prevalence of karst, paleo-shoreline, marine erosion and deposition in Florida, these processes are significant to the identification of both terrains and districts. Several of the northern Florida district names are a continuation of naming conventions used in previous work in Georgia (Clark and Zisa, 1976).

Based on the work of Williams et al., (in preparation), the study area falls within a single geomorphic district: the Barrier Island Sequence District (OFMS 108; Plate 3, Figure 3). This district is further subdivided into six terrains: the Atlantic Coastal Complex, the Duval Upland, the Sea Islands, the Lower St. Johns River Valley, the St. Marys Plain, and Trail Ridge (Figure 5). The geomorphic units listed below are discussed in alphabetical, not geographical, order.

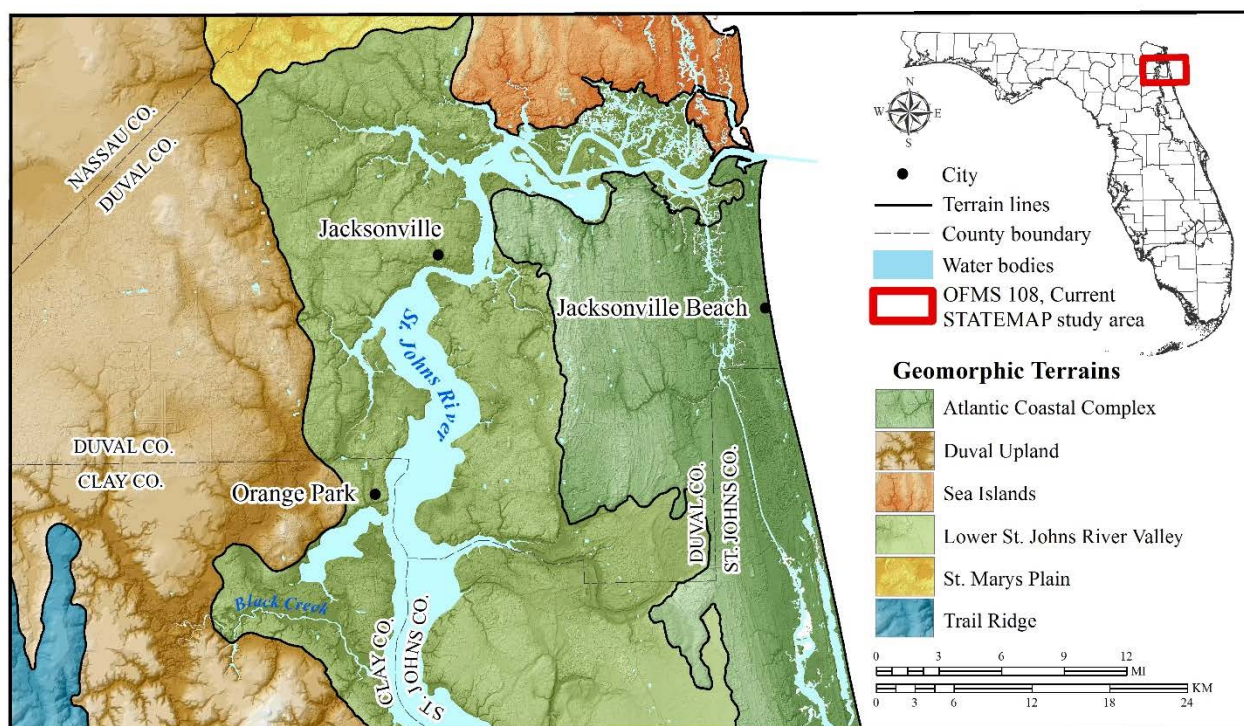


Figure 5. Geomorphic Terrains in the study area (after Williams et al., in preparation).

Barrier Island Sequence District

The Barrier Island Sequence District extends into Florida from Georgia (Clark and Zisa, 1976). The district is characterized by beach ridges, dunes, and paleo-lagoons. Its Florida extent begins at the Georgia-Florida state line in northeastern Florida, and continues southward to the region east of Lake Okeechobee. It lies east of the Okefenokee Basin District, the Central Lakes District, and north of the eastern portion of the Everglades District. The surficial and shallow subsurface sediments of the district were deposited during the Plio-Pleistocene and lie unconformably on sediments ranging from the Middle Eocene Avon Park Formation to the Oligocene-Miocene Hawthorn Group. Elevations within the study area range from sea level to nearly 260 feet (79.2 meters) above mean sea level (MSL).

Beach ridge plains occur in two main areas of the Barrier Island Sequence District within the study area: the Duval Upland and the Atlantic Coastal Complex. Drainage patterns in these areas may be strongly controlled by the relict beach ridges forming, in some cases, a distinct trellis drainage pattern. 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 in the headwaters of the St. Johns River. One such paleo-lagoon lies between the Atlantic Coastal Complex to the east and a prominent erosional scarp and the Osceola Plain on the west. The scarp toe occurs at approximately 30 feet (9.1 meters) MSL and extends 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. The lagoon can be recognized from southern Flagler County to as far north as the vicinity of Jacksonville.

Shallow depressions, generally only a few feet (one meter) deep, are found throughout much of the Barrier Island Sequence District. The depressions are most numerous in the southernmost part of this district and decrease in abundance toward the north. The depressions are likely the result of dissolution of shell material incorporated in the sediments. The percentage of shell in the sediment is greatest in southern Florida. Also, in the southern portion of the state, the sediment contains more fine-grained carbonate and less clay. As a result, the sediment is more permeable and more soluble. The depressions formed cover subsidence sinkholes as the uppermost shell material dissolved, allowing the land surface to slowly subside. In northern Florida, these features, though not common, are most often associated with the Anastasia Formation outcrops and subcrops near the Atlantic Ocean coastline.

Atlantic Coastal Complex

The Atlantic Coastal Complex extends from the St. Johns River in Duval County to central Palm Beach County (OFMS 108, Plate 3, Figure 4). In the map area, the terrain consists of Pliocene through recent barrier beach ridges and dunes. Many of these features are coast parallel and numerous rivers, creeks, swamps, and wetlands are established in the swales between barrier beach ridges. Surface water drainage is often within the broad scale development of trellis drainage common to much of the Atlantic Coastal Complex. Elevations range from sea level to 115 feet (35.1 meters) MSL within the study area. Adjacent to the recent beaches on the Atlantic Ocean coastline, construction of the Intracoastal Waterway, at times, separates the modern barrier island

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from the mainland to the west. Many portions of the modern barrier islands are separated from the mainland by the estuaries along the Atlantic Ocean coastline. The segment connecting San Pablo Creek to the Tolomato River created open water through former salt marsh between the beach and the beach ridge plain uplands to the west. The terrain has varying thickness of undifferentiated Quaternary sediments (Qu) and undifferentiated Tertiary and Quaternary shelly sediments (TQsu) within the study area.

Duval Upland

The Duval Upland is a broad feature extending from Putnam County in the south to Nassau County and the Florida-Georgia boundary along the St. Marys River in the north (OFMS 108, 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. It is underlain by sediments of the Pliocene-Pleistocene Cypresshead Formation along the southern portion of the study area and undifferentiated Quaternary sediments (Qu) along the northern portion of the study area. Notably, across the Duval Upland, mixed dendritic and trellis drainage reveal that, at least in part, this terrain was originally deposited having some aspect of ridge and swale topography akin to the Atlantic Coastal Complex. This affinity is why the Duval Upland terrain is included within the Barrier Island Sequence District. Locally, elevations range from sea level along Black Creek to approximately 140 feet (42.7 meters) above MSL.

Lower St. Johns River Valley

The Lower St. Johns River Valley has been hypothesized by Scott (2013, personal communication) to be part of a paleo-lagoon. The relict lagoon feature extends nearly continuously from the headwaters of the St. Johns River in Martin and Saint Lucie counties, north to central Duval County (OFMS 108, Plate 3, Figure 4). In Volusia County, the paleo-lagoon is either 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 (Green, et al., 2013a and Green, et al., 2013b). 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. A combination of beach ridge uplands and low elevation drainage divides separate the Lower St. Johns River Valley from the St. Marys Plain associated with the Nassau and St. Marys rivers. Within the study area, elevations range from sea level to 90 feet (27.4 meters) MSL. Variable thicknesses of undifferentiated Quaternary sediments lie on undifferentiated Tertiary/Quaternary shelly sediments or the Hawthorn Group in the terrain.

St. Marys Plain

The St. Marys Plain is an area in which LiDAR reveals a network of paleo valleys, largely related to the Nassau River. The terrain also includes examples of stream capture of waters that formerly flowed to the St. Johns River or the Nassau River, as in the route of the Little St. Marys River today. White (1970) described what he called the St. Marys Meander Plain as “the meandering of a plexus of muddy sediment laden streams.” The terrain consists of the “Nassau and St. Marys Rivers and their network of tortuous abandoned channels, tributaries and distributaries (White, 1970, pp 110-111).” The morphology of this region is not unlike the

meandering tidal creeks that are common in the Sea Islands terrain. A string of barrier islands exists in the mesotidal environments that are common on the Atlantic Ocean coastline from the vicinity of Jacksonville, Florida, north to Myrtle Beach, South Carolina. The main distinctions between the St. Marys Plain and the Duval Upland to the west are its reduced elevation and dendritic drainage, which is different than the modified trellis drainage of the northern extent of the Duval Upland. Elevations in the study area range from sea level on the Nassau River to approximately 50 feet (15.2 meters) MSL. Elevation models based on Light Detection and Ranging (LiDAR) make it possible to identify the broad, short relict barrier islands and wide former coastal salt marsh plains found in the Sea Islands terrain to the east of the St. Marys Plain.

Sea Islands

The Sea Islands terrain (OFMS 108, Plate 3, Figure 4) was separated from the St. Marys Meander Plain of White (1970) based upon interpretations made possible with the use of LiDAR. While it is clear on USGS 7.5 minute topographic maps and aerial photography, as White (1970) discussed, that the coastal portion of the St. Marys Plain shares coastal affinities to the Sea Islands, LiDAR reveals the relatively broad and short barrier island features that exist inland from the Atlantic Ocean coastline as well as the extensive, possible former salt marshes that existed from north to south between them and parallel to the modern coastal environments. The region, defined by generally north to south oriented uplands, broad trellis drainage, and the modern extensive tidal rivers and salt marshes, is named the Sea Islands terrain by Williams et al. (in preparation). It is partially cut in two by the valley and floodplain of the Nassau River which narrows toward the coast, passing between older barrier islands before emptying to Nassau Sound. Elevations in the study area range from sea level to 110 feet (33.5 meters) above MSL. Former Pleistocene barrier islands include the core of Amelia Island and most of Big Talbot and Fort George islands. Holocene deposition formed the northern and southern portions of Amelia Island, the Bird Islands in Nassau Sound, Little Talbot Island and the spit on the north side of the St. Johns River including the City of Jacksonville's Huguenot Memorial Park.

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 Florida (OFMS 108, Plate 3, Figure 4). It is bound to the west by the Southern Okefenokee Basin, to the east by the Duval Upland and to the south by the Hawthorne Lakes. Elevations in the study area range from 100 feet (30.5 meters) MSL along tributaries of Black Creek to nearly 175 feet (53.3 meters) MSL. Trail Ridge consists of unconsolidated to slightly indurated white to tan, medium to fine quartz sand containing an average of three percent heavy minerals in some areas, of which approximately 45 percent are titanium-rich minerals; ilmenite, leucosene, and rutile. Other accessory heavy minerals include staurolite, zircon, kyanite, sillimanite, corundum, topaz, and tourmaline.

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LITHOSTRATIGRAPHIC UNITS

Tertiary System

Eocene Series

Avon Park Formation

The Middle Eocene Avon Park Formation (Tap), first described by Applin and Applin (1944), is a subsurface unit within the USGS Jacksonville 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 108, Plate 2).

The 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.

Throughout most of the study area, the boundary between the Middle Eocene Avon Park Formation and the unconformably overlying Upper Eocene Ocala Limestone, is marked by a moderately to highly recrystallized, thin, pale brown dolostone at the top of the Avon Park. It contrasts distinctly with the foraminifera-rich Ocala Limestone (grainstone to packstone), making the contact relatively easy to discern even in cuttings. The fossil fauna in this area were only somewhat helpful in determining the contact. This contrasts with the Orlando Quadrangle to the south (Green, et al., 2015a; Green et al., 2015b), where the contact was more easily determined due to textural changes in the grain and matrix of the limestones, in addition to a more abrupt change in fossil fauna from benthic forams, mollusks and gastropods to the cone-shaped foram *Cushmania* [*Dictyoconus*] *americana*.

The top of the Avon Park Formation is generally deeper than most borehole samples in the area. Therefore, the total thickness of the Avon Park Formation was not investigated in this study. The top of the Avon Park ranges from approximately 494 feet (150.6 meters) below MSL in W-16535 (OFMS 108; Plate 2, cross-section E-E') to approximately 827 feet (252.1 meters) below MSL in W-3788 (OFMS 108; Plate 2, cross-sections A-A' and E-E'). 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 sits unconformably on the Avon Park Formation throughout the study area.

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, is highest along the southern portion of the map area, and deepens towards the central portion of the study area in the Jacksonville Basin (OFMS 108, Plate 2). The top of the Ocala Limestone ranges from 243 feet (74.1 meters) below MSL in W-18418, (OFMS 108; Plate 2, cross-section F-F') to 536 feet (163.4 meters) below MSL in W-7104 (OFMS 108; Plate 2, cross-sections E-E'). In these wells, the thickness of the Ocala Limestone ranges from 190 feet (57.9 meters) in W-3416 (OFMS 108; Plate 2, cross-section B-B' and E-E') to 337 feet (102.7 meters) in W-3788 (OFMS 108; Plate 2, cross-section A-A' and E-E'). 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 thickest in the Jacksonville Basin (Scott, 1983; 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, miliolids, and molluscs. Benthic foraminifera characteristic of the Hawthorn Group include *Archaias* spp. and *Sorites* sp.

Within the mapped area, the Hawthorn Group is composed of (in ascending order) the Penney Farms Formation (Thpf), the Marks Head Formation (Thmh), the Coosawhatchie Formation (Thc), and the Charlton Member of the Coosawhatchie Formation (Thcc; OFMS 108, Plate 2, Figure 2). While these units can be identified and delineated in cores, they often can be difficult to differentiate in cuttings, particularly where cavings or large sample intervals cause mixing of the sediments during drilling. After much effort, the authors were able to break out the units on cross-section wells; however, the contacts were often uncertain in wells with larger sample intervals, and are therefore dashed.

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

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overlain by undifferentiated Pliocene/Pleistocene shelly sediments (TQsu), Cypresshead Formation (TQc), and undifferentiated Quaternary sediments (Qu).

Hawthorn Group sediments occur throughout the mapped area (OFMS 108, Plate 2) and thickens in the Jacksonville Basin. The top of the Hawthorn Group ranges between 44 feet (13.4 meters) above MSL in W-14219 (OFMS 108; Plate 2, cross-section C-C' and D-D') to 156 feet (47.6 meters) below MSL in W-16381 (OFMS 108; Plate 2, cross-section C-C'). The Hawthorn Group sediments range in thickness from 180 feet (54.9 meters) in well W-18418 (OFMS 108; Plate 2, cross-section F-F') to 460 feet (140.2 meters) in well W-3416 (OFMS 108; Plate 2, cross-section B-B' and E-E'). 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 sometimes present 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. This hard, fine-grained dolostone was less commonly observed in the unit than in areas further south (Green, et al, 2013a; Green, et al, 2013b). Limestone, which occurs sporadically in the lower portion of the unit, is generally dolomitic, phosphatic, and contains quartz sand. The Penney Farms Formation unconformably overlies the Ocala Limestone within the mapped area. It is overlain unconformably by the Marks Head Formation (Hawthorn Group). The top of the Penney Farms Formation is placed at the contact between the darker-colored sands and clays of the upper Penney Farms and the lighter-colored interbedded sands, clays, and dolostone of the Marks Head Formation (Scott, 1988). Sediments of the Penney Farms Formation occur throughout the mapped area (OFMS 108, Plate 2). The top of the unit ranges from 122 feet (37.2 meters) above MSL in W-12859 (OFMS 108; Plate 2, cross-section B-B') to 377 feet (114.9 meters) below MSL in W-13567 (OFMS 108; Plate 2, cross-sections A-A'). The Penney Farms Formation ranges in thickness from 52 feet (15.9 meters) in W-18736 (OFMS 108; Plate 2, cross-section A-A') to 135 feet (41.1 meters) in well W-3788 (OFMS 108; Plate 2, cross-section A-A').

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). It was observed in concentrations higher than typically expected within the study area. More commonly observed in core, the calcareous component of this unit was present primarily as benthic forams and miliolids which have undergone various states of weathering. 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 sands tend to be finer grained than the sands in either the Penney Farms or Coosawhatchie Formations. 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 the mapped area (OFMS 108, Plate 2). The top of the Marks Head Formation ranges from 80 feet (24.4 meters) below MSL in W-13571 (OFMS 108; Plate 2, cross-section C-C') to 300 feet (91.4 meters) below MSL in W-16381 (OFMS 108; Plate 2, cross-section C-C'). The Marks Head Formation ranges in thickness from 20 feet (6.1 meters) in well W-18529 (OFMS 108; Plate 2, cross-section C-C') to 160 feet (48.8 meters) in well W-3416 (OFMS 108; Plate 2, cross-sections B-B' and E-E').

Coosawhatchie Formation

The Middle Miocene Coosawhatchie Formation (Thc) consists of quartz sand, dolostone, limestone, and clay. The unit ranges in color from yellowish gray and light gray to olive gray. The most common lithology in the upper section of the unit is a sandy to very sandy dolostone which may be interbedded with quartz sands and clays (Scott, 1988). Quartz sand and clay dominate and dolostones become subordinate in the lower portion of the formation. The quartz sands are fine- to medium-grained, generally phosphatic, clayey, and dolomitic. On occasion, shell fragments, consisting primarily of leached and weathered mollusc fragments, are found in the upper portion of the unit. 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. Phosphate grains, ranging from sand to pebble-sized, while not common in the unit, may be present. The unit crops out along parts of the north and south forks of Black Creek in the southwest portion of the mapped area (OFMS 108, Plates 1 and 2), where it is unconformably overlain by the Pliocene/Pleistocene Cypresshead Formation (TQc). It is unconformably overlain by undifferentiated Pliocene/Pleistocene shelly sediments (TQsu), and undifferentiated Quaternary sediments (Qu) elsewhere in the study area (OFMS 108, Plate 2). The top of the Coosawhatchie Formation ranges between 44 feet (13.4 meters) above MSL in W-14219 (OFMS 108; Plate 2, cross-section C-C' and D-D') to 156 feet (47.6 meters) below MSL in W-16381 (OFMS 108; Plate 2, cross-section C-C'). The Coosawhatchie Formation, which includes the Charlton Member discussed below, ranges in thickness from 40 feet (12.2 meters) in well W-13751 (OFMS 108; Plate 2, cross-section C-C') to 250 feet (76.2 meters) in well W-7104 (OFMS 108; Plate 2, cross-section E-E').

Charlton Member

The Middle Miocene Charlton Member of the Coosawhatchie Formation (Thcc) consists of moldic dolostones, limestones, clays, and sands. The sediments range in color from white and yellowish gray to pale yellowish green. Induration ranges from poor to moderate. Moldic porosity dominates, with occasional intercrystalline porosity in more dolomitic sections. The most common molds observed are from molluscs. Quartz and phosphatic sand are usually present but

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concentrations are characteristically low, often less than ten percent, although they may be higher. Quartz sand is more prevalent than phosphatic sand and ranges in size from fine to coarse. Phosphate content is low, often less than two percent, and the phosphate is typically black to dark brown in color. In some locations, especially near the St. Marys River (north of the mapped area), the Charlton Member is present as a clay phase. The clays are calcareous to dolomitic, poorly to moderately indurated, silty, and are light gray to greenish gray in color (Scott, 1988). The top of the Charlton Member ranges between 10 feet (3.1 meters) above MSL in W-17744/W-18015 (OFMS 108; Plate 2, cross-section C-C') to 68 feet (20.7 meters) below MSL in W-19437 (OFMS 108; Plate 2, cross-sections A-A' and F-F'). The Charlton Member is absent in various wells (OFMS 108; Plate 2), but attains a thickness of 75 feet (22.9 meters) in well W-4197 (OFMS 108; Plate 2, cross-section B-B' and D-D').

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, heavy minerals, mica, and ghosts of nearshore marine molluscs are rarely present. The Cypresshead Formation is present in the southwestern portion of the study area along the southern Duval Upland, east of Trail Ridge (OFMS 108, Plates 1 and 3).

Scott, et al., (2001) mapped the entire Duval Upland as Cypresshead Formation. Upon analysis of all available sample sets in the area, the authors of this study do not believe that the sediments in the central portion of the Duval Upland in the study area are Cypresshead Formation and have mapped this area as undifferentiated Quaternary sediments (OFMS 108, Plates 1 and 3). While the occasional set of samples in the area may have some grain-size affinities to the Cypresshead Formation, they generally lack the overall characteristics defining the unit and characteristically have a medium to dark brown clay matrix. The sands in this area tend to be uniformly fine in grain size and low in clay content, often less than ten percent. Mica and heavy minerals are present in a trace amounts.

Elevations of the top of the formation range from approximately 30 feet (9.1 meters) above MSL to around 100 feet (30.5 meters) above MSL in the southwestern corner of the mapped area near Trail Ridge. The Cypresshead Formation thickness ranges up to 60 feet (18.3 meters) in study area wells.

These sediments sit unconformably on the Coosawhatchie Formation (Thc), Charlton Member (Coosawhatchie Formation; Thcc), or undifferentiated Pliocene/Pleistocene shelly sediments (TQsu) in the vicinity of Trail Ridge (OFMS 108; 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).

Undifferentiated Tertiary/Quaternary Shelly Sediments

A sequence of undifferentiated Pliocene/Pleistocene shelly sediments lies east of Trail Ridge. Huddleston (1988) named this unit the Nashua Formation. Much of the evidence listed by Huddleston (1988) was based on biostratigraphic correlation and not lithologic distinction. As a result of the lithologic variability of the unit, the use of biostratigraphic correlation of Huddleston (1988) and minimal field exposures, these sediments are mapped as undifferentiated Tertiary/Quaternary shelly sediments (TQsu) in this study. 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 or the Charlton Member of the Coosawhatchie Formation (OFMS 108; Plate 2). Huddleston (1988) indicated that the unit grades laterally into the Cypresshead Formation (TQc) in the vicinity of the Trail Ridge. Evidence from previous studies (Green et al., 2013a, and Green et al., 2013b), however, indicates that the unit is, at least in part, older than the Cypresshead Formation. This may be a result of prograding of Cypresshead Formation sediments over TQsu marine sediments during changes in sea level. These undifferentiated shelly sands are overlain by the Cypresshead Formation in the Crescent City and DeLand ridges south of the current study area (Green et al., 2013a, and Green et al., 2013b). Elsewhere, the unit is unconformably overlain by undifferentiated Quaternary sediments (Qu), Quaternary beach ridge and dune sediments (Qbd), or Holocene sediments (Qh; OFMS 108, Plate 2). The TQsu sediments are missing in several wells in the study area (OFMS 108, Plate 2), hypothesized to be due to the influence of the St. Johns River and erosion during sea-level fluctuations or dissolution of the carbonates.

Undifferentiated Tertiary/Quaternary shelly sediments (TQsu) consist of fine-to-medium quartz sand with variable amounts of calcilutite, fossil shells, and clay. Fossil shells can be weathered, fragmented, or whole and can be the dominant lithologic component of the unit. Gray clay is a more common matrix material in TQsu in the western portion of the study area, while calcilutite matrix is more common in the eastern portion of the study area, especially near the coast. Clay content ranges from a trace amount up to 15 percent. Other accessory minerals include calcite, aragonite, mica, heavy minerals, and phosphate. Colors range from light gray to light olive gray.

The top of the undifferentiated Tertiary/Quaternary shelly sediments ranges from 24 feet (7.3 meters) above MSL in W-14521, (OFMS 108; Plate 2, cross-section D-D') to 70 feet (21.3 meters) below MSL in W-18283 (OFMS 108; 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 108; Plate 2, cross-sections B-B' and D-D') to 95 feet (28.9 meters) in W-18254 (OFMS 108; Plate 2, cross-section D-D'). Permeable sediments of the undifferentiated Tertiary/Quaternary shelly sediments form part of the surficial aquifer system (SAS; Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986).

Pleistocene to Holocene Series

Undifferentiated Quaternary Sediments

Undifferentiated Quaternary sediments (Qu) in the study area lie unconformably on the Coosawhatchie Formation of the Hawthorn Group, Charlton Member of the Coosawhatchie

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Formation, undifferentiated Pliocene/Pleistocene shelly sediments or Cypresshead Formation (OFMS 108, 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 brown, 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 surficial aquifer system (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. 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 sands. They contain an average of three percent heavy minerals, 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 undifferentiated Quaternary sediments (Qu) in the eastern part of the study area (OFMS 108; Plates 1 and 2).

Beach ridge and dune sediments are dominantly siliciclastic sands and are unconsolidated to poorly consolidated. Organics occur as disseminated organic matrix, roots and plant debris, carbonized remains, or charcoal. The unit is considered part of the surficial aquifer system (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, minor carbonate sands, and mud. They may also include fresh-water mollusc shells. Within the study area, they occur as modern barrier islands and floodplain deposits in the vicinity of the St. Johns, Guana, and Tolomato rivers, and along the east coast. These sediments are considered part of the surficial aquifer system (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 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 in the study area. The SAS is comprised of the Cypresshead Formation, undifferentiated Pliocene/Pleistocene shelly sediments (TQsu), undifferentiated Quaternary sediments (Qu), beach ridge and dune sediments (Qbd), and Holocene sediments (Qh).

GEOPHYSICAL LOGGING

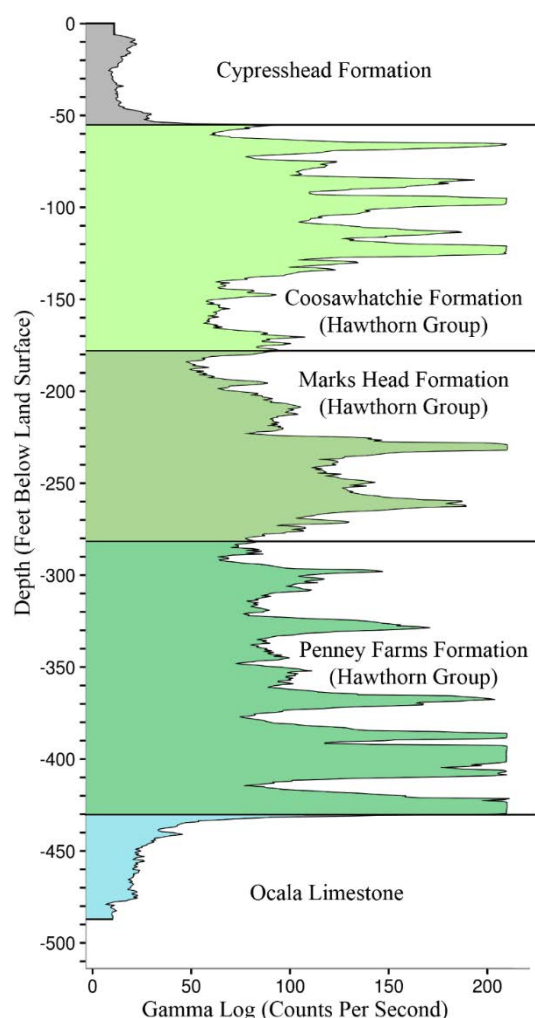


Figure 6. Gamma Log of W-14219 (see OFMS 108, plate 2, cross section C-C' and D-D').

As part of this project, the Florida Geological Survey (FGS) conducted geophysical logging on new wells drilled in the study area. Boreholes were logged with a variety of geophysical tools, including Gamma (natural gamma log), Caliper, and Resistivity logs. 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-ray 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 are measured in counts per second (CPS). In Figure 6, gamma-ray intensity units are shown on the log horizontal axis in CPS for W-14219 (see OFMS 108, Plate 2, cross-section C-C' and D-D'). Carbonates of the Ocala Limestone have the lowest intensity gamma-ray peaks, in contrast to the high intensity radioactivity of the Hawthorn Group. Formations above the Hawthorn

Group, such as the Cypresshead Formation, 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

Cypresshead Formation

Cypresshead Formation sediments (TQc) unconformably overlie sediments of the Hawthorn Group (OFMS 108, Plate 2) in the southwestern corner of the study area. Cypresshead Formation 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 clay. The presence of minor phosphate and material reworked from the underlying Hawthorn Group sediments can cause basal spikes in the gamma-ray log, making the base of this unit in such cases problematic to distinguish from the underlying Coosawhatchie Formation (Thc; Hawthorn Group).

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 easy to discern on geophysical logs (Figure 6).

The Hawthorn Group in the study area consists of, in descending order, the Charlton Member of the Coosawhatchie Formation (Thcc), Coosawhatchie (Thc), Marks Head (Thmh), and Penney Farms (Thpf) formations. According to Scott (1988), the gamma-ray logs for Hawthorn Group in north Florida consist of five generalized zones which may show significant variation in thickness and intensity of peaks within these zones. While it is possible to differentiate formations within the Hawthorn Group using gamma-ray logs, it is best practice to combine the study of geophysical logs along with lithologic inspection in order to break out units within the Hawthorn Group.

The upper, higher-intensity zone and part of the subjacent, lower-intensity zone correlate to the Coosawhatchie Formation (Figure 6). The variable lithologic nature and phosphate content of the Coosawhatchie Formation, particularly in the upper portion of the unit, is readily apparent in the gamma-ray log. This is reflected by the numerous high-intensity peaks and relatively thin beds. 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 two and 10 percent.

The Marks Head Formation correlates with part of the low-intensity zone, reflecting the decreased phosphate concentrations, less carbonate, and decrease in clay content. This is followed by the upper part of the high-intensity zone, and the upper part of the second low-intensity zone (Figure 6).

In general, the gamma-ray log of the Penny Farms Formation includes the lower portion of the second low-intensity zone, consisting of sands, clays and dolostones with one to five percent phosphate, followed by a higher intensity 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 5 to 10 percent phosphate sand and gravel which is represented on the log by the presence of a higher-intensity spike. Overall, 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 apparent (Figure 6).

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).

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 Jacksonville 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 108. The first 40 wells in the table were utilized for geologic cross-sections and appear on Plates 1 and 2 of OFMS 108.

Map ID	Well Label	Sample Type	Latitude	Longitude	24K Quad	Elevation (ft.)	Total Depth (ft.)
1	W-1045	Cuttings	30.41932	-81.80168	DINSMORE	19	75
2	W-2208	Cuttings	30.14971	-81.38403	PALM VALLEY	7	410
3	W-2280	Cuttings	30.28219	-81.72343	JACKSONVILLE	11	1250
4	W-3416	Cuttings	30.29610	-81.59051	ARLINGTON	9	1000
5	W-3509	Cuttings	30.29691	-81.64259	JACKSONVILLE	22	1500
6	W-3567	Cuttings	30.42389	-81.64861	TROUT RIVER	24	740
7	W-3788	Cuttings	30.42785	-81.60282	EASTPORT	10	1012
8	W-3990	Cuttings	30.23552	-81.89871	FIFTONE	75	964
9	W-4197	Cuttings	30.26750	-81.90730	BALDWIN	83	1300
10	W-4883	Cuttings	30.40940	-81.72239	TROUT RIVER	13	1225
11	W-5882	Cuttings	30.39107	-81.41453	MAYPORT	7	814
12	W-6542	Cuttings	30.31643	-81.39858	JACKSONVILLE BEACH	7	1201
13	W-7104	Cuttings	30.35494	-81.60450	ARLINGTON	44	1300
14	W-8736	Cuttings	30.40468	-81.87372	DINSMORE	85	708
15	W-10773	Cuttings	30.36396	-81.42082	JACKSONVILLE BEACH	5	705
16	W-11273	Cuttings	30.30393	-81.43830	JACKSONVILLE BEACH	6	616
17	W-11777	Cuttings	30.18472	-81.37778	PALM VALLEY	7	1014
18	W-12224	Cuttings	30.28638	-81.80419	MARIETTA	76	761
19	W-12859	Cuttings	30.28496	-81.97344	BALDWIN	84	905
20	W-13751	Core	30.08499	-81.45837	DURBIN	63	342
21	W-14219	Core	30.11528	-81.88250	MIDDLEBURG SW	89	492
22	W-15217	Cuttings	30.26705	-81.39625	JACKSONVILLE BEACH	18	890
23	W-16250	Cuttings	30.09500	-81.61433	ORANGEDALE	11	500
24	W-16381	Cuttings	30.09524	-81.76527	MIDDLEBURG	12	651
25	W-16535	Cuttings	30.03555	-81.65361	FLEMING ISLAND	6	961
26	W-16559	Cuttings	30.22750	-81.58444	BAYARD	21	860
27	W-16564	Cuttings	30.29542	-81.50942	ARLINGTON	38	1090
28	W-16679	Cuttings	30.45730	-81.90913	BRYCEVILLE	69	90
29	W-16825	Cuttings	30.04253	-81.89531	MIDDLEBURG SW	76	441
30	W-17544	Cuttings	30.40250	-81.92111	BRYCEVILLE	78	500
31	W-17774	Cuttings	30.15721	-81.93774	FIFTONE	79	82
32	W-17778	Cuttings	30.15750	-81.57528	BAYARD	25	420
33	W-18015	Cuttings	30.15722	-81.93777	FIFTONE	79	540
34	W-18418	Core	30.02283	-81.32763	SOUTH PONTE VEDRA BEACH	2	320
35	W-18529	Cuttings	30.08389	-81.72305	FLEMING ISLAND	11	290
36	W-19437	Core	30.44498	-81.41803	MAYPORT	17	435
37	W-19462	Core	30.45192	-81.46951	MAYPORT	11	160
38	W-19561	Core	30.16700	-81.88261	FIFTONE	79	325

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Map ID	Well Label	Sample Type	Latitude	Longitude	24K Quad	Elevation (ft.)	Total Depth (ft.)
39	W-19570	Core	30.08592	-81.34956	SOUTH PONTE VEDRA BEACH	11	325
40	W-19587	Core	30.33033	-81.90794	BALDWIN	85	339.5
41	W-27	Cuttings	30.24096	-81.68734	ORANGE PARK	15	669
42	W-28	Cuttings	30.31191	-81.70538	JACKSONVILLE	24	547
43	W-48	Cuttings	30.33625	-81.65478	JACKSONVILLE	12	981
44	W-73	Cuttings	30.33195	-81.72150	JACKSONVILLE	24	600
45	W-78	Cuttings	30.16580	-81.70204	ORANGE PARK	21	370
46	W-116	Cuttings	30.33072	-81.78815	MARIETTA	59	1060
47	W-157	Cuttings	30.31246	-81.70954	JACKSONVILLE	18	1260
48	W-303	Cuttings	30.33968	-81.65759	JACKSONVILLE	12	1244
49	W-304	Cuttings	30.34080	-81.65926	JACKSONVILLE	16	1249
50	W-306	Cuttings	30.31107	-81.65649	JACKSONVILLE	9	1307
51	W-322	Cuttings	30.30191	-81.64704	JACKSONVILLE	17	1278
52	W-392	Cuttings	30.31517	-81.39927	JACKSONVILLE BEACH	8	622
53	W-513	Cuttings	30.22080	-81.67398	ORANGE PARK	11	1005
54	W-514	Cuttings	30.21901	-81.68517	ORANGE PARK	9	1015
55	W-521	Cuttings	30.26560	-81.63015	JACKSONVILLE	25	610
56	W-523	Cuttings	30.33118	-81.60344	ARLINGTON	24	748
57	W-544	Cuttings	30.41884	-81.64703	TROUT RIVER	19	1019
58	W-581	Cuttings	30.22802	-81.88594	FIFTON	78	990
59	W-599	Cuttings	30.30302	-81.66232	JACKSONVILLE	4	700
60	W-659	Cuttings	30.29052	-81.97900	BALDWIN	86	750
61	W-661	Cuttings	30.22996	-81.70482	ORANGE PARK	6	987
62	W-731	Cuttings	30.24885	-81.89844	FIFTON	79	780
63	W-741	Cuttings	30.32880	-81.55817	ARLINGTON	50	1050
64	W-743	Cuttings	30.05774	-81.64009	FLEMING ISLAND	29	300
65	W-826	Cuttings	30.30051	-81.64510	JACKSONVILLE	22	1064
66	W-827	Cuttings	30.35971	-81.68660	JACKSONVILLE	25	1073
67	W-830	Cuttings	30.35603	-81.68658	JACKSONVILLE	26	1356
68	W-831	Cuttings	30.35577	-81.68955	JACKSONVILLE	20	1053
69	W-897	Cuttings	30.38857	-81.41093	MAYPORT	8	764
70	W-900	Cuttings	30.15985	-81.65224	ORANGE PARK	13	633
71	W-1043	Cuttings	30.41547	-81.69361	TROUT RIVER	15	46
72	W-1045	Cuttings	30.41932	-81.80168	DINSMORE	19	75
73	W-1046	Cuttings	30.40393	-81.89101	BRYCEVILLE	79	106
74	W-1071	Cuttings	30.03685	-81.88472	MIDDLEBURG SW	22	136
75	W-1075	Cuttings	30.10096	-81.76827	MIDDLEBURG	8	55
76	W-1076	Cuttings	30.07379	-81.86005	MIDDLEBURG	24	65
77	W-1077	Cuttings	30.03724	-81.88513	MIDDLEBURG SW	23	60
78	W-1078	Cuttings	30.06631	-81.97896	MIDDLEBURG SW	79	80
79	W-1590	Core	30.09047	-81.80779	MIDDLEBURG	20	5862
80	W-2182	Cuttings	30.35878	-81.69053	JACKSONVILLE	17	1322
81	W-2207	Cuttings	30.29325	-81.50981	ARLINGTON	36	1105
82	W-2276	Cuttings	30.24444	-81.72317	ORANGE PARK	18	775

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Map ID	Well Label	Sample Type	Latitude	Longitude	24K Quad	Elevation (ft.)	Total Depth (ft.)
83	W-2443	Cuttings	30.28691	-81.56872	ARLINGTON	5	750
84	W-2558	Cuttings	30.39591	-81.63594	TROUT RIVER	16	1015
85	W-2803	Cuttings	30.30256	-81.97444	BALDWIN	85	716
86	W-2888	Cuttings	30.24274	-81.73371	ORANGE PARK	4	672
87	W-2953	Cuttings	30.28014	-81.64722	JACKSONVILLE	19	750
88	W-2960	Cuttings	30.22941	-81.88594	FIFTON	76	950
89	W-3013	Cuttings	30.23444	-81.69530	ORANGE PARK	13	460
90	W-3074	Cuttings	30.31418	-81.64844	JACKSONVILLE	0	760
91	W-3120	Cuttings	30.42167	-81.60083	EASTPORT	14	1006
92	W-3282	Cuttings	30.28451	-81.59187	ARLINGTON	22	1006
93	W-3344	Cuttings	30.31667	-81.65667	JACKSONVILLE	10	760
94	W-3345	Cuttings	30.44000	-81.75445	DINSMORE	18	750
95	W-3361	Cuttings	30.47829	-81.62566	TROUT RIVER	31	1000
96	W-3435	Cuttings	30.24686	-81.60828	BAYARD	17	1150
97	W-3464	Cuttings	30.16607	-81.62759	ORANGE PARK	18	940
98	W-3492	Cuttings	30.40389	-81.69556	TROUT RIVER	12	0
99	W-3542	Cuttings	30.24289	-81.77439	JACKSONVILLE HEIGHTS	87	1204
100	W-3591	Cuttings	30.16137	-81.60077	BAYARD	21	528
101	W-3674	Cuttings	30.28774	-81.39503	JACKSONVILLE BEACH	10	800
102	W-3718	Cuttings	30.32638	-81.40107	JACKSONVILLE BEACH	8	1008
103	W-3786	Cuttings	30.31302	-81.71899	JACKSONVILLE	22	705
104	W-3961	Cuttings	30.03774	-81.89668	MIDDLEBURG SW	79	359
105	W-4012	Cuttings	30.40107	-81.64482	TROUT RIVER	6	1009
106	W-4202	Cuttings	30.30083	-81.97267	BALDWIN	85	715
107	W-4210	Cuttings	30.19935	-81.62862	ORANGE PARK	19	720
108	W-4695	Cuttings	30.20500	-81.69389	ORANGE PARK	27	522
109	W-4913	Cuttings	30.37504	-81.58614	EASTPORT	22	1045
110	W-5298	Cuttings	30.24639	-81.76986	JACKSONVILLE HEIGHTS	77	1149
111	W-5311	Cuttings	30.37875	-81.72514	TROUT RIVER	6	920
112	W-5322	Cuttings	30.33218	-81.56037	ARLINGTON	26	1012
113	W-5323	Cuttings	30.24718	-81.62287	BAYARD	20	1170
114	W-5374	Cuttings	30.29786	-81.77389	MARIETTA	17	704
115	W-5459	Cuttings	30.33552	-81.59621	ARLINGTON	44	1411
116	W-5460	Cuttings	30.35192	-81.56901	ARLINGTON	43	1301
117	W-5521	Cuttings	30.33815	-81.52351	ARLINGTON	43	752
118	W-5632	Cuttings	30.29941	-81.77483	MARIETTA	24	1000
119	W-5749	Cuttings	30.20756	-81.58157	BAYARD	26	670
120	W-6254	Cuttings	30.37441	-81.73040	JACKSONVILLE	10	1326
121	W-6301	Cuttings	30.28659	-81.79077	MARIETTA	80	1043
122	W-6465	Cuttings	30.39360	-81.55847	EASTPORT	15	801
123	W-7508	Cuttings	30.03782	-81.87611	MIDDLEBURG SW	9	107
124	W-7509	Cuttings	30.08844	-81.86878	MIDDLEBURG	21	107
125	W-7510	Cuttings	30.07470	-81.85179	MIDDLEBURG	4	100
126	W-7514	Cuttings	30.07028	-81.52750	ORANGEDALE	32	100

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Map ID	Well Label	Sample Type	Latitude	Longitude	24K Quad	Elevation (ft.)	Total Depth (ft.)
127	W-7517	Cuttings	30.08860	-81.83488	MIDDLEBURG	27	102
128	W-7996	Cuttings	30.30496	-81.63010	JACKSONVILLE	18	2486
129	W-8207	Cuttings	30.16421	-81.74185	ORANGE PARK	65	125
130	W-8306	Cuttings	30.48691	-81.67844	TROUT RIVER	22	1098
131	W-8371	Cuttings	30.48693	-81.67847	TROUT RIVER	21	1098
132	W-10359	Cuttings	30.38552	-81.49371	MAYPORT	14	700
133	W-10630	Cuttings	30.14285	-81.74613	ORANGE PARK	31	864
134	W-10633	Cuttings	30.17812	-81.71316	ORANGE PARK	11	616
135	W-10634	Cuttings	30.48846	-81.63368	TROUT RIVER	29	815
136	W-10635	Cuttings	30.36608	-81.58038	ARLINGTON	16	1104
137	W-10636	Cuttings	30.48632	-81.70427	TROUT RIVER	24	1105
138	W-10919	Cuttings	30.21417	-81.61667	BAYARD	6	740
139	W-10920	Cuttings	30.45885	-81.63815	TROUT RIVER	29	1330
140	W-10921	Cuttings	30.35913	-81.47376	JACKSONVILLE BEACH	25	704
141	W-11281	Cuttings	30.11583	-81.60278	ORANGEDALE	14	600
142	W-11548	Cuttings	30.42449	-81.66037	TROUT RIVER	23	1296
143	W-11581	Cuttings	30.20302	-81.71454	ORANGE PARK	18	850
144	W-11582	Cuttings	30.20793	-81.73676	ORANGE PARK	12	950
145	W-11584	Cuttings	30.14281	-81.74641	ORANGE PARK	32	864
146	W-11585	Cuttings	30.04841	-81.82793	MIDDLEBURG	75	616
147	W-11778	Cuttings	30.36052	-81.41148	JACKSONVILLE BEACH	7	618
148	W-12056	Cuttings	30.17790	-81.73869	ORANGE PARK	57	1014
149	W-12223	Cuttings	30.28638	-81.80419	MARIETTA	76	762
150	W-12278	Cuttings	30.19941	-81.62844	ORANGE PARK	24	1000
151	W-12383	Cuttings	30.38080	-81.60807	EASTPORT	11	1009
152	W-12532	Cuttings	30.24014	-81.76884	JACKSONVILLE HEIGHTS	78	1130
153	W-12782	Cuttings	30.30552	-81.64982	JACKSONVILLE	12	1296
154	W-12847	Cuttings	30.33515	-81.59203	ARLINGTON	46	1360
155	W-13189	Cuttings	30.17758	-81.73839	ORANGE PARK	56	1002
156	W-13343	Cuttings	30.41473	-81.61009	EASTPORT	17	660
157	W-13411	Cuttings	30.31274	-81.78094	MARIETTA	60	681
158	W-13492	Cuttings	30.45361	-81.61833	EASTPORT	11	1280
159	W-13562	Cuttings	30.14256	-81.74622	ORANGE PARK	29	861
160	W-14193	Core	30.15167	-81.76028	JACKSONVILLE HEIGHTS	44	357
161	W-14278	Cuttings	30.38412	-81.41147	MAYPORT	9	1000
162	W-14300	Cuttings	30.22135	-81.67621	ORANGE PARK	10	1000
163	W-14311	Cuttings	30.38495	-81.40926	MAYPORT	5	1000
164	W-14619	Core	30.39250	-81.56306	EASTPORT	9	510
165	W-14731	Cuttings	30.38385	-81.49703	MAYPORT	15	204
166	W-14733	Cuttings	30.00897	-81.42562	DURBIN	31	74
167	W-14734	Cuttings	30.43991	-81.41491	MAYPORT	9	94
168	W-15214	Cuttings	30.27068	-81.39514	JACKSONVILLE BEACH	16	906
169	W-16169	Cuttings	30.28294	-81.98455	BALDWIN	85	100
170	W-16209	Cuttings	30.00896	-81.69977	FLEMING ISLAND	16	1000

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Map ID	Well Label	Sample Type	Latitude	Longitude	24K Quad	Elevation (ft.)	Total Depth (ft.)
171	W-16228	Cuttings	30.06635	-81.53965	ORANGEDALE	29	610
172	W-16292	Cuttings	30.25361	-81.58222	ARLINGTON	21	0
173	W-16293	Cuttings	30.04449	-81.80428	MIDDLEBURG	87	983
174	W-16551	Cuttings	30.46829	-81.57121	EASTPORT	24	798
175	W-17253	Cuttings	30.37821	-81.84077	DINSMORE	92	45
176	W-17256	Cuttings	30.00611	-81.69444	FLEMING ISLAND	21	32
177	W-17545	Cuttings	30.40250	-81.92111	BRYCEVILLE	78	500
178	W-17548	Cuttings	30.40250	-81.92111	BRYCEVILLE	78	42
179	W-17772	Cuttings	30.40250	-81.92111	BRYCEVILLE	78	120
180	W-18259	Cuttings	30.04500	-81.44945	DURBIN	42	81
181	W-18285	Cuttings	30.04500	-81.44945	DURBIN	42	680
182	W-18366	Cuttings	30.12722	-81.54417	BAYARD	20	200
183	W-18423	Cuttings	30.06000	-81.83444	MIDDLEBURG	82	200
184	W-18468	Cuttings	30.47278	-81.48695	MAYPORT	18	200
185	W-18517	Cuttings	30.47278	-81.48695	MAYPORT	18	570
186	W-18617	Cuttings	30.11806	-81.84861	MIDDLEBURG	65	540
187	W-18618	Cuttings	30.11829	-81.84846	MIDDLEBURG	65	90
188	W-18818	Cuttings	30.48106	-81.82429	DINSMORE	14	195
189	W-19218	Core	30.22917	-81.70444	ORANGE PARK	10	124
190	W-19433	Cuttings	30.16444	-81.39222	PALM VALLEY	5	410